COASTAL

FRONTIERS

Encinitas, May 2016

2016 REGIONAL BEACH MONITORING PROGRAM

ANNUAL REPORT

Coastal Frontiers Corporation
882A Patriot Drive
Moorpark, CA 93021
(818) 341-8133

MN Project N0. 6734-05
CFC-993-16

SANDAG
2016 REGIONAL BEACH MONITORING PROGRAM

ANNUAL REPORT

Prepared for:

SANDAG

Under contract to:

Moffatt and Nichol

Prepared by:

Coastal Frontiers Corporation

882A Patriot Drive.
Moorpark, CA 93021

June 2017

EXECUTIVE SUMMARY

This report presents the findings of the SANDAG 2016 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 monitor the fate of nourishment material introduced at eight receiver beaches under the Regional Beach Sand Project II (RBSP II). The RBSP II provided a total of 1.5 million cubic yards (cy) of sand to eight beaches between September 7 and December 7, 2012. This monitoring report is the fifth prepared since the implementation of the RBSP II, with the 2016 Monitoring Year representing the fourth year following nourishment.

The beach monitoring component included semi-annual profiling on 60 shore-perpendicular transects. The lagoon entrance component addressed five sites in the Oceanside Littoral Cell: the jetty-stabilized entrances at Agua Hedionda and Batiquitos Lagoons, and the unstabilized entrances at San Elijo, San Dieguito, and Los Peñasquitos Lagoons. Observations and ground photographs at the three unstabilized entrances were obtained monthly.

To provide continuity with SANDAG's previous monitoring work, November 2015 through October 2016 was defined as the 2016 Monitoring Year and the prior fifteen one-year periods as the 2015 through 2001 Monitoring Years. In keeping with definitions adopted during previous monitoring work, the five-year period encompassing the RBSP II Project (November 2011 to October 2016) is termed the RBSP II Monitoring Period. In addition, emphasis also is placed on the evolution of the County's beaches during the most recent sixteen-year period encompassing both the RBSP I and RBSP II (November 2000 to October 2016).

The principal study findings are as follows:

1. ***El Niño*:** The 2016 Monitoring Year was characterized by "very strong" El Niño conditions. Increased rainfall, higher wave energy, a southerly shift in wave direction, and elevated water levels typically accompany these conditions. Similar circumstances 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.

2. ***Precipitation and Streamflow*:** Below-average precipitation (7.8 inches) prevailed during the 2016 Monitoring Year, despite the occurrence of "very strong" El Niño conditions. The streamflow during the 2016 Monitoring Year also was below average. When the entire four-year post-RBSP II period is considered, both precipitation and streamflow fell below the respective historical averages. The implications are twofold: (1) the scant precipitation and low streamflows failed to deliver significant quantities of beach-quality sediment to the coast during the first four years following the RBSP II nourishment activities, and (2) the low streamflows failed to flush coastal sediment from the lagoon entrances in the Oceanside Cell.

3. ***Wave Conditions*:** The wave conditions were particularly mild during the first three years following the implementation of the RBSP II – a scenario that helped to prolong the life of the beach fills. In contrast, the El Niño conditions that prevailed during the 2016 Monitoring Year produced unusually energetic conditions. The energy index during the 2016 Monitoring Year was exceeded only during the 1998 El Niño year. In addition, the maximum significant wave height measured during the 2016 Monitoring Year (17.8 ft) was the largest recorded during the 19-year period of record.

4. ***Beach Nourishment*:** A substantial number of beach nourishment projects were undertaken in San Diego County prior to the RBSP II. With the exception of the RBSP I, nearly all of the nourishment projects depended on "sand of opportunity" that was derived from activities whose primary motive was other than beach replenishment. During the eleven-year period preceding the RBSP II and including the RBSP I, approximately 42,000 cy/yr were placed on the beaches in the Silver Strand Cell. In the Mission Beach Cell, approximately 55,000 cy/yr were placed on the beaches during this period (primarily from 450,000 cy of opportunistic material provided by the U.S. Army Corps of Engineers in 2010). Approximately 171,000 cy/yr were provided to the beaches in the Oceanside Cell, of which the RBSP I was the largest contributor. A portion of the RBSP II material serves to compensate for the average annual nourishment material provided in prior years, while the remaining material represents incremental nourishment. The incremental volume relative to the pre-RBSP II average was 48,000 cy/yr in the Silver Strand Cell and 45,000 cy/yr in the Oceanside Cell. In the Mission Beach Cell, which did not receive RBSP II nourishment, a deficit of 55,000 cy/yr persisted relative to the historical average.

5. ***Sand Bypassing*:** Sand bypassing operations were not conducted at San Dieguito Lagoon during the five-year RBSP II Monitoring Period. The bypassing rate at Oceanside Harbor during this period (232,000 cy/yr) was slightly less than the historical

average values. Bypassing was conducted at Agua Hedionda in 2015 for the first time in four years. The resulting bypassing rate for the RBSP II Monitoring Period (59,000 cy/yr) was well below the historical average. At San Elijo Lagoon, the five-year bypassing rate (23,000 cy/yr) was slightly higher than the annual average value for the 11 years preceding the RBSP II (22,000 cy/yr). Approximately 35,000 cy/yr were bypassed at Los Peñasquitos Lagoon during the RBSP II Monitoring Period, surpassing the recent historical average of 18,000 cy/yr. The bypassing rate at Batiquitos Lagoon (22,000 cy/yr) greatly exceeded the recent historical average annual bypass rate (11,000 cy/yr during the 11 years preceding the RBSP II). The increased bypassing quantities at Batiquitos and Los Peñasquitos constituted a direct benefit to the receiving beaches, which were located south of the lagoon entrances.

6. ***Beach Changes During 2016 Monitoring Year*:** During the 2016 Monitoring Year, shoreline retreat predominated in each the three littoral cells. In contrast, the shorezone volume increased in the Silver Strand Cell and was relatively stable in the Oceanside and Mission Beach Cells.

7. ***RBSP II Receiver Sites:*** The receiver sites in the Oceanside Cell have been characterized by a general trend of decreasing beach widths and sediment volume consistent with the dispersal of the placed material. A similar trend of diminishing beach widths and shorezone volumes prevailed at the lone receiver site located in the Silver Strand Cell (Imperial Beach) during the first two years following nourishment. This trend was reversed, however, with gains occurring during 2015 and 2016.

8. ***Beach Changes During the RBSP II Monitoring Period*:** During the five-year RBSP II Monitoring Period (2011 to 2016), shoreline advance and shorezone volume gains prevailed in the Silver Strand Cell. These gains appear to be attributable to the RBSP II nourishment. The shoreline position and shorezone volume in the Oceanside Cell was nearly identical to the pre-RBSP II condition at the time of the Fall 2016 survey, suggesting that gains realized from the nourishment program have largely dissipated over the five-year period. In the Mission Beach Cell, which did not receive sand as part of the RBSP II, the shoreline retreated and the shorezone volume was relatively unchanged.

   The impact of the RBSP II fills beyond the placement sites was assessed by evaluating the post-RBSP II outcome in selected sub-reaches. The persistence of post-RBSP I shoreline and shorezone volume gains was investigated for nine sub-reaches in the study area. Beach width and shorezone volume gains persisted for at least four years in five of the nine sub-reaches.

9. ***Beach Changes Following RBSP I*:** When the entire 16-year post-RBSP I period (2000 to 2016) is considered, the average shoreline position fell slightly 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 from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated during the 16-yr period. 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. Similarly, a portion of the RBSP I and II material has been retained in the Oceanside Cell.

10. ***Impact of 2015-2016 El Niño:*** Beaches provide a buffer to protect coastal infrastructure and sea cliffs from wave-induced storm damage and erosion. This buffer becomes particularly important during a strong El Niño winter, when more energetic wave conditions typically prevail. 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. 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.

    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 19 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.

    While shoreline advance predominated in the San Diego region during Summer 2016, the gains were not sufficient to offset the losses sustained during the preceding winter. On average, less than 50% of the losses incurred in the ten sub-reaches over the winter were recovered during the following summer. The net result yielded Fall 2016 beach widths that fell near the lower boundary of historical conditions in much of the study area.

11. ***Borrow Sites:*** Comparison of the 2012 and 2014 bathymetry profiles along the borrow site monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. Additional smoothing and infilling occurred at SO-5 and SO-6 between the 2014 and 2016 surveys, while the changes at MB-01 were modest. Over the four-year period following dredging, the shoaling at SO-6 and SO-5 averaged 0.6 and 0.9 ft, respectively. At MB-1, the depths increased by an average of 0.7 ft. The greatest changes, shoaling of up 4 ft, prevailed at the onshore portion of the SO-6 dredge area between the 2014 and 2016 surveys.

    At MB-1, the grain size distribution curves for the samples obtained in 2014 and 2016 generally fell within the envelope of sediment sizes derived from the 2008 geophysical investigation. Similarly, the grain size distribution curves for the samples obtained at SO-5 were near the middle of the envelope of in-situ sediment sizes. At SO-6, the grain size distribution curves for three of the four samples obtained in 2014 and 2016 fell near the "coarse" end of the envelope of in-situ sediment sizes. The exception was the 2016 sample retrieved from the onshore portion of the dredge area where shoaling of up to 4 ft was noted. This sample contained finer sediment than identified in the 2008 investigation, with a fines content (32%) well in excess of the in-situ range. While the deposition of fine material may be attributable to high energy wave conditions during the 2015-2016 El Nino winter, the biennial nature of the borrow site surveys make it impossible to determine if the shoaling occurred during this season.

12. ***Lagoon Entrances*:** During the post-RBSP II period (2013 through 2016 Monitoring Years), the jetty-stabilized entrance channels at Agua Hedionda and Batiquitos remained open to the full range of tidal exchange. At San Dieguito Lagoon, where lagoon restoration was completed in 2011, the inlet also remained open for the entire four-year period. No maintenance dredging was conducted at Batiquitos or San Dieguito during the post-RBSP period, while dredging was conducted at Agua Hedionda in 2015 for the first time since 2011.

    At San Elijo, the unstabilized entrance channel remained open for the first three years following the RBSP II with the help of maintenance operations conducted each year. The lagoon closed briefly for the first time during the post-RBSP II period in April 2016, requiring mechanical intervention to re-establish tidal exchange. The lagoon was open 98% of the time during the post-RBSP II period. Approximately 93,000 cy of material were removed from the lagoon channels during five maintenance operations, equating to a dredge rate of 23,000 cy/yr during the post-RBSP II period. This rate was slightly more than the pre-RBSP II average (22,000 cy/yr).

The unstabilized entrance channel at Los Peñasquitos closed 11 times, with six of the closures occurring in 2016. Mechanical intervention was required to re-establish tidal exchange on nine occasions, while the lagoon opened naturally after two of the closures. Additional channel enlargements were performed in 2014 and 2016. As a result, the inlet was open 80% of the time during the post-RBSP II period. Approximately 41,000 cy/yr were removed from the lagoon channels during the four-year post-RBSP II period. This rate was substantially greater than the average annual dredge volume during the pre-RBSP I and pre-RBSP II periods (11,000 and 22,000 cy/yr, respectively). The 2016 profiles at the two transects located nearest the lagoon entrance contain distinct nearshore bars, suggesting sediment from the north arrived in this region during the 2015-2016 El Niño winter. This sediment, coupled with the unusually high wave energy may have contributed to the numerous closures and unusually high dredge quantities in 2016.

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SANDAG
2016 REGIONAL BEACH
MONITORING PROGRAM

ANNUAL REPORT

1. INTRODUCTION

This report presents the findings of the SANDAG 2016 Regional Beach Monitoring Program. As in the case of twenty prior annual monitoring programs conducted between 1996 and 2015 (Coastal Frontiers, 1997 through 2016), the 2016 effort was performed on behalf of the San Diego Association of Governments (SANDAG) by Coastal Frontiers Corporation. This monitoring report represents the fifth prepared since the implementation of SANDAG's second Regional Beach Sand Project (RBSP II) in late-2012.

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 2016 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 monitor the fate of nourishment material introduced at eight receiver beaches under the RBSP II. The RBSP II, to be discussed in Section 2.2.1, provided a total of 1.5 million cubic yards (cy) of sand to eight receiver beaches between September 7 and December 7, 2012.

The 2016 Monitoring Program consisted of three components: beach monitoring, lagoon entrance monitoring, and offshore borrow site monitoring. The beach component included semi-annual profiling along 60 shore-perpendicular transects. The lagoon entrance component addressed five sites in the Oceanside Littoral Cell: the jetty-stabilized entrances at Agua Hedionda and Batiquitos Lagoons, and the unstabilized entrances at San Elijo, San Dieguito, and Los Peñasquitos Lagoons (Figure 1). Monthly observations and ground photographs were acquired at the three unstabilized entrances by SANDAG Staff. The borrow site monitoring included obtaining bathymetry at each site (MB-1, SO-5 and SO-6) and collecting sediment samples. Surf spot monitoring (administered by the Surfrider Foundation) was included in the 2012 and 2013 Monitoring Programs, but was not conducted in 2014, 2015, or 2016. Although most of the 2016 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.

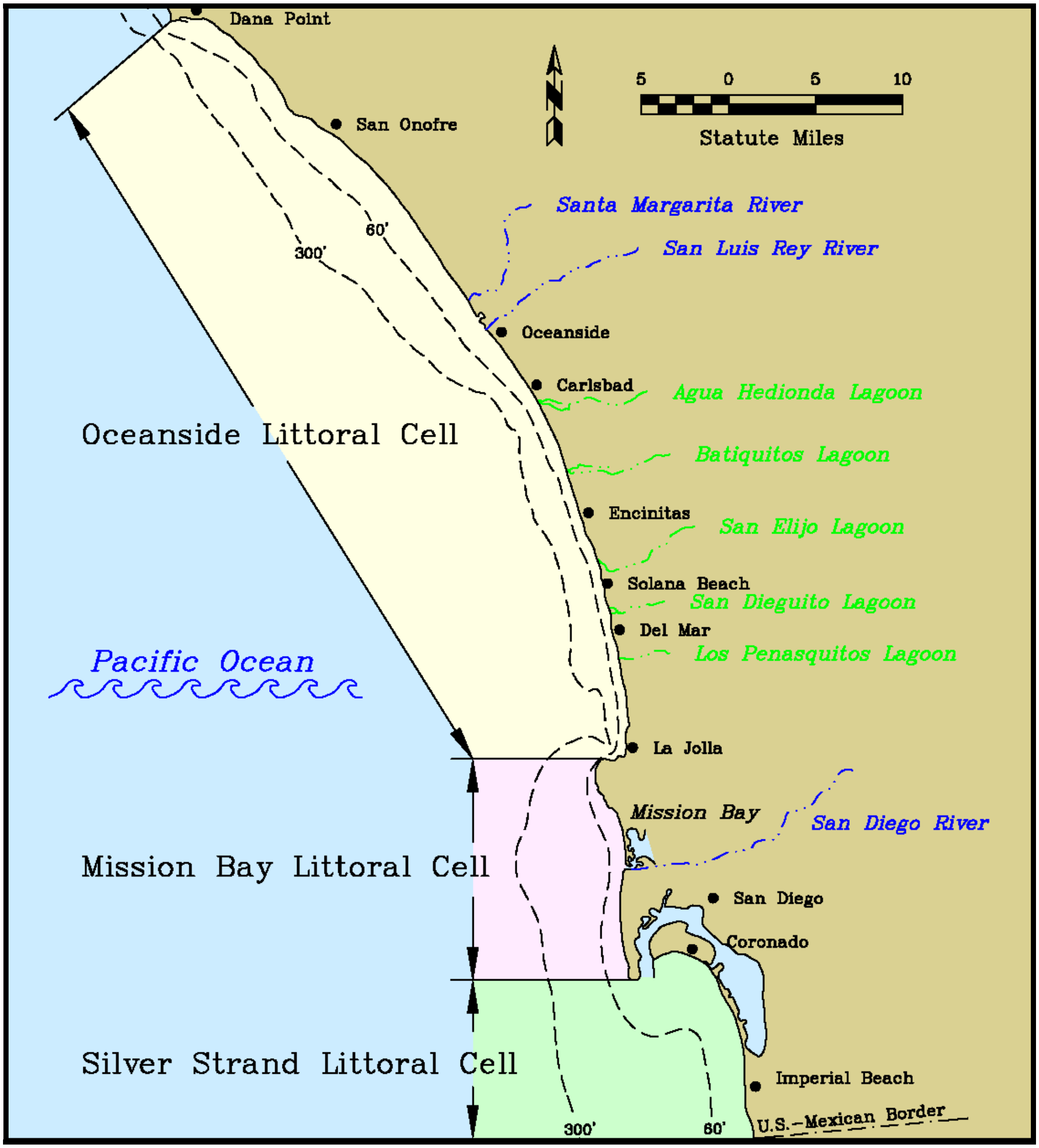


Figure 1. The Coast of San Diego County

To provide continuity with SANDAG's previous monitoring work, a monitoring year is defined as a one-year period from November to October (*e.g.*, the 2016 Monitoring Year extends from November 2015 to October 2016). The primary focus of this report is the 2016 Monitoring Year and the outcome of the RBSP II project (November 2011 to October 2016). In keeping with definitions adopted during previous monitoring work, the latter five-year period is termed the RBSP II Monitoring Period. In addition, emphasis also is placed on the evolution of the County's beaches during the most recent sixteen-year period encompassing both the RBSP I and RBSP II (November 2000 to October 2016).

The survey control network for all of the transects in the SANDAG program was updated in April 2013. This task was undertaken because many of the control points had not been updated in 30 or more years. The horizontal discrepancies relative to the published control typically were small in each of the littoral cells, averaging less than 3 ft for each cell. A portion of these differences are attributable to adjusting the positions to the current horizontal epoch, which accounts for approximately 1.3 ft in the project area. Similarly, the vertical discrepancies typically were small in the Silver Strand and Oceanside Cells (averaging 0.2 ft). However, vertical differences in the Mission Beach Cell were found to be greater, averaging approximately 0.7 ft.

The revised control information was used to process all beach profile data obtained between Fall 2012 and Fall 2016. In addition, all of the beach profile data from the Fall 2011 and Spring 2012 surveys were re-processed using the updated control information. The latter two data sets were revised because they mark the start of the monitoring for RBSP II. In the case of the transects located in the Mission Beach Cell, where the vertical discrepancies were greatest, 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. A similar revision in the Silver Strand and Oceanside Cells was not warranted because the vertical discrepancies were small.

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*** (note that the beach profile data for the Silver Strand and Oceanside Cells remains unchanged for the Fall 2000 to Spring 2011 surveys).

The remainder of this report provides a detailed account of the 2016 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 2016 Monitoring Year and the recent past. Monitoring methods are described in Section 3, while Section 4 presents the results. The condition of San Diego County's beaches is analyzed in Section 5, while Section 6 discusses the condition of the five lagoon entrances in the Oceanside Cell. An assessment of changes at the offshore borrow sites is provided in Section 7. Conclusions are presented in Section 8. 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 the performance of the eight RBSP II beach fills and their impact on coastal lagoons. Environmental conditions are discussed in Section 2.1, followed by sediment management activities (including the RBSP II) in Section 2.2. In Section 2.3, the conditions that prevailed during the RBSP II Monitoring Period (November 2011 to October 2016) are compared with those in the recent past. All data are presented in terms of "monitoring years" that commence on November 1 and end on October 31 of the following year. The 2016 Monitoring Year, for example, extends from November 1, 2015 through October 31, 2016.

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, the 2016 Monitoring Year was characterized by "very strong" El Niño conditions. 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 (Hapke, *et. al.*, 1998; Dean, *et. al.*, 1984).

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-

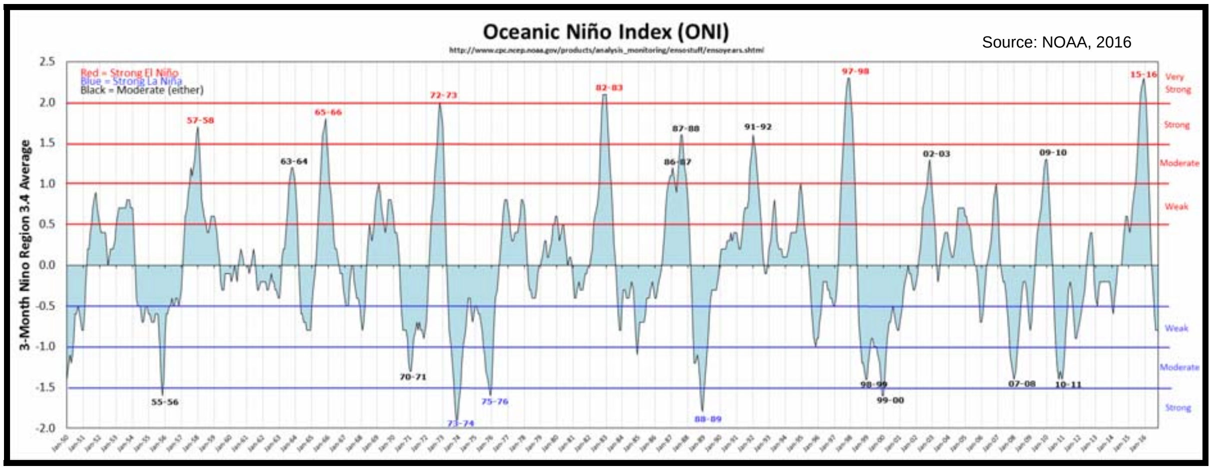


Figure 2. Oceanic Niño Index (1950-2016)

or below-average rainfall at one site can be used to infer similar conditions at other sites (Elwany, *et al*., 1998). The data acquired at San Diego's Lindberg 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 Lindberg Field from 1915 through 2016 (Western Regional Climate Center, 2016). The average value prior to implementation of the RBSP II was 10.1 inches, with a maximum of 26.4 inches in 1941 and a minimum of 3.4 inches in 2002. During the 15-year period that preceded the RBSP II (1997-2011), above-average precipitation was recorded in 1998, 2005, 2010, and 2011. As indicated in Figure 2, 1998 was characterized as a "very strong" El Niño, while "weak" and "moderate" El Niño conditions prevailed in 2005 and 2010, respectively. In contrast, 2011 corresponded to a "strong" La Niña period.

Despite the occurrence of "very strong" El Niño conditions during the 2016 Monitoring Year, below-average precipitation (7.8 inches) prevailed. The year ranked as the 34th driest year since 1915. When the five-year RBSP II Monitoring Period is considered, rainfall was below average during all but one year (2015). The average precipitation during this period was only 7.9 inches.

The cumulative residual rainfall at Lindberg 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-

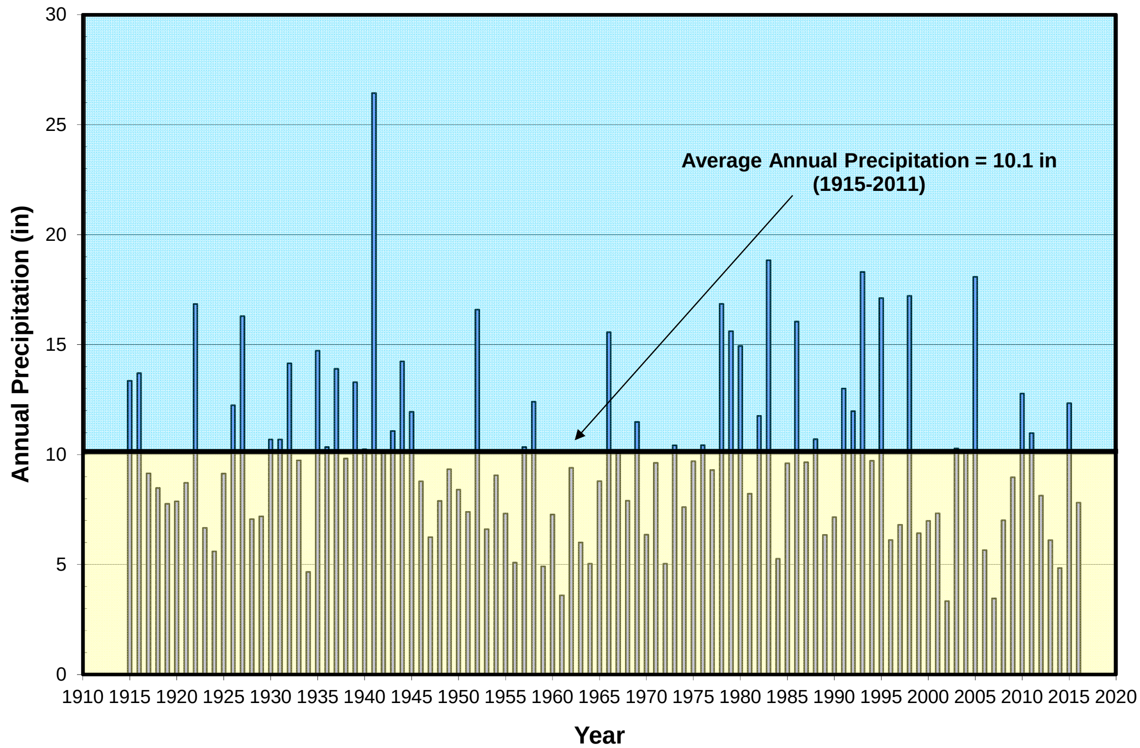


Figure 3. Annual Precipitation at Lindberg Field, 1915-2016

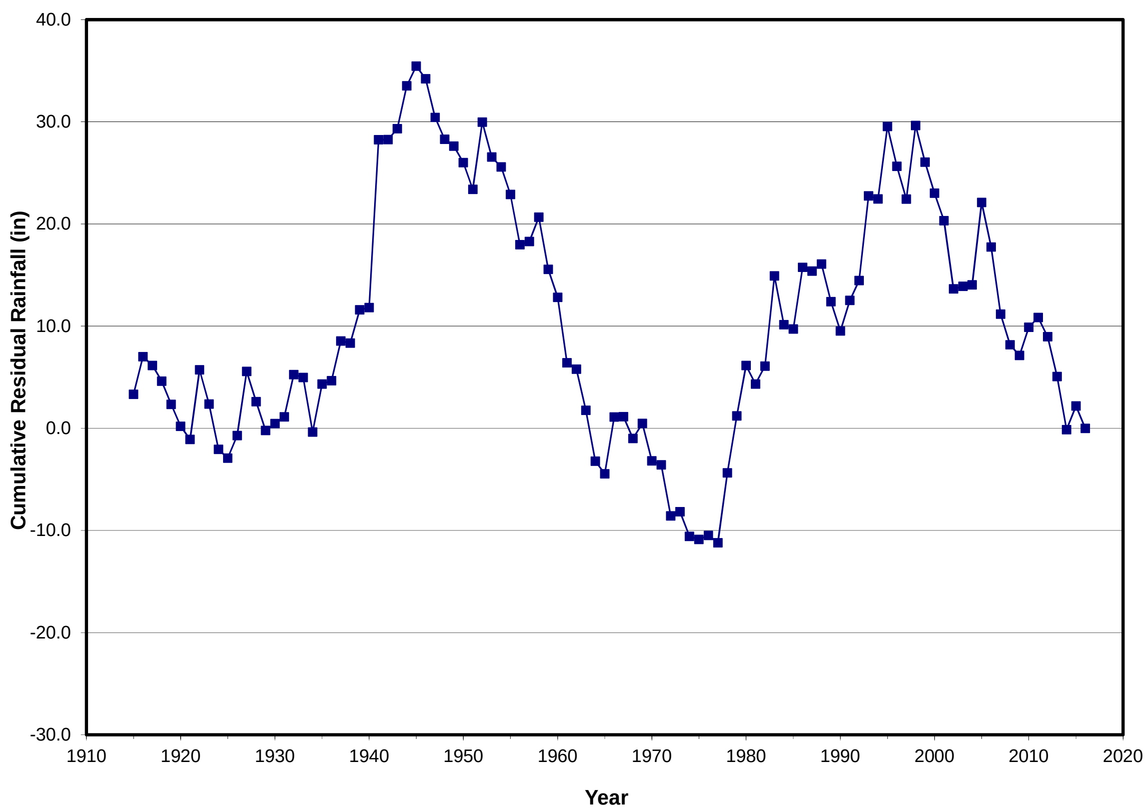


Figure 4. Cumulative Residual Rainfall at Lindberg Field, 1915-2016

average precipitation, while a negative slope denotes a “dry” period of below-average precipitation.

Notwithstanding several short-term exceptions, the period from 1945 through 1977 can be characterized as dry, while the period from 1978 through the mid-1990’s can be characterized as wet. More recently, below- or near-average rainfall persisted in 14 of the 18 years following the 1997-1998 El Niño event, with 2005, 2010, 2011 and 2015 being the exceptions. 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, indicating a continuation of the dry period that has persisted since the 1997-1998 El Niño event. Similarly, the above-average rainfall recorded in 2015 was followed by below-average rainfall in 2016.

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, 2016). The mouth of the San Luis Rey River is located approximately 0.5 miles southeast of Oceanside Harbor, while that of the San Diego River adjoins the entrance to Mission Bay (Figure 1). These rivers were selected for analysis because they are among the largest in the study area, and because streamflow data are available for an extended period of record that includes the current monitoring year.

Figure 5 presents the annual mean streamflow measured in each river between 1983 and 2016. Similar to the precipitation trends (Section 2.1.1), the flow in both rivers remained below the long-term average for 15 of the 18 years following the 1997-1998 El Niño. 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.

The streamflow in both rivers was below average during the 2016 Monitoring Year. For the third consecutive year, no flow was recorded in the San Luis Rey River. The annual mean streamflow in the San Diego River during the 2016 Monitoring Year was the 13^{th} lowest on record. The RBSP II averages for San Diego and San Luis Rey Rivers are approximately 65% and 95% below the respective long-term values.

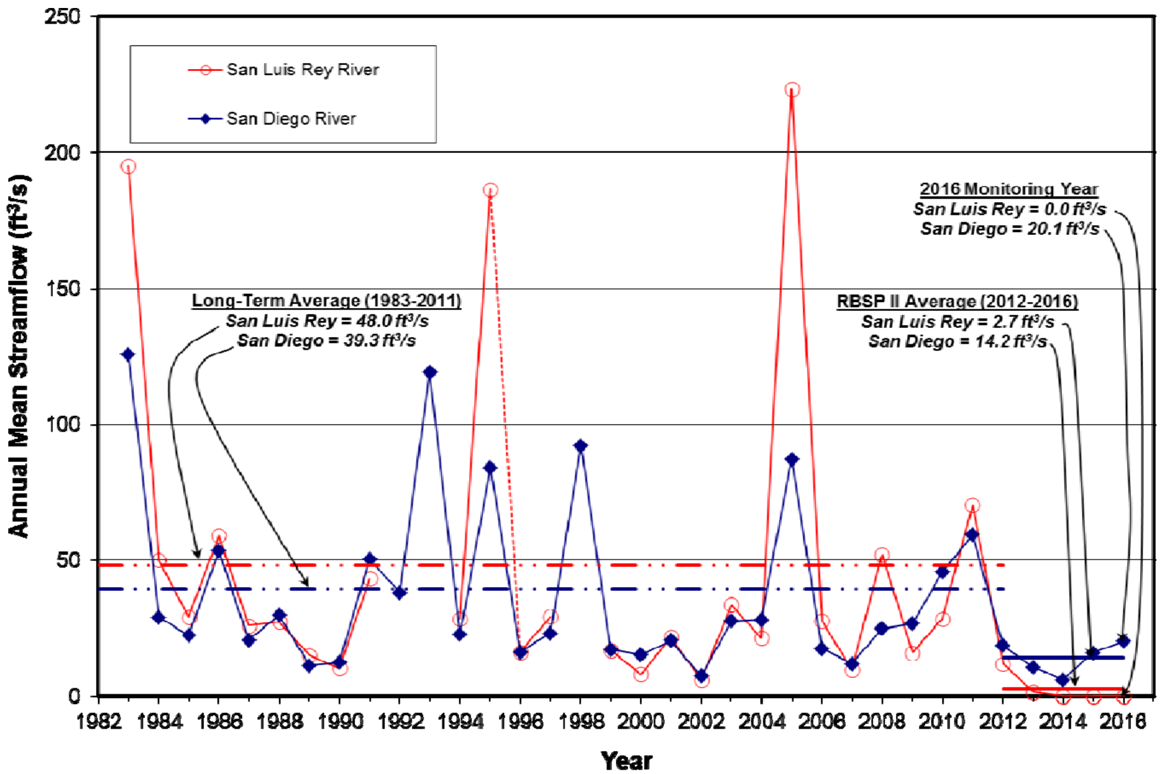


Figure 5. Annual Mean Streamflow in the San Luis Rey and San Diego Rivers, 1983-2016

2.1.3. Wave Climate

Three measures of the wave climate were used to compare the potential for sediment transport during the 2016 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 (2016). 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 2016 Monitoring Year are presented as a time series in Figure 6. Southerly swell typical of summer months prevailed into

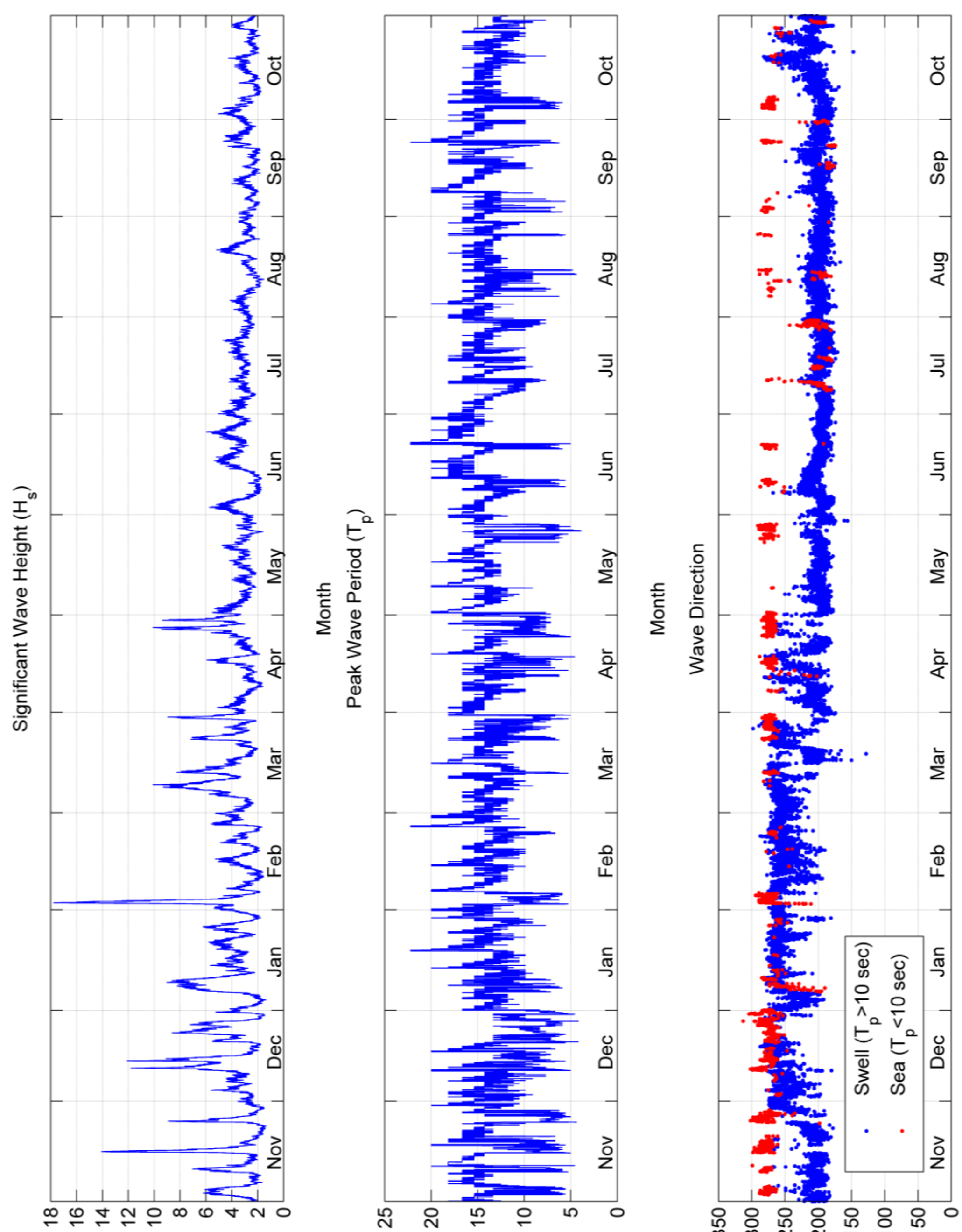


Figure 6. Wave Characteristics at the CDIP Oceanside Buoy, 2016 Monitoring Year

late-November, transitioning to predominantly northerly swell from December through March. April was characterized by a mixture of both northerly and southerly swell. The remainder of the monitoring year (May through October) was typified by southerly swell.

Figure 7 shows the significant wave height (H_s) for each storm event with H_s exceeding 7 ft (2.1 m) for the 19-year period from 1998 to 2016. 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. Table 1 shows the maximum significant wave height measured at the CDIP Oceanside Buoy for each Monitoring Year.

As indicated in Figures 7 and 8, sixteen storms with H_s surpassing 7 ft surpassing occurred during 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 two 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.

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 19-year period of record (Table 1). The storm occurred on February 1 with waves arriving from the west (278°) with a peak period of 9.9 seconds.

The total wave energy in each Monitoring Year from 1998 through 2016 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):

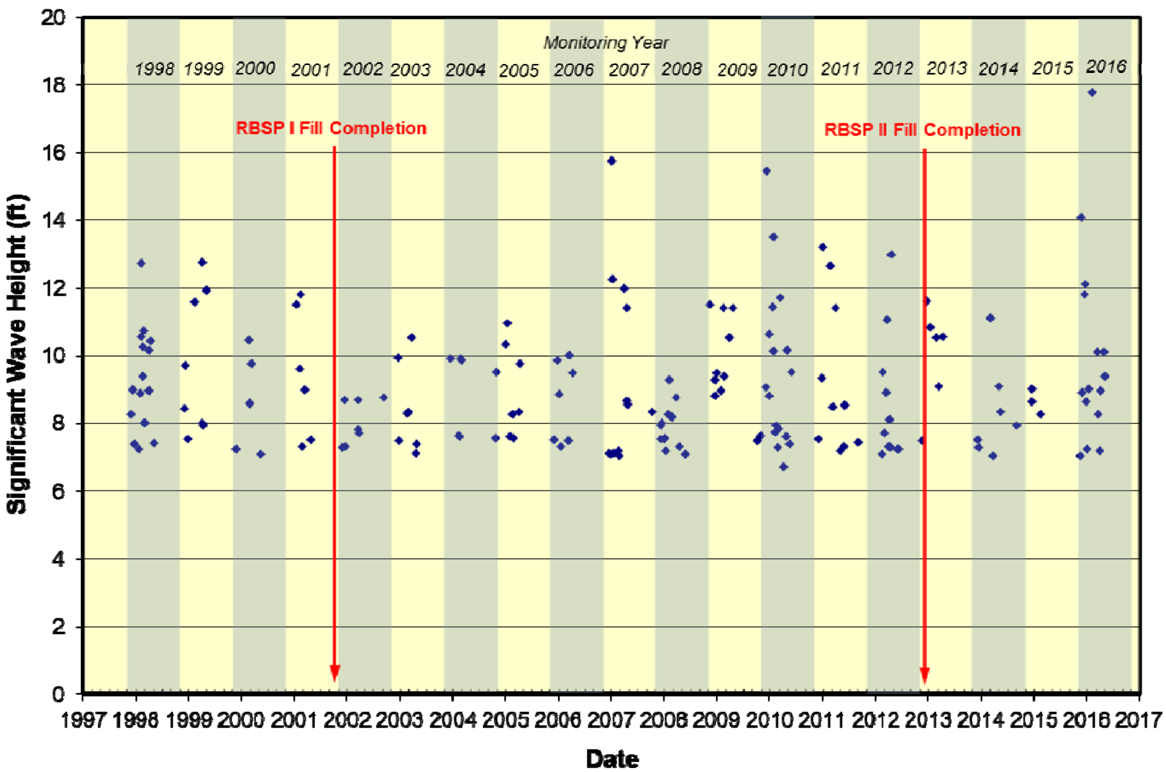


Figure 7. Storm Events with Significant Wave Heights Exceeding 7 ft, 1998-2016

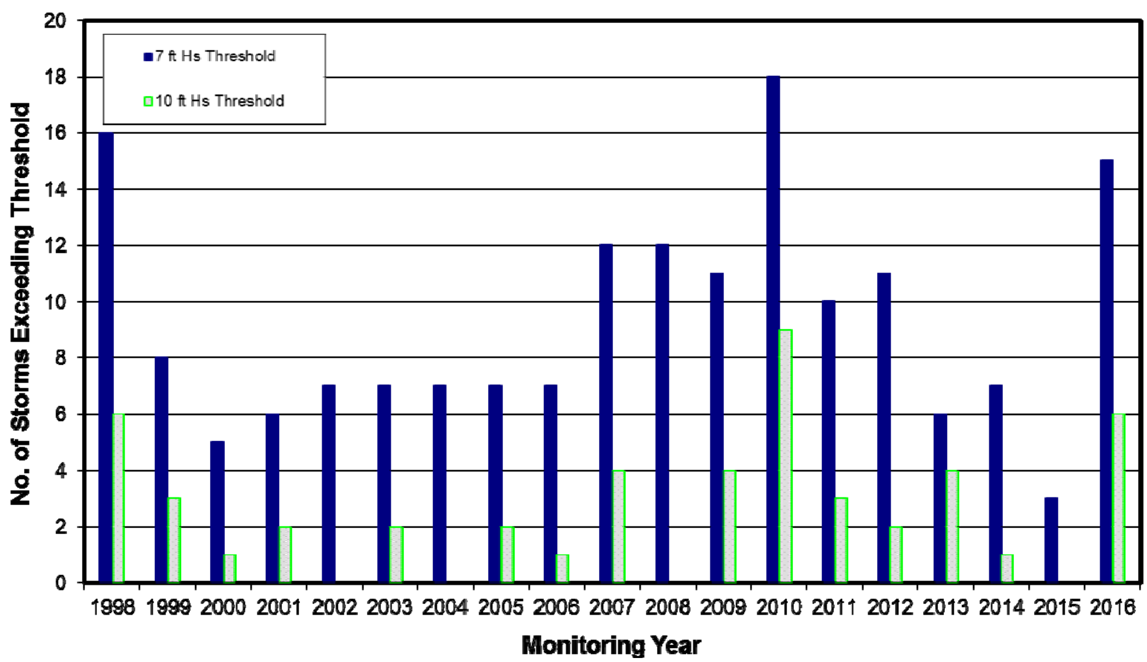


Figure 8. Storm Events per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2016

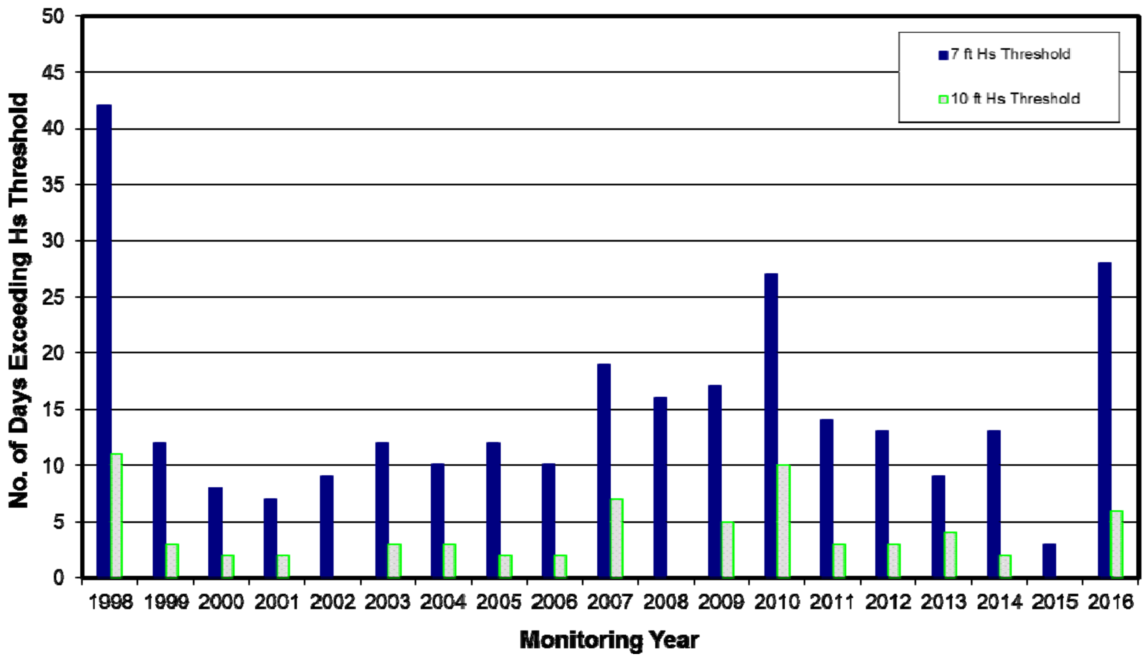


Figure 9. Days per Year with Significant Wave Heights Exceeding 7 ft and 10 ft, 1998-2016

Table 1. Maximum Significant Wave Height for Each Monitoring Year, 1998-2016

Monitoring Year	Date	Hs (ft)	Tp (sec)	Direction (degrees)
1998	Feb. 4, 1998	12.7	8.3	253°
1999	Apr. 4, 1999	12.8	9.1	276°
2000	Feb. 22, 2000	10.5	14.3	276°
2001	Feb. 13, 2001	11.8	8.3	197°
2002	Sep. 4, 2002	8.8	11.8	180°
2003	Mar. 17, 2003	10.5	7.7	272°
2004	Feb. 27, 2004	9.9	15.4	262°
2005	Jan. 8, 2005	11.2	7.7	193°
2006	Mar. 10, 2006	10.0	8.3	287°
2007	Dec. 27, 2006	15.7	9.1	287°
2008	Feb. 4, 2008	9.3	7.7	289°
2009	Nov. 9, 2008	11.5	9.1	277°
2010	Dec. 8, 2009	15.5	8.3	259°
2011	Dec. 30, 2010	13.2	9.1	275°
2012	Apr. 14, 2012	13.0	8.3	268°
2013	Dec. 19, 2012	11.6	9.1	269°
2014	March 1, 2014	11.1	13.3	264°
2015	Dec. 12, 2014	9.0	6.3	181°
2016	Feb. 1, 2016	17.8	9.9	278°

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

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 ranging from 87 to 113.

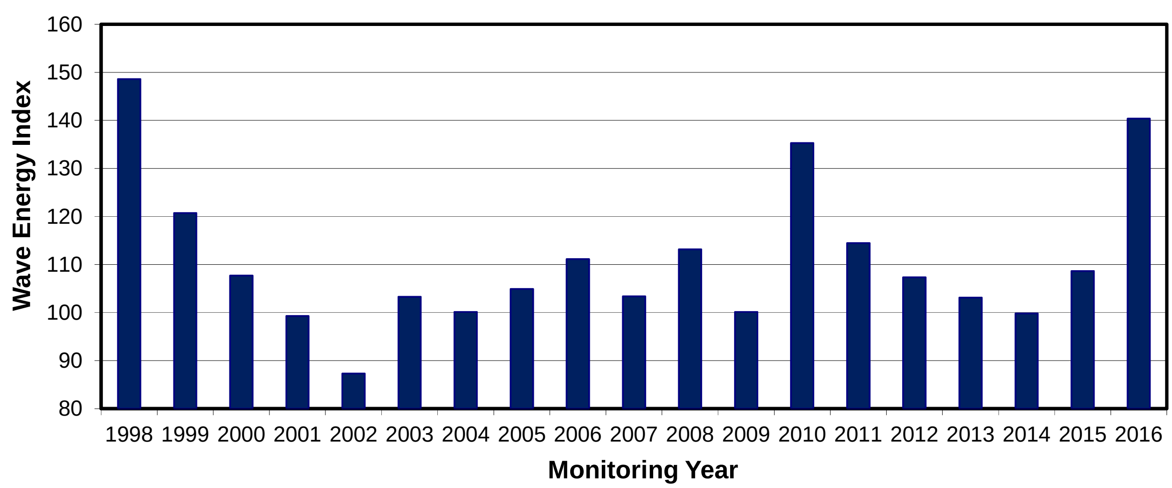


Figure 10. Relative Incident Energy Index at the CDIP Oceanside Buoy, 1998-2016

Table 2 summarizes the wave conditions during the 19-year period of record (1998-2016). 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 2. Summary of Wave Conditions, 1998-2016

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***
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 II is discussed in Section 2.2.1, nourishment projects preceding the RBSP II (including the RBSP I) in Section 2.2.2, and sand bypassing in Section 2.2.3. No additional nourishment projects have been conducted in the region following the completion of RBSP II.

2.2.1. Regional Beach Sand Project II (RBSP II)

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.

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

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.

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).

2.2.2. Nourishment Projects Preceding the RBSP II

A substantial number of beach nourishment projects were undertaken in San Diego County prior to the RBSP II. These projects included the RBSP I and 23 additional projects of varying size (conducted both before and after the RBSP I). Nearly all of the non-RBSP I 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 RBSP I and non-RBSP nourishment projects conducted between November 1993 and October 2011 are summarized below. Two periods are considered: (1) the seven-year span from November 1993 through October 2000, and (2) the 11-year period including the RBSP I and preceding the RBSP II (November 2000 through October 2011). 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 includes the RBSP I and all of the nourishment activities leading up to the RBSP II.

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 4. 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.

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 5, these projects resulted in an average annual nourishment rate of 73,000 cubic yards/year (cy/yr).

As indicated in Table 4, the RBSP I provided 120,000 cy of nourishment to the Silver Strand Cell. Four opportunistic sand replenishment projects have been undertaken in the Silver Strand Cell since the placement of the RBSP I fill material in 2001 (Table 6). 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

Table 4. 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.
(2) All nourishment activities were conducted in 2001.

Source: Noble Consultants, 2001

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 US 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 45,000 cy/yr during the 11-year period preceding the RBSP II.

Table 5. 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 6. Beach Nourishment in the Silver Strand Littoral Cell Preceding the RBSP II, November 2000 through October 2011

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
Average Annual Nourishment Rate in the Silver Strand Cell = 45,000 cy/yr				

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

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 1993-2000 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 11-year period preceding the RBSP II (Table 7).

Table 7. Beach Nourishment in the Mission Beach Littoral Cell Preceding the RBSP II, November 2000 through October 2011

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 = 55,000 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 8, 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 9 lists the RBSP I fills and four other nourishment projects undertaken in the Oceanside Cell during the 11-year period preceding the RBSP II. 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

Table 8. 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 9. Beach Nourishment in the Oceanside Littoral Cell Preceding the RBSP II, November 2000 through October 2011

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
Average Annual Nourishment Rate in the Oceanside Cell = 171,000 cy/yr				

Notes: (1) See Table 4.
Source: Frenken, 2002; Keeley, 2003; Weldon, 2009; Weldon , *et al.*, 2011; Noble Consultants, 2001

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). These amounts equate to an average annual nourishment rate of 171,000 cy/yr during the 11-year period preceding the RBSP II.

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 11-year period including the RBSP I and preceding the RBSP II (November 2000 through October 2011). In addition, the bypassing activities conducted during the five-year RBSP II Monitoring Period (November 2011 to October 2016) also are tabulated.

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 10. The maintenance records for San Elijo and Los Peñasquitos do not segregate bypass quantities from entrance channel breaching quantities. The values shown in Table 10 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.

Table 10. 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).

During the pre-RBSP I period (Table 10), relatively high bypass rates, averaging 252,000 and 143,000 cy/yr, were maintained at Oceanside and Agua Hedionda, 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 11-year period preceding the RBSP II (November 2000-October 2011) are presented in Table 11. At Oceanside Harbor, bypass operations were conducted in each of the eleven Monitoring Years. The average rate of 246,000 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, and 2011. The average rate during the 11-year period, 182,000 cy/yr, was higher 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 and 2007. Although the resulting average rate of 11,000 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 11-year period preceding the RBSP II if this material had been returned to the littoral system.

During the 11-year period preceding the RBSP II, 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).

Table 11. Sand Bypassing in the Oceanside Littoral Cell Preceding the RBSP II, November 2000 through October 2011

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Batiquitos Lagoon	2001	South of Entrance	45,000
	2007	South of Entrance	66,000
	Average Annual Bypass Rate at Batiquitos Lagoon = 11,000 cy/yr		
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
	Average Annual Bypass Rate at Agua Hedionda Lagoon = 182,000 cy/yr		
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
	Average Annual Bypass Rate at Oceanside Harbor = 246,000 cy/yr		

(continued)

Table 11. Sand Bypassing in the Oceanside Littoral Cell Preceding the RBSP II, November 2000 through October 2011

(continued)

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
	Average Annual Bypass Rate at San Elijo Lagoon = 22,000 cy/yr		
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
	Average Annual Bypass Rate at San Dieguito Lagoon = 9,000 cy/yr		
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
	Average Annual Bypass Rate at Los Peñasquitos Lagoon = 18,000 cy/yr		

Sources: Dillingham, 2002, 2008; Tucker, 2002; Hughes, 2003, Ryan, 2003, 2005-2012; Gibson, 2005, 2006, 2007, 2012; Shiffer, 2006; Henika, 2008, 2010, 2012; Trujillo, 2008, 2009, 2010, 2011; Elwany, 2011, 2012; Coastal Environments, 2011.

Bypassing was conducted on five occasions at San Dieguito Lagoon during the 11-year period preceding the RBSP II, yielding an estimated average bypassing rate of 9,000 cy/yr. This rate was slightly higher 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 ten of the eleven years preceding the RBSP II. The estimated average bypassing rate (18,000 cy/yr) during this period exceeded the corresponding pre-RBSP I value (13,000 cy/yr) by 5,000 cy/yr.

The sediment quantities bypassed at each site during the RBSP II Monitoring Period (November 2011-October 2016) are presented in Table 12. Bypassing was not conducted at San Dieguito Lagoon during the RBSP II Monitoring Period. The quantity bypassed at Oceanside Harbor (245,000 cy) in 2016 was consistent the historical averages shown in Tables 10 and 11. At, Agua Hedionda bypassing was conducted only in 2015 - the first time since 2011. While the quantity (295,000 cy) greatly exceeded the historical averages, the annualized rate (59,000) during the RBSP II Monitoring Period was well below average. The 2016 bypass quantity at San Elijo (22,000 cy) approximated the Pre-RBSP II average, while the amount bypassed at Los Peñasquitos (35,000 cy) was greater than the corresponding pre-RBSP II average.

2.3. The RBSP II Monitoring Period in Perspective

Table 13 compares the environmental conditions that prevailed during the RBSP II Monitoring Period with those in the recent past. When the five-year RBSP II Monitoring Period is considered (Table 13), precipitation and streamflow were below average. Wave energy approximated the long-term average, while storm frequency and duration were slightly below average. The implications of these relatively mild conditions are threefold:

- The absence of large wave events during the first three years following the RBSP II helped preserve the shoreline and shorezone volume gains attributable to the nourishment.
- The scant precipitation and low streamflows failed to deliver significant quantities of beach-quality sediment to the coast.
- The low streamflows failed to flush coastal sediment from the lagoon entrances in the Oceanside Cell.

Table 12. Sand Bypassing in the Oceanside Littoral Cell, RBSP II Monitoring Period

Bypass Project	Date	Placement Location	Bypass Quantity (cy)
Batiquitos Lagoon	2012	South of Entrance	112,000
	Average Annual Bypass Rate at Batiquitos Lagoon = 22,000 cy/yr		
Agua Hedionda	2015	Carlsbad	295,000
	Average Annual Bypass Rate at Agua Hedionda = 59,000 cy/yr		
Oceanside Harbor	2012	Oceanside	246,000
	2013	Oceanside	194,000
	2014	Oceanside	275,000
	2015	Oceanside	200,000
	2016	Oceanside	245,000
	Average Annual Bypass Rate at Oceanside Harbor = 232,000 cy/yr		
San Elijo Lagoon	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
	Average Annual Bypass Rate at San Elijo Lagoon = 23,000 cy/yr		
San Dieguito Lagoon		n/a	
	Average Annual Bypass Rate at San Dieguito Lagoon = n/a		
Los Peñasquitos Lagoon	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
	Average Annual Bypass Rate at Los Peñasquitos Lgn = 35,000 cy/yr		

Sources: Merkel, 2012; Ryan, 2013, 2014, 2015, 2016, 2017; Gibson, 2013, 2014, 2015, 2016, 2017; Elwany, 2013; Hastings, 2013, 2014, 2015; Henika, 2015; Los Peñasquitos Lagoon Foundation, 2016, 2017

In Table 14, the beach nourishment volume provided to each littoral cell during the RBSP II Monitoring Period is compared with the average annual volume provided during the seven monitoring years preceding the RBSP I and the 11 years preceding the RBSP II. All of the nourishment provided during the five-year RBSP II Monitoring Period was attributable to the RBSP II. A portion of the this material serves to compensate for the average annual nourishment material provided in prior years (468,000 cy/yr relative to the

Table 13. Environmental Conditions: RBSP II Monitoring Period vs. Historical Ave.

Parameter[1]	Historical Average	RBSP II Average[5]	% of Hist. Average[6]
Precipitation[2] (in.)	10.1	7.9	77%
Streamflow[3] (cfs)			
San Luis Rey River	48.0	2.7	6%
San Diego River	39.3	14.2	36%
Wave Climate[4]			
Energy Index	111	112	101%
Storms w/ H_s*>7 ft*	9.5	8.4	88%
Storms w/ H_s*>10 ft*	2.6	2.6	98%
Days w/ H_s*>7 ft*	15.4	13.2	86%
Days w/ H_s*>10 ft*	3.8	3.0	79%

Notes: (1) Parameters represent annual values.
(2) Historical Average Precipitation based on the period 1915-2011.
(3) Historical Average Streamflow based on the period 1983-2011.
(4) Historical Average Energy Index and Storms based on the period 1998-2011.
(5) RBSP II Average based on period 2012-2016.
(6) % of Hist. Average represents RBSP II Average value divided by Historical Average.

Table 14. Beach Nourishment Rates: RBSP II Monitoring Period vs. Historical Ave.

Littoral Cell	Historical Average[1] (cy/yr)		RBSP II Average[2] (cy/yr)	Difference[3] (cy/yr)	
	Pre-RBSP I (1993-2000)	Pre-RBSP II (2001-2011)		vs Pre-RBSP I	vs Pre-RBSP II
Silver Strand	73,000	42,000	90,000	+17,000	+48,000
Mission Beach	2,000	55,000	0	(2,000)	(55,000)
Oceanside	393,000	171,000	216,000	(177,000)	+45,000
Total	468,000	263,000	306,000	(162,000)	+43,000

Notes: (1) Historical Averages based on the periods 1993-2000 (Pre-RBSP I) and 2001-2011 (Pre-RBSP II)
(2) RBSP II Average based on RBSP II Monitoring Period (2012-2016).
(3) Difference represents RBSP II Average minus Historical Average.

pre-RBSP I average and 263,000 cy/yr relative to the pre-RBSP II average). The RBSP II material provided incremental nourishment (43,000 cy/yr) relative to the pre-RBSP II average. However, despite the placement of the RBSP II material, a 162,000 cy/yr deficit currently exists relative to the pre-RBSP I average.

The incremental volume relative to the pre-RBSP I and Pre-RBSP II averages was substantial in the Silver Strand Cell (17,000 cy/yr and 48,000 cy/yr, respectively). In the Oceanside Cell, the RBSP II nourishment produced a surplus of 45,000 cy/yr relative to the pre-RBSP II average. However, a deficit of 177,000 cy/yr persisted relative to the pre-RBSP I average. In the Mission Beach Cell, which did not receive RBSP II nourishment, deficits of 2,000 and 55,000 cy/yr persisted relative to the historical averages.

The sand bypass rates at Oceanside Harbor, Agua Hedionda, Batiquitos, San Elijo, San Dieguito, and Los Peñasquitos during the RBSP II Monitoring Period are displayed with the average annual bypass rates during the seven monitoring years preceding the RBSP I and the 11 years following the RBSP I and preceding the RBSP II in Table 15.

Table 15. Sand Bypass Rates: RBSP II Monitoring Period vs. Historical Average

Location	Historical Average[(1)] (cy/yr)		RBSP II Average[(2)] (cy/yr)	Difference[(3)] (cy/yr)	
	Pre-RBSP I (1993-2000)	Pre-RBSP II (2001-2011)		vs Pre-RBSP I	vs Pre-RBSP II
Batiquitos	3,000	11,000	22,000	+19,000	+11,000
Agua Hedionda	143,000	182,000	59,000	(84,000)	(123,000)
Oceanside Harbor	252,000	246,000	232,000	(20,000)	(14,000)
San Elijo	14,000	22,000	23,000	+9,000	+1,000
San Dieguito	8,000	9,000	0	(8,000)	(9,000)
Los Peñasquitos	13,000	18,000	35,000	+22,000	+17,000
Total	433,000	488,000	371,000	(62,000)	(117,000)

Notes: (1) Historical Averages based on the periods 1993-2000 (Pre-RBSP I) and 2001-2011 (Pre-RBSP II).
(2) RBSP II Average based on RBSP II Monitoring Period (2012-2016).
(2) Difference represents RBSP II Average minus Historical Average.

At Batiquitos, the increased bypassing during the RBSP II Monitoring 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 were sporadic during the pre-RBSP II period, comparison of the rates is not meaningful. At Oceanside Harbor, the volume bypassed during the RBSP II Monitoring Period was slightly below the historical rates. The RBSP II average bypass volume exceeded the corresponding historical values at Los Peñasquitos, providing a direct benefit to the beaches at Torrey Pines. At San Elijo, the RBSP II average bypass volume exceeded the pre-RBSP I average and was nearly identical to the pre-RBSP II value. Bypassing was conducted at Agua Hedionda in 2015 for the only time during the RBSP II Monitoring Period. The resulting bypassing rate was well below the historical average. No bypassing was conducted at San Dieguito during the RBSP II Monitoring Period.

3. MONITORING METHODS

As indicated in Section 1, the general objective of the 2016 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 monitor the fate of nourishment material introduced at eight receiver beaches under the RBSP II. The 2016 program includes three primary components - beach monitoring, lagoon entrance monitoring, and borrow site monitoring.

3.1. Program History

SANDAG has conducted a shoreline monitoring program since 1996. The beach monitoring has consisted primarily of beach profile surveys, beach width measurements, and oblique aerial photography. Additional beach profile data are provided through similar programs conducted by the Cities of Carlsbad, Encinitas, and Solana Beach. The lagoon entrances have been monitored through topographic surveys, oblique aerial photos, and monthly inspections. Borrow site monitoring was included for the first time in 2014. The program has evolved to meet changing needs and budgetary constraints, most notably the monitoring requirements associated with the RBSP I and the RBSP II. The details for the programs conducted between 1996 and 2016 are summarized in Table 16.

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 16. Monitoring Program Components, 1996-2016

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	✓	✓

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.

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 this 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 2016 SANDAG monitoring effort (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.

The data acquisition and reduction methods for the 2016 program are described in the subsections that follow.

3.2. Beach Monitoring

Beach profile data were obtained in the Spring and Fall of 2016, 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 Fall survey was conducted approximately four years after completion of the RBSP II. The locations of the transects are listed in Table 17 and illustrated in Figures 11a and 11b.

The Spring 2016 beach survey activities in the Oceanside Cell were conducted between May 16 and 20. The field program continued in the Silver Strand and Mission Beach Littoral Cells on May 23 and 24, respectively. The Fall 2016 beach survey activities were conducted in the Oceanside Cell between October 4 and 8, while beach profile data in the Mission Beach Cell were acquired on October 8 and 11. Survey activities in the Silver Strand Cell were conducted on October 10. Conditions were favorable during both surveys, and typically consisted of light winds and seas less than 3 ft.

Table 17. 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]	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[2,4]	Mission Beach	SANDAG			
	MB-0340	Mission Beach	SANDAG			
Oceanside Littoral Cell	LJ-0443	La Jolla	SANDAG	SD-0690[2]	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	Torrey Pines	SANDAG	CB-0740	South Carlsbad	Carlsbad
	TP-0530	Torrey Pines	SANDAG	CB-0760	Ponto Beach	SANDAG
	DM-0565[2,4]	South Del Mar	SANDAG	CB-0775[1,2]	South Carlsbad	SANDAG
	DM-0560[3]	Del Mar	SANDAG	CB-0780	Carlsbad	Carlsbad
	DM-0580	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	SANDAG	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[2,4,5]	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]	Crosswaithe	SANDAG
	SD-0663[6]	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 II nourishment site (red type).
(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 Spr 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

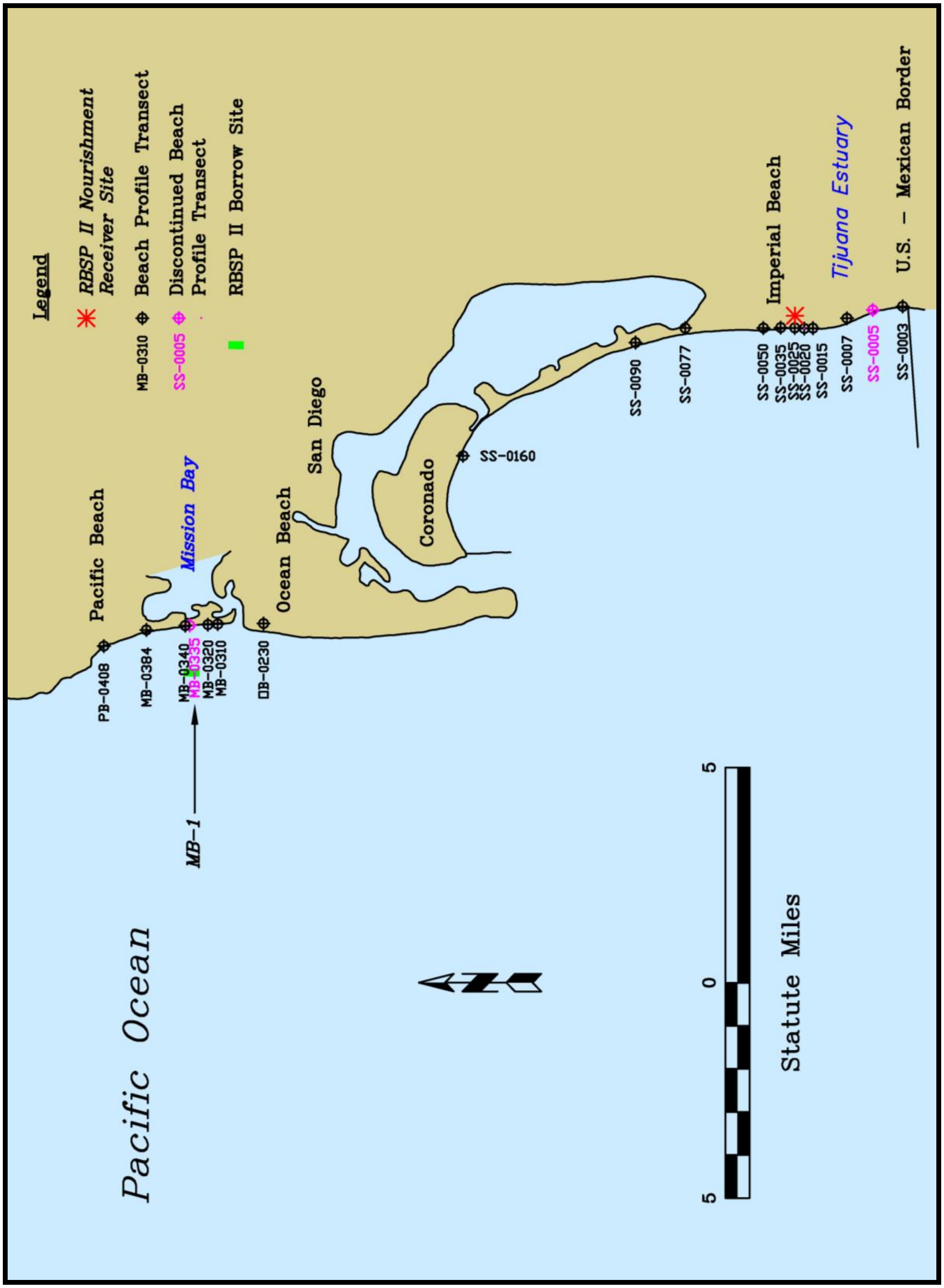


Figure 11a. Beach Profile Transects in the Silver Strand and Mission Beach Littoral Cells

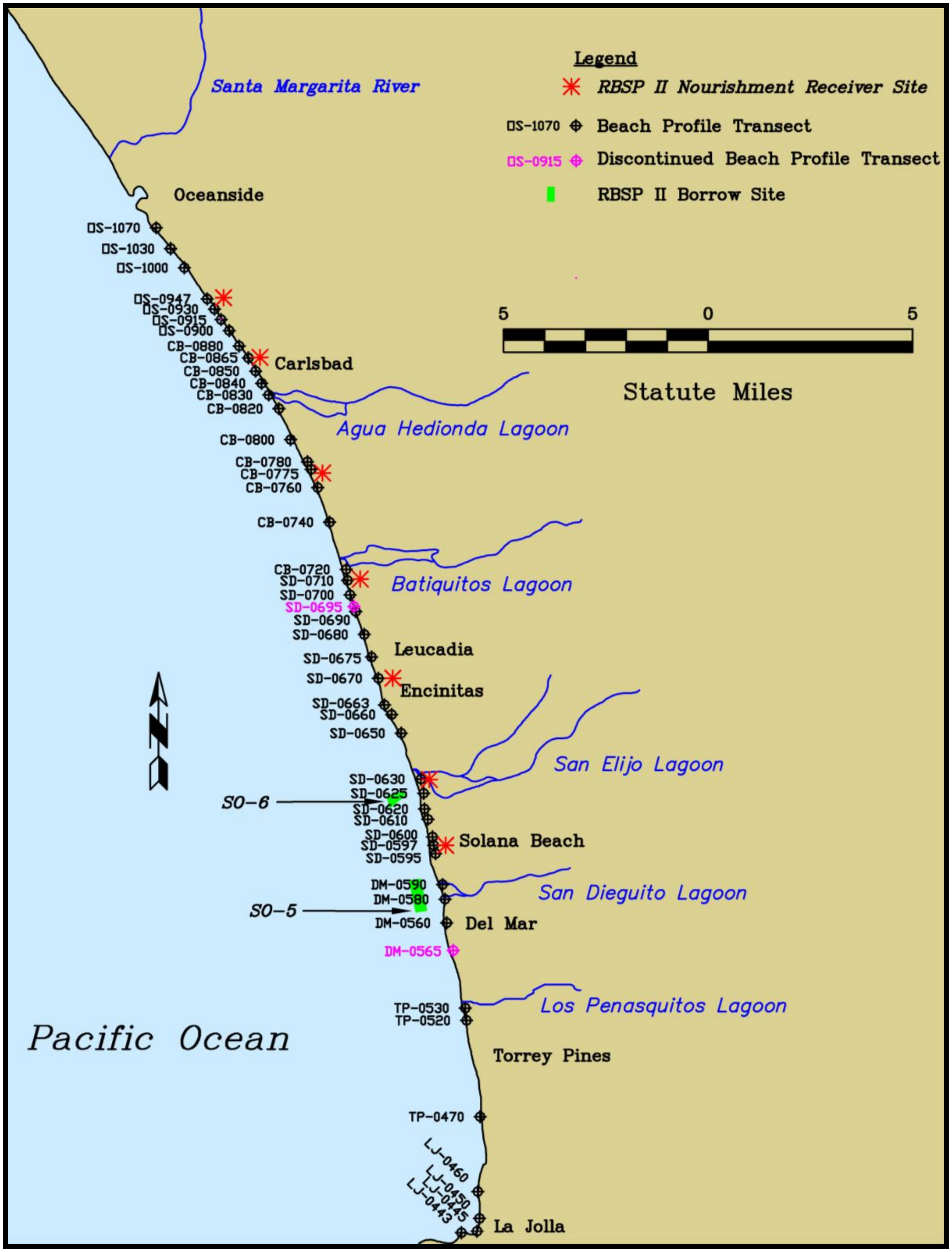


Figure 11b. Beach Profile Transects and Lagoon Entrances in the Oceanside Littoral Cell

The data acquisition and processing methods used for the 2016 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.

3.4. Borrow Site Monitoring

The borrow site monitoring component consisted of obtaining bathymetric data and sediment samples at each of the three dredge sites utilized for the RBSP II (MB-1 in the Mission Beach Cell, and SO-6 and SO-5 in the Oceanside Cell). The borrow site locations are shown in Figures 11a and 11b. The monitoring data were acquired at the time of the Fall 2016 beach profile survey.

3.4.1. Bathymetric Surveys

At each borrow site, bathymetry was obtained along one transverse and one longitudinal transect passing through the approximate center of the dredged depression. Data were obtained at the two borrow sites in the Oceanside Cell (SO-5 and SO-6) on October 7, while the site in the Mission Bach Cell (MB-1) was surveyed on October 11. Data were acquired from the inflatable vessel using data acquisition and processing methods identical to the beach profile survey (Section 3.2). The processed soundings were projected onto the transect alignments, and the resulting range and elevation data were used to create bathymetric cross-sections of the sea bottom through the borrow sites.

3.4.2. Sediment Samples

Two representative sediment samples were obtained within the dredged footprint of each borrow site at the time of the Fall 2016 survey. The sediment was acquired with a Petit Ponar sampler deployed from the inflatable survey vessel. The position of each sample was determined with DGPS. The particle size distribution of each sample was derived in accordance with American Society for Testing and Materials (ASTM) D 422-63 (Test

Method of Particle-Size Analysis of Soils). Gradation curves were generated for each sample, with "fines" defined as that material passing the #200 sieve (less than 0.074 mm).

4. MONITORING DATA

This section presents the results of the 2016 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. The borrow site monitoring data are discussed in Section 4.3

4.1. Beach Data

As discussed in Section 3.2, beach data acquisition consisted of semi-annual profile surveys conducted in the Spring and Fall. Although aerial photography was omitted from the program in 2016, the photos obtained between 2011 and 2015 are included in the Sections 5 and 6. 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 2016 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**. To facilitate the identification of changes in beach condition attributable to the RBSP II, those transects that cross the RBSP II fill sites are identified by red type.

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 2016 data, the plots display profiles from Fall 2000, Fall 2011, Fall 2012, Fall 2013, Fall 2014, and Fall 2015. 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 (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 42 Spring and Fall surveys conducted from 1996 to 2016 (Table 16) 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 twenty-one most recent summers (1996 through 2016), and twenty most recent winters (1996-

1997 through 2015-2016). 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 16-year period encompassing the RBSP I and RBSP II (Fall 2000 to Fall 2016). In addition, the shoreline changes were calculated for the five-year period encompassing the RBSP II (Fall 2011 to Fall 2016). 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 2016.

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 beach 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 18, which provides the computed range of closure and associated depth of closure for each transect. These values will serve as the basis for all shorezone volume computations throughout the period in which the fate of the RBSP II fills remains under investigation. 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 nineteen most recent summers (1998 through 2016) and 19 most recent winters (1997-1998 through 2015-2016). Annual volume changes were calculated for the nineteen one-year intervals between Fall 1997 and Fall 2016. Long-term changes were determined for the three year period preceding the RBSP I (Fall 1997 to Fall 2000), the five-year period encompassing the RBSP II (Fall 2011 to Fall 2016), and the 16-year period encompassing the RBSP I and RBSP II (Fall 2000 to Fall 2016).

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 (Section 5, Appendix E)

As indicated in Section 3.1, aerial photography was eliminated from the program in 2016. Representative aerial photographs obtained at the eight RBSP II receiver sites from 2011 through 2015 are provided in Section 5 of this report, while a more comprehensive set (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 from 2011 through 2015 are provided in Section 6.

Table 18. 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	Tijuana Estuary	1041	-22
	SS-0007	Tijuana Estuary	1129	-17
	SS-0015	Imperial Beach	1480	-19
	SS-0020[1]	Imperial Beach	1597	-24
	SS-0025[1]	Imperial Beach	1873	-28
	SS-0035[1]	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	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	Del Mar	1213	-12
	DM-0560[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[1,4]	Surfsong	994	-16
	SD-0600[1]	Fletcher Cove	1066	-16
	SD-0610	Tide Park	1520	-24
	SD-0620	Seaside Park	1304	-21

(continued)

Table 18. 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[1]	Cardiff	1598	-28
	SD-0650	San Elijo St. Bch	1136	-18
	SD-0660	Swami's	875	-12
	SD-0663[4]	J Street	1602	-24
	SD-0670[1]	Moonlight Bch.	1630	-30
	SD-0675	Stone Steps	875	-12
	SD-0680	Leucadia	1108	-17
	SD-0690	Leucadia	929	-14
	SD-0695	Leucadia	876	-12
	SD-0700	Grandview	1203	-20
	SD-0710[1]	Leucadia	1231	-23
	CB-0720	Batiquitos	1450	-24
	CB-0740	S. Carlsbad	1349	-22
	CB-0760	Ponto Beach	1152	-21
	CB-0775[1]	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[1]	Carlsbad	1088	-17
	CB-0880[1]	Buena Vista	908	-14
	OS-0900	S. Oceanside	1160	-24
	OS-0915	Oceanside	1010	-22
	OS-0930[1]	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 crosses RBSP II nourishment site (shown in red type).
(2) Transect locations are indicated in Figures 10a and 10b.
(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.

4.3. Borrow Site Monitoring Data

The borrow site data consisted of representative bathymetry and sediment samples at each of the three dredge sites utilized for the RBSP II (SO-6, SO-5, and MB-1). Bathymetric profiles through the borrow sites obtained at the time of the Fall 2016 survey are provided in Section 7. To facilitate an assessment of changes that have occurred since completion of the RBSP II, each plot also includes profiles developed from a 2012 post-construction survey and the Fall 2014 survey (Scott, 2013; Coastal Frontiers, 2015).

Gradation curves for the sediment samples obtained in the borrow sites are provided in Section 7. Each plot also shows the range of grain sizes determined during the 2008 geophysical investigation of the borrow sites (URS, 2009). In each case, “fines” are defined as material passing the #200 sieve (less than 0.074 mm in diameter).

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 2016 Monitoring Year (November 2014 through October 2016), the five-year RBSP II Monitoring Period (November 2011 to October 2016), and the 16-year period encompassing both the RBSP I and RBSP II (November 2000 through October 2016). Section 5.1 provides a regional overview, while Section 5.2 summarizes the performance of the eight RBSP II beach fills. The post-RBSP II outcome in selected sub-reaches is described in Section 5.3. Finally, the impact of the 2015-2016 El Niño is assessed in Section 5.4. Location maps showing the fills and all beach profile transects located in the vicinity of each receiver site are shown at the end of this section in Figures 31 through 34.

Statistical characterizations of shoreline and volume changes for the 2016 Monitoring Year and the RBSP II Monitoring Period are derived from the 60 transects with measurements dating back to Fall 2011 (predating the RBSP II), 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 (Section 5.4) utilizes the 38 transects common to both the Fall 1997 and Fall 2015 surveys, while the assessment of shoreline changes during the 2015-2016 El Niño utilizes the 44 pre-RBSP I transects.

5.1. Regional Overview

Table 19 summarizes the shoreline and shorezone volume changes that occurred during the 2016 Monitoring Year, the RBSP II Monitoring Period, and the post-RBSP I period. During the 2016 Monitoring Year, shoreline retreat predominated in each of the three littoral cells. In contrast, shorezone volume increased in the Silver Strand Cell and was relatively stable in the Oceanside and Mission Beach Cells.

During the five-year RBSP II Monitoring Period (2011 to 2016), shoreline advance and shorezone volume gains prevailed in the Silver Strand Cell. These gains appear to be attributable to the RBSP II nourishment. The shoreline position and shorezone volume in the Oceanside Cell was nearly identical to the pre-RBSP II condition at the time of the Fall 2016 survey, suggesting that gains realized from the nourishment program have largely dissipated over the five-year period. In the Mission Beach Cell, which did not receive sand as part of the RBSP II, the shoreline retreated and the shorezone volume was relatively unchanged.

Table 19. Average MSL Shoreline Changes and Shorezone Volume Changes (1, 2)

Littoral Cell	2016 Monitoring Year (Fall 2015-Fall 2016) (1)		RBSP II Monitoring Period (Fall 2011-Fall 2016) (1)		Post-RBSP I (Fall 2000-Fall 2016) (2,3)	
	MSL Shoreline Change (ft)	Shorezone Vol. Change (cy/ft)	MSL Shoreline Change (ft)	Shorezone Vol. Change (cy/ft)	MSL Shoreline Change (ft)	Shorezone Vol. Change (cy/ft)
Silver Strand Cell	-28	14	39	35	-1	-7
Mission Beach Cell	-58	1	-22	7	-7	19
Oceanside Cell	-27	-4	-2	0	-9	6
All Cells Combined	-30	-1	2	6	-8	5

Notes: (1) Shoreline change statistics are derived from the 60 transects with measurements dating back to Fall 2011.
(2) Shoreline change 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 2016).

When the entire 16-year post-RBSP I period (2000 to 2016) is considered, the average shoreline position fell slightly 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 Oceanside and Silver Strand from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated during the 16-yr period. 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. However, shoreline positions failed to remain above the pre-RBSP I value.

5.1.1. Beach Widths

The MSL beach widths measured in Spring 2016 and Fall 2016 are shown in Figures 12a and b. The envelope of widths measured subsequent to the RBSP I and prior to RBSP II (Fall 2001-Spring 2012, to the extent that data are available) also is shown for the transects with measurements dating back to 2001.

The Spring 2016 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, and North Carlsbad. Beach widths fell below the envelope at two locations

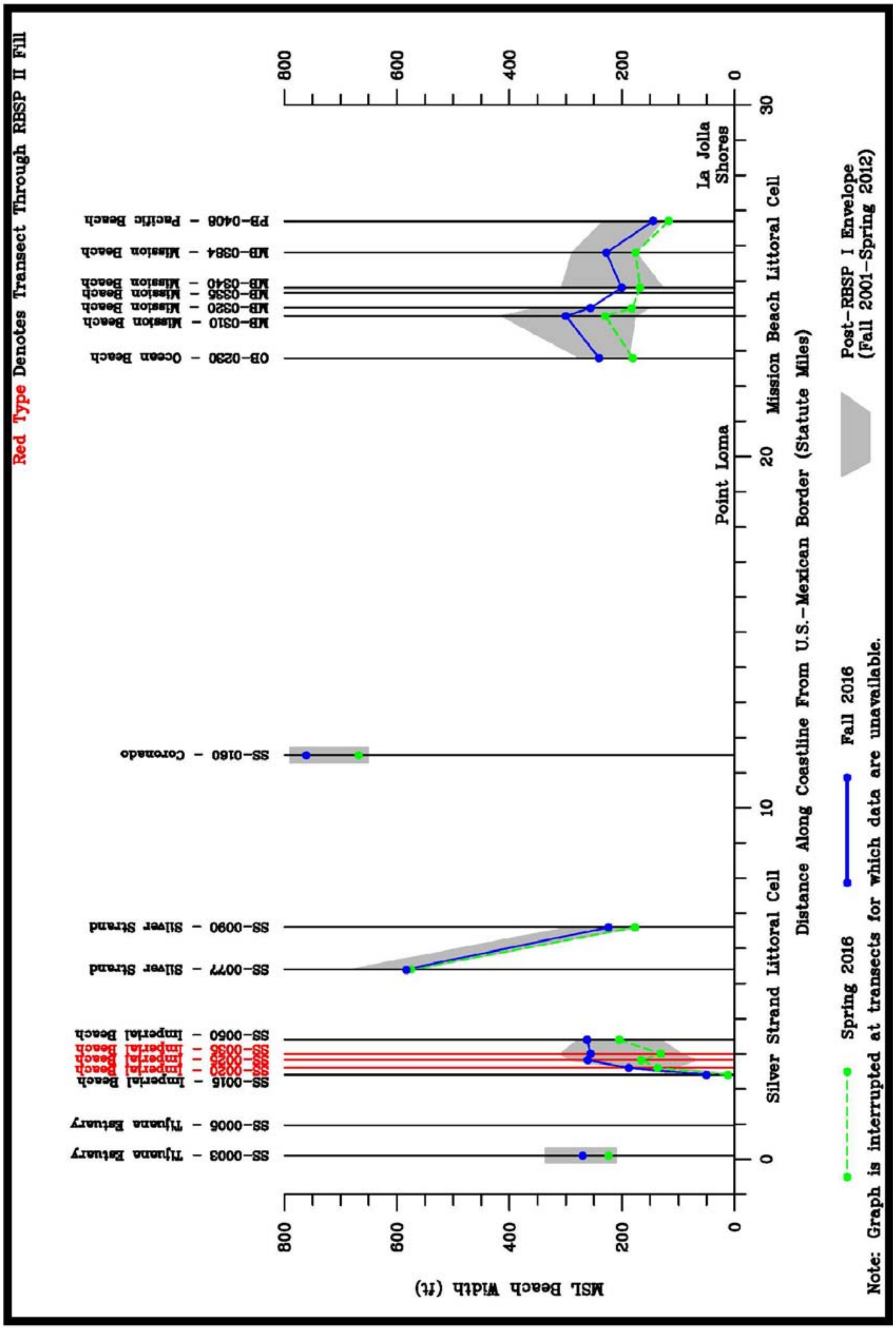


Figure 12a. Comparison of 2016 MSL Beach Widths with the Post-RBSP I Envelope in the Silver Strand and Mission Beach Littoral Cells

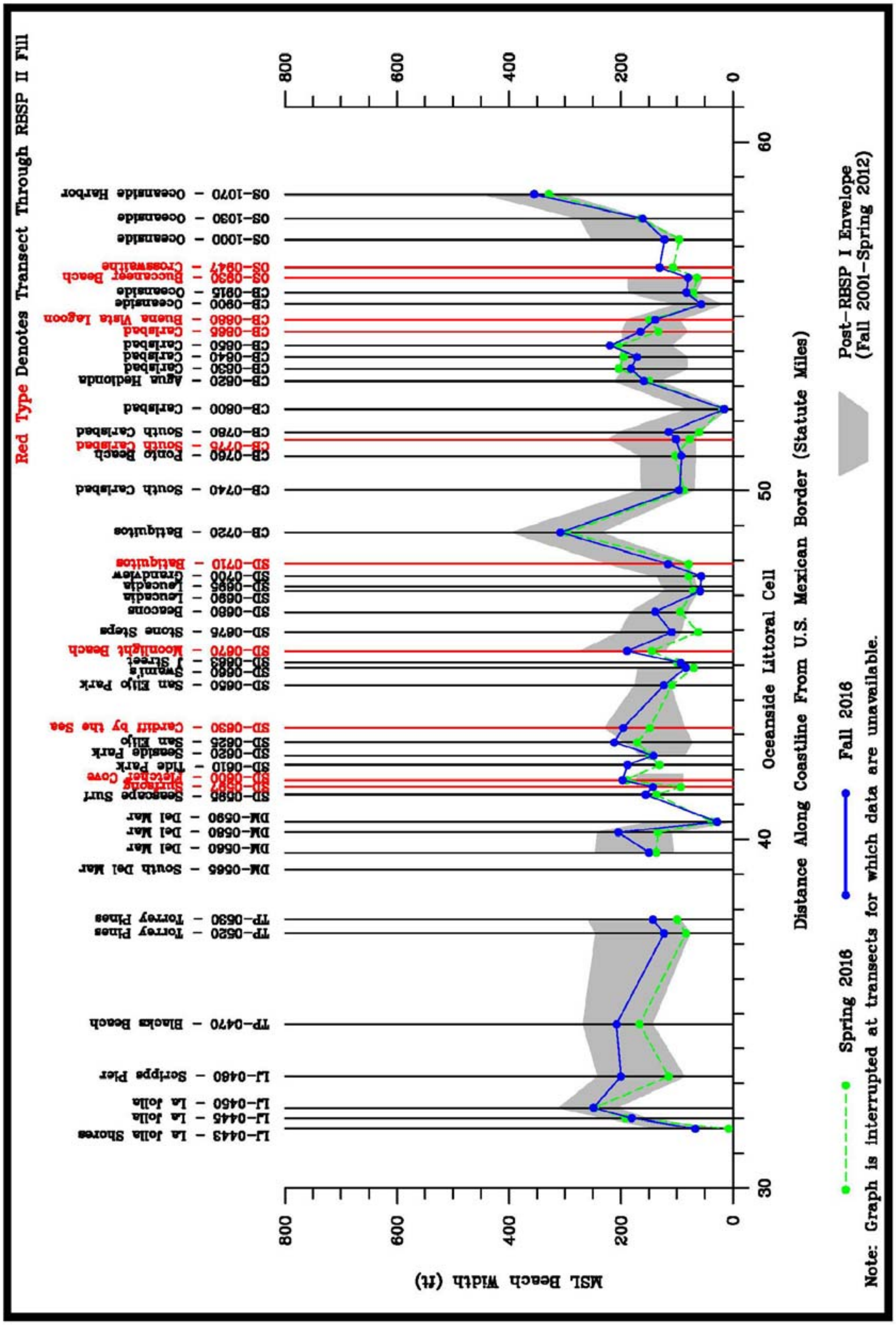


Figure 12b. Comparison of 2016 MSL Beach Widths with the Post-RBSP I Envelope in the Oceanside Littoral Cell

in the Mission Beach Cell (Ocean Beach and Pacific Beach) and at six locations in the Oceanside Cell (La Jolla Shores, four sites in Encinitas, and South Carlsbad). The Spring 2016 beach widths exceeded the envelope at Solana Beach and at two sites in North Carlsbad.

Beach widths at the time of the Fall 2016 survey generally exceeded those measured in Spring 2016. However, they tended to lie in the lower half of the post-RBSP I envelope. Notable exceptions included portions of Solana Beach, Cardiff and North Carlsbad in the Oceanside Cell, and Imperial Beach in the Silver Strand Cell. The Fall 2016 beach width exceeded the envelope at one transect in each of these reaches. They fell short of the envelope at three sites in Encinitas and one location in Oceanside.

5.1.2. Shoreline Changes

Table 20 summarizes the MSL shoreline changes that occurred during the 2016 Monitoring Year, the five-year RBSP II Monitoring Period, and the 16-year period encompassing both the RBSP I and II (2000 to 2016). Figure 12 provides a graphical representation of the changes that prevailed during the 2016 Monitoring Year and the RBSP II Monitoring Period. Figures 13 and 14 summarize the changes during the 16-year period including both the RBSP I and II. Detailed supporting data appear in Appendix C.

2016 Monitoring Year

The average shoreline position in the Silver Strand Cell decreased by 28 ft during the 2016 Monitoring Year. As shown in Figure 13a, shoreline retreat prevailed at all but one transect located within the Cell. Shoreline losses ranged from 26 ft at Borderfield to 56 ft at Imperial Beach. The average shoreline change in Imperial Beach was a loss of 38 ft. The only occurrence of shoreline advance was a gain of 48 ft in Coronado.

In the Mission Beach Cell, which did not receive RBSP II material, the shoreline position decreased at all six transects during the 2016 Monitoring Year. These changes produced and an average shoreline loss of 58 ft in the Cell. Shoreline retreat ranged from 24 ft (Ocean Beach) to 108 ft (Pacific Beach). The average loss in Mission Beach was 58 ft.

Shoreline retreat also predominated in the Oceanside Cell during the 2016 Monitoring Year, with the average shoreline position decreasing by 27 ft. The greatest shoreline loss (88 ft) occurred at Oceanside Harbor (Transect OS-1070). Shoreline advance in excess of 10 ft occurred at just one location, Transect SD-0663 in Encinitas.

Table 20. MSL Shoreline Changes during the 2016 Monitoring Year, the RBSP II Monitoring Period and Post-RBSP I

Littoral Cell	MSL Shoreline Change (no. of transects)			Average Change (ft)
	Advance	No Change[4]	Retreat	
Silver Strand Cell				
2016 Mon. Year [1]	1	1	7	-28
RBSP II Mon. Period [1]	7	1	1	39
Post-RBSP I [2,3]	2	2	2	-1
Mission Beach Cell				
2016 Mon. Year [1]	0	0	6	-58
RBSP II Mon. Period [1]	0	2	4	-22
Post-RBSP I [2,3]	0	3	2	-7
Oceanside Cell				
2016 Mon. Year [1]	1	11	33	-27
RBSP II Mon. Period [1]	14	12	19	-2
Post-RBSP I [2,3]	11	4	18	-9
All Cells Combined				
2016 Mon. Year [1]	2	12	46	-30
RBSP II Mon. Period [1]	21	15	24	2
Post-RBSP I [2,3]	13	9	22	-8

Notes: (1) Shoreline change statistics are derived from the 60 transects with measurements dating back to Fall 2011.
(2) Shoreline change 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 2016).
(4) "No Change" indicates a shoreline change of 10 ft or less.

RBSP II Monitoring Period

When the five-year RBSP II monitoring Period is considered (Table 20), shoreline gains prevailed only in the Silver Strand Cell. These gains likely are attributable to the RBSP II nourishment. The shoreline advanced at seven of the nine transects located in the Silver Strand Cell, yielding an average gain of 39 ft. As indicated in Figure 13a, the shoreline gains were most pronounced in the Imperial Beach region. The greatest advance, 93 ft, occurred at the Imperial Beach receiver site (Transect SS-0025). The average shoreline gain among the Imperial Beach transects was 63 ft.

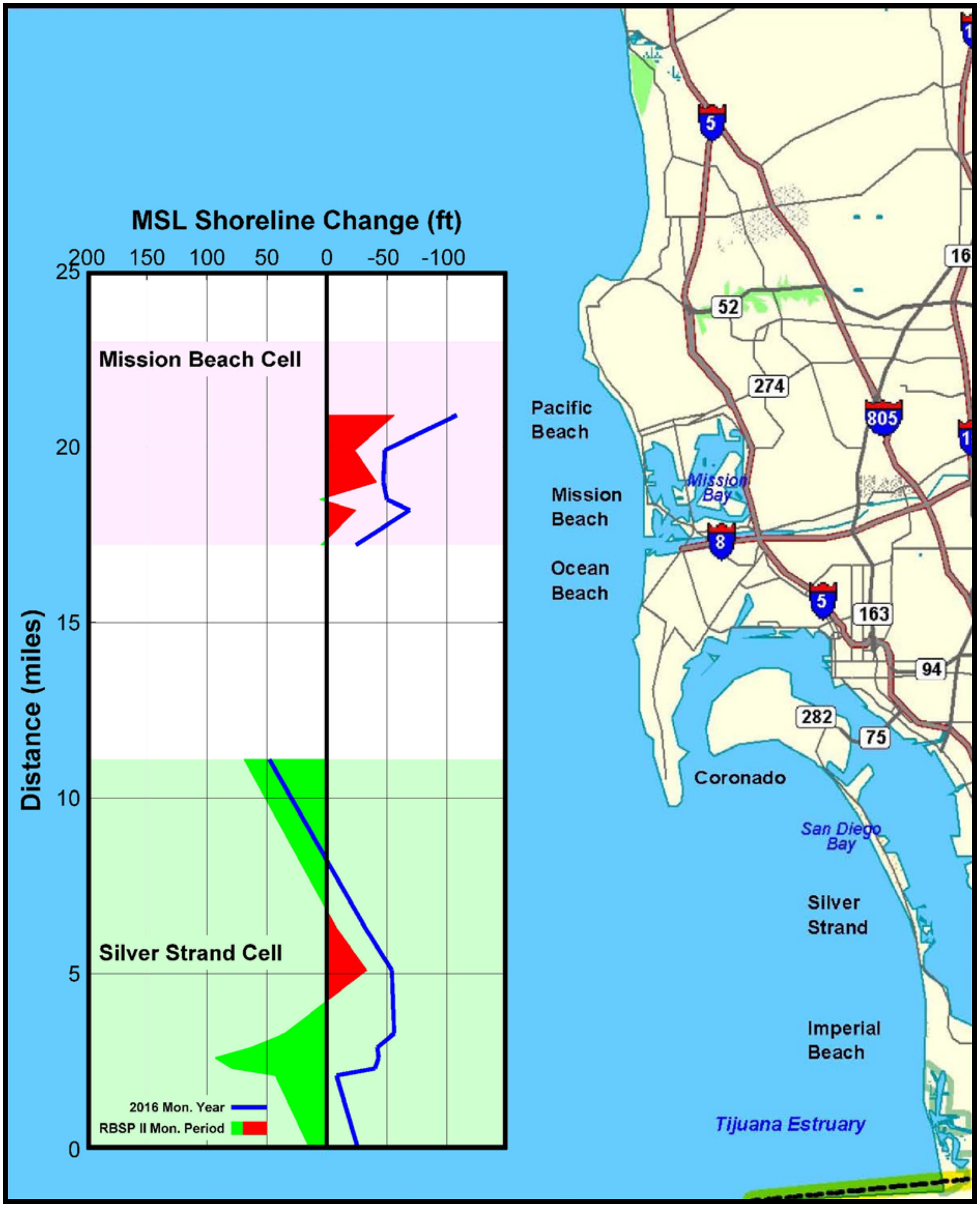


Figure 13a. MSL Shoreline Changes during the 2016 Monitoring Year and RBSP II Monitoring Period in the Silver Strand and Mission Beach Littoral Cells

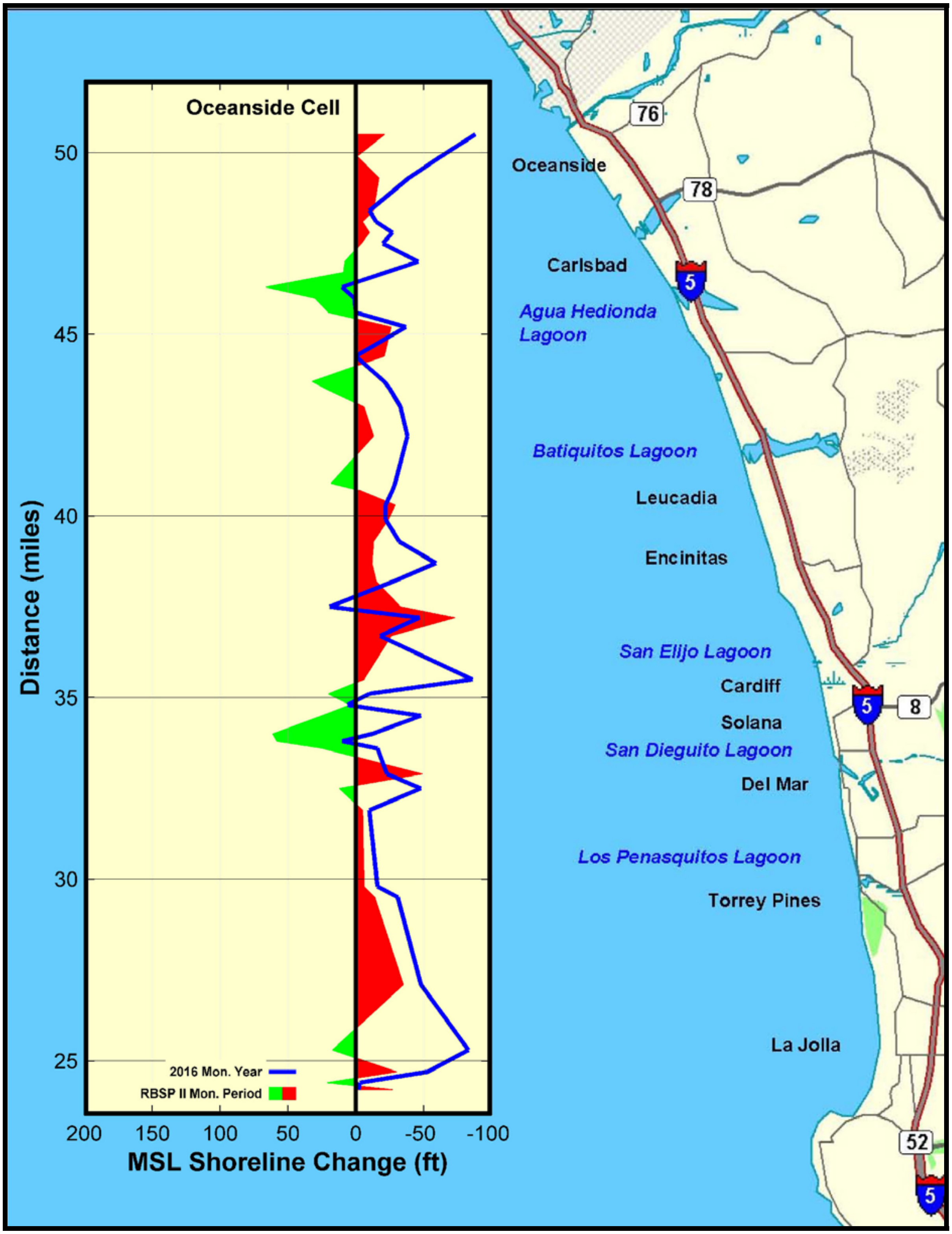


Figure 13b. MSL Shoreline Changes during the 2016 Monitoring Year and RBSP II Monitoring Period in the Oceanside Littoral Cell

Shoreline retreat predominated in the Mission Beach Cell, producing an average loss of 22 ft relative to the pre-RBSP II condition. The greatest shoreline loss (56 ft) occurred in Pacific Beach (Transect PB-0408). As discussed previously, sand nourishment was not provided to the Mission Beach Cell as part of the RBSP II.

Despite the placement of nearly 1.1 million cy of sand as part of RBSP II, the average shoreline position in the Oceanside Cell at the time of the Fall 2016 survey approximated the pre-RBSP II value. This outcome suggests that most of the nourishment material has been dispersed from the above-water beach during the four years since placement. The greatest shoreline retreat, 73 ft, occurred in Encinitas (Transect SD-0660). As suggested by Figure 13b, shoreline gains have persisted in several localized areas, with shoreline advance exceeding 50 ft in North Carlsbad and Solana Beach. The greatest shoreline advance measured 66 ft at Transect CB-0850 in North Carlsbad. The positive outcome in the North Carlsbad region is partially attributable to the resumption of sediment bypassing at Agua Hedionda in 2015 after a four year hiatus.

Post-RBSP I

Time series of the average shoreline change at the time of each Fall Survey relative to the pre-RBSP I condition (Fall 2000) are presented for the three littoral cells and the entire region in Figure 14. In 2001, substantial shoreline advance occurred in each cell in response to the RBSP I. The shoreline position also advanced in the Silver Strand and Oceanside Cells following the placement of the RBSP II material in these cells (2012).

In the Silver Strand Cell, 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 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

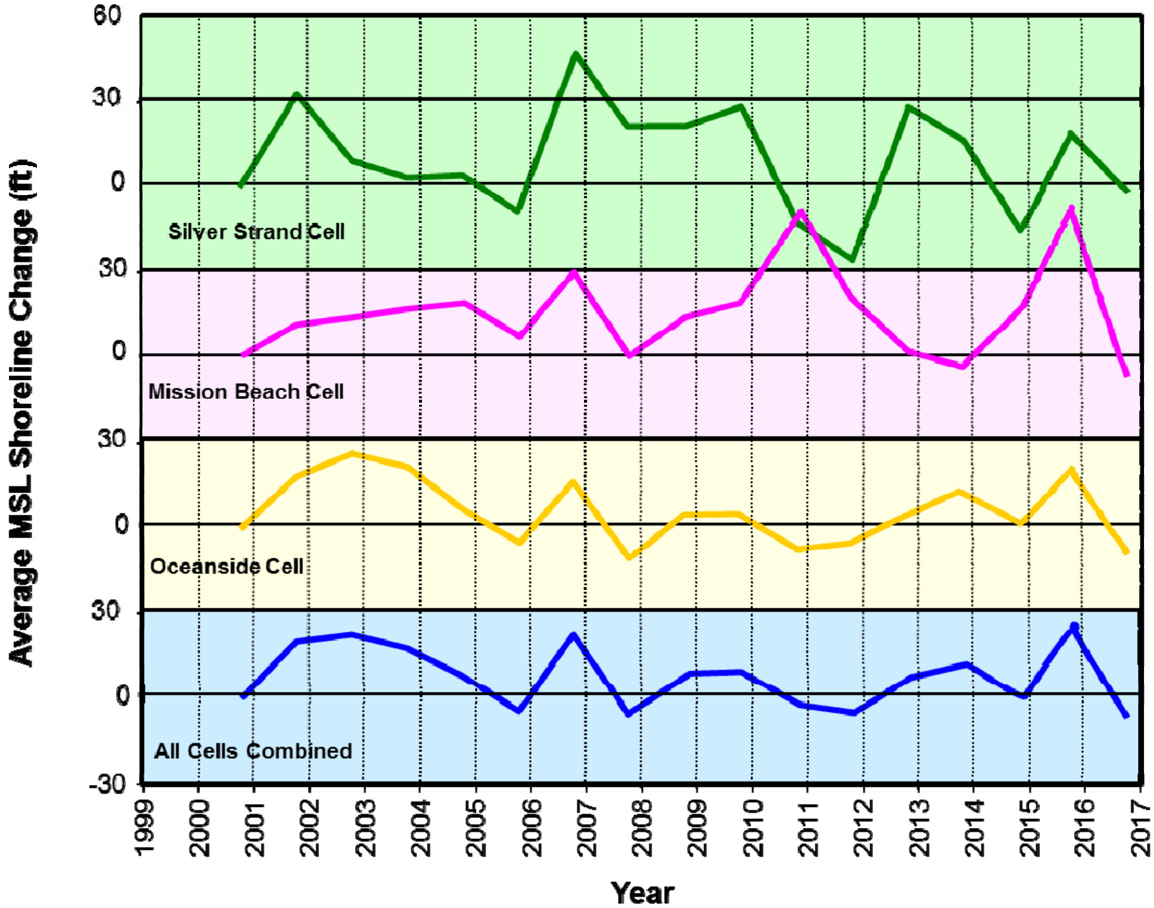


Figure 14. Time Series of Average MSL Shoreline Change Relative to Pre-RBSP I Condition

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 positon to pre-RBSP I levels. Despite the predominance of shoreline retreat in the Silver Strand Cell, gains have persisted in the Imperial Beach region (Figure 15a).

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 initial gains in this cell persisted through 2005. 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,

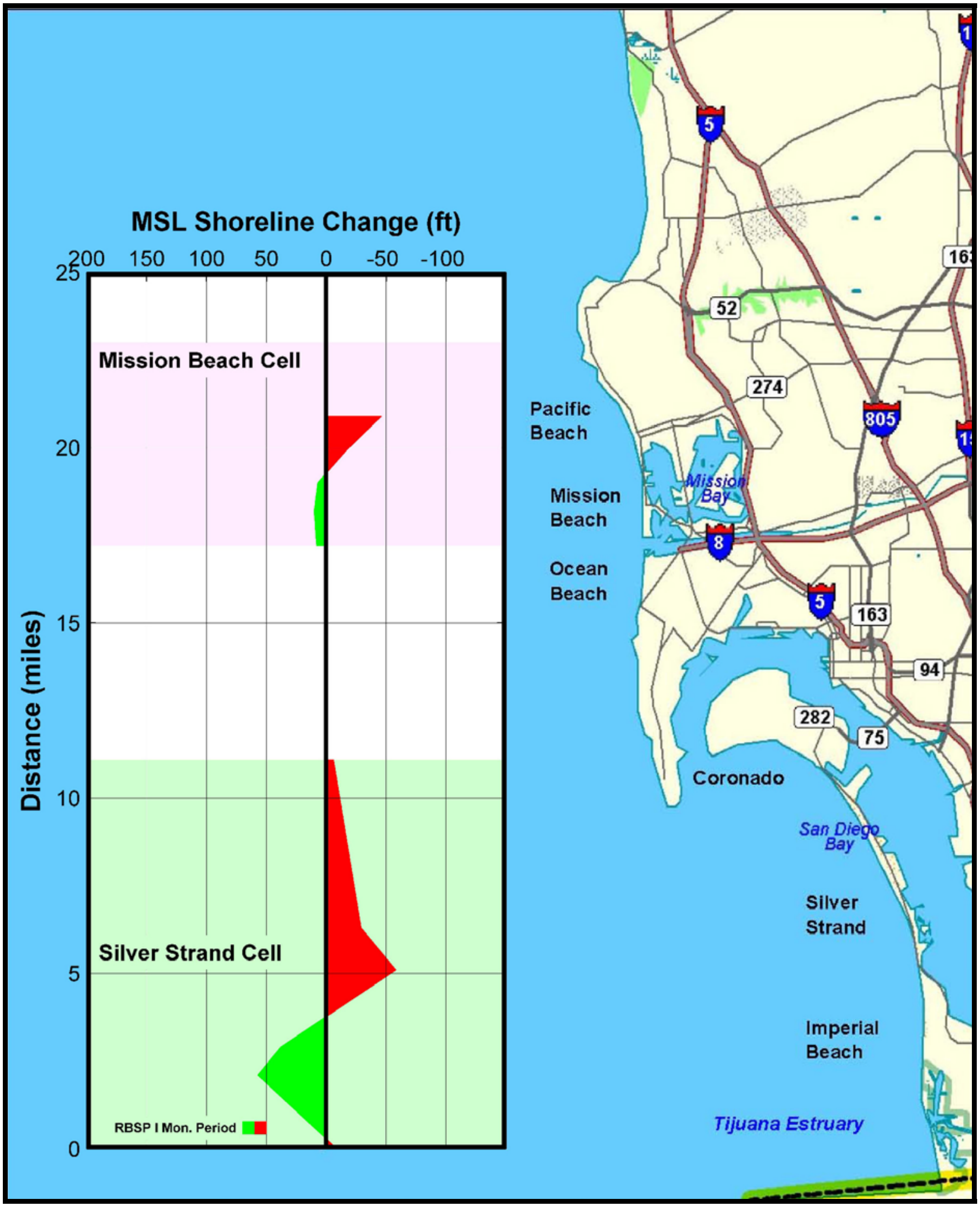


Figure 15a. MSL Shoreline Changes during the RBSP I Monitoring Period in the Silver Strand and Mission Beach Littoral Cells

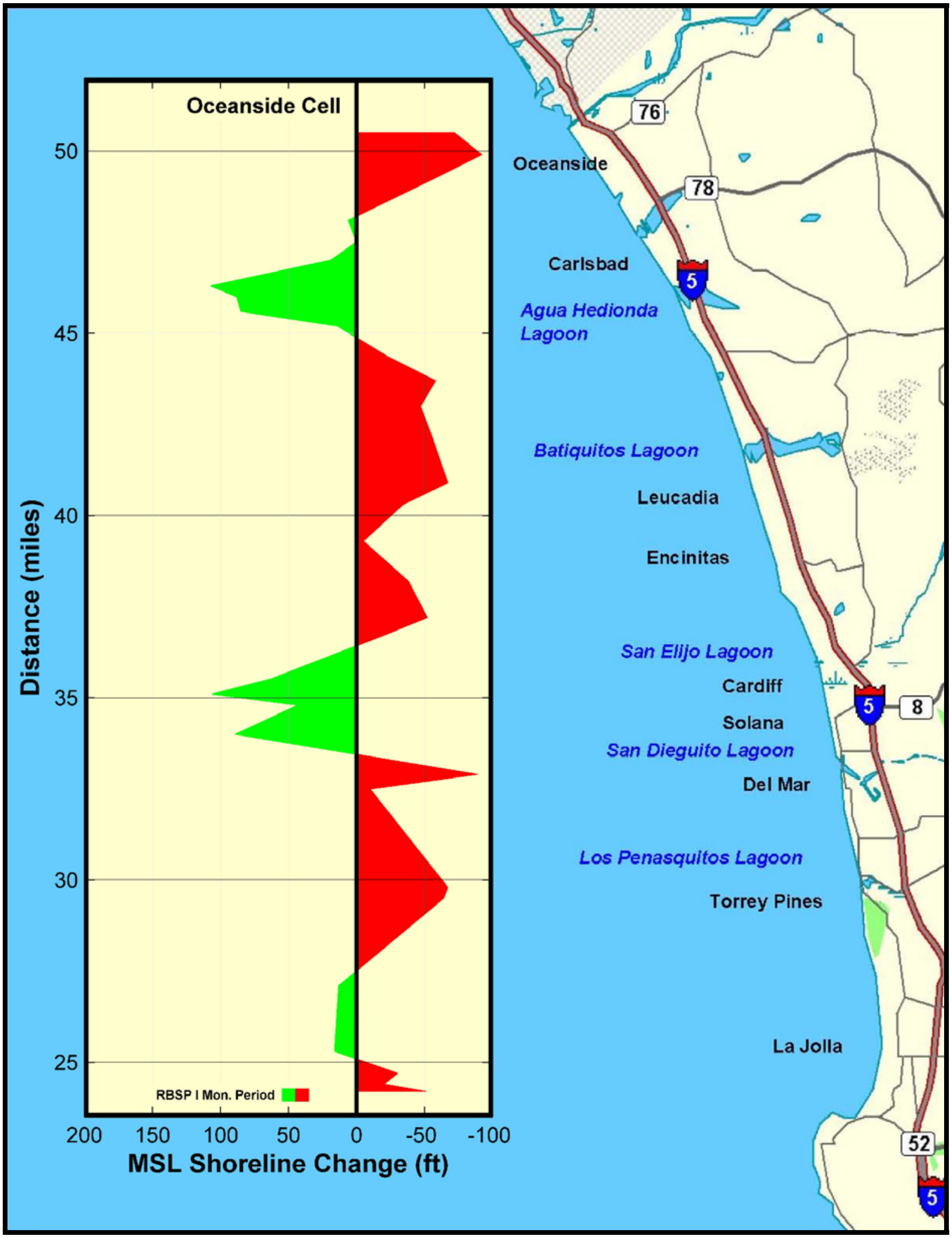


Figure 15b. **MSL Shoreline Changes during the RBSP I Monitoring Period in the Oceanside Littoral Cell**

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 the highest levels observed during the period of record. However, substantial losses sustained during 2016 reduced the average beach width to the lowest value during the 16-year period. As discussed previously, no RBSP II nourishment was provided to the Mission Beach Cell in 2012.

In the Oceanside Cell, additional gains were realized in 2002 as RBSP I fill material dispersed alongshore to 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. When the entire 16-year period encompassing the RBSP I and II is considered, the average shoreline position in the Oceanside Cell falls 9 ft below the pre-RBSP I value – the greatest shortfall since 2007 (Figure 14). Despite the prevalence of shoreline loss in the region, three areas have sustained significant shoreline gains: North Carlsbad, Cardiff, and Solana Beach (Figure 15b).

As discussed in the 2006 Annual Report (Coastal Frontiers, 2007), the unexpected predominance of shoreline advance that occurred in each cell during 2006 appears to have resulted from the onshore transport of sand from just below the waterline (typically between 0 and -10 ft) to the above-water portion of the profile. This outcome was further enhanced in the Silver Strand Cell due to the presence of the nourishment material placed in the nearshore during 2005. Based on a preliminary investigation of the CDIP wave data conducted by Dr. William O'Reilly (2007), it was speculated that the wave conditions in

Summer 2006 were particularly conducive to the onshore transport of sand. These unanticipated gains in beach width were quickly reversed by less favorable wave conditions in 2007. A similar set of circumstances appears to have occurred in 2015 and 2016.

5.1.3. Shorezone Volume Changes

Table 21 summarizes the volume changes that occurred in the shorezone (inside the range of closure) during the 2016 Monitoring Year, the five-year RBSP II Monitoring Period, and the 16-year period encompassing both the RBSP I and II. The shorezone volume changes during the 2016 Monitoring Year and the RBSP II Monitoring Period are detailed in Figure 16, while those during the 16-year period including both RBSP I and II are summarized in Figures 17 and 18. The supporting data are provided in Appendix D.

2016 Monitoring Year

The shorezone volume in the Silver Strand Cell increased by 14 cy/ft during the 2016 Monitoring Year. As shown in Figure 16a, the greatest gains occurred at Coronado and near the US/Mexico Border. In the Imperial Beach region, gains were concentrated at the southern portion of the city, with minimal changes elsewhere.

In the Mission Beach Cell, the shorezone volume was essentially unchanged during the 2016 Monitoring Year, with losses in the northern portion of the cell nearly balanced by gains further to the south. The greatest loss occurred at Pacific Beach (40 cy/ft), while largest gain occurred at Ocean Beach (51 cy/ft).

The shorezone volume in the Oceanside Cell was relatively stable during the 2016 Monitoring Year, with losses among the transects slightly outnumbering gains (Table 21). The net outcome was an average shorezone volume decrease of 4 cy/ft. Losses were most prevalent from Oceanside to Cardiff, while the largest gains were concentrated in the region from Solana Beach to La Jolla (Figure 16b). The greatest loss occurred in Cardiff (99 cy/ft at Transect SD-0630). The greatest gain occurred in Del Mar (77 cy/ft at Transect DM-0560).

RBSP II Monitoring Period

When the five-year RBSP II Monitoring Period (2011-2016) is considered, significant shorezone volume gains occurred only in the Silver Strand Cell (Table 21). The

Table 21. Shorezone Volume Changes during the 2016 Monitoring Year, the RBSP II Monitoring Period and Post-RBSP I

Littoral Cell	Shorezone Volume Change (no. of transects)			Average Change (cy/ft)
	Increase	No Change[4]	Decrease	
Silver Strand Cell				
2016 Mon. Year [1]	4	5	0	14
RBSP II Mon. Period [1]	7	2	0	35
Post-RBSP I [2,3]	1	3	2	-7
Mission Beach Cell				
2016 Mon. Year [1]	2	2	2	1
RBSP II Mon. Period [1]	3	1	2	7
Post-RBSP I [2,3]	3	2	0	19
Oceanside Cell				
2016 Mon. Year [1]	13	17	15	-4
RBSP II Mon. Period [1]	14	10	21	0
Post-RBSP I [2,3]	13	10	10	6
All Cells Combined				
2016 Mon. Year [1]	19	24	17	-1
RBSP II Mon. Period [1]	24	13	23	6
Post-RBSP I [2,3]	17	15	12	5

Notes: [1] Volume change statistics are derived from the 60 transects with measurements dating back to Fall 2011.
[2] Volume change 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 2016).
[4] "No Change" indicates a shorezone volume change of 10 cy/ft or less.

average shorezone volume in the Oceanside Cell was identical to the pre-RBSP II value. Similarly, the shorezone volume in the Mission Beach Cell was only slightly greater than the pre-RBSP II value.

Despite losses during the first several years following nourishment, the average net shorezone volume in the Silver Strand increased by 35 cy/ft during the RBSP II Monitoring Period. As shown in Figure 16a, the greatest gains occurred in Imperial Beach. The average shorezone volume gain in this region was 50 cy/ft. This outcome suggests an enduring benefit from the RBSP II nourishment placed at Imperial Beach.

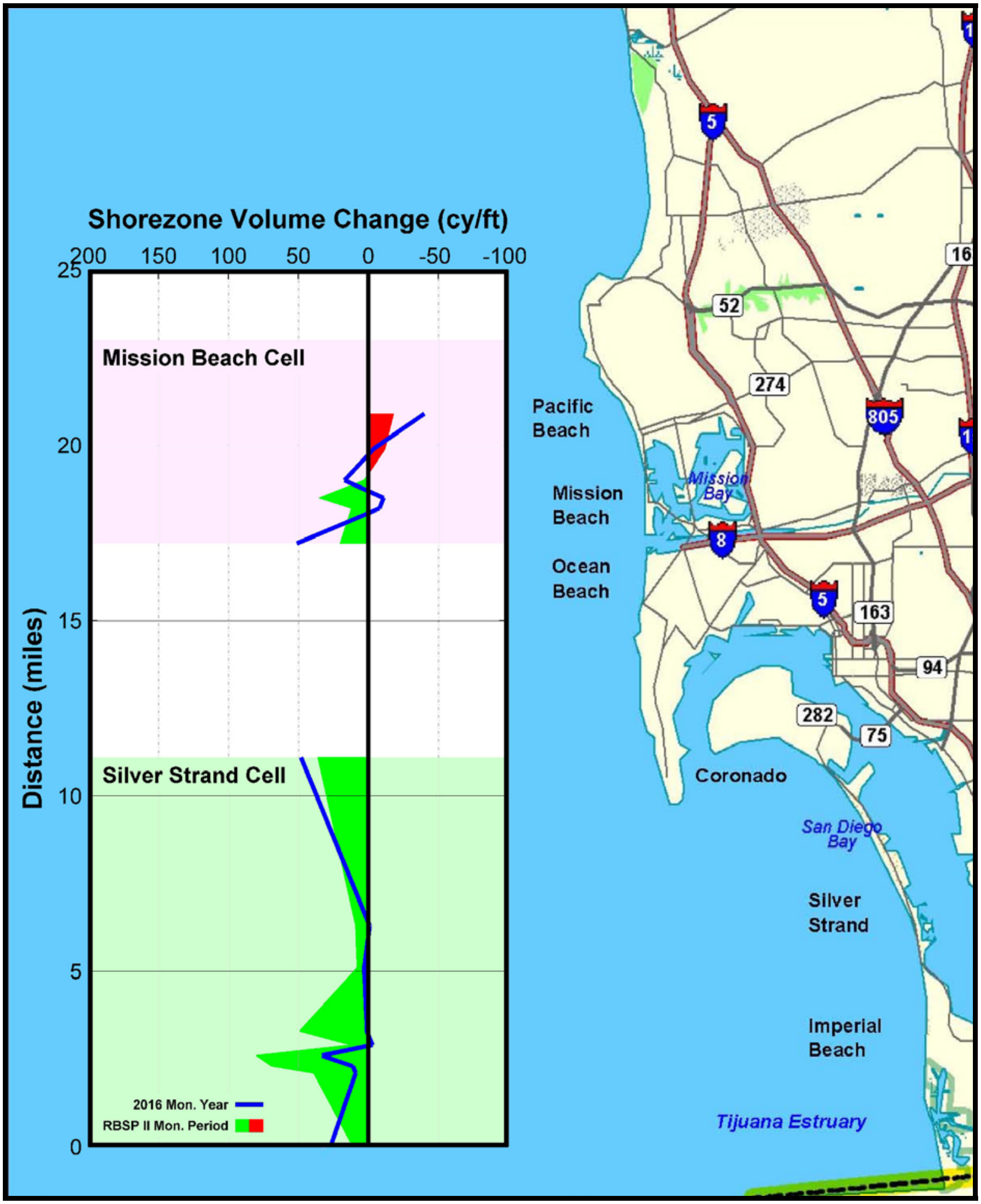


Figure 16a. Shorezone Volume Changes during the 2016 Monitoring Year and RBSP II Monitoring Period in the Silver Strand and Mission Beach Littoral Cells

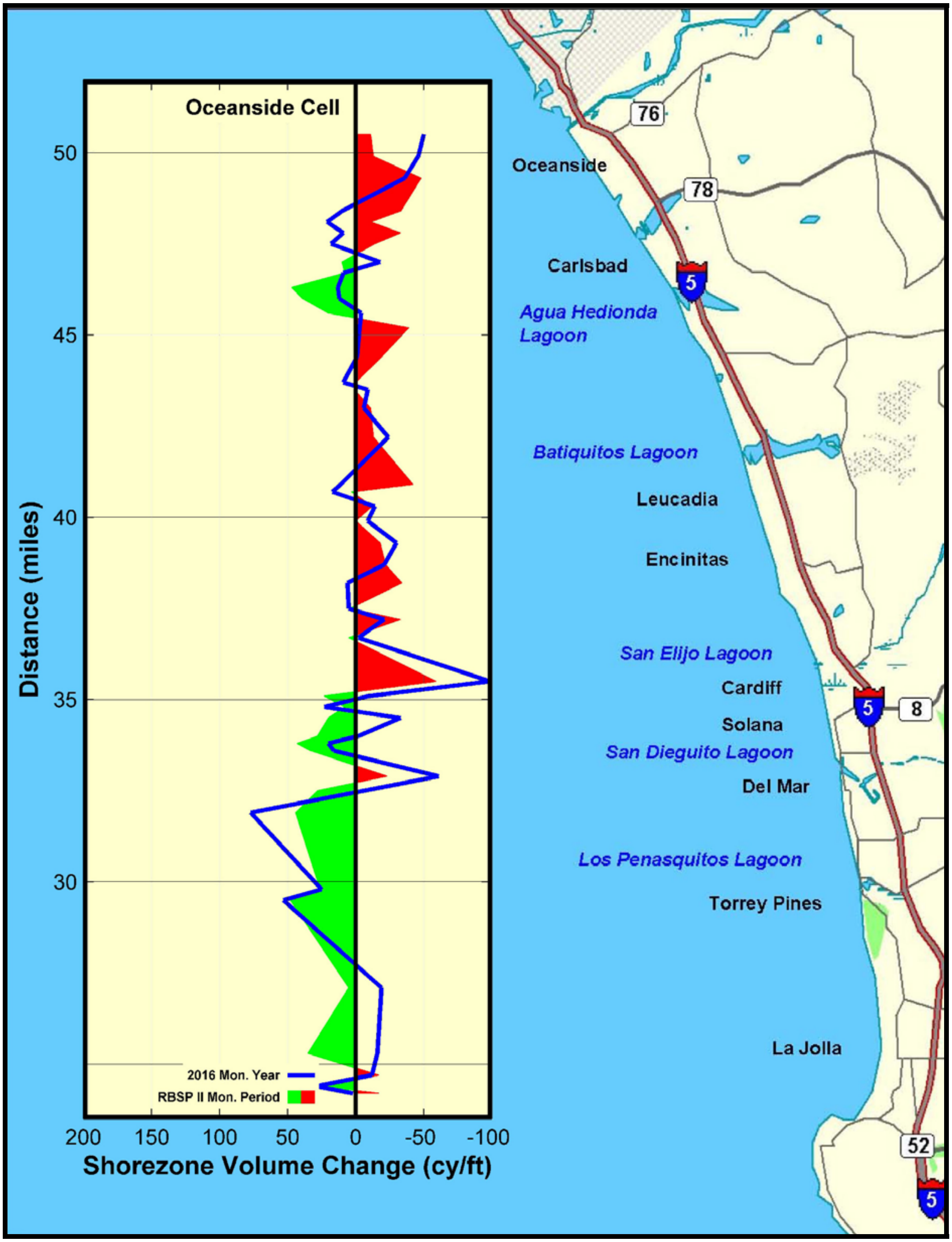


Figure 16b. Shorezone Volume Changes during the 2016 Monitoring Year and RBSP II Monitoring Period in the Oceanside Littoral Cell

In the Mission Beach Cell, the shorezone volume increased by an average of 7 cy/ft during the RBSP II Monitoring Period (Table 21). As indicated in Figure 16a, losses in the northern portion of the cell were nearly balanced by gains further to the south. This outcome is consistent with the lack of nourishment during the period.

Shorezone volume gains and losses were balanced in the Oceanside Cell during the RBSP II Monitoring Period, with essentially no change in shorezone volume over the five-year period. This outcome suggests that the gains realized following the RBSP II have been largely diminished during the four years following fill placement. As indicated in Figure 16b, volume gains were concentrated in the southern portion of the cell (Solana Beach to La Jolla). Losses predominated from Oceanside to Cardiff, with North Carlsbad being the primary exception. The greatest gain occurred near Los Peñasquitos Lagoon (48 cy/ft at Transect TP-0520), while the greatest loss occurred in Cardiff (59 cy/ft at Transect SD-0630).

Post-RBSP I

When the entire 16-year period encompassing both RBSP I and II is considered, the shorezone volume increased 19 cy/ft in the Mission Beach Cell (Table 21). While the RBSP I contributed to these gains, the majority of the increase resulted from the much larger opportunistic nourishment project conducted by the U.S. Army Corps of Engineers in 2010. In the Oceanside Cell, the shorezone volume increased a modest 6 cy/ft. The gains in this cell may be attributed to the RBSP I and II fills and the opportunistic nourishment projects in Encinitas. Despite receiving nourishment material as part of both RBSP efforts and several opportunistic projects, the average shorezone volume in the Silver Strand Cell fell 7 cy/ft below the pre-RBSP I value.

Time series of the average shorezone volume change at the time of each Fall survey relative to the pre-RBSP I condition (Fall 2000) are presented for each littoral cell and the entire region in Figure 17. In the Silver Strand Cell, 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 Monitoring Period and the volume gains at these transects were not included in the calculations. Following a modest gain in 2005, 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.

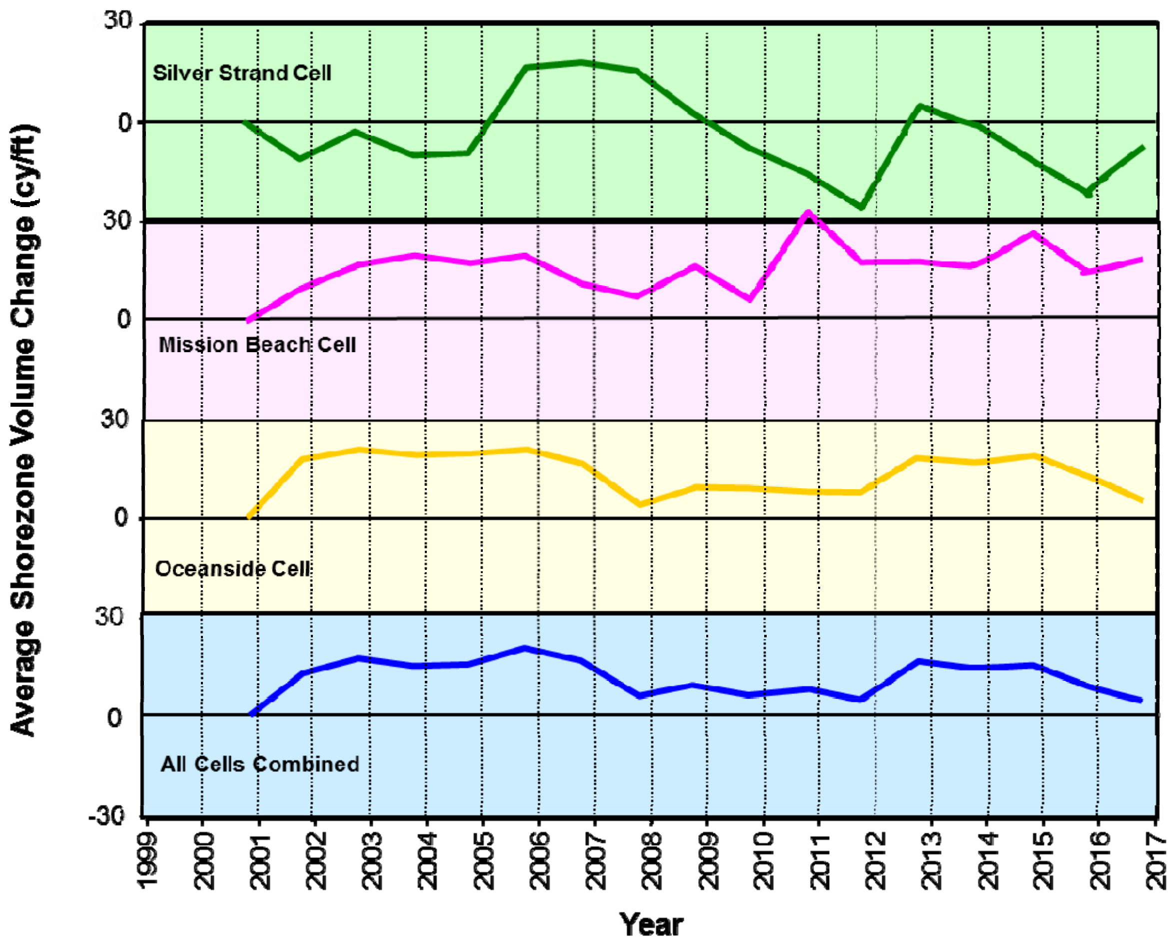


Figure 17. Time Series of Average Shorezone Volume Change Relative to Pre-RBSP I Condition

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 not sufficient to reach the pre-RBSP I value. As indicated in Figure 18a, volume gains in excess of 10 cy/ft were sustained at only one location in the cell during the 16-year period (Transect SS-0015 in Imperial Beach).

In the Mission Beach Cell, 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

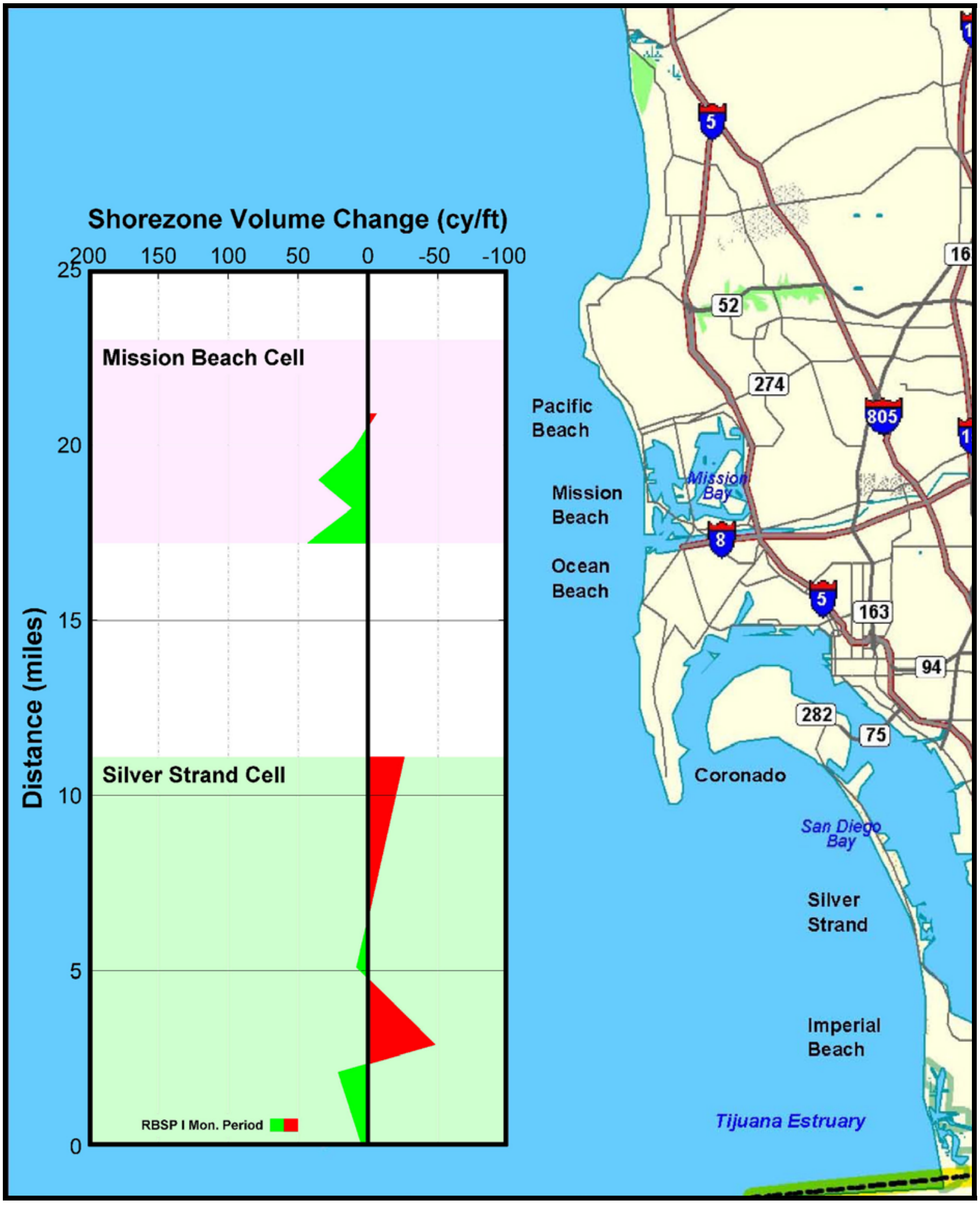


Figure 18a. Shorezone Volume Changes during the RBSP I Monitoring Period in the Silver Strand and Mission Beach Littoral Cells

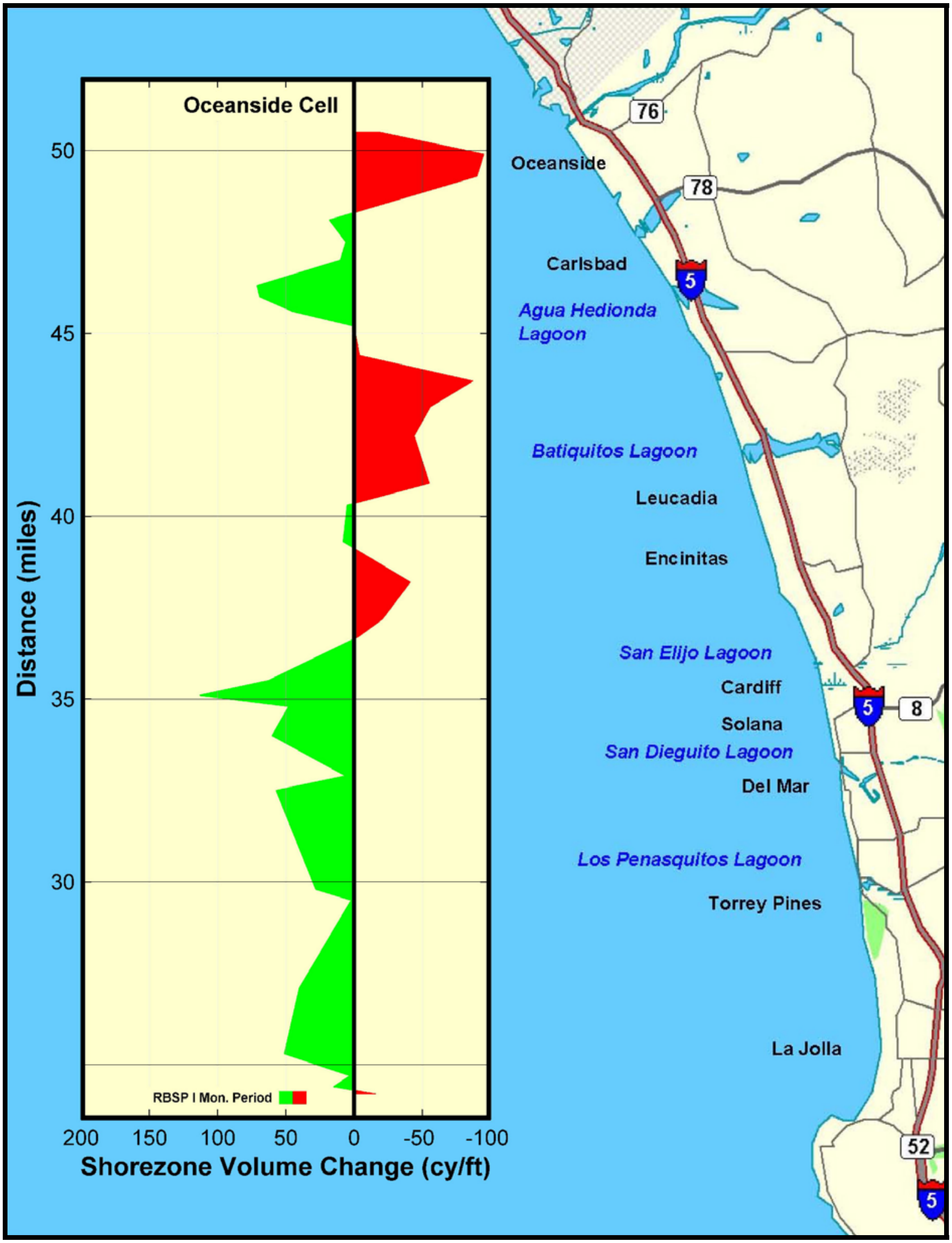


Figure 18b. Shorezone Volume Changes during the RBSP I Monitoring Period in the Oceanside Littoral Cell

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. These gains were reversed in 2015, reducing the average shorezone volume to a level similar to that observed from 2011 to 2013. Changes in 2016 were modest. As shown in Figure 18a, shorezone volumes gains were greatest in Mission Beach and Ocean Beach.

The sediment volume gains that occurred in the Oceanside Cell following the RBSP I persisted with minimal change through 2006. 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 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 2015 and 2016 reduced the shorezone volume to near the pre-RBSP II value (2011). The shorezone volume gains were concentrated in the southern portion of the cell (Cardiff to La Jolla) and in North Carlsbad (Figure 18b). Losses were most extensive in the Oceanside and South Carlsbad area.

5.2. RBSP II Beach Fill Performance

This section provides an overview of the performance of the RBSP II beach fills. As indicated in Section 2, the RBSP II provided 1.5 million cy of beach-quality sand to eight receiver sites located between Imperial Beach and Oceanside. The nourishment quantities at these sites ranged from 89,000 cy at Cardiff to 450,000 cy at Imperial Beach (Table 3). Nourishment activities were conducted between September 7 and December 7, 2012.

Noteworthy differences compared to the RBSP I effort include providing nearly four times more sand in the Silver Strand Cell, omitting all nourishment in the Mission Beach Cell, and reducing both the number of fill sites (7 vs. 10) and placement quantities (approximately 40% less) in the Oceanside Cell. Another key distinction was the use of coarser material for the RBSP II fills. The average median grain size (d_{50}) among the eight RBSP II receiver beaches was 0.56 mm, compared to an average of 0.41 mm for the twelve RBSP I sites. More importantly, nourishment material as fine as 0.14 mm (d_{50}) was used for several RBSP I receiver sites, while the lowest d_{50} among the RBSP II sites was 0.48 mm.

Location maps showing the fills and all beach profile transects located in the vicinity are shown at the end of this section in Figures 31 through 34. Although aerial photos of the receiver sites were omitted in 2016, select pre- and post-nourishment photos of each receiver beach obtained between 2011 and 2015 are provided in Plates 1 through 8 at the end of this section for general reference. A more comprehensive set of photos obtained from 2001 to 2015, including those of the RBSP I receiver sites not included in the RBSP II, is provided in Appendix E.

Table 22 provides the MSL shoreline change, subaerial volume change and shorezone volume change that occurred between Fall 2011 (pre-nourishment) and Fall 2016 (approximately four years after nourishment) at a single indicator transect selected to characterize each receiver site. In those instances where more than one transect crossed the fill, the transect that was located nearest the middle of the fill was adopted as the indicator. Time series of the MSL shoreline change and shorezone volume change at the time of each Fall Survey relative to Fall 2011 (the pre-RBSP II condition) are presented for each indicator transect in Figures 19 and 20.

Table 22. Shoreline and Volume Changes at RBSP II Receiver Sites

Receiver Beach	Indicator Transect	Fill Volume (cy)	Change RBSP II Monitoring Period; Fall 2011 to Fall 2016 (Pre-Nourishment to 4-years Post-Nourishment)		
			MSL Shoreline (ft)	**Subaerial Volume (cy/ft)**	**Shorezone Volume (cy/ft)**
Imperial Bch	SS-0025	450,000	93	38	80
Solana Beach	SD-0597	142,000	58	18	43
Cardiff	SD-0630	89,000	-6	4	-59
Moonlight Bch	SD-0670	92,000	-15	5	-34
Batiquitos	SD-0710	106,000	-3	1	3
S. Carlsbad	CB-0775	141,000	22	3	1
N. Carlsbad	CB-0865	219,000	9	10	8
Oceanside	OS-0947	293,000	-13	-4	-33
Average			***18***	***9***	***1***
Maximum			***93***	***38***	***80***
Minimum			***-15***	***-4***	***-59***

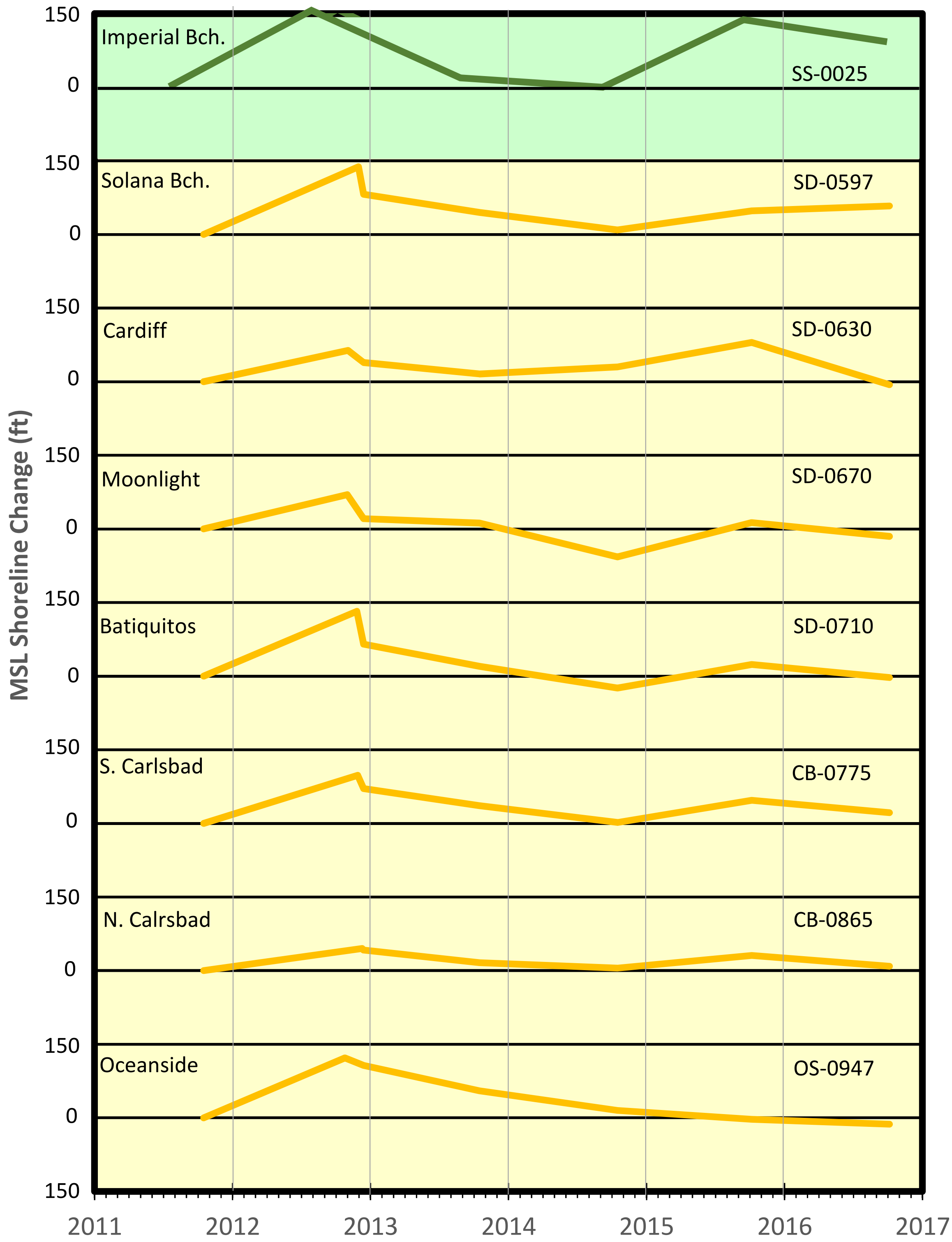


Figure 19. Time Series of MSL Shoreline Change at RBSP II Receiver Sites

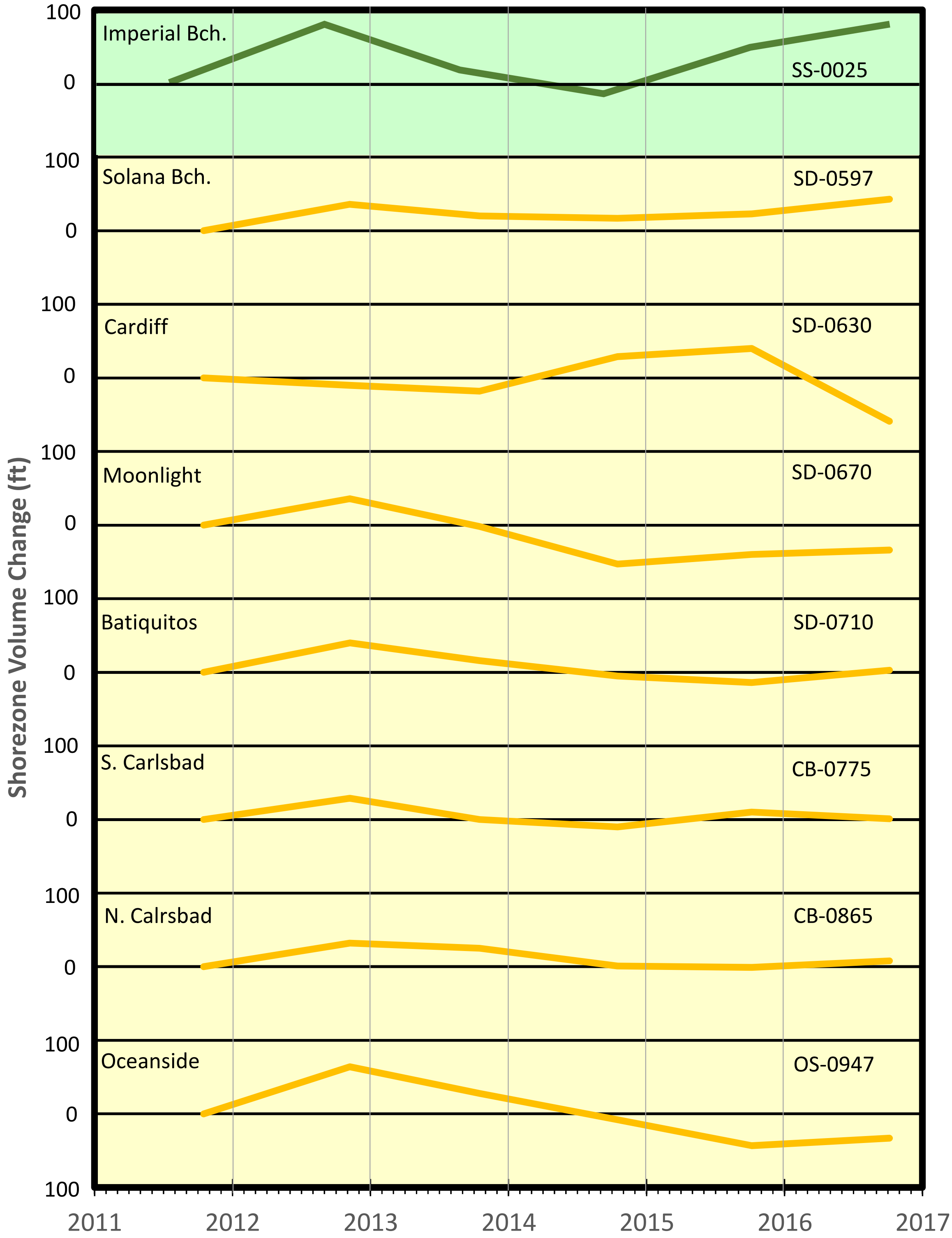


Figure 20. Time Series of Shorezone Volume Change at RBSP Receiver Sites

Despite the limitations associated with the use of a single transect to represent each site, the changes shown in Figures 19 and 20, and summarized in Table 22 provide a reasonable depiction of the post-nourishment outcome at each receiver site during the RBSP II Monitoring Period. While the selected transects provide a useful representation of the changes at the fill sites, they offer no indication of changes at adjacent beaches attributable to redistribution of the nourishment material. ***As such, the receiver site outcome should not be used to judge to overall success of the nourishment program.***

The receiver sites in the Oceanside Cell have been characterized by a general trend of decreasing beach widths and sediment volume consistent with the dispersal of the placed material (Figures 19 and 20). The exception was Solana Beach, where the shorezone volume increased modestly following nourishment. A similar trend of diminishing beach widths and shorezone volumes prevailed at lone receiver site located in the Silver Strand Cell (Imperial Beach) during the first two years following nourishment. This trend was reversed, however, with gains occurring during 2015 and 2016.

During the five-year RBSP II Monitoring Period, the shoreline position advanced at three receiver beaches, retreated at two sites, and remained essentially unchanged (change of 10 ft or less) at three sites. The largest advance was 93 ft at Imperial Beach, while the greatest retreat was 15 ft at Moonlight Beach. Subaerial volumes increased at two of the sites and was essentially unchanged (change of 10 cy/ft or less) at the remaining six sites. In keeping with the shoreline changes, the greatest subaerial volume gain (38 cy/ft) occurred at Imperial Beach.

The shorezone volume increased at two sites, decreased at three locations, and remained essentially unchanged (change of 10 cy/ft or less) at the three remaining sites during the five-year RBSP II Monitoring Period. The greatest shorezone volume gain, 80 cy/ft, also occurred at the Imperial Beach receiver site. The highest deficit, 59 cy/ft, occurred at the Cardiff receiver site.

5.3. Post-RBSP II Outcome in Sub-Reaches

This section summarizes the post-RBSP II outcome for selected sub-reaches within the study area. Unlike the receiver site evaluation (Section 5.2), the sub-reach assessment quantifies the impact of the RBSP II 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 program.

Figures 21 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 II condition (Fall 2011) for nine sub-reaches located in the Oceanside and Silver Strand Littoral Cells. All but two of the sub-reaches received direct nourishment as part of the RBSP II (Del Mar and La Jolla being the exceptions). Sub-reaches in the Mission Beach Cell are not included because RBSP II nourishment was not placed in this cell. To account for the uneven spacing between transects, the average value was weighted according to the alongshore distance associated with each transect.

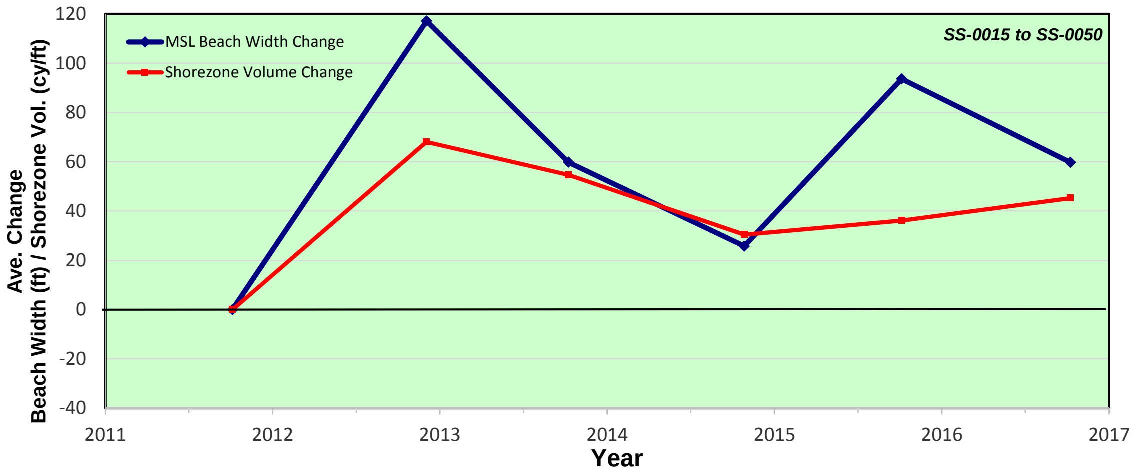


Figure 21. Beach Width and Shorezone Volume Changes in the Imperial Beach Sub-Reach

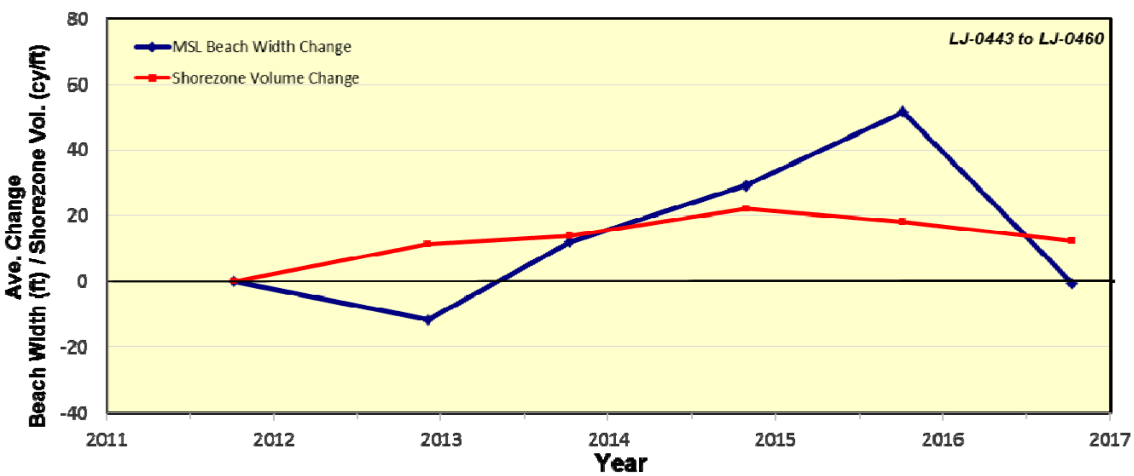


Figure 22. Beach Width and Shorezone Volume Changes in the La Jolla Sub-Reach

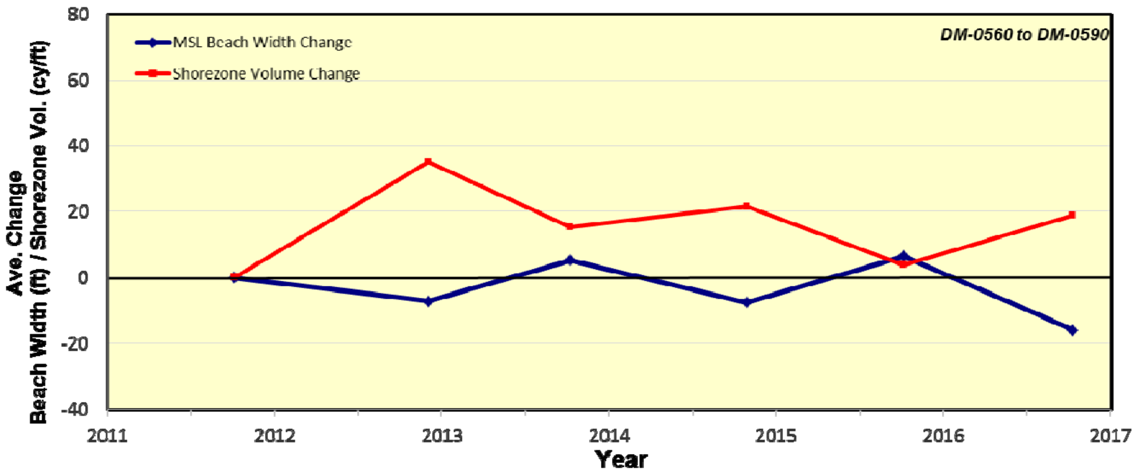


Figure 23. Beach Width and Shorezone Volume Changes in the Del Mar Sub-Reach

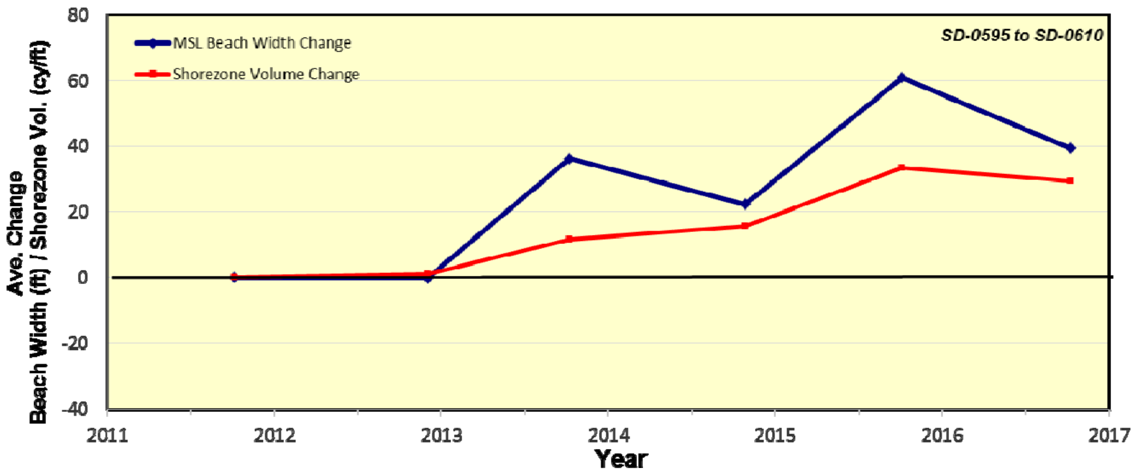


Figure 24. Beach Width and Shorezone Vol. Changes in the Solana Bch Sub-Reach

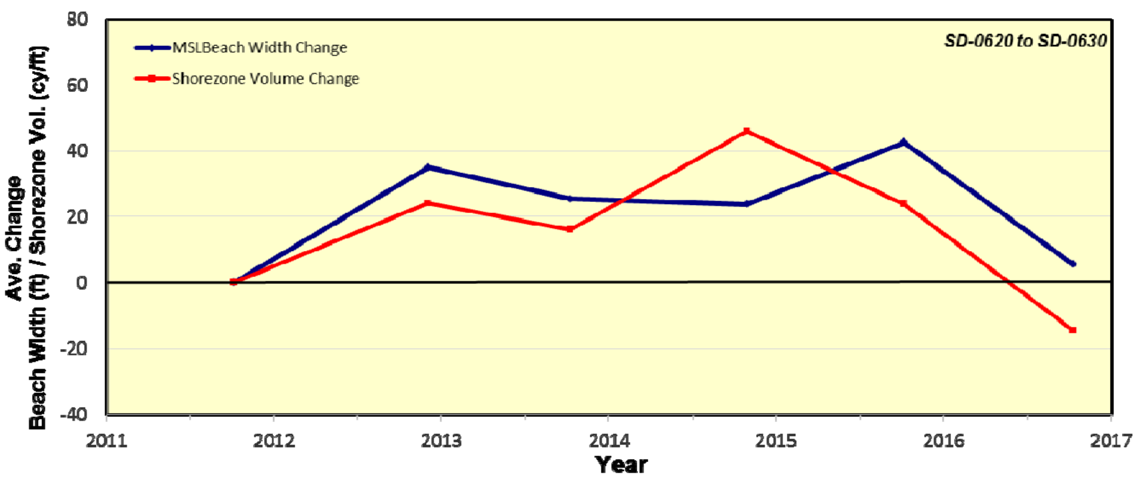


Figure 25. Beach Width and Shorezone Volume Changes in the Cardiff Sub-Reach

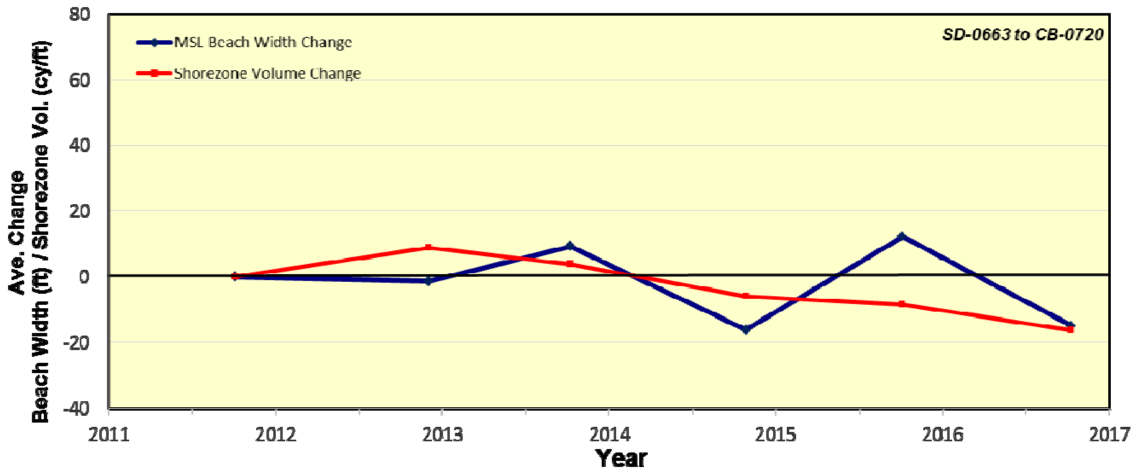


Figure 26. Beach Width and Shorezone Volume Changes in the Encinitas/Leucadia Sub-Reach

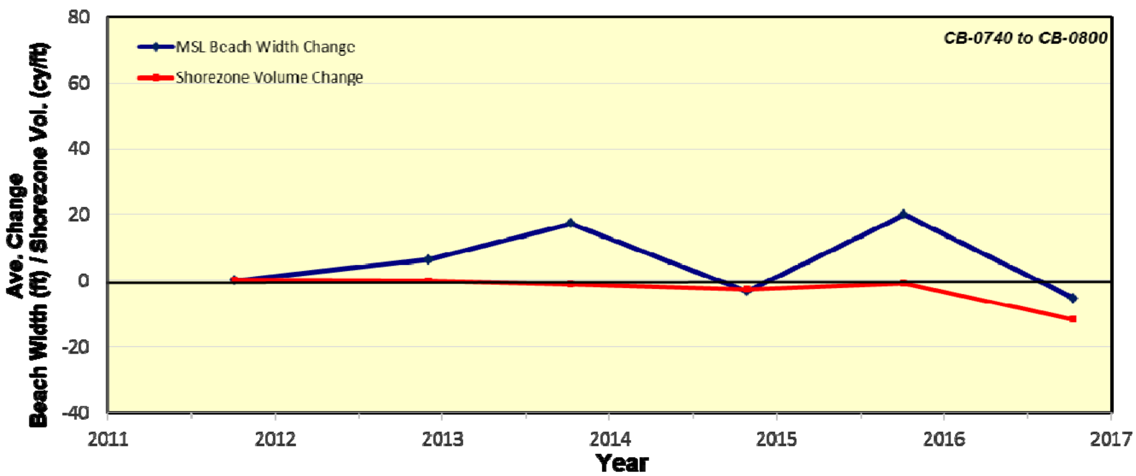


Figure 27. Beach Width and Shorezone Vol. Changes in the S. Carlsbad Sub-Reach

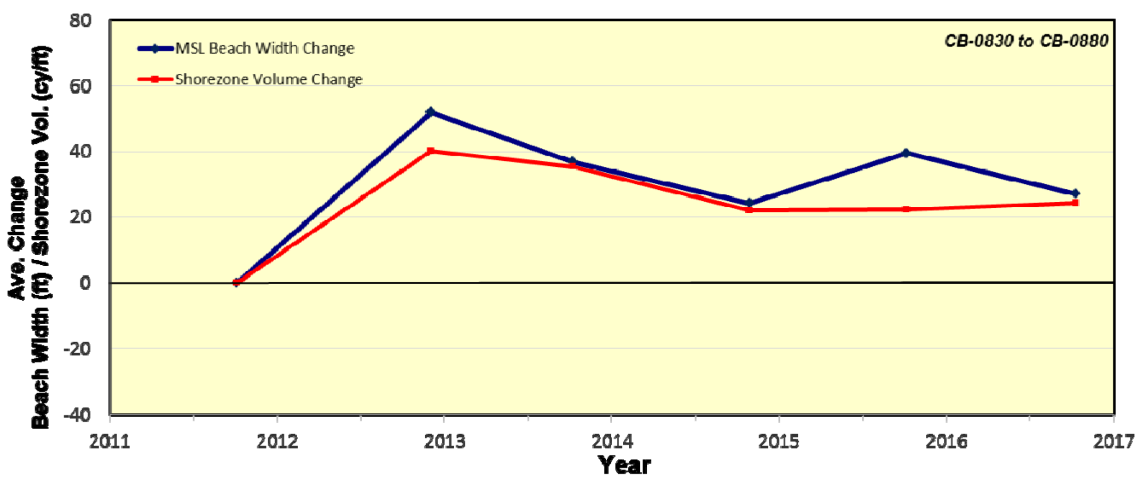


Figure 28. Beach Width and Shorezone Vol. Changes in the N. Carlsbad Sub-Reach

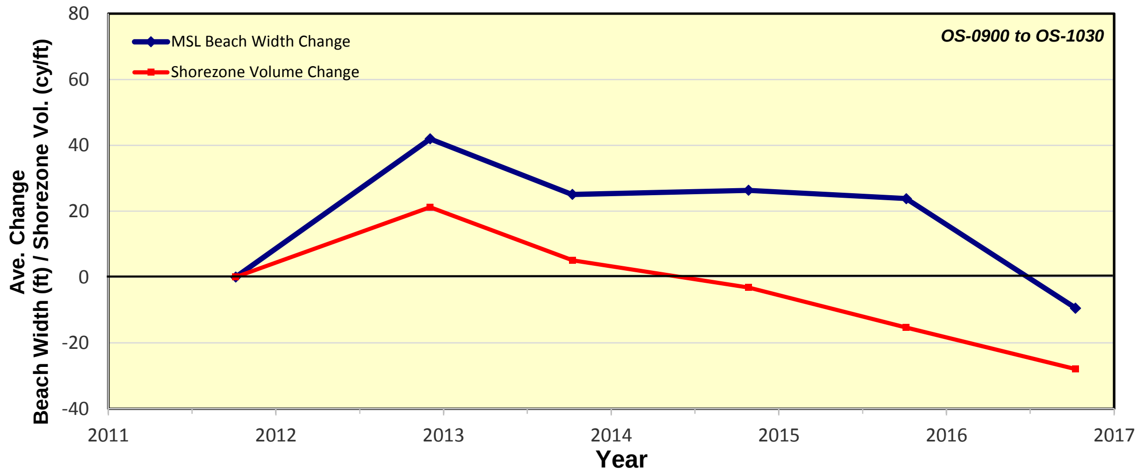


Figure 29. Beach Width and Shorezone Vol. Changes in the Oceanside Sub-Reach

Tables 23 and 24 summarize the beach width and shorezone volume changes following the RBSP II in the selected sub-reaches. The persistence of post-RBSP II gains was defined in terms of the number of consecutive years immediately following the RBSP II in which the average change at the time of each Fall Survey relative to the pre-RBSP II condition (Fall 2011) 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 2012 or 2013. Three categories were adopted to classify the persistence of post-RBSP II gains: Long-Term (5 years), Transient (2 to 4 years), and Negligible (1 year or less).

Long-term beach width gains prevailed at two sub-reaches – Imperial Beach and North Carlsbad (Table 23). During the five-year period, the average beach width increased 60 ft at Imperial Beach and 27 ft at North Carlsbad. Transient beach width gains occurred at four sub-reaches, while the remaining three sub-reaches were characterized by negligible gains. Del Mar and Leucadia/Encinitas sustained a net decrease in average beach width in excess of 10 ft during the five-year period (16 and 15 ft, respectively).

When shorezone volume persistence is considered, the number of sub-reaches characterized by long-term gains increases to three (Table 24). Similar to the beach width gain persistence, the volume gains at Imperial Beach and North Carlsbad were sustained for the entire five-year period. The volume gains in La Jolla also persisted for the entire post-RBSP II period. Transient shorezone volume gains prevailed at three sub-reaches, while negligible gains also occurred to three locations. It is noteworthy that Leucadia/Encinitas

Table 23. Post-RBSP II Average Beach Width Gain Persistence in Sub-Reaches

Sub-Reach	Average Beach Width Gain Persistence	Fall 2016 Average Beach Width Change [1]
Long-Term Beach Width Gains (5 Years)		
Imperial Beach	5 years	60 ft
North Carlsbad	5 years	27 ft
Transient Beach Width Gains (2 to 4 Years)		
Solana	4 years	39 ft
Cardiff	4 years	6 ft
Oceanside	4 years	-9 ft
La Jolla	3 years	-1 ft
Negligible Beach Width Gains (1 Year or Less)		
South Carlsbad	1 year	-5 ft
Del Mar	<1 year	-16 ft
Leucadia/Encinitas	<1 year	-15 ft

Note: [1] Beach width change relative to pre-RBSP II condition (Fall 2011)

Table 24. Post-RBSP II Average Shorezone Volume Gain Persistence in Sub-Reaches

Sub-Reach	Average Shorezone Volume Gain Persistence	Fall 2016 Average [1] Shorezone Volume Change
Long-Term Shorezone Volume Gains (5 Years)		
Imperial Beach	5 years	45 cy/ft
La Jolla	5 years	12 cy/ft
North Carlsbad	5 years	24 cy/ft
Transient Shorezone Volume Gains (2 to 4 Years)		
Solana	4 years	29 cy/ft
Cardiff	4 years	-15 cy/ft
Del Mar	3 years	19 cy/ft
Negligible Shorezone Volume Gains (1 Year or Less)		
Oceanside	1 year	-28 cy/ft
Leucadia/Encinitas	<1 year	-16 cy/ft
South Carlsbad	<1 year	-12 cy/ft

Note: [1] Shorezone volume change relative to pre-RBSP II condition (Fall 2011) and South Carlsbad were the only sub-reaches where both the beach width and shorezone volume gains were categorized as negligible. Similarly, Imperial Beach and North Carlsbad, were the only sub-reaches that appeared in the long-term gain category for both beach width and shorezone volume persistence.

5.4. 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 that occurred during the following summer (Spring 2016 to Fall 2016).

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

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 in 38 transects common to Fall surveys conducted from 1997 to 2015.

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 sub-reaches 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 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 19 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

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	-60	-106	1 of 19
Mission Beach	MB-0310 to PB-408	-114	-46	-114	1 of 19
La Jolla	LJ-0443 to LJ-0460	-98	-47	-94	2 of 19
Del Mar	DM-0580 to DM-0590	-90	-47	-85	2 of 19
Solana	SD-0600	-63	-25	-18	13 of 19
Cardiff	SD-0620 to SD-0630	-70	-31	-70	1 of 12 (1)
Leucadia/Encinitas	SD-0670 to SD-0720	-74	-33	-51	4 of 14 (1)
South Carlsbad	CB-0740 to CB-0800	-49	-16	-35	3 of 19
North Carlsbad	CB-0830 to CB-0880	-16	5	-5	5 of 19
Oceanside	OS-0900 to OS-1030	-50	-16	-46	2 of 19

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

findings of Barnard, *et. al.* (2017) indicating that the winter shoreline retreat on the US West Coast in 2016 was among the highest on record.

The Spring 2016 profiles indicate that above-water erosion during the El Niño winter was accompanied by the formation of a pronounced nearshore bar at many locations (Appendix B). The elevation of the bar exceeded the envelope of historical profile changes at several transects - most notably, sites in the southern portion of the Oceanside Cell (Cardiff to La Jolla; *e.g.*, Transect DM-0580), Mission Beach (*e.g.*, Transect MB-0310) and Imperial Beach region (*e.g.*, Transect SS-0020). This finding suggests that the energetic wave conditions that prevailed during the winter season were sufficient to transport material further offshore than in the recent past.

As shown in Table 27, summer seasonal shoreline changes between the Spring 2016 to Fall 2016 surveys ranged from an advance of 81 ft at Imperial Beach to a loss of 7 ft at North Carlsbad. While shoreline advance predominated in the San Diego region during Summer 2016, the gains were not sufficient to offset the losses sustained during the preceding winter. On average, less than 50% of the losses incurred in the ten sub-reaches over the winter were recovered during the following summer. The net result yielded Fall 2016 beach widths that fell near the lower boundary of historical conditions in much of the study area (Figures 30a and b).

Table 27. Summer Seasonal Shoreline Recovery in Sub-Reaches

Sub-Reach	Transect Range	Beach Width Change (ft)		% Recovery
		Winter Fall 2015-Spr. 2016	Summer Spr 2016-Fall 2016	
Imperial Beach	SS-0015 to SS-0035	-106	81	76%
Mission Beach	MB-0310 to PB-408	-114	46	40%
La Jolla	LJ-0443 to LJ-0460	-94	41	44%
Del Mar	DM-0580 to DM-0590	-85	45	53%
Solana	SD-0600	-18	6	33%
Cardiff	SD-0620 to SD-0630	-70	32	46%
Leucadia/Encinitas	SD-0670 to SD-0720	-51	23	45%
South Carlsbad	CB-0740 to CB-0800	-35	10	29%
North Carlsbad	CB-0830 to CB-0880	-5	-7	-
Oceanside	OS-0900 to OS-1030	-46	12	26%

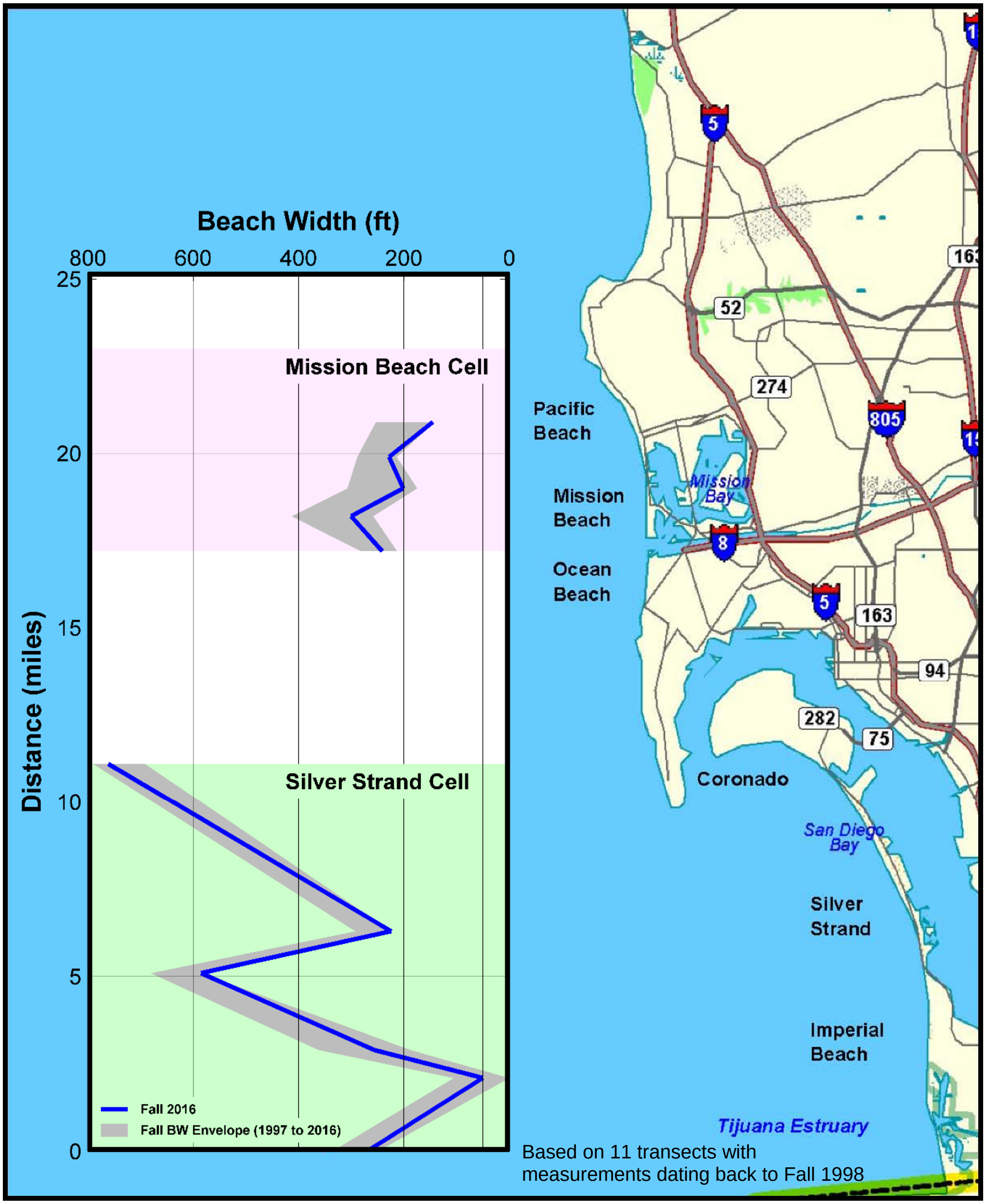


Figure 30a. Fall 2016 Beach Widths in the Silver Strand and Mission Beach Littoral Cells

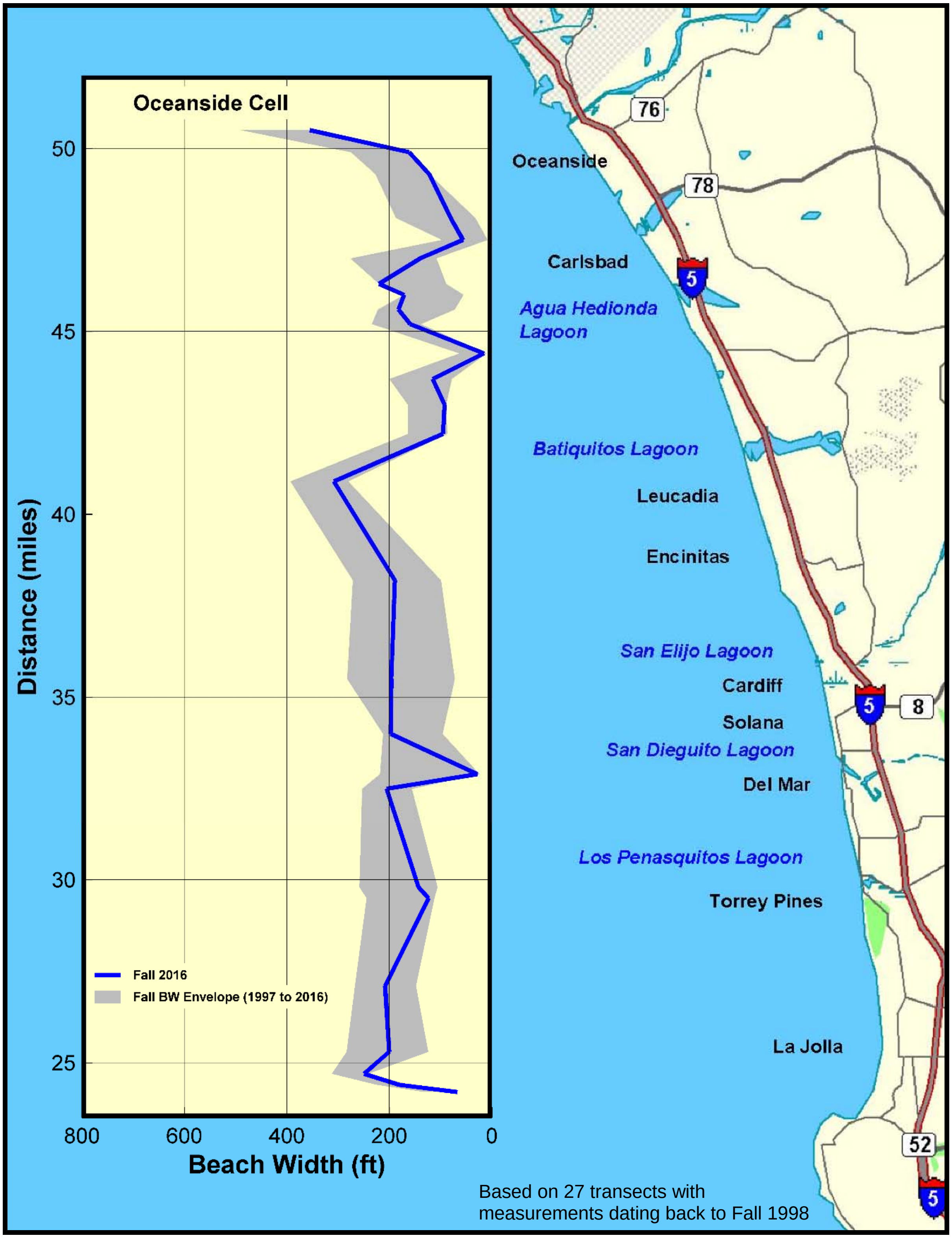


Figure 30b. Fall 2016 Beach Widths in the Oceanside Littoral Cell

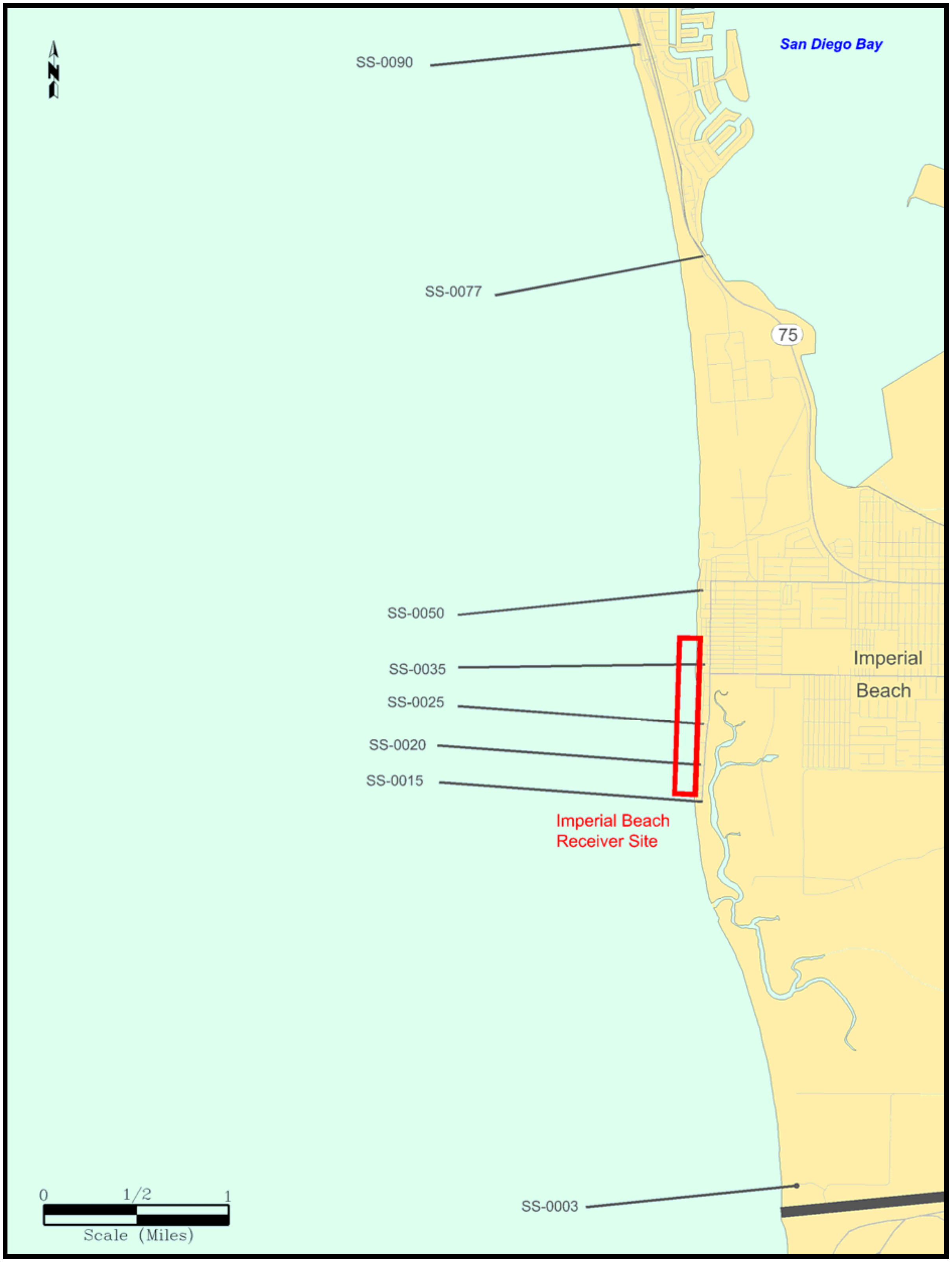


Figure 31. Location Map for Imperial Beach Receiver Site

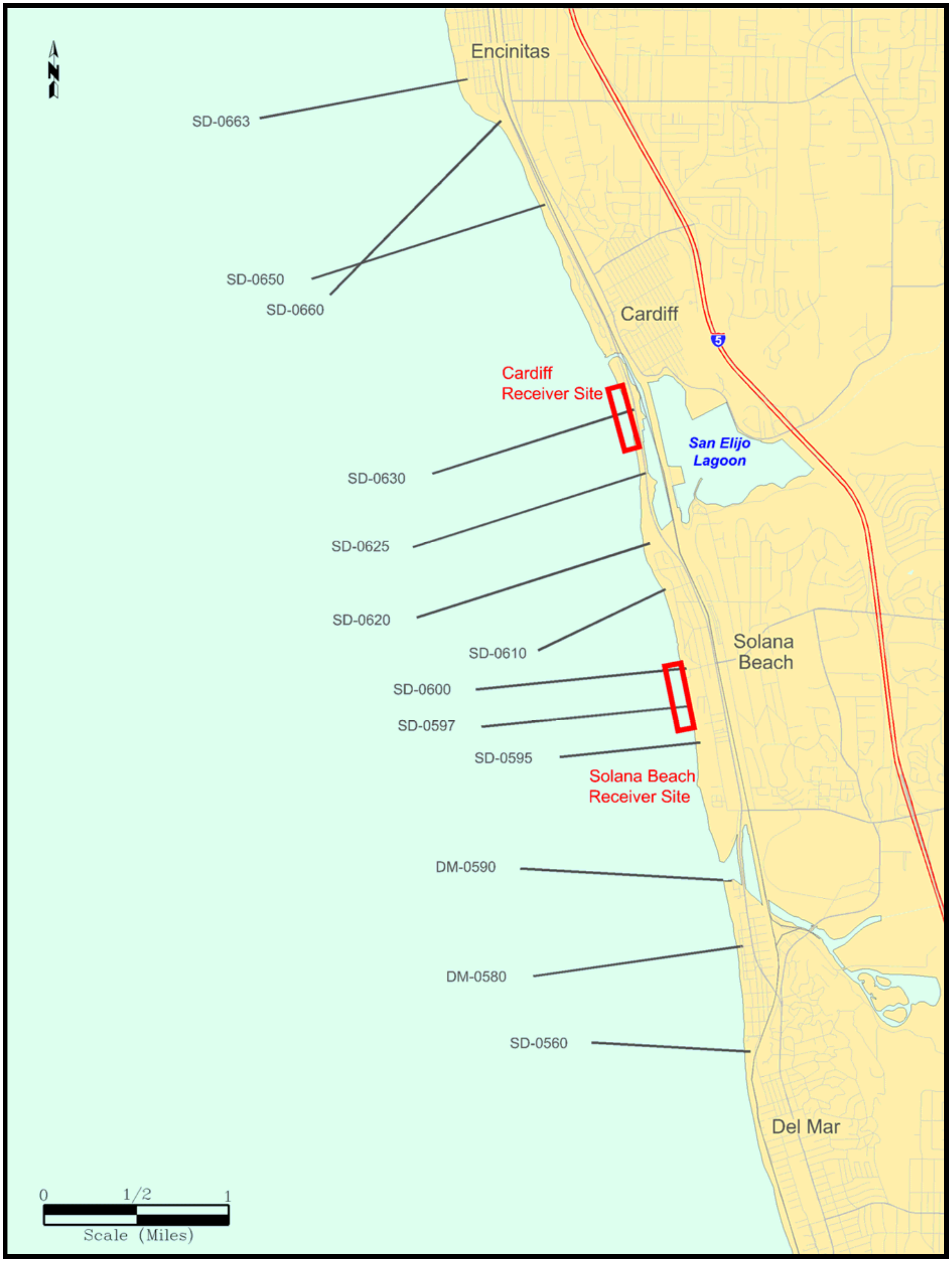


Figure 32. Location Map for Solana Beach and Cardiff Receiver Sites

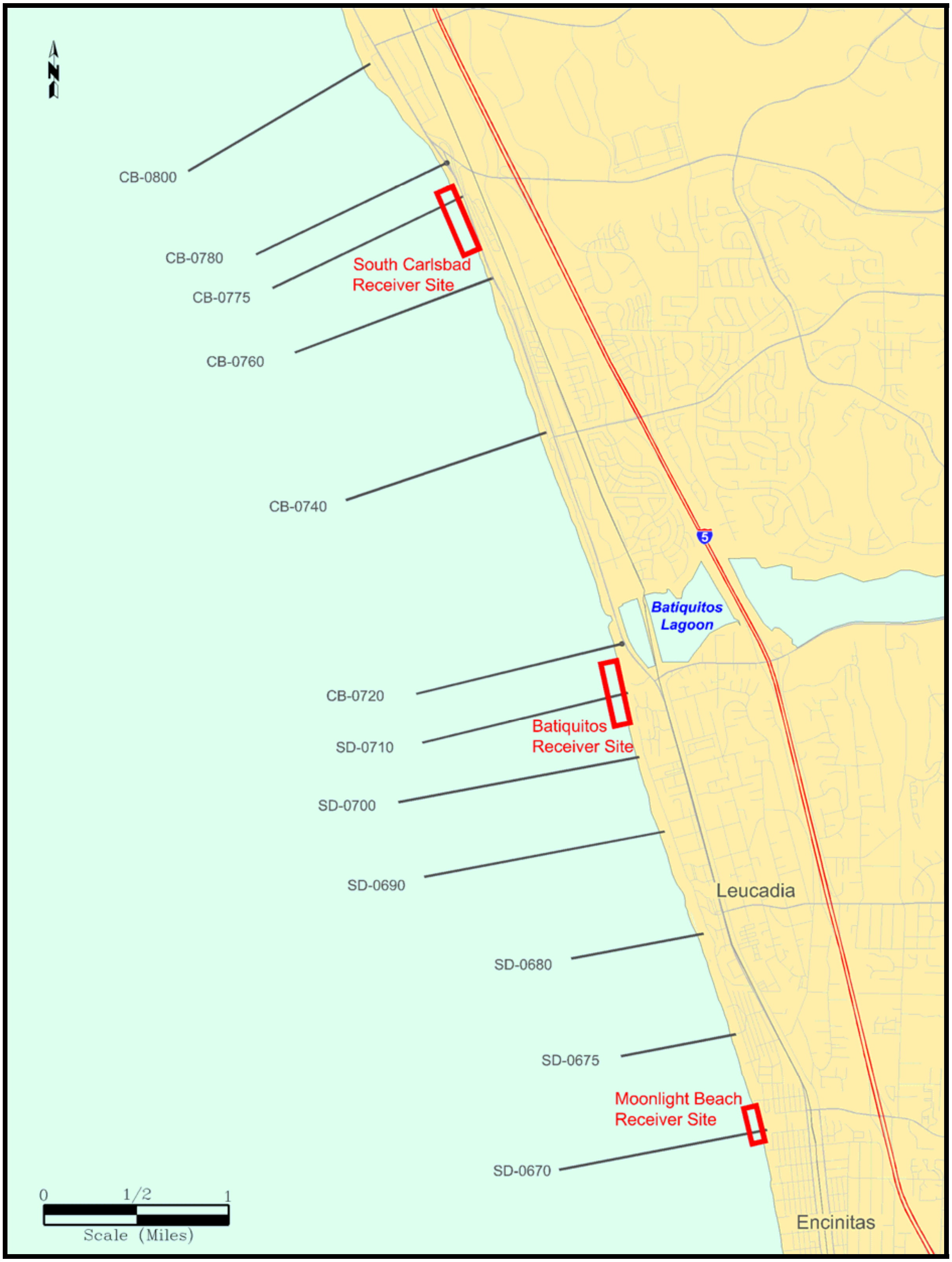


Figure 33. Location Map for Moonlight, Batiquitos and S. Carlsbad Receiver Sites

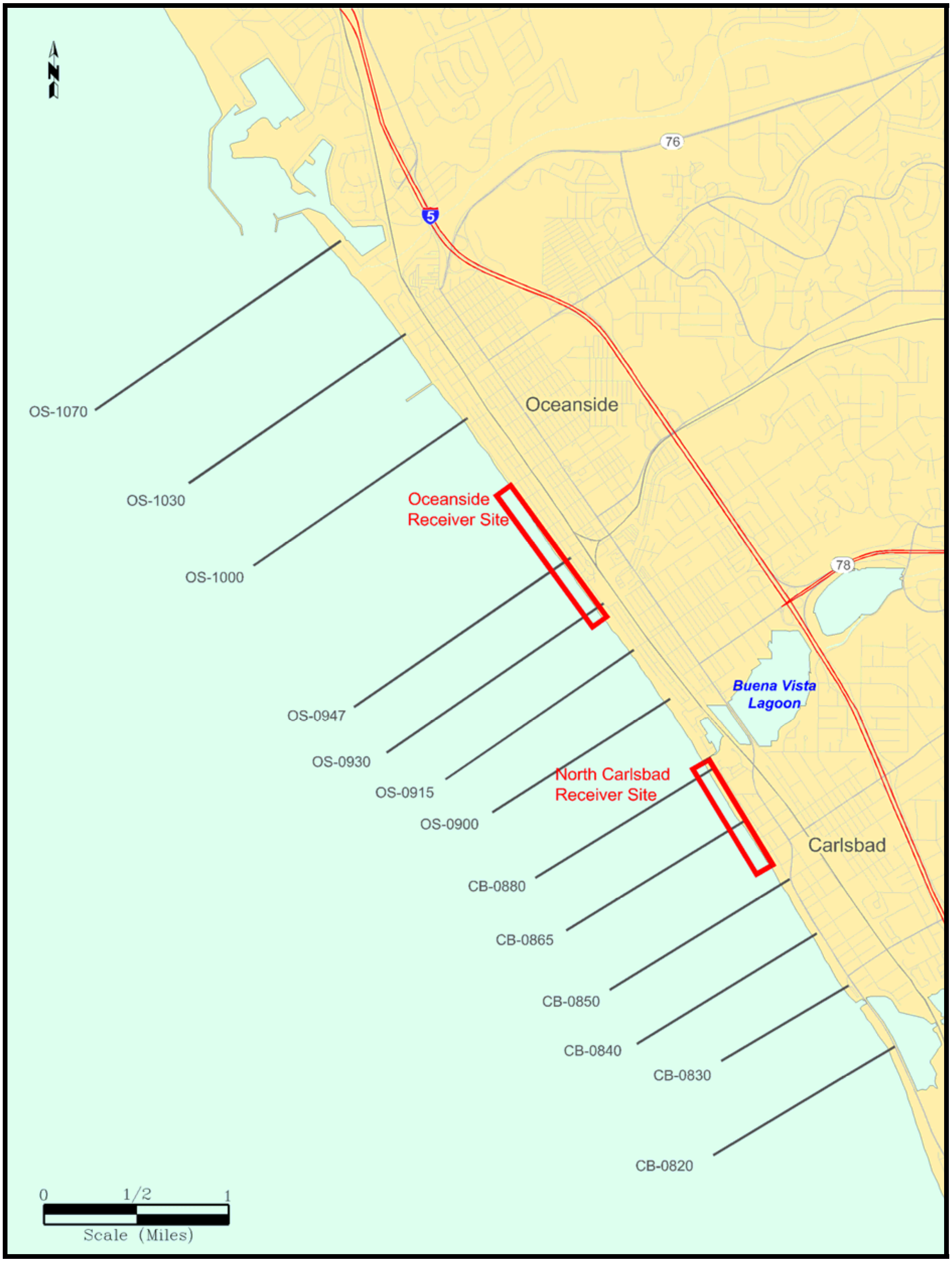


Figure 34. Location Map for North Carlsbad and Oceanside Receiver Sites

November 2011 (Pre-RBSP II)

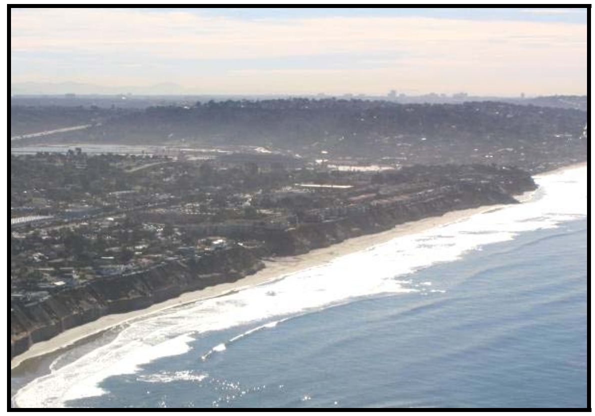
December 2012 (2.5 months after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 1. Imperial Beach Receiver Site, November 2011 through October 2015

November ***2011 (Pre-****RBSP II)*



December 2012 (1 month after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 2. Solana Beach Receiver Site, November 2011 through October 2015

November 2011 (Pre-RBSP II)

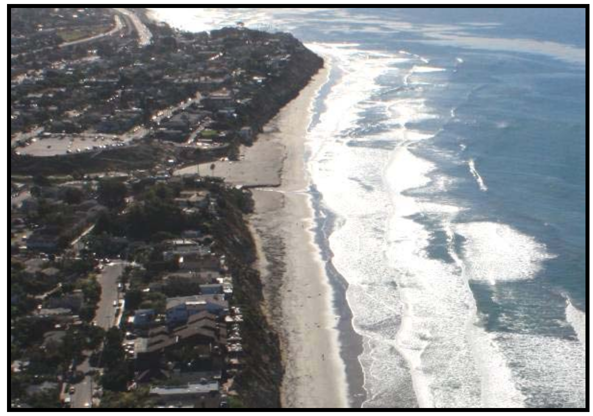
December 2012 (2 months after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 3. Cardiff Receiver Site, November 2011 through October 2015

November 2011 (Pre-RBSP II)

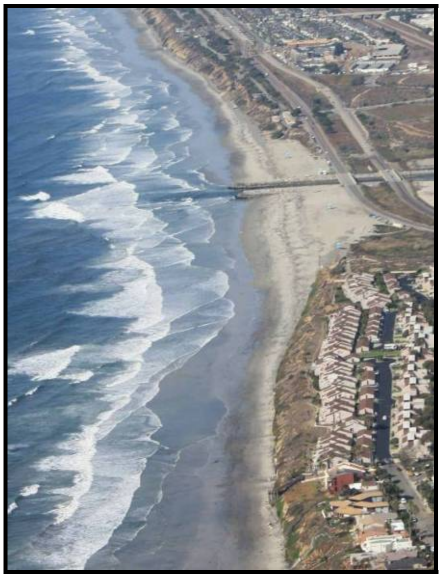


December 2012 (2 months after nourishment)

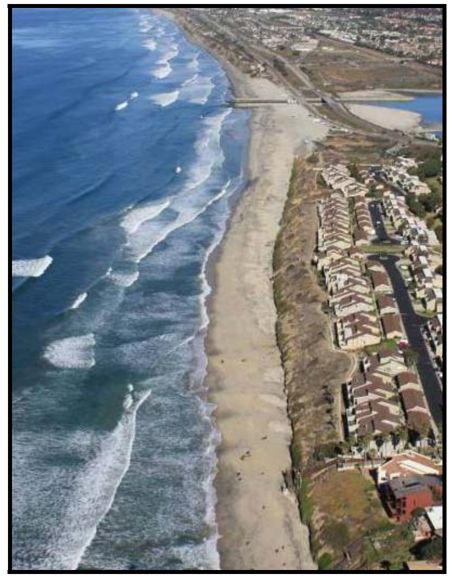
October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 4. Moonlight Beach Receiver Site, November 2011 through October 2015



Nov. 2011 (Pre-RBSP II)



December 2012 (1 month after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 5. Batiquitos Receiver Site, November 2011 through October 2015

November 2011 (Pre-RBSP II)

December 2012 (1 month after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 6. South Carlsbad Receiver Site, November 2011 through October 2015

November 2011 (Pre-RBSP II)

December 2012 (1 month after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 7. North Carlsbad Receiver Site, November 2011 through October 2015

November 2011 (Pre-RBSP II)

December 2012 (2 months after nourishment)

October 2014 (2 years after nourishment)

October 2015 (3 years after nourishment)

Plate 8. Oceanside Receiver Site, November 2011 through October 2015

6. LAGOON ENTRANCE CONDITION

Section 6 evaluates the condition of five lagoon entrances in the Oceanside Littoral Cell. The focus of this section is the four-year period between Fall 2012 to Fall 2016 rather than the entire five-year RBSP II Monitoring Period. This approach was adopted based on the assumption that the fills exerted no material impacts to the lagoon entrances prior to Fall 2012 because the RBSP II fill construction commenced late during the 2012 Monitoring Year (Table 3).

An overview is provided in Section 6.1, followed by a discussion of each entrance in Section 6.2. The location of each entrance is indicated in Figure 1. Although aerial photos of the lagoons were omitted in 2016, photos of each site obtained between 2011 and 2015 are provided in Plates 9 through 13 at the end of this section 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- or near-average rainfall persisted during 14 of the 18 years that followed the 1997-98 El Niño event (1999 to 2016). The exceptions were 2005 (18.1 inches), 2010 (12.8 inches), 2011 (11.0 inches), and 2015 (12.3 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. During the four years following the RBSP II, above-average precipitation occurred only in 2015.

Two periods are considered to represent baseline conditions by which to measure the potential impacts of the RBSP II. Each period encompasses time frames that were judged to be uninfluenced by the RBSP I. The frequency of lagoon entrance closures and openings (both natural and mechanically assisted) were assessed for each period. In addition, the estimated dredging rates associated with maintenance operations also were evaluated. The baseline period prior to RBSP I varies among the lagoons from five to 47 years in accordance to the data available. When considering maintenance dredging volumes, the pre-RBSP I period was restricted to the eight-year period between 1994 and 2001 (where such data were available). The six-year span from 2007 to 2012 was selected to represent the pre-RBSP II condition. This period was chosen because the influence of the RBSP I fills in the Oceanside Cell (both in terms of shoreline and shorezone volume gains) had largely diminished by 2007, and the RBSP II fills did not exert any impacts to the lagoons during the 2012 Monitoring Year.

Figure 35 shows the average percentage of time that each of the five lagoons in the Oceanside Littoral Cell remained open to tidal exchange prior to both the RBSP I and the RBSP II, and subsequent to the RBSP II. As indicated in the figure, the pre-RBSP I period of record for each lagoon varies from five to 47 years. The two jetty-stabilized entrances, Agua Hedionda and Batiquitos, have 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. Prior to RBSP I, the lagoons were open 43% of the time at San Elijo, 77% at San Dieguito, and 93% at Los Peñasquitos. More recently, during the six year period preceding the RBSP II, the values varied from 94% at San Elijo, 96% at San Dieguito, and 89% at Los Peñasquitos.

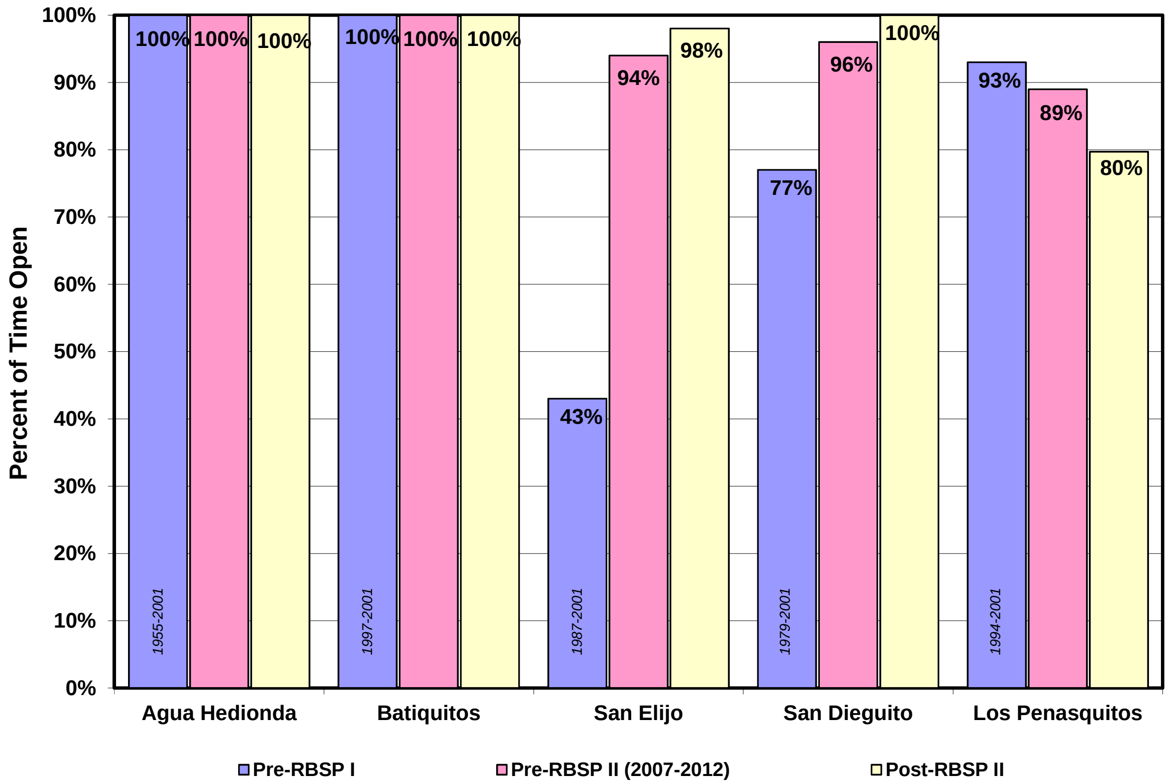


Figure 35. Percentage of Time Lagoon Entrances Open to Tidal Exchange Prior to RBSP I and RBSP II, and Subsequent to RBSP II

The two jetty-stabilized entrance channels remained open to the full range of tidal exchange during the post-RBSP II period (2013 through 2016 Monitoring Years). At San Dieguito Lagoon, where lagoon restoration was completed in 2011, the inlet also remained open for the entire post-RBSP II period. The unstabilized entrance channel at San Elijo remained open for the first three years following the RBSP II with the help of maintenance operations conducted each year (Figure 36). The lagoon closed briefly for the first time during the post-RBSP II period in April 2016. The entrance was opened mechanically in May, with a channel enlargement performed in June. Although the lagoon was closed on purpose for 19 days in 2015 to support maintenance activities, this brief artificial closure was not included in the post-RBSP II statistics. As such, the lagoon was open 98% of the time during the post-RBSP II period. At Los Peñasquitos, the unstabilized channel closed 11 times during the four-year period following the RBSP II, with six of the closures occurring in 2016. Mechanical intervention was required to re-establish tidal exchange on nine occasions, while the lagoon opened naturally after two of the closures (Figure 49). Additional channel enlargements were performed in 2014 and 2016. As a result, the inlet was open 80% of the time during the post-RBSP II period.

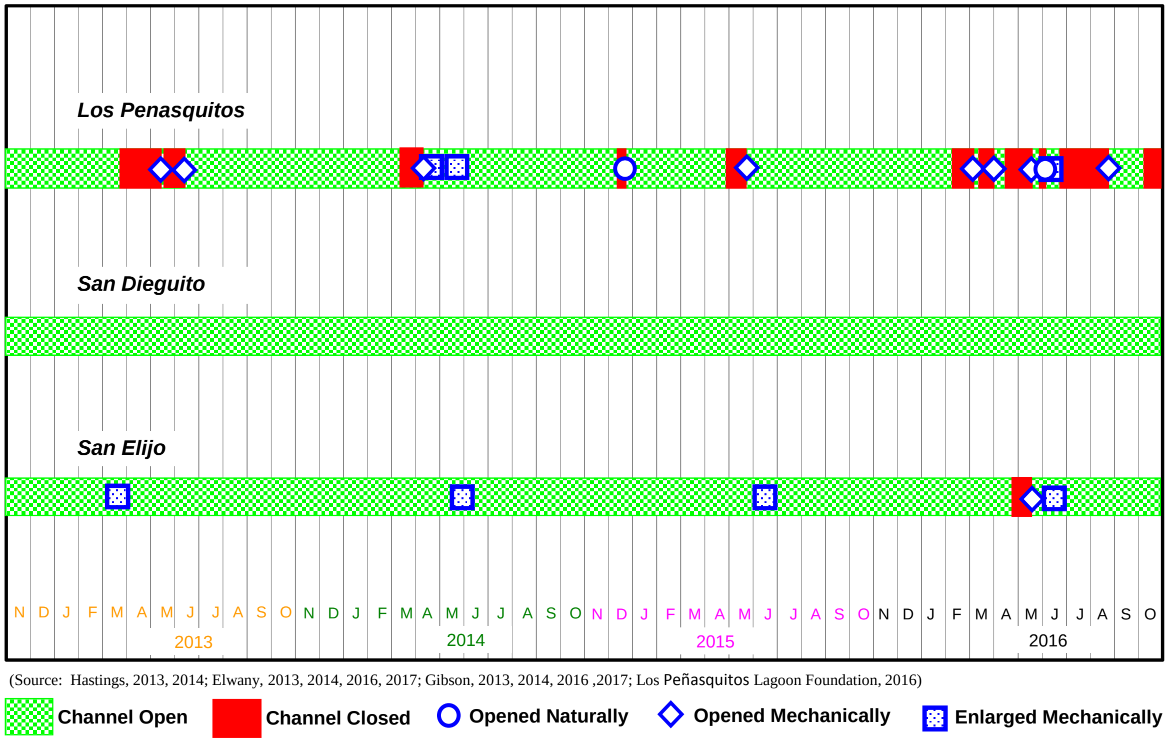


Figure 36. Condition of Unstabilized Lagoon Entrances Following the RBSP II

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 pre-RBSP II period (2007 to 2012) are shown in Tables 28 and 29, respectively. Table 30 provides the bypassing quantities attributable to the post-RBSP II period (2013 to 2015). Many of these values were presented previously in Section 2.2.3. The dredge rates following the RBSP II are compared with those during the baseline periods (pre-RBSP I and pre-RBSP II) in Figure 37.

As described in Section 2, 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 in Tables 28 through 30 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.

Table 28. Lagoon Dredging Attributable to Sedimentation Occurring Between November 1993 and October 2001 (Pre-RBSP I)

Bypass Project	Date	Activity	Dredge Quantity (cy)
Agua Hedionda Lagoon	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)**		
Batiquitos Lagoon	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 **(2)**		
San Elijo Lagoon	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 **(3)**		
San Dieguito Lagoon	2000	Bypassing	5,000
	2001	Bypassing	5,000
	Average Annual Dredge Rate at San Dieguito Lagoon = 5,000 cy/yr **(4)**		
Los Peñasquitos Lagoon	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 **(5)**		

Source: Dillingham, 2002; Tucker, 2002; Gibson, 2005; Elwany 2011

Notes:
(1) Rate computed for the seven-year period (1995 to 2001).
(2) Rate computed for the four-year period following lagoon restoration (1998 to 2001).
(3) Rate computed for the eight-year period (1994 to 2001).
(4) Rate computed for the two-year period for which data are available (2000 to 2001).
(5) Rate computed for the six-year period for which data are available (1996 to 2001).

Table 29. Lagoon Dredging Attributable to Sedimentation Occurring Between November 2006 and October 2012 (Pre-RBSP II)

Bypass Project	Date	Activity	Dredge Quantity (cy)
Agua Hedionda Lagoon	2009	Bypassing	299,000
	2011	Bypassing	226,000
	2012	Bypassing	74,000 [1]
	Average Annual Dredge Rate at Agua Hedionda Lagoon = 120,000 cy/yr [2]		
Batiquitos Lagoon	2012	Bypassing	112,000
	Average Annual Dredge Rate at Batiquitos Lagoon = 22,000 cy/yr [2]		
San Elijo Lagoon	2008	Bypassing	23,000
	2009	Bypassing	19,000
	2010	Bypassing	21,000
	2011	Bypassing	23,000
	2012	Bypassing	24,000
	Average Annual Dredge Rate at San Elijo Lagoon = 22,000 cy/yr [2]		
San Dieguito Lagoon	2008	Bypassing	8,000
	2011	Bypassing	40,000
	Average Annual Dredge Rate at San Dieguito Lagoon = 12,000 cy/yr [3]		
Los Peñasquitos Lagoon	2008	Bypassing	29,000
	2009	Bypassing	23,000
	2010	Bypassing	24,000
	2011	Bypassing	23,000
	2012	Bypassing	13,000
	Average Annual Dredge Rate at Los Peñasquitos Lagoon = 22,000 cy/yr [2]		

Source: Gibson, 2012, 2013; Trujillo, 2009, 2010, 2011; Henika, 2010, 2012; Elwany 2009, 2011, 2012; Merkel, 2012; Hastings, 2013

Notes: (1) No dredging conducted in 2012. Quantity represents 25% of the volume removed in 2015.
(2) Rate computed for the five-year period (2008 to 2012).
(3) Rate computed for the four-year period (2008 to 2011).

Table 30. Lagoon Dredging Attributable to Sedimentation Occurring Between November 2012 and October 2016 (Post-RBSP II)

Bypass Project	Date	Activity	Dredge Quantity (cy)
Agua Hedionda	2015	Bypassing	221,000
	Average Annual Bypass Rate at Agua Hedionda = 74,000 cy/yr (1)		
Batiquitos Lagoon	-	-	-
	Average Annual Bypass Rate at Batiquitos Lagoon = n/a		
San Elijo Lagoon	2013	Bypassing	26,000
	2014	Bypassing	23,000
	2015	Bypassing	22,000
	2016	Bypassing	22,000
	Average Annual Bypass Rate at San Elijo Lagoon = 23,000 cy/yr (2)		
San Dieguito Lagoon			-
	Average Annual Bypass Rate at San Dieguito Lagoon = n/a		
Los Peñasquitos Lagoon	2013	Bypassing	33,000
	2014	Bypassing	48,000
	2015	Bypassing	23,000
	2016	Bypassing	60,000
	Average Annual Bypass Rate at Los Peñasquitos Lgn = 41,000 cy/yr (2)		

Sources: Gibson 2013, 2014, 2015, 2016, 2017; Elwany, 2017; Hastings, 2014, 2015; Los Peñasquitos Lagoon Foundation, 2016, 2017

Notes: (1) Rate computed for three-year period (2013 to 2015). (2) Rate computed for four-year period (2013 to 2016)

At Los Peñasquitos Lagoon, dredging was conducted in 2000 and 2002 (Section 2.2.3). Hence, the material removed in 2002 represented sedimentation that occurred in both 2001 (pre-RBSP I) and 2002 (after RBSP I). In this case, half of the volume removed in 2002 was attributed to the pre-RBSP I period and half was assumed to occur after the implementation of the RBSP I. The first bypassing operation conducted at Los Peñasquitos during the pre-RBSP I period was not included because it was not possible to determine the period of sedimentation for this event.

Dredging was conducted at San Dieguito Lagoon in 1999 and 2002. In this case 2/3 of the volume removed in 2002 was attributed to sedimentation during the pre-RBSP I period. More recently, San Dieguito Lagoon was dredged in 2006 and 2008. As such, half of the volume removed in 2008 was attributed to the pre-RBSP II period, while the balance was eliminated from consideration. Similar to Los Peñasquitos, the first bypassing operation conducted at San Dieguito during the pre-RBSP I period was not included because it was not possible to determine the period of sedimentation.

Bypassing was conducted at Agua Hedionda for the first time during the post-RBSP II period in 2015 (the first time dredging has been conducted since 2011). In this case, 3/4 of the volume removed in 2015 was attributed to the post-RBSP II period and 1/4 was assumed to have occurred prior the implementation of the RBSP II. The pre-RBSP II amount is attributed to 2012 in Table 29, even though no actual dredging occurred that year.

The baseline average annual dredge rates (Figure 37) were highest at Agua Hedionda, ranging from 182,000 cy/yr (pre-RBSP I) to 120,000 cy/yr (pre-RBSP II). At Batiquitos, the rates ranged from 16,000 to 22,000 cy/yr. However, because lagoon restoration was undertaken at Batiquitos during the pre-RBSP I period, this rate is not meaningful. At the three unstabilized lagoons (San Elijo, San Dieguito, and Los Peñasquitos) the dredge rates were modest, varying between 5,000 and 22,000 cy/yr. With the exception of Agua Hedionda, the pre-RBSP II dredge rates slightly exceeded the corresponding pre-RBSP I values.

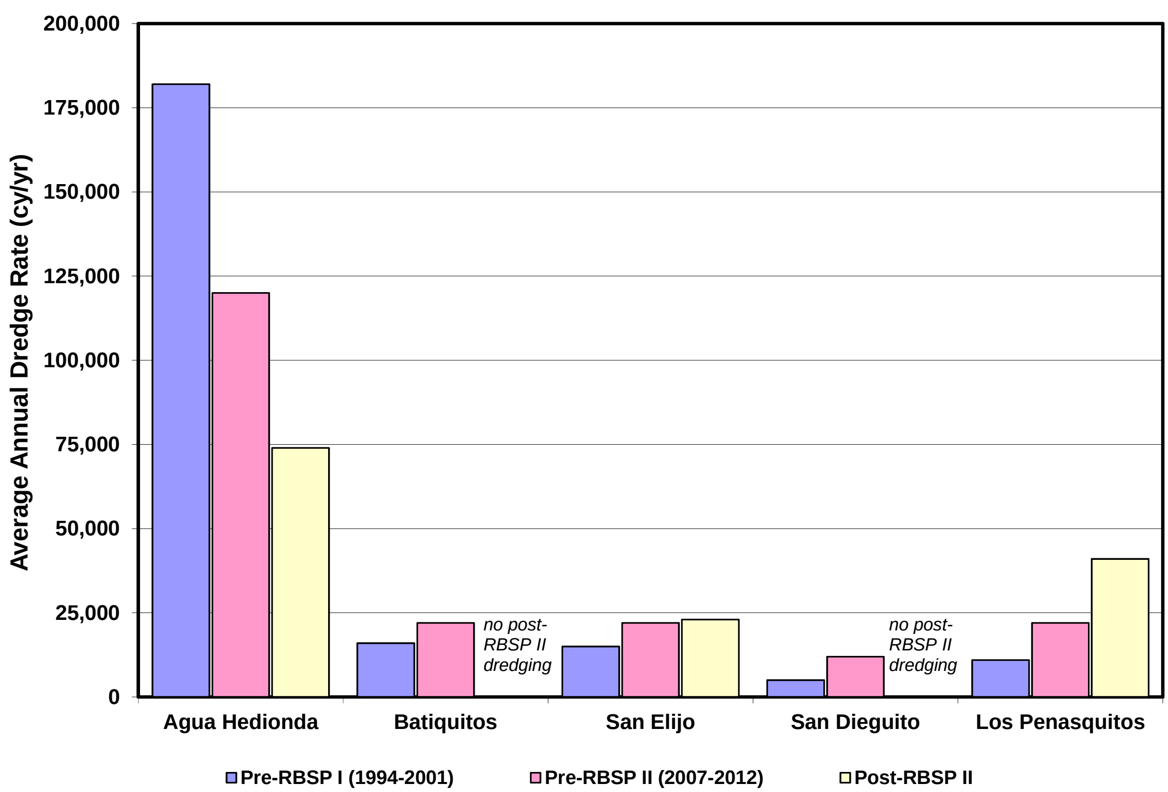


Figure 37. Average Annual Dredge Rates Preceding RBSP I and RBSP II, and Subsequent to RBSP II

Dredging has not been performed at Batiquitos or San Dieguito Lagoon since implementation of the RBSP II. Bypassing was conducted at Agua Hedionda on one occasion during the post-RBSP II period, equating to 74,000 cy/yr (taken over the 3-year period from 2013 to 2015). Maintenance dredging was conducted during all four years of the post-RBSP II period at San Elijo and Los Peñasquitos (23,000 and 41,000 cy/yr, respectively). The post-RBSP II rate was well below the historical average rates at Agua Hedionda, exceeded the historical average rates at Los Peñasquitos, and was nearly identical to the pre-RBSP II average rate at San Elijo.

6.2. Lagoon Entrance Performance

The condition of each lagoon entrance during the post-RBSP II period (2013 through 2016 Monitoring Years) is described below. To provide a basis for post-project comparisons, the pre-RBSP I and pre-RBSP II performance also is summarized. As discussed previously, the RBSP II fills exerted no material impacts to the lagoon entrances during the 2012 Monitoring Year. As such, the pre-RBSP II baseline period includes the 2012 Monitoring Year. Ground photographs of the three unstabilized channels appear in Appendix F.

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.

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. The average annual dredge rate was approximately 182,000 cy/yr. More recently, during the pre-RBSP II period (2007 to 2012) maintenance dredging was conducted in 2009 (299,000 cy) and 2011 (226,000 cy). As discussed above, 1/4 of the 2015 dredge (74,000 cy) quantity was attributed to the pre-RBSP II period. Taken together these operations equate to an average annual rate of 120,000 cy during the pre-RBSP II period. The bypassing rate produced by the single dredging operation conducted during the post-RBSP II period (74,000 cy/yr, taken over the 3-year period from 2013 to 2015) was well below the baseline averages.

Plate 9 displays the condition of the north entrance to Agua Hedionda Lagoon from November 2011 through October 2015. The 2011 dredging operations were conducted several months before the November 2011 photo was obtained. The next five photos (December 2012 through October 2014) show the progressive return of the flood tide shoal in the region landward of the jetties. The shoal is absent from the final photo, having been removed during the 2015 dredging operations. Photos were not obtained as part of the 2016 monitoring program.

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.

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 previously in Table 28, 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.

Maintenance dredging was conducted only once during the pre-RBSP II period (2007 to 2012). In 2012, approximately 112,000 cy were removed from the lagoon and placed on the adjacent beaches. Taken over the five-year period from 2008 to 2012, this amount equates to a dredging rate of approximately 22,000 cy/yr. Dredging has not been performed during the post-RBSP II period.

Plate 10 illustrates the condition of the Batiquitos Lagoon entrance channel from November 2011 through October 2015. In the first photo (November 2011), substantial shoals are evident in the middle basin landward of the railroad trestle. These features are much less pronounced in the May 2012 and December 2012 photos, having been removed during the 2012 dredging operations. The next five photos (May 2013 through October 2015) show the progressive return of the shoal. Photos were not obtained in 2016.

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.

During the pre-RBSP II period (2007 to 2012), the lagoon was open to tidal exchange 94% of the time. The most plausible explanation for the improved performance of the entrance relative to the pre-RBSP I period is the increased dredging within the lagoon commencing in 2000 made possible by additional funding. The average closure frequency during the pre-RBSP II period was 1.0 times per year, while the average frequency of mechanical opening was 1.2 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 pre-RBSP II period.

The 2013 beach profiles indicate that material from the RBSP II Moonlight Beach fill arrived at Transect SD-0660 (Swamis) during the first winter following nourishment, and reached Transect SD-0650 (San Elijo State Beach) within the first year. Additional gains occurred at Transect SD-0650 in 2014 as the material continued to disperse downcoast. Recent profile gains at Transects SD-0630 and SD-0625 suggest that the nourishment material may have reached the Cardiff area (south of the lagoon entrance) during 2015. These gains were largely reversed during the 2015-2016 El Niño year.

Plate 11 shows the condition of the San Elijo entrance channel between November 2011 and October 2015 (no photos were obtained in 2016). The lagoon entrance remained open to tidal exchange during the first two years of the post-RBSP II period, with one maintenance operation conducted each year during May (Figure 36). The lagoon was closed on purpose for eight days in June 2015 to support maintenance activities. The lagoon closed in April 2016 and was opened mechanically 19 days later. The channel was further enlarged in May. Approximately 93,000 cy of material were removed from the lagoon channels during the five maintenance operations, equating to a dredge rate of 23,000 cy/yr during the post-RBSP II period. This rate was slightly more than the pre-RBSP II average (22,000 cy/yr). The occurrence of just one natural closure and the historically similar maintenance effort in the post-RBSP II period suggest that any impact from the RBSP II beach fill at Cardiff was modest and short-lived. Comparison to the pre-RBSP I dredge rate is not meaningful because maintenance practices changed in 2000.

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.

The lagoon was open to tidal exchange 96% of the time during the pre-RBSP II period (2007 to 2012). The entrance closed on only two occasions during this period, yielding an average closure frequency of 0.3 times per year. Mechanical intervention was required to re-establish tidal exchange after each of these closures, resulting in an identical frequency of mechanical openings of 0.3 times per year. The average annual dredge rate during the pre-RBSP II period was approximately 12,000 cy/yr. However, this rate is not representative of the true long-term dredging requirement because a lagoon restoration project was initiated near the end of 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 29) because the excavation represents a change in the lagoon configuration that is outside of the bounds of the maintenance operations undertaken during recent decades.

The second phase of the restoration project consisted of excavating approximately 40,000 cy of sand from the lagoon channels adjacent to Highway 101, and placing the material on the beaches both north and south of the lagoon entrance. During this period, the lagoon was purposely closed to tidal exchange for approximately 21 days before the entrance was opened mechanically on September 29th. No maintenance dredging has been conducted since this time.

The entrance channel (Plate 12) remained open to tidal exchange during the entire post-RBSP II period (Figure 36). In addition, no maintenance has been performed during the post-RBSP II period, The November 2011 photo was obtained shortly after dredging operations were completed in the lagoon channels adjacent to Highway 101. The following photos (December 2012 to October 2015) show shoaling in these channels. No photos were obtained in 2016.

The profiles obtained at Transects DM-0590 and DM-0560 suggest that material from the Solana Beach fill did not reach the vicinity of the lagoon entrance until 2014. Additional profile gains noted at these sites in 2015 indicate that additional nourishment material from Solana Beach or Cardiff may have migrated to northern Del Mar the following year. However, the arrival of this material was not sufficient to cause an inlet closure.

6.2.5. Los Peñasquitos

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 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.

During the pre-RBSP II period (2007 to 2012), the lagoon was open to tidal exchange 89% of the time. The average closure frequency during the pre-RBSP II period was 1.7 times per year, which was identical to the average frequency of mechanical opening. Maintenance dredging was performed each year during the pre-RBSP II period, resulting in an average annual dredge rate of approximately 22,000 cy/yr.

The condition at the Los Peñasquitos entrance channel at the time of the overflights conducted between November 2011 and October 2015 is shown in Plate 13 (no photos were obtained in 2016). As indicated in Figure 36, the entrance channel closed twice during the 2013 Monitoring Year (late-March and mid-May), on one occasion during the 2014 Monitoring Year (mid-March), and twice during the 2015 Monitoring Year (December and early-April). The entrance channel closed six time during the 2016 Monitoring Year. Mechanical excavation was required to re-establish tidal exchange following nine of the closures. The channel closed a few days after the May 2013 operation, which only removed sand near the PCH bridge. Following the June 2013 maintenance operation, which consisted of removing material from the lagoon channels, the inlet remained open for the next nine months. Three maintenance operations conducted in April and May 2014 were sufficient to keep the inlet open for the remainder of the year. Although the lagoon closed in December 2014, it re-opened naturally. Only one maintenance operation was required in 2015 to re-establish tidal access. The numerous closures in 2016 suggests that the capacity of the tidal prism to maintain an opening was marginal for much of the year. The high wave energy and lack of significant rainfall during the 2015-2016 El Niño likely contributed to this condition.

Approximately 33,000 cy were removed from the lagoon channels during the two maintenance operations performed in May and June 2013. In 2014, approximately 48,000 cy of sediment were removed during three dredging operations (commencing on April 7, April 21, and May 19). The 2015 dredging activities accounted for about 23,000 cy. In keeping with the numerous closures and maintenance operations, approximately 60,000 cy were removed from the lagoon in 2016. Taken together, these amounts equate to a dredge rate of 41,000 cy/yr during the four-year post-RBSP II period. This rate was substantially greater than the average annual dredge volume during the pre-RBSP I and pre-RBSP II periods (11,000 and 22,000 cy/yr, respectively). The frequency of closures during the post-RBSP II period (2.8 times per year) exceeded the historical values (2.3 and 1.7 times per year). The frequency of maintenance operations during the post-RBSP II period (2.8 times per year) also exceed the historical values (1.6 and 1.7 times per year).

It is unlikely that the RBSP II nourishment material placed at Solana Beach in November 2012 contributed a significant amount of material to the shoaling that occurred in the lagoon channels prior to the 2013 maintenance activities. Although downcoast dispersal of the fill was evident at the south end of Solana Beach at the time of the May 2013 survey (Transect SD-0595, about 3.5 miles from the lagoon entrance), the influence of the fill material did not appear to reach the Del Mar transects (Section 5.2.2). It is estimated that approximately 50% of the RBSP II material placed at Solana Beach remained in the general area at the time of the October 2013 survey (Hearon, 2015).

The 2014 profiles obtained at Transect DM-0590 and DM-0560 suggest that material from the fill may have migrated to within about 2 miles from the lagoon entrance by the time of the May 2014 survey (Coastal Frontiers, 2015). About 60% of Solana Beach RBSP II material could be accounted for within the general placement area at the time of the October 2014 survey (Hearon, 2015). Above-water gains at Transects LJ-0460 and LJ-0450 at the time of the October 2015 survey suggest that some of the Solana Beach nourishment may have been dispersed as far south as La Jolla during the following year. While this finding suggests that material from the fill reached the lagoon mouth sometime in 2014 or 2015, it is difficult to determine how much of the sediment contributed to lagoon shoaling prior to the 2014 and 2015 dredging operations. The 2016 profiles at the two transects located nearest the lagoon entrance (TP-0520 and TP-0530) contain distinct nearshore bars, suggesting sediment from the north arrived in this region during the 2015-2016 El Niño winter. This sediment, coupled with the unusually high wave energy may have contributed to the numerous closures in 2016.

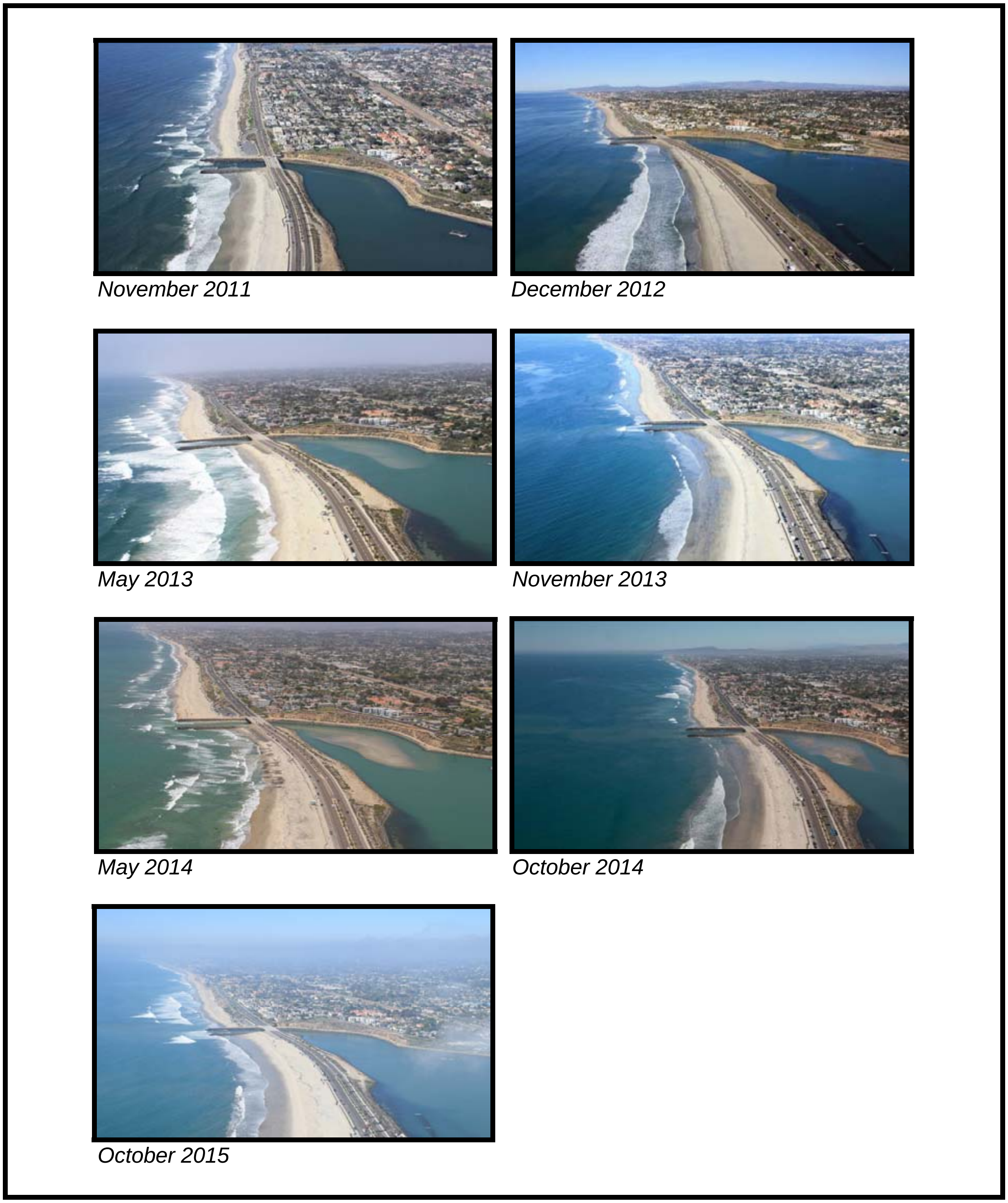


Plate 9. Agua Hedionda Lagoon North Entrance, Nov. 2011 through Oct. 2015

November 2011

December 2012

May 2013

November 2013

May 2014

October 2014

October 2015

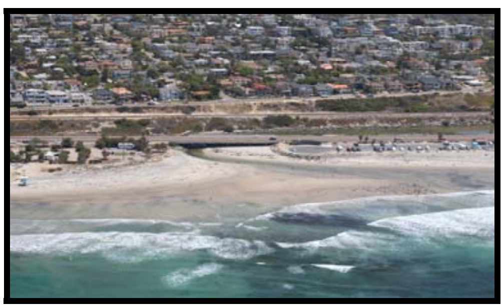
Plate 10. Batiquitos Lagoon Entrance, Nov. 2011 through Oct. 2015

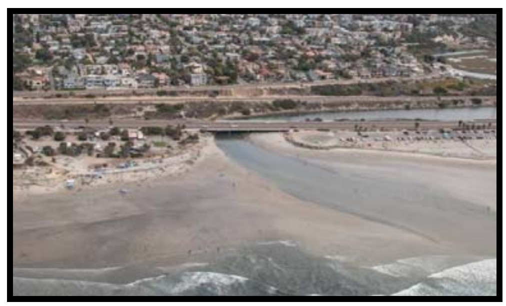

November 2011


December 2012


May 2013


November 2013


May 2014


October 2014


October 2015

Plate 11. San Elijo Lagoon Entrance, Nov. 2011 through Oct. 2015

November 2011

December 2012

May 2013

November 2013

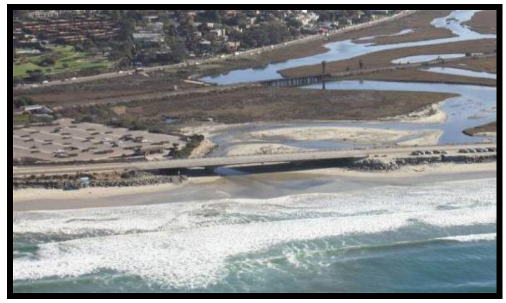
May 2014

October 2014

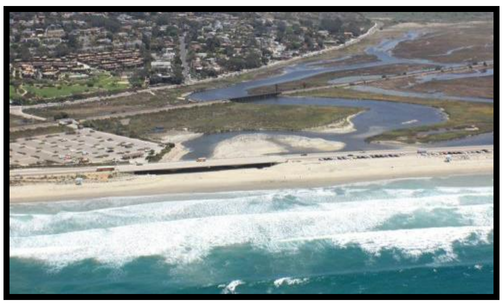
October 2015

Plate 12. San Dieguito Lagoon Entrance, Nov. 2011 through Oct. 2015

November 2011



December 2012



May 2013

November 2013

May 2014

October 2014

October 2015

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

7. OFFSHORE BORROW SITE CONDITIONS

This section assesses the condition of the three offshore borrow sites utilized for the RBSP II. Borrow site monitoring consisted of obtaining bathymetric data and sediment samples at each of the three dredge sites utilized for the RBSP II (MB-1 in the Mission Beach Cell, and SO-6 and SO-5 in the Oceanside Cell). The general location of the each borrow site was shown previously in Figures 10a and 10b, while more detailed maps are provided in Figures 38 and 39. The results of the bathymetric surveys are described in Section 7.1, followed by a discussion of the sediment sample analysis in Section 7.2. All figures are provided at the end of this section.

7.1. Bathymetric Changes

Bathymetry was obtained along one transverse and one longitudinal transect passing through the approximate center of each dredged depression (Figure 38 through 40). As discussed in Section 3.4, the data were acquired at the time of the Fall 2016 survey. Bathymetric profiles through the borrow sites along each of the transects are shown in Figures 41 through 43. To facilitate an assessment of changes that have occurred since completion of the RBSP II, each plot also includes profiles developed from a similar effort conducted in 2014 (Coastal Frontiers, 2015), and from the 2012 post-construction survey (Scott, 2013). A summary of the elevation changes on each transect is provided in Table 31.

Table 31. Elevation Changes along Borrow Site Transects Occurring Between December 2012 and October 2016

Borrow Site	Transect	Average Elevation Change		
		Dec 2012-Oct 2014	Oct 2014-Oct 2016	Dec 2012-Oct 2016
MB-1	MB-1A	-1.1 ft	-0.3 ft	-1.4 ft
	MB-1B	0.0 ft	0.0 ft	0.0 ft
	average	*-0.6 ft*	*-0.1 ft*	*-0.7 ft*
SO-5	SO-5A	0.3 ft	1.2 ft	1.5 ft
	SO-5B	0.1 ft	0.2 ft	0.3 ft
	average	*0.2 ft*	*0.7 ft*	*0.9 ft*
SO-6	SO-6A	0.1 ft	0.0 ft	0.1 ft
	SO-6B	0.4 ft	0.7 ft	1.1 ft
	average	*0.3 ft*	*0.3 ft*	*0.6 ft*

The sea bottom configuration at each borrow site following dredging was characterized by distinct ridges and furrows indicative of the dredging method. As shown in Figure 40, these features were oriented along the long axis of each dredge footprint (roughly north-south at MB-1 and SO-5, and east-west at SO-6). The transects established for the borrow site monitoring were oriented both parallel and perpendicular to the ridge/furrow features.

Comparison of the 2012 and 2014 bathymetry profiles along the monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. The average elevation change along the transects oriented perpendicular to the ridge/furrow pattern was 0.1 ft or less (Table 31; Transect B for MB-1 and SO-5, and Transect A for SO-6). For the transects located parallel to these features, the average elevation change was greater, varying from shoaling of 0.4 ft to erosion of 1.1 ft (Table 31; Transect A for MB-1 and SO-5, and Transect B for SO-6). This apparent discrepancy can be explained by the orientation of the transects relative to the ridges and furrows, with those oriented perpendicular to the features displaying a near balance of erosion of the ridge tops accompanied by filling of the furrow valleys (*e.g.*, Figure 41, MB-1 Transect B). In contrast, the profiles on the transects oriented parallel to these features contain large sections dominated by either ridge erosion or furrow infilling which creates an apparent imbalance (*e.g.*, Figure 44, MB-1 Transect A from a range of 1,175 to 1,200 ft). As such, the transects oriented perpendicular to the ridge/furrow pattern are believed to provide a more accurate estimate of the bathymetric changes at the borrow sites during this period.

Additional smoothing and infilling occurred at SO-5 and SO-6 between the 2014 and 2016 surveys. The average infilling at the two SO-5 transects ranged from 0.2 to 1.2 ft. At SO-6, the depths along Transect A were essentially unchanged over the two-year period. In contrast, shoaling of up 4 ft prevailed at the onshore portion of the SO-6 dredge area (Transect B), producing and average change of 0.7 ft. Changes at MB-01 were modest during the past two-year period, with depths essentially unchanged.

Over the four-year period following dredging, the shoaling at SO-6 and SO-5 averaged 0.6 and 0.9 ft, respectively. These changes equate to an infilling rate of about 0.2 ft/yr. At MB-01, the depths Transects A and B increased by an average of 0.7 ft.

7.2. Sediment Characteristics

Two representative sediment samples were obtained within the dredged footprint of each borrow site at the time of the Fall 2016 survey. The sample locations are shown in Figures 38 and 39. Gradation curves for each sample are provided in Figures 44 through 46.

Each plot also shows gradation curves for samples acquired in 2014 (Coastal Frontiers, 2015) and the range of grain sizes determined during the 2008 geophysical investigation of the borrow sites (URS, 2009). "Fines" are defined as that material passing the #200 sieve (less than 0.074 mm in diameter). The results are summarized in Table 32.

Table 32. Sediment Size Characterization at Borrow Sites

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

At MB-1, the grain size distribution curves for the samples obtained in 2014 and 2016 fell within the envelope of sediment sizes derived from the 2008 geophysical investigation with the exception of a small deviation in particle sizes near 0.8 mm for one of the 2014 samples (Figure 44). The grain size distribution curves for the samples obtained at SO-5 in 2014 and 2016 were near the middle of the envelope of in-situ sediment sizes (Figure 45). One of the 2016 samples contained a notably higher percentage of sediment in the range of fine sands (0.30 to 0.08 mm).

At SO-6, the grain size distribution curves for three of the four samples obtained in 2014 and 2016 fell near the "coarse" end of the envelope of in-situ sediment sizes (Figure 46). The exception was the 2016 sample retrieved from the onshore portion of the dredge area where shoaling of up to 4 ft was noted (Figure 43). This sample contained finer sediment than identified in the 2008 investigation, with a fines content (32%) well in excess of the in-situ range. In addition, the fines content exceeded that found in the native beach material near the site (up to 13% at the offshore end of Transect SD-0630; Richmond, 2010). This outcome suggests the preferential deposition of fine material at the onshore portion of the SO-6 dredge area. The deposition of fine material may be attributable to high energy wave conditions during the 2015-2016 El Nino winter. However, the biennial nature of the borrow site surveys make it impossible to determine if the shoaling occurred during this season.

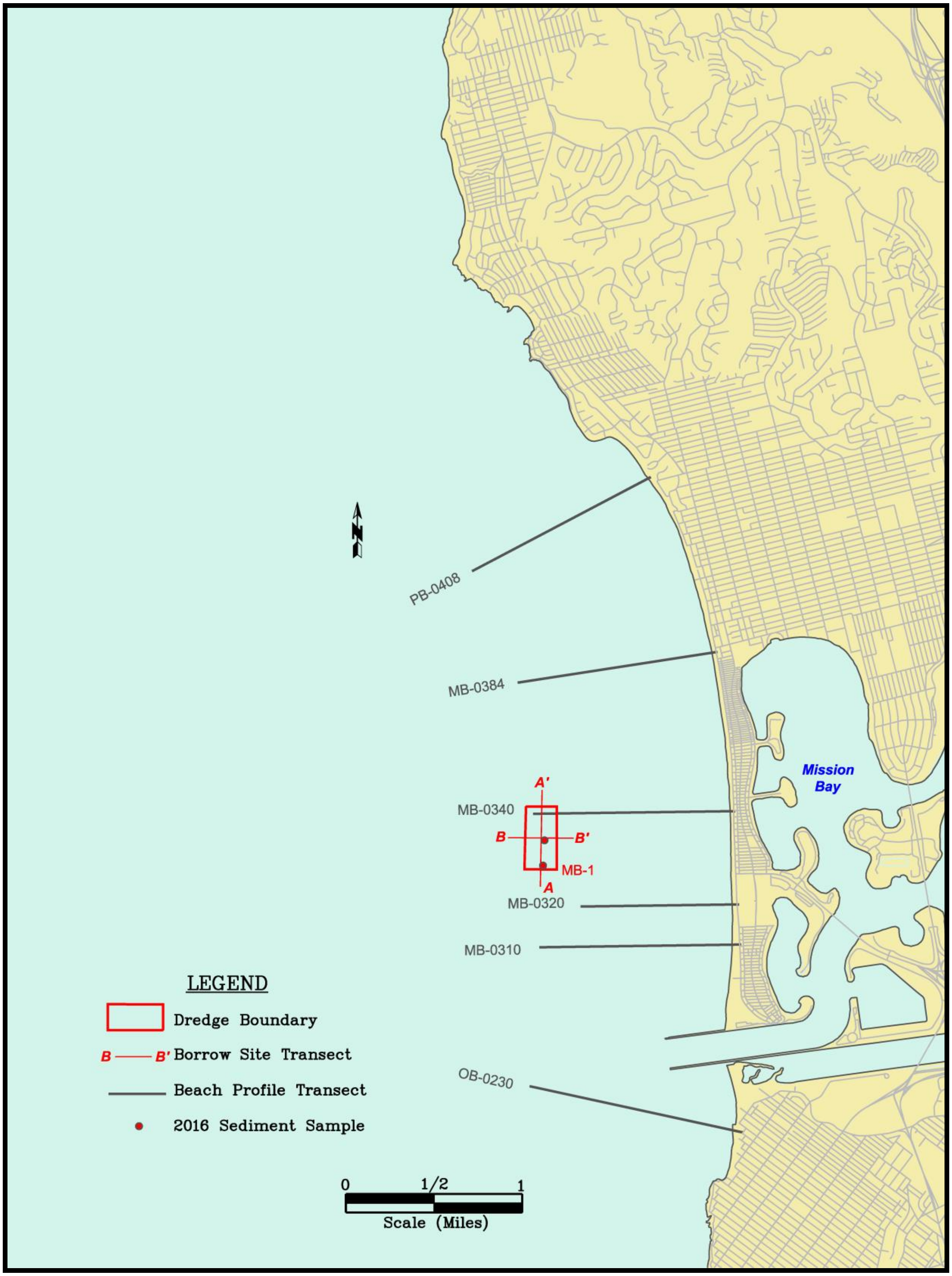


Figure 38. Borrow Site MB-1 Location Map

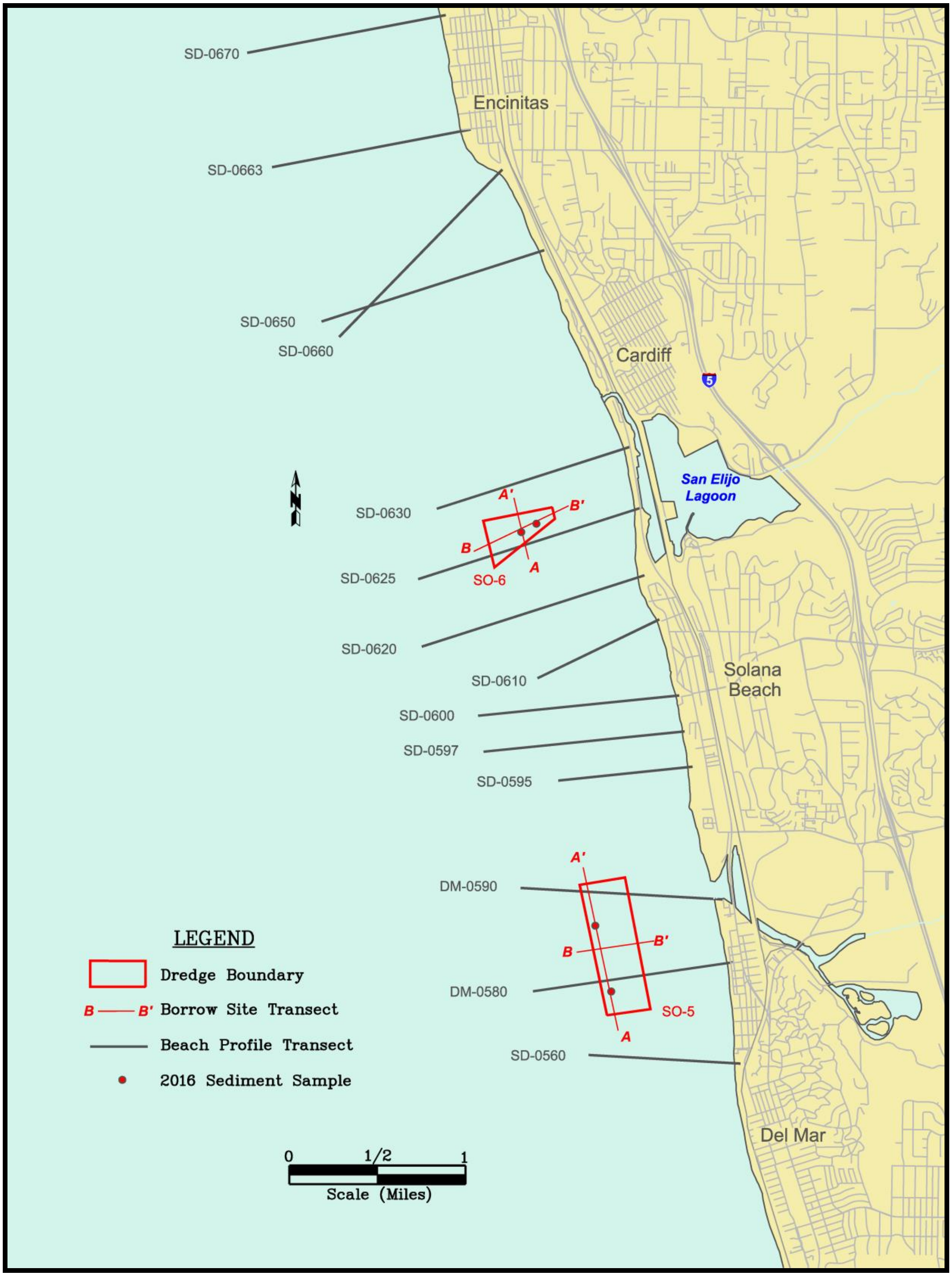


Figure 39. Borrow Sites SO-5 and SO-6 Location Map

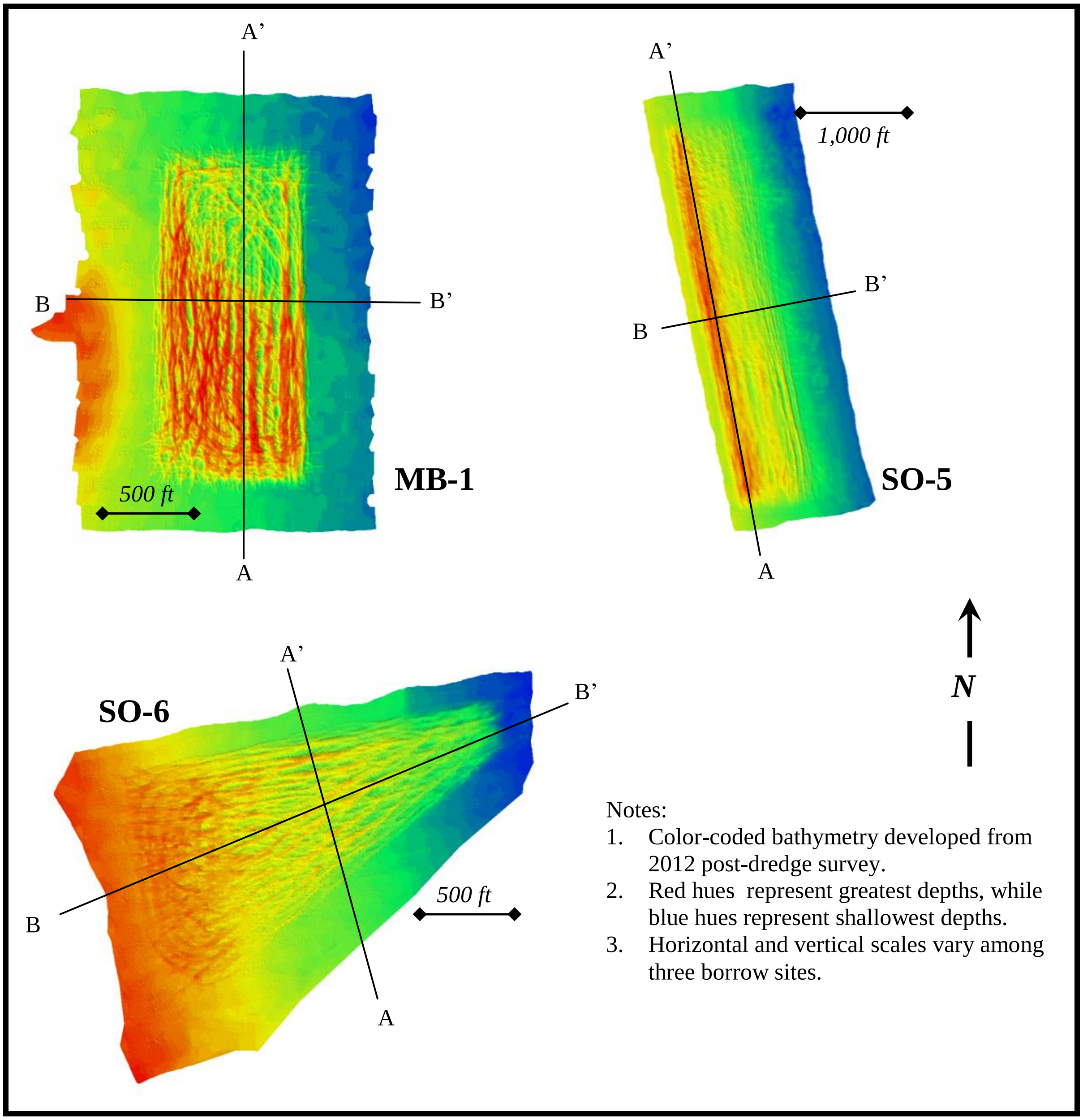


Figure 40. 2012 Post-Dredge Bathymetric Configuration of Borrow Sites

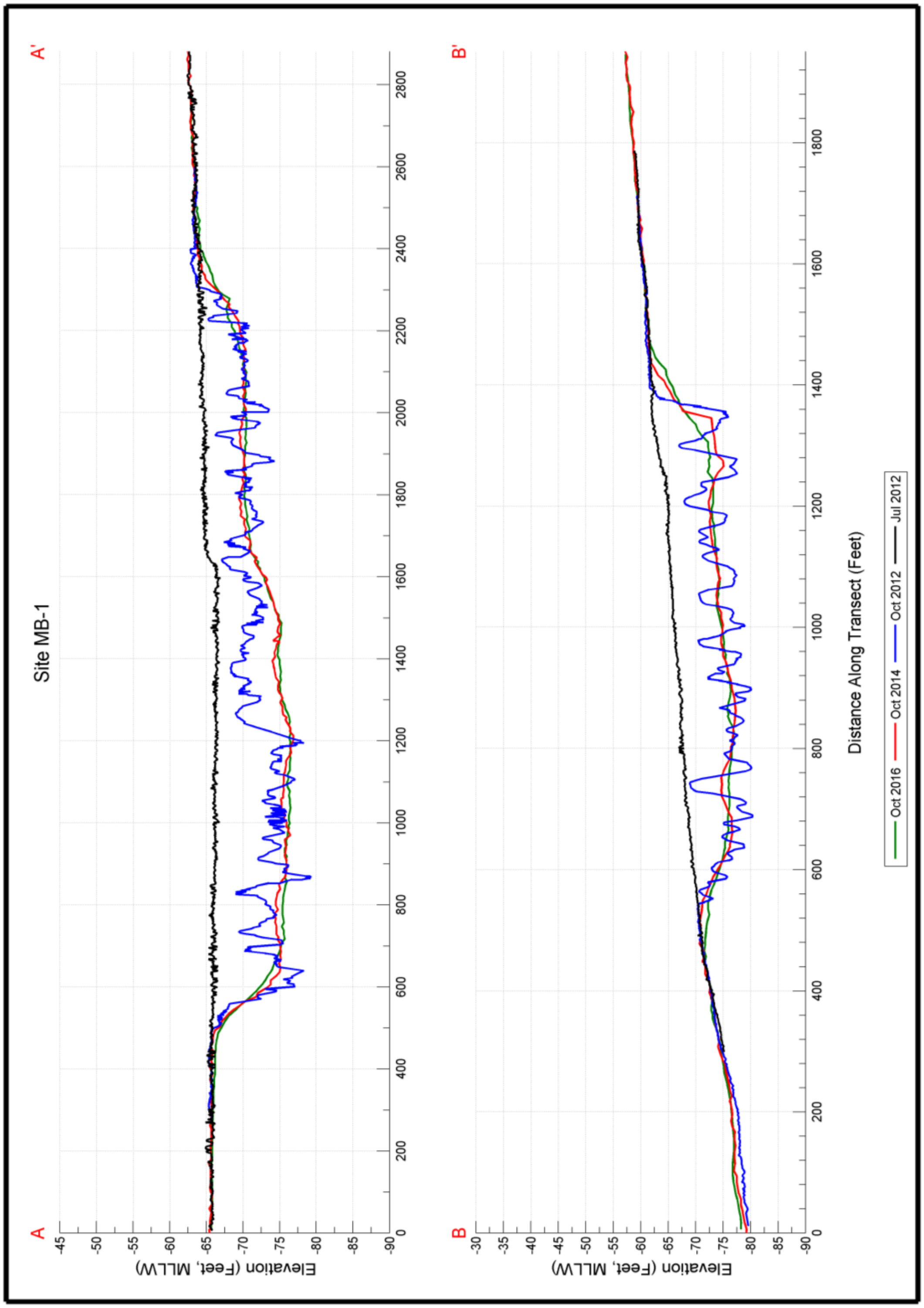


Figure 41. Bathymetric Profiles along MB-1 Borrow Site Transects

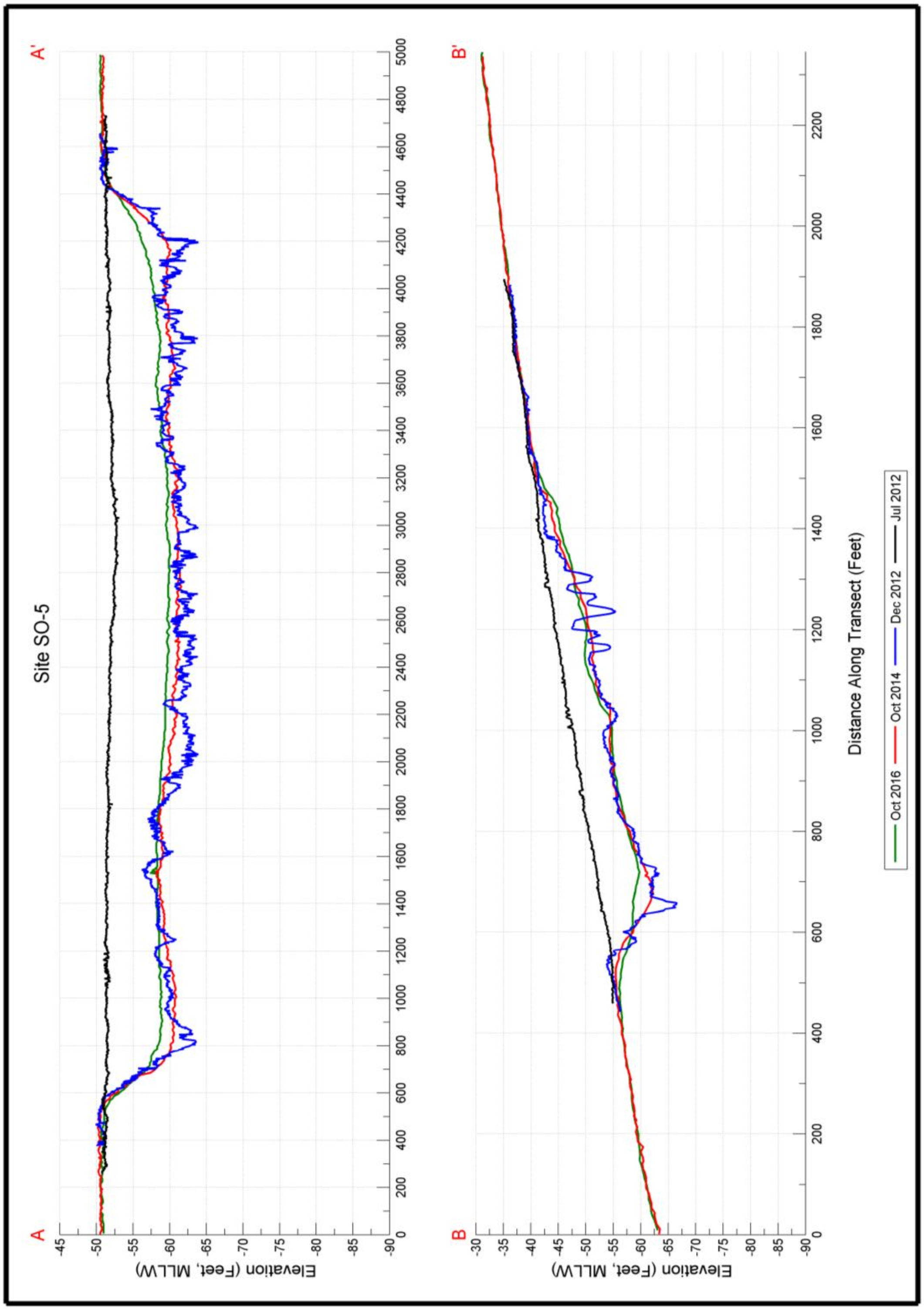


Figure 42. Bathymetric Profiles along SO-5 Borrow Site Transects

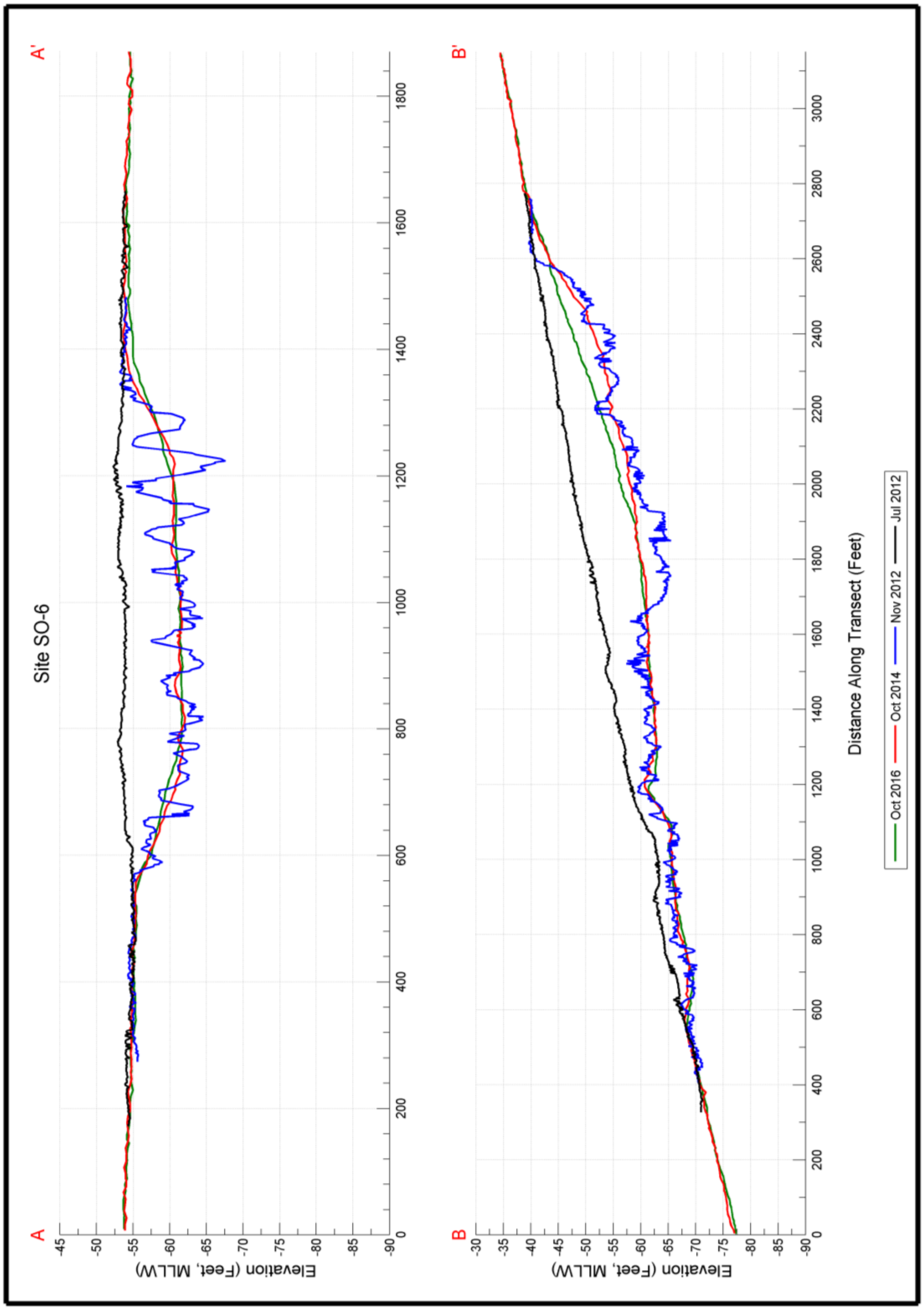


Figure 43. Bathymetric Profiles along SO-6 Borrow Site Transects

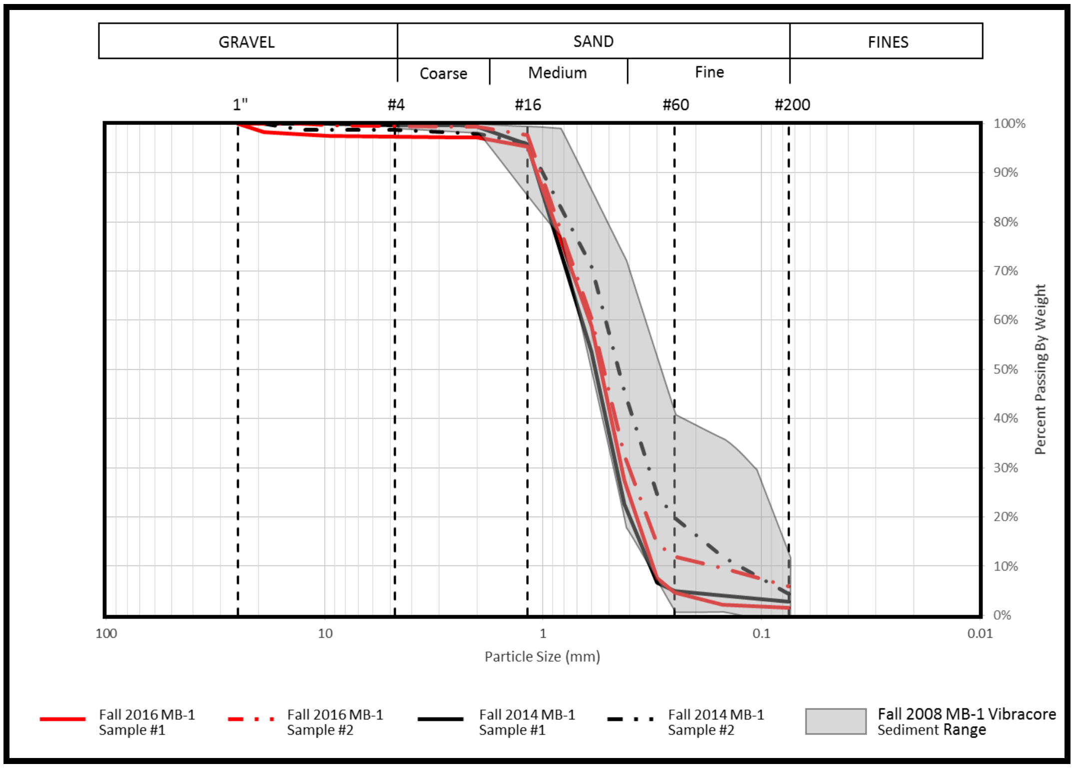


Figure 44. Grains Size Distribution Curves, MB-1

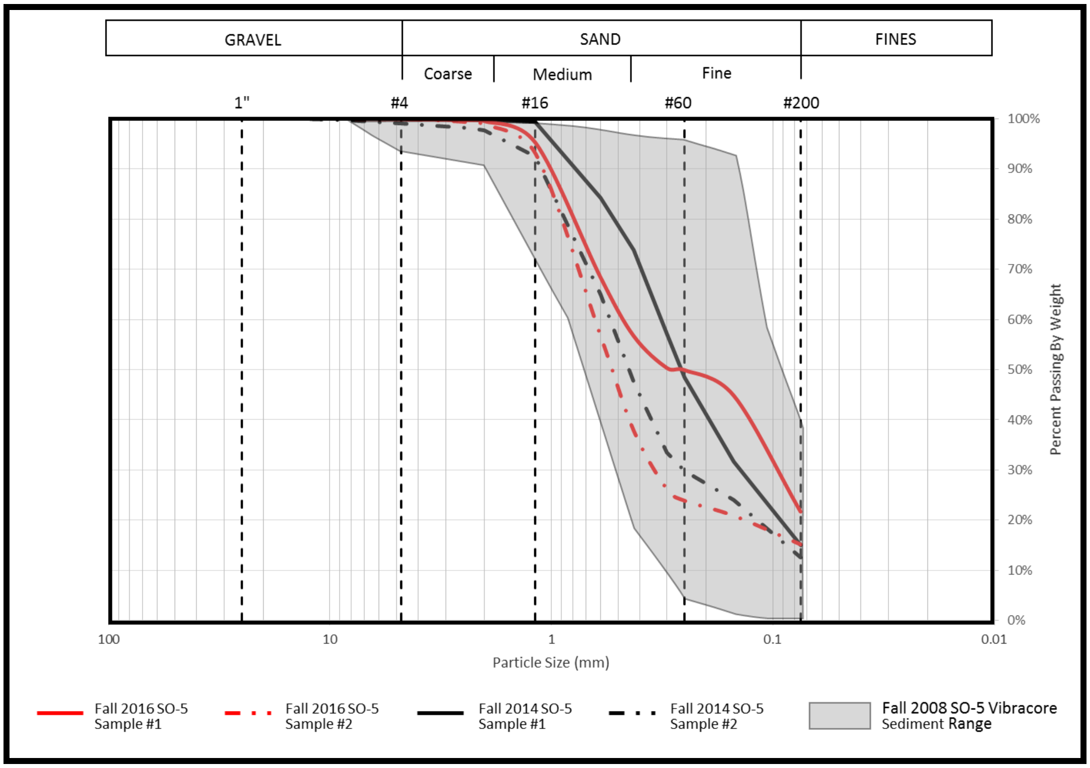


Figure 45. Grains Size Distribution Curves, SO-5

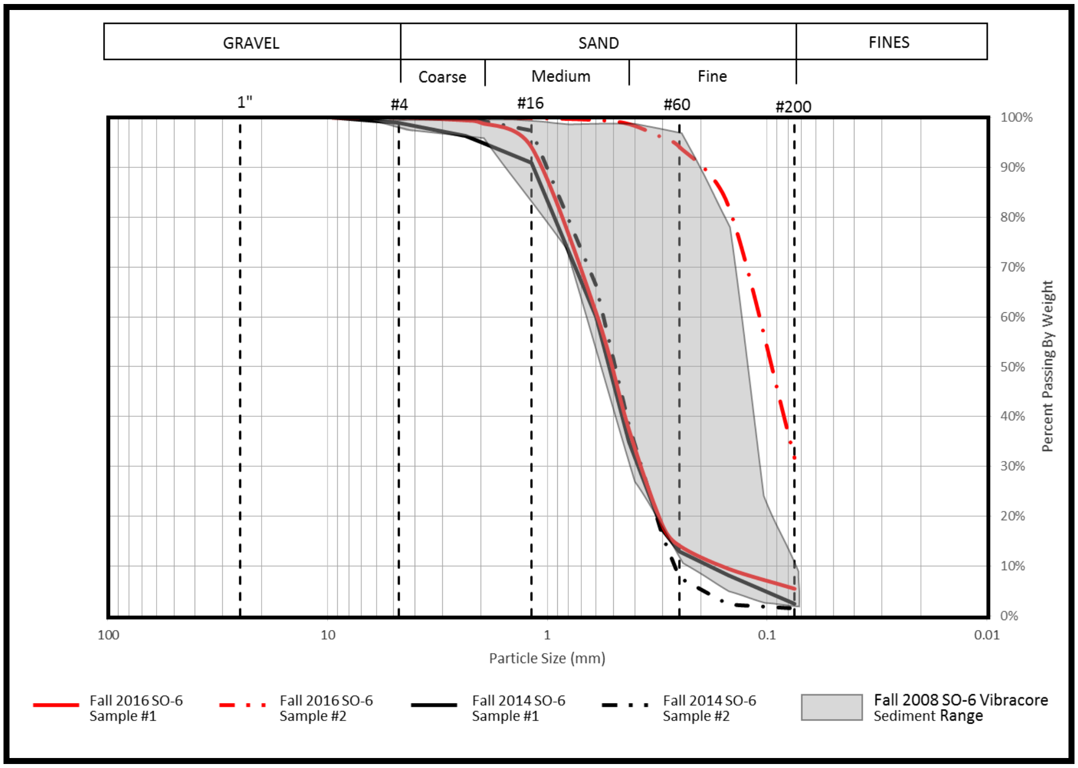


Figure 46. Grains Size Distribution Curves, SO-6

8. CONCLUSIONS

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

1. ***El Niño*:** The 2016 Monitoring Year was characterized by "very strong" El Niño conditions. Increased rainfall, higher wave energy, a southerly shift in wave direction, and elevated water levels typically accompany these conditions. Similar circumstances 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.

2. ***Precipitation and Streamflow*:** Below-average precipitation (7.8 inches) prevailed during the 2016 Monitoring Year, despite the occurrence of "very strong" El Niño conditions. The streamflow during the 2016 Monitoring Year also was below average. When the entire four-year post-RBSP II period is considered, both precipitation and streamflow fell below the respective historical averages. The implications are twofold: (1) the scant precipitation and low streamflows failed to deliver significant quantities of beach-quality sediment to the coast during the first four years following the RBSP II nourishment activities, and (2) the low streamflows failed to flush coastal sediment from the lagoon entrances in the Oceanside Cell.

3. ***Wave Conditions*:** The wave conditions were particularly mild during the first three years following the implementation of the RBSP II – a scenario that helped to prolong the life of the beach fills. In contrast, the El Niño conditions that prevailed during the 2016 Monitoring Year produced unusually energetic conditions. The energy index during the 2016 Monitoring Year was exceeded only during the 1998 El Niño year. In addition, the maximum significant wave height measured during the 2016 Monitoring Year (17.8 ft) was the largest recorded during the 19-year period of record.

4. ***Beach Nourishment*:** A substantial number of beach nourishment projects were undertaken in San Diego County prior to the RBSP II. With the exception of the RBSP I, nearly all of the nourishment projects depended on "sand of opportunity" that was derived from activities whose primary motive was other than beach replenishment. During the eleven-year period preceding the RBSP II and including the RBSP I, approximately 42,000 cy/yr were placed on the beaches in the Silver Strand Cell. In the Mission Beach Cell, approximately 55,000 cy/yr were placed on the beaches during this

period (primarily from 450,000 cy of opportunistic material provided by the U.S. Army Corps of Engineers in 2010). Approximately 171,000 cy/yr were provided to the beaches in the Oceanside Cell, of which the RBSP I was the largest contributor. A portion of the RBSP II material serves to compensate for the average annual nourishment material provided in prior years, while the remaining material represents incremental nourishment. The incremental volume relative to the pre-RBSP II average was 48,000 cy/yr in the Silver Strand Cell and 45,000 cy/yr in the Oceanside Cell. In the Mission Beach Cell, which did not receive RBSP II nourishment, a deficit of 55,000 cy/yr persisted relative to the historical average.

5. ***Sand Bypassing*:** Sand bypassing operations were not conducted at San Dieguito Lagoon during the five-year RBSP II Monitoring Period. The bypassing rate at Oceanside Harbor during this period (232,000 cy/yr) was slightly less than the historical average values. Bypassing was conducted at Agua Hedionda in 2015 for the first time in four years. The resulting bypassing rate for the RBSP II Monitoring Period (59,000 cy/yr) was well below the historical average. At San Elijo Lagoon, the five-year bypassing rate (23,000 cy/yr) was slightly higher than the annual average value for the 11 years preceding the RBSP II (22,000 cy/yr). Approximately 35,000 cy/yr were bypassed at Los Peñasquitos Lagoon during the RBSP II Monitoring Period, surpassing the recent historical average of 18,000 cy/yr. The bypassing rate at Batiquitos Lagoon (22,000 cy/yr) greatly exceeded the recent historical average annual bypass rate (11,000 cy/yr during the 11 years preceding the RBSP II). The increased bypassing quantities at Batiquitos and Los Peñasquitos constituted a direct benefit to the receiving beaches, which were located south of the lagoon entrances.

6. ***Beach Changes During 2016 Monitoring Year*:** During the 2016 Monitoring Year, shoreline retreat predominated in each the three littoral cells. In contrast, the shorezone volume increased in the Silver Strand Cell and was relatively stable in the Oceanside and Mission Beach Cells.

7. ***RBSP II Receiver Sites:*** The receiver sites in the Oceanside Cell have been characterized by a general trend of decreasing beach widths and sediment volume consistent with the dispersal of the placed material. A similar trend of diminishing beach widths and shorezone volumes prevailed at the lone receiver site located in the Silver Strand Cell (Imperial Beach) during the first two years following nourishment. This trend was reversed, however, with gains occurring during 2015 and 2016.

8. ***Beach Changes During the RBSP II Monitoring Period*:** During the five-year RBSP II Monitoring Period (2011 to 2016), shoreline advance and shorezone volume gains prevailed in the Silver Strand Cell. These gains appear to be attributable to the RBSP II nourishment. The shoreline position and shorezone volume in the Oceanside Cell was nearly identical to the pre-RBSP II condition at the time of the Fall 2016 survey, suggesting that gains realized from the nourishment program have largely dissipated over the five-year period. In the Mission Beach Cell, which did not receive sand as part of the RBSP II, the shoreline retreated and the shorezone volume was relatively unchanged.

   The impact of the RBSP II fills beyond the placement sites was assessed by evaluating the post-RBSP II outcome in selected sub-reaches. The persistence of post-RBSP I shoreline and shorezone volume gains was investigated for nine sub-reaches in the study area. Beach width and shorezone volume gains persisted for at least four years in five of the nine sub-reaches.

9. ***Beach Changes Following RBSP I*:** When the entire 16-year post-RBSP I period (2000 to 2016) is considered, the average shoreline position fell slightly 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 from the RBSP nourishment programs and several opportunistic nourishment projects have largely dissipated during the 16-yr period. 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. Similarly, a portion of the RBSP I and II material has been retained in the Oceanside Cell.

10. ***Impact of 2015-2016 El Niño:*** Beaches provide a buffer to protect coastal infrastructure and sea cliffs from wave-induced storm damage and erosion. This buffer becomes particularly important during a strong El Niño winter, when more energetic wave conditions typically prevail. 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. 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.

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 19 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.

While shoreline advance predominated in the San Diego region during Summer 2016, the gains were not sufficient to offset the losses sustained during the preceding winter. On average, less than 50% of the losses incurred in the ten sub-reaches over the winter were recovered during the following summer. The net result yielded Fall 2016 beach widths that fell near the lower boundary of historical conditions in much of the study area.

11. Borrow Sites: Comparison of the 2012 and 2014 bathymetry profiles along the borrow site monitoring transects indicates a general smoothing of the sea bottom during the two-year period following the dredging activities. Additional smoothing and infilling occurred at SO-5 and SO-6 between the 2014 and 2016 surveys, while the changes at MB-01 were modest. Over the four-year period following dredging, the shoaling at SO-6 and SO-5 averaged 0.6 and 0.9 ft, respectively. At MB-1, the depths increased by an average of 0.7 ft. The greatest changes, shoaling of up 4 ft, prevailed at the onshore portion of the SO-6 dredge area between the 2014 and 2016 surveys.

At MB-1, the grain size distribution curves for the samples obtained in 2014 and 2016 generally fell within the envelope of sediment sizes derived from the 2008 geophysical investigation. Similarly, the grain size distribution curves for the samples obtained at SO-5 were near the middle of the envelope of in-situ sediment sizes. At SO-6, the grain size distribution curves for three of the four samples obtained in 2014 and 2016 fell near the “coarse” end of the envelope of in-situ sediment sizes. The exception was the 2016 sample retrieved from the onshore portion of the dredge area where shoaling of up to 4 ft was noted. This sample contained finer sediment than identified in the 2008 investigation, with a fines content (32%) well in excess of the in-situ range. While the deposition of fine material may be attributable to high energy wave conditions during the 2015-2016 El Nino winter, the biennial nature of the borrow site surveys make it impossible to determine if the shoaling occurred during this season.

12. ***Lagoon Entrances*****:** During the post-RBSP II period (2013 through 2016 Monitoring Years), the jetty-stabilized entrance channels at Agua Hedionda and Batiquitos remained open to the full range of tidal exchange. At San Dieguito Lagoon, where lagoon restoration was completed in 2011, the inlet also remained open for the entire four-year period. No maintenance dredging was conducted at Batiquitos or San Dieguito during the post-RBSP period, while dredging was conducted at Agua Hedionda in 2015 for the first time since 2011.

At San Elijo, the unstabilized entrance channel remained open for the first three years following the RBSP II with the help of maintenance operations conducted each year. The lagoon closed briefly for the first time during the post-RBSP II period in April 2016, requiring mechanical intervention to re-establish tidal exchange. The lagoon was open 98% of the time during the post-RBSP II period. Approximately 93,000 cy of material were removed from the lagoon channels during five maintenance operations, equating to a dredge rate of 23,000 cy/yr during the post-RBSP II period. This rate was slightly more than the pre-RBSP II average (22,000 cy/yr).

The unstabilized entrance channel at Los Peñasquitos closed 11 times, with six of the closures occurring in 2016. Mechanical intervention was required to re-establish tidal exchange on nine occasions, while the lagoon opened naturally after two of the closures. Additional channel enlargements were performed in 2014 and 2016. As a result, the inlet was open 80% of the time during the post-RBSP II period. Approximately 41,000 cy/yr were removed from the lagoon channels during the four-year post-RBSP II period. This rate was substantially greater than the average annual dredge volume during the pre-RBSP I and pre-RBSP II periods (11,000 and 22,000 cy/yr, respectively). The 2016 profiles at the two transects located nearest the lagoon entrance contain distinct nearshore bars, suggesting sediment from the north arrived in this region during the 2015-2016 El Niño winter. This sediment, coupled with the unusually high wave energy may have contributed to the numerous closures and unusually high dredge quantities in 2016.

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