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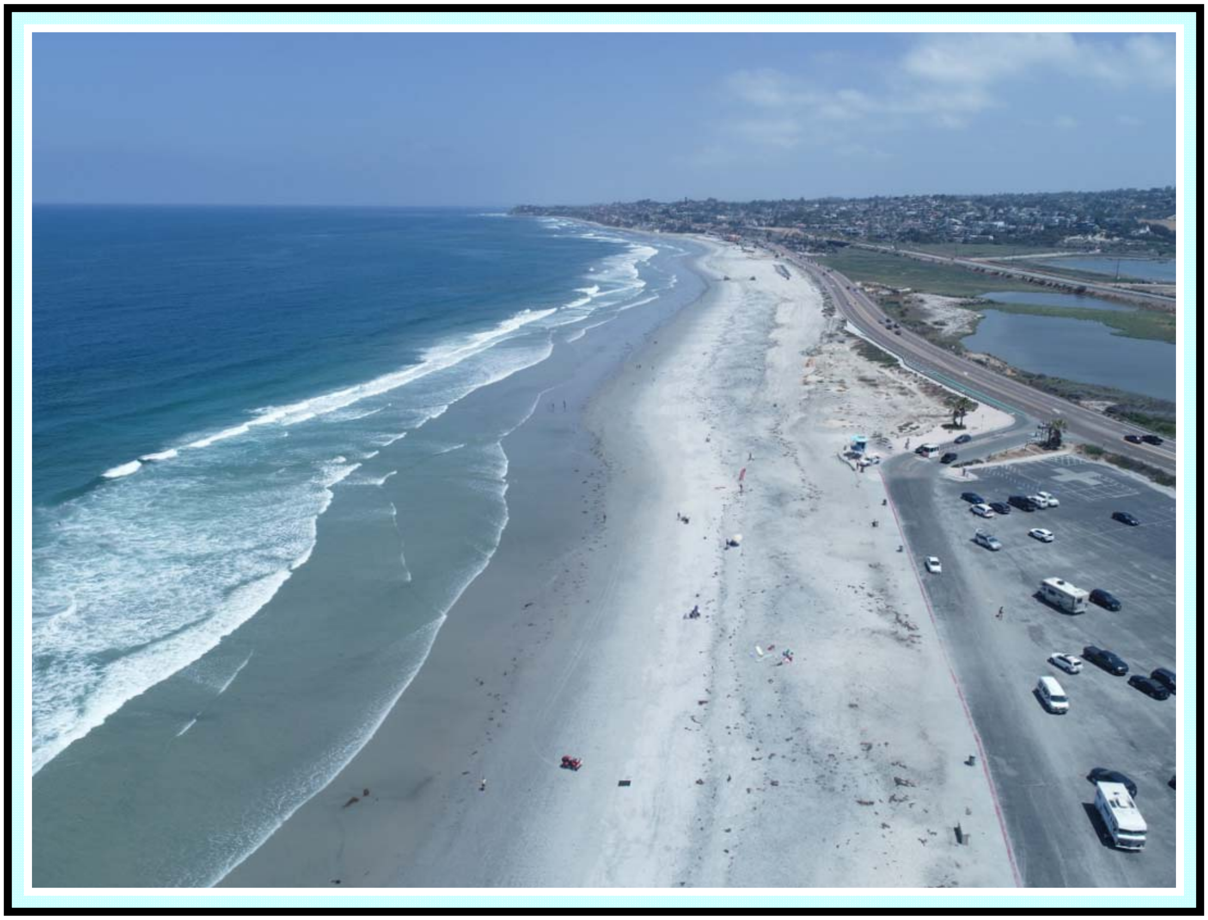

***Cardiff**, Post-Nourishment Beach Condition on June 19, 2018*

SANDAG

2018 REGIONAL BEACH MONITORING PROGRAM

ANNUAL REPORT

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SANDAG
2018 REGIONAL BEACH MONITORING PROGRAM

ANNUAL REPORT

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SANDAG

Under contract to:

BRG Consulting

Prepared by:

Coastal Frontiers Corporation

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June 2019

EXECUTIVE SUMMARY

This report presents the findings of the SANDAG 2018 Regional Beach Monitoring Program. As in past years, the general objective of the program was to document changes in the condition of the shorezone, thereby providing a basis for evaluating the impacts of natural events and human intervention. The specific focus was to document the evolution of the County's beaches following the placement of nourishment material under SANDAG's Regional Beach Sand Projects (RBSP I and II). The RBSP I and II provided a total of 3.6 million cubic yards (cy) of sand to the County's beaches in 2001 and 2012, respectively.

The beach monitoring component included semi-annual profiling on 54 shore-perpendicular transects. The lagoon entrance component addressed five sites in the Oceanside Littoral Cell: the jetty-stabilized entrances at Agua Hedionda and Batiquitos Lagoons, and the unstabilized entrances at San Elijo, San Dieguito, and Los Peñasquitos Lagoons. Observations and ground photographs at the three unstabilized entrances were obtained monthly.

To provide continuity with SANDAG's previous monitoring work, November 2017 through October 2018 was defined as the 2018 Monitoring Year and the prior seventeen one-year periods as the 2017 through 2001 Monitoring Years. The primary focus of this report is the 2018 Monitoring Year and the evolution of the County's beaches during the 18-year period encompassing both the RBSP I and RBSP II (November 2000 to October 2018). The latter 18-year period is termed the Post-RBSP I Period.

The principal study findings are as follows:

1. ***Precipitation and Streamflow:*** The precipitation during the 2018 Monitoring Year was exceptionally low by historical standards (3.9 inches). The streamflow in both the San Luis Rey and San Diego Rivers also was well below average.

2. ***Wave Conditions:*** Wave conditions were mild during the 2018 Monitoring Year, with only six storms with H_s exceeding 7 ft. The 10-ft threshold was achieved only once. In keeping with this outcome, the Energy Index also was below average.

3. ***Beach Nourishment:*** A substantial number of beach nourishment projects have been undertaken in San Diego County, with the RBSP I and II providing 3.6 million cy of sand. Nearly all of the other nourishment projects conducted in the county depended on "sand of opportunity". In 2018, approximately 446,000 cy of beach quality sand were placed at Cardiff and Solana Beach in the framework of the San Elijo Lagoon Restoration Project. Despite the material provided in recent years, a nourishment deficit of 204,000 cy/yr persisted relative to the historical average in the Oceanside Cell. In the Silver Strand Cell, a deficit of 20,000 cy/yr prevailed. Only in the Mission Beach Cell, where the historical average nourishment rate was a paltry 2,000 cy/yr, has incremental nourishment been received relative to the historical condition (a surplus of 31,000 cy/yr).

4. ***Sand Bypassing:*** The bypassing rate at Oceanside Harbor during the 18-year Post-RBSP I Period (255,000 cy/yr) was nearly identical to the historical average value (252,000 cy/yr). The recent and historical bypassing rates at San Dieguito also were nearly identical (7,000 vs. 8,000 cy/yr, respectively). At Agua Hedionda, the bypassing rate for the Post-RBSP I Period (139,000 cy/yr) was slightly below the historical average (143,000 cy/yr). The post-RBSP I bypassing rates at Batiquitos, San Elijo, and Los Peñasquitos exceeded the historical rates (12,000 vs. 3,000 cy/yr, 22,000 vs. 14,000 cy/yr, and 24,000 vs. 13,000 cy/r, respectively). The increased bypassing quantities at these lagoons constituted a direct benefit to the receiving beaches, which were located south of the lagoon entrances.

5. ***Beach Changes During 2018 Monitoring Year:*** During the 2018 Monitoring Year, shoreline advance predominated in the three littoral cells. The average change ranged from an increase of 25 ft in the Mission Beach Cell to a gain 33 ft in the Oceanside Cell. In contrast, the shoreline volume decreased an average of 15 cy/ft in the Silver Strand and was essentially unchanged in the Mission Beach and Oceanside Cells.

6. ***Beach Changes Following RBSP I:*** When the entire 18-year Post-RBSP I Period (2000 to 2018) is considered, the average Mean Sea Level shoreline position in the Silver Strand and Mission Beach Cells was essentially unchanged. In the Oceanside Cell, the shoreline advanced an average of 17 ft during the Post-RBSP I Period. The 2018 shorezone volumes in the Mission Beach and Oceanside Cells are comparable to the respective pre-RBSP I values, while that in the Silver Strand Cell falls below the pre-RBSP I condition. These observations suggest that the positive effects of the RBSP I, RBSP II and opportunistic nourishment projects in the region have largely dissipated.

7. ***Recovery after the 2015-2016 El Niño:*** The 2015-2016 El Niño was among the three strongest such events on record, and the corresponding winter season was characterized by well-above average shoreline retreat along the study area. Post-El Niño recovery progressed in all sub-reaches during the 2018 Monitoring Year, and beach widths attained pre-El Niño levels in the Solana Beach, Cardiff and Oceanside sub-reaches. The recovery in Solana Beach and Cardiff was greatly aided by the San Elijo Lagoon Restoration Project nourishment material placed in 2018. The gains at Oceanside are likely influenced by the timing of the bypassing operations at Oceanside Harbor. Beach widths in the other seven sub-reaches remained below the pre-El Niño condition, but the deficit was reduced relative to Fall 2017.

8. ***Lagoon Entrances:*** Following the RBSP I, the two jetty-stabilized entrance channels at Agua Hedionda and Batiquitos remained open to the full range of tidal exchange. Maintence dredging at Agua Hedionda was conducted seven times during this period, producing an average bypassing rate of 122,000 cy/yr (about 33% below the pre-RBSP I rate). Approximately 23,000 cy/yr were removed from Batiquitos Lagoon after RBSP I, surpassing the pre-RBSP I rate of 13,000 cy/yr. However the historical value at this site likely underestimates the long-term maintenance requirement because lagoon restoration efforts occurred during the Pre-RBSP I Period.

   The three unstabilized lagoon entrances closed periodically following RBSP I despite efforts to maintain tidal exchange. The entrance channel was open more than the historical average at San Elijo (95% vs. 43%) and San Dieguito (88% vs. 76%), and slightly less than the historical average at Los Peñasquitos (87% vs. 93%). At San Elijo Lagoon, the dredging rate following the RBSP I (21,000 cy/yr) exceeded the historical average (15,000 cy/yr) by approximately 40%. The higher rate is attributable, at least in part, to an increased level of maintenance made possible by additional funding. The post-RBSP I dredge rate at San Dieguito (7,000 cy/yr) slightly exceeded the pre-RBSP I rate (5,000 cy/yr). At Los Peñasquitos, the post-RBSP I dredge rate (25,000 cy/yr) exceeded the pre-RBSP I average (11,000 cy/yr) by a factor of more than two.

9. ***Borrow Sites:*** Comparison of the 2012 and 2014 bathymetry profiles along the borrow site monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. Additional smoothing and infilling occurred at SO-5 and SO-6 between the 2014 and 2016 surveys, while the changes at MB-01 were modest. Changes were modest between the Fall 2016 and Fall 2018 surveys, with the most noteworthy changes consisting of additional flattening of the side slopes at each borrow site. Over the six-year period following dredging,

shoaling at SO-5 and SO-6 averaged 1.2 and 0.7 ft, respectively. These changes equate to infilling rates of about 0.2 ft/yr at SO-5 and 0.1 ft/yr at SO-6. In contrast, during the same period sea bottom elevations decreased by an average of 0.7 ft at MB-01.

At MB-1, the grain size distribution curves corresponding to the samples obtained in 2014, 2016 and 2018 generally fell within the envelope of sediment sizes derived from the 2008 geophysical investigation. The grain size distribution curves for the samples obtained at SO-5 were near the middle of the envelope of in-situ sediment sizes. At SO-6, the grain size distribution curves for five of the six samples obtained between 2014 and 2018 tended to fall near the "coarse" end of the envelope of in-situ sediment sizes. The exception was a 2016 sample retrieved from the onshore portion of the dredge area where shoaling of up to 4 ft was noted. This sample contained finer sediment than identified in the 2008 investigation, suggesting the preferential deposition of fine material at the onshore portion of the SO-6 dredge area.

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SANDAG
2018 REGIONAL BEACH
MONITORING PROGRAM

ANNUAL REPORT

1. INTRODUCTION

This report presents the findings of the SANDAG 2018 Regional Beach Monitoring Program. As in the case of twenty-two prior annual monitoring programs conducted between 1996 and 2017 (Coastal Frontiers, 1997 through 2018a), the 2018 effort was performed on behalf of the San Diego Association of Governments (SANDAG) by Coastal Frontiers Corporation.

The study area extends 59 miles from the U.S.-Mexico Border to Oceanside Harbor, and contains the Silver Strand Littoral Cell, the Mission Beach Littoral Cell, and the southern half of the Oceanside Littoral Cell (Figure 1). As in past years, the general objective of the 2018 Monitoring Program was to document changes in the condition of the shorezone, thereby providing a basis for evaluating the impacts of natural events and human intervention. The specific focus was to document the evolution of the County's beaches following the placement of nourishment material under SANDAG's Regional Beach Sand Projects (RBSP I and II). The RBSP I and II, to be discussed in Section 2.2.1, provided a total of 3.6 million cubic yards (cy) of sand to the County's beaches in 2001 and 2012, respectively.

The 2018 Monitoring Program consisted of three components: beach monitoring, lagoon entrance monitoring, and offshore borrow site monitoring. The beach component included semi-annual profiling along 54 shore-perpendicular transects. The lagoon entrance component addressed five sites in the Oceanside Littoral Cell: the jetty-stabilized entrances at Agua Hedionda and Batiquitos Lagoons, and the unstabilized entrances at San Elijo, San Dieguito, and Los Peñasquitos Lagoons (Figure 1). Monthly observations and ground photographs were acquired at the three unstabilized entrances by SANDAG Staff. The borrow site monitoring included obtaining bathymetry at each site (MB-1, SO-5 and SO-6) and sediment sample collection. Although most of the 2018 Monitoring Program was conducted under contract to SANDAG, beach profile data for fifteen transects were provided by the San Elijo Lagoon Restoration Project and by the Cities of Carlsbad, Encinitas, and Solana Beach. Their contributions are gratefully acknowledged by SANDAG.

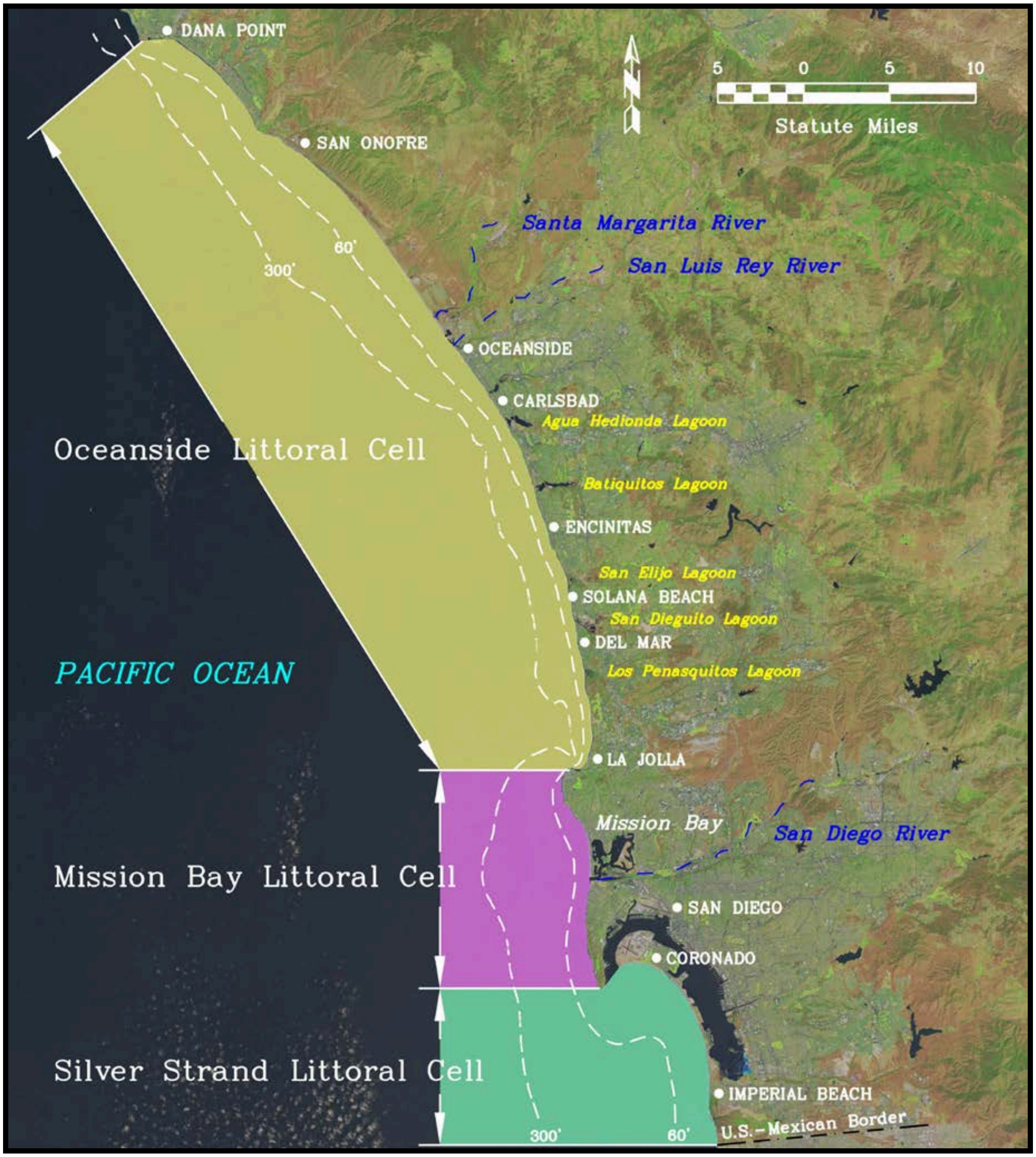


Figure 1. The Coast of San Diego County

To provide continuity with SANDAG's previous monitoring work, a monitoring year is defined as a one-year period from November to October (*e.g.*, the 2018 Monitoring Year extends from November 2017 through October 2018). The primary focus of this report is the 2018 Monitoring Year and the evolution of the County's beaches during the period encompassing both the RBSP I and RBSP II (November 2000 to October 2018). This 18-year period is termed the Post-RBSP I Period.

The remainder of this report provides a detailed account of the 2018 Regional Beach Monitoring Program. Pertinent background information is provided in Section 2, which discusses the environmental conditions and sediment management activities that occurred during the 2018 Monitoring Year and the recent past. Monitoring methods are described in Section 3, while Section 4 presents the results. The condition of San Diego County's beaches is analyzed in Section 5, while Section 6 discusses the condition of the five lagoon entrances in the Oceanside Cell. An assessment of changes at the offshore borrow sites is provided in Section 7. Conclusions are presented in Section 8, and references listed in Section 9. Selected tables, figures, and plates are interspersed with the text, while the remaining tables, plots and plates are provided digitally in Appendices A through F. All elevations are referenced to Mean Lower Low Water (MLLW for the 1983-2001 Tidal Datum Epoch), which lies 2.73 ft below Mean Sea Level (MSL).

2. BACKGROUND INFORMATION

This section presents background information on the natural and human factors that exert a significant influence on the state of the San Diego County coast. It is intended to provide a general context for the monitoring data and to aid in evaluating changes to the beaches and coastal lagoons. Environmental conditions are discussed in Section 2.1, followed by sediment management activities in Section 2.2. All data are presented in terms of "monitoring years" that commence on November 1 and end on October 31 of the following year. The 2018 Monitoring Year, for example, extends from November 1, 2017 through October 31, 2018.

2.1. Environmental Conditions

Environmental conditions of importance to the shorezone include precipitation, streamflow, and waves. During periods of heavy precipitation, rivers and streams can transport substantial quantities of beach-quality sediment to the coast and flush coastal sediment from lagoon entrances. Conversely, riverine sediment input becomes negligible during dry periods (Inman and Masters, 1991). The nature and severity of the wave conditions control the rate of coastal sediment transport, particularly during storms.

Climate variability associated with El Niño Southern Oscillation (ENSO) can produce anomalous oceanographic conditions along the U.S. West Coast. The El Niño component of the cycle typically is accompanied by increased rainfall, higher wave energy, a southerly shift in wave direction, and elevated water levels (Barnard, *et al.*, 2017). As indicated in Figure 2, "very strong" El Niño conditions prevailed in 1972-1973, 1982-1983, 1997-1998, and 2015-2016. The most recent event was the strongest on record. Increased storm frequency and intensity during the latter three events caused significant coastal erosion and infrastructure damage in Southern California (Barnard *et al.*, 2017; Ainsworth, 2016; Hapke, *et. al.* 1998; Dean, *et. al.*, 1984). During the 2018 Monitoring Year, the Oceanic Niño Index fluctuated in the range between "moderate" La Niña and "weak" El Niño conditions.

2.1.1. Precipitation

Although the amount of precipitation varies with location in San Diego County, rainfall patterns tend to be similar throughout the region. In other words, periods of above- or below-average rainfall at one site can be used to infer similar conditions at other sites

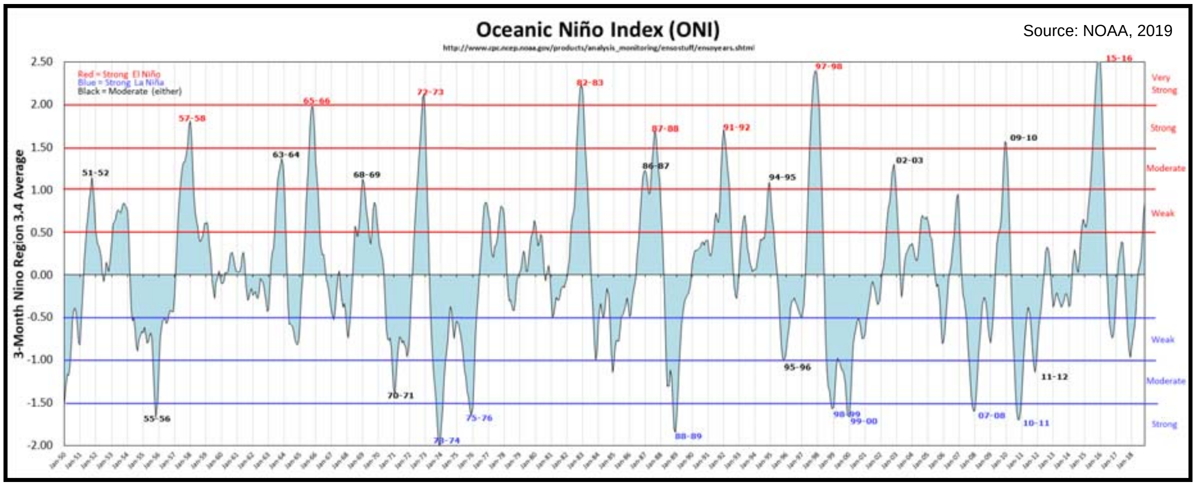


Figure 2. Oceanic Niño Index (1950-2018)

(Elwany, *et al*., 1998). The data acquired at San Diego's Lindbergh Field were selected to represent precipitation in the entire study area, based on this station's extended period of record (1915-present).

Figure 3 shows the annual precipitation measured at Lindbergh Field from 1915 through 2018 (Western Regional Climate Center, 2018). The average value during the period of record was 10.0 inches, with a maximum of 26.4 inches in 1941 and a minimum of 3.4 inches in 2002. Well below-average precipitation (3.9 inches) prevailed during the 2018 Monitoring Year. The year ranked as the fourth driest year since 1915.

The cumulative residual rainfall at Lindbergh Field is shown in Figure 4. Residual rainfall represents the difference between the rainfall observed in a particular year and the average annual rainfall. When the residual values are summed over extended periods of time, the resulting cumulative values provide an indication of long-term climatic trends (Inman and Jenkins, 1999). A positive slope to the graph denotes a "wet" period of above-average precipitation, while a negative slope denotes a "dry" period of below-average precipitation.

Notwithstanding several short-term exceptions, the period from 1945 through 1977 can be characterized as dry, while the period from 1978 through the mid-1990's can be characterized as wet. More recently, predominately dry conditions have persisted since the 1997-98 El Niño event. In this period, below-average rainfall was recorded during 13 out of 20 years. The abnormally high precipitation in 2005 appears to be a short-term anomaly similar to those noted above. The exceptionally low precipitation in 2018 contrasts with the occurrence of above-average precipitation in 2015 and 2017, which appeared to signal a reversal of the trend.

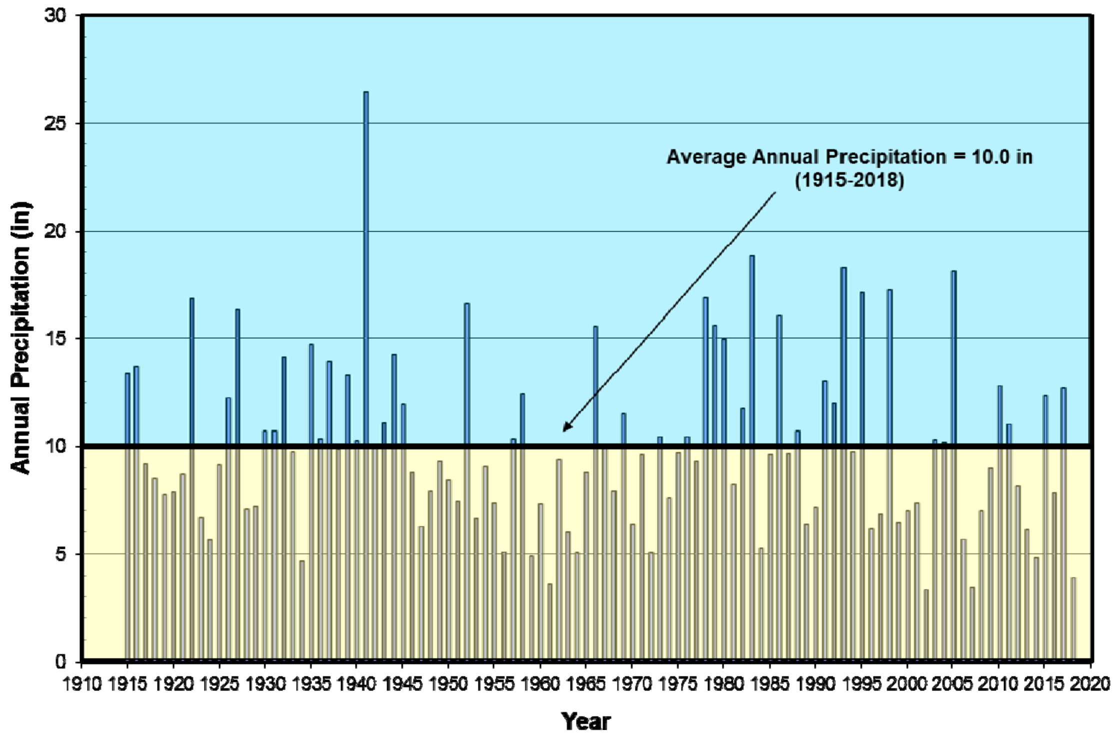


Figure 3. Annual Precipitation at Lindbergh Field, 1915-2018

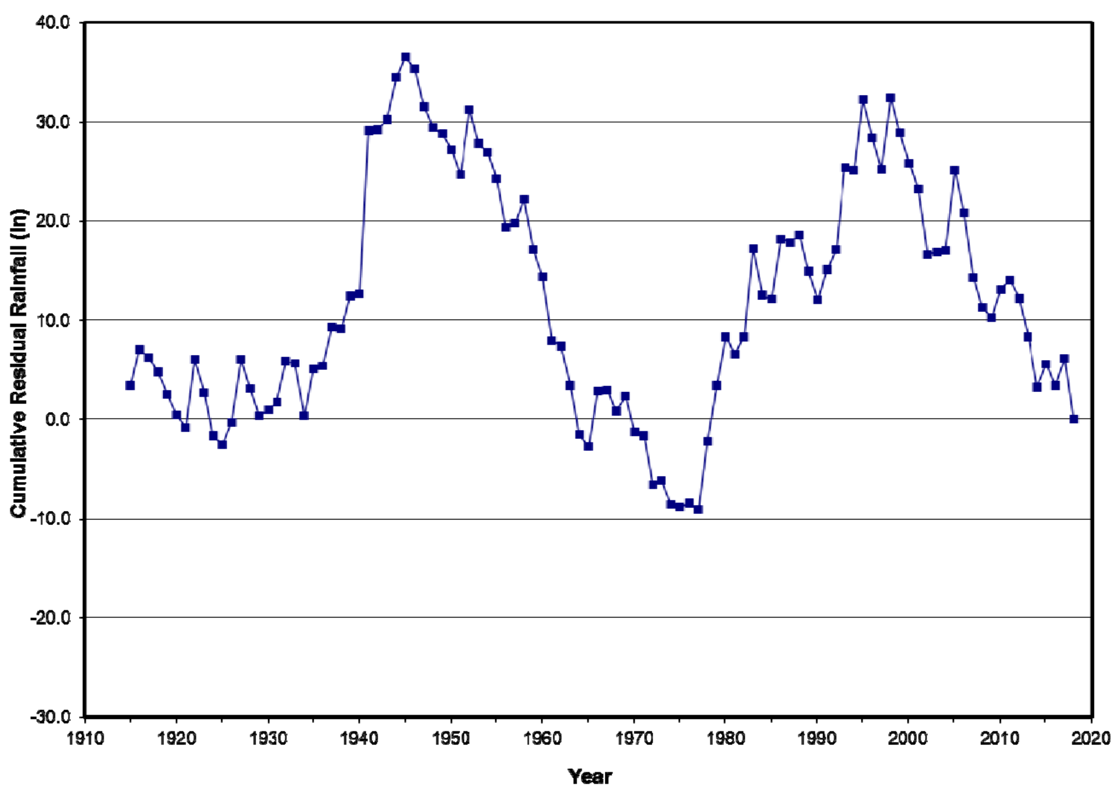


Figure 4. Cumulative Residual Rainfall at Lindbergh Field, 1915-2018

2.1.2. Streamflow

Daily streamflow measurements for the San Luis Rey and San Diego Rivers were obtained from the U.S. Geological Survey (USGS, 2018). The mouth of the San Luis Rey River is located approximately 0.5 miles southeast of Oceanside Harbor, while that of the San Diego River adjoins the entrance to Mission Bay (Figure 1). These rivers were selected for analysis because they are among the largest in the study area, and because streamflow data are available for an extended period of record that includes the current monitoring year.

Figure 5 presents the annual mean streamflow measured in each river between 1983 and 2018. Similar to the precipitation trends (Section 2.1.1), the flow in both rivers was below the long-term average for most of the past two decades. The flow exceeded the long-term average in one or both rivers during only five of the past 20 years. It should be noted that two substantial gaps exist in the data for the San Luis Rey River: (1) October 1992-August 1993, and (2) November 1997-May 1998. Both of these periods were characterized by high streamflow rates in the San Diego River, suggesting that the true long-term average for the San Luis Rey is higher than that shown in Figure 5.

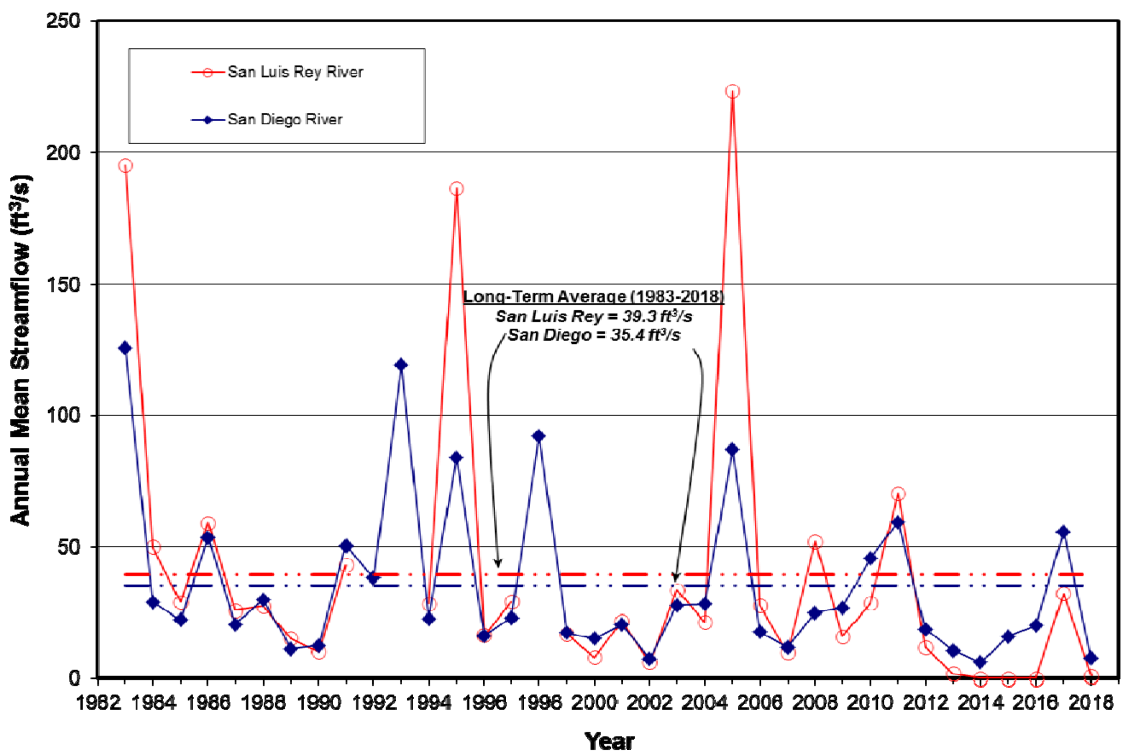


Figure 5. Annual Mean Streamflow in the San Luis Rey and San Diego Rivers, 1983-2018

During the 2018 Monitoring Year the streamflow in both rivers was well-below average. Virtually no flow was recorded in the San Luis Rey River, which after registering slightly below-average streamflow in 2017 returned to the very dry conditions that prevailed during the 2013-2016 period. Similarly, the annual mean streamflow in the San Diego River was the third lowest on record.

2.1.3. Wave Climate

Three measures of the wave climate were used to compare the potential for sediment transport during the 2018 Monitoring Year with that in previous years: (1) the number of storms, (2) the duration of storm conditions, and (3) total wave energy. Although each measure is imperfect, they nevertheless provide a first-order basis for the desired inter-annual comparison.

The analysis was undertaken with wave measurements acquired under the auspices of the Coastal Data Information Program (CDIP), which is operated by Scripps Institution of Oceanography (2018). The CDIP Oceanside Buoy was selected as the data source, primarily because the period of record (May 1997-present) exceeds that of the other active offshore measurement stations in the area.

The significant wave height (H_s), peak wave period (T_p), and wave direction recorded half-hourly at the Oceanside Buoy during the 2018 Monitoring Year are presented as a time series in Figure 6. Southerly swell typical of summer months prevailed into mid-November, transitioning to a mixture of northerly and southerly swell later in the month and through December. Northerly swell then predominated through most of January. Mixed swell conditions occurred again during the months of February, March and April. The remainder of the monitoring year (May through October) was characterized by southerly swell.

Figure 7 shows the significant wave height (H_s) for each storm event with H_s exceeding 7 ft (2.1 m) for the 21-year period from 1998 to 2018. The number of storms per year with H_s exceeding threshold values of 7 ft (2.1 m) and 10 ft (3.0 m) is summarized in Figure 8, while the total number of days each year with H_s exceeding these thresholds is shown in Figure 9.

As indicated in Figures 7 and 8, sixteen storms with H_s surpassing 7 ft occurred during the 1997-1998 El Niño. Milder conditions prevailed from 1999 through 2006 (including the first six years following implementation of the RBSP I nourishment - 2001 to

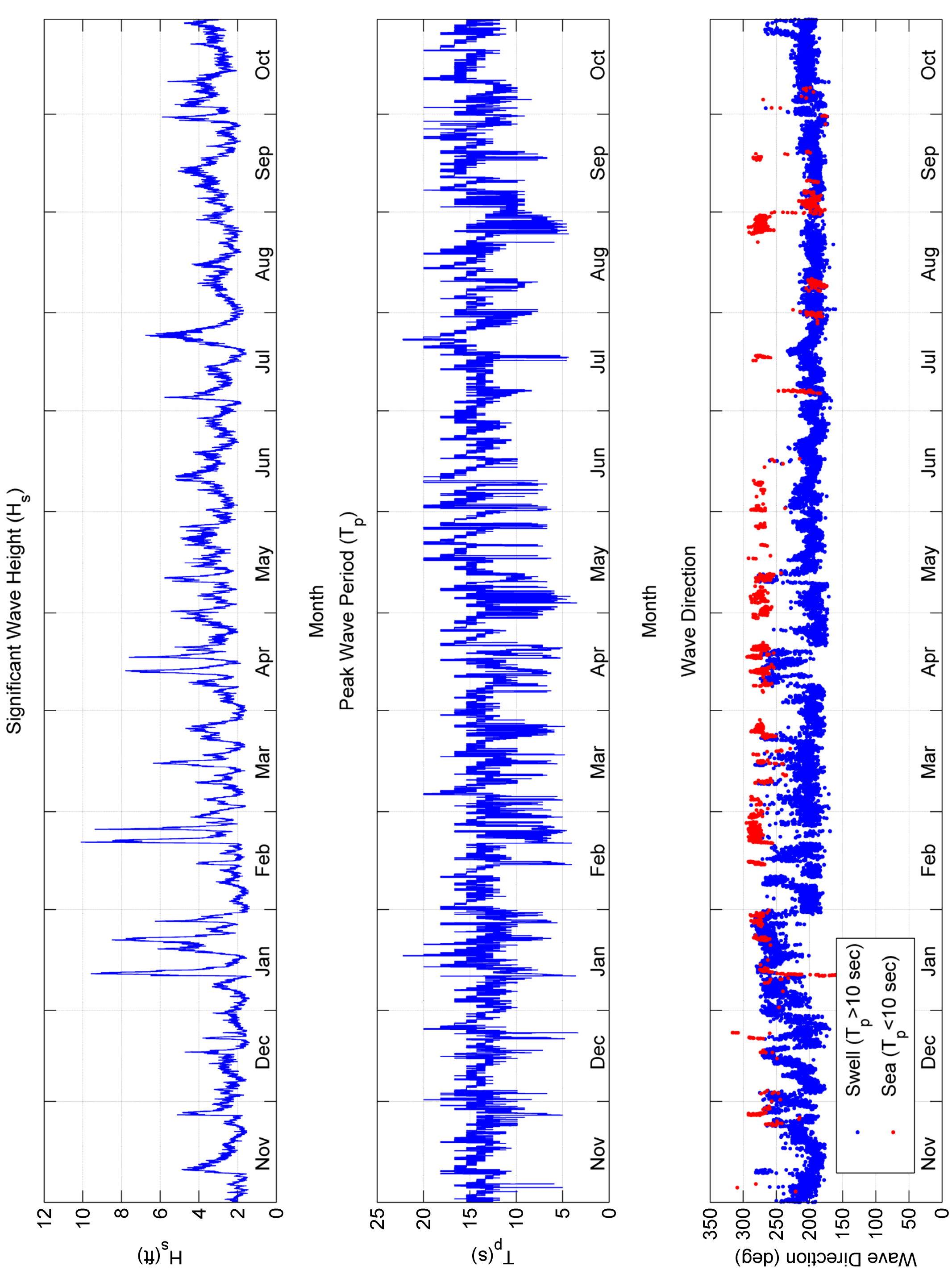


Figure 6. Wave Characteristics at the CDIP Oceanside Buoy, 2018 Monitoring Year

2006), with H_s surpassing 7 ft between five and eight times per year, and surpassing 10 ft between zero and three times per year. Conditions were more severe during the next six years leading up to RBSP II (2007 to 2012), when H_s surpassed 7 ft between ten and eighteen times per year, and surpassed 10 ft between zero and nine times per year. The storm frequency in 2010 (a "moderate" El Niño Year, Figure 2) was the highest during the period of record, surpassing that achieved during the 1997-1998 El Niño event. However, the storm persistence (Figure 9) was greater in 1998, with a higher number of days with H_s exceeding the threshold values of 7 ft and 10 ft.

As indicated in Figures 7 and 8, sixteen storms with H_s surpassing 7 ft occurred during the 1997-1998 El Niño. Milder conditions prevailed from 1999 through 2006 (including the first six years following implementation of the RBSP I nourishment - 2001 to 2006), with H_s surpassing 7 ft between five and eight times per year, and surpassing 10 ft between zero and three times per year. Conditions were more severe during the next six years leading up to RBSP II (2007 to 2012), when H_s surpassed 7 ft between ten and eighteen times per year, and surpassed 10 ft between zero and nine times per year. The storm frequency in 2010 (a "moderate" El Niño Year, Figure 2) was the highest during the period of record, surpassing that achieved during the 1997-1998 El Niño event. However, the storm persistence (Figure 9) was greater in 1998, with a higher number of days with H_s exceeding the threshold values of 7 ft and 10 ft.

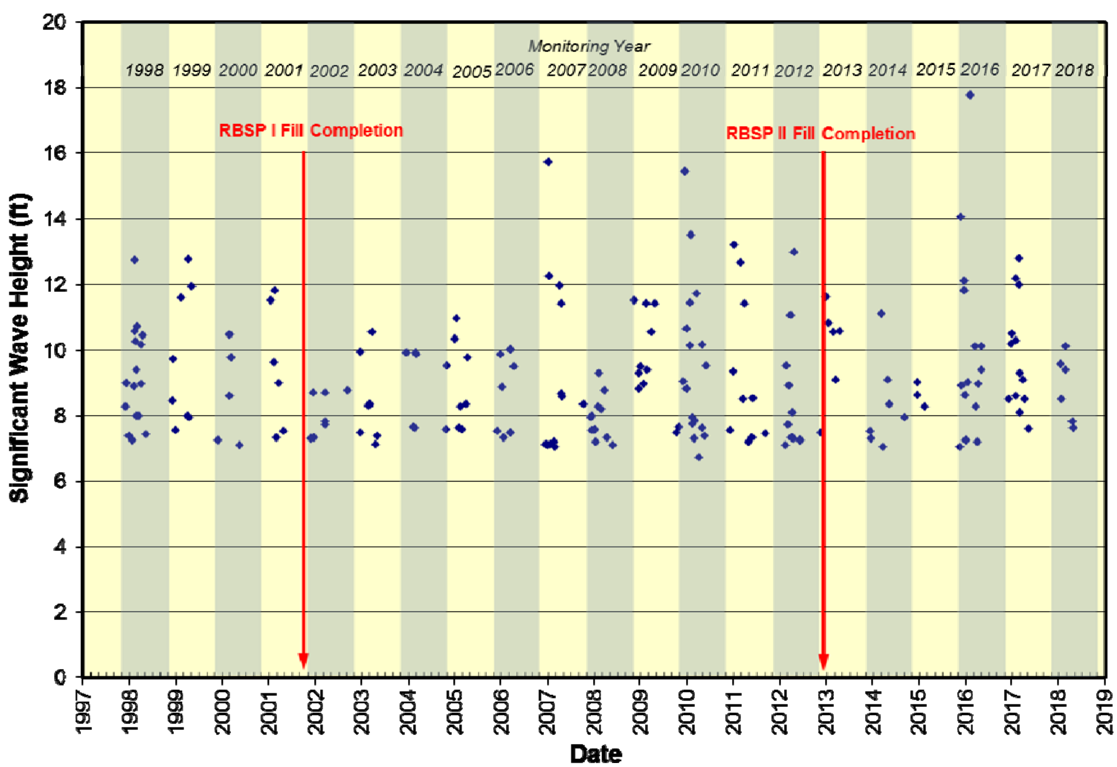


Figure 7. Storm Events with Significant Wave Heights Exceeding 7 ft, 1998-2018

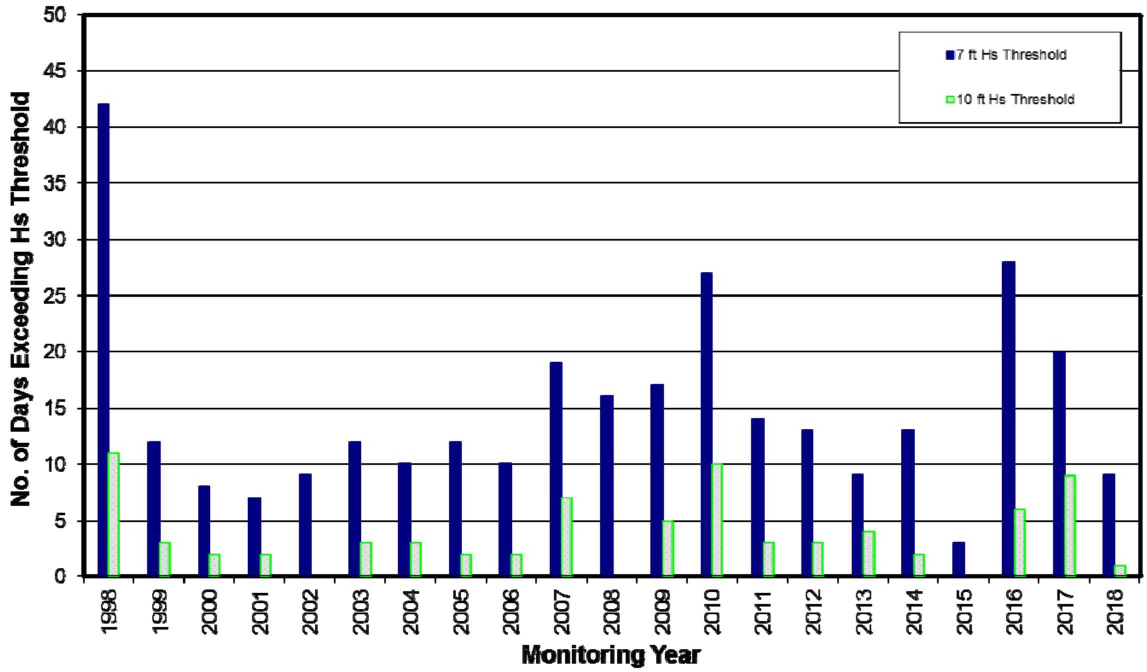


Figure 8. Storm Events per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2018

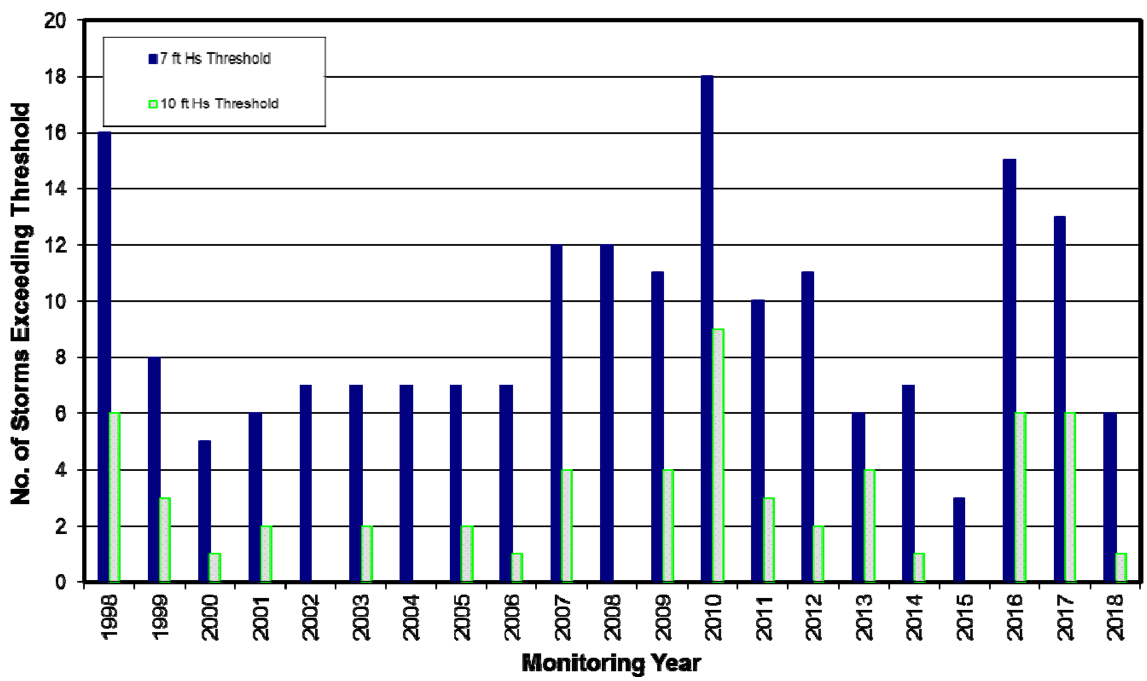


Figure 9. Days per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2018

The total wave energy in each Monitoring Year from 1998 through 2018 is compared using the Relative Incident Energy Index (E_r) developed by Seymour (1998) in concert with the data from the CDIP Oceanside Buoy. This index is based on the following proportionality between the wave power per unit crest length (P) in deep water, the significant wave height (H_s) and the peak wave period (T_p):

$$P \sim H_s^2 T_p \qquad (1)$$

The total energy per unit crest length (E) delivered in a year is found by integrating the wave power (P) over the time (t):

$$E = \int P\, dt \qquad (2)$$

Using Equations (1) and (2) with the wave height expressed in meters, the wave period in seconds, and the duration in hours, Seymour defined E_r as follows:

$$E_r = E/1000 \qquad (3)$$

Gaps in the CDIP Oceanside Buoy data were accounted for by assuming that the average wave power during the remainder of the year prevailed during the periods lacking measurements.

The computed values of E_r are shown in Figure 10. The highest Energy Index values correspond to the 1998, 2010 and 2016 El Niño years. The wave conditions in 1998 yielded the highest Energy Index value (149), followed by 2016 (140). Conditions were comparatively mild during the rest of the period of record. During the first eight years following the RBSP I (2002 to 2009) and the first three years following the RBSP II (2013 to 2015), the Energy Index values ranged from 87 to 113. The Energy Index in 2018 (102) was below average, and the sixth lowest since 1998.

Table 1 summarizes the wave conditions during the 21-year period of record (1998-2018). The highest values during the period are denoted by red italicized type. As described above, the greatest number of days with H_s exceeding the 7 ft and 10 ft thresholds and the highest energy index occurred in 1998. The greatest storm frequency occurred in 2010, while the highest significant wave height was measured in 2016. All of the maximums occurred during El Niño years.

2.2. Sediment Management Activities

Human activities that exert a significant influence on the San Diego County coast include beach nourishment projects such as the two Regional Beach Sand Projects, and sand

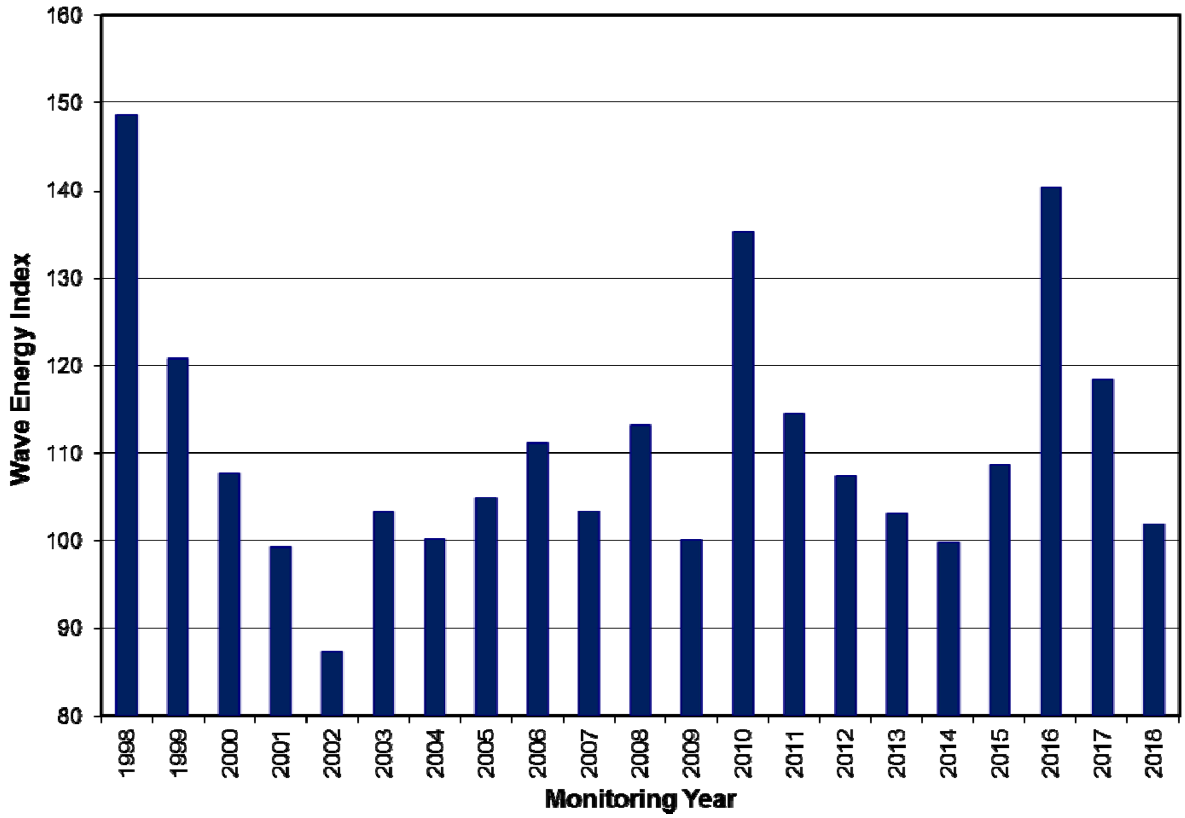


Figure 10. Relative Incident Energy Index at the CDIP Oceanside Buoy, 1998-2018

bypassing at littoral barriers such as Oceanside Harbor. The RBSP I and II are discussed in Section 2.2.1, while all nourishment projects conducted since 1994 are summarized in Section 2.2.2. Sand bypassing activities are described in Section 2.2.3. The nourishment and bypassing rates are summarized in Section 2.2.4.

2.2.1. Regional Beach Sand Projects

In 1993, SANDAG adopted a comprehensive plan for erosion mitigation known as the "Shoreline Preservation Strategy for the San Diego Region". The Strategy proposed an extensive beach building and maintenance program to provide for environmental quality, recreation, and storm protection in the coastal zone. Following a number of modest beach nourishment projects that were undertaken primarily on an opportunistic basis (*i.e*., when sand became available from other sources), the Regional Beach Sand Project I (RBSP I) was conceived and implemented in 2001 as a more comprehensive approach to restoring the County's sand-starved beaches. Based on the success of RBSP I, a second Regional Beach Sand Project (the RBSP II) was conducted eleven years later in 2012.

Table 1. Summary of Wave Conditions, 1998-2018

Monitoring Year	No. of Storms Exceeding Threshold		No. of Days with H_s Exceeding Threshold		Energy Index	Maximum H_s (ft)
	7 ft	10 ft	7 ft	10 ft		
1998	16	6	***42***	***11***	***149***	12.7
1999	8	3	12	3	121	12.8
2000	5	1	8	2	108	10.5
2001	6	2	7	2	99	11.8
2002	7	0	9	0	87	8.8
2003	7	2	12	3	103	10.5
2004	7	0	10	3	100	9.9
2005	7	2	12	2	105	11.2
2006	7	1	10	2	111	10.0
2007	12	4	19	7	103	15.7
2008	12	0	16	0	113	9.3
2009	11	4	17	5	100	11.5
2010	***18***	***9***	27	10	135	15.5
2011	10	3	14	3	114	13.2
2012	11	2	13	3	107	13.0
2013	6	4	9	4	103	11.6
2014	7	1	13	2	100	11.1
2015	3	0	3	0	109	9.0
2016	15	6	28	6	140	***17.8***
2017	13	6	20	9	119	12.8
2018	6	1	9	1	102	10.1
Average	9	3	15	4	111	11.8

Regional Beach Sand Project I (RBSP I)

Between April 6 and September 23, 2001, the RBSP I provided 2.1 million cy of beach-quality sand to twelve receiver beaches located between Imperial Beach and Oceanside. The material was excavated from six offshore borrow areas using a trailing suction hopper dredge, and pumped onto the subaerial portion of each receiver beach (Noble, 2002). The median grain size (d_{50}) varied considerably among the borrow areas, ranging from 0.14 mm (fine sand) to 0.62 mm (coarse sand) (Noble Consultants, 2001).

The volume, dimensions, and median grain size of each RBSP I beach fill, along with the construction period are shown in Table 2. The majority of the sand, 1.8 million cy, was used to nourish ten receiver beaches in the Oceanside Littoral Cell. The nourishment quantities at these sites ranged from 421,000 cy at Oceanside to 101,000 cy at Cardiff. Approximately 151,000 cy of sand were placed at Mission Beach, while in the Silver Strand Cell, 120,000 cy were placed at Imperial Beach.

Regional Beach Sand Project II (RBSP II)

The RBSP II project was smaller in scope than RBSP I, providing approximately 1.5 million cubic yards of beach quality sand to eight receiver beaches located between Imperial Beach and Oceanside. The receiver sites were nearly identical to eight of the RBSP I sites, but four receiver beaches nourished in RBSP I were not included in the second project (Mission Beach, Torrey Pines, Del Mar, and Leucadia).

The material was excavated from three offshore borrow areas using the trailing suction hopper dredge Liberty Island, operated by Great Lakes Dredge And Dock. The sand was pumped onto the subaerial portion of each receiver beach and shaped to the design configuration using conventional earth-moving equipment.

Table 3 provides the volume, dimensions, and median grain size of each beach fill, along with the construction period. The nourishment quantities ranged from 450,000 cy at Imperial Beach to 89,000 cy at Cardiff. The majority of the sand, 1.1 million cy, was used to nourish seven receiver beaches in the Oceanside Littoral Cell. The average median grain size varied from 0.48 mm to 0.66 mm (coarse sand). This was a marked improvement over the RBSP I, where several receiver beaches received material with a median grain size as small as 0.14 mm (fine sand).

Table 2. RBSP I Beach Fills

Littoral Cell	Receiver Beach	Fill Characteristics				Construction Period[2]
		Volume (cy)	Length (ft)	Width (ft)	d_{50} (mm)[1]	
Silver Strand	Imperial Bch	120,000	2,300	120	0.24-0.52	5/22 - 6/04
	Total Nourishment in Silver Strand Cell = 120,000 cy					
Mission Beach	Mission Bch	151,000	2,300	200	0.52	5/10 – 5/21
	Total Nourishment in Mission Beach Cell = 151,000 cy					
Oceanside	Torrey Pines	245,000	1,600	160	0.14	4/06 – 4/27
	Del Mar	183,000	3,200	120	0.14	4/27 – 5/10
	Fletcher Cove	146,000	1,900	70	0.14	6/15 – 6/24
	Cardiff	101,000	900	150	0.34	8/02 – 8/10
	Moonlight Bch	105,000	1,100	180	0.34-0.62	8/10 – 8/16
	Leucadia	132,000	2,700	120	0.62	6/04 – 6/15
	Batiquitos	117,000	1,500	180	0.62	8/16 – 8/23
	S. Carlsbad	158,000	2,000	180	0.62	6/25 – 7/06
	N. Carlsbad	225,000	3,100	100	0.14-0.62	7/06 – 8/02
	Oceanside	421,000	4,400	185	0.62	8/24 – 9/23
	Total Nourishment in Oceanside Cell = 1,833,000 cy					
Total RBSP I Nourishment = 2,104,000 cy						

Notes: (1) d_{50} represents median grain size of fill material.
(2) All nourishment activities were conducted in 2001.

Source: Noble Consultants, 2001

2.2.2. Nourishment Projects, 1994 to 2018 Monitoring Years

A substantial number of beach nourishment projects have been undertaken in San Diego County. In addition to RBSP I and II, 24 other projects of varying size have been conducted since 1994. Nearly all of the non-RBSP nourishment projects depended on "sand of opportunity" that was derived from activities whose primary motive was other than beach replenishment. The largest sources of opportunistic nourishment were the dredge spoils associated with lagoon restoration and harbor maintenance.

Table 3. RBSP II Beach Fills

Littoral Cell	Receiver Beach	Fill Characteristics				Construction Period[2]
		Volume (cy)	Length (ft)	Width (ft)	d_{50} (mm)[1]	
Silver Strand	Imperial Bch	450,000	4,100	285	0.53	9/07 - 10/04
	Total Nourishment in Silver Strand Cell = 450,000 cy					
Oceanside	Solana Beach	142,000	1,600	220	0.55	11/04 – 11/27
	Cardiff	89,000	1,600	110	0.57	10/25 – 10/28
	Moonlight Bch	92,000	800	230	0.48	10/20 – 10/25
	Batiquitos	106,000	1,400	190	0.59	10/28 – 11/24
	S. Carlsbad	141,000	1,600	180	0.66	11/15 – 11/23
	N. Carlsbad	219,000	3,100	165	0.57	11/24 – 12/07
	Oceanside	293,000	4,300	100	0.54	10/05 – 10/20
	Total Nourishment in Oceanside Cell = 1,082,000 cy					
Total RBSP II Nourishment = 1,532,000 cy						

Notes: (1) d_{50} represents median grain size of fill material. Derived from average of multiple samples. Source: Webb, 2013
(2) All nourishment activities were conducted in 2012.

Silver Strand Littoral Cell

Five opportunistic beach nourishment projects were undertaken in the Silver Strand Littoral Cell during the seven-year period that preceded the RBSP I. One was associated with lagoon enhancement at the Tijuana Estuary, while the other four originated with construction and maintenance activities in San Diego Harbor. As shown in Table 4, these projects resulted in an average annual nourishment rate of 73,000 cubic yards per year (cy/yr).

As indicated in Tables 2 and 3, the RBSP I and II provided 570,000 cy of nourishment material to the Silver Strand Cell. Four opportunistic sand replenishment projects have been undertaken in the Silver Strand Cell since RBSP I (Table 5). Approximately 301,000 cy of material dredged from San Diego Harbor were placed offshore, south of the pier in Imperial Beach, between October 2004 and February 2005 (Ryan, 2005). This nourishment quantity is attributed to the 2005 Monitoring Year. In November 2007, approximately 2,000 cy of sand dredged from the Silver Gate Yacht club

Table 4. Beach Nourishment in the Silver Strand Littoral Cell Preceding the RBSP I, November 1993 through October 2000

Project	Date	Sediment Source	Placement Location	Nourishment Quantity (cy)
U.S. Navy Pier 2 Dredging	1995	San Diego Harbor	Imperial Beach (nearshore)	233,000
U.S. Coast Guard Ballast Point Dredging	1995	San Diego Harbor	Imperial Beach (nearshore)	41,000
SIO Nimitz Marine Facility Dredging	1996	San Diego Harbor	Imperial Beach (nearshore)	47,000
San Diego Harbor Maintenance Dredging	1996	San Diego Harbor	Silver Strand State Beach (nearshore)	175,000
Tijuana Estuary Tidal Restoration Project	1997	Tijuana Estuary	South of River Mouth	18,000
Average Annual Nourishment Rate in the Silver Strand Cell = 73,000 cy/yr				

Source: SANDAG, 1996 and 1999a; Sachs, 2002

Table 5. Beach Nourishment in the Silver Strand Littoral Cell During the post-RBSP-I Period, November 2000 through October 2018

Project	Date	Sediment Source	Placement Location	Nourishment Quantity (cy)
RBSP I	2001	Offshore	Imperial Beach	120,000
San Diego Harbor Maintenance Dredging	2005	San Diego Harbor	Imperial Beach (nearshore)	301,000
Silver Gate Yacht Club Dredging	2008	Silver Gate Yacht Club	Imperial Beach (nearshore)	2,000
Tijuana Estuary Sediment Fate and Transport Study	2009	Inland Debris Basin	Borderfield State Park	45,000
Ballast Point Maintenance Dredging	2011	Ballast Pt. Coast Guard Station	Imperial Beach (nearshore)	31,000
RBSP II	2012	Offshore	Imperial Beach	450,000
Average Annual Nourishment Rate in the Silver Strand Cell = 53,000 cy/yr				

Source: Ryan, 2005; Reemts, 2009; Leslie, 2010; Jellison, 2011; Noble Consultants, 2001; Webb, 2013

were placed in the same location (Reemts, 2009). Between November 2008 and October 2009, approximately 45,000 cy of material were placed on the beach at Borderfield State Park as part of the Tijuana Estuary Sediment Fate and Transport Study (Leslie, 2010). In

2011, approximately 31,000 cy were dredged from the U.S. Coast Guard Station at Ballast Point and placed at the Imperial Beach offshore site. Taken together, these amounts equate to an average annual nourishment rate of about 53,000 cy/yr during the 18-year period.

Mission Beach Littoral Cell

Nourishment activity in the Mission Beach Cell preceding the RBSP I was limited to the placement of approximately 12,000 cy of sand in Mission Beach as part of the aborted U.S. Navy Homeporting Project. This small amount translates in an average annual nourishment rate of about 2,000 cy/yr for the 1994-2000 period.

Only one opportunistic sand replenishment project has been undertaken in the Mission Beach Cell after the placement of the RBSP I fill material. Approximately 450,000 cy of material dredged from Mission Bay were placed along a 5,000 ft stretch of Mission Beach between September 27 and November 7, 2010 as part of the U.S. Army Corps of Engineers San Diego River and Mission Bay Maintenance Dredging Project (Ryan, 2011). This nourishment is attributed to the 2010 Monitoring Year. The equivalent average annual nourishment rate in the Mission Beach littoral cell during the 18-year period is about 33,000 cy/yr (Table 6). The cell was not included in RBSP II.

Table 6. Beach Nourishment in the Mission Beach Littoral Cell During the Post-RBSP I Period, November 2000 through October 2018

Project	Date	Sediment Source	Placement Location	Nourishment Quantity (cy)
RBSP I	2001	Offshore	Mission Beach	151,000
USACE Mission Bay Maintenance Dredging	2010	Mission Bay	Mission Beach	450,000
Average Annual Nourishment Rate in the Mission Beach Cell = 33,000 cy/yr				

Source: Noble Consultants, 2001; Ryan, 2011

Oceanside Littoral Cell

Eight nourishment projects, seven of which were opportunistic, were undertaken in the Oceanside Cell between 1994 and 2000. Approximately 2.75 million cy of sand were placed in the littoral cell during that period, averaging 393,000 cy/yr (Table 7). Nearly two thirds of the material were spoils derived from the Batiquitos Lagoon restoration project, which provided 1.8 million cy of sand for beach replenishment in Carlsbad. The only non-opportunistic beach fill undertaken in the Oceanside Cell prior to RBSP I was the annual

Table 7. Beach Nourishment in the Oceanside Littoral Cell Preceding the RBSP I, November 1993 through October 2000

Project	Date	Sediment Source	Placement Location	Nourishment Quantity (cy)
Batiquitos Lagoon Enhancement	1994-97	Batiquitos Lagoon	Carlsbad	1,800,000
Descanso/Carlsbad Blvd. Lot Division	1994	Inland	Carlsbad	20,000
Santa Margarita River Desiltation	1995	River Mouth	Oceanside	40,000
Moonlight Beach Nourishment	1996-2000	Inland (non-opportunistic)	Encinitas	5,000
U.S. Navy Homeporting	1997	North Island	Oceanside	102,000
			Del Mar (nearshore)	170,000
Sand-for-Trash Pilot Program	1997	Inland	Oceanside	1,000
Agua Hedionda Facilities Modification	1998	Agua Hedionda Lagoon	Carlsbad	560,000
North County Commuter Rail Project	1999	Inland	Solana Beach	54,000
Average Annual Nourishment Rate in the Oceanside Cell = 393,000 cy/yr				

Source: SANDAG, 1996, 1999a; Sachs, 2002

placement of approximately 1,000 cy of sand at Moonlight Beach to create a protective berm (years 1996 through 2000).

Table 8 lists the RBSP I and II fills and five other nourishment projects undertaken in the Oceanside Cell during the 18-year period from 2001 through 2018. At Moonlight Beach, the annual beach nourishments continued in 2001 and 2002. After 2002, the berm was created from sediment already present on the beach rather than from imported material (Frenken, 2007). In 2009, the City of Encinitas placed approximately 40,000 cy of material derived from the construction of Pacific Station on the beach near Batiquitos Lagoon (Weldon, 2009). In March 2010, approximately 5,000 cy of material derived from construction of the parking structure at Scripps Memorial Hospital Encinitas were placed at Moonlight Beach (Weldon, *et. al.*, 2011). More recently, in 2018 the San Elijo Lagoon Restoration Project (SELRP) included the reuse of dredged materials from the lagoon as beach nourishment (Coastal Frontiers, 2018c). Approximately 300,000 cy of beach quality

Table 8. Beach Nourishment in the Oceanside Littoral Cell During the Post-RBSP I Period, November 2000 through October 2018

Project	Date	Sediment Source	Placement Location	Nourishment Quantity (cy)
RBSP I	2001	Offshore	10 Receiver Sites (1)	1,833,000
Moonlight Beach Nourishment	2001	Inland (non-opportunistic)	Encinitas	1,000
Moonlight Beach Nourishment	2002	Inland (non-opportunistic)	Encinitas	1,000
Pacific Station Construction	2009	Inland	Leucadia	40,000
Scripps Hospital Parking Structure	2010	Inland	Encinitas	5,000
RBSP II	2012	Offshore	7 Receiver Sites (2)	1,082,000
SELRP	2018	San Elijo Lagoon	Cardiff and Solana Beach	446,000
Average Annual Nourishment Rate in the Oceanside Cell = 189,000 cy/yr				

Notes: (1) See Table 2. (2) See Table 3
Source: Frenken, 2002; Keeley, 2003; Weldon, 2009; Weldon , *et al.*, 2011; Noble Consultants, 2001; Webb 2013; Coastal Frontiers, 2018c

sand were placed at Cardiff during two construction periods: February 15 to April 26, and June 11 to 15. In addition, between April 27 and June 8 approximately 146,000 cy of material were placed at Solana Beach. Both receiver sites were similar to those used during SANDAG's RBSP I and RBSP II. In total, these activities translate in an average annual nourishment rate of 189,000 cy/yr during the 18-year period following RBSP I.

2.2.3. Sand Bypassing

Sand bypassing is used to return to the littoral system sediment that has been trapped by coastal features such as harbors, lagoon entrances, and jetties. Although bypassing does not increase the quantity of sediment in the littoral cell, it plays a crucial role in maintaining the distribution of sediment within the system. Because sediment trapping is a continuous process, bypassing operations typically are conducted at periodic intervals. As with the nourishment activities, two historical periods are considered in this analysis: (1) the seven-year span from November 1993 through October 2000, and (2) the 18-year period commencing with RBSP I implementation (November 2000 through October 2018).

Bypassing is not undertaken in the Silver Strand and Mission Beach Cells. In the Oceanside Cell, bypassing operations occur at Batiquitos Lagoon, Agua Hedionda Lagoon, Oceanside Harbor, San Elijo Lagoon, San Dieguito Lagoon, and Los Peñasquitos Lagoon. Sand bypassing has been undertaken at Agua Hedionda and Oceanside Harbor on a regular basis for decades, while bypassing operations at Batiquitos were initiated in 1997 following lagoon restoration. At San Elijo, a form of bypassing has been conducted in conjunction with the entrance channel maintenance activities since 1994. A similar type of bypassing also has been conducted at San Dieguito since 1999. Bypassing data for Los Peñasquitos are available from 1995 to present, although earlier operations are known to have been conducted (Hastings, 2011).

The sediment quantities bypassed at each site between November 1993 and October 2000 (pre-RBSP I) are shown in Table 9. The maintenance records for San Elijo and Los Peñasquitos do not discriminatre bypass quantities from entrance channel breaching quantities. The values shown in Table 9 for these lagoons were derived by reducing the reported maintenance volumes by 15% for San Elijo and 10% for Los Peñasquitos, based on guidance provided by the respective lagoon foundations (Gibson, 2005; Hastings, 2011). The bypassing volumes for San Dieguito are estimated to be accurate within 1,000 cy (Elwany, 2011). As a result, the quantities for San Elijo, San Dieguito and Los Peñasquitos should be regarded as first-order estimates.

During the Pre-RBSP I Period (Table 9), relatively high bypass rates were maintained at Oceanside Harbor and Agua Hedionda, averaging 252,000 and 143,000 cy/yr, respectively. The estimated average bypass rates at San Elijo and Los Peñasquitos were 14,000 and 13,000 cy/yr, respectively. At San Dieguito, where bypassing was conducted on one occasion prior to the RBSP I, the rate was approximately 8,000 cy/yr. The relatively low rate at Batiquitos (3,000 cy/yr) may be explained by the aforementioned lagoon restoration project. The entrance channel was first opened to continuous tidal exchange in late 1995 (Webb, 2004), and the restoration project was not completed until 1997. In consequence, the years preceding the RBSP I represented a transition period for the lagoon, and the low bypass rate at Batiquitos should be regarded as anomalous.

The sediment quantities bypassed at each site during the 18-year period commencing with RBSP I implementation (November 2000-October 2018) are presented in Tables 10 through 15. At Oceanside Harbor, bypass operations were conducted in each year. The average rate of 255,000 cy/yr is nearly identical to the pre-RBSP I rate of 252,000 cy/yr. It is noteworthy that the 2018 bypassing operations were performed in Fall rather than during the typical Winter/Spring period.

Table 9. Sand Bypassing in the Oceanside Littoral Cell Preceding the RBSP I, November 1993 through October 2000

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Batiquitos Lagoon	1999	South of Entrance	6,000
	2000	South of Entrance	4,000
	Average Annual Bypass Rate at Batiquitos Lagoon = 3,000 cy/yr (1)		
Agua Hedionda Lagoon	1994	Carlsbad	159,000
	1996	Carlsbad	443,000
	1997	Carlsbad	197,000
	1999	Carlsbad	203,000
	Average Annual Bypass Rate at Agua Hedionda Lagoon = 143,000 cy/yr		
Oceanside Harbor	1994	Oceanside	483,000
	1995	Oceanside	161,000
	1996	Oceanside	162,000
	1997	Oceanside	130,000
	1998	Oceanside	315,000
	1999	Oceanside	187,000
	2000	Oceanside	327,000
	Average Annual Bypass Rate at Oceanside Harbor = 252,000 cy/yr		
San Elijo Lagoon	1995	South of Entrance	6,000
	1996	South of Entrance	8,000
	1997	South of Entrance	31,000
	1998	South of Entrance	12,000
	1999	South of Entrance	17,000
	2000	South of Entrance	23,000
	Average Annual Bypass Rate at San Elijo Lagoon = 14,000 cy/yr		
San Dieguito Lagoon	1999	South of Entrance	16,000
	Average Annual Bypass Rate at San Dieguito Lagoon = 8,000 cy/yr (2)		
Los Peñasquitos Lagoon	1995	South of Entrance	22,000
	1996	South of Entrance	5,000
	1997	South of Entrance	17,000
	1998	South of Entrance	8,000
	1999	South of Entrance	8,000
	2000	South of Entrance	20,000
	Average Annual Bypass Rate at Los Peñasquitos Lagoon = 13,000 cy/yr (3)		

Sources: Dillingham, 2002; Tucker, 2002; Ryan, 2003; Gibson, 2005; Elwany, 2011

Notes: (1) Rate computed for the three-year period following lagoon restoration (1998 to 2000).
(2) Rate computed for the two-year period following initiation of bypassing (1999 to 2000).
(3) Rate computed for the six-year period for which data were available (1995 to 2000).

Table 10. Sand Bypassing at Oceanside Harbor, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Oceanside Harbor	2001	Oceanside	80,000
	2002	Oceanside	400,000
	2003	Oceanside	438,000
	2004	Oceanside	220,000
	2005	Oceanside	275,000
	2006	Oceanside	228,000
	2007	Oceanside	194,000
	2008	Oceanside	160,000
	2009	Oceanside	262,000
	2010	Oceanside	270,000
	2011	Oceanside	180,000
	2012	Oceanside	246,000
	2013	Oceanside	194,000
	2014	Oceanside	275,000
	2015	Oceanside	200,000
	2016	Oceanside	245,000
	2017	Oceanside	435,000
	2018	Oceanside	286,000
	Average Annual Bypass Rate at Oceanside Harbor = 255,000 cy/yr		

Sources: Tucker, 2002; Ryan, 2003, 2005-2019

Table 11. Sand Bypassing at Agua Hedionda Lagoon, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Agua Hedionda Lagoon	2001	Carlsbad	429,000
	2003	Carlsbad	337,000
	2005	Carlsbad	375,000
	2007	Carlsbad	335,000
	2009	Carlsbad	299,000
	2011	Carlsbad	226,000
	2015	Carlsbad	295,000
	2018	Carlsbad	205,000
	Average Annual Bypass Rate at Agua Hedionda Lagoon = 139,000 cy/yr		

Sources: Tucker, 2002; Hughes, 2003; Shiffer, 2006; Henika, 2008, 2010, 2012, 2015; Coastal Frontiers, 2018b

Table 12. Sand Bypassing at Batiquitos Lagoon, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Batiquitos Lagoon	2001	South of Entrance	45,000
	2007	South of Entrance	66,000
	2012	South of Entrance	112,000
	Average Annual Bypass Rate at Batiquitos Lagoon = 12,000 cy/yr		

Sources: Dillingham, 2002, 2008; Merkel, 2012

Table 13. Sand Bypassing at San Elijo Lagoon, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
San Elijo Lagoon	2001	South of Entrance	23,000
	2002	South of Entrance	18,000
	2003	South of Entrance	32,000
	2004	South of Entrance	30,000
	2005	South of Entrance	17,000
	2006	South of Entrance	18,000
	2007	South of Entrance	19,000
	2008	South of Entrance	23,000
	2009	South of Entrance	19,000
	2010	South of Entrance	21,000
	2011	South of Entrance	23,000
	2012	South of Entrance	24,000
	2013	South of Entrance	26,000
	2014	South of Entrance	23,000
	2015	South of Entrance	22,000
	2016	South of Entrance	22,000
	2017	South of Entrance	17,000
	2018	South of Entrance (Cardiff Beach Living Shoreline Project)	11,000
	Average Annual Bypass Rate at San Elijo Lagoon = 22,000 cy/yr		

Sources: Tucker, 2002; Gibson, 2005, 2006, 2007, 2012-2019; Trujillo, 2008, 2009, 2010, 2011

Table 14. Sand Bypassing at San Dieguito Lagoon, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
San Dieguito Lagoon	2002	South of Entrance	16,000
	2003	South of Entrance	16,000
	2006	South of Entrance	16,000
	2008	South of Entrance	16,000
	2011	N. (5%) and S. (95%) of Entrance	40,000
	2016	N. (30%) and S. (70%) of Entrance	14,000
	2018	South of Entrance	16,000
	Average Annual Bypass Rate at San Dieguito Lagoon = 7,000 cy/yr		

Sources: Elwany, 2011, 2012, 2018, 2019; Coastal Environments, 2011

Table 15. Sand Bypassing at Los Peñasquitos Lagoon, Nov 2000 through Oct 2018

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Los Peñasquitos Lagoon	2002	South of Entrance	20,000
	2003	South of Entrance	33,000
	2004	South of Entrance	5,000
	2005	South of Entrance	5,000
	2006	South of Entrance	14,000
	2007	South of Entrance	22,000
	2008	South of Entrance	29,000
	2009	South of Entrance	23,000
	2010	South of Entrance	22,000
	2011	South of Entrance	23,000
	2012	South of Entrance	13,000
	2013	South of Entrance	33,000
	2014	South of Entrance	48,000
	2015	South of Entrance	23,000
	2016	South of Entrance	60,000
	2017	South of Entrance	29,000
	2018	South of Entrance	31,000
	Average Annual Bypass Rate at Los Peñasquitos Lagoon = 24,000 cy/yr		

Sources: Elwany, 2011, 2012, 2013; Hastings, 2013, 2014, 2015, 2019; Los Peñasquitos Lagoon Foundation, 2016, 2017a, 2017b

At Agua Hedionda, bypassing operations were undertaken in 2001, 2003, 2005, 2007, 2009, 2011, 2015, and 2018. The average rate during the 18-year Post-RBSP I Period, 139,000 cy/yr, was slightly lower than the pre-RBSP I rate of 143,000 cy/yr. It is noteworthy that the unusually high quantity of material bypassed in 2001 (429,000 cy) was dredged prior to or concurrent with the start of the RBSP I nourishment program.

At Batiquitos, bypassing was undertaken in 2001, 2007, and 2012. Although the resulting average rate of 12,000 cy/yr during the Post-RBSP I Period exceeded the pre-RBSP I average of 3,000 cy/yr, the latter figure is anomalously low for the reasons presented above. In addition, 75,000 cy of sediment were dredged from the lagoon in 2003 but used to enhance least tern nesting sites within the lagoon rather than for bypassing (Dillingham, 2004). Hence, the bypass rate could have been substantially higher during the 18-year Post-RBSP I Period if this material had been returned to the littoral system.

The estimated average bypass rate at San Elijo during the Post-RBSP I Period was 22,000 cy/yr. Although this rate exceeded the pre-RBSP I average of 14,000 cy/yr, the higher rate is attributable at least in part to a conscious increase in the level of maintenance activities commencing in 2000. Bypassing has been conducted during each year since 2001. This change reflects an increase in the funding available to conduct such activities (Gibson, 2005). The material dredged during the 2018 bypassing operation was used for dune construction south of the lagoon entrance in the framework of the Cardiff Beach Living Shoreline Project (Leslie, 2019).

At San Dieguito Lagoon, bypassing operations have been conducted on seven occasions since RBSP I, yielding an estimated average bypassing rate of 7,000 cy/yr. This rate was slightly lower than the pre-RBSP I average (8,000 cy/yr). The higher quantity associated with the 2011 bypassing operations is attributable to increased dredging as part of the initial phase of restoration work at the lagoon (Coastal Environments, 2011).

At Los Peñasquitos Lagoon, bypassing was conducted during each year since 2002. The estimated average bypassing rate (24,000 cy/yr) during the Post-RBSP I Period exceeded the corresponding pre-RBSP I value (13,000 cy/yr) by 11,000 cy/yr.

2.2.4. Sand Management Summary

The beach nourishment quantities placed in each littoral cell during the Pre- and Post-RBSP I Periods are compared in Table 16. In the Oceanside Cell, and despite the placement of over three million cubic yards of material during the RBSP I, RBSP II and

Table 16. Beach Nourishment Rates: Post-RBSP I vs. Historical Average

Littoral Cell	Historical Average[(1)] (cy/yr)	Post-RBSP I Average[(2)] (cy/yr)	Difference[(3)] (cy/yr)
Silver Strand	73,000	53,000	(20,000)
Mission Beach	2,000	33,000	+31,000
Oceanside	393,000	189,000	(204,000)
Total	468,000	275,000	(193,000)

Notes: (1) Historical Average based on the period 1993-2000.
(2) Post-RBSP I Average based on the period 2001-2018.
(3) Difference represents post-RBSP I Average minus Historical Average.

several smaller nourishments, a deficit of 204,000 cy/yr persisted relative to the historical average. The deficit in the Silver Strand Cell is 20,000 cy/yr. Post-RBSP I nourishment rates exceed the historical average only in the Mission Beach Cell, where the historical average nourishment rate was as low as 2,000 cy/yr but reached 33,000 cy/yr between 2001 and 2018.

The sand bypass rates at Oceanside Harbor, Agua Hedionda, Batiquitos, San Elijo, San Dieguito, and Los Peñasquitos during the Post-RBSP I Period are shown in Table 17 in concert with the average annual bypass rates during the seven monitoring years preceding the RBSP I. At Batiquitos, the increased bypassing during the Post-RBSP I Period relative to the historical averages constituted a direct benefit to the beach south of the entrance. However, because lagoon restoration was undertaken during the pre-RBSP I monitoring years and bypassing intervals and volumes have been sporadic, comparison of the rates is not meaningful. At Oceanside Harbor, the volume bypassed during the Post-RBSP I Period was very close to the historical rates. Similarly, the respective bypass rates at San Dieguito Lagoon were nearly identical. The Post-RBSP I Period average bypass rates exceeded the corresponding historical values at San Elijo and Los Peñasquitos, providing a direct benefit to the beaches at Cardiff and Torrey Pines, respectively. The Post-RBSP I Period bypass rate at Agua Hedionda was slightly below the historical average.

Table 17. Sand Bypassing Rates: Post-RBSP I vs. Historical Average

Location	Historical Average(1) (cy/yr)	Post-RBSP I Average(2) (cy/yr)	Difference(3) (cy/yr)
Batiquitos	3,000	12,000	+9,000
Agua Hedionda	143,000	139,000	(4,000)
Oceanside Harbor	252,000	255,000	+3,000
San Elijo	14,000	22,000	+8,000
San Dieguito	8,000	7,000	(1,000)
Los Peñasquitos	13,000	24,000	+11,000
Total	433,000	459,000	+26,000

Notes: (1) Historical Average based on the period 1993-2000.
(2) Post-RBSP I Average based on the period 2001-2018.
(2) Difference represents post-RBSP I Average minus Historical Average.

3. MONITORING METHODS

As indicated in Section 1, the general objective of the 2018 Regional Beach Monitoring Program was to detect changes in the condition of the shorezone between the U.S.-Mexico Border and Oceanside Harbor. The specific focus was to document the evolution of the County's beaches following the placement of nourishment material under SANDAG's Regional Beach Sand Projects (RBSP I and II). The 2018 program includes three components - beach monitoring, lagoon entrance monitoring and offshore borrow site monitoring.

3.1. Program History

SANDAG has conducted a shoreline monitoring program since 1996. The beach monitoring has consisted primarily of beach profile surveys, beach width measurements, and oblique aerial photography. Additional beach profile data are provided through similar programs conducted by the Cities of Carlsbad, Encinitas, and Solana Beach. The lagoon entrances have been monitored through topographic surveys, oblique aerial photos, and monthly inspections. Borrow site monitoring was included for the first time in 2014. The program has evolved to meet changing needs and budgetary constraints, most notably the monitoring requirements associated with the RBSP I and the RBSP II. The details for the programs conducted between 1996 and 2018 are summarized in Table 18.

The program was expanded in 2001 to develop more detailed information about the outcome of the RBSP I nourishment activities. The underlying rationale was to provide coverage of each of the twelve receiver beaches, more detailed coverage of four of these sites (North Carlsbad, Leucadia, Mission Beach, and Imperial Beach), and enhanced coverage of the three unstabilized lagoon entrances in the Oceanside Cell (San Elijo, San Dieguito, and Los Peñasquitos). The program was further expanded in 2002 by adding four beach profile transects and removing one transect of questionable utility. The 2003 and 2004 monitoring programs were identical to that undertaken in 2002.

In 2005, in deference to budgetary constraints, the beach and lagoon monitoring components were reduced by eliminating those elements deemed to be of marginal utility. Specifically, the monthly beach width measurements were discontinued and the lagoon entrance topographic surveys were terminated. In 2006, the program was further condensed by discontinuing the Spring aerial photo reconnaissance and omitting six beach profile transects. The 2007 and 2008 programs were identical to that undertaken in 2006. However,

Table 18. Monitoring Program Components, 1996-2018

YEAR	BEACH MONITORING				LAGOON ENTRANCE MONITORING			BORROW SITE MONITORING
	Beach Profile Transects [1]	Oblique Aerial Photos	Monthly Beach Widths [2]	Ortho-Photos [3]	Topo Surveys	Oblique Aerial Photos	Monthly Inspections	Bathymetric Surveys [10]
1996	24	x	x	✓	x	x	x	x
1997	39	x	x	x	✓	x	x	x
1998	39	x	x	x	✓	x	x	x
1999	40	x	x	x	✓	✓	x	x
2000	45	x	x	x	✓	✓	x	x
2001	58	✓	✓	x	✓	✓	✓	x
2002	61	✓	✓	x	✓	✓	✓	x
2003	61	✓	✓	x	✓	✓	✓	x
2004	61	✓	✓	x	✓	✓	✓	x
2005	61	✓	x	x	✓ [5]	✓	✓	x
2006	55	✓ [4]	x	x	x	✓ [4]	✓	x
2007	55 [6]	✓ [4]	x	x	x	✓ [4]	✓	x
2008	55 [6]	✓ [4]	x	x	x	✓ [4]	✓	x
2009	55 [7]	x	x	x	x	x	✓	x
2010	56 [8]	x	x	x	x	x	✓	x
2011	60 [6, 9]	✓ [4]	x	x	x	✓ [4]	✓	x
2012	60	✓	x	x	x	✓	✓	x
2013	60	✓	x	x	x	✓	✓	x
2014	60	✓	x	x	x	✓	✓	✓
2015	60	✓[4]	x	x	x	✓ [4]	✓	x
2016	60	x	x	x	x	x	✓	✓
2017	60/54[11]	x	x	x	x	x	✓	x
2018	54	x	x	x	x	x	✓	✓

Notes: [1] Includes city sponsored transects. [2] North Carlsbad, Leucadia, Mission Bch, and Imperial Bch.
[3] Ortho-photographs were taken on April 29, 1996. [4] Fall only. [5] Spring 2005 only.
[6] Only 49 transects in Spring 2007, Spring 2008, and Spring 2011 because City of Encinitas program not conducted.
[7] Only 50 transects in Spring 2009 because City of Encinitas program limited to one transect.
[8] One transect added to the City of Encinitas program in Spring 2010.
[9] Transects added in Fall 2011 to support RBSP II .
[10] Borrow site monitoring surveys conducted in Fall 2014 and 2016.
[11] Transects removed from monitoring program in Fall 2017.

because the City of Encinitas program was not conducted in Spring 2007 and 2008, the total number of transects for the combined SANDAG and City programs was reduced from 55 to 49 for the spring period. In Spring 2009, the City of Encinitas obtained profile data at only one location, reducing the total number of transects for the combined programs to 50 for that season. The Fall aerial photo reconnaissance was eliminated in 2009. In Spring 2010, one additional beach profile transect was incorporated into the City of Encinitas monitoring program. Inclusive of the City programs, a total of 56 beach profile transects were surveyed as part of the 2010 SANDAG monitoring effort. Similar to 2008 and 2009, The City of Encinitas program was not conduced in Spring 2011.

The program was expanded in Fall 2011 to provide enhanced monitoring for the RBSP II. Similar to the RBSP I effort, the objective was to provide coverage of each of the receiver beaches, and enhanced coverage of the three unstabilized lagoon entrances in the Oceanside Cell (San Elijo, San Dieguito, and Los Peñasquitos). As such, semi-annual oblique aerial photography of lagoons and the receiver sites was resumed. Seven beach profile transects also were added to the program, including the reinstatement of five sites (two of which had been incorporated into City programs since 2006) and the establishment of three new transects. A total of 60 beach profile transects were surveyed as part of the 2011-2016 SANDAG monitoring programs (including City contributions). In keeping with the lessons learned from the RBSP I monitoring, the previously discontinued lagoon entrance topographic surveys and beach width measurement programs were not re-established. In Fall 2017, the program was further condensed by discontinuing eight beach profile transects. However, two of the sites omitted from the SANDAG program were incorporated into the City of Carlsbad and City of Solana Beach programs, resulting in a total of 54 surveyed transects. More recently, in Fall 2018 six of the beach transects historically surveyed on behalf of the cities were sponsored by the San Elijo Lagoon Restoration Project (SELRP).

The borrow site monitoring component was conducted in 2014, 2016 and 2018. The oblique aerial photography interval was reduced to annually in 2015 (Fall only) and eliminated in 2016.

3.2. Beach Monitoring

Beach profile data along previously established transects were obtained in the Spring and Fall of 2018, corresponding to the transitions between the winter and summer wave seasons. The SELRP and city-sponsored beach profile survey programs discussed above were conducted at the same time, using identical methods. Transect locations are listed in Table 19 and illustrated in Figures 11a and 11b. The Spring 2018 beach survey activities were conducted between May 3 and 9, and the Fall 2018 activities between October 21 and 26. Conditions were favorable during both surveys, and typically consisted of light winds and seas less than 3 ft.

Table 19. Beach Profile Transect Locations

	TRANSECT	LOCATION	2018 SPONSOR	TRANSECT	LOCATION	2018 SPONSOR
Silver Strand Littoral Cell	SS-0003	Tijuana Estuary	SANDAG	SS-0035[1]	Imperial Beach	SANDAG
	SS-0005[3,4]	Tijuana Estuary	-	SS-0050[2]	Imperial Beach	SANDAG
	SS-0015	Imperial Beach	SANDAG	SS-0077	Silver Strand	SANDAG
	SS-0020[1,2,4,5,8]	Imperial Beach	-	SS-0090	Silver Strand	SANDAG
	SS-0025[1,2]	Imperial Beach	SANDAG	SS-0160	Coronado	SANDAG
Mission Beach Littoral Cell	OB-0230	Ocean Beach	SANDAG	MB-0384	Mission Beach	SANDAG
	MB-0310	Mission Beach	SANDAG	PB-0408	Pacific Beach	SANDAG
	MB-0320[2]	Mission Beach	SANDAG			
	MB-0335[1,2,4]	Mission Beach	-			
	MB-0340[1]	Mission Beach	SANDAG			
Oceanside Littoral Cell	LJ-0443	La Jolla	SANDAG	SD-0690[1,2,9]	Leucadia	-
	LJ-0445	La Jolla	SANDAG	SD-0695[2,4]	Leucadia	-
	LJ-0450	La Jolla	SANDAG	SD-0700	Grandview	Encinitas
	LJ-0460	Scripps Pier	SANDAG	SD-0710[1,2]	Batiquitos	SANDAG
	TP-0470	Blacks Beach	SANDAG	CB-0720	Batiquitos	SANDAG
	TP-0520[1]	Torrey Pines	SANDAG	CB-0740	South Carlsbad	Carlsbad
	TP-0530[1]	Torrey Pines	SANDAG	CB-0760	Ponto Beach	SANDAG
	DM-0565[2,4]	South Del Mar	-	CB-0775[1,2]	South Carlsbad	Carlsbad
	DM-0560[3,8]	Del Mar	-	CB-0780	Carlsbad	Carlsbad
	DM-0580[1]	Del Mar	SANDAG	CB-0800	Carlsbad	Carlsbad
	DM-0590	Del Mar	SANDAG	CB-0820	Aqua Hedionda	Carlsbad
	SD-0595[3]	Seascape Surf	Solana/SELRP	CB-0830	Carlsbad	SANDAG
	SD-0597[1, 7]	Surfsong	Solana/SELRP	CB-0840	Carlsbad	Carlsbad
	SD-0600[1]	Fletcher Cove	SANDAG	CB-0850	Carlsbad	Carlsbad
	SD-0610[3]	Tide Park	Solana/SELRP	CB-0865[1,2]	Carlsbad	SANDAG
	SD-0620	Seaside Park	Encinitas/SELRP	CB-0880[1]	Buena Vista	SANDAG
	SD-0625	San Elijo	Encinitas/SELRP	OS-0900	Oceanside	Carlsbad
	SD-0630[1]	Cardiff	SANDAG	OS-0915[1,2,4,5,9]	Oceanside	-
	SD-0650	San Elijo Park	Encinitas/SELRP	OS-0930[1]	Buccaneer Bch	SANDAG
	SD-0660	Swami's	Encinitas	OS-0947[1,7,9]	Crosswaithe	-
	SD-0663[6,8]	J Street	SANDAG	OS-1000	Oceanside	SANDAG
	SD-0670[1]	Moonlight Beach	SANDAG	OS-1030	Oceanside	SANDAG
	SD-0675[2]	Stone Steps	SANDAG	OS-1070	Oceanside	SANDAG
	SD-0680	Beacons	SANDAG			

Notes:
(1) Transect crosses RBSP I or II nourishment site.
(2) New transect established to support RBSP I in 2001.
(3) Transect added to monitoring program in 2002.
(4) Transect removed from monitoring program in Spring 2006.
(5) Transect reinstated to monitoring program in Fall 2011.
(6) Transect added to monitoring program in Spring 2010.
(7) New transect established to support RBSP II in 2011.
(8) Transect removed from monitoring program in Fall 2017.

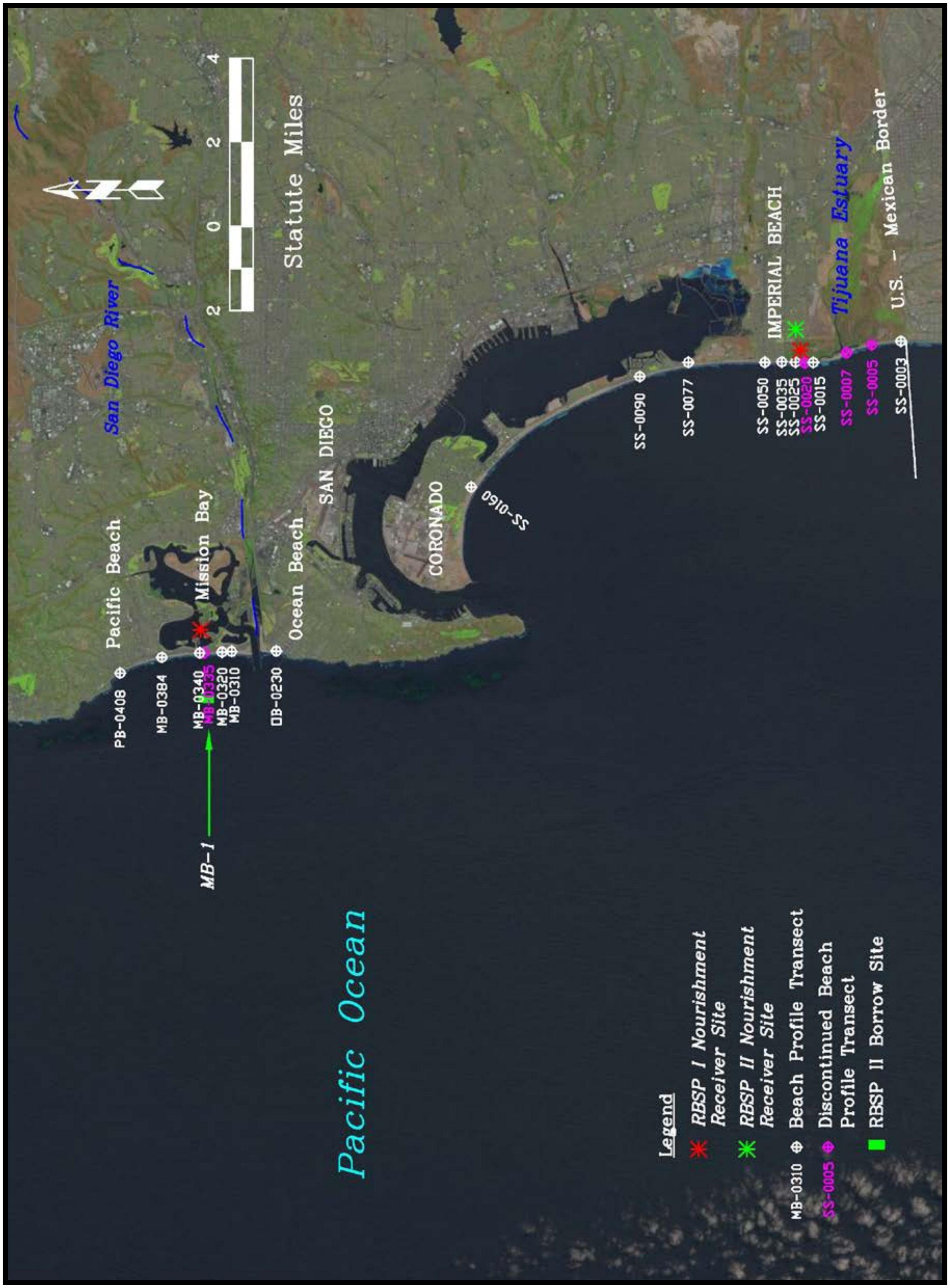


Figure 11a. Beach Profile Transects in the Silver Strand and Mission Beach Littoral Cells

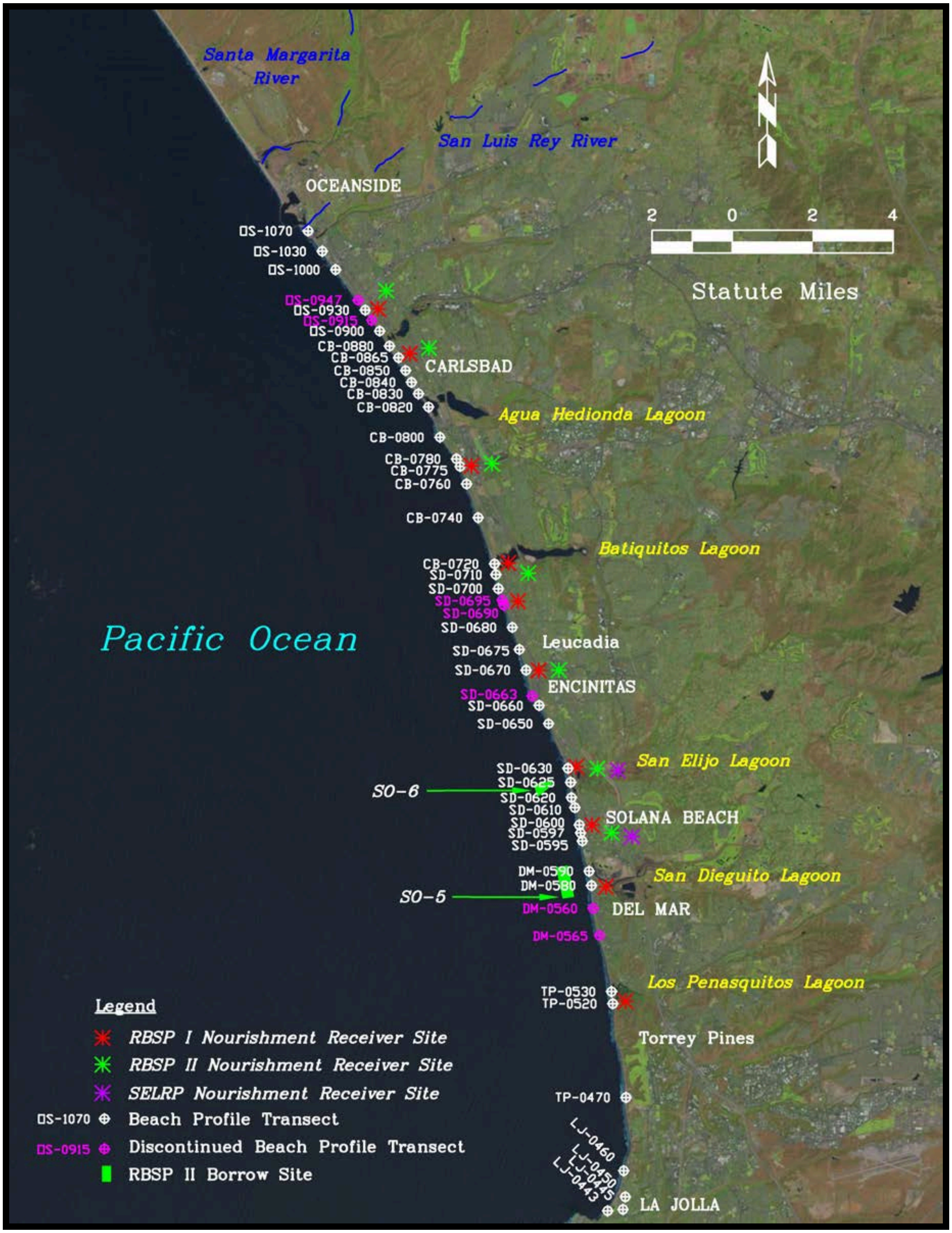


Figure 11b. Beach Profile Transects and Lagoon Entrances in the Oceanside Littoral Cell

The data acquisition and processing methods used for the 2018 profile surveys are described below. The methods remained similar to those employed in previous SANDAG and city monitoring programs (Leidersdorf, *et al.*, 1999). In consequence, the results are directly comparable.

Data Acquisition

The wading and bathymetric portions of the survey were performed concurrently by two crews. Data were acquired along each transect from the survey marker to an offshore limit that ranged from the 35-ft isobath in the Silver Strand Cell to the 50-ft isobath in the northern portion of the Oceanside Cell. Survey markers were located at the back beach, while the offshore limit of each transect was located seaward of the "depth of closure" as indicated by prior survey data. The depth of closure is the depth at which sediment transport is not substantially affected by littoral processes.

The subaerial beach and surf zone were surveyed using an electronic total station and a survey rodman. The total station was used to determine the position and elevation of the beach at each location occupied by the rodman. Each transect was surveyed from the back beach seaward through the surf zone until the rod no longer protruded above the water surface when held erect. This location, typically in a water depth of 10 to 12 ft below MLLW, provided substantial overlap with the landward portion of the bathymetric survey.

Bathymetric data were collected with a digital acoustic echo sounder operated from a shallow-draft survey vessel. A dynamic motion sensor, which provides real-time corrections to the echo sounder for wave-induced vessel heave, also was utilized. A dual antenna GPS receiver was used to determine the vessel heading and the position of each sounding. To improve the accuracy of each position, differential corrections transmitted in real-time from the Wide Area Augmentation System (WAAS) were utilized (DGPS). All systems were interfaced to a laptop computer using the Hypack survey software package.

The boat traveled along each transect from the offshore terminus to the surf zone guided by DGPS navigation. Soundings were acquired on a continuous basis, with the ping rate based on the local water depth. Positions were recorded at 1 Hz. The DGPS position data and sounding data were merged using Hypack, with interpolated positions being assigned to the soundings acquired between position fixes.

The calibration of the echo sounder was checked at the beginning and end of each survey day, and at periodic intervals during each session, using a standard "bar check" procedure. In addition, the speed of sound in the water column was obtained at the offshore end of each transect using a conductivity, temperature, and depth instrument (CTD).

Data Processing

The raw total station data from the wading portion of the survey were acquired using Carlson SurvCE software, and coordinate and elevation data were calculated in real time. Following the survey, the processed data were inserted into a surface modeling utility for comparison with the bathymetric survey data (Trimble Terramodel).

Data from the bathymetric portion of the survey were processed using Hypack. The raw soundings were edited for outliers and corrected based on the speed-of-sound profiles obtained at the end of each transect. The soundings were adjusted to MLLW datum using tide measurements made by the U.S. Department of Commerce, NOAA, at La Jolla (Station ID 9410230).

The processed soundings were thinned to a nominal horizontal spacing of 10 ft and inserted into the surface modeling utility containing the topographic data. No bias was used in the thinning process. As indicated above, the field work was conducted in such a manner as to provide overlap between the wading and bathymetric portions of the survey. The data were examined in this region to ensure that the two data sets were compatible. Once this confirmatory inspection had been completed, only the more detailed data in the region of overlap were retained (typically the bathymetric data). The survey points then were projected onto the transect alignment, and the resulting range and elevation data were used to create a continuous beach profile plot.

Based on past experience, the vertical accuracy of the processed bathymetric soundings is approximately ±0.5 ft. According to the Hemisphere GPS equipment specifications, the root mean square (RMS) accuracy of horizontal positions obtained in the manner described above is 2.0 ft. The electronic total station used to conduct the survey is capable of measuring elevation differences to within ±0.1 ft and ranges to within ±0.5 ft. However, because the swimmer was subjected to waves and currents in the surf zone, the horizontal position perpendicular to each transect (parallel to the shoreline) varied from minimal at short ranges to approximately ±15 ft at the offshore end.

3.3. Lagoon Entrance Monitoring

The unstabilized entrance channels at San Elijo, San Dieguito, and Los Peñasquitos were inspected and photographed on a monthly basis. In addition to obtaining photographs from repeatable locations, the site visits included notes on whether the channels were open to tidal exchange. The monthly channel inspections were undertaken by SANDAG. As indicated in Section 3.1, aerial photography was eliminated in 2016.

3.4. Borrow Site Monitoring

The borrow site monitoring consisted of obtaining bathymetric data and sediment samples at each of the three dredge pits utilized for the RBSP II (MB-1 in the Mission Beach Cell, and SO-6 and SO-5 in the Oceanside Cell). The borrow pits locations are shown in Figures 11a and 11b. Data were acquired at the time of the Fall 2018 beach profile survey.

3.4.1. Bathymetric Surveys

At each borrow site, bathymetric data were obtained along one transverse and one longitudinal transect passing through the approximate center of the dredged depression. The field work was undertaken on October 24 using the same inflatable survey vessel and methods as during the beach profile survey (Section 3.2).

3.4.2. Sediment Samples

Two sediment samples were obtained within the dredged footprint of each borrow site using a Petit Ponar sampler deployed from the inflatable survey vessel. The position of each sample was determined with DGPS. The particle size distribution of each sample was derived in accordance with American Society for Testing and Materials (ASTM) D 422-63 (Test Method of Particle-Size Analysis of Soils). Gradation curves were generated for each sample, with “fines” defined as that material passing the #200 sieve (less than 0.074 mm).

4. MONITORING DATA

This section presents the results of the 2018 Regional Beach Monitoring Program. Beach monitoring data are described in Section 4.1, while lagoon entrance products are described in Section 4.2. The borrow site monitoring data are discussed in Section 4.3

4.1. Beach Data

As discussed in Section 3.2, beach data acquisition consisted of semi-annual profile surveys conducted in the Spring and Fall. Although aerial photography was omitted from the program in 2016, the photos obtained during prior missions are included in Appendix E.

4.1.1. Beach Profile Data (Appendices A-E, Digital Only)

The 2018 beach profile data were used in conjunction with data from the prior surveys to create profile plots and compute changes in shoreline position, beach width, and sediment volume. Selected historical data acquired prior to the SANDAG Monitoring Program also were utilized. A summary of the publically available historical beach profile data for the San Diego region and an inventory of the recent profile data acquired by SANDAG, Carlsbad, Encinitas, and Solana Beach is provided in **Appendix A**.

Beach profile plots for each transect are provided in **Appendix B**. Each plot provides separate panels showing the nearshore region and the entire length of each profile. In addition to the Spring and Fall 2018 data, the plots display Fall profiles from 2000, 2011, 2012, 2013, 2014, 2015, 2016 and 2017. The Fall 2000 profile represents the pre-RBSP I condition, while the Fall 2011 profile serves as the pre-RBSP II condition. The Fall 2012 survey was the first conducted after completion of the RBSP II fills. To the extent that data are available, select plots include envelopes of all profiles obtained during the SANDAG monitoring period that preceded the RBSP I (Spring 1996-Spring 2001) and the period following RBSP I and preceding RBSP II (Fall 2001 to Spring 2012).

When reviewing Appendix B, it is important to note that the marked vertical relief evident in profiles obtained after Fall 2000 resulted from the improved survey resolution rather than from actual changes in the sea bottom. A likely explanation for the “jaggedness” is the presence of exposed rock reefs which were not identifiable until the on-board dynamic motion sensor and data acquisition computer were added to the equipment suite in 2002. Although the data obtained in such areas can vary considerably from survey to survey due to differences in the vessel track and wave conditions, the improved resolution afforded by this technology is beneficial in identifying potential hard-bottom habitat.

Comparing the Spring and Fall profiles provides an indication of seasonal changes, while comparing consecutive Fall profiles illustrates the nature of inter-annual and long-term changes. A significant difference between one of the historical envelopes (pre-RBSP I or post-RBSP I) and one or more of the post-RBSP II profiles indicates a material change in the beach condition that may have resulted from the RBSP II nourishment activities.

Tables and plots of shoreline position and beach width derived from the profile data are provided in **Appendix C**. Data from a pre-1984 survey, Fall 1984, Fall 1989, and the 46 Spring and Fall surveys conducted from 1996 to 2018 were used to the extent that they were available. Because the survey data acquired prior to 1984 are relatively sparse in both time and space, it was not possible to select a single survey from this period that encompassed more than a small percentage of the transects. Therefore, pre-1984 data for each transect were selected on an individual basis, with preference given to data collected during the fall. The Fall 1984 and Fall 1989 data were selected for analysis because many of the historical transects were surveyed at these times.

The following shoreline and beach width tables were prepared:

MSL Shoreline Positions

The shoreline position was computed as the horizontal distance, in feet, between the transect origin (typically a permanent marker located near the back beach) and the point at which the beach profile intersected the plane of MSL Datum. Notwithstanding the use of MLLW as the elevation reference for the profile data, MSL was adopted as the shoreline reference in the belief that it provides a more accurate indicator of changes in beach configuration.

Seasonal Changes in MSL Shoreline Position

Seasonal changes in MSL shoreline position were determined for the 23 most recent summers (1996 through 2018), and 22 most recent winters (1996-1997 through 2017-2018). The changes are expressed in feet, with positive values denoting shoreline advance and negative values denoting shoreline retreat.

Long-term Changes, Long-term Change Rates, and Annual Changes

Long-term shoreline changes were calculated for three intervals that preceded the RBSP I: pre-1984 to Fall 1984; Fall 1984 to Fall 1989 (5 years); and Fall 1989 to Fall 2000 (11 years), as well as the 18-year period encompassing the RBSP I and RBSP II (Fall 2000 to Fall 2018). In addition, the shoreline changes were calculated for the seven-year period encompassing the RBSP II (Fall 2011 to Fall 2018). Long-term change rates were calculated by dividing the change in MSL shoreline position by the corresponding time interval. To reflect the seasonal nature of changes in beach configuration, the time interval was computed in one-quarter year increments (winter, spring, summer, and fall). For example, the time interval between surveys conducted in September 1984 (Fall 1984) and November 1989 (Fall 1989) was taken as 5 years rather than 5.17 years. The change rates are expressed in feet/year, with positive values denoting shoreline advance and negative values denoting retreat. To facilitate comparisons between long- and short-term changes, the long-term changes and change rates are tabulated with the annual changes in shoreline position recorded between Fall 1996 and Fall 2018.

MSL Beach Widths

Beach width provides an indication of recreational area as well as the protection afforded to upland facilities. The width was computed as the distance between the landward edge of the beach sand and the MSL shoreline position.

Sediment volume changes are tabulated in **Appendix D**. The changes were computed along each transect for the entire width of the shorezone, and for that portion of the profile located above MSL.

The onshore boundary of the control volume for both the shorezone and the beach above MSL was placed at either the landward limit of the sandy beach or the transect origin. The offshore boundary of the control volume for the beach above MSL was placed at the intersection of the profile and a horizontal line corresponding to the elevation of MSL. The offshore boundary for the shorezone was placed at the "statistical range of closure". This parameter represents the distance seaward of the transect origin beyond which profile variations are smaller than the accuracy of the survey technique. As implied by its definition, the statistical range of closure was adopted as the offshore boundary to separate the signal of true profile change from the noise of survey inaccuracy. The sea bottom elevation at the range of closure corresponds to the "depth of closure" described in Section 3.2.

The statistical range of closure for each transect first developed in 2001 (Coastal Frontiers, 2002) was re-derived following the Fall 2012 survey in order to incorporate the additional beach profile data obtained from 2002 through 2012. The method for developing the range of closure was similar to that used in 2001, and is described below:

- The successive survey profiles were interpolated to obtain sea bottom elevations at a common set of ranges spaced 15 ft apart.
- The sample standard deviation of the sea bottom elevations was computed at each 15-ft range increment.
- Statistical closure was assumed to occur at the smallest range at which σ decreased below the survey accuracy of 0.5 ft, provided that the average value of σ remained less than or equal to 0.5 ft seaward of that point. If this condition was not satisfied by the first downcrossing below 0.5 ft, the next downcrossing seaward of that location was checked.
- In determining statistical closure, attention was restricted to depths greater than 12 ft (MLLW) to insure that the berm-bar portion of the profile would be included in the control volume.

To the extent that data were available, the determination of statistical closure was based on the 31 semi-annual surveys that commenced in Fall 1997 and ended in Fall 2012. Surveys prior to Fall 1997 were not used, because they tended either to omit a significant number of the current transects, or to terminate landward of the depth of profile closure. In the case of transects that were surveyed for the first time in Fall 2011, the range of closure was estimated from one or more adjoining transects with similar exposure and characteristics.

In a limited number of cases, the statistical range of closure as calculated using the method above was found to lie landward of the point where all of the profiles appeared to "pinch" together. This situation typically was associated with one of the 1998 post-El Niño profiles falling outside of the tighter cluster of profiles. Rather than arbitrarily move the range of closure further offshore, the calculated value was retained to maintain an unbiased methodology and because the 1998 surveys predate the primary analysis period for the RBSP-era (2000 to present).

The results of the assessment are presented in Table 20, which provides the computed range of closure and associated depth of closure for each transect. All of the

Table 20. Range and Depth of Closure at Each Profile Location

	Transect[2]	Location	Range of Closure[3]	Depth of Closure[5]
Silver Strand Littoral Cell	SS-0003	Tijuana Estuary	1431	-31
	SS-0005[1]	Tijuana Estuary	1041	-22
	SS-0007[1]	Tijuana Estuary	1129	-17
	SS-0015	Imperial Beach	1480	-19
	SS-0020[1]	Imperial Beach	1597	-24
	SS-0025	Imperial Beach	1873	-28
	SS-0035	Imperial Beach	2289	-30
	SS-0050[4]	Imperial Beach	1173	-22
	SS-0077	Silver Strand	1793	-29
	SS-0090	Silver Strand	1435	-29
	SS-0160	Coronado	1965	-24
Mission Beach Littoral Cell	OB-0230	Ocean Beach	2459	-25
	MB-0310	Mission Beach	1545	-26
	MB-0320	Mission Beach	1407	-24
	MB-0335[1]	Mission Beach	1209	-20
	MB-0340	Mission Beach	1641	-29
	MB-0384	Mission Beach	1602	-26
	PB-0408	Pacific Beach	1029	-12
Oceanside Littoral Cell	LJ-0443	La Jolla Shores	1014	-12
	LJ-0445	La Jolla	818	-12
	LJ-0450	La Jolla	1271	-19
	LJ-0460	Scripps	1042	-19
	TP-0470	Blacks Beach	1421	-26
	TP-0520	Torrey Pines	1796	-32
	TP-0530	Torrey Pines	1446	-26
	DM-0565[1]	Del Mar	1213	-12
	DM-0560[(1, 4]	Del Mar	1585	-26
	DM-0580	Del Mar	1933	-30
	DM-0590	San Dieguito	1110	-16
	SD-0595	Seascape Surf	1122	-16
	SD-0597[4]	Surfsong	994	-16
	SD-0600	Fletcher Cove	1066	-16
	SD-0610	Tide Park	1520	-24
	SD-0620	Seaside Park	1304	-21

(continued)

Table 20. Range and Depth of Closure at Each Profile Location (continued)

	Transect[2]	Location	Range of Closure[3]	Depth of Closure[5]
Oceanside Littoral Cell (continued)	SD-0625	San Elijo Lagoon	1156	-21
	SD-0630	Cardiff	1598	-28
	SD-0650	San Elijo St. Bch	1136	-18
	SD-0660	Swami's	875	-12
	SD-0663[1,4]	J Street	1602	-24
	SD-0670	Moonlight Bch.	1630	-30
	SD-0675	Stone Steps	875	-12
	SD-0680	Leucadia	1108	-17
	SD-0690[1]	Leucadia	929	-14
	SD-0695[1]	Leucadia	876	-12
	SD-0700	Grandview	1203	-20
	SD-0710	Leucadia	1231	-23
	CB-0720	Batiquitos	1450	-24
	CB-0740	S. Carlsbad	1349	-22
	CB-0760	Ponto Beach	1152	-21
	CB-0775	South Carlsbad	957	-12
	CB-0780	Carlsbad	1463	-24
	CB-0800	Carlsbad	1105	-12
	CB-0820	Agua Hedionda	1172	-21
	CB-0830	Carlsbad	1005	-18
	CB-0840	Carlsbad	1064	-20
	CB-0850	Carlsbad	946	-12
	CB-0865	Carlsbad	1088	-17
	CB-0880	Buena Vista	908	-14
	OS-0900	S. Oceanside	1160	-24
	OS-0915[1]	Oceanside	1010	-22
	OS-0930	Buccaneer	1329	-25
	OS-947[1,4]	Crosswaithe	1339	-23
	OS-1000	Oceanside	1178	-21
	OS-1030	Oceanside	1237	-21
	OS-1070	Oceanside	1759	-21

Notes:
(1) Transect not included in 2018 program.
(2) Transect locations are indicated in Figures 11a and 11b.
(3) Range of closure measured in feet from transect origin, and based on Fall 1997 through Fall 2012 survey data unless otherwise noted.
(4) Range of closure estimated from nearby transects due to insufficient data.
(5) Depth of closure provided in feet relative to MLLW.

volume changes reported in Appendix D pertaining to the prior monitoring years have been adjusted to reflect the change.

The shorezone volume per linear foot of shoreline (cy/ft) of each profile was calculated as the area between the profile and an arbitrary basement elevation located at -60 ft. Seasonal volume changes were computed for the 21 most recent summers (1998 through 2018) and 21 most recent winters (1997-1998 through 2017-2018). Annual volume changes were calculated for the 21 one-year intervals between Fall 1997 and Fall 2018. Long-term changes were determined for the three year period preceding the RBSP I (Fall 1997 to Fall 2000), the seven-year period encompassing the RBSP II (Fall 2011 to Fall 2018), and the 18-year period encompassing the RBSP I and RBSP II (Fall 2000 to Fall 2018).

Similar to the beach width, the beach volume above MSL provides an indication of the available recreational area and the protection afforded to upland facilities. Beach volume changes were computed for the same periods described above.

4.1.2. Aerial Photographs (Appendix E)

As indicated in Section 3.1, aerial photography was eliminated from the program in 2016. A comprehensive set of photos obtained between 2001 and 2015 (including four additional RBSP I sites not included in the RBSP II construction) is provided in **Appendix E**. Additional aerial photographs covering the twelve sites were provided to SANDAG in digital form following each overflight.

4.2. Lagoon Entrance Data

Lagoon entrance monitoring data consisted of monthly observations and photographs at the unstabilized entrances to San Elijo, San Dieguito, and Los Peñasquitos. Selected ground photographs obtained by SANDAG at these entrances are provided in **Appendix F**. As indicated in Section 3.1, aerial photography was eliminated from the program in 2016. However, representative aerial photos obtained in 2015 are provided in Section 6.

4.3. Borrow Site Data

Borrow site monitoring data consisted of representative sea bottom profiles and sediment samples taken at each of the three RBSP II dredge sites (SO-6, SO-5, and MB-1). Bathymetric data and grain size distribution curves are provided in Section 7. To provide historical perspective, profiles developed from a 2012 post-construction survey and the Fall

2014 and Fall 2016 surveys also are provided (Scott, 2013; Coastal Frontiers, 2015 and 2017). Similarly, grain size distribution curves are plotted in concert with equivalent data from 2014 and 2016. In addition, the range of grain sizes determined during the 2008 geophysical investigation of the borrow sites also are inlcuded (URS, 2009).

5. BEACH CONDITION

Based on the data presented in Sections 2 and 4, this chapter assesses the condition of San Diego County's beaches during the 2018 Monitoring Year (November 2017 through October 2018) and the 18-year period encompassing both the RBSP I and RBSP II (November 2000 through October 2018, the Post-RBSP I Period). Section 5.1 provides a regional overview, while Section 5.2 summarizes the post-RBSP I outcome in selected sub-reaches. Lastly, the regional recovery after the 2015-2016 El Niño is discussed in Section 5.3.

Statistical characterizations of shoreline and volume changes for the 2018 Monitoring Year are derived from the 54 transects included in the Fall 2018 Survey, while those for the Post-RBSP I Period are derived from the 44 transects with measurements dating back to Fall 2000 (*i.e.*, predating the RBSP I).

5.1. Regional Overview

Table 21 summarizes the MSL shoreline and shorezone volume changes that occurred in the Silver Strand, Mission Beach and Oceanside Cells during the 2018 Monitoring Year and the Post-RBSP I Period.

Table 21. Average MSL Shoreline Changes and Shorezone Volume Changes During the 2018 Monitoring Year and Post-RBSP I Period (1, 2)

Littoral Cell	2018 Monitoring Year (1)		post-RBSP I (2000 to 2018) (2,3)	
	MSL Shoreline Change (ft)	Shorezone Vol. Change (cy/ft)	MSL Shoreline Change (ft)	Shorezone Vol. Change (cy/ft)
Silver Strand Cell	29	-15	1	-38
Mission Beach Cell	25	-6	9	1
Oceanside Cell	33	2	17	6
All Cells Combined	31	-1	14	-1

Notes: (1) Shoreline change statistics are derived from the 54 transects included in the Fall 2018 Survey.
(2) Shoreline change statistics are derived from the 44 transects with measurements dating back to Fall 2000.
(3) Post-RBSP I Period extends from November 2000 through October 2018.

During the 2018 Monitoring Year, shoreline advance predominated in the three littoral cells. The average change ranged from an increase of 25 ft in the Mission Beach Cell to a gain 33 ft in the Oceanside Cell. In contrast, the shoreline volume decreased an average of 15 cy/ft in the Silver Strand and was essentially unchanged in the Mission Beach and Oceanside Cells.

When the entire 18-year Post-RBSP I Period (2000 to 2018) is considered, the average MSL shoreline position in the Silver Strand and Mission Beach Cells was essentially unchanged. In the Oceanside Cell, the shoreline advanced an average of 17 ft during the Post-RBSP I Period. The 2018 shorezone volumes in the Mission Beach and Oceanside Cells are comparable to the respective pre-RBSP I values, while that in the Silver Strand Cell falls below the pre-RBSP I condition. These observations suggest that the positive effects of the RBSP I, RBSP II and opportunistic nourishment projects in the region have largely dissipated.

The MSL beach widths in Spring 2018 and Fall 2018 are shown in Figures 12a and 12b. In the case of the transects that have been consistently surveyed in Fall and Spring since the RBSP I, the figures also include the envelope of beach widths for the period Fall 2001 to Fall 2017.

In the Mission Beach and Silver Strand Cells, the Spring 2018 beach widths tended to fall in the middle of the post-RBSP I envelope. The Fall 2018 beach widths in these littoral cells generally exceeded the Spring 2018 beach widths and were in the upper portion of the historical envelope. Exceptions included Coronado and the southern portion of Imperial Beach.

In the Oceanside Cell, the Spring 2018 beach widths ranged from slightly-below the historical values in South Oceanside to slightly-above in the area surrounding the Agua Hedionda Lagoon entrance. The occurrence of historically low Spring beach widths in South Oceanside may be attributable to the timing of bypassing operations at Oceanside Harbor, which occurred in Fall (2018) rather than the more typical Winter/Spring timeframe (Section 2.2.3). Similarly, the historically wide beaches near Agua Hedionda are likely attributable to bypassing operations that were completed shortly before the Spring 2018 survey. The Fall 2018 beach widths tended to exceed the Spring values, but exceptions included South Carlsbad, Leucadia and the Torrey Pines area. Fall beach widths exceeded the historical values in Cardiff, Solana Beach and parts of Oceanside. In the case of Cardiff and Solana Beach, the wide beaches reflect the nourishment placed at these sites in Spring and Summer 2018 as part of the SELRP (Section 2.2.2).

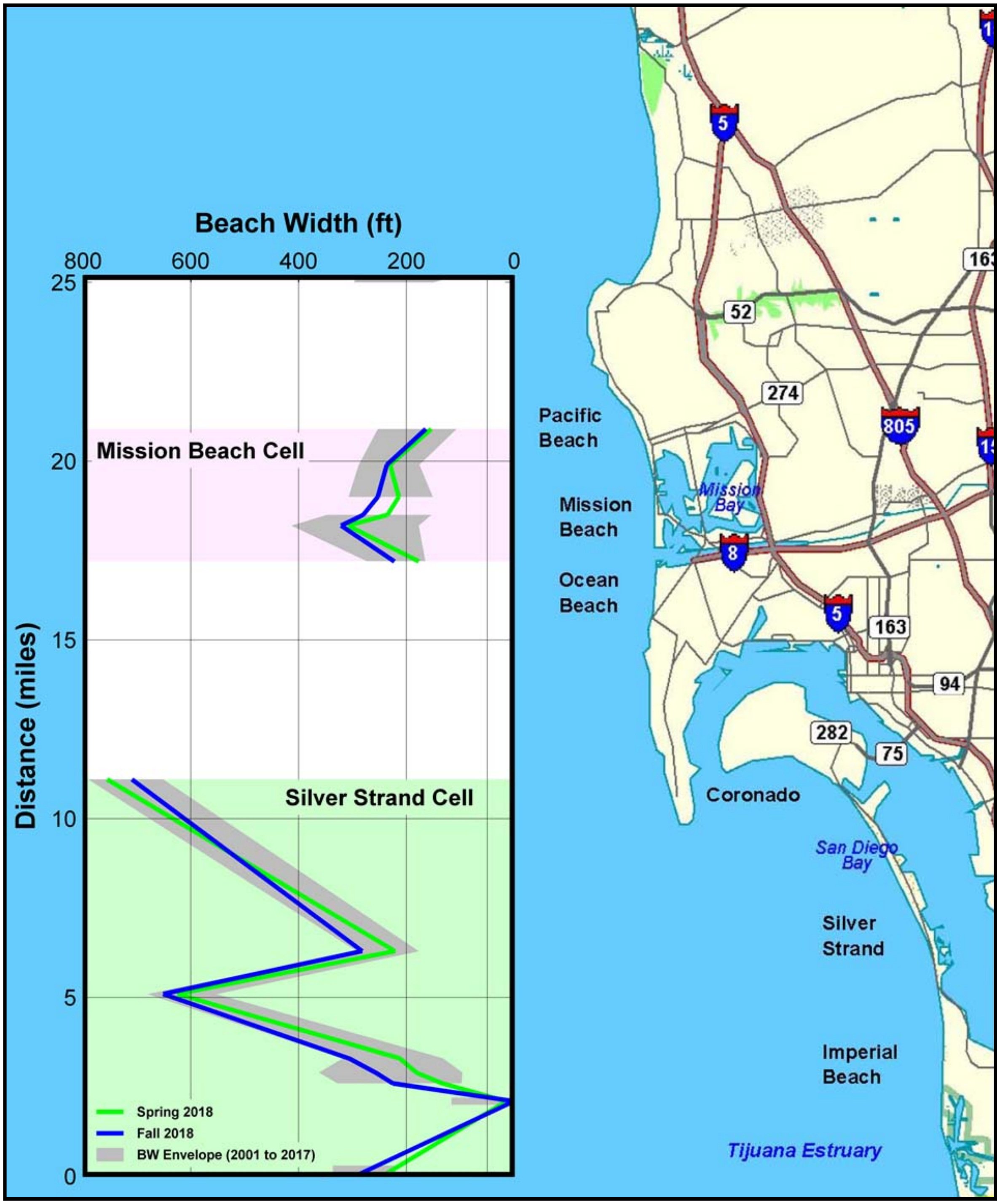


Figure 12a. Comparison of 2018 MSL Beach Widths with the Post-RBSP I Envelope in the Silver Strand and Mission Beach Littoral Cells

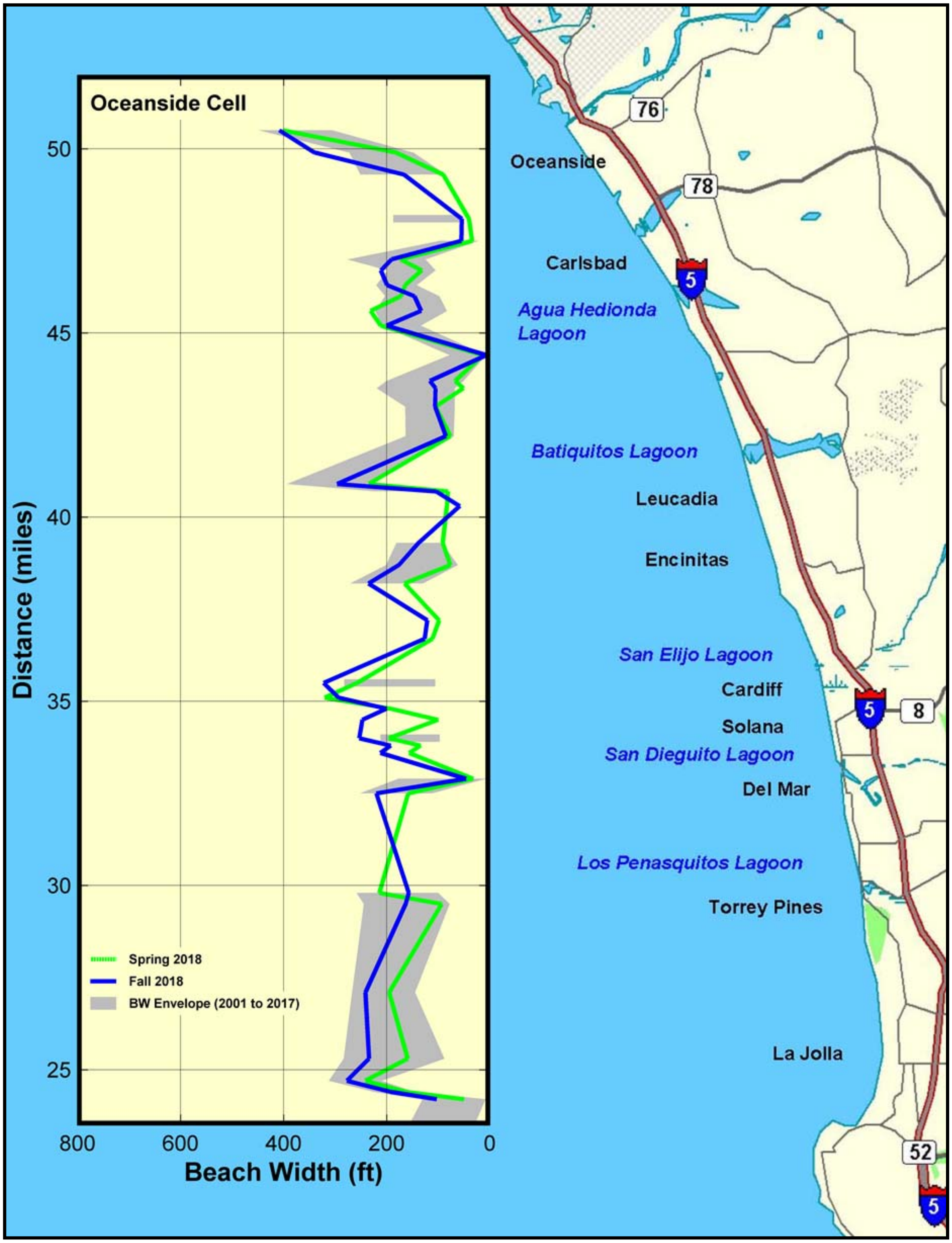


Figure 12b. Comparison of 2018 MSL Beach Widths with the Post-RBSP I Envelope in the Oceanside Littoral Cell

5.1.1 Silver Strand Littoral Cell

Table 22 summarizes the MSL shoreline changes that occurred in the Silver Strand Cell during the 2018 Monitoring Year and during the 18-year period encompassing both the RBSP I and II (2000 to 2018). Figures 13 and 14 show the spatial distribution of the changes that occurred during those periods. Comprehensive supporting data are provided in Appendices C and D.

Table 22. MSL Shoreline and Shorezone Volume Changes in the Silver Strand Littoral Cell during the 2018 Monitoring Year and the Post-RBSP I Period

Period	MSL Shoreline Change (no. of transects)			Average Change (ft)
	Advance	No Change[4]	Retreat	
2018 Mon. Year [1]	6	0	2	29
Post-RBSP I [2,3]	3	1	2	1
Period	**Shorezone Volume Change (no. of transects)**			**Average Change (cy/ft)**
	Increase	**No Change[4]**	**Decrease**	
2018 Mon. Year [1]	1	4	3	-15
Post-RBSP I [2,3]	1	1	4	-38

Notes: [1] Statistics are derived from the 54 transects included in the Fall 2018 Survey.
[2] Statistics are derived from the 44 transects with measurements dating back to Fall 2000.
[3] Post-RBSP I Period encompasses RBSP I and RBSP II (Fall 2000 through Fall 2018).
[4] "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

2018 Monitoring Year

The average shoreline position in the Silver Strand Cell advanced by 29 ft during the 2018 Monitoring Year. As shown in Figure 13, shoreline gains were registered at six of the eight transects located within the cell. In Imperial Beach, and despite the fact that shoreline retreated by 25 ft at the south end of the city, the average shoreline change was a gain of 25 ft. Shoreline advance also occurred at Silver Strand State Beach (an average of 42 ft) and at the U.S.-Mexico border (63 ft). In contrast, moderate shoreline retreat (18 ft) occurred at Coronado.

The average shorezone volume in the Silver Strand Cell decreased by 15 cy/ft during the 2018 Monitoring Year. As shown in Figure 14, the greatest losses occurred in Imperial Beach (up to 68 cy/ft). Shorezone volume losses also occurred at Coronado (26 cy/ft), while volumes in the Silver Strand State Beach remained virtually unchanged.

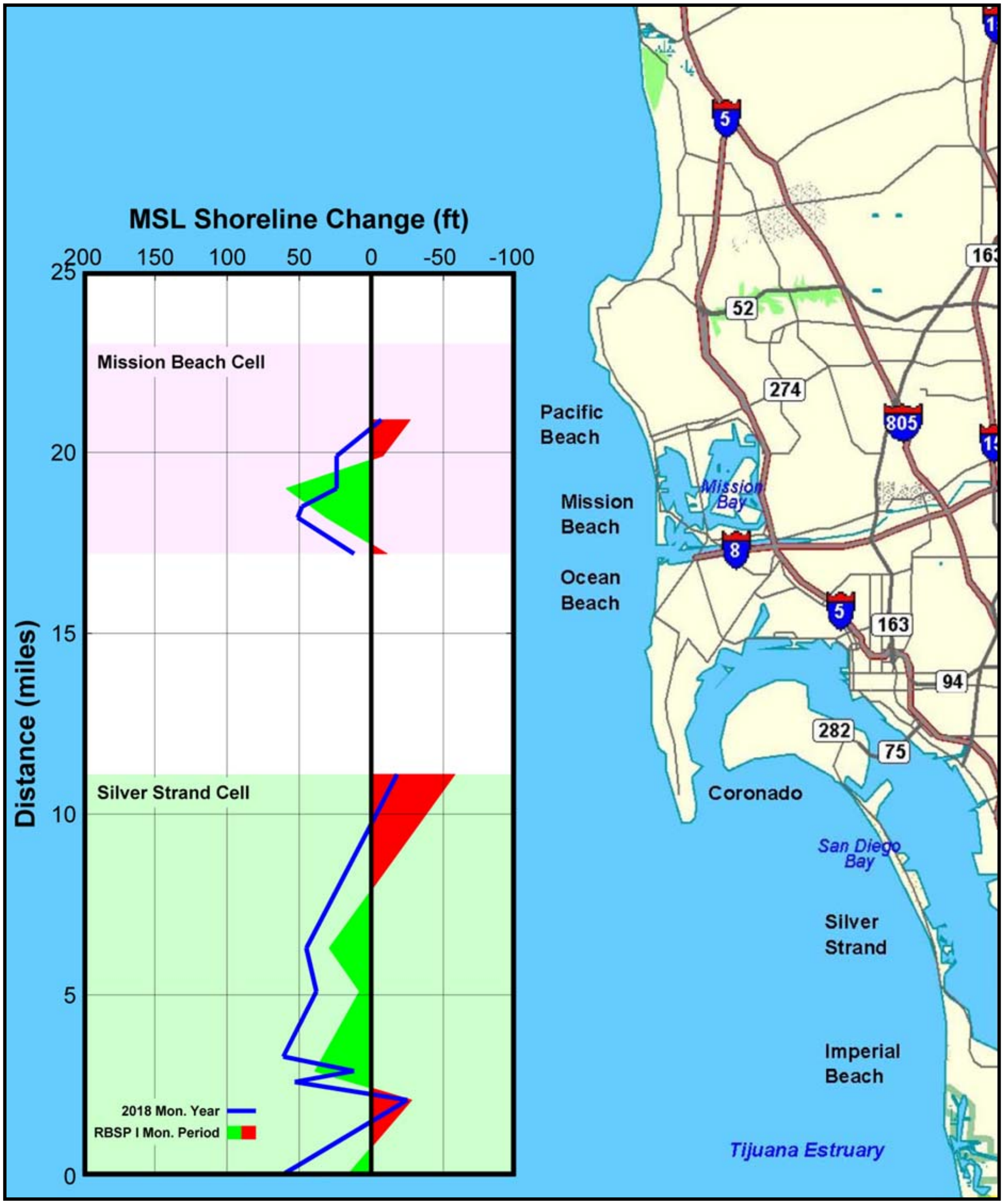


Figure 13. MSL Shoreline Changes during the 2018 Monitoring Year and Post-RBSP I Period in the Silver Strand and Mission Beach Littoral Cells

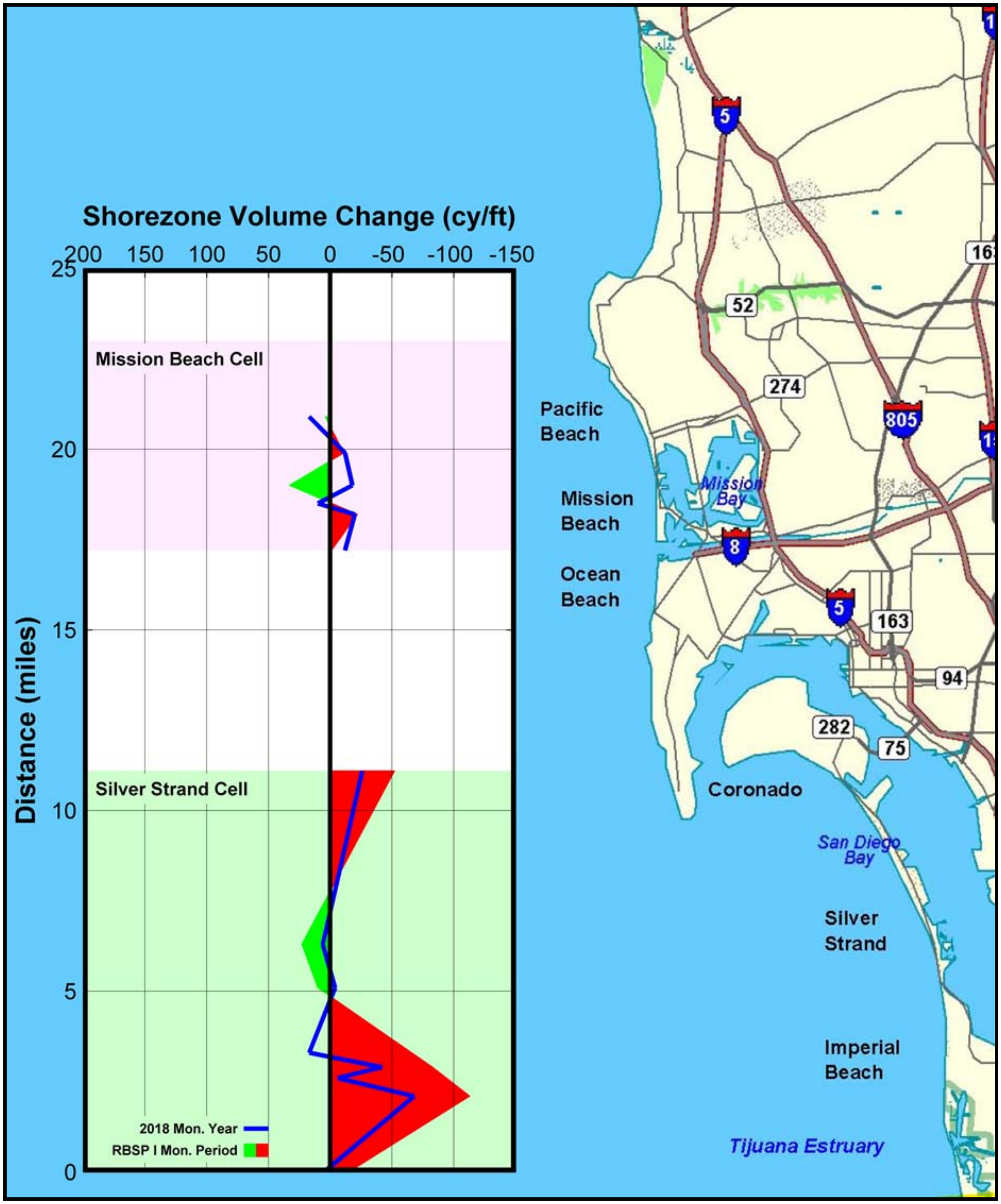


Figure 14. Shorezone Volume Changes during the 2018 Monitoring Year and Post-RBSP I Period in the Silver Strand and Mission Beach Littoral Cells

Post-RBSP I

Figure 15 presents the average shoreline position and average shorezone volume in the Silver Strand Cell at the time of each Fall survey relative to the pre-RBSP I condition (Fall 2000). The initial shoreline advance resulting from RBSP I was short-lived, and by 2005 the shoreline had retreated to pre-RBSP I levels. This response may be explained by the relatively small nourishment quantity and the use of only one receiver site in the cell.

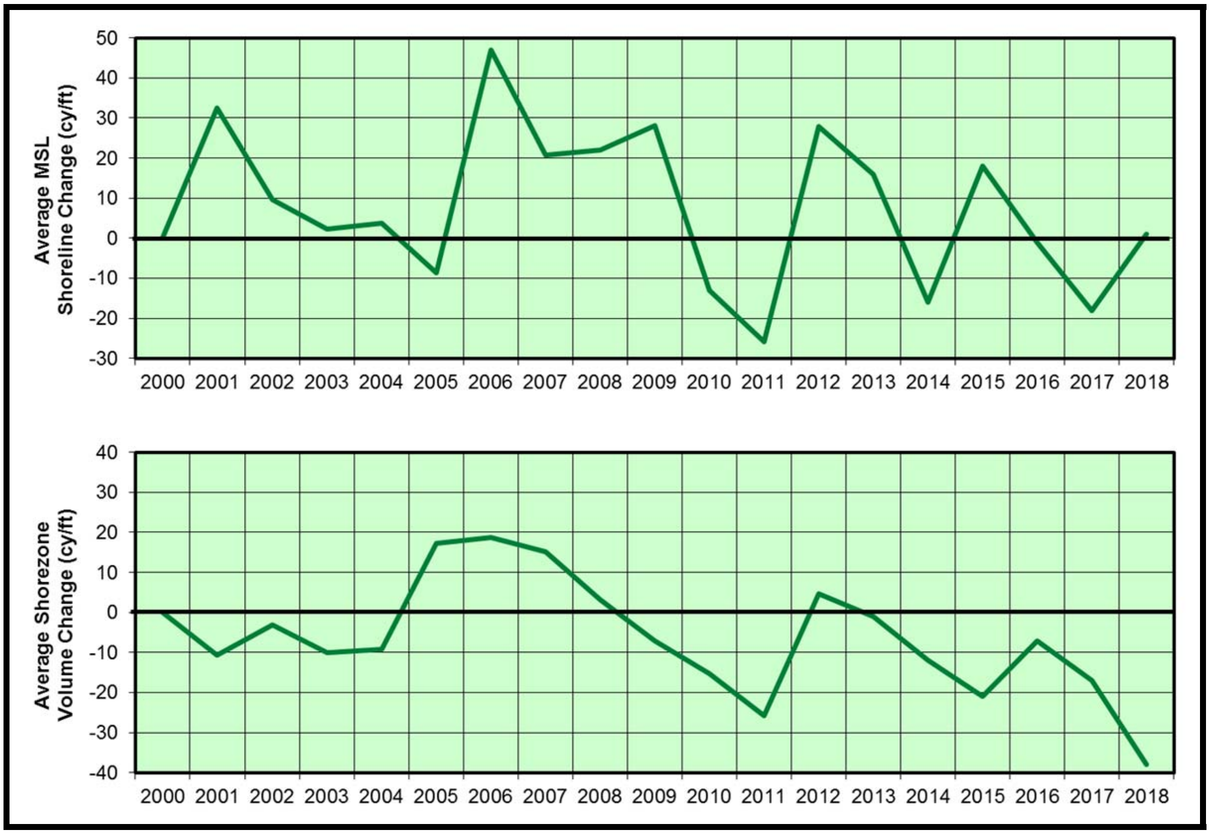


Figure 15. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Silver Strand Littoral Cell

In 2006, the shoreline advanced by over 50 ft on average. These gains can be attributed, at least in part, to the onshore migration of nourishment material placed in the nearshore at Imperial Beach in 2005. A general trend of shoreline retreat then prevailed through 2011, briefly interrupted by modest reversals in 2008 and 2009. By 2011, the average beach width was 26 ft below the pre-RBSP I value.

In 2012, the placement of 450,000 cy of sand in the cell during RBSP II yielded an average shoreline advance of 54 ft. The resulting average beach width in the cell was well-above the pre-RBSP I value. The nourishment quantity during RBSP II was nearly four times higher than that provided under RBSP I. Despite shoreline advances in 2015 and 2018, a general trend of shoreline retreat has prevailed since after the 2012 sand placement. By the end of the 2018 Monitoring Year, the average MSL shoreline position at the Silver Strand Cell was essentially the same as the pre-RBSP I value. Isolated shoreline gains have persisted only at Imperial Beach (Figure 13).

The shorezone volume decreased following the RBSP I and remained below the pre-RBSP I value until opportunistic nourishment activities were conducted in 2005. The initial losses in this cell may reflect the fact that the two transects located within the Imperial Beach fill do not pre-date the RBSP I, and thus the likely volume gains at these transects were not included in the calculations. In 2005, the opportunistic beach nourishment produced a modest shorezone volume gain. The shorezone volume then gradually decreased during the next five years (2007 to 2011). As a result, by the time of the Fall 2011 survey the shorezone volume was well-below the pre-RBSP I value.

Although the RBSP II fill at Imperial Beach produced significant volume gains, the average shorezone volume in 2012 was only slightly higher than the pre-RBSP I value. A trend of decreasing shorezone volumes has prevailed since RBSP II, with a reversal occurring only in 2016. As a result, by the end of the 2018 Monitoring Year the shorezone volume was well below the pre-RBSP I value. The average loss in the littoral cell was 38 cy/ft. Volume gains persisted at only one location in the cell during the 18-year period (an average increase of 16 cy/ft at Silver Strand State Beach).

5.1.2. Mission Beach Littoral Cell

The MSL shoreline and shorezone volume changes that prevailed in the Mission Beach Cell during the 2018 Monitoring Year and the Post-RBSP I Period (2000 to 2018) are summarized in Table 23 and in Figures 13 and 14. Supporting data are provided in Appendices C and D.

2018 Monitoring Year

During the 2018 Monitoring Year, the shoreline position in the Mission Beach Cell advanced at five transects and remained essentially unchanged at one (Transect PB-0408). These changes yielded an average shoreline advance of 25 ft in the cell. The average gain in Mission Beach was 37 ft, with the greatest shoreline advance occurring at the south end of the reach (51 ft at Transect MB-0310).

Table 23. MSL Shoreline and Shorezone Volume Changes in the Mission Beach Littoral Cell during the 2018 Monitoring Year and the Post-RBSP I Period

Period	MSL Shoreline Change (no. of transects)			Average Change (ft)
	Advance	No Change[4]	Retreat	
2018 Mon. Year [1]	5	1	0	25
Post-RBSP I [2,3]	2	1	2	9
Period	**Shorezone Volume Change (no. of transects)**			**Average Change (cy/ft)**
	Increase	**No Change[4]**	**Decrease**	
2018 Mon. Year [1]	1	1	4	-6
Post-RBSP I [2,3]	1	2	2	1

Notes: [1] Statistics are derived from the 54 transects included in the Fall 2018 Survey.
[2] Statistics are derived from the 44 transects with measurements dating back to Fall 2000.
[3] Post-RBSP I Period encompasses RBSP I and RBSP II (Fall 2000 through Fall 2018).
[4] "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

In contrast, shorezone volume loss predominated during the 2018 Monitoring Year. Shorezone volume decreased at four transects, increased at one site, and was essentially unchanged at the remaining location. The volume losses were modest, ranging from 12 cy/ft at Ocean Beach to 20 cy/ft at the south end of Mission Beach. The only gain occurred at Pacific Beach (17 cy/ft at Transect PB-0480) . The average shorezone volume change in the cell was a loss of 6 cy/ft.

Post-RBSP I

The RBSP I beach nourishment in the Mission Beach Cell was limited to a relatively small sand placement at one receiver site. The shoreline gains attributable to the RBSP I persisted through 2005 (Figure 16). Unanticipated shoreline advance then occurred in 2006, but significant shoreline retreat in 2007 returned the average beach width in the cell to the pre-RBSP I condition. Shoreline advance in 2008 and 2009 restored the beach widths to above the pre-RBSP I levels.

In 2010, the placement of 450,000 cy of sand during opportunistic beach nourishment activities produced significant shoreline gains. The resulting average shoreline position exceeded the pre-RBSP I value by nearly 50 ft. As the above-water nourishment material dispersed, three consecutive years of shoreline retreat (2011 through 2013) reduced beach widths to below pre-RBSP I levels. This trend then was reversed, with shoreline

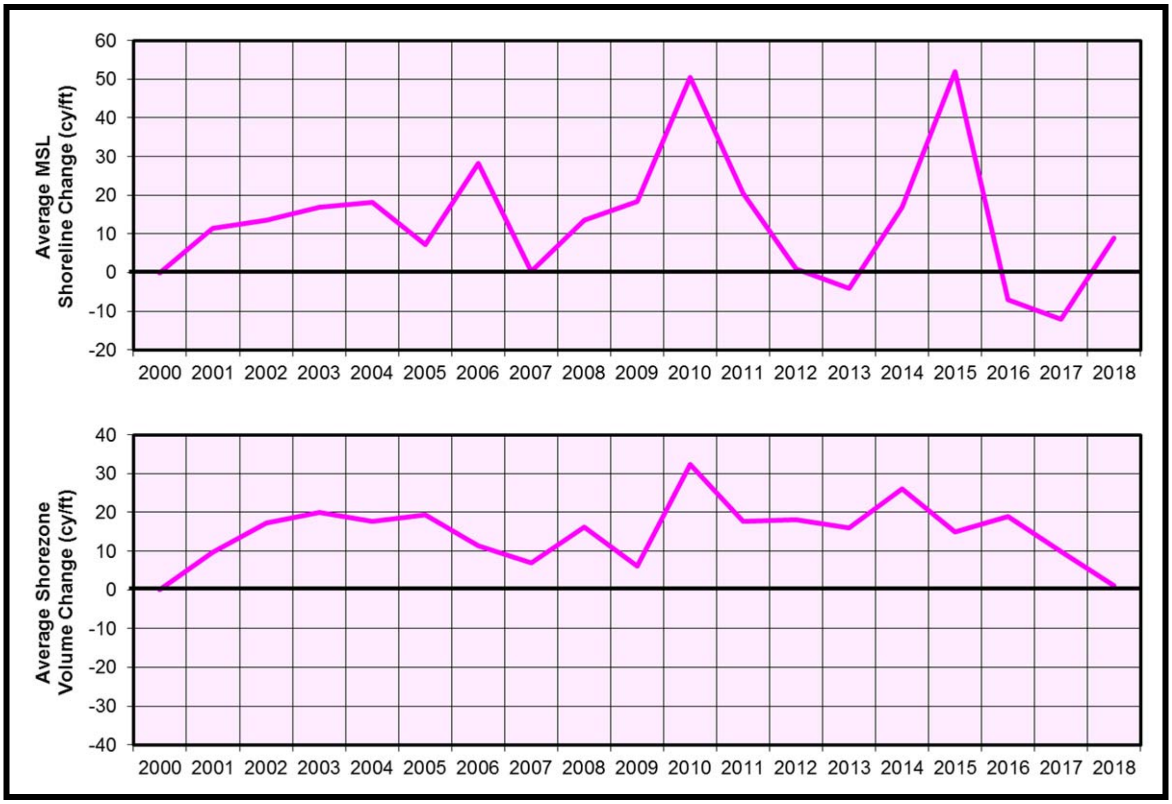


Figure 16. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Mission Beach Littoral Cell

advance in both 2014 and 2015 increasing the average beach width in the cell to the highest levels observed during the period of record.

The El Niño conditions that prevailed in 2016 produced substantial shoreline retreat. Additional losses during 2017 reduced the average beach width to the lowest value recorded during the 18-year Post-RBSP I Period. The shoreline advanced during the 2018 Monitoring Year, resulting in an average MSL shoreline position in the cell above the pre-RBSP I condition. As suggested in Figure 13, the gains were concentrated in Mission Beach.

Similar to the shoreline changes, the sediment volume gains that followed the RBSP I persisted with minimal change for several years. After 2005, a general trend of decreasing volumes persisted through 2009. This trend was reversed in 2010, with significant shorezone volume gains occurring in response to the Corps-sponsored opportunistic beach nourishment. Modest losses then prevailed in 2011 as the nourishment material dispersed. The average shorezone volume remained relatively stable between 2012 and 2016, but decreased in 2017 and 2018. By the end of the 2018 Monitoring Year, the average shorezone volume in the littoral cell approximated the pre-RBSP I value. As shown in Figure 14, shorezone volume gains relative to the pre-RBSP I condition were limited to one site in Mission Beach (Transect MB-0340).

5.1.3. Oceanside Littoral Cell

The MSL shoreline and shorezone volume changes that prevailed in the Oceanside Cell during the 2018 Monitoring Year and the 18-year period encompassing both the RBSP I and II (2000 to 2018) are summarized in Table 24. Figures 17 and 18 show the spatial distribution of those changes, while detailed supporting data are provided in Appendices C and D.

Table 24. MSL Shoreline and Shorezone Volume Changes in the Oceanside Littoral Cell during the 2018 Monitoring Year and the Post-RBSP I Period

Period	MSL Shoreline Change (no. of transects)			Average Change (ft)
	Advance	No Change[4]	Retreat	
2018 Mon. Year [1]	28	10	2	33
Post-RBSP I [2,3]	12	6	15	17
Period	**Shorezone Volume Change (no. of transects)**			**Average Change (cy/ft)**
	Increase	**No Change[4]**	**Decrease**	
2018 Mon. Year [1]	14	11	15	2
Post-RBSP I [2,3]	15	6	12	6

Notes: [1] Statistics are derived from the 54 transects included in the Fall 2018 Survey.
[2] Statistics are derived from the 44 transects with measurements dating back to Fall 2000.
[3] Post-RBSP I Period encompasses RBSP I and RBSP II (Fall 2000 through Fall 2018).
[4] "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

2018 Monitoring Year

The 2018 Monitoring Year was characterized by shoreline advance, with losses occurring at only two transects. The average MSL shoreline position in the cell advanced by 33 ft. As shown in Figure 17, the greatest shoreline gain occurred in Oceanside (158 ft at Transect OS-1030). Shoreline advance in excess of 50 ft occurred in Cardiff and Solana Beach in response to the nourishment material placed during the SELRP (Section 2.2.2). Shoreline retreat was confined to the Carlsbad area, with the greatest loss (64 ft) occurring at Transect CB-0830.

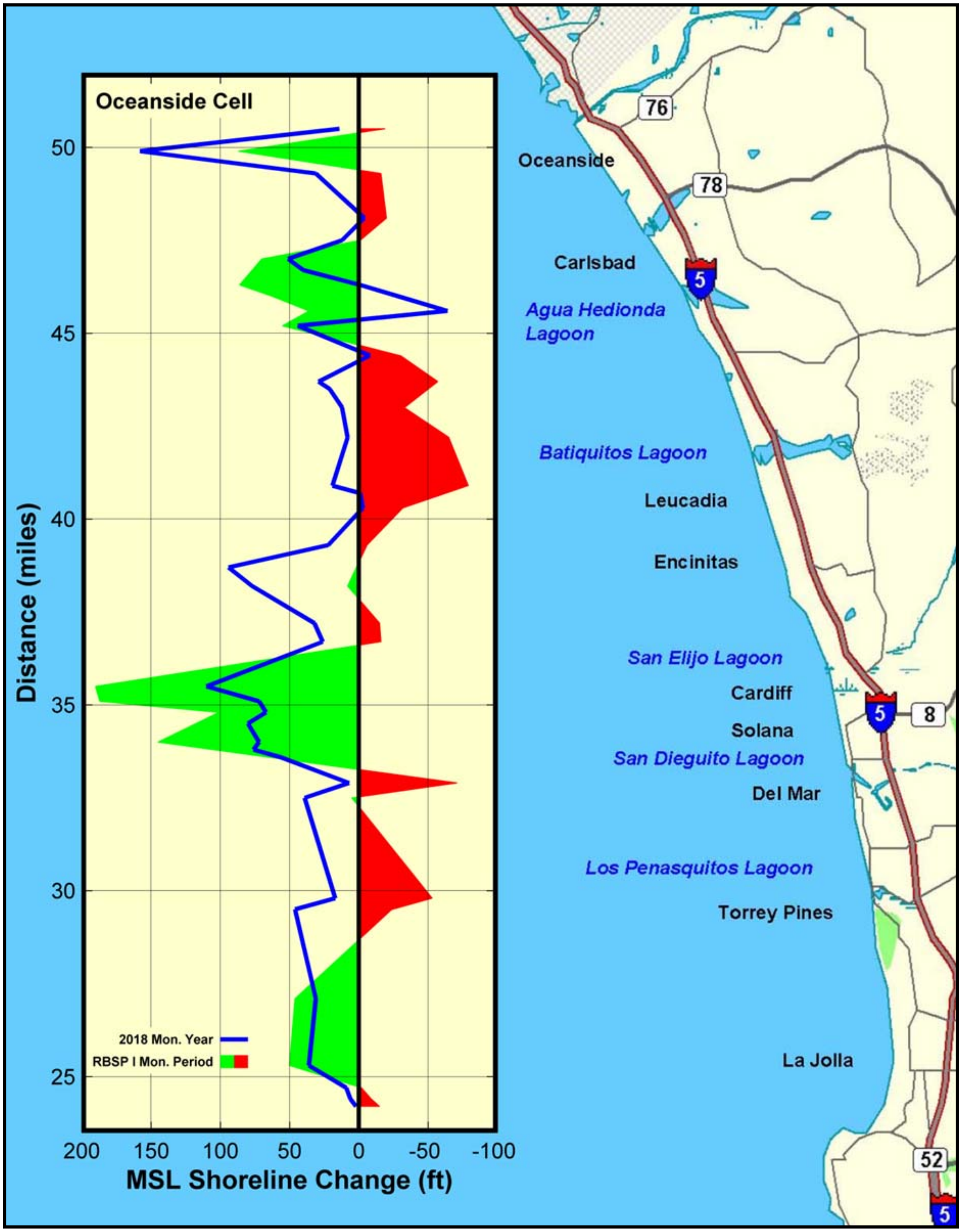


Figure 17. MSL Shoreline Changes during the 2018 Monitoring Year and Post-RBSP I Period in the Oceanside Littoral Cell

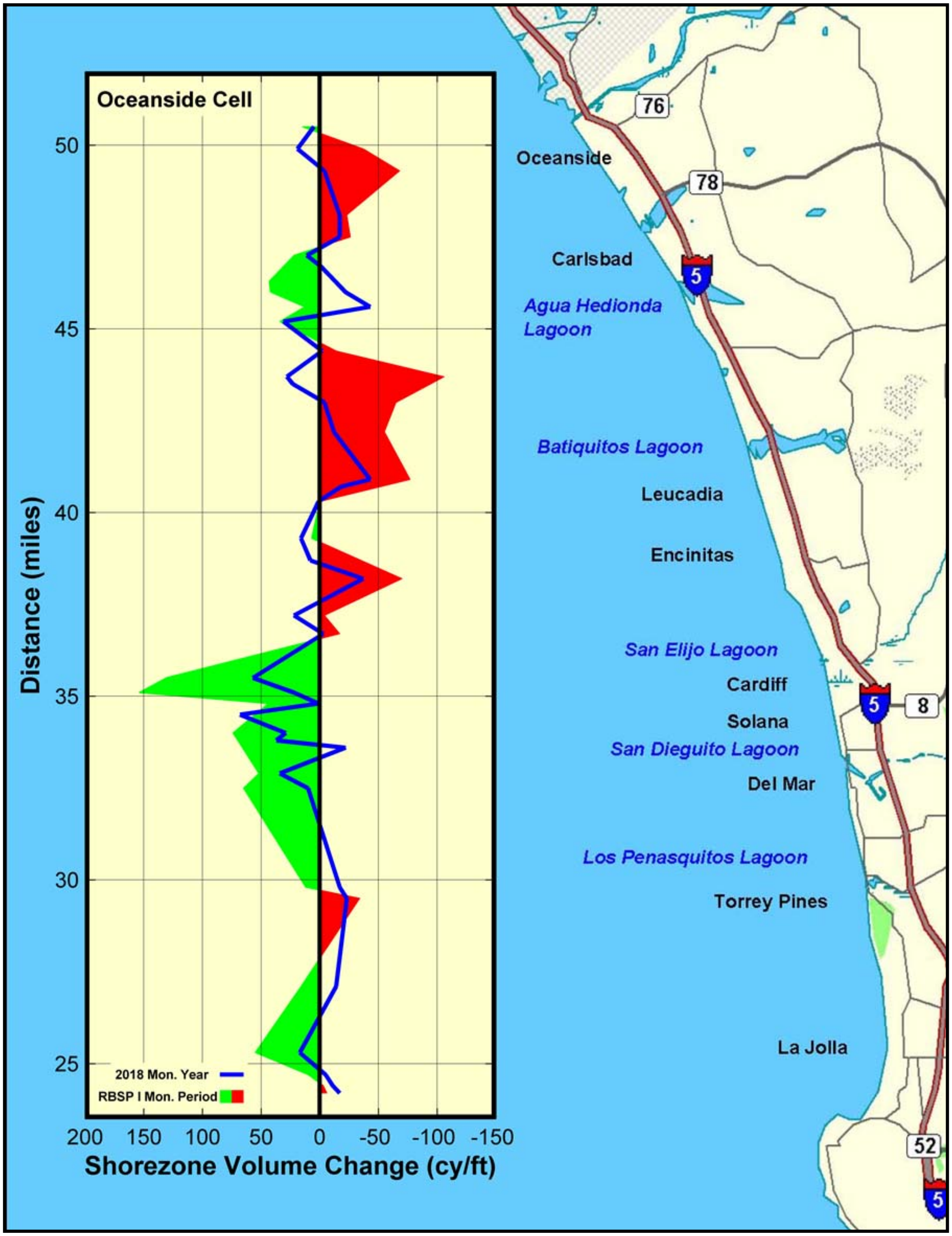


Figure 18. Shorezone Volume Changes during the 2018 Monitoring Year and Post-RBSP I Period in the Oceanside Littoral Cell

The average shorezone volume in the cell remained virtually unchanged relative to the 2017 condition, as sediment losses and gains among the transects were nearly balanced. (Table 24, Figure 18). Gains were most prevalent in Cardiff and Solana Beach (up to 68 cy/ft), where 446,000 cy of sand were placed as part of the SELRP. The greatest losses occurred at isolated sites in North Carlsbad (43 cy/ft), Encinitas (37 cy/ft), and near Batiquitos Lagoon (43 cy/ft).

Post-RBSP I

Time series of the average shoreline and shorezone volume change at the time of each Fall survey relative to the pre-RBSP I condition (Fall 2000) are presented in Figure 19. The RBSP I produced substantial shoreline advance in 2001. Additional gains occurred in 2002 as the fill material dispersed alongshore to adjacent beaches. A trend of shoreline loss then prevailed, with reversals in 2016, 2008, and 2011. At the end of the 2011 Monitoring Year, the average shoreline position was below the pre-RBSP I level.

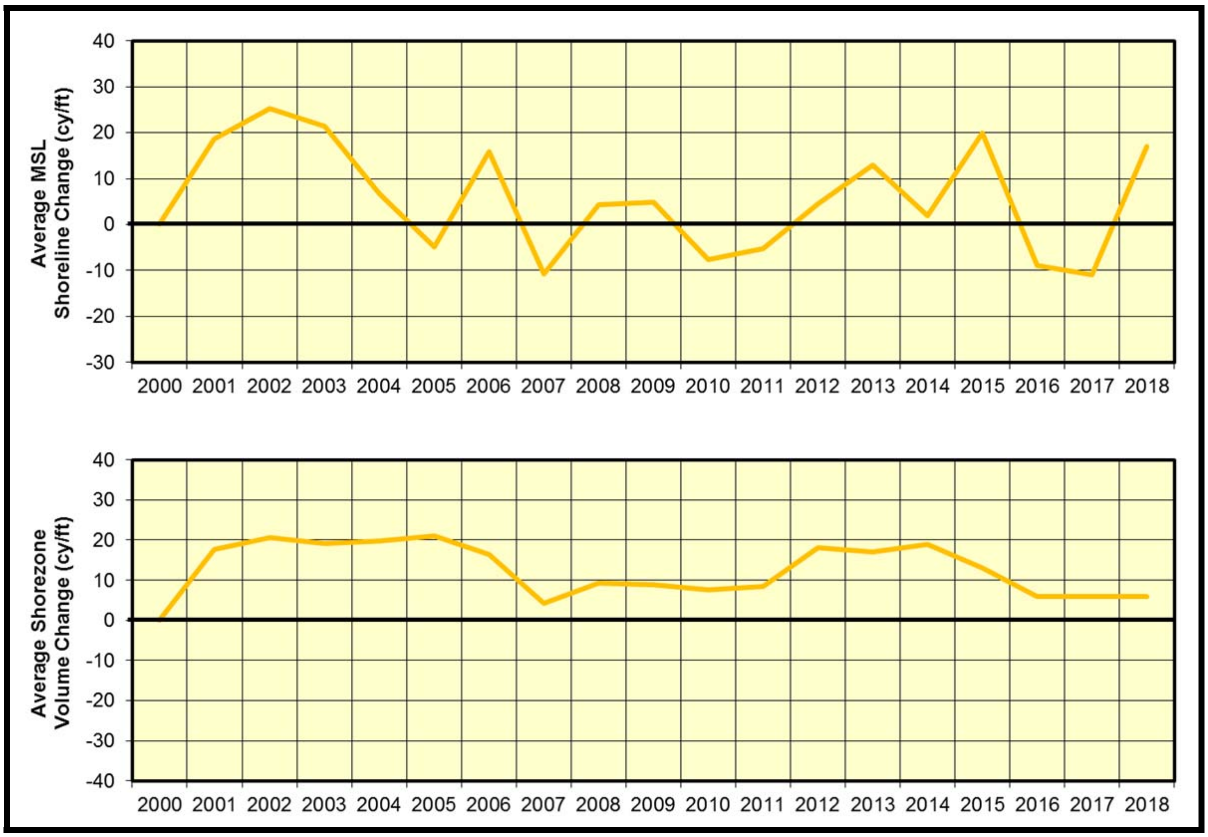


Figure 19. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Oceanside Littoral Cell

In 2012, the RBSP II beach nourishment restored the beach widths in the cell to above the pre-RBSP I values. The magnitude of the post-nourishment beach width gain was less than that which occurred following the RBSP I. This can be attributed to fewer receiver sites (7 vs. 10) and a smaller nourishment quantity (1.1 million cy vs. 1.8 million cy) utilized for the RBSP II.

Additional beach width gains occurred in 2013 as the nourishment material dispersed alongshore to adjacent beaches. The shoreline retreated in 2014, but unexpectedly advanced again in 2015. However, these gains were reversed during the 2016 El Niño and in 2017, with shoreline positions retreating to below pre-RBSP I levels. As indicated above, shoreline advance prevailed during 2018, with the most notable gains occurring in Cardiff and Solana Beach in response to the SELRP nourishment. At the end of the 2018 Monitoring Year, the average MSL shoreline position in the Oceanside Cell exceeded the pre-RBSP I value. As indicated in Figure 17, the greatest post-RBSP I gains were concentrated in Cardiff and Solana Beach regions, while the greatest losses occurred in South Carlsbad.

The sediment volume gains that occurred in the Oceanside Cell following the RBSP I persisted with minimal change through 2006 – outlasting the shoreline gains. The shorezone volume decreased in 2007 in response to energetic wave conditions, and then remained relatively constant through 2011. The RBSP II nourishment material provided in 2012 yielded additional gains. Similar to the shoreline changes, the magnitude of the volume increase was less than that produced after RBSP I due to the reduced nourishment quantities. However, building on a foundation of modest gains persisting from the RBSP I and several small opportunistic nourishment efforts, the net result was an average shorezone volume similar to that resulting from the RBSP I (2001). The shorezone volume then remained relatively stable in 2013 and 2014. Modest losses during the next two years reduced the shorezone volume to near the pre-RBSP I value, where it remained nearly unchanged through 2018 despite of the placement of the SELRP beach nourishment material.

As shown in Figure 18, the relative stability of the average shorezone volume in the Oceanside Cell reflects the balance between areas with volume losses (*e.g.*, South Carlsbad) and areas with volume gains (*e.g.*, Cardiff and Solana Beach) rather than generalized shorezone stability along the entire littoral cell.

5.2. Post-RBSP I Outcome in Sub-Reaches

This section summarizes the post-RBSP I outcome for selected sub-reaches within the study area. The sub-reach assessment quantifies the impact of the RBSP fills beyond the placement sites by accounting for the redistribution of the nourishment material over a broader area. As such, the sub-reach outcome provides a more appropriate indication of overall success and longevity of the nourishment programs. Figures 20 through 29 show time series of the average beach width change and shorezone volume change at the time of each Fall survey relative to the pre-RBSP I condition (Fall 2000) for ten sub-reaches. The uneven spacing between transects was accounted for by weighting each value according to the alongshore distance associated with the corresponding transect. Only La Jolla did not receive direct nourishment as part of the RBSP I, while Del Mar, La Jolla and Mission Beach did not receive direct nourishment as part of RBSP II.

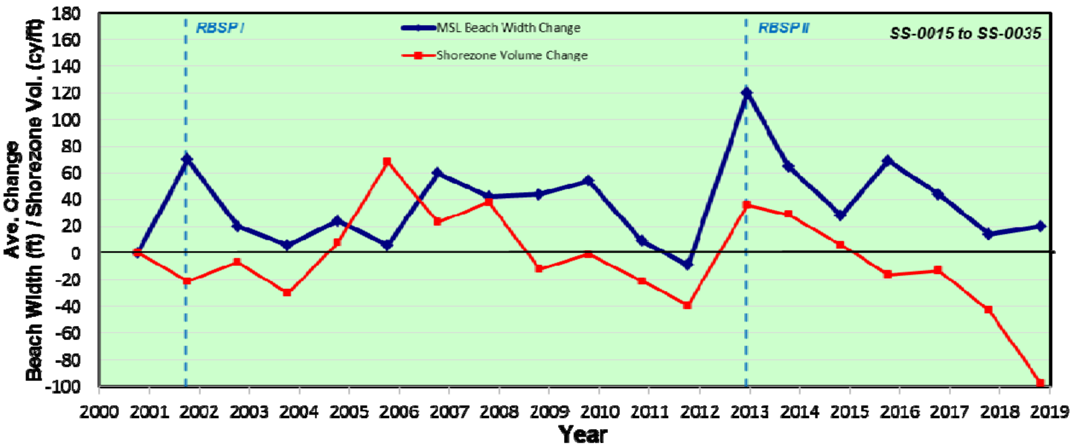


Figure 20. Beach Width and Shorezone Volume Changes in the Imperial Beach Sub-Reach

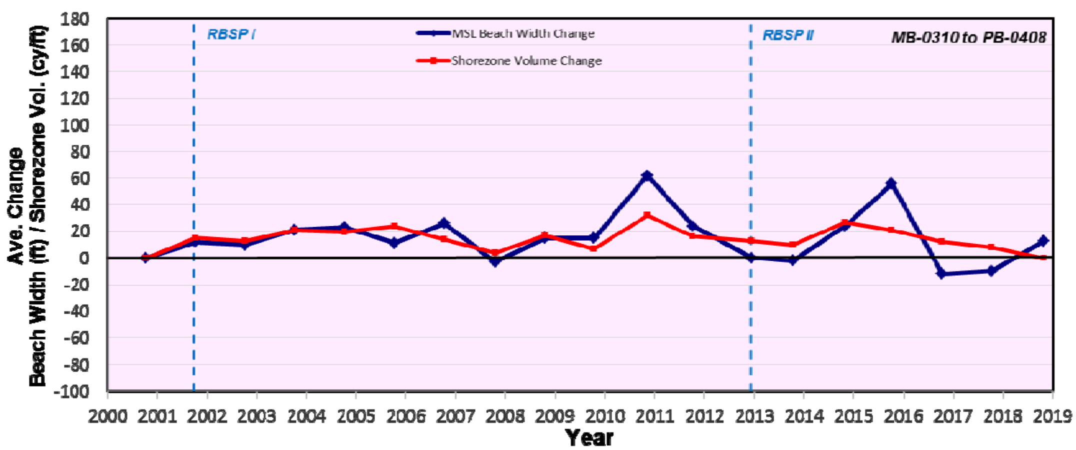


Figure 21. Beach Width and Shorezone Volume Changes in the Mission Beach Sub-Reach

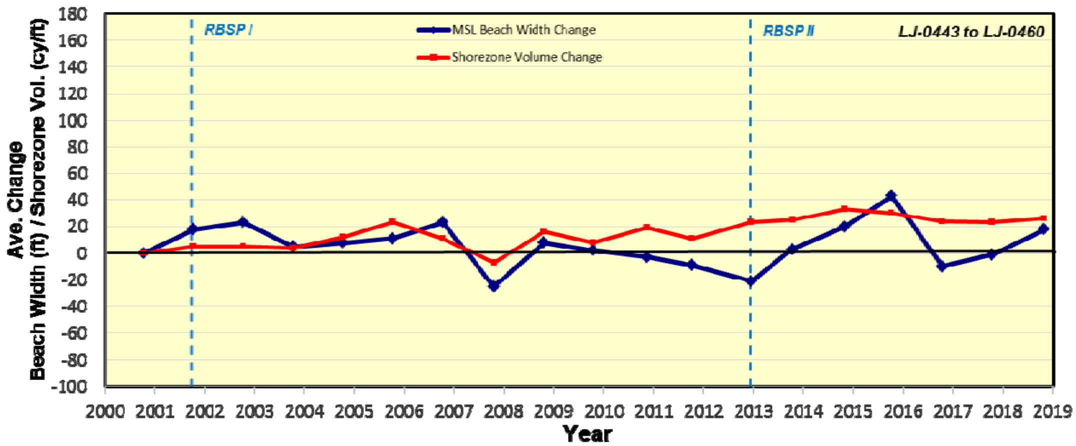


Figure 22. Beach Width and Shorezone Volume Changes in the La Jolla Sub-Reach

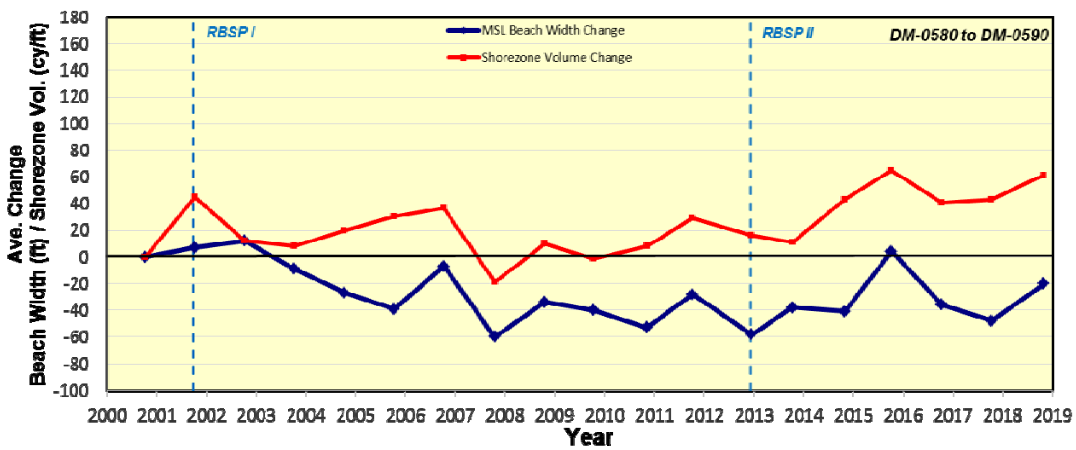


Figure 23. Beach Width and Shorezone Volume Changes in the Del Mar Sub-Reach

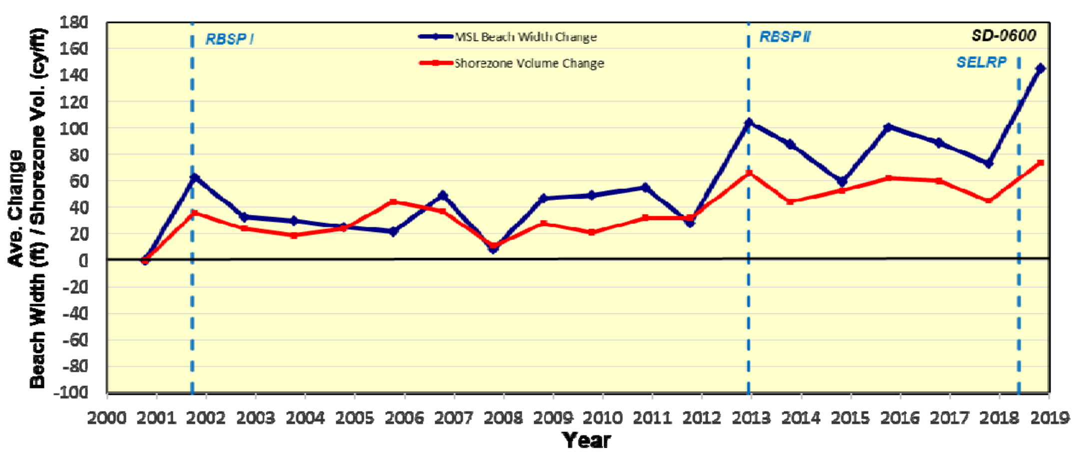


Figure 24. Beach Width and Shorezone Vol. Changes in the Solana Beach Sub-Reach

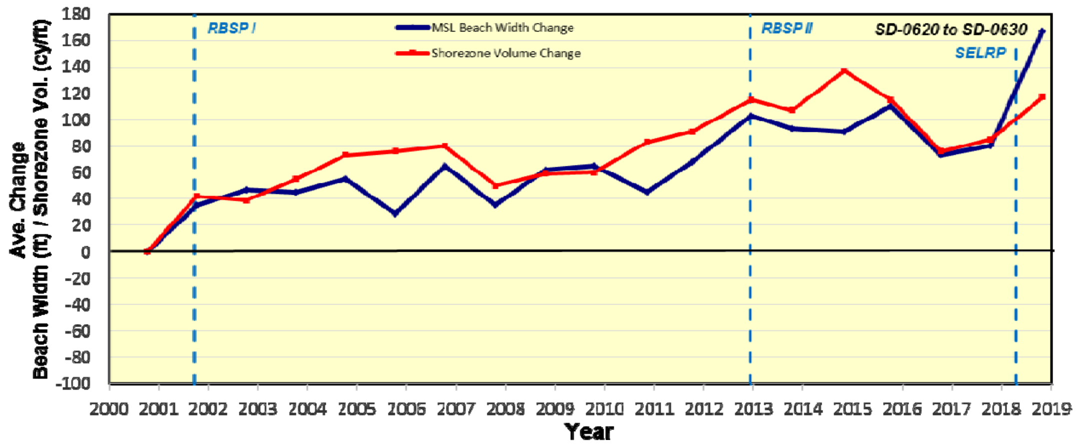


Figure 25. Beach Width and Shorezone Volume Changes in the Cardiff Sub-Reach

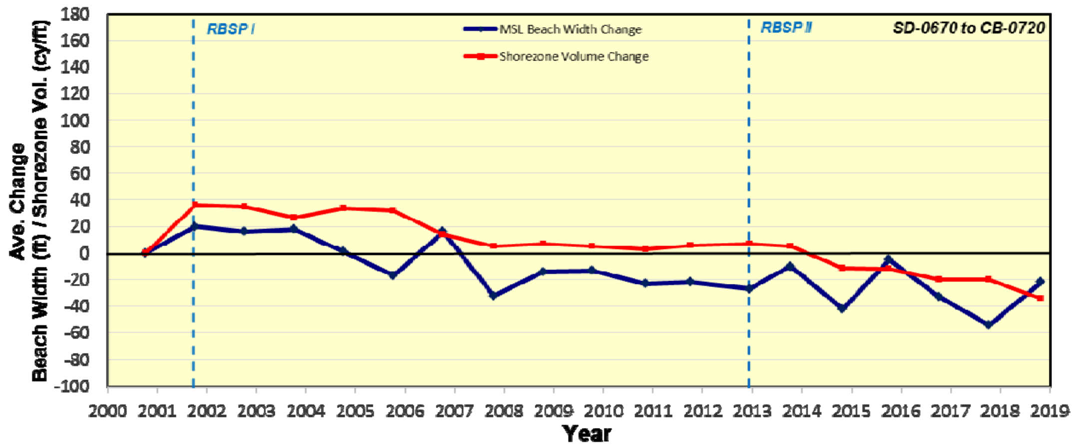


Figure 26. Beach Width and Shorezone Volume Changes in the Encinitas/Leucadia Sub-Reach

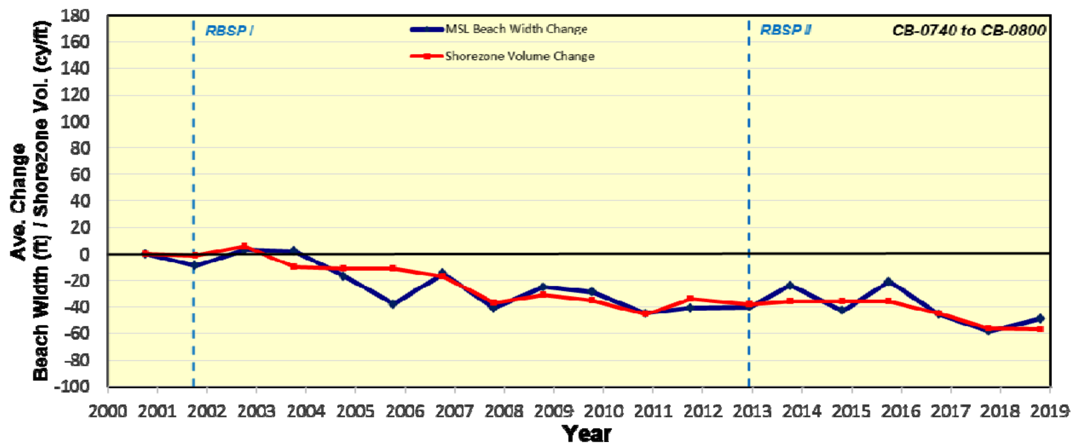


Figure 27. Beach Width and Shorezone Volume Changes in the South Carlsbad Sub-Reach

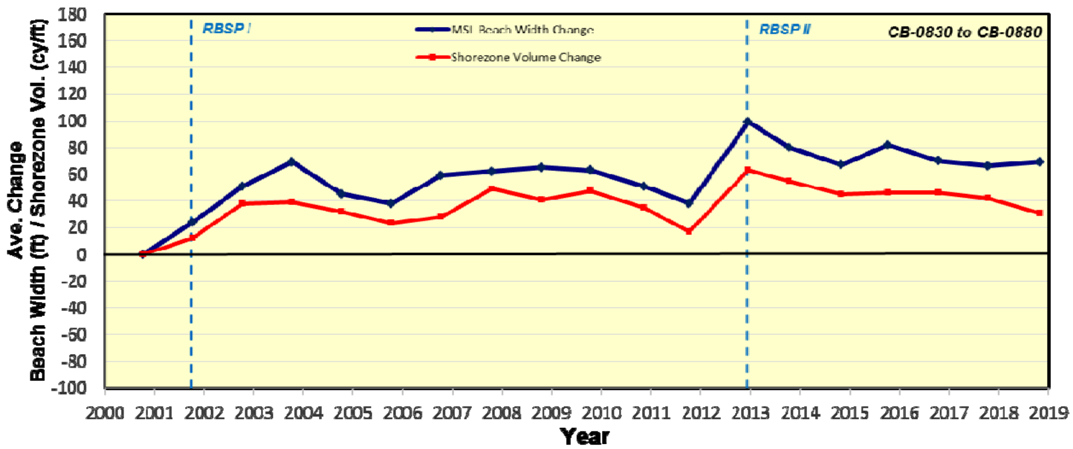


Figure 28. Beach Width and Shorezone Volume Changes in the North Carlsbad Sub-Reach

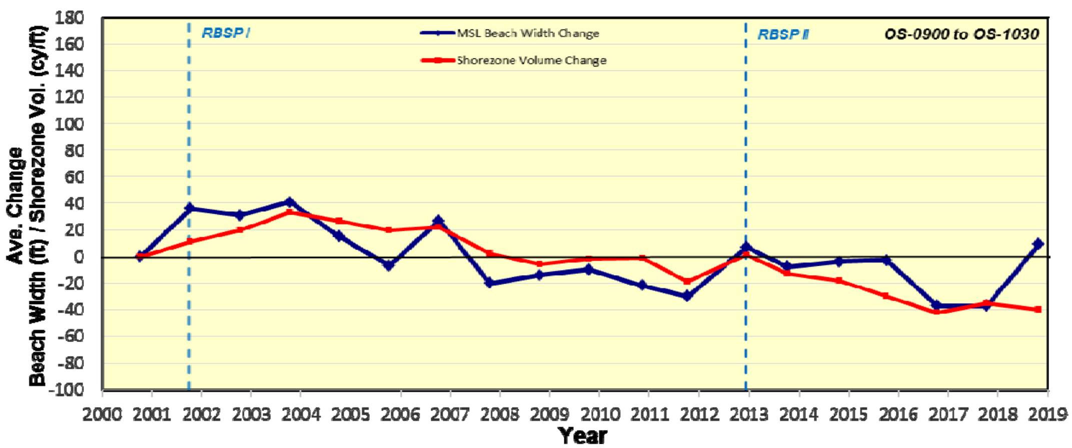


Figure 29. Beach Width and Shorezone Volume Changes in the Oceanside Sub-Reach

Imperial Beach

The initial beneficial effects of the 120,000-cy RBSP I sand placement in Imperial Beach were short-lived, and by 2005 beach widths in the sub-reach were only slightly above the pre-RBSP I condition. However, the placement of 301,000 cy of opportunistic sand in 2005, and of 450,000 cy of material in 2012 as part of the RBSP II, helped maintain beach widths above the pre-RBSP I values for all but one year since 2002 (2011). The RBSP II brought considerably more gains than the RBSP I due to the substantially larger nourishment volume placed during the second project. Steadily decreasing shorezone volumes after each of the nourishment projects suggest that the net sediment budget in Imperial Beach is negative, and that beach material is gradually leaving the sub-reach.

Mission Beach

In Mission Beach, the positive effects of the RBSP I (151,000 cy) were modest but sustained. Both the beach width and shorezone volume gains persisted long-term, and in 2010 the 450,000 cy Corps-sponsored beach nourishment further improved the condition of the beach. No additional fill material was placed in the sub-reach during the RBSP II, and the shorezone volume has been slowly but steadily decreasing since 2015. The shorezone volume fell below the pre-RBSP I condition for the first time in 2018. The average beach width in the sub-reach displays greater interannual variability than the shorezone volume, but it has remained at or slightly above pre-RBSP I levels for most of the study period.

La Jolla

Of the ten sub-reaches studied, only La Jolla was not included in the beach nourishment activities of either the RBSP I or the RBSP II. In addition, no opportunistic sand placement has occurred in the area in recent years. Hence, the shorezone volume gains observed in the sub-reach since 2000 are most likely due to the gradual migration of nourishment material placed in upcoast sites along the Oceanside Littoral Cell. The shorezone volume fell under the pre-RBSP I condition in only one of the last 17 years (2007). A trend of increasing beach widths prevailed between the RBSP I and 2006, followed by decreasing beach widths from 2007 to 2012. With the exception of a sharp drop which occurred following the 2016 El Niño, beach widths have tended to increase since the RBSP II material was placed at upcoast beaches in 2012.

Del Mar

Del Mar received 183,000 cy of sediment during the RBSP I, and also benefited from the sand placements directly upcoast in neighboring Solana Beach and Cardiff. The initial shorezone volume gains were modest, but the average sand volume in the sub-reach has remained above the pre-RBSP I level for most of the Post-RBSP I Period (with years 2007 and 2009 being the exceptions). Even though there have been no additional beach nourishments in Del Mar after the RBSP I, both shorezone volumes and MSL shorelines have trended upward since 2013. This suggests that, similarly to La Jolla, Del Mar has benefited from the gradual migration of nourishment material placed in upcoast sites.

Solana Beach

Solana Beach received 146,000 cy of nourishment material during the RBSP I, and an additional 142,000 cy as part of the RBSP II. In addition, the sub-reach is located directly downcoast of the Cardiff receiver site. The beach restoration projects have yielded long-lasting gains in both shorezone volume and beach width, which have remained above the pre-RBSP I values for the entire Post-RBSP I Period. In 2018, the placement of additional 146,000 cy of fill material in the framework of the SELRP resulted in historical maxima for both parameters.

Cardiff

Similar to Solana Beach, Cardiff has benefited from sand placements during the RBSP I (101,000 cy in year 2001), the RBSP II (89,000 cy in 2012) and the SELRP (300,000 cy in 2018). As a result, the average shorezone sand volume and beach width in the sub-reach have trended notably upward during the Post-RBSP I Period. While the values for both parameters were greatly reduced during the 2016 El Niño season, the nourishment provided during the SELRP in 2018 reversed these losses.

Encinitas/Leucadia

Encinitas/Leucadia received 354,000 cy of material during the RBSP I, and 198,000 cy as part of the RBSP II. Moreover, an additional 47,000 cy of opportunistic sand were placed in the sub-reach in the 10-year period between the two programs. Despite this influx of sediment, a trend of declining average shorezone volume and average beach width has persisted since the completion of the RBSP I. The average beach width has remained below the pre-RBSP I value since 2007, and the shorezone volume since 2015.

South Carlsbad

Both the average shorezone volume and average beach width in South Carlsbad have trended downward since the completion of the RBSP I, when 158,000 cy of material were placed in the sub-reach. The placement of additional 141,000 cy of sand as part of the RBSP II in 2012 slowed this trend only temporarily. No opportunistic nourishment activities have taken place in South Carlsbad in recent years.

North Carlsbad

North Carlsbad received 225,000 cy of sand during the RBSP I. The beneficial effects of the program were sustained long-term, and the additional 219,000 cy of material placed in 2012 during the RBSP II built on the gains of the first project. As a result, beach witdh and shoreline volume in the sub-reach have remained well-above the pre-RBSP I condition for the entire Post-RBSP I Period. The sub-reach appears to be relatively resilient, and withstood the impact of the 2016 El Niño season with less changes than the rest of the reaches.

Oceanside

The Oceanside sub-reach received 421,000 cy of sand during the RBSP I, and the beach width and shorezone volume gains attributable to the nourishment were sustained through 2003. Shorezone volume has trended downward since 2004, with only modest gains following the placement of additional 293,000 cy of sediment as part of the RBSP II nourishment activities in 2012. The beneficial effects of this second program persisted until the 2016 El Niño season. By the end of the 2018 Monitoring Year, the average beach width in the sub-reach was slightly above the pre-RBSP I condition. However, this outcome was most likely the result of the timing of 2018 bypassing operations at Oceanside Harbor.

5.3. Recovery after the 2015-2016 El Niño

The 2015-2016 El Niño was among the three strongest such events on record (Section 2), and the corresponding winter season was characterized by severe erosion. Well-above average shoreline retreat occurred in all but one of the study area sub-reaches, and beach widths in the region had not recovered to pre-El Niño levels by the time of the Fall 2017 survey (Coastal Frontiers, 2018).

As shown in Table 25, post-El Niño recovery progressed in all sub-reaches during the 2018 Monitoring Year. Beach widths attained pre-El Niño levels in the Solana Beach, Cardiff and Oceanside sub-reaches. The recovery in Solana Beach and Cardiff was greatly aided by the SELRP nourishment material placed in 2018. The gains at Oceanside are likely influenced by the timing of the bypassing operations at Oceanside Harbor, which were delayed from Winter/Spring 2018 to Fall 2018 (just before the Fall survey). Beach widths in the other seven sub-reaches remained below the pre-El Niño condition, but the deficit was reduced relative to Fall 2017.

Table 25. Post El Niño Shoreline Recovery by Sub-Reach

Sub-Reach	Transect Range	MSL Beach Width Changes Relative to the Fall 2015 Pre-El Niño Condition (ft)		
		Fall 2016 1yr after El Niño	**Fall 2017** 2yrs after El Niño	**Fall 2018** 3yrs after El Niño
Imperial Beach	SS-0015 to SS-0035	**-25**	**-55**	**-49**
Mission Beach	MB-0310 to PB-408	**-68**	**-66**	**-43**
La Jolla	LJ-0443 to LJ-0460	**-53**	**-44**	**-25**
Del Mar	DM-0580 to DM-0590	**-40**	**-52**	**-24**
Solana Beach	SD-0595 to SD-0610	**-21**	**-37**	**+35**
Cardiff	SD-0620 to SD-0630	**-37**	**-30**	**+57**
Leucadia/Encinitas	SD-0670 to SD-0720	**-33**	**-53**	**-12**
South Carlsbad	CB-0740 to CB-0800	**-25**	**-37**	**-28**
North Carlsbad	CB-0830 to CB-0880	**-13**	**-13**	**-8**
Oceanside	OS-0900 to OS-1030	**-34**	**-34**	**+12**

Note: (1) Based on 38 transects common to Fall surveys conducted between 2015 and 2018.

6. LAGOON ENTRANCE CONDITION

Section 6 evaluates the condition of five lagoon entrances in the Oceanside Littoral Cell: Agua Hedionda, Batiquitos, San Elijo, San Dieguito, and Los Peñasquitos Lagoons (Figure 1). The assessment focuses on the 2018 Monitoring Year (November 2017 through October 2018) and the 17-year period following the RBSP I (November 2002 through October 2018). The second period was adopted based on the assumption that the RBSP I fills exerted no material impacts to the lagoon entrances prior to Fall 2001. Recent lagoon conditions also are compared to those that prevailed prior to RBSP I.

An overview is provided in Section 6.1, followed by a discussion of each entrance in Section 6.2. Although acquisition of aerial photos of the lagoons was discontinued in 2016, photos of each site obtained in October 2015 are provided in Plates 1 through 5 for general reference. Ground photographs obtained by SANDAG on a monthly basis at the unstabilzed entrances are provided in Appendix F.

6.1. Overview

Lagoon entrances in the Oceanside Cell are influenced by a combination of coastal processes, fluvial processes, and human activities. The entrance channels can close when littoral drift overwhelms the capacity of tidal currents and river discharge to remove the arriving sediment. Conversely, tidal exchange can be restored or enhanced during periods of high rainfall, when sediment is flushed from the channels by increased river discharge. The desire for sustained or enhanced tidal exchange also has lead to human intervention, consisting primarily of inlet stabilization and mechanical excavation.

Using a probabilistic approach, Elwany, *et al.* (1998), estimated that San Dieguito, a typical southern California lagoon, would remain open to tidal exchange only 34% of the time under natural conditions. The percent varies with the climatic cycle, however, increasing to 66% during periods of above-average precipitation and decreasing to only 12% during periods of below-average precipitation.

Elwany asserts that the duration of the period that a lagoon remains open is highly dependent on the condition of the inner channels. When the inner channels have been flushed by strong river flows, the tidal prism often is sufficient to maintain an ocean outlet with limited human intervention. Conversely, during prolonged dry periods, the interior channels fill with sand. As the tidal prism diminishes, the ocean outlet becomes increasingly susceptible to closure. In the case of San Dieguito Lagoon, Elwany estimates that the interior channels must be flushed free of sand by strong river flows every three to five years in order for the lagoon to remain open to tidal exchange with minimal maintenance.

As indicated in Section 2, below-average rainfall persisted during 13 of the 20 years that followed the 1997-98 El Niño event. The 2005 precipitation total (18.1 inches) represented the fourth highest annual total on record since 1915. Although no lagoon closures occurred in 2005, each of the unstabilized lagoons closed on numerous occasions during the following three years (2006 to 2008). This outcomes suggests that the interior channels of these lagoons were not sufficiently flushed free of sand by the heavy precipitation and strong river flows during 2005.

Figure 30 shows the average percentage of time that each of the five lagoons in the Oceanside Littoral Cell remained open to tidal exchange during the 2018 Monitoring Year, and prior to and subsequent to the RBSP I. The Pre-RBSP I Period of record for each lagoon varies from five to 47 years in accordance with the available data. Prior to the RBSP I, the two jetty-stabilized entrances, Agua Hedionda and Batiquitos, never closed. In contrast, the three unstabilized entrances closed periodically despite efforts to maintain tidal exchange. The percentage of time open varied widely among these lagoons, with values of 43% at San Elijo, 76% at San Dieguito, and 93% at Los Peñasquitos.

As shown in Figure 31, Los Peñasquitos closed for 42 days (open 88% of the time) during the 2018 Monitoring Year. San Dieguito Lagoon and the stabilized entrances at Agua Hedionda and Batiquitos remained open the entire year. San Elijo Lagoon closed for six days in April, and in June the SELRP contractors temporarily closed it again for three days in order to install a construction dike within the lagoon main channel (Bradley, 2019). As a result, the lagoon was open 98% of the time during the 2018 Monitoring Year.

Following the RBSP I, the two jetty-stabilized entrance channels remained open to the full range of tidal exchange. The entrance channel was open to tidal exchange more than the historical average at San Elijo (95% vs. 43%) and San Dieguito (88% vs. 76%), and slightly less than the historical average at Los Peñasquitos (87% vs. 93%).

6.2. Lagoon Entrance Performance

The condition of each lagoon entrance during the Post-RBSP I Period (2002 through 2018 Monitoring Years) is described below. To provide a basis for post-project comparisons, the pre-RBSP I performance also is summarized. Ground photographs of the three unstabilized channels appear in Appendix F.

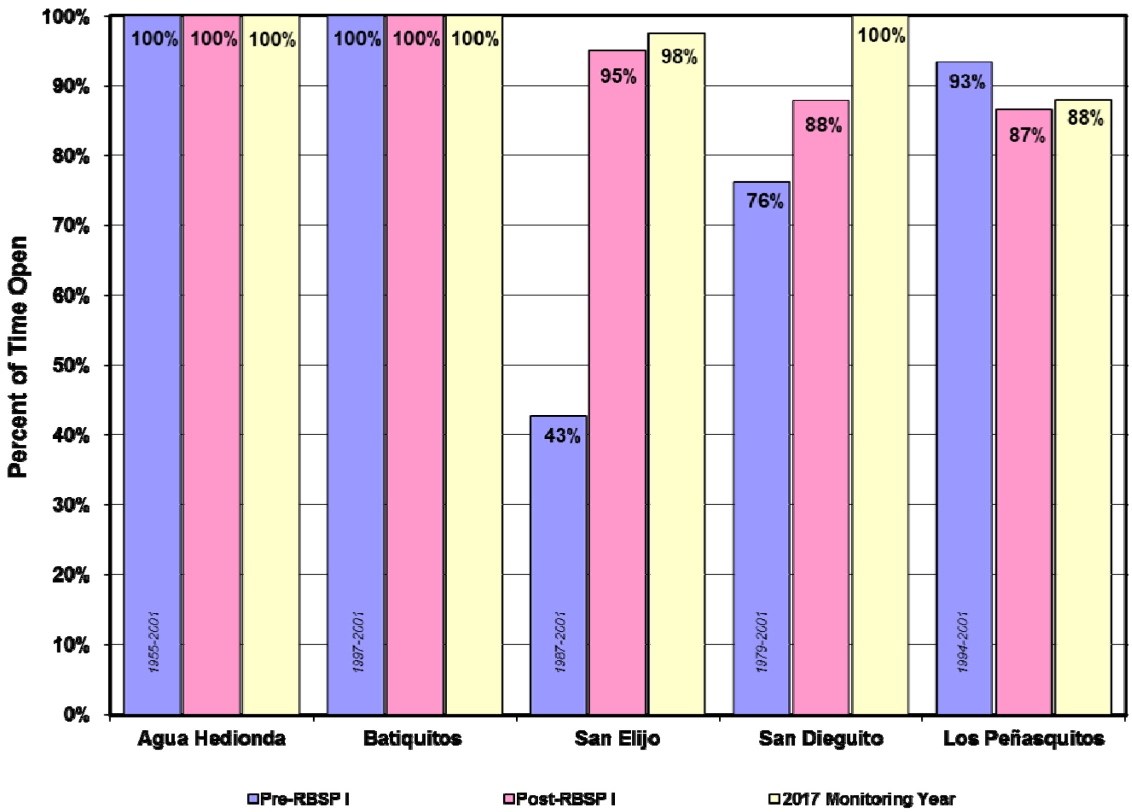


Figure 30. Percentage of Time Lagoon Entrances Open to Tidal Exchange

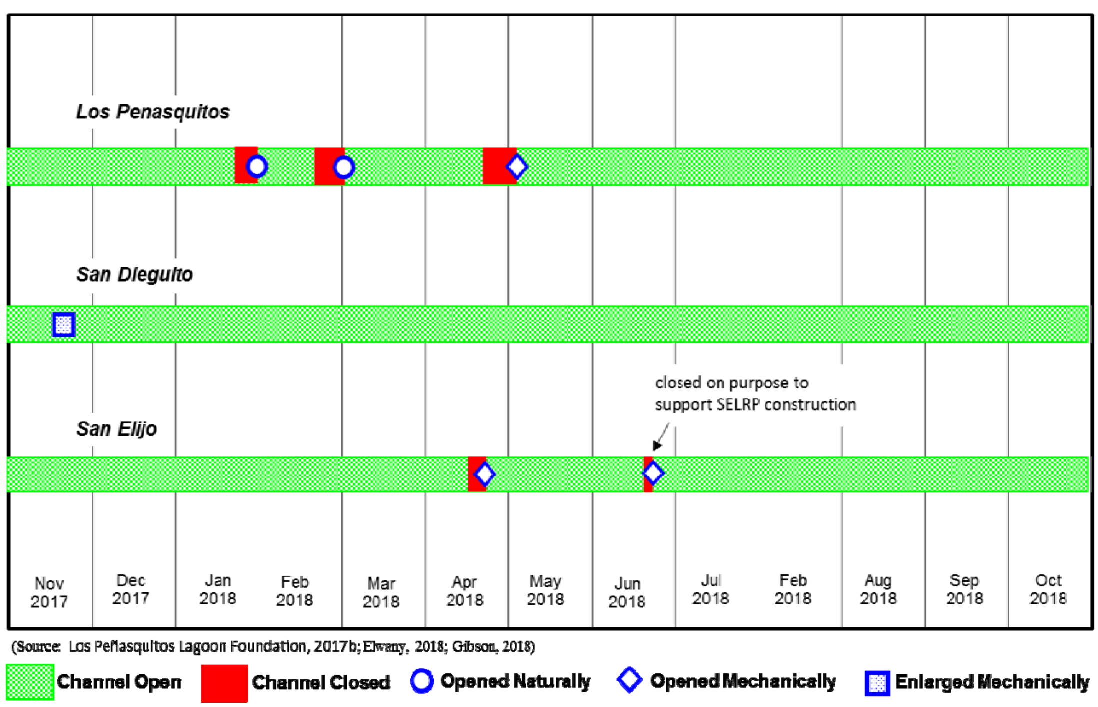


Figure 31. Condition of Unstabilized Lagoon Entrances During 2018 Monitoring Year

As discussed in Section 2.2, sand bypassing is conducted at all five of the lagoons. For the purpose of evaluating sedimentation in the entrance channels, the dredge rate (*i.e.*, the rate of sediment removal) provides a more accurate indicator than the bypassing rate. The dredge rate includes bypassing operations and, in the case of Batiquitos Lagoon, enhancing least tern nesting sites with dredge spoils. The dredge quantities attributable to sedimentation occurring during the Pre-RBSP I Period (1994 to 2001) and Post-RBSP I Period (2002 to 2018) are provided in the sections below. Many of these values were presented previously in Section 2.2.3. Dredge quantities attributable to sedimentation during both periods were distributed proportionally according to time.

The maintenance records for San Elijo and Los Peñasquitos do not segregate the amount of material removed from the interior of the lagoon from that required to breach an entrance channel on the beach face. To provide the best indication of sedimentation within the interior lagoon channels, the values shown for these lagoons were derived by reducing the reported maintenance volumes by 15% for San Elijo and 10% for Los Peñasquitos based on guidance provided by the respective lagoon foundations (Section 2).

6.2.1. Agua Hedionda

The rubble mound jetties at the Agua Hedionda Lagoon entrance were constructed in 1954 to maintain a stable inlet for the Encina Power Plant seawater intake (Shaw, 1980). Extensive dredging was performed at the same time to create a cooling water basin. As a result of these modifications, as well as ongoing maintenance dredging, the lagoon entrance has remained open to tidal exchange since 1955. The lagoon entrance is shown in Plate 1.

Historically, maintenance dredging has been required at intervals of one to two years to remove a flood-tide shoal that forms in the cooling basin. Dredge quantities have ranged from 90,000 to 459,000 cy (Tucker, 2002). Over the 46-yr period preceding the RBSP I (1955-2001), an average of 140,000 cy/yr was removed from the lagoon and placed on the adjacent beaches (Note: this rate does not include material derived from basin modifications in 1998 and 1999). As discussed in Section 2.2, the dredging operation returns sediment to the littoral system that has been trapped in the interior basin, and therefore represents sand bypassing.

During the Pre-RBSP I Period (1994-2001), dredging operations were conducted on four occasions. The dredge quantities ranged from 443,000 cy in 1996 to 197,000 cy in 1997 (Table 26). The average annual dredge rate was approximately 182,000 cy/yr.

Plate 1. Agua Hedionda Lagoon North Entrance, October 2015

Table 26. Lagoon Dredging at Agua Hedionda Lagoon Attributable to Sedimentation Occurring Before and After RBSP I

Period	Date	Activity	Dredge Quantity (cy)
Pre-RBSP I (1994 to 2001)	1996	Bypassing	443,000
	1997	Bypassing	197,000
	1999	Bypassing	203,000
	2001	Bypassing	429,000
	Average Annual Dredge Rate at Agua Hedionda Lagoon = 182,000 cy/yr (1)		
Post-RBSP I (2002 to 2018)	2003	Bypassing	337,000
	2005	Bypassing	375,000
	2007	Bypassing	335,000
	2009	Bypassing	299,000
	2011	Bypassing	226,000
	2015	Bypassing	295,000
	2018	Bypassing	205,000
	Average Annual Dredge Rate at Agua Hedionda Lagoon = 122,000 cy/yr (2)		

Notes: (1) Rate computed for the eight-year period (1994 to 2001).
(2) Rate computed for the 17-year period (2002 to 2018).

Maintenance dredging has been conducted seven times in Agua Hedionda following the RBSP I. Approximately 205,000 cy of sediment were removed from the lagoon during the 2018 maintenance dredging operations. The resulting average dredging rate following the RBSP I is 122,000 cy/yr (about 33% below the pre-RBSP I rate).

6.2.2. Batiquitos

Prior to 1994, the entrance to Batiquitos Lagoon was unstabilized and prone to frequent closure (SANDAG, 1999b). As part of the Batiquitos Lagoon Restoration Project conducted between 1994 and 1997, two rubble mound jetties were constructed at the entrance and 1.8 million cy of sediment were dredged from the wetlands. Plate 2 shows the condition of the Batiquitos Lagoon entrance channel in October 2015.

Plate 2. Batiquitos Lagoon Entrance, October 2015

Since completion of the initial wetland restoration effort, the lagoon has remained open to tidal exchange. Periodic dredging has been required, however, to maintain the tidal prism. As indicated Table 27, an average of 16,000 cy/yr were removed from the lagoon and either placed on the adjacent beaches or used for habitat enhancement prior to the RBSP I. It is believed that this rate underestimates the long-term dredging requirement, because the major dredge activities associated with the lagoon restoration effort had just been completed.

Table 27. Lagoon Dredging at Batiquitos Lagoon Attributable to Sedimentation Occurring Before and After RBSP I

Period	Date	Activity	Dredge Quantity (cy)
Pre-RBSP I (1994 to 2001)	1999	Bypassing and Habitat Enhancement	11,000
	2000	Bypassing	4,000
	2001	Bypassing and Habitat Enhancement	49,000
	Average Annual Dredge Rate at Batiquitos Lagoon = 16,000 cy/yr [(1)]		
Post-RBSP I (2002 to 2017)	2003	Habitat Enhancement	75,000
	2007	Bypassing	66,000
	2012	Bypassing	112,000
	Average Annual Dredge Rate at Batiquitos Lagoon = 23,000 cy/yr [(2)]		

Notes: (1) Rate computed for the four-year period following lagoon restoration (1998 to 2001).
(2) Rate computed for the 11-year period (2002 to 2012).

Dredging was conducted on three occasions subsequent to the RBSP I (Table 27). In 2003, approximately 75,000 cy of sediment were dredged from the lagoon and used to enhance least tern nesting sites within the lagoon (Dillingham, 2004). Approximately 66,000 cy were removed from the lagoon in 2007 and placed on the beach. In 2012, approximately 112,000 cy were removed from the lagoon and placed on the adjacent beaches. Taken over the 11-year period from 2002 to 2012, this amount equates to a dredging rate of approximately 23,000 cy/yr. Although this rate exceeded the pre-RBSP I average of 16,000 cy/yr, the latter figure is anomalously low as explained above.

6.2.3. San Elijo

Based on records maintained by the San Elijo Lagoon Conservancy (Gibson, 2003), San Elijo Lagoon was open to tidal exchange during only 43% of the 15-year period preceding the RBSP I (1987-2001). The average closure frequency during this period was 4.4 times per year, while the frequency of mechanical opening was 2.9 times per year. The difference between these two frequencies is attributable to natural opening of the entrance channel. During the Pre-RBSP I Period (1994 to 2001), approximately 15,000 cy/yr were dredged from the lagoon (Table 28).

During the 2018 Monitoring Year, the lagoon entrance was closed to tidal exchange for six days in April and for three days in June (open 98% of the time). The latter event corresponded to a mechanical closure carried out by the SELRP contractors to allow the installation of a construction dike across the main channel of the lagoon (Bradley, 2019).

Table 28. Lagoon Dredging at San Elijo Attributable to Sedimentation Occurring Before and After RBSP I

Period	Date	Activity	Dredge Quantity (cy)
Pre-RBSP I (1994 to 2001)	1995	Bypassing	6,000
	1996	Bypassing	8,000
	1997	Bypassing	31,000
	1998	Bypassing	12,000
	1999	Bypassing	17,000
	2000	Bypassing	23,000
	2001	Bypassing	23,000
	Average Annual Dredge Rate at San Elijo Lagoon = 15,000 cy/yr [(1)]		
Post-RBSP I (2002 to 2018)	2002	Bypassing	18,000
	2003	Bypassing	32,000
	2004	Bypassing	30,000
	2005	Bypassing	17,000
	2006	Bypassing	18,000
	2007	Bypassing	19,000
	2008	Bypassing	23,000
	2009	Bypassing	19,000
	2010	Bypassing	21,000
	2011	Bypassing	23,000
	2012	Bypassing	24,000
	2013	Bypassing	26,000
	2014	Bypassing	23,000
	2015	Bypassing	22,000
	2016	Bypassing	22,000
	2017	Bypassing	17,000
	2018	Bypassing (Cardiff Beach Living Shoreline Project)	11,000
	Average Annual Dredge Rate at San Elijo Lagoon = 21,000 cy/yr [(2)]		

Notes: [(1)] Rate computed for the eight-year period (1998 to 2001).
[(2)] Rate computed for the 17-year period (2002 to 2018).

Following the RBSP I (2002 to 2018), the lagoon was open to tidal exchange 95% of the time. The most plausible explanation for the improved performance of the entrance relative to the Pre-RBSP I Period is the increased dredging within the lagoon commencing in 2000 made possible by additional funding. The average closure frequency during the Post-RBSP I Period was 0.9 times per year, while the average frequency of mechanical opening was 1.3 times per year. In this case, the higher frequency of mechanical openings is attributable to conducting planned maintenance operations (mechanical enlargements) even when the lagoon was open to tidal exchange. The increased level of maintenance performed after 2000 yielded an average annual dredge rate of approximately 21,000 cy/yr during the Post-RBSP I Period. Plate 3 shows the San Elijo entrance channel in October 2015.

Plate 3. San Elijo Lagoon Entrance, October 2015

6.2.4. San Dieguito

Based on data compiled by Elwany, *et al.* (1998, 2003), San Dieguito Lagoon was open to tidal exchange 76% of the time between 1979 and 2001. On average, the channel closed 0.6 times per year, and was opened mechanically 0.6 times per year. The relatively low closure frequency can be attributed in part to the above-average rainfall during the period of record. During the Pre-RBSP I Period (1994 to 2001), approximately 5,000 cy/yr were dredged from the lagoon (Table 29). The lagoon entrance is shown in Plate 4.

Table 29. Lagoon Dredging at San Dieguito Attributable to Sedimentation Occurring Before and After RBSP I

Period	Date	Activity	Dredge Quantity (cy)
Pre-RBSP I (1994 to 2001)	2000	Bypassing	5,000
	2001	Bypassing	5,000
	Average Annual Dredge Rate at San Dieguito Lagoon = 5,000 cy/yr (1)		
Post-RBSP I (2002 to 2018)	2002	Bypassing	5,000
	2003	Bypassing	16,000
	2006	Bypassing	16,000
	2008	Bypassing	16,000
	2011	Bypassing	40,000
	2016	Bypassing	14,000
	2018	Bypassing	16,000
	Average Annual Dredge Rate at San Dieguito Lagoon = 7,000 cy/yr (2)		

Notes: (1) Rate computed for the two-year period for which data are available (2000 to 2001).
(2) Rate computed for the 17-year period (2002 to 2018).

Plate 4. San Dieguito Lagoon Entrance, October 2015

As indicated in Figure 31, the lagoon inlet remained open during the 2018 Monitoring Year. The lagoon was open to tidal exchange 88% of the time following the RBSP I (2002 to 2018). The entrance closed on 16 occasions during this period, with nine of the closures occurring in 2006. The average closure frequency was 0.9 time per year. Mechanical intervention was required to re-establish tidal exchange after only nine of these closures, with the inlet opening naturally after the other closures. As a result, the frequency of mechanical openings was 0.5 times per year. The average annual dredge rate during following the RBSP I was approximately 7,000 cy/yr (Table 9). However, this rate is not representative of the true long-term dredging requirement because a lagoon restoration project was initiated during the period (discussed below).

The San Dieguito Lagoon Restoration Project commenced in 2011, with the objective of enhancing and maintaining the continuous tidal exchange within the lagoon (Coastal Environments, 2011). The initial phase included excavating approximately 74,000 cy of material from the interior lagoon channels east of the railroad bridge. This material was placed at nesting sites within the lagoon. Elwany estimates that these channels have not been dredged since the 1980's. This material is not accounted for in the post-RBSP I dredging rates (Table 29) because the excavation represents a change in the lagoon configuration that is outside of the bounds of the maintenance operations undertaken during recent decades.

The second phase of the restoration project consisted of excavating approximately 40,000 cy of sand from the lagoon channels adjacent to Highway 101, and placing the material on the beaches both north and south of the lagoon entrance. During this period, the lagoon was purposely closed to tidal exchange for 21 days before the entrance was opened mechanically on September 29th. Approximately 14,000 cy of material were removed from the lagoon channels during maintenance dredging activities in November 2015, and an additional 16,000 cy in November 2017.

6.2.5. Los Peñasquitos

The Los Peñasquitos entrance channel is shown in Plate 5. Prior to the RBSP I, the unstabilized entrance to Los Peñasquitos Lagoon typically closed several times per year. Efforts to re-establish the entrance channel with earth-moving equipment date back to the 1960's. Based on data compiled by the Los Peñasquitos Lagoon Foundation (West, 2003), the lagoon was open to tidal access about 50% of the time between 1965 and 1984. More recently, the Los Peñasquitos Lagoon Foundation has funded a sustained effort to maintain tidal flow by mechanically opening or widening the channel several times each year (KEA

Plate 5. Los Peñasquitos Lagoon Entrance, October 2015

Environmental, 2001). As a result, the lagoon was open to tidal exchange over 90% of the time between 1994 and 2001 (Williams, 1996, 1997; Williams *et al.*, 1995, 1998, 1999; Ward *et al.*, 2000, 2001, 2003; West, 2003, 2004). During this period, the entrance closed an average of 2.3 times per year, and was mechanically opened or widened 1.6 times per year. The Pre-RBSP I Period (1994 to 2001) dredge rate at Los Peñasquitos Lagoon was approximately 11,000 cy/yr (Table 30).

Los Peñasquitos Lagoon entrance closed to tidal exchange three times during the 2018 Monitoring Year. The first two closures occurred in January and February, and were followed by natural openings of the inlet. The inlet closed to again on April 10^{th}, requiring mechanical intervention to restore tidal exchange in early May. Approximately 31,000 cy of sediment were removed during the dredging operations.

After the RBSP I (2002 to 2018), the lagoon was open to tidal exchange 87% of the time. The average closure frequency was 2.1 times per year, which was slightly greater than the average frequency of mechanical opening (1.5 times per year). The difference can be attributed to natural openings following some closures. Maintenance dredging was performed each year, resulting in an average annual dredge rate of approximately 25,000 cy/yr.

Table 30. Lagoon Dredging at Los Peñasquitos Attributable to Sedimentation Occurring Before and After RBSP I

Period	Date	Activity	Dredge Quantity (cy)
Pre-RBSP I (1994 to 2001)	1996	Bypassing	5,000
	1997	Bypassing	17,000
	1998	Bypassing	8,000
	1999	Bypassing	8,000
	2000	Bypassing	20,000
	2001	Bypassing	10,000
	Average Annual Dredge Rate at Los Peñasquitos Lagoon = 11,000 cy/yr (1)		
Post-RBSP I (2002 to 2018)	2002	South of Entrance	10,000
	2003	South of Entrance	33,000
	2004	South of Entrance	5,000
	2005	South of Entrance	5,000
	2006	South of Entrance	14,000
	2007	South of Entrance	22,000
	2008	South of Entrance	29,000
	2009	South of Entrance	23,000
	2010	South of Entrance	22,000
	2011	South of Entrance	23,000
	2012	South of Entrance	13,000
	2013	South of Entrance	33,000
	2014	South of Entrance	48,000
	2015	South of Entrance	23,000
	2016	South of Entrance	60,000
	2017	South of Entrance	29,000
	2018	South of Entrance	31,000
	Average Annual Dredge Rate at Los Peñasquitos Lagoon = 25,000 cy/yr (2)		

Notes: (1) Rate computed for the six-year period for which data are available (1996 to 2001).
(2) Rate computed for the 17-year period (2002 to 2018).

7. OFFSHORE BORROW SITE CONDITIONS

This section assesses the condition of the three offshore borrow sites used during the RBSP II. Borrow site monitoring consisted of obtaining bathymetric data and sediment samples at each of the three dredge sites utilized for the RBSP II (MB-1 in the Mission Beach Cell, and SO-6 and SO-5 in the Oceanside Cell). Figures 32 and 33 show the borrow site locations, the transects surveyed at each dredge pit, and the sediment sample locations. The results of the bathymetric surveys are described in Section 7.1, followed by a discussion of the sediment sample analysis in Section 7.2. All figures are provided at the end of this section.

7.1. Bathymetric Changes

Figure 34 shows the sea bottom configuration at each borrow site following dredging in 2012, when multi-beam surveys of the three dredge pits were conducted (Scott, 2013). The post-construction bottom was characterized by distinct ridges and furrows indicative of the dredging method. These features were oriented along the long axis of each dredge footprint, roughly north-south at MB-1 and SO-5, and east-west at SO-6. The transects established for borrow site monitoring were oriented parallel and perpendicular to the ridge/furrow features.

Sea bottom profiles developed from bathymetric data obtained at the time of the Fall 2018 are shown in Figures 35 through 37. In order to assess the changes that have occurred in the pits since completion of the completion of the RBSP II, the 2018 profiles are plotted in concert with equivalent data corresponding to the 2012 post-construction survey, the Fall 2014 survey and the Fall 2016 survey (Coastal Frontiers, 2015 and 2017). A summary of the elevation changes on each transect is provided in Table 31.

Comparison of the 2012 and 2014 bathymetry profiles along the monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. The average elevation change was 0.1 ft or less along the transects oriented perpendicular to the ridge/furrow pattern, and varied between -0.4 ft and 1.1 ft at the transects oriented parallel to these features. This apparent discrepancy can be explained by the orientation of the transects relative to the ridges and furrows, with those oriented perpendicular to the features displaying a near balance of erosion of the ridge tops accompanied by filling of the furrow valleys (*e.g.*, Figure 35, MB-1 Transect B). In contrast, the profiles on the transects oriented parallel to these features contain large sections

Table 31. Elevation Changes along Borrow Site Transects Occurring between December 2012 and October 2018

Borrow Site	Transect	Average Elevation Change			
		Dec 2012-Oct 2014	Oct 2014-Oct 2016	Oct 2016-Oct 2018	Dec 2012-Oct 2018
MB-1	MB-1A	-1.1 ft	-0.3 ft	0.0 ft	-1.4 ft
	MB-1B	0.0 ft	0.0 ft	0.1 ft	0.0 ft
	average	*-0.6 ft*	*-0.1 ft*	*0.0 ft*	*-0.7 ft*
SO-5	SO-5A	0.3 ft	1.2 ft	0.8 ft	2.2 ft
	SO-5B	0.1 ft	0.2 ft	-0.1 ft	0.1 ft
	average	*0.2 ft*	*0.7 ft*	*0.3 ft*	*1.2 ft*
SO-6	SO-6A	0.1 ft	0.0 ft	-0.1 ft	0.0 ft
	SO-6B	0.4 ft	0.7 ft	0.3 ft	1.3 ft
	average	*0.3 ft*	*0.3 ft*	*0.1 ft*	*0.7 ft*

dominated by either ridge erosion or furrow infilling which creates an apparent imbalance (*e.g.*, Figure 35, MB-1 Transect A from a range of 1,175 to 1,200 ft). As such, the transects oriented perpendicular to the ridge/furrow pattern are believed to provide a more accurate estimate of the bathymetric changes at the borrow sites during this period.

Between the 2014 and 2016 surveys, additional smoothing occurred at the three sites. Notably, the side slopes of the pits were milder in 2016 than in 2014. Changes at MB-01 were modest during this period, with elevations essentially unchanged. The average infilling at the two SO-5 transects ranged from 0.2 to 1.2 ft. At SO-6, the elevations along Transect A were essentially unchanged over the two-year period. In contrast, shoaling of up 4 ft prevailed at the onshore portion of the SO-6 dredge area (Transect B).

The Fall 2018 cross-sections bore a close resemblance to those in 2016. The most noteworthy changes consisted of additional flattening of the side slopes at each borrow site. The sea bottom elevations were essentially unchanged at MB-01 during this period. Modest infilling occurred at SO-5 and SO-6 (averaging 0.3 and 0.1 ft, respectively).

Over the six-year period following dredging, shoaling at SO-5 and SO-6 averaged 1.2 and 0.7 ft, respectively. These changes equate to infilling rates of about 0.2 ft/yr at SO-5 and 0.1 ft/yr at SO-6. In contrast, during the same period elevations decreased by an average of 0.7 ft at MB-01.

7.2. Sediment Characteristics

Two sediment samples were obtained within the dredged footprint of each borrow site at the time of the Fall 2018 survey (Figures 32 and 33). Grain size distribution curves for each sample are provided in Figures 38 through 40. Each plot also includes the curves corresponding to the samples acquired in 2014 and 2016 (Coastal Frontiers, 2015 and 2017) and the range of grain sizes sampled during the 2008 geophysical investigation (URS, 2009). "Fines" are defined as that material passing the #200 sieve (less than 0.074 mm in diameter). The results are summarized in Table 32.

Table 32. Sediment Size Characterization at Borrow Sites

Borrow Site	Median Grain Size (d_{50}, mm)				Fines Content (%) (< 0.074 m; passing #200 sieve)			
	2008	Oct 2014	Oct 2016	Oct 2018	2008	Oct 2014	Oct 2016	Oct 2018
MB-1	0.33-0.65	0.45-0.60	0.53-0.55	0.39-0.53	0 – 12%	3 – 4%	2 – 6%	4-14%
SO-5	0.09-0.73	0.26-0.45	0.26-0.54	0.49-0.54	1 - 39%	13 - 15%	15 – 22%	10-23%
SO-6	0.13-0.62	0.50-0.53	0.10-0.52	0.37-0.58	2 – 9%	2 – 3%	5 – 32%	5-17%

At MB-1, the grain size distribution curves corresponding to the samples obtained in 2014, 2016 and 2018 fell within the envelope of sediment sizes derived from the 2008 geophysical investigation with the exception of two small deviations: one in particle sizes near 0.8 mm for one of the 2014 samples, and a second one in particle sizes around 0.08 mm for one of the 2018 samples (Figure 38). The grain size distributions for five of the samples collected at this site since 2014 were very similar, while the remaining one (2018, Sample #1) contained a higher percentage of fine grained material.

The grain size distribution curves for the six samples obtained at SO-5 between 2014 and 2018 were near the middle of the envelope of in-situ sediment sizes (Figure 39). The samples taken in this pit show considerable variability in the content of finer grained sand.

At SO-6, the grain size distribution curves of the two samples obtained in 2014 and of one of the samples obtained on 2016 fell near the "coarse" side of the envelope of in-situ sediment sizes sampled in 2008 (Figure 40). However, the second 2016 sample, which was retrieved from the onshore portion of the dredge pit where shoaling of up to 4 ft was noted, contained finer sediment than that identified in the 2008 investigation. This outcome suggests the preferential deposition of fine material at the onshore portion of the SO-6 dredge area. The deposition of fine material may be attributable to high energy wave conditions during the 2015-2016 El Nino winter. However, the biennial nature of the borrow site surveys make it impossible to determine if the shoaling occurred during that season. The samples collected in 2018 fell within the envelope of sediment sizes derived from the 2008 geophysical investigation with the exception of a notably higher fines content at Sample #1.

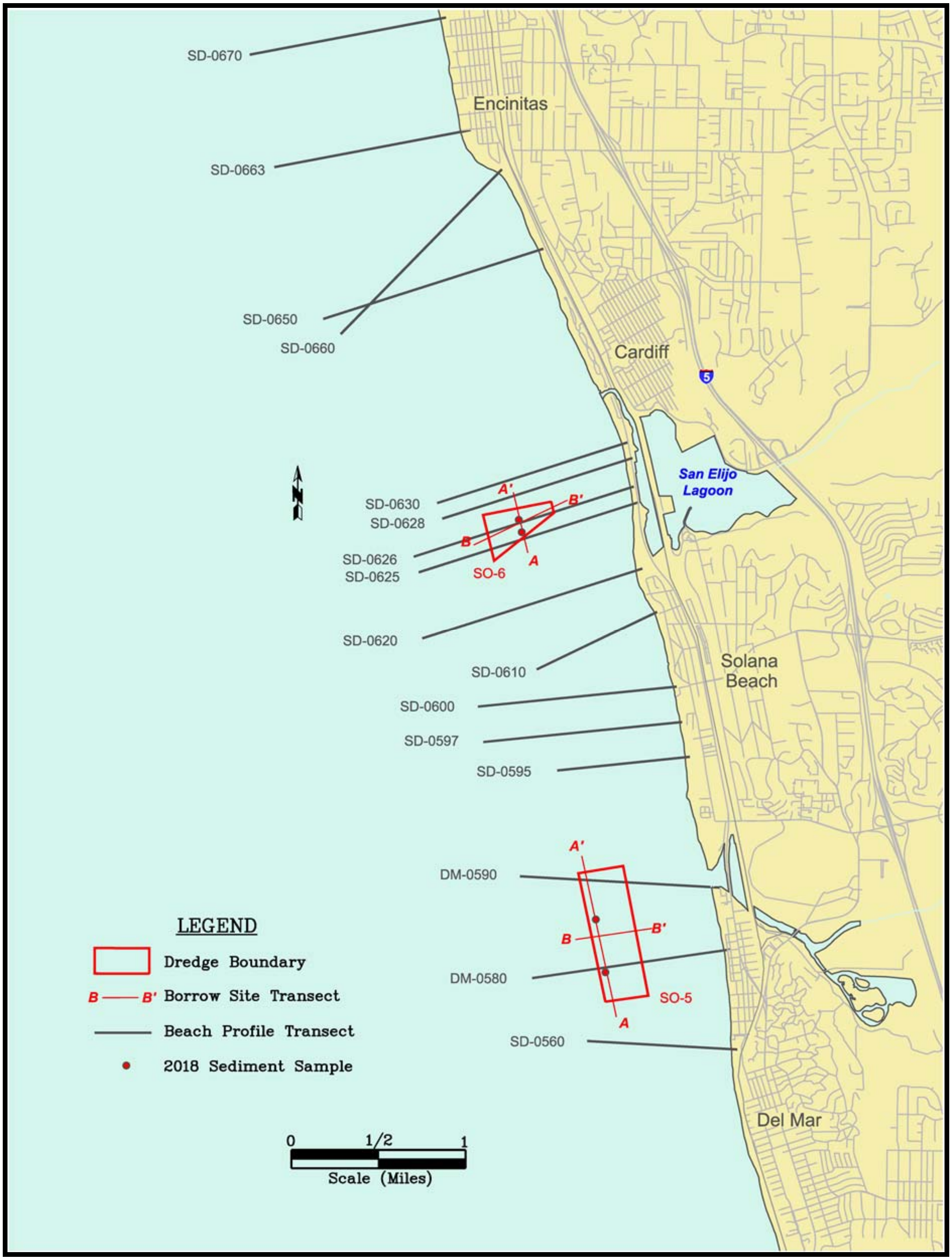


Figure 32. Location of Borrow Site MB-1

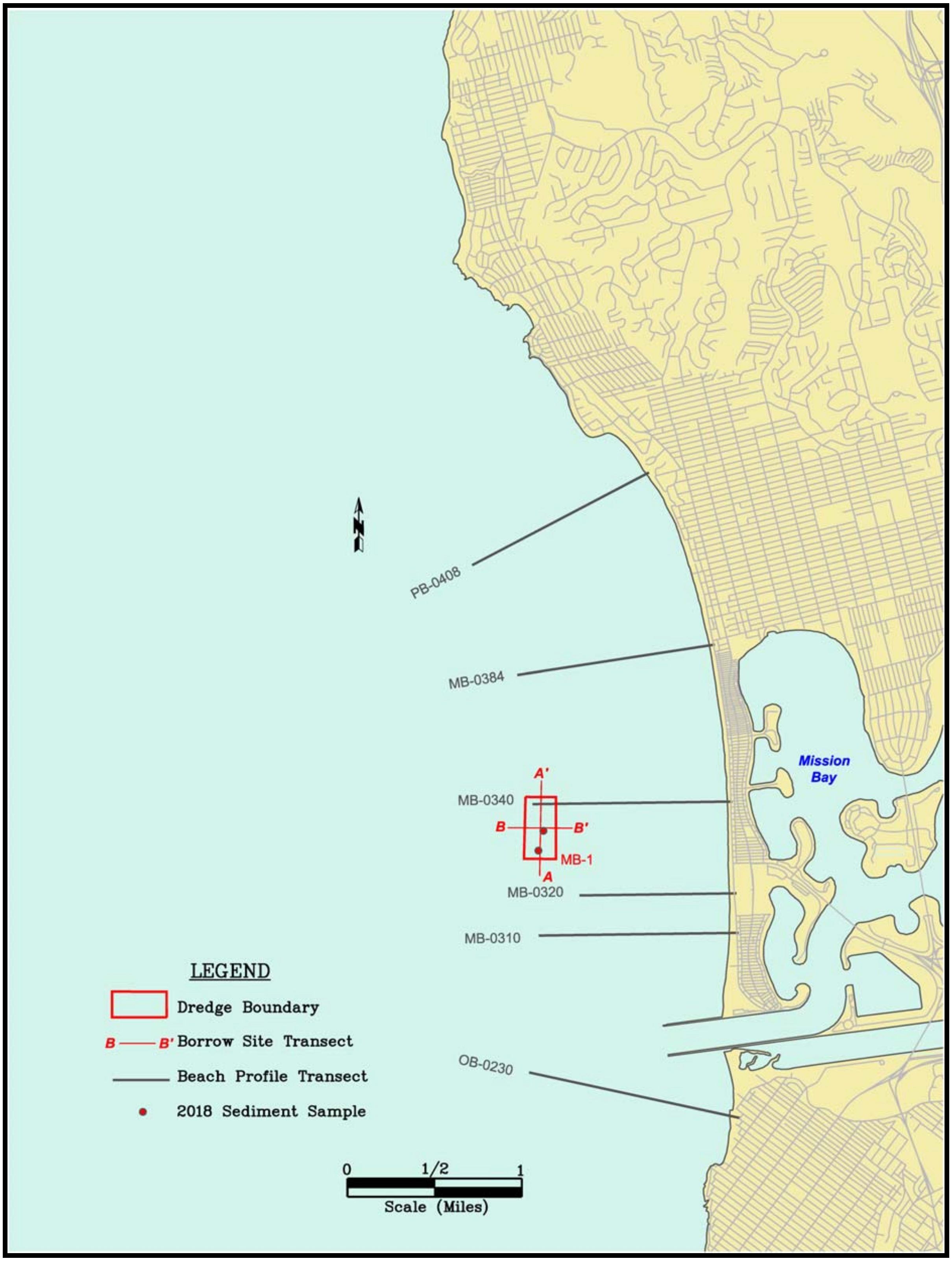
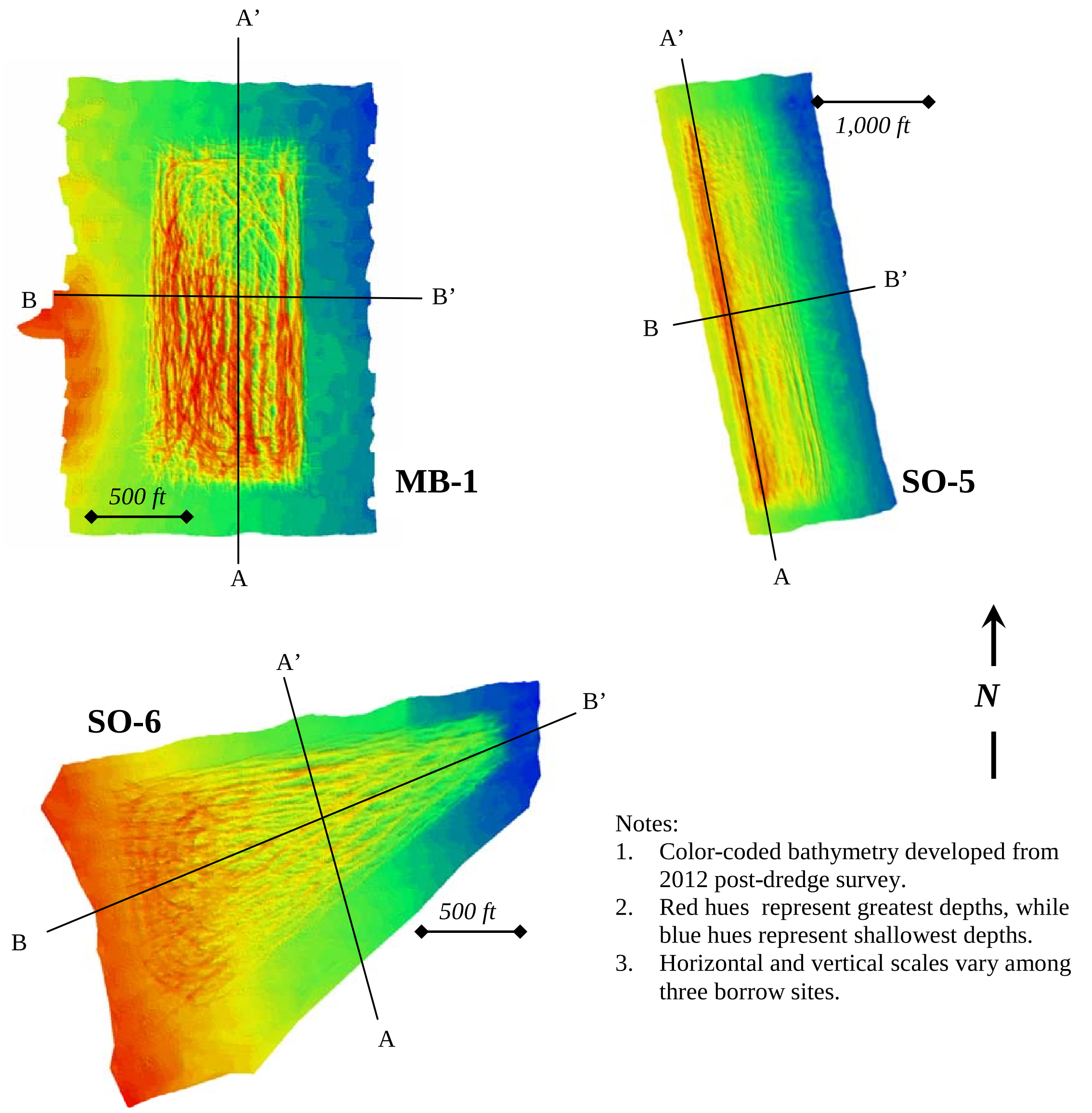


Figure 33. Location of Borrow Sites SO-5 and SO-6



Notes:
1. Color-coded bathymetry developed from 2012 post-dredge survey.
2. Red hues represent greatest depths, while blue hues represent shallowest depths.
3. Horizontal and vertical scales vary among three borrow sites.

Figure 34. 2012 Post-Dredge Bathymetry of Borrow Sites

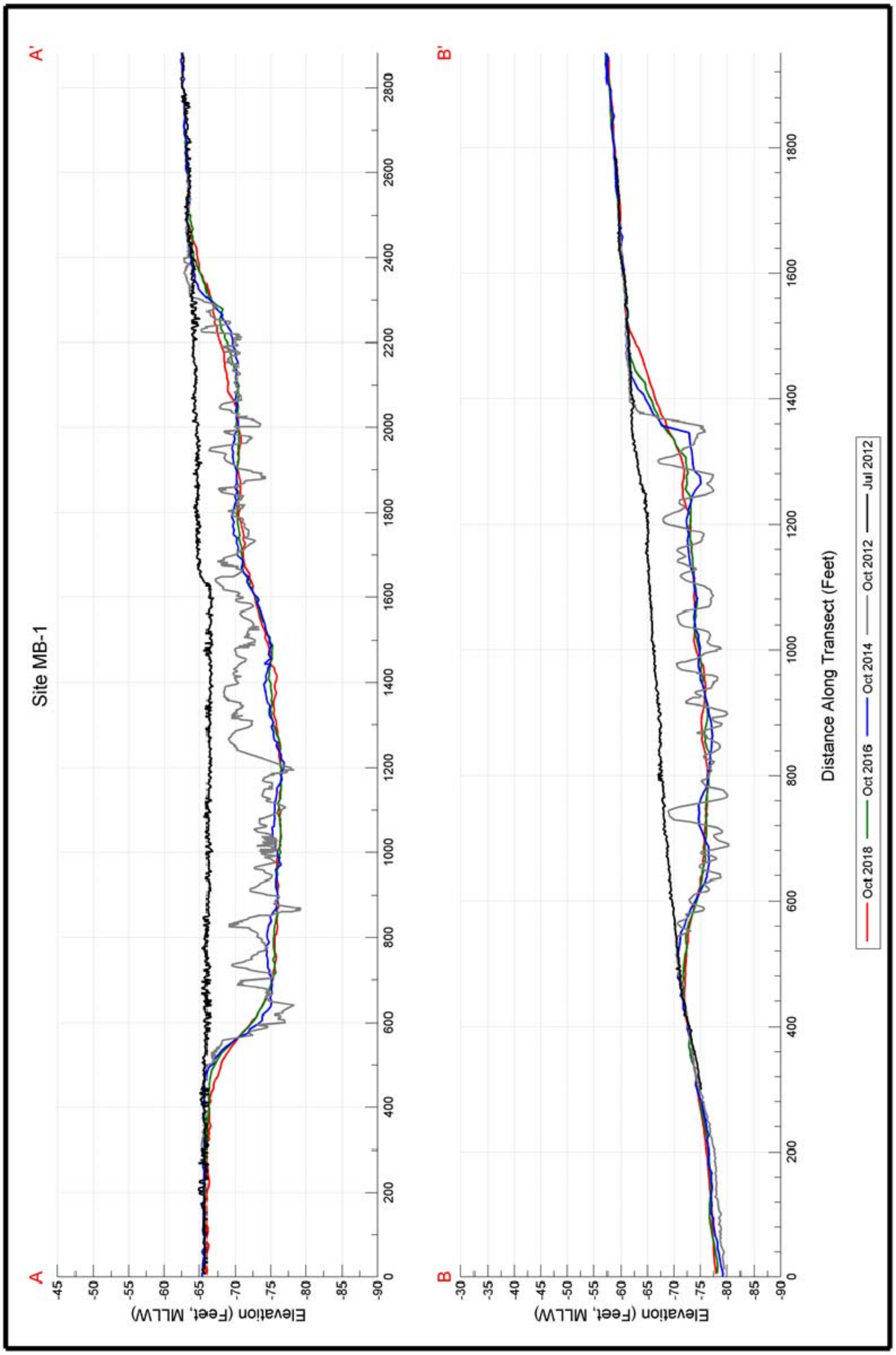


Figure 35. Bathymetric Profiles along MB-1 Borrow Site Transects

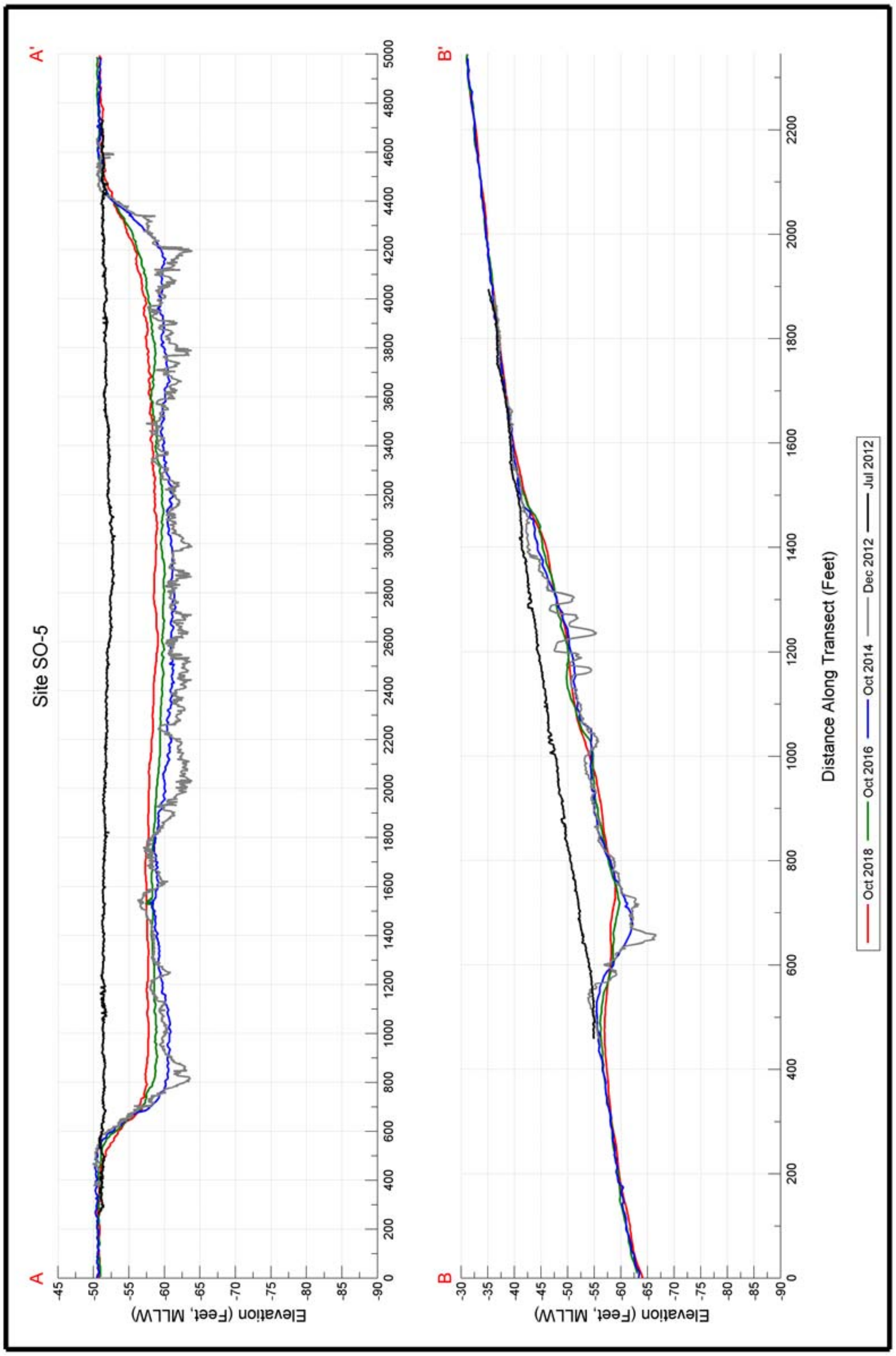


Figure 36. Bathymetric Profiles along SO-5 Borrow Site Transects

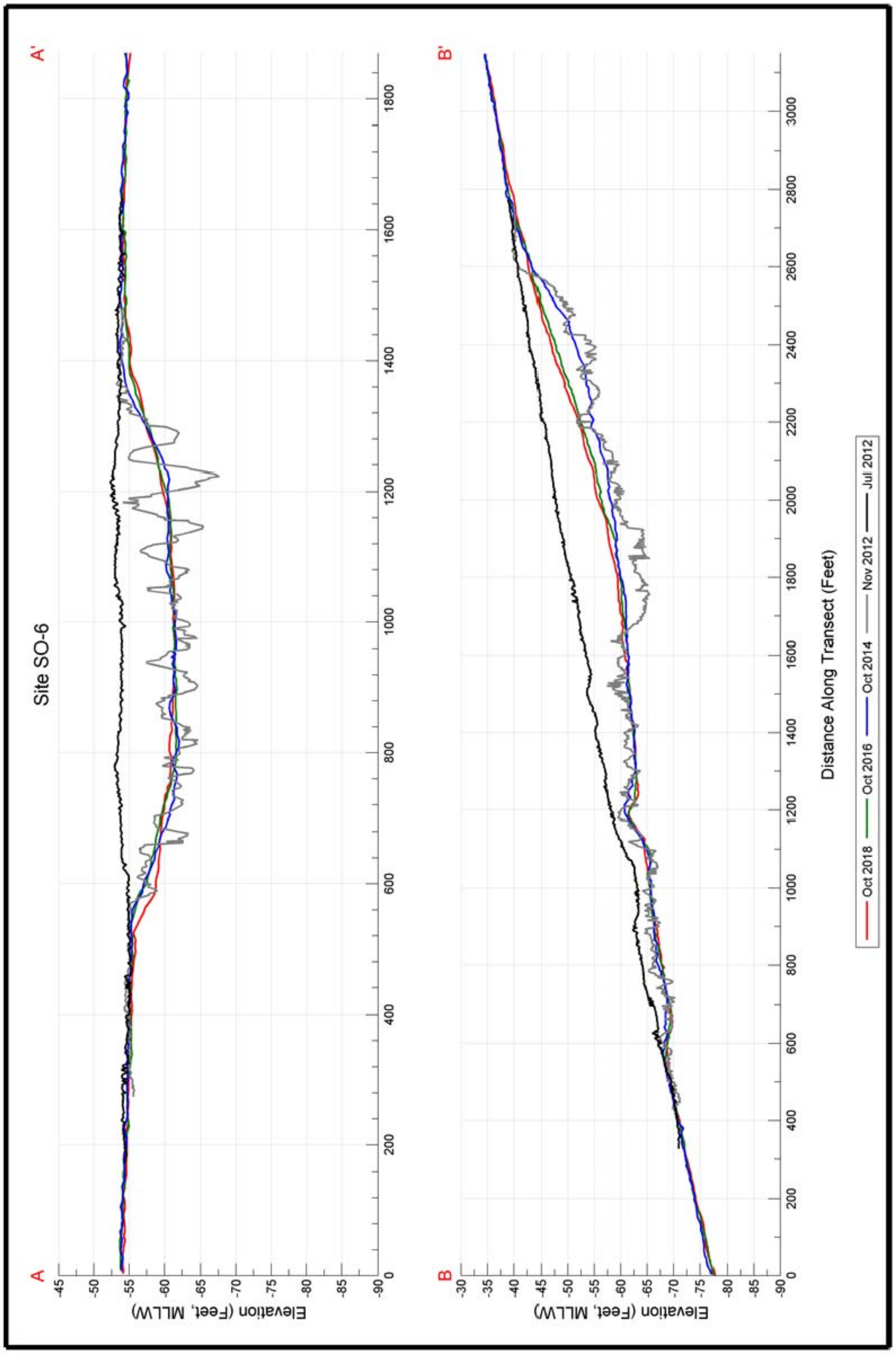


Figure 37. Bathymetric Profiles along SO-6 Borrow Site Transects

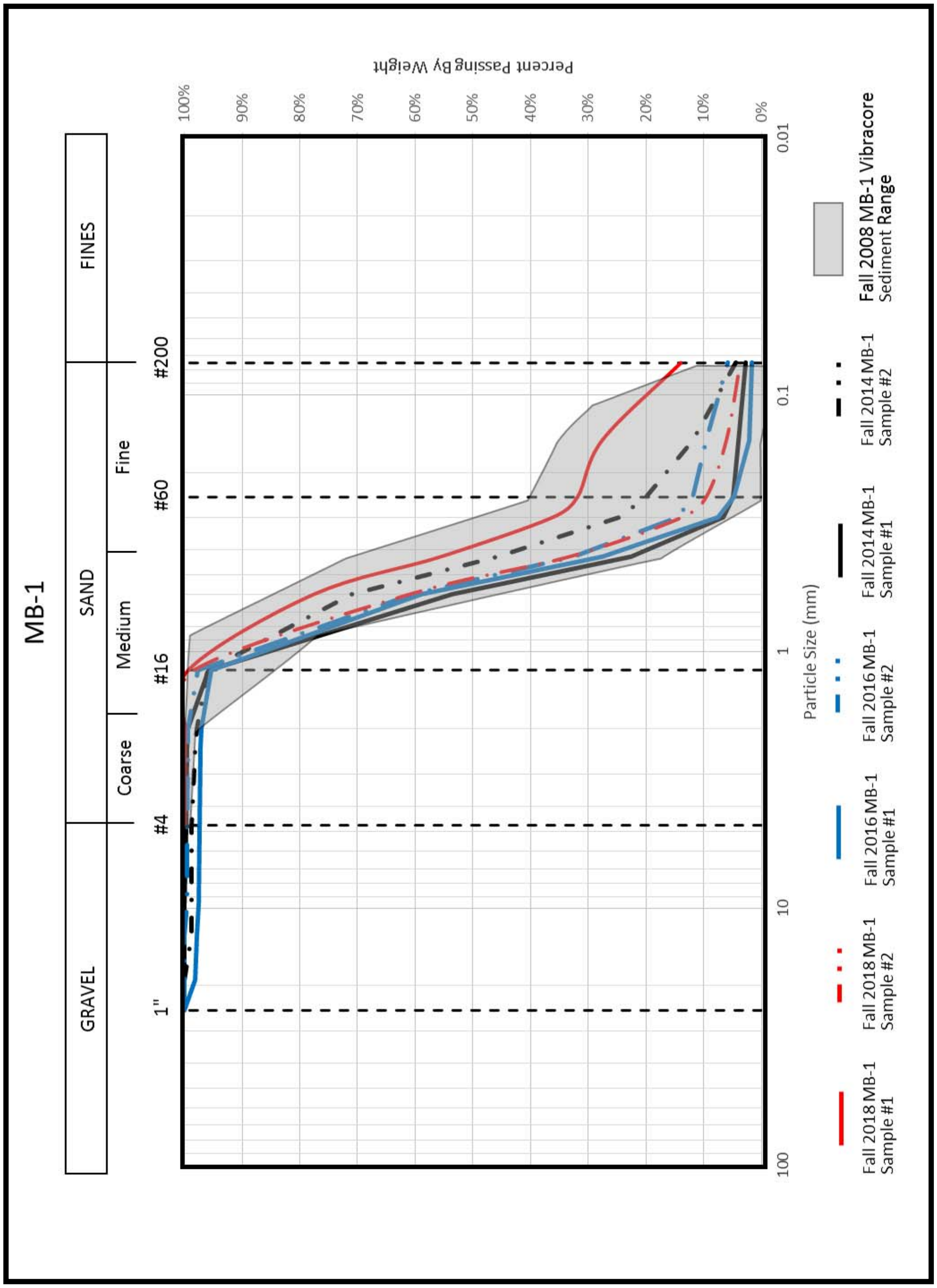


Figure 38. Grains Size Distribution Curves, MB-1

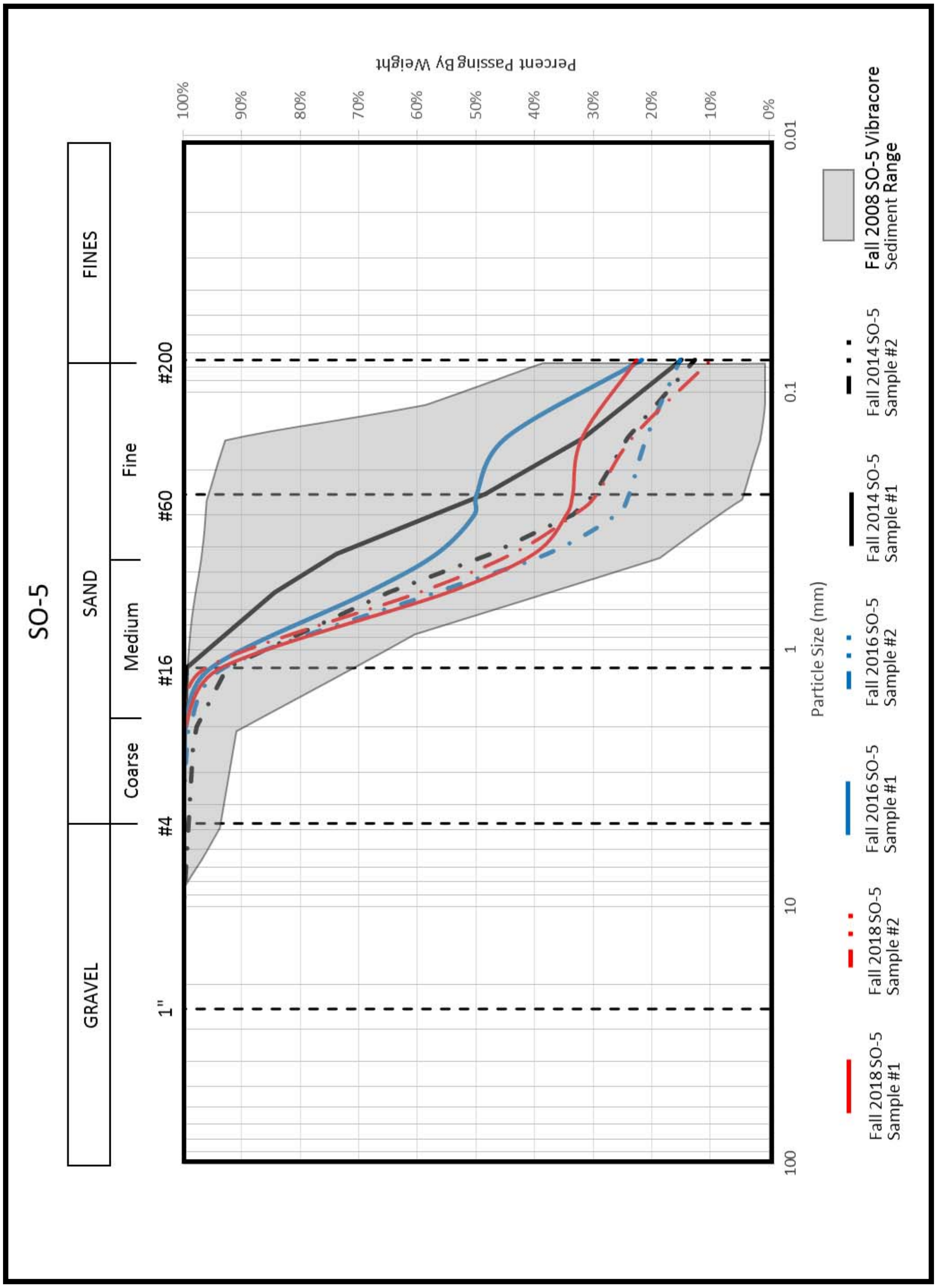


Figure 39. Grains Size Distribution Curves, SO-5

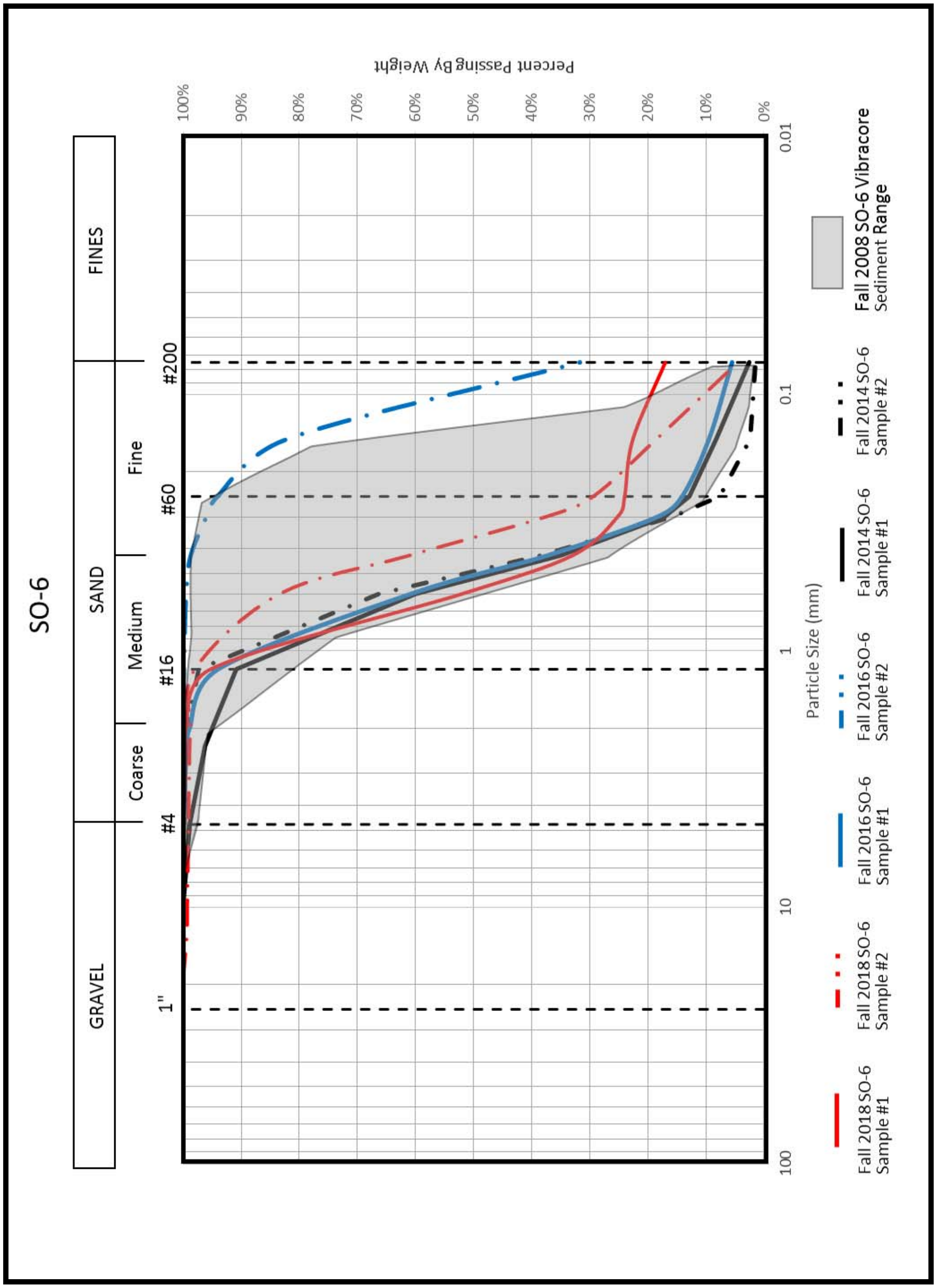


Figure 40. Grains Size Distribution Curves, SO-6

8. CONCLUSIONS

Conclusions pertaining to the condition of San Diego County's shorezone are summarized below:

1. ***Precipitation and Streamflow:*** The precipitation during the 2018 Monitoring Year was exceptionally low by historical standards (3.9 inches). The streamflow in both the San Luis Rey and San Diego Rivers also was well below average.

2. ***Wave Conditions:*** Wave conditions were mild during the 2018 Monitoring Year, with only six storms with H_s exceeding 7 ft. The 10-ft threshold was achieved only once. In keeping with this outcome, the Energy Index also was below average.

3. ***Beach Nourishment:*** A substantial number of beach nourishment projects have been undertaken in San Diego County, with the RBSP I and II providing 3.6 million cy of sand. Nearly all of the other nourishment projects conducted in the county depended on "sand of opportunity". In 2018, approximately 446,000 cy of beach quality sand were placed at Cardiff and Solana Beach in the framework of the San Elijo Lagoon Restoration Project. Despite the material provided in recent years, a nourishment deficit of 204,000 cy/yr persisted relative to the historical average in the Oceanside Cell. In the Silver Strand Cell, a deficit of 20,000 cy/yr prevailed. Only in the Mission Beach Cell, where the historical average nourishment rate was a paltry 2,000 cy/yr, has incremental nourishment been received relative to the historical condition (a surplus of 31,000 cy/yr).

4. ***Sand Bypassing:*** The bypassing rate at Oceanside Harbor during the 18-year Post-RBSP I Period (255,000 cy/yr) was nearly identical to the historical average value (252,000 cy/yr). The recent and historical bypassing rates at San Dieguito also were nearly identical (7,000 vs. 8,000 cy/yr, respectively). At Agua Hedionda, the bypassing rate for the Post-RBSP I Period (139,000 cy/yr) was slightly below the historical average (143,000 cy/yr). The post-RBSP I bypassing rates at Batiquitos, San Elijo, and Los Peñasquitos exceeded the historical rates (12,000 vs. 3,000 cy/yr, 22,000 vs. 14,000 cy/yr, and 24,000 vs. 13,000 cy/r, respectively). The increased bypassing quantities at these lagoons constituted a direct benefit to the receiving beaches, which were located south of the lagoon entrances.

5. ***Beach Changes During 2018 Monitoring Year:*** During the 2018 Monitoring Year, shoreline advance predominated in the three littoral cells. The average change ranged

from an increase of 25 ft in the Mission Beach Cell to a gain 33 ft in the Oceanside Cell. In contrast, the shoreline volume decreased an average of 15 cy/ft in the Silver Strand and was essentially unchanged in the Mission Beach and Oceanside Cells.

6. ***Beach Changes Following RBSP I:*** When the entire 18-year Post-RBSP I Period (2000 to 2018) is considered, the average Mean Sea Level shoreline position in the Silver Strand and Mission Beach Cells was essentially unchanged. In the Oceanside Cell, the shoreline advanced an average of 17 ft during the Post-RBSP I Period. The 2018 shorezone volumes in the Mission Beach and Oceanside Cells are comparable to the respective pre-RBSP I values, while that in the Silver Strand Cell falls below the pre-RBSP I condition. These observations suggest that the positive effects of the RBSP I, RBSP II and opportunistic nourishment projects in the region have largely dissipated.

7. ***Recovery after the 2015-2016 El Niño:*** The 2015-2016 El Niño was among the three strongest such events on record, and the corresponding winter season was characterized by well-above average shoreline retreat along the study area. Post-El Niño recovery progressed in all sub-reaches during the 2018 Monitoring Year, and beach widths attained pre-El Niño levels in the Solana Beach, Cardiff and Oceanside sub-reaches. The recovery in Solana Beach and Cardiff was greatly aided by the SELRP nourishment material placed in 2018. The gains at Oceanside are likely influenced by the timing of the bypassing operations at Oceanside Harbor. Beach widths in the other seven sub-reaches remained below the pre-El Niño condition, but the deficit was reduced relative to Fall 2017.

8. ***Lagoon Entrances:*** Following the RBSP I, the two jetty-stabilized entrance channels at Agua Hedionda and Batiquitos remained open to the full range of tidal exchange. Maintence dredging at Agua Hedionda was conducted seven times during this period, producing an average bypassing rate of 122,000 cy/yr (about 33% below the pre-RBSP I rate). Approximately 23,000 cy/yr were removed from Batiquitos Lagoon after RBSP I, surpassing the pre-RBSP I rate of 13,000 cy/yr. However the historical value at this site likely underestimates the long-term maintenance requirement because lagoon restoration efforts occurred during the Pre-RBSP I Period.

   The three unstabilized lagoon entrances closed periodically following RBSP I despite efforts to maintain tidal exchange. The entrance channel was open more than the historical average at San Elijo (95% vs. 43%) and San Dieguito (88% vs. 76%), and slightly less than the historical average at Los Peñasquitos (87% vs. 93%). At San Elijo Lagoon, the dredging rate following the RBSP I (21,000 cy/yr) exceeded the historical average (15,000 cy/yr) by approximately 40%. The higher rate is attributable, at least in part, to an increased level of maintenance made possible by additional funding. The post-RBSP I dredge rate at San Dieguito (7,000 cy/yr) slightly exceeded the pre-RBSP I rate (5,000 cy/yr). At Los Peñasquitos, the post-RBSP I dredge rate (25,000 cy/yr) exceeded the pre-RBSP I average (11,000 cy/yr) by a factor of more than two.

9. ***Borrow Sites:*** Comparison of the 2012 and 2014 bathymetry profiles along the borrow site monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. Additional smoothing and infilling occurred at SO-5 and SO-6 between the 2014 and 2016 surveys, while the changes at MB-01 were modest. Changes were modest between the Fall 2016 and Fall 2018 surveys, with the most noteworthy changes consisting of additional flattening of the side slopes at each borrow site. Over the six-year period following dredging, shoaling at SO-5 and SO-6 averaged 1.2 and 0.7 ft, respectively. These changes equate to infilling rates of about 0.2 ft/yr at SO-5 and 0.1 ft/yr at SO-6. In contrast, during the same period sea bottom elevations decreased by an average of 0.7 ft at MB-01.

At MB-1, the grain size distribution curves corresponding to the samples obtained in 2014, 2016 and 2018 generally fell within the envelope of sediment sizes derived from the 2008 geophysical investigation. The grain size distribution curves for the samples obtained at SO-5 were near the middle of the envelope of in-situ sediment sizes. At SO-6, the grain size distribution curves for five of the six samples obtained between 2014 and 2018 tended to fall near the “coarse” end of the envelope of in-situ sediment sizes. The exception was a 2016 sample retrieved from the onshore portion of the dredge area where shoaling of up to 4 ft was noted. This sample contained finer sediment than identified in the 2008 investigation, suggesting the preferential deposition of fine material at the onshore portion of the SO-6 dredge area.

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