**COASTAL**
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*Ocean Beach, October 2017*

SANDAG

# 2017 REGIONAL BEACH MONITORING PROGRAM

# ANNUAL REPORT

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# SANDAG
# 2017 REGIONAL BEACH MONITORING PROGRAM

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# ANNUAL REPORT

**Prepared for:**

**SANDAG**

*Under contract to:*

*BRG Consulting*

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# EXECUTIVE SUMMARY

This report presents the findings of the SANDAG 2017 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 60 shore-perpendicular transects in the Spring and 54 transects in the Fall. 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 2016 through October 2017 was defined as the 2017 Monitoring Year and the prior sixteen one-year periods as the 2016 through 2001 Monitoring Years. The primary focus of this report is the 2017 Monitoring Year and the evolution of the County's beaches during the 17-year period encompassing both the RBSP I and RBSP II (November 2000 to October 2017). The latter 17-year period is termed the Post-RBSP I Period.

The principal study findings are as follows:

1. ***Precipitation and Streamflow*:** Above-average precipitation (12.7 inches) prevailed during the 2017 Monitoring Year. The streamflow in the San Diego River was above average, while that in the San Luis Rey River was slightly below average.

2. ***Wave Conditions*:** The storm frequency during the 2017 Monitoring Year was the fourth highest on record, with the significant waver height ($H_s$) exceeding 7 ft on thirteen occasions (six of which surpassed the 10 ft threshold). The three years with higher storm frequencies (1998, 2010, and 2016) were characterized by El Niño conditions. The

Energy Index and the number of days with waves exceeding the 7 ft and 10 ft threshold values also were high by historical standards.

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". Despite the material provided by the RBSP I and II and several opportunistic programs, a nourishment deficit of 219,000 cy/yr persisted relative to the historical average in the Oceanside Cell. In the Silver Strand Cell, a deficit of 17,000 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 33,000 cy/yr).

4. ***Sand Bypassing***: The bypassing rate at Oceanside Harbor during the 17-year Post-RBSP I Period (253,000 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 (135,000 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 rate (13,000 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 2017 Monitoring Year***: During the 2017 Monitoring Year, shoreline retreat and shorezone volume losses predominated in the Silver Strand Cell. The shoreline position was relatively stable in the Mission Beach and Oceanside Cells. While modest shorezone volume losses occurred in the Mission Beach Cell, the changes in the Oceanside Cell were negligible.

6. ***Beach Changes Following RBSP I***: When the entire 17-year Post-RBSP I Period (2000 to 2017) is considered, the average shoreline position fell below the pre-RBSP I value in all three littoral cells. The average shorezone volume exceeded the respective pre-RBSP I values in the Mission Beach and Oceanside Cells, but failed to achieve the pre-RBSP I condition in the Silver Stand Cell. The outcome suggests that that gains realized in the Silver Strand Cell from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated during the 17-yr period. The

RBSP efforts and other nourishment projects yielded a modest residual benefit in the Oceanside Cell in the form of increased sediment volume. In the Mission Beach Cell, the RBSP I and a much larger opportunistic nourishment project conducted during the 2010 Monitoring Year produced lasting shorezone volume gains.

7. ***Post-RBSP I Outcome in Sub-Reaches:*** Long-term (5+ years) post-RBSP I beach width gains prevailed at Mission Beach and at three sub-reaches in the Oceanside Cell. Most notably, the gains at North Carlsbad and Cardiff persisted for the entire eleven-year period. These beaches benefited from both the RBSP I fills and increased bypassing at San Elijo Lagoon and Agua Hedionda Lagoon. Transient beach width gains (2 to 4 years) occurred at four sub-reaches, while the remaining two sub-reaches were characterized by negligible gains (1 year or less). When shorezone volume persistence is considered, the number of sub-reaches characterized by long-term gains (5+ years) increased to seven. All but one of the sub-reaches was located in the Oceanside Cell, the exception being Mission Beach. Similar to the beach width gain persistence, the volume gains at North Carlsbad and Cardiff were sustained for the entire 11-year period preceding the RBSP II. The remaining three sub-reaches were characterized by negligible gains (1 year or less). South Carlsbad was the only sub-reach where both the beach width and shorezone volume gains were categorized as negligible. Similarly, Mission Beach, North Carlsbad, Cardiff, and Solana Beach were the only sub-reaches that appeared in the long-term gain category for both beach width and shorezone volume persistence.

8. ***Post-RBSP II Outcome in Sub-Reaches:*** Following the RBSP II, long-term (5+ years) beach width gains prevailed at three of the nine sub-reaches considered – Imperial Beach, Solana Beach, and North Carlsbad (Mission Beach was not included in the assessment because RBSP II material was not placed in this littoral cell). Transient beach width gains (2 to 4 years) occurred at three sub-reaches, while three sub-reaches were characterized by negligible gains. Four of sub-reaches were characterized by long-term post-RBSP II shorezone volume gains (5+ years). Similar to the beach width gain persistence, the volume gains at Solana Beach and North Carlsbad were sustained for the entire six-year period following the project. Transient shorezone volume gains (2 to 4 years) prevailed at one sub-reach (Cardiff), while negligible gains (1 year or less) occurred at four locations. Del Mar, Leucadia/Encinitas and South Carlsbad were the only sub-reaches where both the beach width and shorezone volume gains were categorized as negligible.

9. ***Impact of 2015-2016 El Niño:*** The shoreline condition preceding the 1997-1998 and 2015-2016 El Niño winters was compared as a means of assessing the relative vulnerability to storm damage prior to each event. Beaches were at least 20 ft wider in Fall 2015 than in Fall 1997 at eight of the ten sub-reaches considered. Relative beach width gains of more than 100 ft prevailed at three sub-reaches (Solana Beach, Cardiff, and Leucadia/Encinitas). While many factors contribute to coastal storm damages, these areas would appear to be less vulnerable during the 2015-2016 El Niño event. The improved conditions at San Diego County beaches in Fall 2015 relative to Fall 1997 can be attributed in large part to the beach nourishment activities undertaken since 1998 - most notably the 3.6 million cy of material placed on the beaches as part of RBSP I and II.

   The 2015-2016 winter season was characterized by severe shoreline erosion, with above average losses occurring in all but one of the sub-reaches (Solana Beach being the exception). Beach widths in the region had not recovered to pre-El Niño levels by the time of the Fall 2017 survey. On average, current beach widths in the ten sub-reaches were about 25% narrower than the pre-El Niño condition. Deficits ranged from 12 ft at North Carlsbad to 66 ft at Mission Beach.

10. ***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 six times during this period, producing an average bypassing rate of 112,000 cy/yr (about 40% 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 (87% vs. 76%), and slightly less than the historical average at Los Peñasquitos (86% vs. 93%). At San Elijo Lagoon, the dredging rate following the RBSP I (22,000 cy/yr) exceeded the historical average (15,000 cy/yr) by approximately 50%. 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.

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**SANDAG**
**2017 REGIONAL BEACH**
**MONITORING PROGRAM**

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**ANNUAL REPORT**

# 1. INTRODUCTION

This report presents the findings of the SANDAG 2017 Regional Beach Monitoring Program. As in the case of twenty-one prior annual monitoring programs conducted between 1996 and 2016 (Coastal Frontiers, 1997 through 2017), the 2017 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 2017 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 2017 Monitoring Program consisted of a beach component and a lagoon entrance component. The beach component included semi-annual profiling along 60 shore-perpendicular transects in the Spring and 54 transects in the Fall. 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. Although most of the 2017 Monitoring Program was conducted under contract to SANDAG, beach profile data for fourteen transects were provided by the Cities of Carlsbad, Encinitas, and Solana Beach. Their contributions are gratefully acknowledged by SANDAG.

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 2017 Monitoring Year

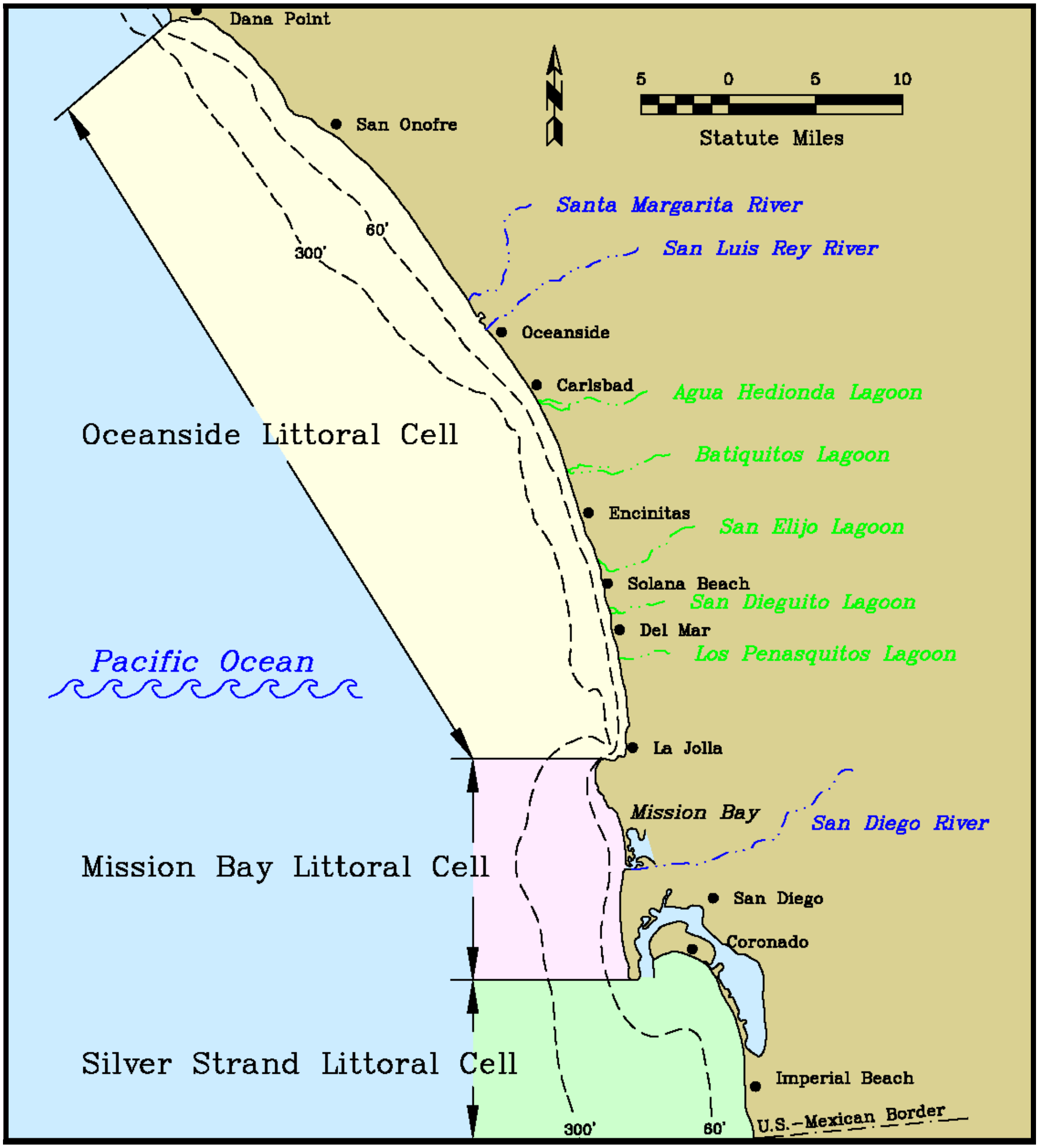


**Figure 1. The Coast of San Diego County**

extends from November 2016 to October 2017). The primary focus of this report is the 2017 Monitoring Year and the evolution of the County's beaches during the 17-year period encompassing both the RBSP I and RBSP II (November 2000 to October 2017. The latter 17-year period is termed the Post-RBSP I Period.

The scope of the SANDAG monitoring program was condensed in Fall 2017 to accommodate budgetary constraints and in recognition that the enhanced monitoring requirements associated with the RBSP II were no longer required. Changes included eliminating the aerial photo reconnaissance and discontinuing six beach profile transects. Additional details regarding these changes are provided in Section 3.

The survey control network for all of the transects in the SANDAG program was updated in April 2013. The revised control information was used to process all beach profile data obtained between Fall 2011 and Fall 2017 (the period corresponding to the RBSP II enhanced monitoring). In the Mission Beach Cell, all of the topographic data from Spring 2000 (the start of the RBSP I monitoring) to Spring 2011 were revised using the updated vertical control. Shoreline positions, beach widths and beach volumes were recomputed based on the adjusted profiles. In consequence, many of the values for these parameters appearing in this report differ from those in reports issued prior to 2012 (Coastal Frontiers, 2013), and should be regarded as superseding the previously-reported values. Furthermore, ***the data products for the Spring 2000 through Spring 2011 surveys provided with the electronic submittal of this report supersede those provided before 2012.*** Additional details are provided in the 2013 Annual Report (Coastal Frontiers, 2014).

The remainder of this report provides a detailed account of the 2017 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 2017 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. Conclusions are presented in Section 7. 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 not only to provide a general context for the monitoring data, but also 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 2017 Monitoring Year, for example, extends from November 1, 2016 through October 31, 2017.

## 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 in the case of storm events.

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, 1998; Dean, *et. al.*, 1984). During the 2017 Monitoring Year, the Ocean Niño Index fluctuated in the range between "weak" 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

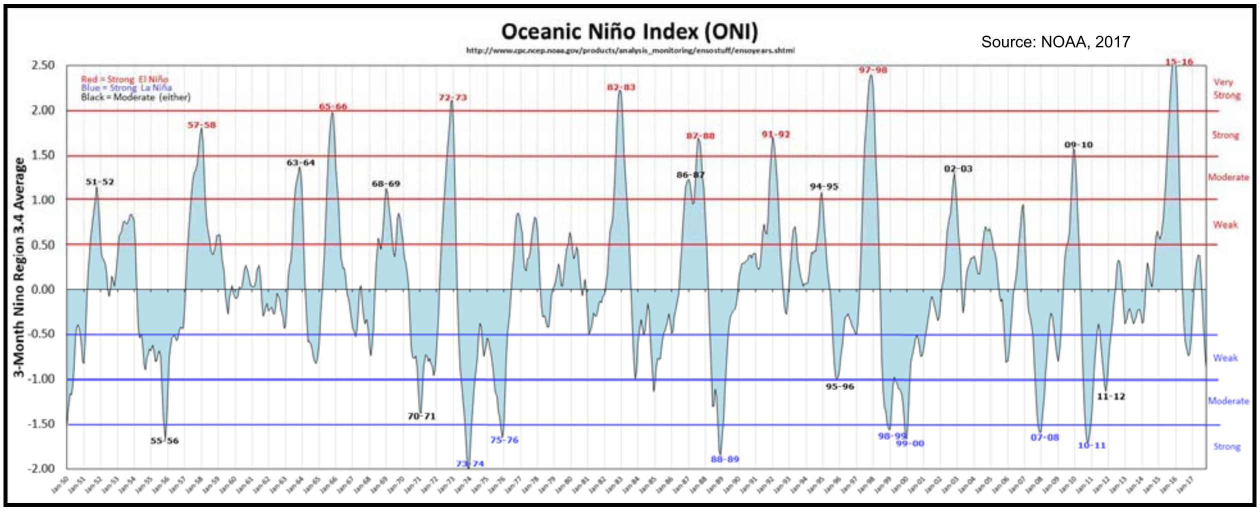


**Figure 2. Oceanic Niño Index (1950-2017)**

(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 2017 (Western Regional Climate Center, 2017). 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. Above-average precipitation (12.7 inches) prevailed during the 2017 Monitoring Year. The year ranked as the 24$^{th}$ wettest year since 1915.

During the last two decades (1997-2017), above-average precipitation was recorded in eight years: 1998, 2003, 2004, 2005, 2010, 2011, 2015, and 2017. As indicated in Figure 2, 1998 was characterized as a "very strong" El Niño, while "weak" to "moderate" El Niño conditions prevailed from 2003 to 2005 and in 2010. In contrast, 2011 corresponded to a "strong" La Niña period. Despite the occurrence of "very strong" El Niño conditions during the 2016 Monitoring Year, precipitation was below average. As described above, 2017 was characterized by a mix of "weak" La Niña and "weak" El Niño conditions.

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.

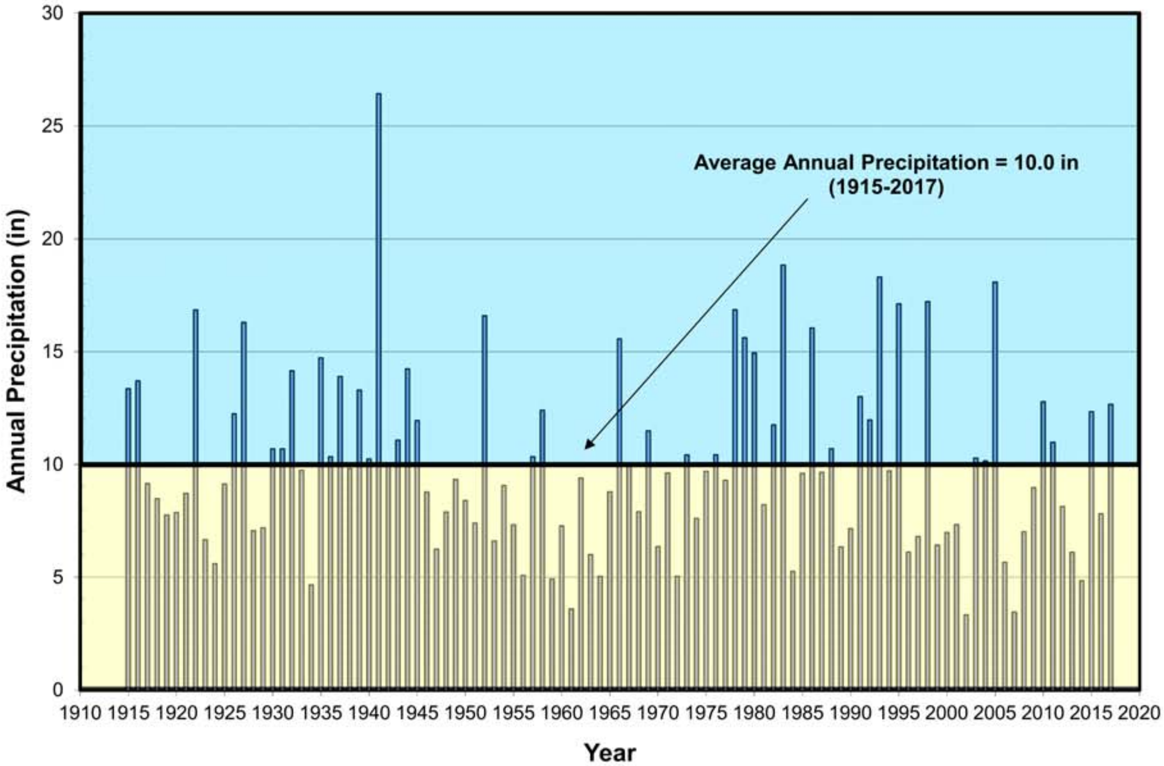


**Figure 3. Annual Precipitation at Lindbergh Field, 1915-2017**

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, below-average rainfall persisted in 12 of the 19 years following the 1997-1998 El Niño event. The abnormally high precipitation in 2005 appears to be a short-term anomaly similar to those noted above. The two consecutive years of above-average rainfall recorded in 2010 and 2011 were followed by three years of below-average precipitation from 2012 to 2014. The occurrence of above-average precipitation during two of the last three years may signal a reversal of the predominately dry period that has persisted since the 1997-98 El Niño event.

### *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, 2017). 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.

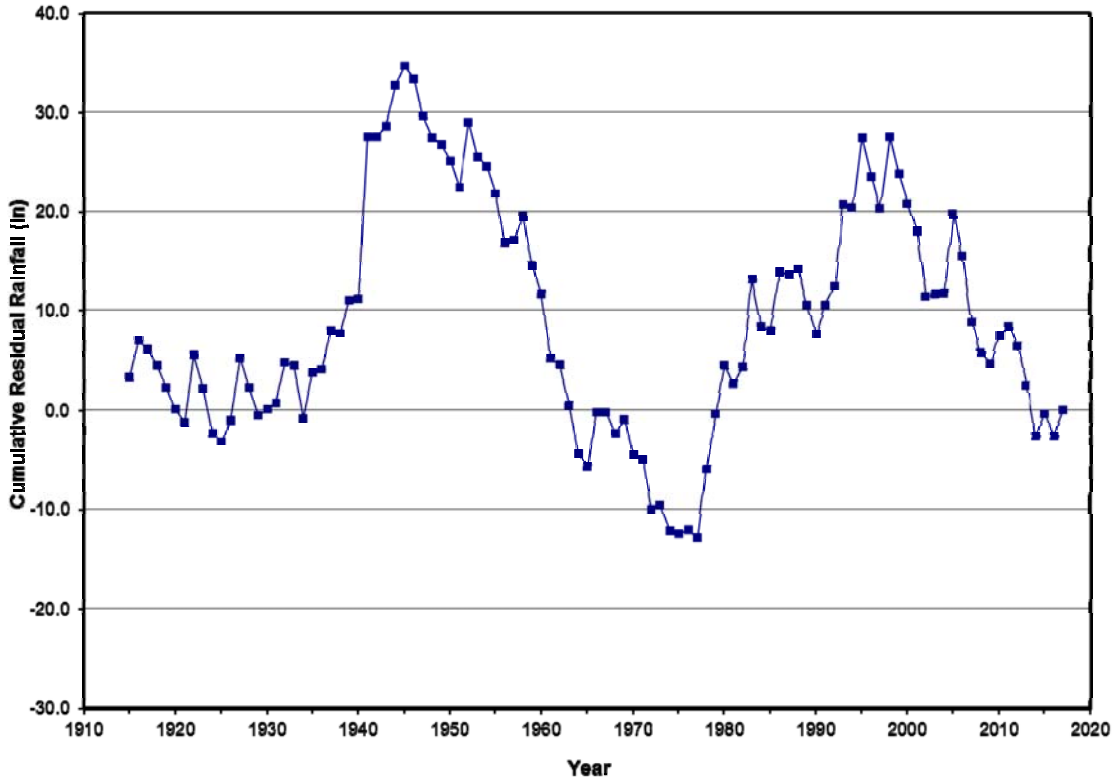


**Figure 4. Cumulative Residual Rainfall at Lindbergh Field, 1915-2017**

Figure 5 presents the annual mean streamflow measured in each river between 1983 and 2017. 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 six 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.

Above-average streamflow prevailed in the San Diego River during the 2017 Monitoring Year. Following three consecutive years of no recorded flow, the streamflow in the San Luis Rey River was slightly below average during the 2017 Monitoring Year. The annual mean streamflow in the San Diego River was the 7th highest on record, while that in the San Luis Rey River was the 9th highest.

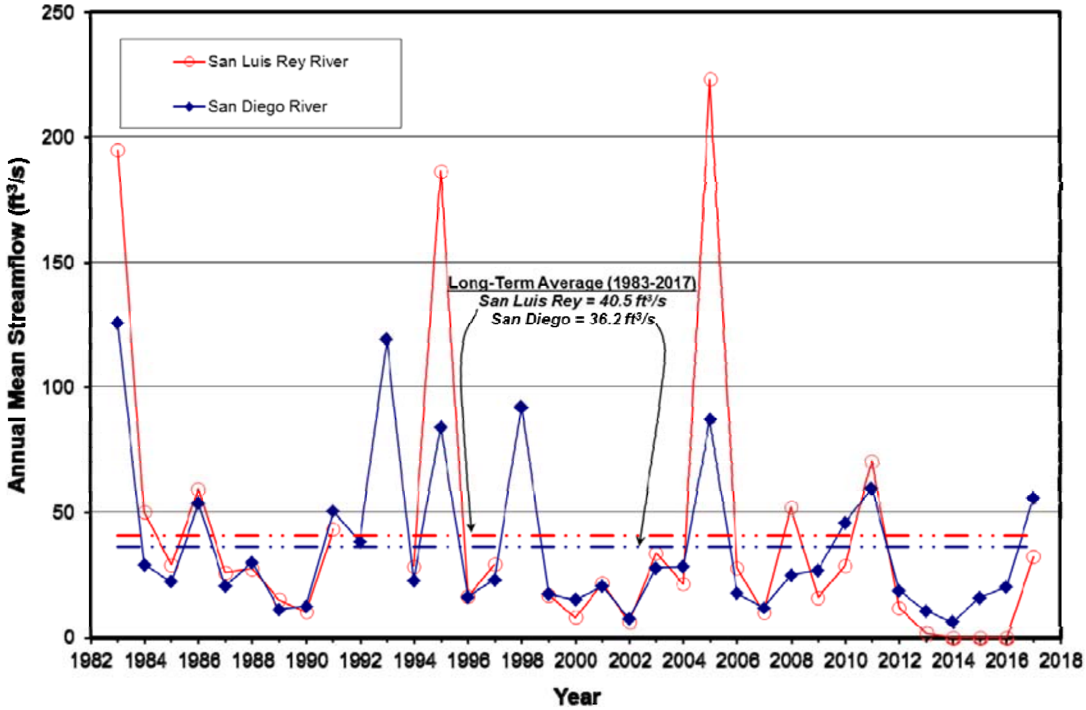


**Figure 5. Annual Mean Streamflow in the San Luis Rey and San Diego Rivers, 1983-2017**

### *2.1.3. Wave Climate*

Three measures of the wave climate were used to compare the potential for sediment transport during the 2017 Monitoring Year with that in previous years: (1) the number of storm events, (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 (2017). 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 2017 Monitoring Year are presented as a time series in Figure 6. The beginning of the monitoring year (November through mid-January) was characterized by a mixture of northerly and southerly swell. Northerly swell then predominated through most of February. Southerly swell typical of summer months prevailed from March through October.

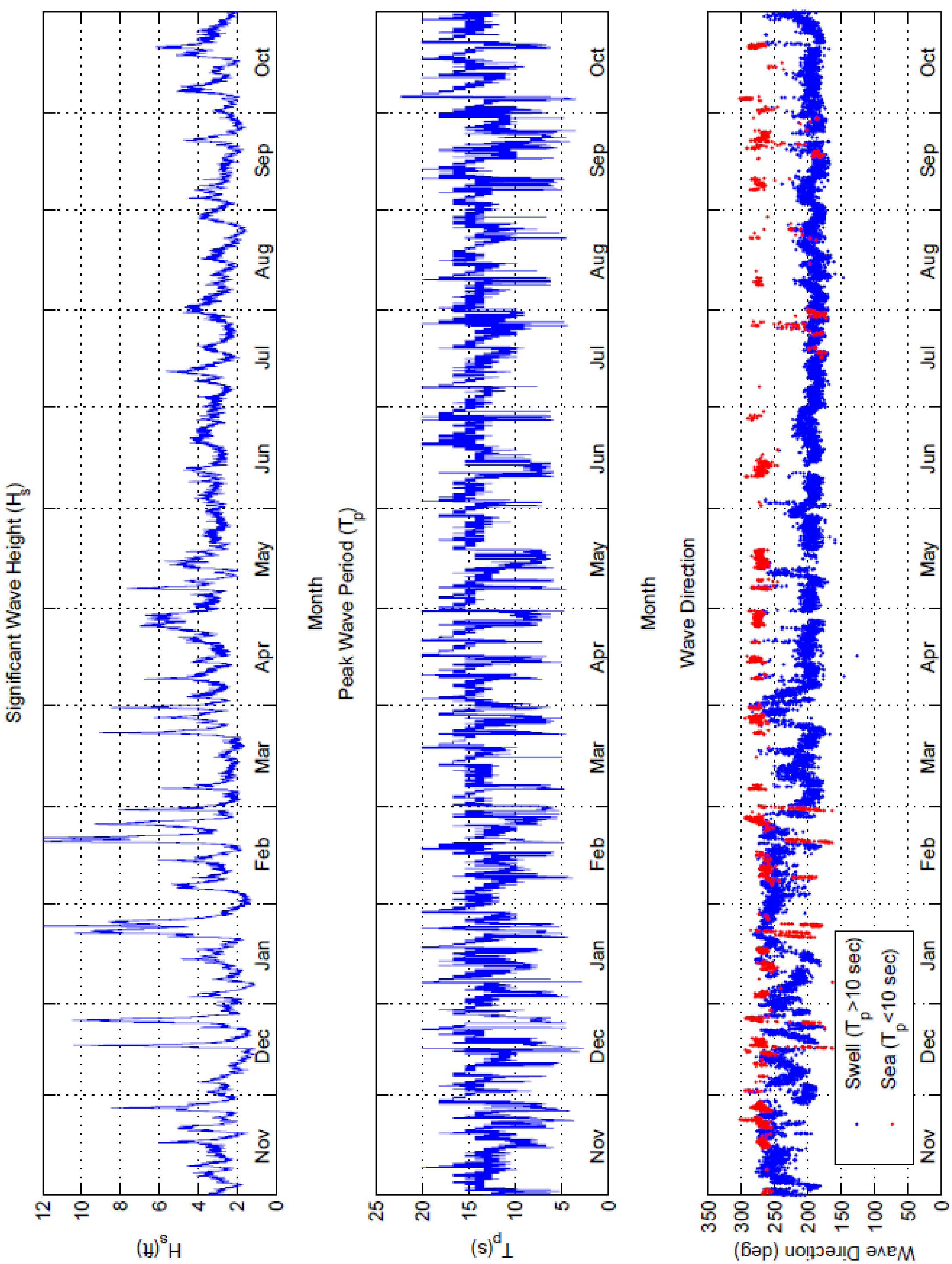


**Figure 6. Wave Characteristics at the CDIP Oceanside Buoy, 2017 Monitoring Year**

Figure 7 shows the significant wave height ($H_s$) for each storm event with $H_s$ exceeding 7 ft (2.1 m) for the 20-year period from 1998 to 2017. 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.

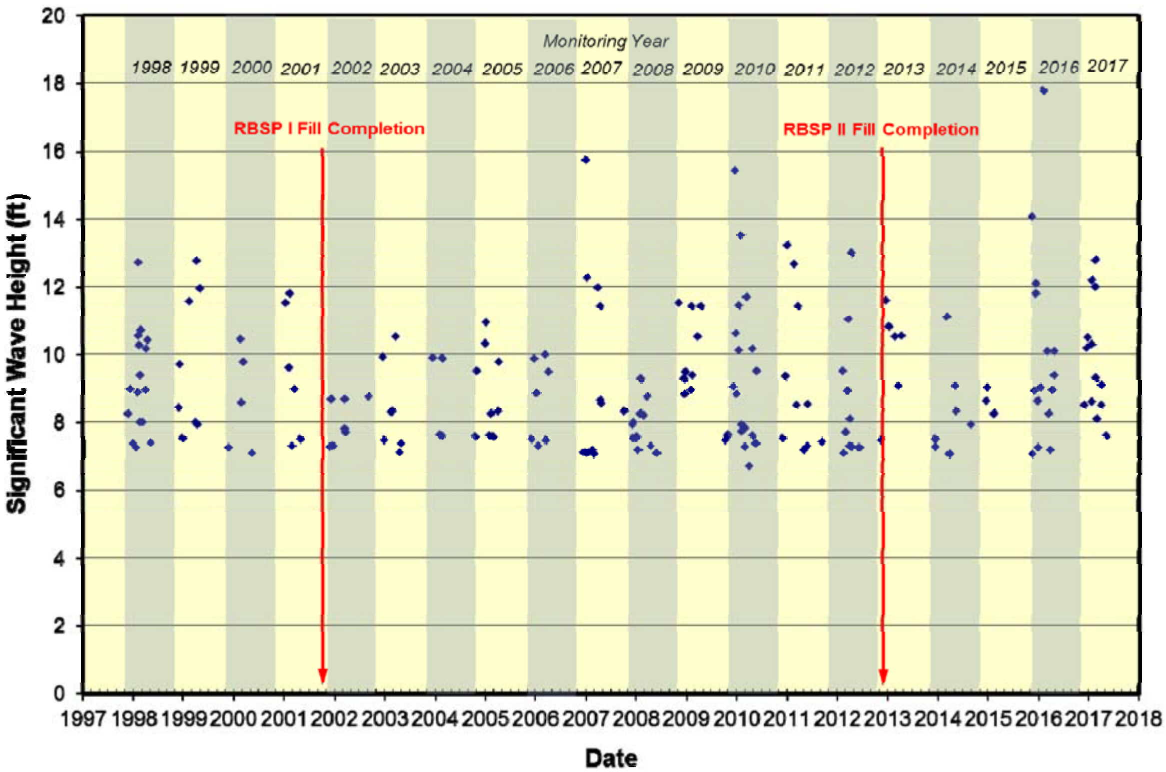


**Figure 7. Storm Events with Significant Wave Heights Exceeding 7 ft, 1998-2017**

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.

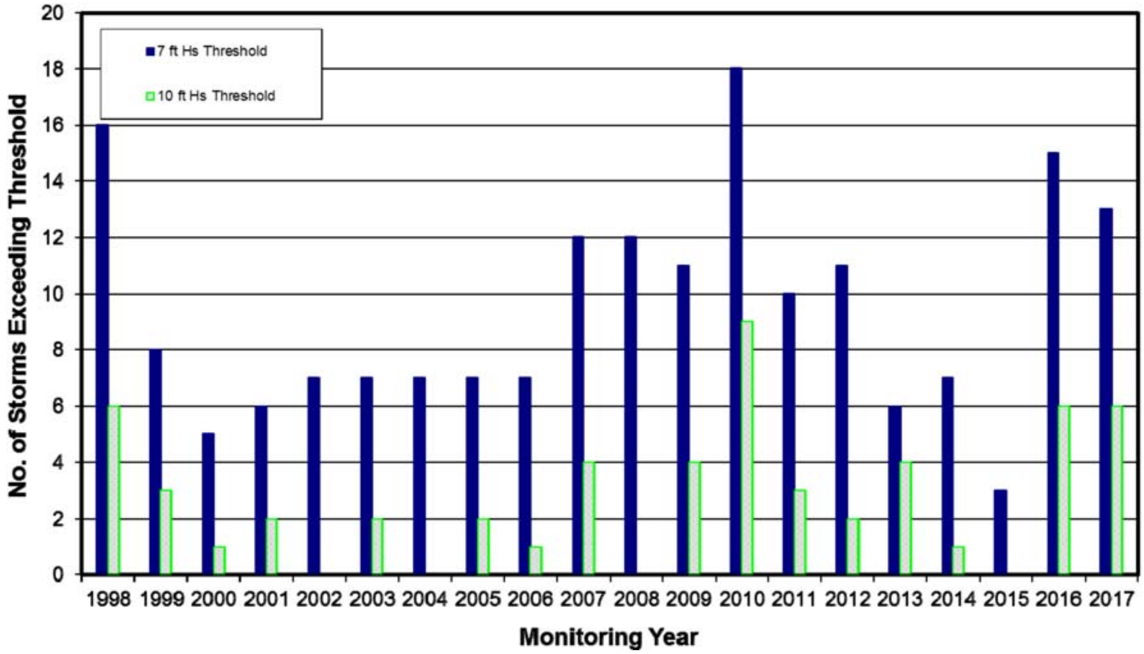


**Figure 8. Storm Events per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2017**

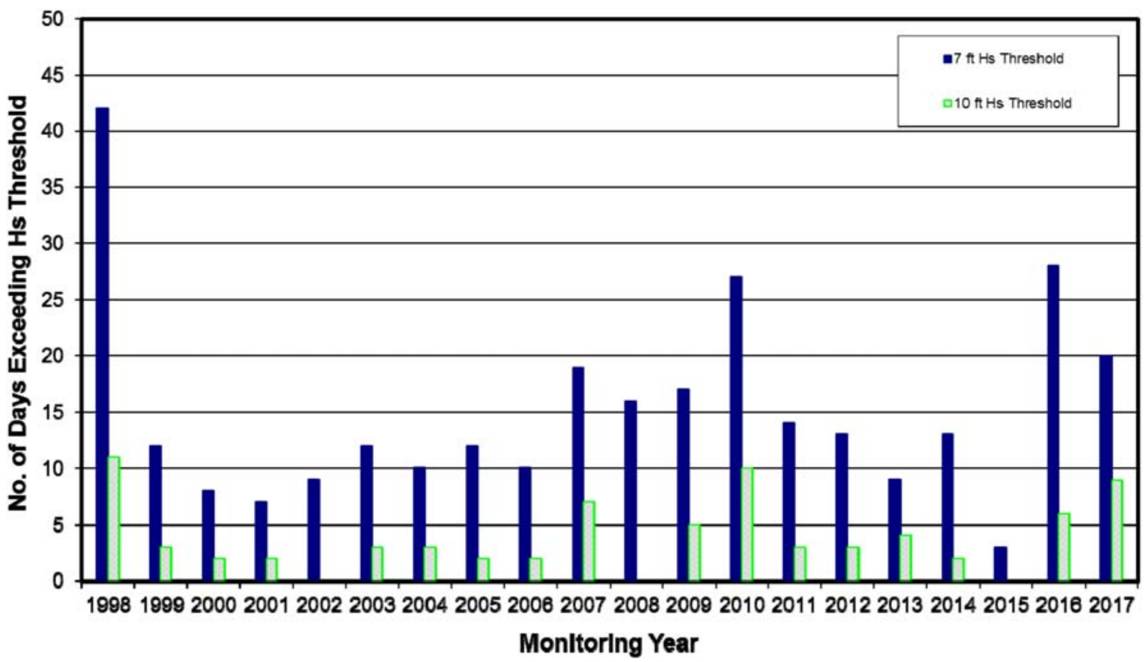


**Figure 9. Days per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2017**

The wave conditions during the first three years following the implementation of the RBSP II (2013 through 2015) were relatively mild, with $H_s$ surpassing 7 ft between three and seven times per year, and surpassing 10 ft between zero and four times per year. During the 2016 Monitoring Year, the El Niño conditions produced fifteen events with $H_s$ exceeding 7 ft, six of which surpassed the 10 ft threshold. The number of days with waves exceeding the exceeding the 7 ft and 10 ft threshold values also was high by historical standards - surpassed only by 1998 and 2010. The maximum significant wave height measured during the 2016 Monitoring Year, 17.8 ft, was the largest measured during the 20-year period of record (Table 1).

The storm frequency during the 2017 Monitoring Year was the fourth highest on record, with $H_s$ exceeding 7 ft on thirteen occasions (six of which surpassed the 10 ft threshold). The three years with higher storm frequencies (1999, 2010, and 2016) were characterized by El Niño conditions. The number of days with waves exceeding the 7 ft and 10 ft threshold values also was high by historical standards. The maximum significant wave height measured during the 2017 Monitoring Year, 12.8 ft, was among the largest waves measured at the gauge (Table 1).

The total wave energy in each Monitoring Year from 1998 through 2017 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. Conditions were comparatively mild during the remaining years. The wave conditions in 1998 yielded the highest Energy Index value (149), followed by 2016 (140). 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 2017 was the fifth highest during the period of record.

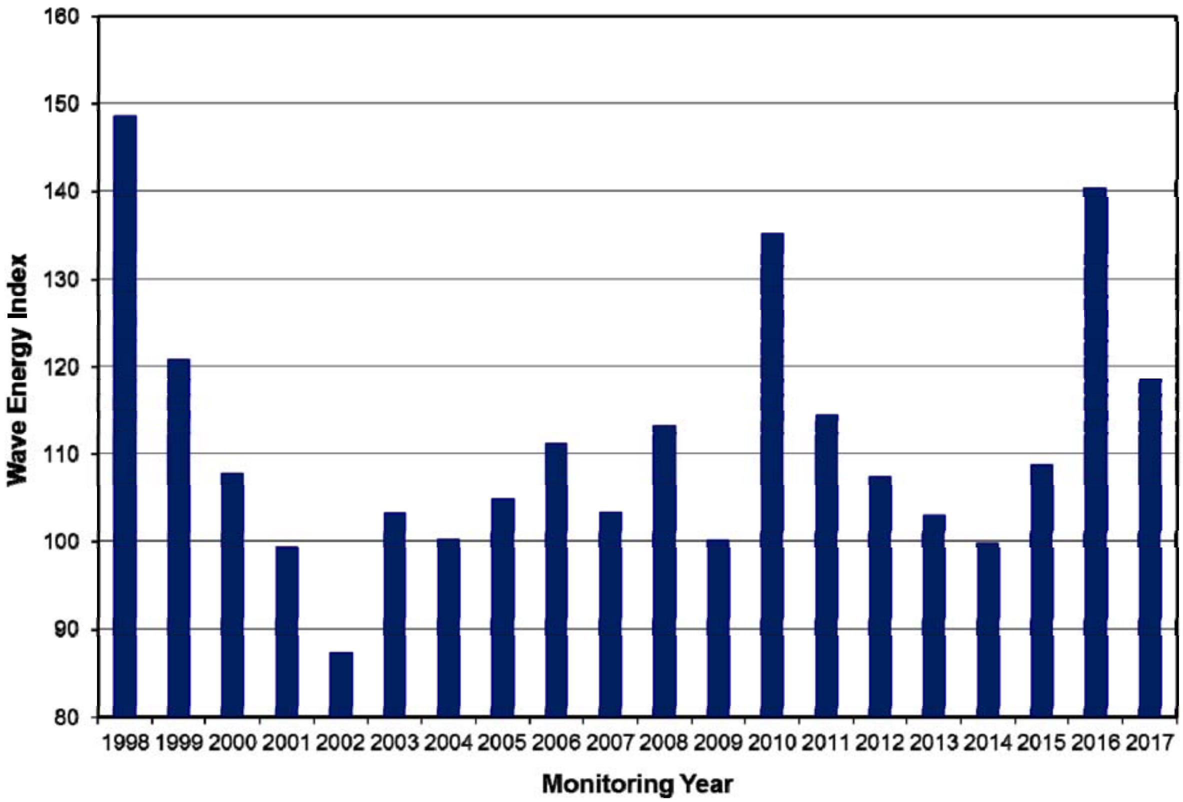


**Figure 10. Relative Incident Energy Index at the CDIP Oceanside Buoy, 1998-2017**

Table 1 summarizes the wave conditions during the 20-year period of record (1998-2017). 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.

**Table 1. Summary of Wave Conditions, 1998-2017**

| 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 |
| Average | 9 | 3 | 15 | 4 | 111 | 11.9 |

## 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 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.

***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. In the Mission Beach Cell, 151,000 cy were placed at Mission Beach, while in the Silver Strand Cell, 120,000 cy were placed at Imperial Beach.

**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 | 2300 | 120 | 0.24-0.52 | 5/22 - 6/04 |
| | *Total Nourishment in Silver Strand Cell = 120,000 cy* | | | | | |
| Mission Beach | Mission Bch | 151,000 | 2300 | 200 | 0.52 | 5/10 – 5/21 |
| | *Total Nourishment in Mission Beach Cell = 151,000 cy* | | | | | |
| Oceanside | Torrey Pines | 245,000 | 1600 | 160 | 0.14 | 4/06 – 4/27 |
| | Del Mar | 183,000 | 3200 | 120 | 0.14 | 4/27 – 5/10 |
| | Fletcher Cove | 146,000 | 1900 | 70 | 0.14 | 6/15 – 6/24 |
| | Cardiff | 101,000 | 900 | 150 | 0.34 | 8/02 – 8/10 |
| | Moonlight Bch | 105,000 | 1100 | 180 | 0.34-0.62 | 8/10 – 8/16 |
| | Leucadia | 132,000 | 2700 | 120 | 0.62 | 6/04 – 6/15 |
| | Batiquitos | 117,000 | 1500 | 180 | 0.62 | 8/16 – 8/23 |
| | S. Carlsbad | 158,000 | 2000 | 180 | 0.62 | 6/25 – 7/06 |
| | N. Carlsbad | 225,000 | 3100 | 100 | 0.14-0.62 | 7/06 – 8/02 |
| | Oceanside | 421,000 | 4400 | 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. Source: Noble Consultants, 2001
(2) All nourishment activities were conducted in 2001.

***Regional Beach Sand Project II (RBSP II)***

The RBSP II project was smaller in scope than the predecessor effort, providing approximately 1.5 million cy 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. 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 hopper capacity of the vessel was approximately 6,500 cy. 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 ($d_{50}$) 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 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 | 4100 | 285 | 0.53 | 9/07 - 10/04 |
| | *Total Nourishment in Silver Strand Cell = 450,000 cy* | | | | | |
| Oceanside | Solana Beach | 142,000 | 1600 | 220 | 0.55 | 11/04 – 11/27 |
| | Cardiff | 89,000 | 1600 | 110 | 0.57 | 10/25 – 10/28 |
| | Moonlight Bch | 92,000 | 800 | 230 | 0.48 | 10/20 – 10/25 |
| | Batiquitos | 106,000 | 1400 | 190 | 0.59 | 10/28 – 11/24 |
| | S. Carlsbad | 141,000 | 1600 | 180 | 0.66 | 11/15 – 11/23 |
| | N. Carlsbad | 219,000 | 3100 | 165 | 0.57 | 11/24 – 12/07 |
| | Oceanside | 293,000 | 4300 | 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.

### *2.2.2. Nourishment Projects, 1994 to 2017 Monitoring Years*

A substantial number of beach nourishment projects have been undertaken in San Diego County. In addition to RBSP I and II, 23 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.

The nourishment projects conducted between November 1993 and October 2017 are summarized below. Two periods are considered: (1) the seven-year span from November 1993 through October 2000, and (2) the 17-year period from November 2000 through October 2017. The November 1993 through October 2000 time period was selected for analysis because it commences with the adoption of SANDAG's Shoreline Preservation Strategy and concludes just prior to the inception of the RBSP I, while the second period encompasses the years when SANDAG was actively involved in managing the shoreline. The nourishment projects conducted since 1994 are summarized by littoral cell below.

***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/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 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 56,000 cy/yr during the 17-year period.

**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 2017**

| 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 = 56,000 cy/yr*** | | | | |

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

### *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 off of Mission Beach as part of the aborted U.S. Navy Homeporting Project. This small amount equates to an average annual nourishment rate of about 2,000 cy/yr for the 1994-2000 period of interest.

One opportunistic sand replenishment project has been undertaken in the Mission Beach Cell since 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). The entire nourishment quantity is attributed to the 2010 Monitoring Year. Taken with the RBSP I fill, these amounts equate to an average annual nourishment rate of about 55,000 cy/yr during the 17-year period (Table 6). The Mission Beach Cell did not receive any nourishment as part of RBSP II.

**Table 6. Beach Nourishment in the Mission Beach Littoral Cell During the Post-RBSP I Period, November 2000 through October 2017**

| 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 = 35,000 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. As enumerated in Table 7, the total volume of 2.75 million cy was equivalent to an average annual nourishment rate of 393,000 cy/yr. Nearly two thirds of the material was derived from the Batiquitos Lagoon restoration project, which provided 1.8 million cy for beach replenishment in Carlsbad. The only non-opportunistic beach fill activity occurred at Moonlight Beach, where approximately 1,000 cy of purchased sand was placed as a protective berm each year from 1996 through 2000.

**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

Table 8 lists the RBSP I and II fills and four other nourishment projects undertaken in the Oceanside Cell during the 17-year period from 2001 to 2017. Two small projects were conducted at Moonlight Beach, where the aforementioned practice of adding 1,000 cy per year to construct a protective berm was 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 on the beach near Batiquitos Lagoon that was derived from the construction of Pacific Station (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). Taken with the RBSP I and II quantities, these amounts equate to an average annual nourishment rate of 174,000 cy/yr during the 17-year period.

**Table 8. Beach Nourishment in the Oceanside Littoral Cell During the Post-RBSP I Period, November 2000 through October 2017**

| 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 |
| ***Average Annual Nourishment Rate in the Oceanside Cell = 174,000 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

### *2.2.3. Sand Bypassing*

Sand bypassing is used to return sediment to the littoral system 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 system, it plays a crucial role in maintaining the distribution of sediment within that system. Because sediment trapping is an ongoing process, bypassing operations typically are conducted at periodic intervals. As with the nourishment activities, two historical periods are considered: (1) the seven-year span from November 1993 through October 2000, and (2) the 17-year period commencing with RBSP I implementation (November 2000 through October 2017).

Bypassing is not undertaken in the Silver Strand and Mission Beach Cells, but occurs at Batiquitos Lagoon, Agua Hedionda Lagoon, Oceanside Harbor, San Elijo Lagoon, San Dieguito Lagoon, and Los Peñasquitos Lagoon in the Oceanside Cell. The bypassing operations at Batiquitos were initiated in 1997 following lagoon restoration, while the bypassing operations at Agua Hedionda and Oceanside Harbor have been performed on a regular basis for decades. A form of bypassing has been conducted at San Elijo since 1994 in conjunction with the entrance channel maintenance activities. A similar type of bypassing also has been conducted at San Dieguito and Los Peñasquitos. The operations began in 1999 at San Dieguito Lagoon. 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 segregate 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 Eljio and 10% for Los Peñasquitos, based on guidance provided by the respective lagoon foundations (Gibson, 2005; Hastings, 2011). The 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 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 17-year period commencing with RBSP I implementation (November 2000-October 2017) are presented in Tables 10 through 15. At Oceanside Harbor, bypass operations were conducted in each year. The average rate of 253,000 cy/yr is nearly identical to the pre-RBSP I rate of 252,000 cy/yr.

At Agua Hedionda, bypassing operations were undertaken in 2001, 2003, 2005, 2007, 2009, 2011, and 2015. The average rate during the 17-year Post-RBSP I Period, 135,000 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 13,000 cy/yr during this 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 17-year Post-RBSP I Period if this material had been returned to the littoral system.

**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 Batiquitos Lagoon, Nov 2000 through Oct 2017**

| 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 = 13,000 cy/yr* | | |

Sources: Dillingham, 2002, 2008; Merkel, 2012

**Table 11. Sand Bypassing at Agua Hedionda Lagoon, Nov 2000 through Oct 2017**

| 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 |
| | *Average Annual Bypass Rate at Agua Hedionda Lagoon = 135,000 cy/yr* | | |

Sources: Tucker, 2002; Hughes, 2003; Shiffer, 2006; Henika, 2008, 2010, 2012, 2015

During the 17-year period commencing with the RBSP I, the estimated average bypass rate at San Elijo 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. This change reflects an increase in the funding available to conduct such activities (Gibson, 2005).

Bypassing was conducted on six occasions at San Dieguito Lagoon during the 17-year Post-RBSP I Period, yielding an estimated average bypassing rate of 7,000 cy/yr. This rate was slightly lower than the pre-RBSP I average of 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.

**Table 12. Sand Bypassing at Oceanside Harbor, Nov 2000 through Oct 2017**

| 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 |
| | ***Average Annual Bypass Rate at Oceanside Harbor = 253,000 cy/yr*** | | |

Sources: Tucker, 2002; Ryan, 2003, 2005-2017

### *2.2.4. Sand Management Summary*

In Table 16, the beach nourishment volume provided to each littoral cell during the Post-RBSP I Period is compared with the average annual volume provided during the seven monitoring years preceding the RBSP I. Despite nearly 3,000,000 cy of material provided by the RBSP I and II and several opportunistic, a deficit of 219,000 cy/yr persisted relative to the historical average in the Oceanside Cell. In the Silver Strand Cell, a deficit of 17,000 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 33,000 cy/yr).

The sand bypass rates at Oceanside Harbor, Agua Hedionda, Batiquitos, San Elijo, San Dieguito, and Los Peñasquitos during the Post-RBSP I Period are displayed with the average annual bypass rates during the seven monitoring years preceding the RBSP I in Table 17.

**Table 13. Sand Bypassing at San Elijo Lagoon, Nov 2000 through Oct 2017**

| 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 |
| | ***Average Annual Bypass Rate at San Elijo Lagoon = 22,000 cy/yr*** | | |

Sources: Tucker, 2002; Gibson, 2005, 2006, 2007, 2012-2018; Trujillo, 2008, 2009, 2010, 2011

**Table 14. Sand Bypassing at San Dieguito Lagoon, Nov 2000 through Oct 2017**

| 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 |
| | ***Average Annual Bypass Rate at San Dieguito Lagoon = 7,000 cy/yr*** | | |

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

**Table 15. Sand Bypassing at Los Peñasquitos Lagoon, Nov 2000 through Oct 2017**

| 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 |
| | ***Average Annual Bypass Rate at Los Peñasquitos Lagoon = 24,000 cy/yr*** | | |

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

**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 | 56,000 | (17,000) |
| Mission Beach | 2,000 | 35,000 | +33,000 |
| Oceanside | 393,000 | 174,000 | (219,000) |
| Total | 468,000 | 85,000 | (203,000) |

Notes: (1) Historical Average based on the period 1993-2000.
(2) Post-RBSP I Average based on the period 2001-2017.
(3) Difference represents post-RBSP I Average minus 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 | 13,000 | +10,000 |
| Agua Hedionda | 143,000 | 135,000 | (8,000) |
| Oceanside Harbor | 252,000 | 253,000 | +1,000 |
| 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 | 454,000 | +21,000 |

Notes: [1] Historical Average based on the period 1993-2000.
[2] Post-RBSP I Average based on the period 2001-2017.
[2] Difference represents post-RBSP I Average minus Historical Average.

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 nearly identical 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 Aqua Hedionda was slightly below the historical average.

# 3. MONITORING METHODS

As indicated in Section 1, the general objective of the 2017 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 2017 program includes two primary components - beach monitoring and lagoon entrance 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 2017 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, 1996-2017**

| 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 |

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

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.

### 3.2. Beach Monitoring

Beach profile data were obtained in the Spring and Fall of 2017, corresponding to the transitions between the winter and summer wave seasons, along previously established transects. The city-sponsored beach profile survey programs discussed above were conducted at the same time, using identical methods. The locations of the transects are listed in Table 19 and illustrated in Figures 11a and 11b.

The Spring 2017 beach survey activities in the Oceanside Cell were conducted between May 8 and 12. The field program continued in the Mission Beach and Silver Strand Littoral Cells on May 15 and 16, respectively. The Fall 2017 beach survey activities were conducted in the Mission Beach and Silver Strand Littoral Cells on October 26 and 27, respectively. In the Oceanside Cell, data were acquired between October 28 and 31. 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 | SPONSOR | TRANSECT | LOCATION | SPONSOR |
|---|---|---|---|---|---|---|
| Silver Strand Littoral Cell | SS-0003 | Tijuana Estuary | SANDAG | SS-0035[1] | Imperial Beach | SANDAG |
| | SS-0005[3,4] | Tijuana Estuary | SANDAG | SS-0050[2] | Imperial Beach | SANDAG |
| | SS-0015 | Imperial Beach | SANDAG | SS-0077 | Silver Strand | SANDAG |
| | SS-0020[1,2,4,5,9] | Imperial Beach | SANDAG | 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 | SANDAG | | | |
| | MB-0340[1] | Mission Beach | SANDAG | | | |
| Oceanside Littoral Cell | LJ-0443 | La Jolla | SANDAG | SD-0690[1,2,9] | Leucadia | SANDAG |
| | LJ-0445 | La Jolla | SANDAG | SD-0695[2,4] | Leucadia | SANDAG |
| | LJ-0450 | La Jolla | SANDAG | SD-0700 | Grandview | Encinitas[8] |
| | 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 | SANDAG | CB-0775[1,2] | South Carlsbad | Carlsbad |
| | DM-0560[3,9] | Del Mar | SANDAG | 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 | CB-0830 | Carlsbad | SANDAG |
| | SD-0597[1, 7] | Surfsong | Solana | CB-0840 | Carlsbad | Carlsbad |
| | SD-0600[1] | Fletcher Cove | SANDAG | CB-0850 | Carlsbad | Carlsbad |
| | SD-0610[3] | Tide Park | Solana | CB-0865[1,2] | Carlsbad | SANDAG |
| | SD-0620 | Seaside Park | Encinitas[8] | CB-0880[1] | Buena Vista | SANDAG |
| | SD-0625 | San Elijo | Encinitas[8] | OS-0900 | Oceanside | Carlsbad |
| | SD-0630[1] | Cardiff | SANDAG | OS-0915[1,2,4,5,9] | Oceanside | SANDAG |
| | SD-0650 | San Elijo Park | Encinitas[8] | OS-0930[1] | Buccaneer Bch | SANDAG |
| | SD-0660 | Swami's | Encinitas[8] | OS-0947[1,7,9] | Crosswaithe | SANDAG |
| | SD-0663[6,9] | 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 sponsored by SANDAG in Spring 2013 & Spring 2014
(9) Transect removed from monitoring program in Fall 2017.

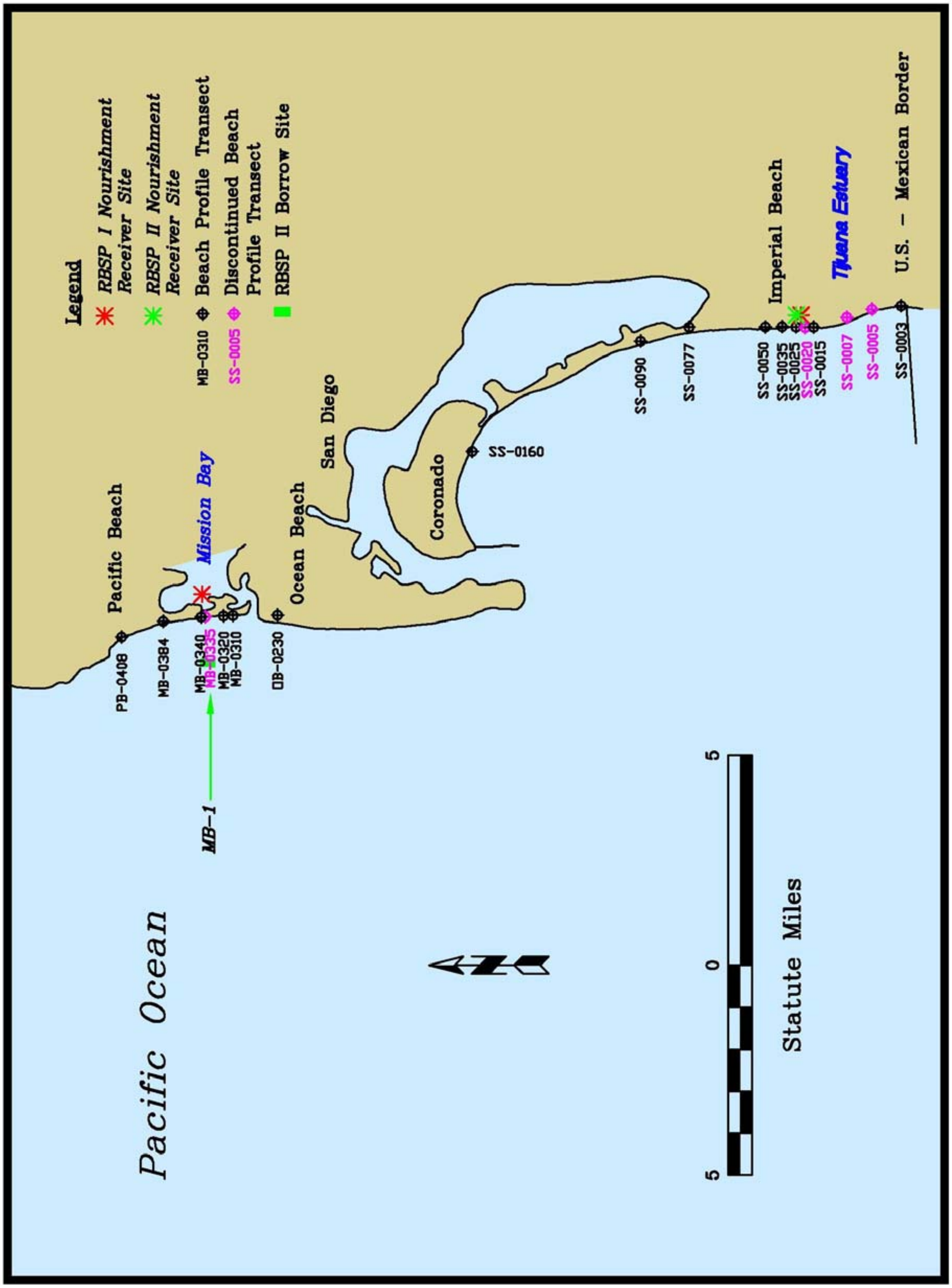


**Figure 11a. Beach Profile Transects in the Silver Strand and Mission Beach Littoral Cells**

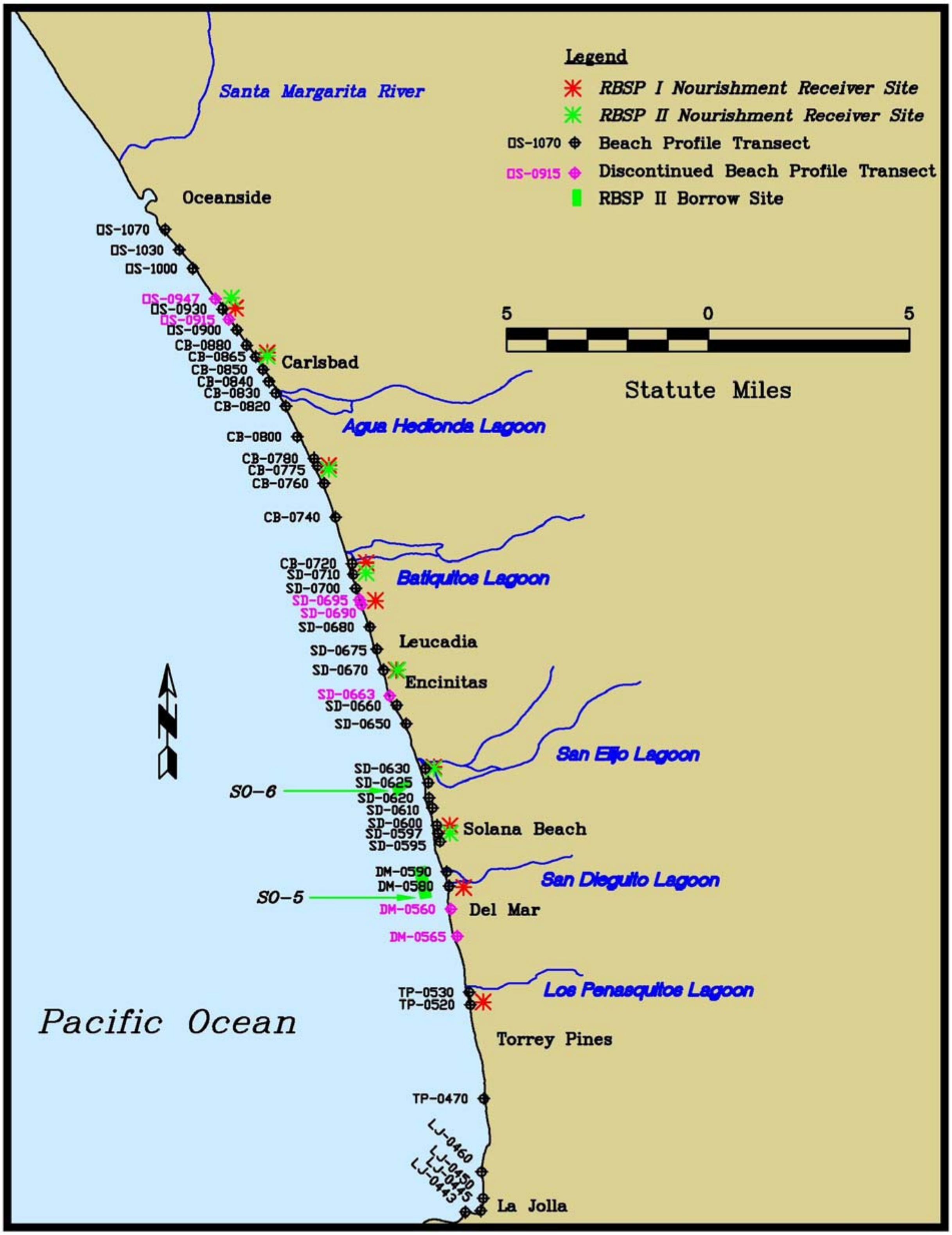


**Figure 11b. Beach Profile Transects and Lagoon Entrances in the Oceanside Littoral Cell**

The data acquisition and processing methods used for the 2017 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. Each survey marker was located at the back beach, while each offshore limit was located seaward of the "depth of closure" indicated by prior survey data. (The depth of closure is the depth at which sediment transport is not substantially affected by littoral processes.)

The 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. This tool improves the resolution of the sonar system, particularly in areas of localized vertical relief. 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 (DGPS) transmitted in real-time from the Wide Area Augmentation System (WAAS) were utilized. All systems were interfaced to a laptop computer using the Hypack survey software package.

At each transect, the boat traveled from the offshore limit 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 10 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, measurements of the speed of sound in sea water were obtained at the offshore end of each transect using a recording conductivity, temperature, and depth (CTD) instrument.

***Data Processing***

The data from the wading portion of each survey were processed using software developed by Spectra Precision Software Corporation. The raw total station data were read by the software, and the coordinates and elevation of each data point were calculated and inserted into a CAD drawing.

The raw data from the bathymetric portion of each survey consisted of Hypack files containing the heave-compensated soundings and corresponding positions. These data were edited for outliers using the Hypack Single-Beam Processing Module. The dynamic motion sensor utilized during the survey removed the majority of the wave contamination from the record. However, to further minimize the influence of wave-induced vessel motion, selected portions of the echo sounder record were filtered using Hypack.

Corrections for the draft of the transducer and the measured speed of sound in sea water then were applied to the measured depths. The speed-of-sound profiles were confirmed using the results of the "bar check" calibration procedure. Finally, the corrected soundings were adjusted to MLLW datum using water level measurements made by the U.S. Department of Commerce, NOAA, at La Jolla.

The adjusted soundings were thinned to a nominal interval of 10 ft to produce a manageable file size suitable for developing beach profile plots. The resulting x, y, z data (easting, northing, and elevation) were inserted into the CAD drawing containing the wading data. As indicated above, the field work was conducted in such a manner as to provide substantial overlap between the wading and bathymetric portions of the survey. The processed data were examined in this region to insure 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 soundings 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 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.

# 4. MONITORING DATA

This section presents the results of the 2017 Regional Beach Monitoring Program, consisting of direct measurements and computed values. The data derived from the beach component of the program are described in Section 4.1, while those derived from the lagoon entrance component are described in Section 4.2.

## 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. The results of these activities are provided in Sections 4.1.1 and 4.1.2.

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

The 2017 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 2017 data, the plots display Fall profiles from 2000, 2011, 2012, 2013, 2014, 2015 and 2016. 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 recognize that the pronounced vertical relief evident in profiles obtained after Fall 2002 resulted from the improved survey resolution rather than from actual changes in the sea bottom. The most 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 somewhat 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 44 Spring and Fall surveys conducted from 1996 to 2017 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 profiled at these times.

The following shoreline and beach width tabulations 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 22 most recent summers (1996 through 2017), and 21 most recent winters (1996-1997 through 2016-2017). 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 17-year period encompassing the RBSP I and RBSP II (Fall 2000 to Fall 2017). In addition, the shoreline changes were calculated for the six-year period encompassing the RBSP II (Fall 2011 to Fall 2017). 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 2017.

***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 volume 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 (σ) 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 closure assessment are presented in Table 20, which provides the computed range of closure and associated depth of closure for each transect. All of the volume changes reported in Appendix D pertaining to the prior Monitoring Years have been adjusted to reflect the change.

For each survey at each transect, the shorezone volume per linear foot of shoreline (cy/ft) was calculated as the area under the profile to an arbitrary basement elevation of -60 ft. Seasonal volume changes were computed for the 20 most recent summers (1998 through 2017) and 20 most recent winters (1997-1998 through 2016-2017). Annual volume changes were calculated for the 20 one-year intervals between Fall 1997 and Fall 2017. Long-term changes were determined for the three year period preceding the RBSP I (Fall 1997 to Fall 2000), the six-year period encompassing the RBSP II (Fall 2011 to Fall 2017), and the 17-year period encompassing the RBSP I and RBSP II ( Fall 2000 to Fall 2017).

The beach volume above MSL, like the beach width, provides an indication of the recreational area and the protection afforded to upland facilities. Changes in beach volume above MSL were developed 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 data acquisition consisted of monthly observations and photographs at the unstabilized entrances to San Elijo, San Dieguito, and Los Peñasquitos. Selected ground photographs obtained by SANDAG on a monthly basis 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.

## 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 2017 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.

# 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 2017 Monitoring Year (November 2016 through October 2017) and the 17-year period encompassing both the RBSP I and RBSP II (November 2000 through October 2017, 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. Finally, the impact of the 2015-2016 El Niño is assessed in Section 5.3.

Statistical characterizations of shoreline and volume changes for the 2017 Monitoring Year are derived from the 54 transects included in the Fall 2017 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). The pre-El Niño comparison utilizes the 38 transects common to both the Fall 1997 and Fall 2015 surveys, while the assessment of shoreline changes following the 2016-2017 El Niño utilizes the 38 transects common to both the Fall 2015 and Fall 2017 Surveys.

## 5.1. Regional Overview

Table 21 summarizes the shoreline and shorezone volume changes that occurred during the 2017 Monitoring Year and the Post-RBSP I Period. During the 2017 Monitoring Year, shoreline retreat and shoreline volume losses predominated in the Silver Strand Cell. The shoreline position was relatively stable in the Mission Beach and Oceanside Cells (averaging a loss of 8 ft and 4 ft, respectively). While modest shorezone volume losses occurred in the Mission Beach Cell, the changes in the Oceanside Cell were negligible.

When the entire 17-year Post-RBSP I Period (2000 to 2017) is considered, the average shoreline position fell below the pre-RBSP I value in all three littoral cells. The average shorezone volume exceeded the respective pre-RBSP I values in the Mission Beach and Oceanside Cells, but failed to achieve the pre-RBSP I condition in the Silver Strand Cell. The outcome suggests that gains realized in the Silver Strand Cell from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated. The RBSP and other nourishment projects yielded a modest residual benefit in the Oceanside Cell in the form of increased sediment volume. In the Mission Beach Cell, the RBSP I and a much larger opportunistic nourishment project conducted during the 2010 Monitoring Year produced lasting shorezone volume gains.

**Table 21. Average MSL Shoreline Changes and Shorezone Volume Changes During the 2017 Monitoring Year and Post-RBSP I Period [1, 2]**

| Littoral Cell | 2017 Monitoring Year [1] | | post-RBSP I (2000 to 2017) [2,3] | |
|---|---|---|---|---|
| | MSL Shoreline Change (ft) | Shorezone Vol. Change (cy/ft) | MSL Shoreline Change (ft) | Shorezone Vol. Change (cy/ft) |
| ***Silver Strand Cell*** | -26 | -21 | -18 | -17 |
| ***Mission Beach Cell*** | -8 | -11 | -12 | 10 |
| ***Oceanside Cell*** | -4 | -2 | -11 | 6 |
| ***All Cells Combined*** | -5 | -2 | -12 | 3 |

Notes: (1) Shoreline change statistics are derived from the 54 transects included in the Fall 2017 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 2017.

The MSL beach widths measured in Spring 2017 and Fall 2017 are shown in Figures 12a and b. The envelope of widths measured subsequent to the RBSP I and prior to the current Monitoring Year (Fall 2001 to Fall 2016) also is shown for the transects with consecutive Fall and Spring measurements dating back to 2001.

The Spring 2017 beach widths tended to fall near the lower boundary of the post-RBSP I envelope throughout most of the study area. Exceptions included parts of Solana Beach, Cardiff, North Carlsbad and North Oceanside. Beach widths fell below the envelope at one site in the Silver Strand Cell (State Beach), at two locations in the Mission Beach Cell (Ocean Beach and Pacific Beach), and at five locations in the Oceanside Cell (two sites in Encinitas, two sites in South Carlsbad, and one site in Oceanside).

Beach widths at the time of the Fall 2017 survey generally exceeded those measured in Spring 2017. However, they tended to lie near the middle or in lower half of the post-RBSP I envelope. Notable exceptions included portions of La Jolla, Solana Beach, North Carlsbad, and North Oceanside. The Fall 2017 beach width did not exceed the envelope at any site, and fell short of the envelope at only one site (Transect OS-0930 in Oceanside).

### *5.1.1 Silver Strand Littoral Cell*

Table 22 summarizes the MSL shoreline changes that occurred in the Silver Strand Cell during the 2017 Monitoring Year and the 17-year period encompassing both the RBSP I and II (2000 to 2017). Figures 13 and 14 provide a graphical representation of the changes that prevailed during these periods. Detailed supporting data appear in Appendices C and D.

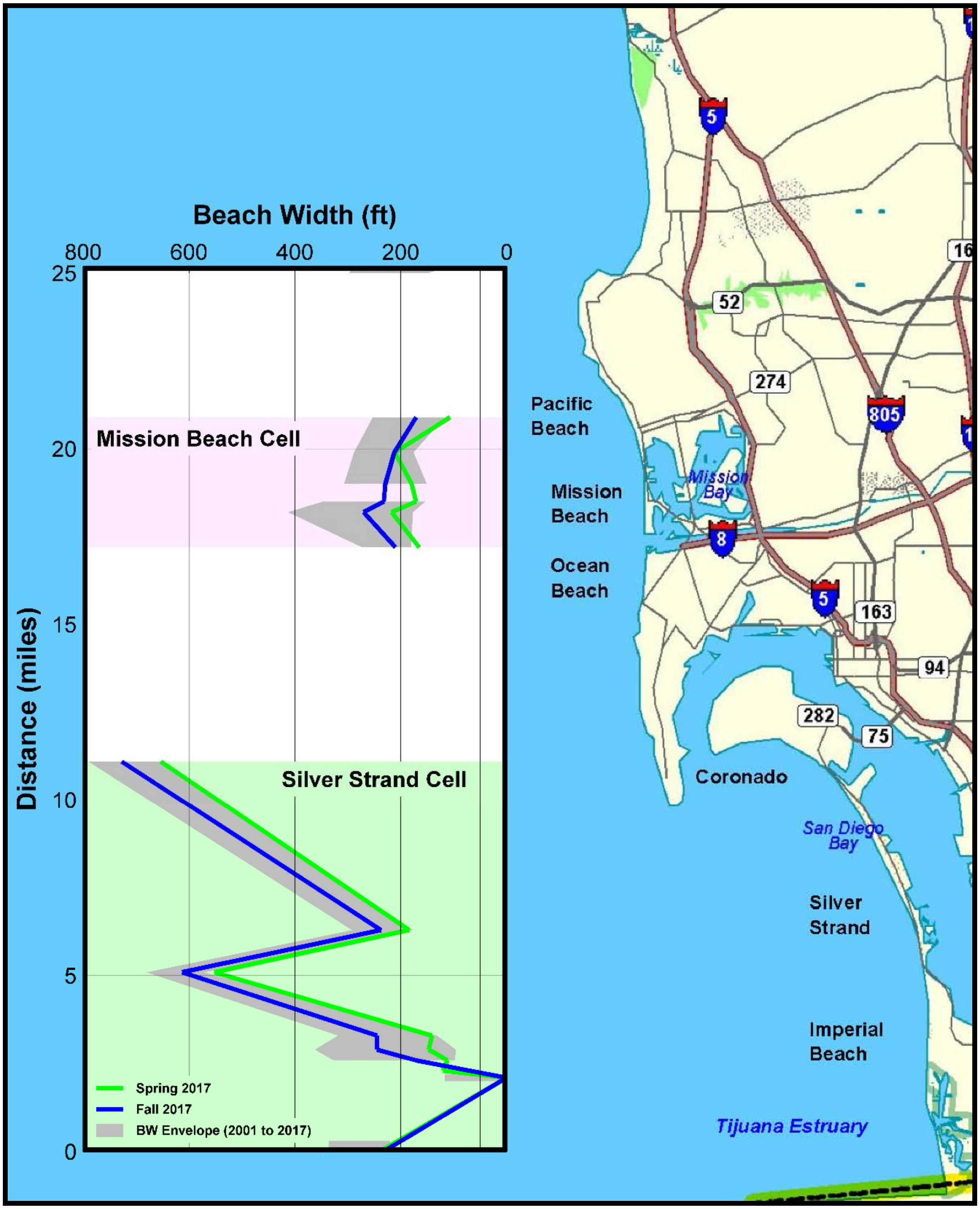


**Figure 12a. Comparison of 2017 MSL Beach Widths with the Post-RBSP I Envelope in the Silver Strand and Mission Beach Littoral Cells**

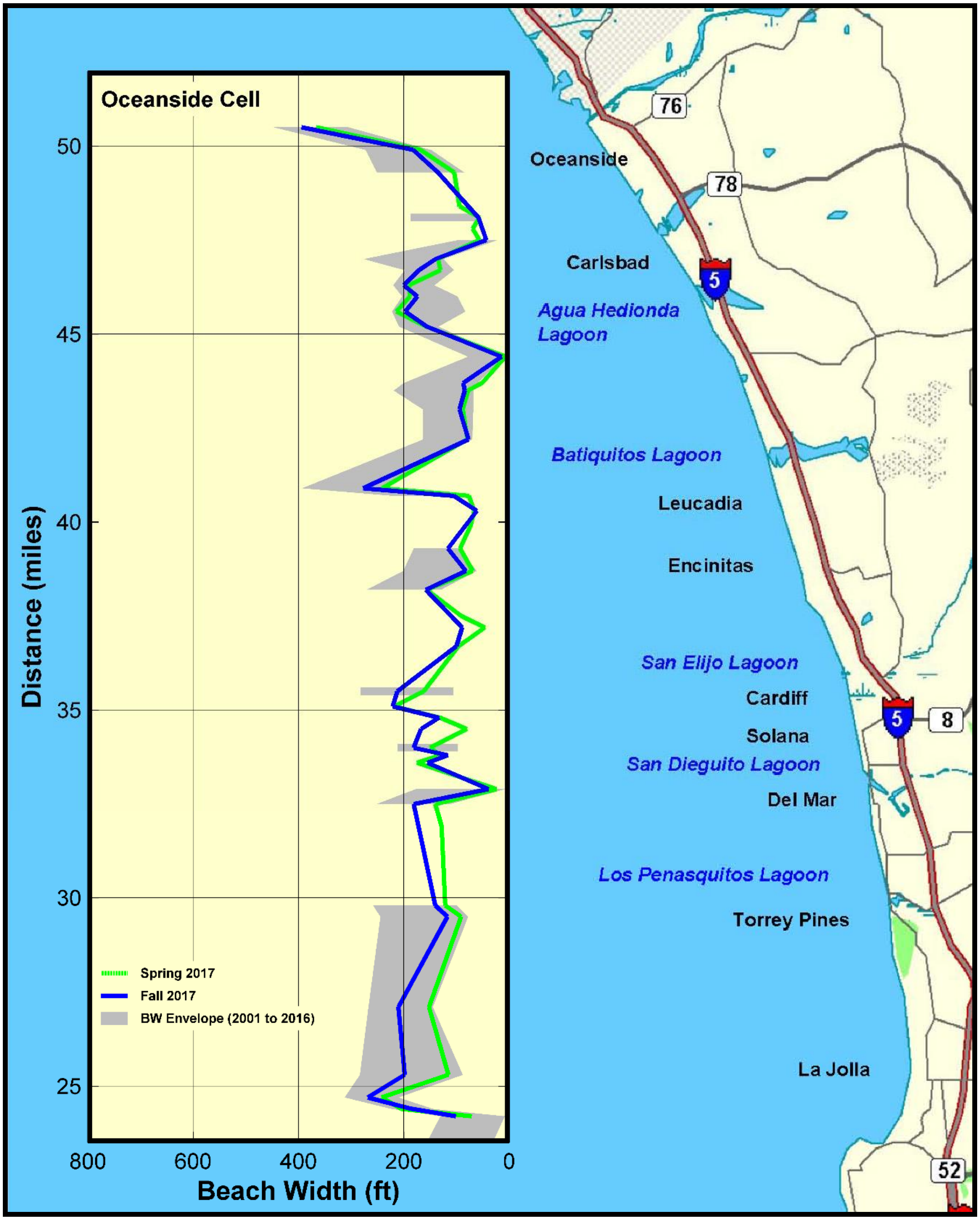


**Figure 12b. Comparison of 2017 MSL Beach Widths with the Post-RBSP I Envelope in the Oceanside Littoral Cell**

**Table 22. MSL Shoreline and Shorezone Volume Changes in the Silver Strand Littoral Cell during the 2017 Monitoring Year and the Post-RBSP I Period**

| Period | MSL Shoreline Change (no. of transects) | | | Average Change (ft) |
|---|---|---|---|---|
| | Advance | No Change[4] | Retreat | |
| 2017 Mon. Year [1] | 2 | 0 | 6 | -26 |
| Post-RBSP I [2,3] | 1 | 1 | 4 | -18 |

| Period | Shorezone Volume Change (no. of transects) | | | Average Change (cy/ft) |
|---|---|---|---|---|
| | Increase | No Change[4] | Decrease | |
| 2017 Mon. Year [1] | 1 | 3 | 4 | -21 |
| Post-RBSP I [2,3] | 2 | 0 | 4 | -17 |

Notes: (1) Statistics are derived from the 54 transects included in the Fall 2017 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 2017).
(4) "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

## ***2017 Monitoring Year***

The average shoreline position in the Silver Strand Cell decreased by 26 ft during the 2017 Monitoring Year. As shown in Figure 13, shoreline retreat prevailed at six of the eight transects located within the Cell. Shoreline losses ranged from 11 to 89 ft. The average shoreline change in Imperial Beach was a loss of 44 ft. The greatest shoreline advance was a gain of 28 ft at Silver Strand State Beach.

The average shorezone volume in the Silver Strand Cell decreased by 21 cy/ft during the 2017 Monitoring Year. As shown in Figure 14, the greatest losses occurred in Imperial Beach (ranging from 21 to 84 cy/ft). Modest gains did occur at Silver Strand State Beach.

## ***Post-RBSP I***

Time series of the average shoreline and shorezone volume change in the Silver Strand Cell at the time of each Fall Survey relative to the pre-RBSP I condition (Fall 2000) are presented in Figure 15. The initial shoreline gain following the RBSP I was short-lived, diminishing to below pre-RBSP I levels by 2005. This response may be explained by the relatively small nourishment quantity and the use of only one receiver site in the cell. In 2006, the shoreline advanced by an average of more than 50 ft. These gains can be

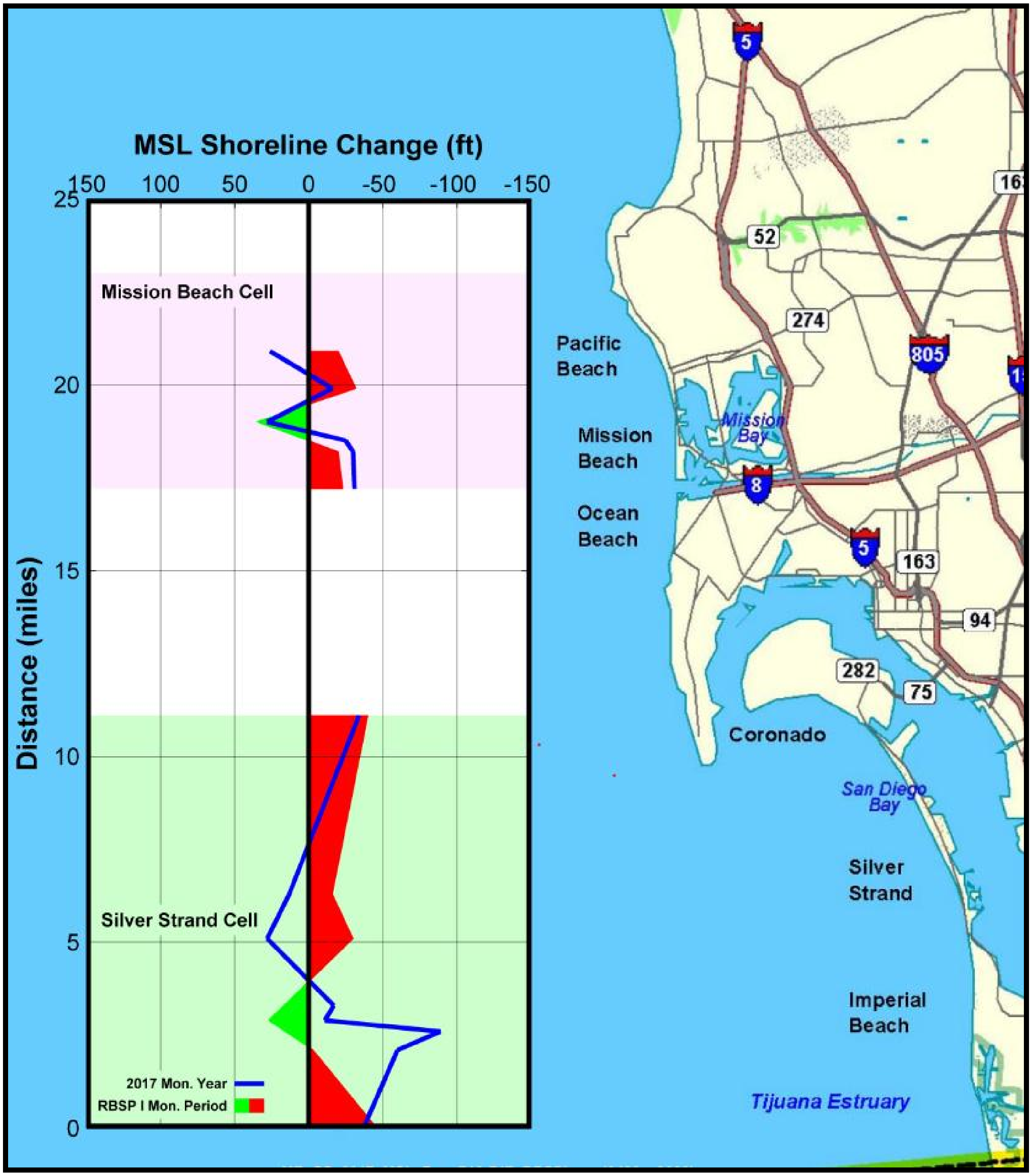


**Figure 13. MSL Shoreline Changes during the 2017 Monitoring Year and Post-RBSP I Period in the Silver Strand and Mission Beach Littoral Cells**

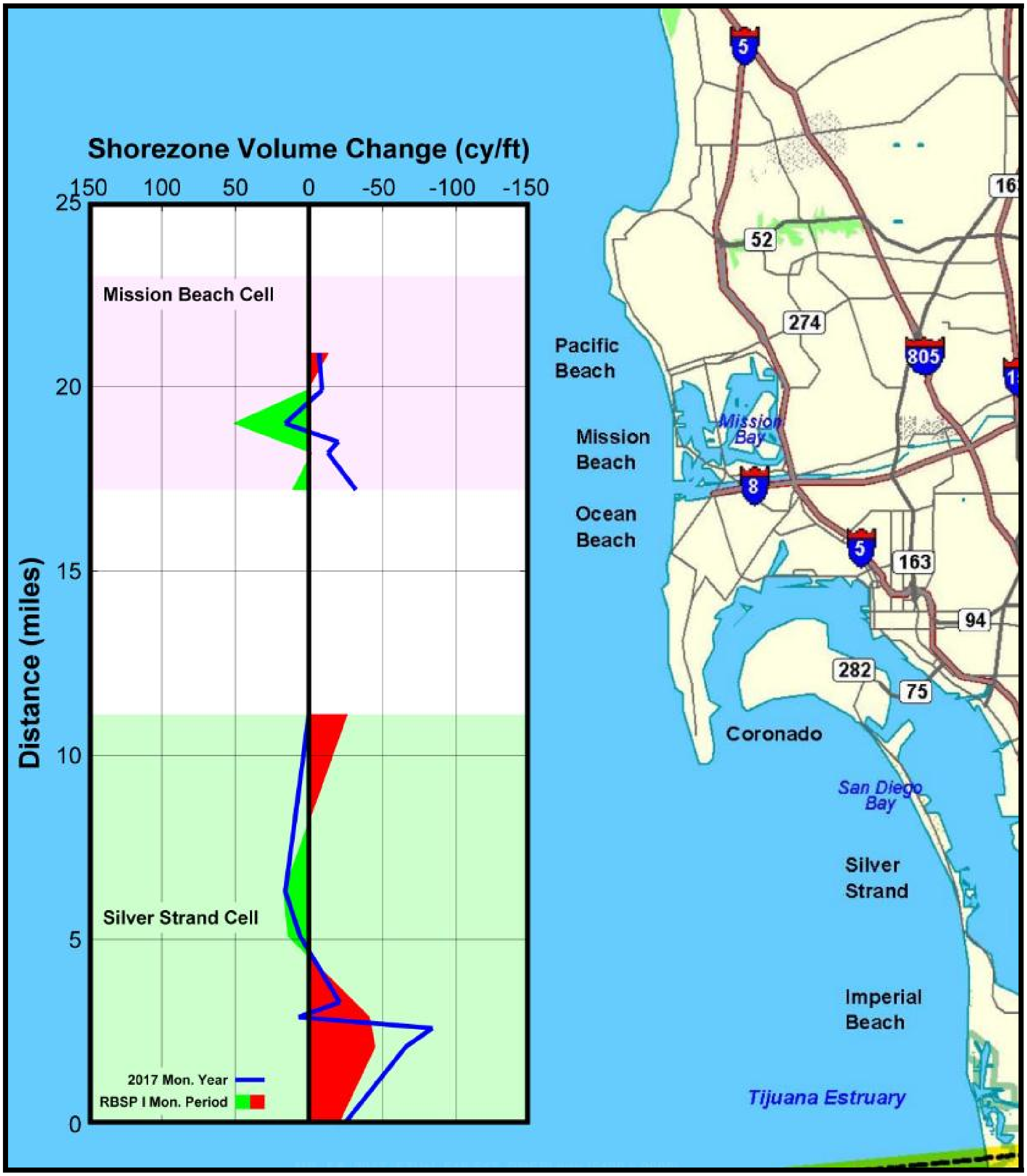


**Figure 14. Shorezone Volume Changes during the 2017 Monitoring Year and Post-RBSP I Period in the Silver Strand and Mission Beach Littoral Cells**

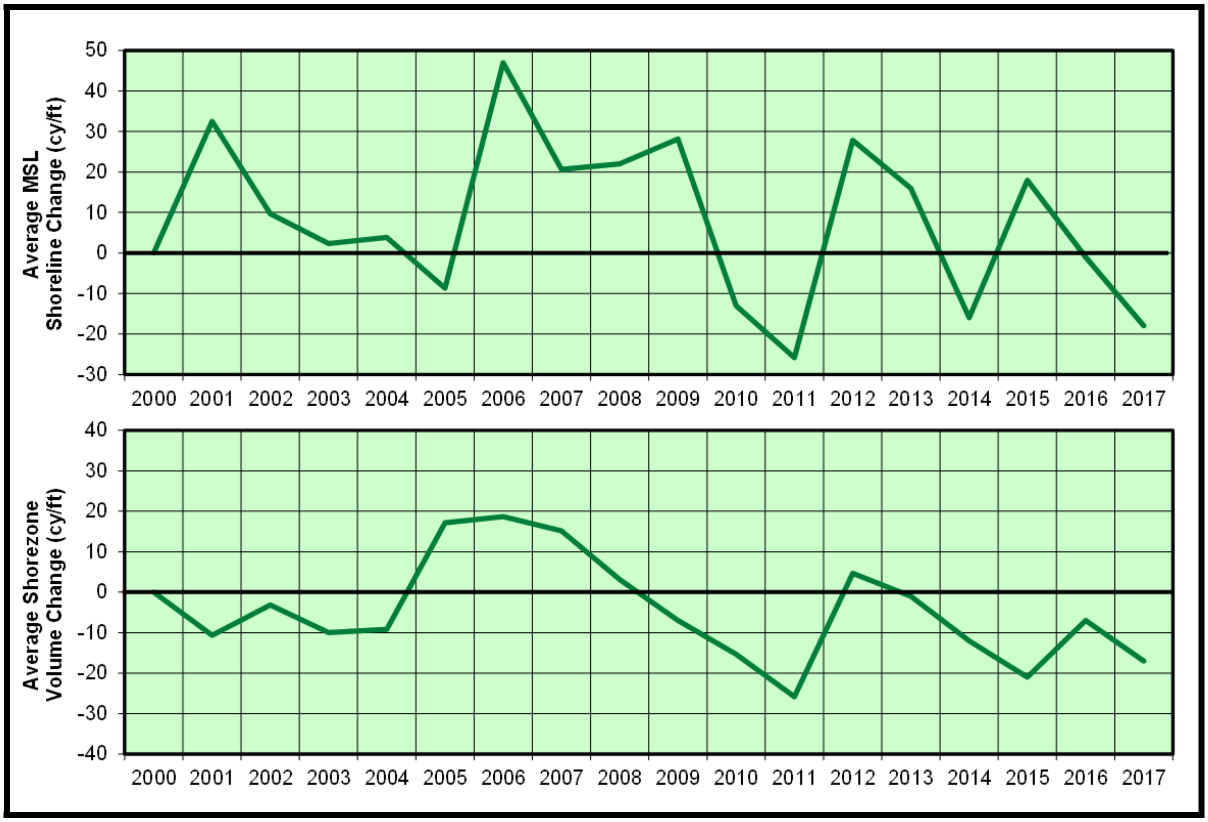


**Figure 15. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Silver Strand Littoral Cell**

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 approximately 26 ft below the pre-RBSP I value.

The introduction of 450,000 cy of RBSP II nourishment material in 2012 (nearly four times that provided under RBSP I) yielded an average shoreline advance of 54 ft, increasing the average beach width in the cell to well above the pre-RBSP I value. Persistent shoreline retreat during 2013 and 2014 then reduced the average shoreline position to 16 ft below the pre-RBSP I value. In 2015, the prevalence of shoreline advance increased the average shoreline position in the cell to 18 ft above the pre-RBSP I value. Losses sustained during the 2015-2016 El Niño reduced the average shoreline position to pre-RBSP I levels. The trend of shoreline retreat continued in 2017, decreasing the average shoreline position to 18 ft below the pre-RBSP I value (a deficit exceeded only in 2011). 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 did not pre-date the RBSP I and the volume gains at these transects were not included in the calculations. Following a modest gain in 2005 produced by the aforementioned opportunistic nourishment, the shorezone volume then diminished during the next five years (2007 to 2011). These losses reduced the shorezone volume to well below the pre-RBSP I value by the time of the Fall 2011 survey.

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. Subsequent losses during the next three years (2013 through 2015) reduced the shorezone volume to well below the pre-RBSP I value. The gains that occurred in 2016 were largely reversed in 2017. As indicated in Figure 14, losses in excess of 40 cy/ft were sustained at Imperial Beach. Volume gains occurred at only two locations in the cell during the 17-year period (Transects SS-0077 and SD-0090 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 2017 Monitoring Year and the Post-RBSP I Period (2000 to 2017) are summarized in Table 23, and in Figures 13 and 14. Detailed supporting data appear in Appendices C and D.

#### ***2017 Monitoring Year***

In the Mission Beach Cell, the shoreline position retreated at four transects and advanced at two. These changes produced and an average shoreline loss of 8 ft in the Cell during the 2017 Monitoring Year. Shoreline retreat ranged from 31 ft (Ocean Beach) to 16 ft (Mission Beach). The average change in Mission Beach was a loss of 11 ft.

In keeping with the shoreline changes, shorezone volume loss also predominated during the 2017 Monitoring Year. The losses were concentrated in the northern and southern portions of the cell, with modest gains prevailing in the middle (Figure 14). The changes produced an average decrease of 11 cy/ft. The greatest loss occurred at Ocean Beach (32 cy/ft), while the only gain (16 cy/ft) occurred at Mission Beach (51 cy/ft).

**Table 23. MSL Shoreline and Shorezone Volume Changes in the Mission Beach Littoral Cell during the 2017 Monitoring Year and the Post-RBSP I Period**

| Period | MSL Shoreline Change (no. of transects) | | | Average Change (ft) |
|---|---|---|---|---|
| | Advance | No Change[4] | Retreat | |
| 2017 Mon. Year [1] | 2 | 0 | 4 | -8 |
| Post-RBSP I [2,3] | 1 | 0 | 4 | -12 |
| **Period** | **Shorezone Volume Change (no. of transects)** | | | **Average Change (cy/ft)** |
| | **Increase** | **No Change[4]** | **Decrease** | |
| 2017 Mon. Year [1] | 1 | 2 | 3 | -11 |
| Post-RBSP I [2,3] | 2 | 2 | 1 | 10 |

Notes: [1] Statistics are derived from the 54 transects included in the Fall 2017 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 2017).
[4] "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

***Post-RBSP I***

Similar to the Silver Strand Cell, the RBSP I nourishment in the Mission Beach Cell was limited to a relatively small quantity at one receiver site. The shoreline initial gains in this cell attributable to the RBSP I nourishment persisted through 2005 (Figure 16). Unanticipated shoreline advance then occurred in 2006. Despite these gains, the shoreline retreat that prevailed in 2007 was sufficient to cause a net loss in beach width relative to the pre-RBSP I condition. Shoreline advance in 2008 and 2009 restored the beach widths to above the pre-RBSP I levels.

The 450,000 cy of opportunistic nourishment material placed at Mission Beach in 2010 produced significant shoreline gains, with the average shoreline position exceeding 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 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 losses. Additional retreat sustained during 2017 reduced the average beach width to the lowest value during the 17-year period. As discussed previously, no RBSP II nourishment was provided to the Mission Beach Cell in 2012.

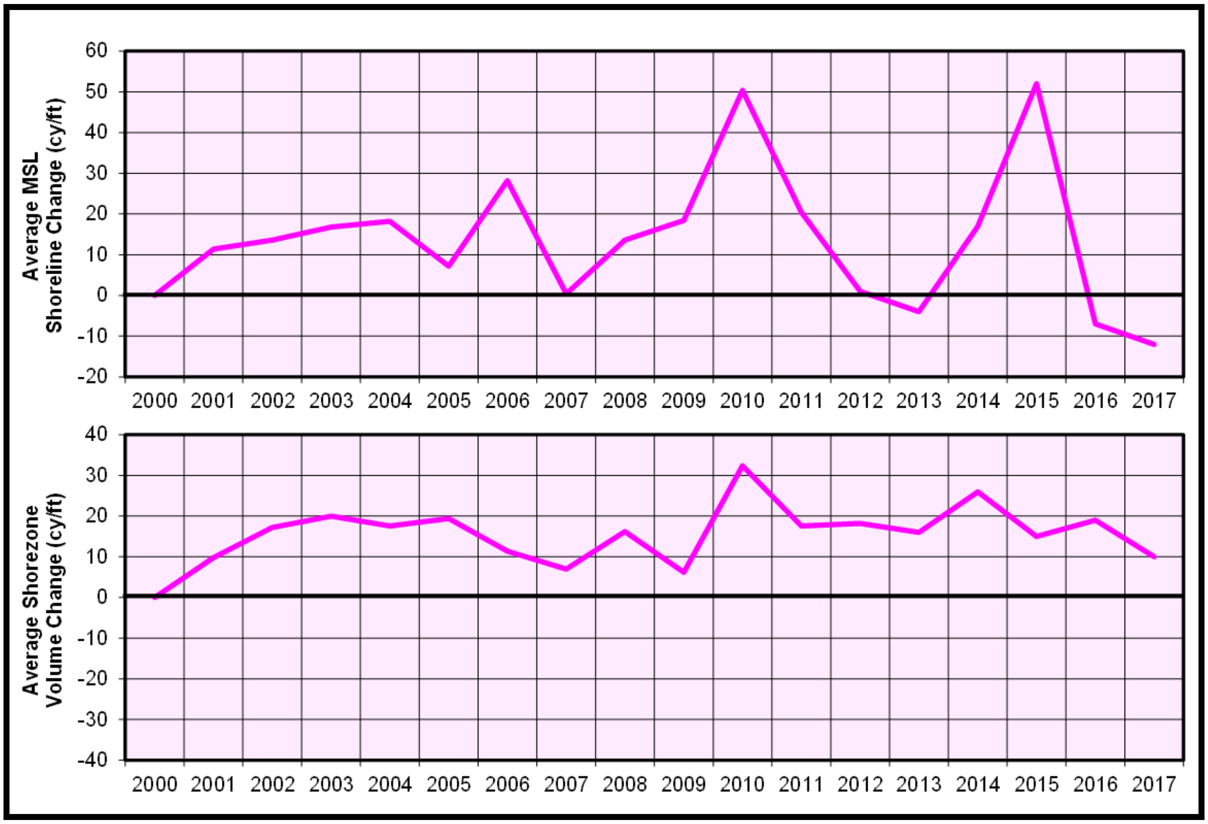


**Figure 16. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Mission Beach Littoral Cell**

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 shorezone volume continued through 2009. This trend was reversed in 2010, with significant shorezone volume gains occurring in response to the Corps sponsored nourishment. Modest losses then prevailed in 2011 as the nourishment material dispersed. The average shorezone volume was stable in 2012 and 2013, before increasing unexpectedly in 2014. While a general trend of shorezone volume loss prevailed over the next three years (2015 to 2017), the average shorezone volume in the cell exceeded the pre-RBSP I value by 10 cy/ft at the end of the period. As shown in Figure 14, shorezone volumes gains were greatest in Mission Beach.

### *5.1.3. Oceanside Littoral Cell*

The MSL shoreline and shorezone volume changes that prevailed in the Oceanside Cell during the 2017 Monitoring Year and the 17-year period encompassing both the RBSP I and II (2000 to 2017) are shown in Figures 17 and 18, and summarized in Table 24. Detailed supporting data appear in Appendices C and D.

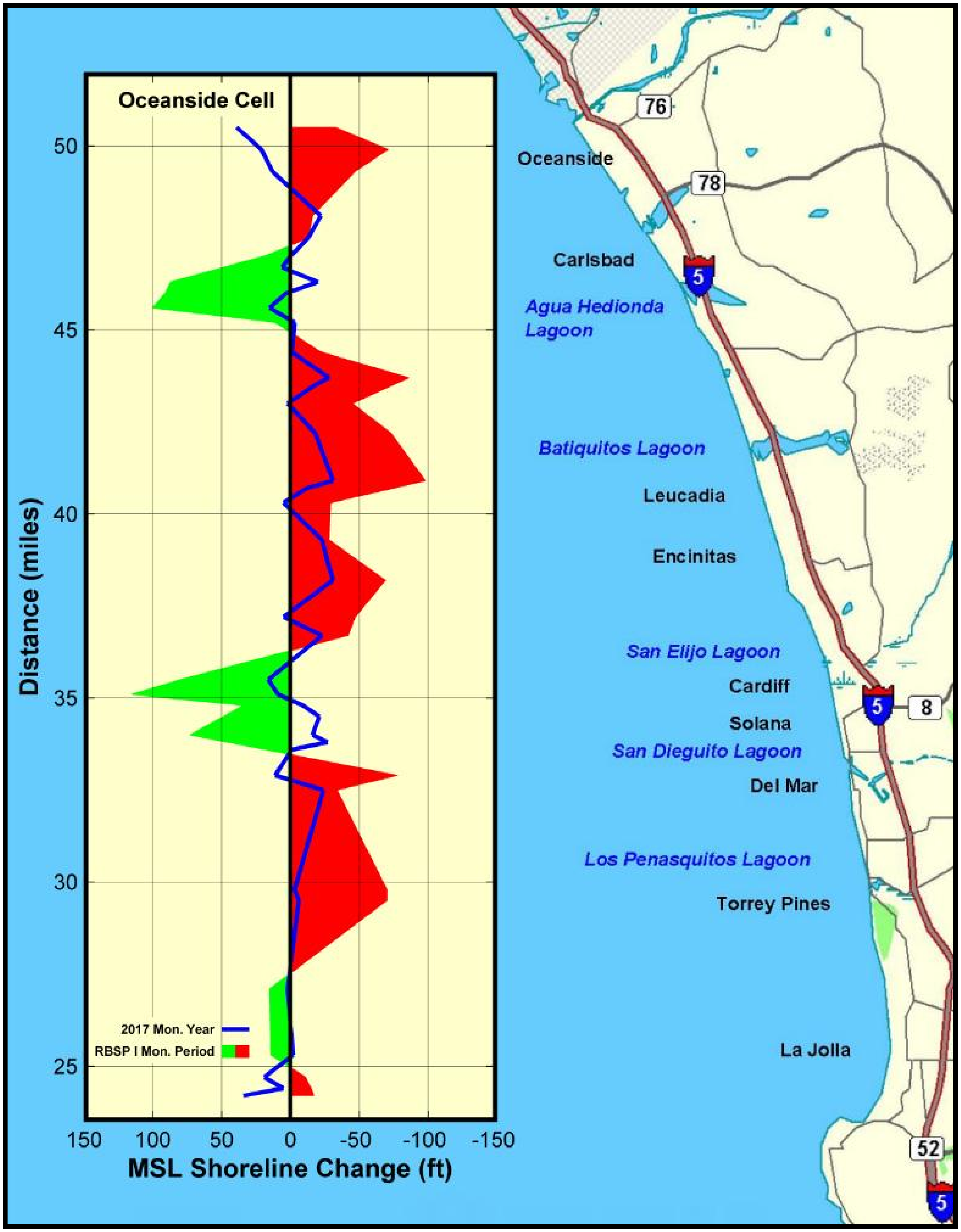


**Figure 17. MSL Shoreline Changes during the 2017 Monitoring Year and Post-RBSP I Period in the Oceanside Littoral Cell**

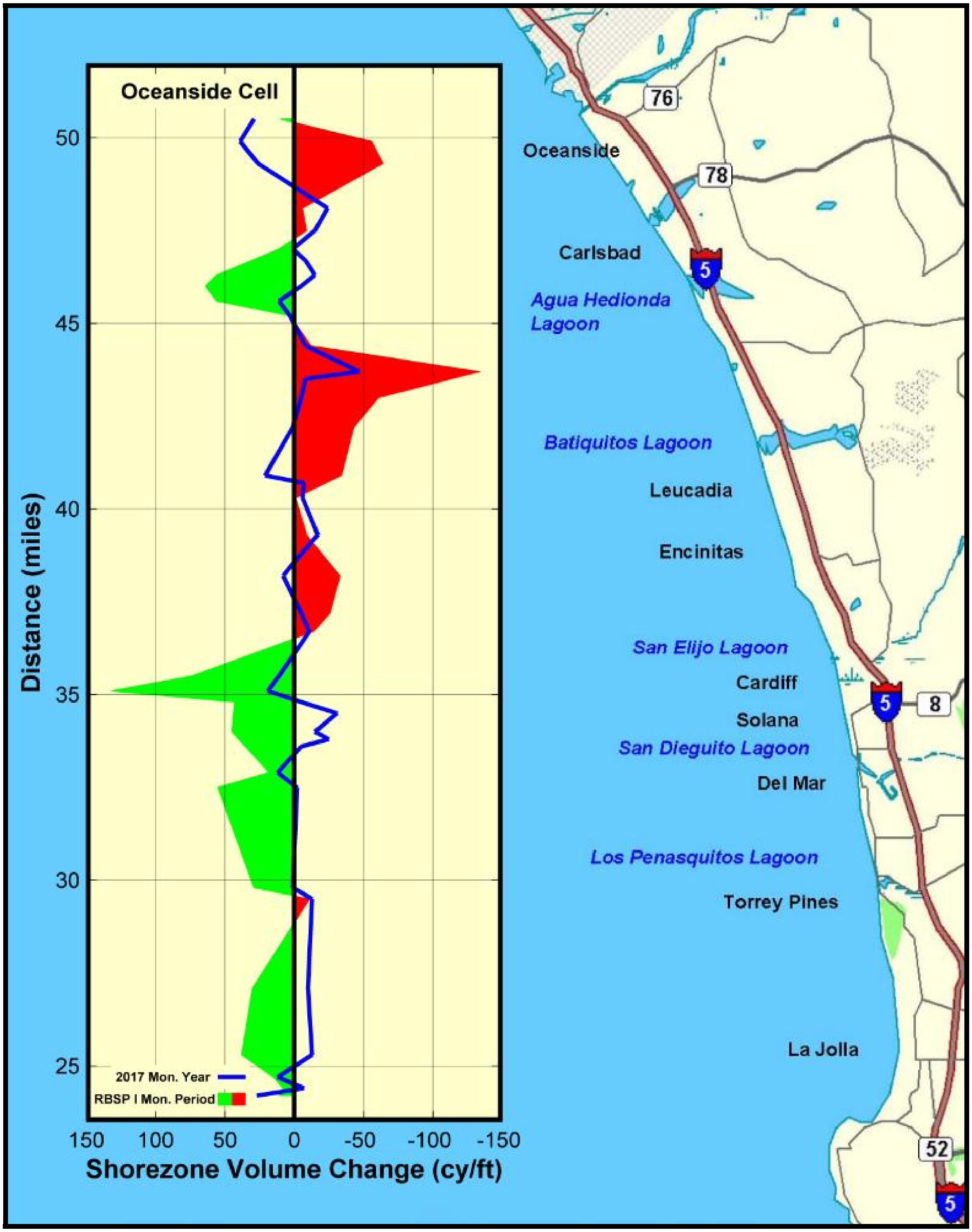


**Figure 18. Shorezone Volume Changes during the 2017 Monitoring Year and Post-RBSP I Period in the Oceanside Littoral Cell**

**Table 24. MSL Shoreline and Shorezone Volume Changes in the Oceanside Littoral Cell during the 2017 Monitoring Year and the Post-RBSP I Period**

| Period | MSL Shoreline Change (no. of transects) | | | Average Change (ft) |
|---|---|---|---|---|
| | Advance | No Change[4] | Retreat | |
| 2017 Mon. Year [1] | 8 | 16 | 16 | -4 |
| Post-RBSP I [2,3] | 11 | 0 | 22 | -11 |
| **Period** | **Shorezone Volume Change (no. of transects)** | | | **Average Change (cy/ft)** |
| | **Increase** | **No Change[4]** | **Decrease** | |
| 2017 Mon. Year [1] | 10 | 19 | 11 | -2 |
| Post-RBSP I [2,3] | 15 | 7 | 11 | 6 |

Notes: [1] Statistics are derived from the 54 transects included in the Fall 2017 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 2017).
[4] "No Change" indicates a shoreline change of 10 ft or less, or shorezone volume change of 10 cy/ft or less.

### *2017 Monitoring Year*

Shoreline changes were mixed in the Oceanside Cell during the 2017 Monitoring Year, with the average shoreline position decreasing by 4 ft. As indicated in Figure 17, the greatest shoreline loss (31 ft) occurred in Encinitas (Transect SD-0670) and South Carlsbad (Transect CB-0720). The shoreline advanced in excess of 10 ft at just eight locations, with the greatest gain (39 ft) occurring at Oceanside Harbor (Transect SD-1070).

The shorezone volume in the Oceanside Cell was relatively stable during the 2017 Monitoring Year, with losses and gains among the transects nearly balanced (Table 24, Figure 18). The net outcome was an average shorezone volume decrease of 2 cy/ft. Losses were distributed along the length of the cell, but greatest at sites in South Carlsbad (47 cy/ft) and Solana Beach (31 cy/ft). Gains were most prevalent in Oceanside (ranging from 26 to 39 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 the Oceanside Cell in 2001. Additional gains were realized in 2002 as RBSP I fill material dispersed alongshore to

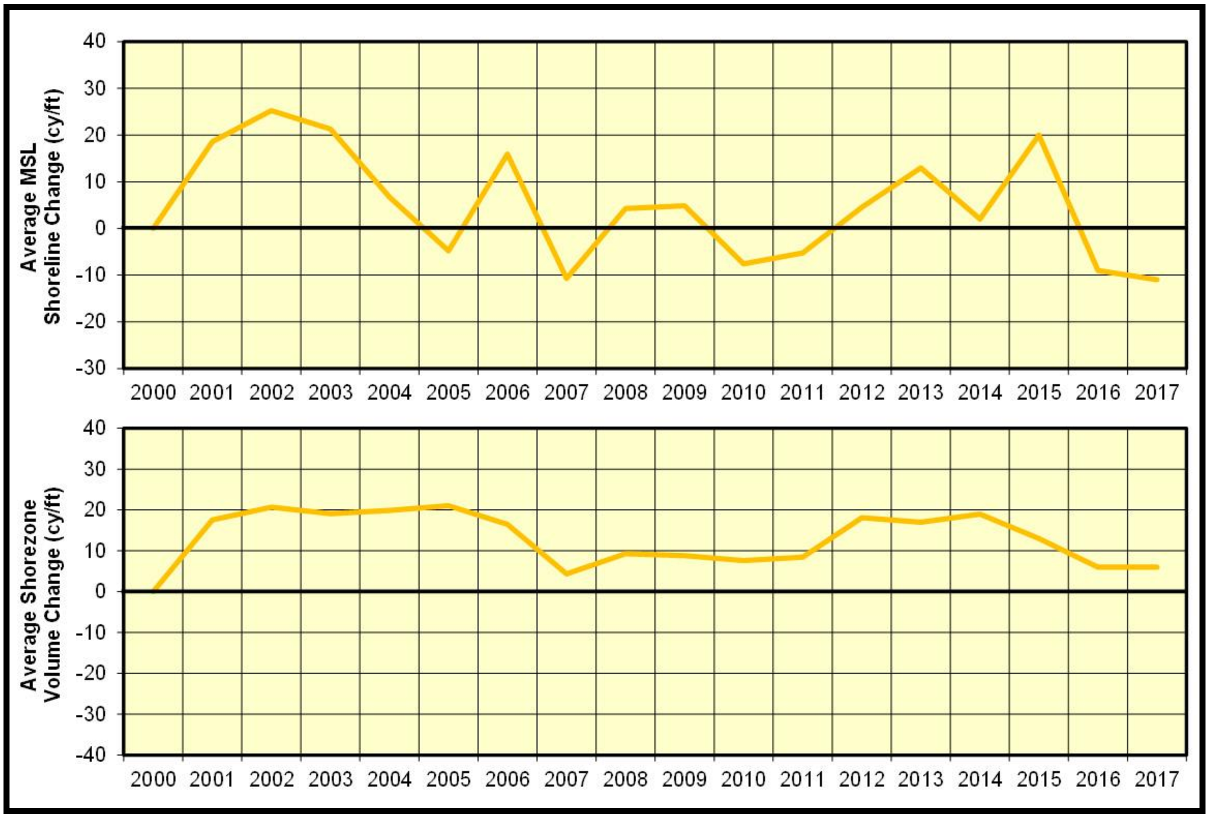


**Figure 19. Time Series of Average MSL Shoreline and Shorezone Volume Change Relative to Pre-RBSP I Condition in the Oceanside Littoral Cell**

adjacent beaches. Shoreline retreat then followed during the next three years, indicative of an ongoing loss of the fill material from the subaerial beach. This trend was unexpectedly reversed in 2006, however, with shoreline advance prevailing. In 2007, significant shoreline retreat occurred, causing the beach widths to fall below the pre-RBSP I value. While shoreline advance in 2008 restored beach widths to values slightly above pre-RBSP I levels, subsequent losses in 2010 reduced the average shoreline position to below the corresponding pre-RBSP I value through 2011.

The introduction of the RBSP II nourishment material in 2012 returned the beach widths in the Oceanside Cell to above the pre-RBSP I value. The magnitude of the 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 gains occurred in 2013 as the nourishment material dispersed alongshore to adjacent beaches. Shoreline retreat then predominated in 2014. Similar to 2006, shoreline positions unexpectedly increased in 2015. However, these gains were reversed in 2016 during the El Niño event. Modest shoreline retreat then occurred in 2017. When the entire 17-year period encompassing the RBSP I and

II is considered, the average shoreline position in the Oceanside Cell falls 11 ft below the pre-RBSP I value – equaling the prior minimum recorded in 2007 (Figure 19). Despite the prevalence of shoreline loss in the region, three areas have sustained significant shoreline gains: North Carlsbad, Cardiff, and Solana Beach (Figure 17).

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 for the next two years (2013 and 2014). Modest losses during the next three years (2015 to 2017) reduced the shorezone volume to near the pre-RBSP I value. The shorezone volume gains were concentrated in the southern portion of the cell (Cardiff to La Jolla) and in North Carlsbad (Figure 18). Losses were most extensive in the Oceanside and South Carlsbad areas.

### 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. To account for the uneven spacing between transects, the average value was weighted according to the alongshore distance associated with each transect. Only La Jolla did not receive direct nourishment as part of RBSP I, while three of the sub-reaches did not receive direct nourishment as part of RBSP II (Del Mar, La Jolla and Mission Beach being the exceptions).

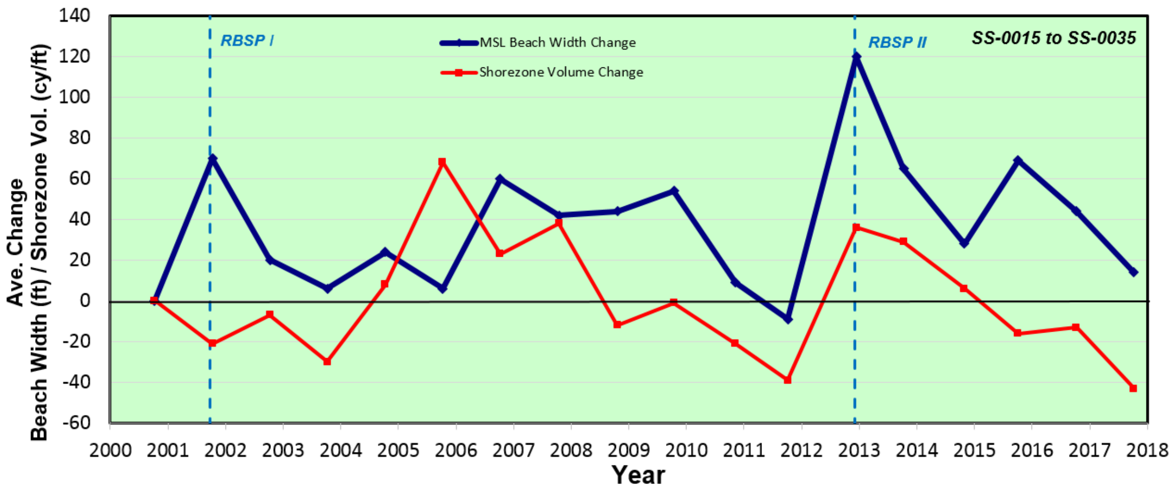


**Figure 20. Beach Width and Shorezone Volume Changes in the Imperial Beach Sub-Reach**

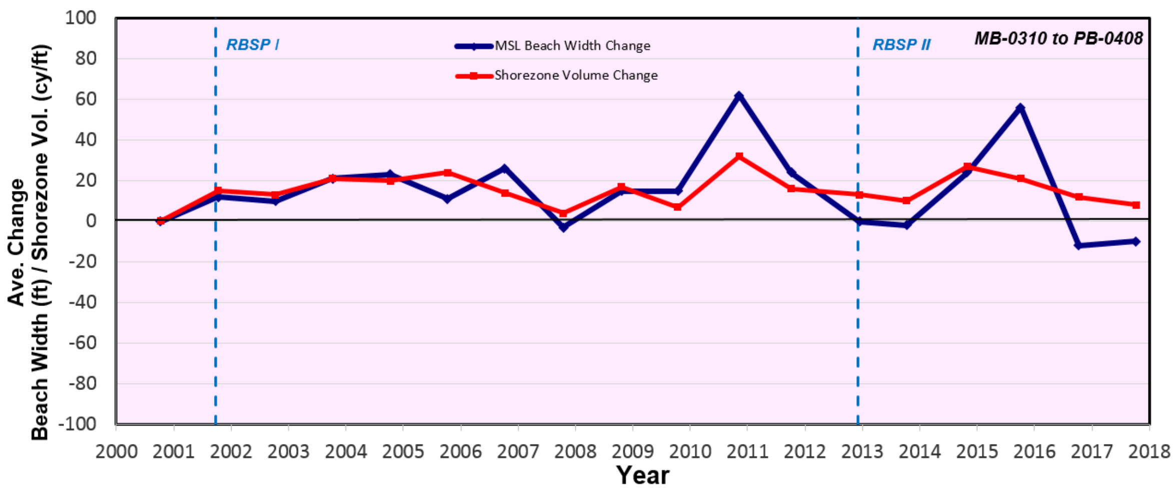


**Figure 21. Beach Width and Shorezone Volume Changes in the Mission Beach Sub-Reach**

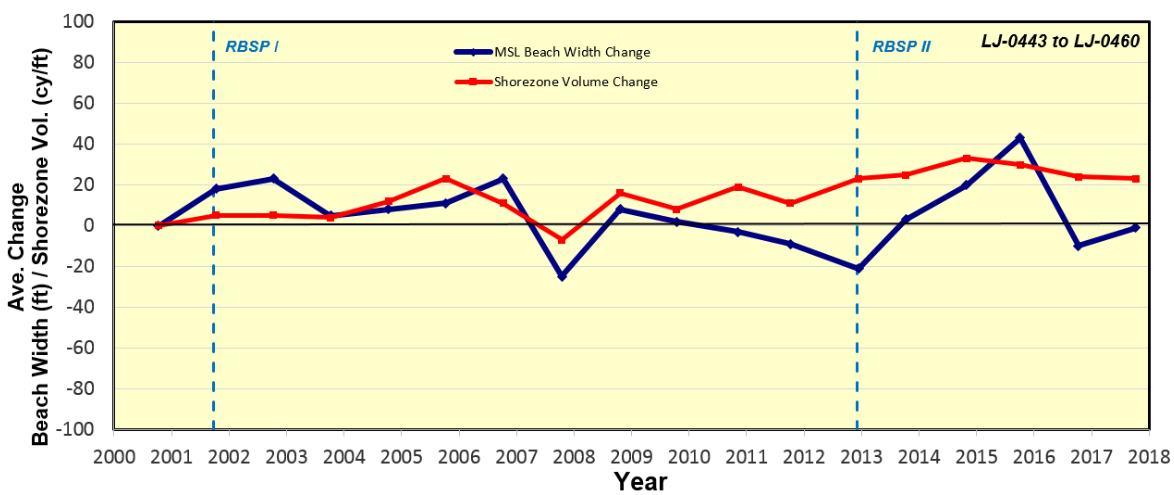


**Figure 22. Beach Width and Shorezone Volume Changes in the La Jolla Sub-Reach**

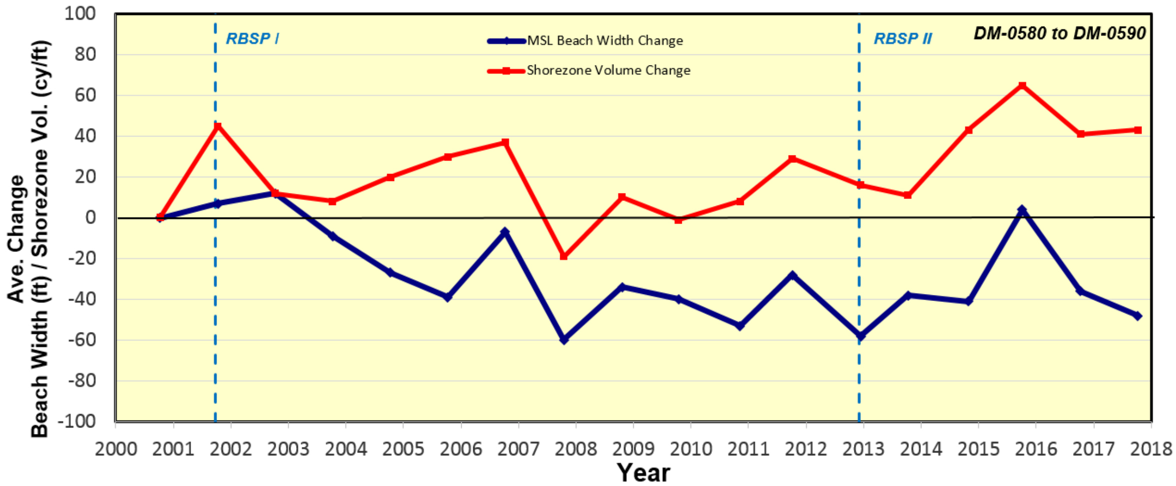


**Figure 23. Beach Width and Shorezone Volume Changes in the Del Mar Sub-Reach**

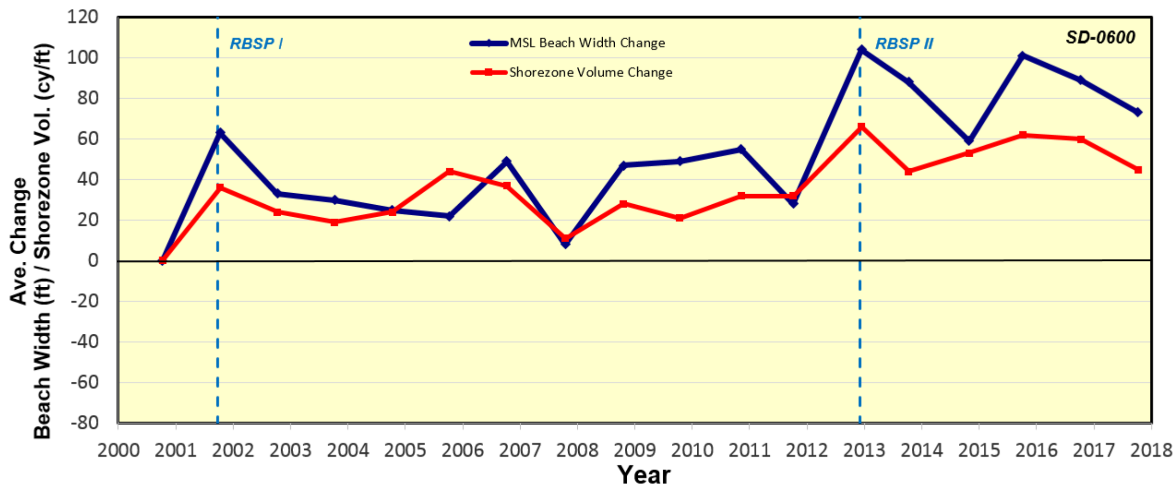


**Figure 24. Beach Width and Shorezone Vol. Changes in the Solana Bch Sub-Reach**

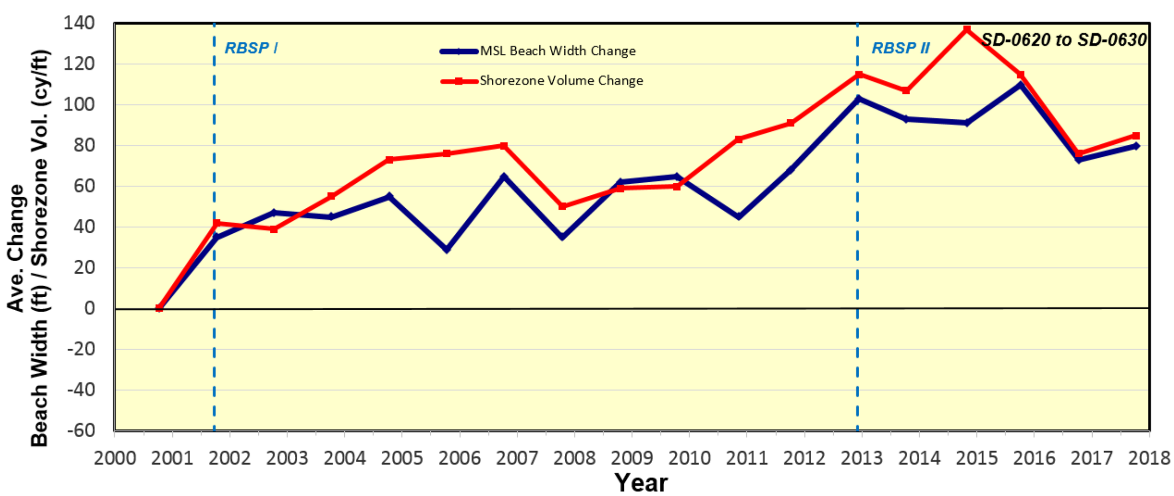


**Figure 25. Beach Width and Shorezone Volume Changes in the Cardiff Sub-Reach**

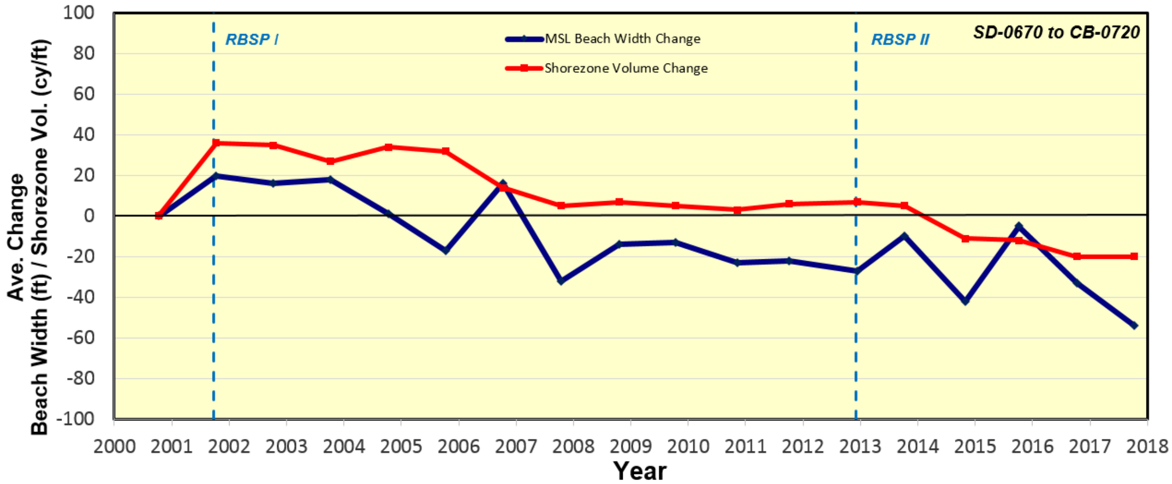


**Figure 26. Beach Width and Shorezone Volume Changes in the Encinitas/Leucadia Sub-Reach**

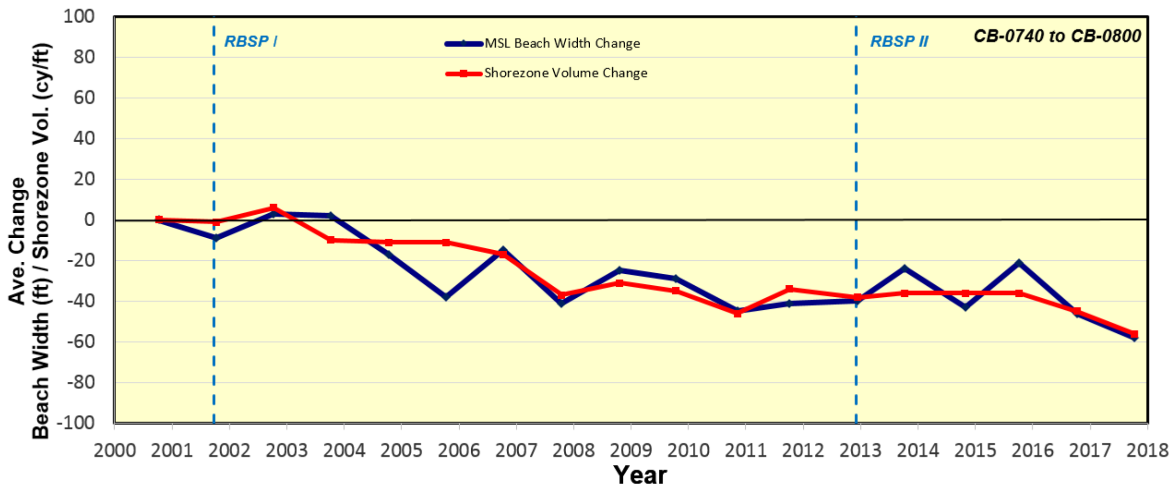


**Figure 27. Beach Width and Shorezone Vol. Changes in the S. Carlsbad Sub-Reach**

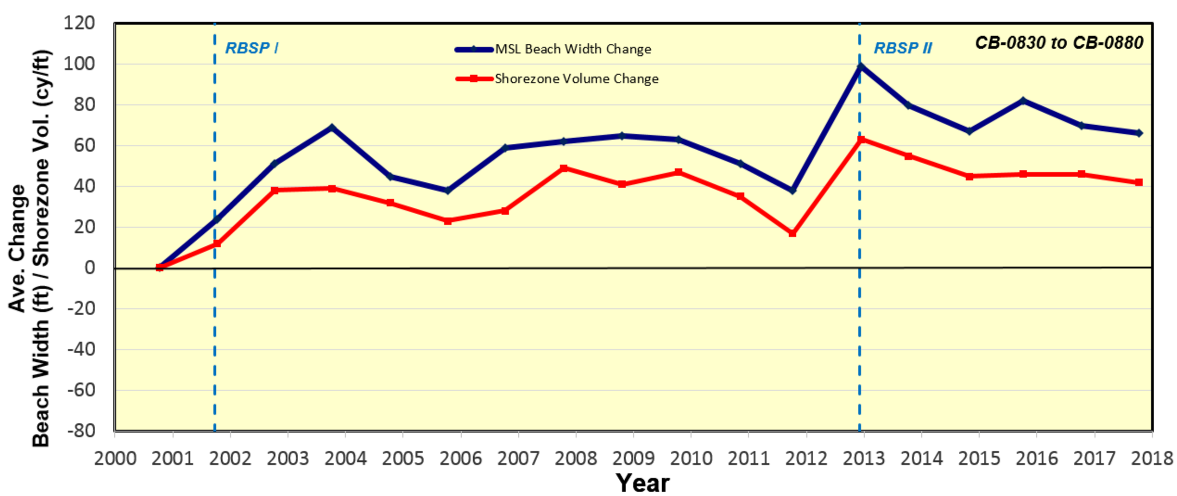


**Figure 28. Beach Width and Shorezone Vol. Changes in the N. Carlsbad Sub-Reach**

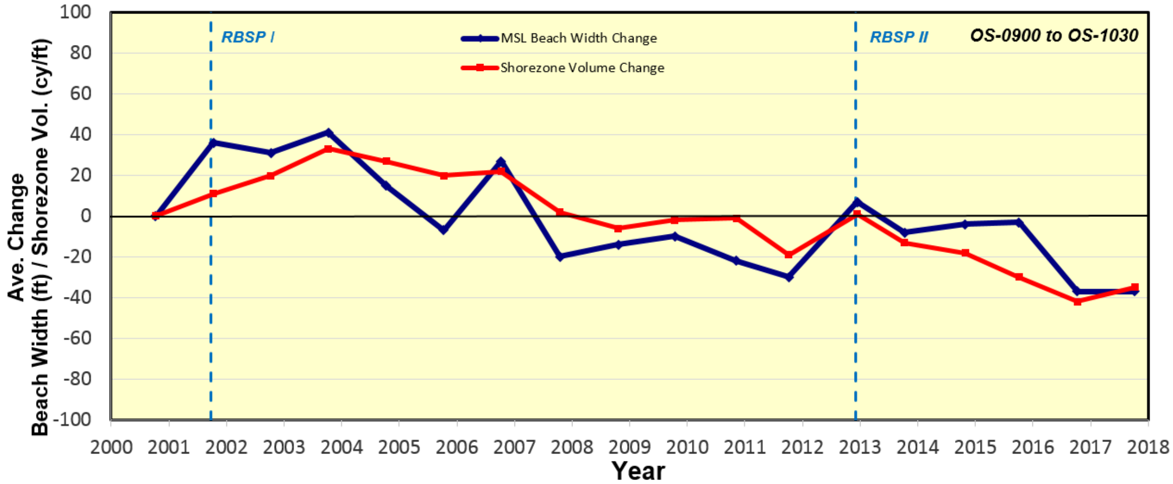


**Figure 29. Beach Width and Shorezone Vol. Changes in the Oceanside Sub-Reach**

Figures 30 and 31 summarize the persistence of beach width and shorezone volume gains in the selected sub-reaches following the RBSP I and II. The persistence of post-RBSP gains was defined in terms of the number of consecutive years immediately following each project in which the average change at the time of each Fall survey relative to the pre-RBSP condition (Fall 2000 for RBSP I and Fall 2011 for RBSP II) exceeded 10 ft (beach widths) or 10 cy/ft (shorezone volumes). In recognition that beach width and shorezone volume gains occurred in the Oceanside Cell during both the first and second year following nourishment as the fill material dispersed alongshore, the accounting of persistence was permitted to commence in the first or second year following the project. Post-RBSP I persistence was limited to 11 years – the period following RBSP I and preceding RBSP II. Three categories were adopted to classify the persistence of post-RBSP gains: Long-Term (5 years), Transient (2 to 4 years), and Negligible (1 year or less).

Long-term post-RBSP I beach width gains prevailed at Mission and at three sub-reaches in the Oceanside Cell (Figure 30). Most notably, the gains at North Carlsbad and Cardiff persisted for the entire 11-year period. Two sub-reaches were characterized by negligible gains (Del Mar and South Carlsbad). Transient beach width gains occurred at the remaining four sub-reaches,

When post-RBSP I shorezone volume persistence is considered, the number of sub-reaches characterized by Post-RBSP I long-term gains increases to seven (Figure 30). All but one of the sub-reaches were located in the Oceanside Cell, the exception being Mission Beach. Similar to the beach width gain persistence, the volume gains at North Carlsbad and Cardiff were sustained for the entire 11-year period. Negligible shorezone volume gains

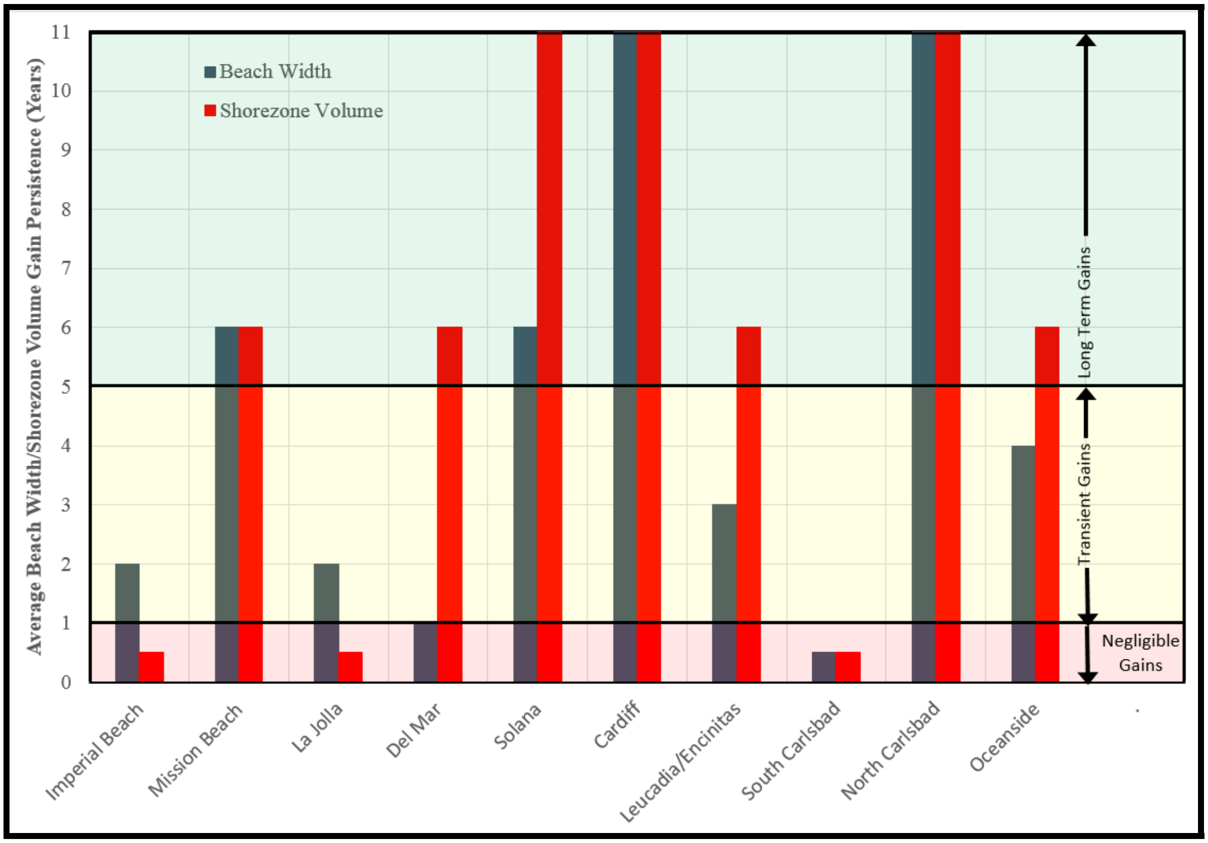


**Figure 30. Post-RBSP I Beach Width and Shorezone Volume Gain Persistence in Sub-Reaches**

prevailed at the remaining three sub-reaches. It is noteworthy that South Carlsbad was the only sub-reach where both the beach width and shorezone volume gains were categorized as negligible. Similarly, Mission Beach, North Carlsbad, Cardiff, and Solana Beach were the only sub-reaches that appeared in the long-term gain category for both beach width and shorezone volume persistence.

Following the RBSP II, long-term beach width gains prevailed at three sub-reaches – Imperial Beach, Solana Beach, and North Carlsbad (Figure 31). Transient beach width gains occurred at three sub-reaches, while three sub-reaches were characterized by negligible gains. Mission Beach is not included in the Post-RBSP II assessment because nourishment was not placed in this littoral cell as part of the project.

Four of sub-reaches were characterized by long-term post-RBSP II shorezone volume gains (Figure 31). Similar to the beach width gain persistence, the volume gains at Solana Beach and North Carlsbad were sustained for the entire six-year period. The volume

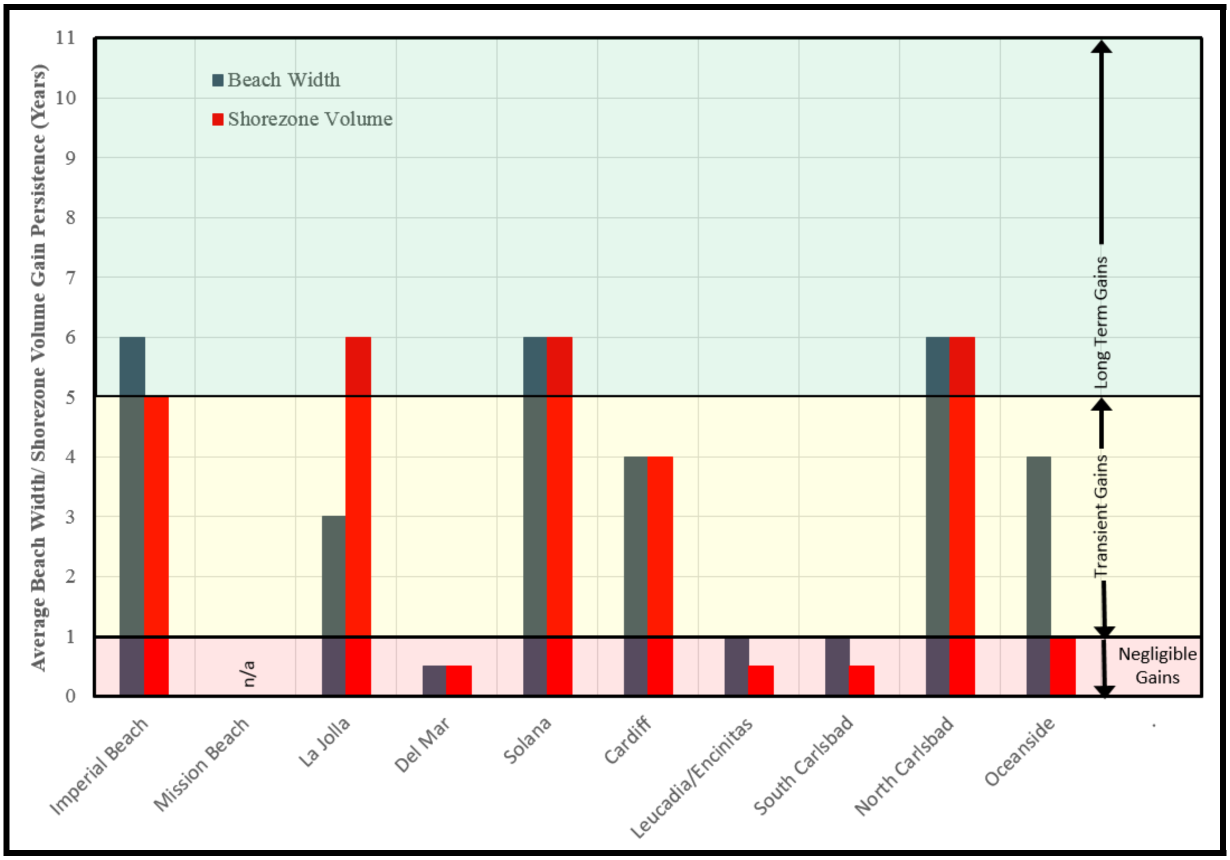


**Figure 31. Post-RBSP II Beach Width and Shorezone Volume Gain Persistence in Sub-Reaches**

gains in La Jolla also lasted for the entire post-RBSP II period. Transient shorezone volume gains prevailed at one sub-reach (Cardiff), while negligible gains occurred at five locations. It is noteworthy that Del Mar, Leucadia/Encinitas and South Carlsbad were the only sub-reaches where both the beach width and shorezone volume gains were categorized as negligible.

North Carlsbad, Cardiff, and Solana Beach fared well following both projects. The improved performance at Imperial Beach following RBSP II compared to RBSP I can be attributed to the substantially larger nourishment volume during the second project (450,000 cy vs. 120,000 cy). Similarly, the poorer performance at Leucadia/Encinitas and Oceanside can be attributed to less nourishment during the second project (354,000 cy vs. 198,000 cy, and 421,000 cy vs. 293,000, respectively). The lack of nourishment at Del Mar during the RBSP II directly contributed to the poor persistence following the second project.

### 5.3. Impact of 2015-2016 El Niño

As discussed in Section 2, the 2015-2016 El Niño was among the three strongest such events on record (as determined by the Oceanic Nino Index, Figure 2). Similar conditions prevailed in 1982-1983 and 1997-1998. Increased storm frequency and intensity during these years caused significant coastal erosion and infrastructure damage in Southern California. While the 2015-2016 El Niño did not produce significant precipitation, the wave energy measured at the CDIP Oceanside Buoy was second only to the 1997-1998 El Niño year. This section compares the shoreline condition preceding the 1997-1998 and 2015-2016 El Niño winters as a means of assessing the relative vulnerability to storm damage prior to each event, summarizes the winter seasonal shoreline changes that prevailed between Fall 2015 and Spring 2016, and assesses the extent of shoreline recovery by the time of the Fall 2017 Survey.

Beaches provide a buffer to protect coastal infrastructure and sea cliffs from wave-induced storm damage and erosion. As such, Fall beach widths offer a first-order indication of the susceptibility to coastal storm damage entering a winter season. This buffer becomes particularly important during a strong El Niño winter, when more energetic wave conditions typically prevail.

Table 25 summarizes the average beach width at the time of the Fall 1997 (pre-1997-1998 El Niño) and Fall 2015 (pre-2015-2016 El Niño) surveys in ten sub-reaches within the study area. Beaches were at least 20 ft wider in Fall 2015 than in Fall 1997 at eight of the ten sub-reaches. Relative beach width gains of more than 100 ft prevailed at three sub-reaches (Solana Beach, Cardiff, and Leucadia/Encinitas). While many factors contribute to coastal storm damages, these areas would appear to be less vulnerable during the 2015-2016 El Niño event. This supposition appears to be substantiated by a comparison of El Niño related emergency permits granted by the California Coastal Commission in the San Diego region during each event, with 23 permits issued in 1997-1998 and just nine in 2015-2016 (Hansch, *et. al.*, 1998; Ainsworth, 2016).

The improved conditions at San Diego County beaches in Fall 2015 relative to Fall 1997 can be attributed in large part to the beach nourishment activities undertaken since 1998 - most notably the 3.6 million cy of material placed on the beaches as part of RBSP I and II. The increased beach widths in the Oceanside Cell can be credited, at least in part, to the RBSP fills and several opportunistic nourishment projects (totaling about 3.6 million cy since 1998). While the RBSP I contributed to beach width gains in the Mission Beach Cell, the majority of the increase resulted from the much larger opportunistic nourishment project

**Table 25. Pre-El Niño Beach Widths in Sub-Reaches**

| Sub-Reach | Transect Range[1] | Ave. MSL Beach Width (ft) | | Average MSL Beach Width Difference (ft) |
|---|---|---|---|---|
| | | Fall 1997 | Fall 2015 | |
| Imperial Beach | SS-0015 to SS-0050 | 120 | 178 | 58 |
| Mission Beach | MB-0310 to PB-408 | 222 | 287 | 65 |
| La Jolla | LJ-0443 to LJ-0460 | 157 | 210 | 53 |
| Del Mar | DM-0580 to DM-0590 | 151 | 152 | 1 |
| Solana | SD-0600 | 96 | 209 | 113 |
| Cardiff | SD-0630 | 72 | 282 | 210 |
| Leucadia/Encinitas | SD-0670 | 99 | 217 | 118 |
| South Carlsbad | CB-0740 to CB-0800 | 125 | 102 | -23 |
| North Carlsbad | CB-0830 to CB-0880 | 104 | 187 | 83 |
| Oceanside | OS-0900 to OS-1030 | 119 | 139 | 20 |

Note: (1) Based on 38 transects common to Fall surveys conducted from 1997 to 2015.

conducted by the Corps of Engineers in 2010. Taken together, about 600,000 cy of nourishment have been placed at Mission Beach since 1998. At Imperial Beach in the Silver Strand Cell, the beaches benefited the nearly 950,000 cy of material placed as part of RBSP I and II and several opportunistic projects.

The shoreline changes that prevailed in the ten sub-reaches during the 2015-2016 El Niño winter (Fall 2015 to Spring 2016) are compared with recent winter seasonal changes in Table 26. The 2015-2016 winter season was characterized by severe shoreline erosion, with above average losses occurring in all but one of the sub-reaches (Solana Beach being the exception). The losses sustained at Imperial Beach and Mission Beach exceeded 100 ft, and were the greatest among the past 20 winter seasons. Shoreline retreat in the Oceanside Cell sub-reaches ranged from 5 to 94 ft, with the erosion in five of the sub-reaches among the top three winter seasonal losses on record. This outcome is in general agreement with the findings of Barnard, *et. al.* (2017) indicating that the winter shoreline retreat on the U.S. West Coast in 2016 was among the highest on record.

**Table 26. Winter Seasonal Shoreline Changes in Sub-Reaches**

| Sub-Reach | Transect Range | Winter Seasonal Beach Width Change (ft) | | | Severity |
|---|---|---|---|---|---|
| | | Max | Ave. | 2016 | |
| Imperial Beach | SS-0015 to SS-0035 | -106 | -61 | -106 | 1 of 20 |
| Mission Beach | MB-0310 to PB-408 | -114 | -46 | -114 | 1 of 20 |
| La Jolla | LJ-0443 to LJ-0460 | -98 | -46 | -94 | 2 of 20 |
| Del Mar | DM-0580 to DM-0590 | -90 | -47 | -85 | 2 of 20 |
| Solana | SD-0600 | -63 | -26 | -18 | 14 of 20 |
| Cardiff | SD-0620 to SD-0630 | -70 | -30 | -70 | 1 of 20 (1) |
| Leucadia/Encinitas | SD-0670 to SD-0720 | -74 | -33 | -51 | 4 of 20 (1) |
| South Carlsbad | CB-0740 to CB-0800 | -49 | -17 | -35 | 3 of 20 |
| North Carlsbad | CB-0830 to CB-0880 | -16 | 5 | -5 | 5 of 20 |
| Oceanside | OS-0900 to OS-1030 | -50 | -16 | -46 | 2 of 20 |

Note: (1) Does not include 1997-1998 El Niño.

As shown in Table 27, beach widths in the region have not recovered to pre-El Niño levels. At the time of the Fall 2017 survey, deficits ranged from 12 ft at North Carlsbad to 66 ft at Mission Beach. On average, the Fall 2017 beach widths in the ten sub-reaches were about 25% narrower than the pre-El Nino condition.

**Table 27. Post El Niño Shoreline Recovery in Sub-Reaches**

| Sub-Reach | Transect Range | MSL Beach Width (ft) | | Difference (ft) |
|---|---|---|---|---|
| | | Fall 2015 pre-El Niño | Fall 2017 2yrs after El Niño | |
| Imperial Beach | SS-0015 to SS-0035 | 178 | 123 | -55 |
| Mission Beach | MB-0310 to PB-408 | 286 | 220 | -66 |
| La Jolla | LJ-0443 to LJ-0460 | 252 | 208 | -44 |
| Del Mar | DM-0580 to DM-0590 | 188 | 136 | -52 |
| Solana | SD-0595 to SD-0610 | 196 | 159 | -37 |
| Cardiff | SD-0620 to SD-0630 | 225 | 195 | -30 |
| Leucadia/Encinitas | SD-0670 to SD-0720 | 174 | 121 | -53 |
| South Carlsbad | CB-0740 to CB-0800 | 105 | 68 | -37 |
| North Carlsbad | CB-0830 to CB-0880 | 187 | 175 | -12 |
| Oceanside | OS-0900 to OS-1030 | 141 | 107 | -34 |

Note: (1) Based on 38 transects common to the Fall 2015 and 2017.

# 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 2017 Monitoring Year (November 2016 through October 2017) and the 16-year period following the RBSP I (November 2002 through October 2017). 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 aerial photos of the lagoons were omitted 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 12 of the 19 years that followed the 1997-98 El Niño event. The exceptions were 2003 (10.3 inches), 2004 (10.2 inches), 2005 (18.1 inches), 2010 (12.8 inches), 2011 (11.0 inches), 2015 (12.3 inches), and 2017 (12.7 inches). The 2005 precipitation total represented the fourth highest annual total on record. 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 32 shows the average percentage of time that each of the five lagoons in the Oceanside Littoral Cell remained open to tidal exchange during the 2017 Monitoring Year, and prior to and subsequent to the RBSP I. As indicated in the figure, 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 33, Los Peñasquitos closed for 74 days (open 80% of the time) during the 2017 Monitoring Year. San Elijo Lagoon was closed on purpose for three days in 2017 to support maintence operations (open 99% of the time). San Dieguito Lagoon and the stabilized entrances at Agua Hedionda and Batiquitos remained open the entire 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 (87% vs. 76%), and slightly less than the historical average at Los Peñasquitos (86% vs. 93%).

### 6.2. Lagoon Entrance Performance

The condition of each lagoon entrance during the post-RBSP I period (2002 through 2017 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.

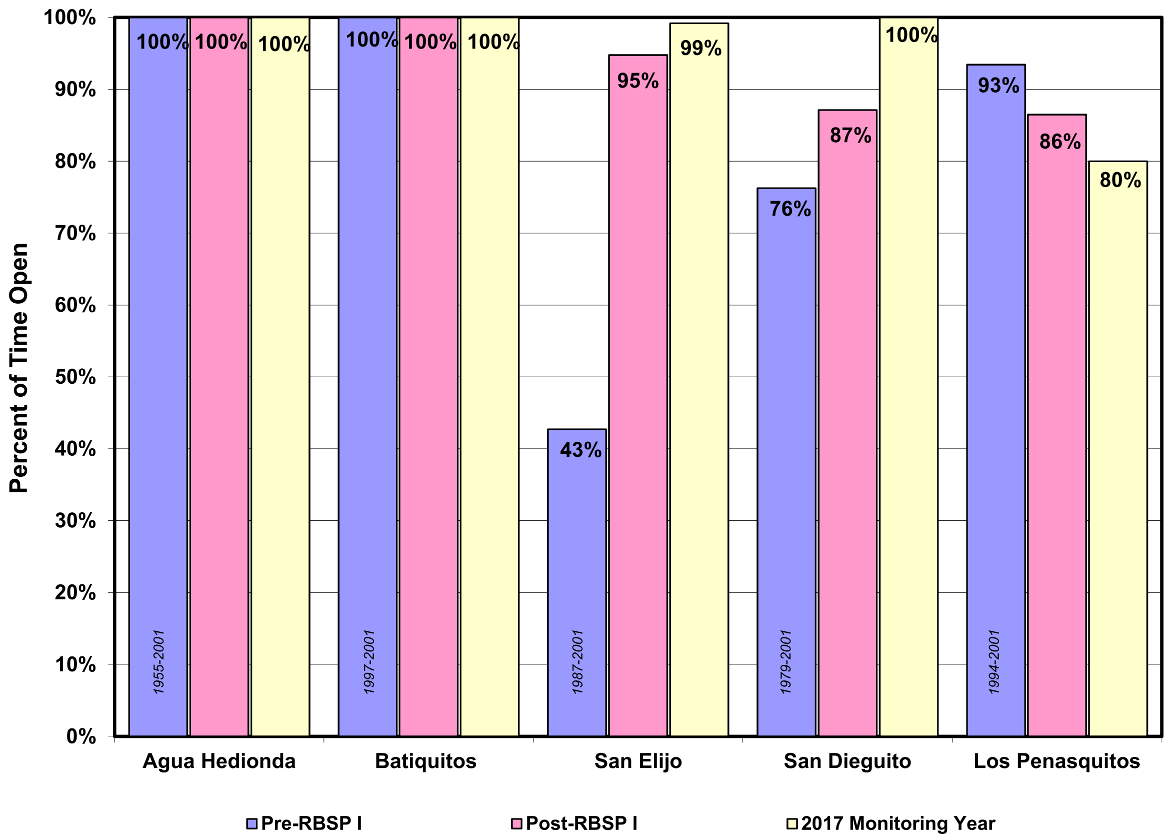


**Figure 32. Percentage of Time Lagoon Entrances Open to Tidal Exchange**

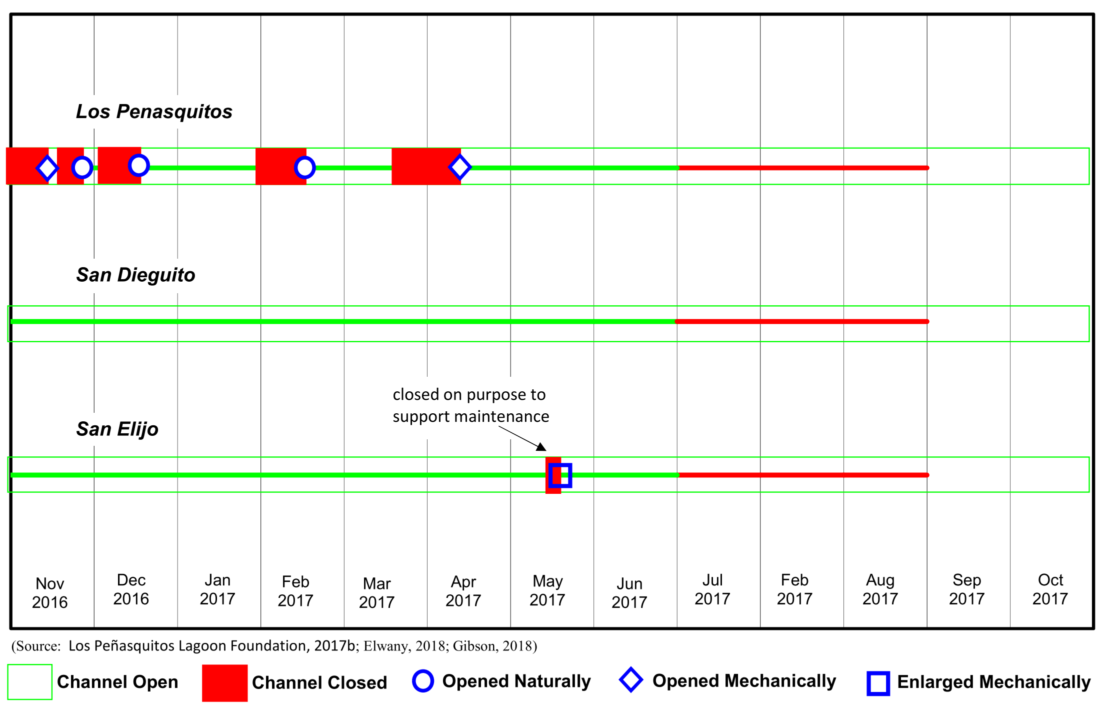


**Figure 33. Condition of Unstabilized Lagoon Entrances During 2017 Monitoring Year**

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 2017) 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 28). The average annual dredge rate was approximately 182,000 cy/yr. Maintenance dredging was conducted six times following the RBSP I, producing an average bypassing rate of 112,000 cy/yr (about 40% below the pre-RBSP I rate).

**Plate 1. Agua Hedionda Lagoon North Entrance, October 2015**

**Table 28. 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 2017) | 2003 | Bypassing | 337,000 |
| | 2005 | Bypassing | 375,000 |
| | 2007 | Bypassing | 335,000 |
| | 2009 | Bypassing | 299,000 |
| | 2011 | Bypassing | 226,000 |
| | 2015 | Bypassing | 221,000 |
| | *Average Annual Dredge Rate at Agua Hedionda Lagoon = 112,000 cy/yr* [2] | | |

Notes: (1) Rate computed for the eight-year period (1994 to 2001).
(2) Rate computed for the 14-year period (2002 to 2015).

### 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 29, an average of 16,000 cy/yr was 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.

Dredging was conducted on three occasions subsequent to the RBSP I (Table 29). 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

**Table 29. 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).

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 30).

The lagoon entrance remained open to tidal exchange during the 2017 Monitoring Year, with the exception of three days in May when the lagoon was purposely closed to accommodate maintence activities. Approximately 17,000 cy of material were removed from the channels and placed on adjacent beaches during the May maintence episode.

Following the RBSP I (2002 to 2017), 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

**Table 30. 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 2017) | 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 |
| | *Average Annual Dredge Rate at San Elijo Lagoon = 22,000 cy/yr* (2) | | |

Notes: (1) Rate computed for the eight-year period (1998 to 2001).
(2) Rate computed for the 16-year period (2002 to 2017).

during the post-RBSP I period was 0.8 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 22,000 cy/yr during the post-RBSP I period (Table 30). 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 77% 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 31). The lagoon entrance is shown in Plate 4.

As indicated in Figure 33, the inlet remained open to tidal exchange during the 2017 Monitoring Year. The lagoon was open to tidal exchange 96% of the time following the RBSP I (2002 to 2017). The entrance closed on 16 occasions during this period,

**Table 31. 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 2017) | 2002 | Bypassing | 5,000 |
| | 2003 | Bypassing | 16,000 |
| | 2006 | Bypassing | 16,000 |
| | 2008 | Bypassing | 16,000 |
| | 2011 | Bypassing | 40,000 |
| | 2016 | Bypassing | 14,000 |
| | ***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 15-year period (2002 to 2016).

**Plate 4. San Dieguito Lagoon Entrance, October2015**

with nine of the closures occurring in 2006. The average closure frequency was 1.0 time per year. Mechanical intervention was required to re-establish tidal exchange after only seven 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 31). 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 pre-RBSP II dredging rates (Table 31) 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 29$^{th}$. Maintenance dredging was conducted in November 2015, consisting of removal of about 14,000 cy from the lagoon channels.

### *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 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, 2000, 2001, 2003; West, 2003, 2004). During this period, the entrance closed an

**Plate 13. Los Peñasquitos Lagoon Entrance, Nov. 2011 through Oct. 2015**

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 32).

The inlet was closed to tidal exchange at the start of the 2017 Monitoring Year, requiring mechanical intervention to restore tidal exchange in mid-November 2016. The lagoon closed again in late-November for six days and in early-December for 13 days - opening naturally after each closure. The lagoon closed for 17 days in February 2017, and once again opened naturally. The last closure of the year occurred in March, and required mechanical intervention to restore tidal exchange 25 days later in mid-April. Approximately 29,000 cy of sediment were removed during the two dredging operations.

After the RBSP I (2002 to 2017), the lagoon was open to tidal exchange 86% of the time. The average closure frequency was 2.0 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 32).

**Table 32. 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 2017) | 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 |
| | ***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 16-year period (2002 to 2017).

# 7. CONCLUSIONS

Conclusions pertaining to the condition of San Diego County's shorezone and the impacts of the RBSP beach fills are summarized below:

1. ***Precipitation and Streamflow*:** Above-average precipitation (12.7 inches) prevailed during the 2017 Monitoring Year. The streamflow in the San Diego River was above average, while that in the San Luis Rey River was slightly below average.

2. ***Wave Conditions*:** The storm frequency during the 2017 Monitoring Year was the fourth highest on record, with $H_s$ exceeding 7 ft on thirteen occasions (six of which surpassed the 10 ft threshold). The three years with higher storm frequencies (1998, 2010, and 2016) were characterized by El Niño conditions. The Energy Index and the number of days with waves exceeding the 7 ft and 10 ft threshold values also were high by historical standards.

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". Despite the material provided by the RBSP I and II and several opportunistic programs, a nourishment deficit of 219,000 cy/yr persisted relative to the historical average in the Oceanside Cell. In the Silver Strand Cell, a deficit of 17,000 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 33,000 cy/yr).

4. ***Sand Bypassing*:** The bypassing rate at Oceanside Harbor during the 17-year Post-RBSP I Period (253,000 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 (135,000 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 rate (13,000 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 2017 Monitoring Year*:** During the 2017 Monitoring Year, shoreline retreat and shorezone volume losses predominated in the Silver Strand Cell. The shoreline position was relatively stable in the Mission Beach and Oceanside Cells. While modest shorezone volume losses occurred in the Mission Beach Cell, the changes in the Oceanside Cell were negligible.

6. ***Beach Changes Following RBSP I*:** When the entire 17-year Post-RBSP I Period (2000 to 2017) is considered, the average shoreline position fell below the pre-RBSP I value in all three littoral cells. The average shorezone volume exceeded the respective pre-RBSP I values in the Mission Beach and Oceanside Cells, but failed to achieve the pre-RBSP I condition in the Silver Stand Cell. The outcome suggests that that gains realized in the Silver Strand Cell from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated during the 17-yr period. The RBSP efforts and other nourishment projects yielded a modest residual benefit in the Oceanside Cell in the form of increased sediment volume. In the Mission Beach Cell, the RBSP I and a much larger opportunistic nourishment project conducted during the 2010 Monitoring Year produced lasting shorezone volume gains.

7. ***Post-RBSP I Outcome in Sub-Reaches:*** Long-term (5+ years) post-RBSP I beach width gains prevailed at Mission Beach and at three sub-reaches in the Oceanside Cell. Most notably, the gains at North Carlsbad and Cardiff persisted for the entire eleven-year period. These beaches benefited from both the RBSP I fills and increased bypassing at San Elijo Lagoon and Agua Hedionda Lagoon. Transient beach width gains (2 to 4 years) occurred at four sub-reaches, while the remaining two sub-reaches were characterized by negligible gains (1 year or less). When shorezone volume persistence is considered, the number of sub-reaches characterized by long-term gains (5+ years) increased to seven. All but one of the sub-reaches was located in the Oceanside Cell, the exception being Mission Beach. Similar to the beach width gain persistence, the volume gains at North Carlsbad and Cardiff were sustained for the entire 11-year period preceding the RBSP II. The remaining three sub-reaches were characterized by negligible gains (1 year or less). South Carlsbad was the only sub-reach where both the beach width and shorezone volume gains were categorized as negligible. Similarly, Mission Beach, North Carlsbad, Cardiff, and Solana Beach were the only sub-reaches that appeared in the long-term gain category for both beach width and shorezone volume persistence.

8. ***Post-RBSP II Outcome in Sub-Reaches:*** Following the RBSP II, long-term (5+ years) beach width gains prevailed at three of the nine sub-reaches considered – Imperial

Beach, Solana Beach, and North Carlsbad (Mission Beach was not included in the assessment because RBSP II material was not placed in this littoral cell). Transient beach width gains (2 to 4 years) occurred at three sub-reaches, while three sub-reaches were characterized by negligible gains. Four of sub-reaches were characterized by long-term post-RBSP II shorezone volume gains (5+ years). Similar to the beach width gain persistence, the volume gains at Solana Beach and North Carlsbad were sustained for the entire six-year period following the project. Transient shorezone volume gains (2 to 4 years) prevailed at one sub-reach (Cardiff), while negligible gains (1 year or less) occurred at four locations. Del Mar, Leucadia/Encinitas and South Carlsbad were the only sub-reaches where both the beach width and shorezone volume gains were categorized as negligible.

9. ***Impact of 2015-2016 El Niño:*** The shoreline condition preceding the 1997-1998 and 2015-2016 El Niño winters was compared as a means of assessing the relative vulnerability to storm damage prior to each event. Beaches were at least 20 ft wider in Fall 2015 than in Fall 1997 at eight of the ten sub-reaches considered. Relative beach width gains of more than 100 ft prevailed at three sub-reaches (Solana Beach, Cardiff, and Leucadia/Encinitas). While many factors contribute to coastal storm damages, these areas would appear to be less vulnerable during the 2015-2016 El Niño event. The improved conditions at San Diego County beaches in Fall 2015 relative to Fall 1997 can be attributed in large part to the beach nourishment activities undertaken since 1998 - most notably the 3.6 million cy of material placed on the beaches as part of RBSP I and II.

   The 2015-2016 winter season was characterized by severe shoreline erosion, with above average losses occurring in all but one of the sub-reaches (Solana Beach being the exception). Beach widths in the region had not recovered to pre-El Niño levels by the time of the Fall 2017 survey. On average, current beach widths in the ten sub-reaches were about 25% narrower than the pre-El Niño condition. Deficits ranged from 12 ft at North Carlsbad to 66 ft at Mission Beach.

10. ***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 six times during this period, producing an average bypassing rate of 112,000 cy/yr (about 40% 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 (87% vs. 76%), and slightly less than the historical average at Los Peñasquitos (86% vs. 93%). At San Elijo Lagoon, the dredging rate following the RBSP I (22,000 cy/yr) exceeded the historical average (15,000 cy/yr) by approximately 50%. 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.

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