Beach Morphodynamic Change Detection using LiDAR during El Niño Periods in Southern California

by

Melodie Grubbs

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List of Abbreviations

DEM	Digital Elevation Model
dGPS	Differential Geographic Positioning System
EBK	Empirical Bayesian Kriging
GIS	Geographic information system
GISci	Geographic information science
LiDAR	Light Detection and Ranging
MHW	Mean High Water
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
OLC	Oceanside Littoral Cell
SOI	Scripps Institute of Oceanography
SSI	Spatial Sciences Institute
USACOE	United States Army Corps of Engineers
USC	University of Southern California

Abstract

Light Detection and Ranging (LiDAR) technology combined with high-resolution differential Global Positioning Systems (dGPS) provide the ability to measure coastal elevation with high precision. This study investigates the use of LiDAR data and GIS to conduct time-series analyses of coastal sediment volume shifts during the 2006-2007 El Niño winter, Summer of 2007 and following 2007-2008 La Niña winter in the Oceanside Littoral Cell (OLC). The OLC, located in Southern California, spans from Dana Point to La Jolla and includes over 84 km of coastline. The ability to quantify sediment volume changes contributes to the scientific understanding of the role El Niño storms play in the OLC sand budget. This study provides a method to analyze LiDAR data to evaluate coastal geomorphologic changes over time. Additionally, identifying specific areas of coastal beach erosion associated with historical El Niño events can aid beach managers, planners, and scientists in protecting the valuable coastline. LiDAR datasets were prepared and formatted which included ground classifying millions of elevation points. Formatted datasets were inputted into an Empirical Bayesian Kriging (EBK) model, creating high-resolution, 1-meter grid cell, Digital Elevation Models (DEMs). The EBK model also incorporated uncertainty into the workflow by producing prediction error surfaces. LiDAR-derived DEMs were used to calculate sediment volume changes through a technique called DEM differencing. Results were visualized through a series of maps and tables. Overall results show that there was a higher rate of beach sediment erosion during the 2006-2007 El Niño winter than the 2007-2008 La Niña winter. Sediment accretion was evident during the intermediary Summer of 2007. Future applications of this study include incorporating bathymetric datasets to understand near-shore sediment transport, evaluating sediment contribution through cliff erosion, and conducting decadal scale studies to evaluate long-term trends with sea level rise scenarios.

Chapter 1 Introduction

This study focuses on using Light Detection and Ranging (LiDAR) data coupled with Geographic Information Systems (GIS) analysis to identify coastal zone sediment changes in a region of Southern California known as the Oceanside Littoral Cell (OLC). The OLC, which spans from Dana Point to La Jolla Point, is an area known to experience heavy coastal effects from El Niño seasons.

Sand budgets are a way scientists can quantify sources and sinks of sand in the OLC and begin to understand the processes that drive a dynamic coastal system. To understand the effects El Niño winters play on the OLC sand budget, it is important to understand the history of sand sinks and sources in the OLC. Sand deficiencies, caused by human modification to major sources of sand, have changed the natural sand budget in the OLC driving the need for beach replenishment to maintain valuable beaches.

El Niño seasons are marked by an increase in frequency and intensity of coastal storms and can cause significant erosion to coastal areas. Additionally, El Niño storm events coupled with projected sea level rise will amplify the effects of erosion into the future.

1.1 Study Objectives

The goal of this study was to determine if coastal time-series LiDAR datasets analyzed using GIS methods can depict coastal sediment volume shifts associated with El Niño seasons in the Oceanside Littoral Cell located in Southern California. GIS methods were used to estimate beach sediment volume changes that occurred during the 2006-2007 El Niño winter, Summer of 2007, and following 2007-2008 La Niña winter. Sediment shifts during the 2006-2007 El Niño were the primary focus, while the analysis of sediment shifts during the 2007-2008 La Niña winter, and intermediary Summer of 2007 were used for comparison. El Niño winters in

Southern California are typically associated with increased coastal erosion and comparing erosion trends during an El Niño winter to a non-El Niño winter provided key data to prove this phenomenon. In general, beaches in Southern California are also heavily influenced by seasonal variation, eroding in the winter and accreting during the summer months. For this reason, the summer immediately following the 2006-2007 El Niño winter was also analyzed to identify any sediment recovery. A series of maps and corresponding statistics were created to visualize the spatial trends of coastal sediment volume shift.

1.2 Study Area

The Oceanside Littoral Cell (OLC) is one of many segments along the Southern California Coast in which littoral sediment transport is bounded or contained (Figure 1). Spanning roughly 84 km (52 mi) from Dana Point to the north and Point La Jolla to the South, the coastal area of the OLC contains some of the most heavily used beaches in Southern California (Chenault 2007). The OLC is also a major study area due to the nearby proximity of Scripps Institute of Oceanography. Beach erosion in the OLC is particularly severe between the cities of Oceanside and Del Mar and a study conducted by the United States Army Corps of Engineers in 1991 identified the southern half of the OLC, from Oceanside Harbor to La Jolla, as sites of critical erosion (USACOE 1991).

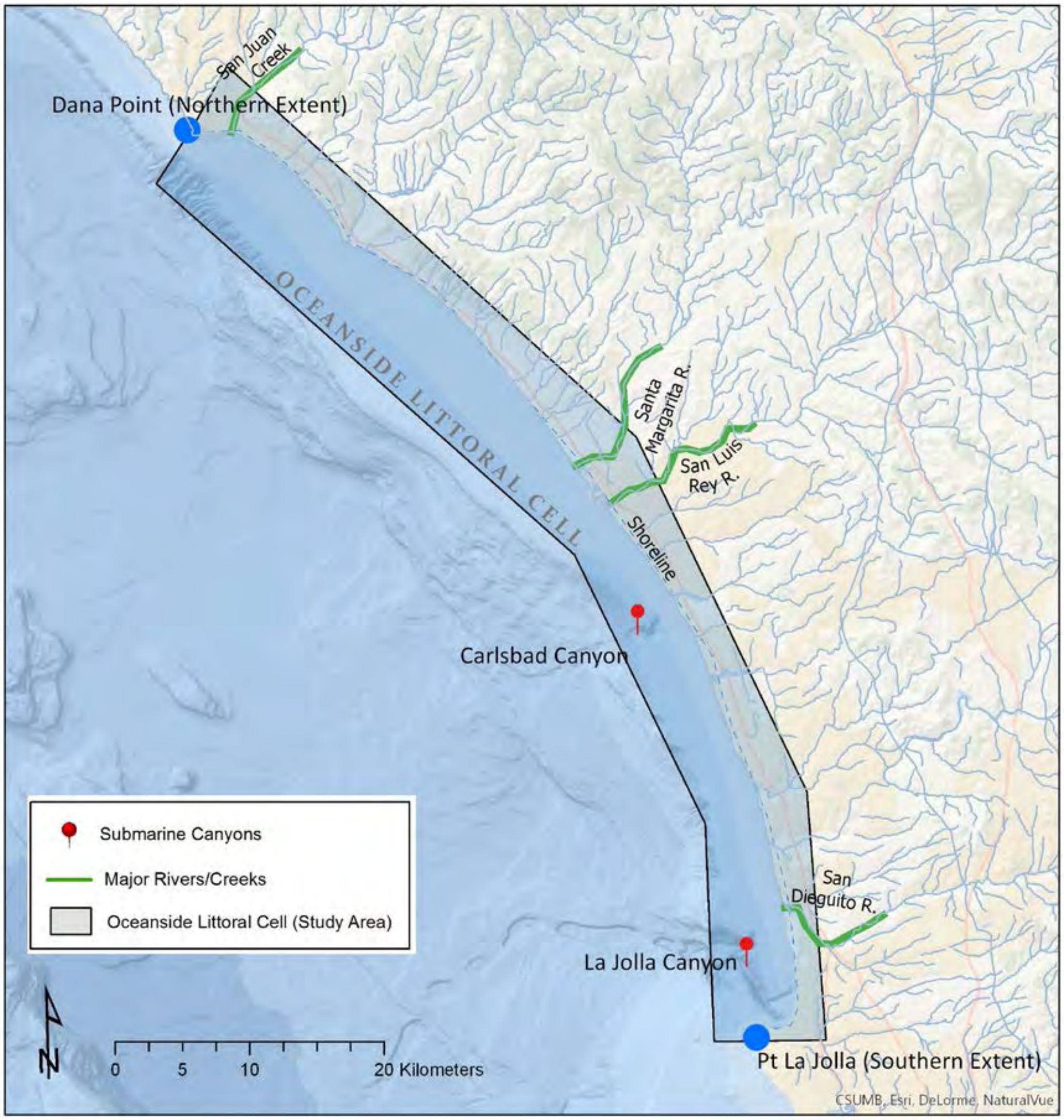

Figure 1 The Oceanside Littoral Cell (OCL)

1.3 Organizational Framework

This thesis document contains four additional chapters. Chapter 2 explores background concepts related to sand budgets in the OLC and previous studies related to the use of remote sensing to measure coastal change. Chapter 3 provides a detailed description of the methodology used for this study. Chapter 4 presents the results of the time-series LiDAR analysis. Chapter 5 concludes with a discussion of the implications of the results, the successes and challenges associated with the methodology, and future applications and opportunities.

Chapter 2 Background and Related Research

The following sections explore background information on the OLC sand budget, including the sources and sinks of beach sand, the role wave climate plays in sand transport, and the effect of El Niño winter storms on the coastline. Specific case studies that used remote sensing, including aerial imagery and more specifically LiDAR technology to measure coastal change were investigated and provide the foundation for the methods developed in this study.

2.1 Sand Budgets

Sand budgets quantify sediment in littoral cells by identifying sources and sinks of sand and is a method that scientists use to better understand the processes that change beaches and influence beach width. LiDAR data has been used to study various components of the OLC sand budget, particularly changes in beach sand movement and erosion from sea cliffs. Previous research in the OLC has identified fluvial streams and coastal rivers, erosion from sea cliffs, and the human addition of sand from beach nourishment as major sources of sand (Chenault 2007). Sand sinks, defined as processes that remove sand out of the OLC, include sand loss to offshore submarine canyons, as well as sand loss via longshore and offshore transport. Coastal storms and associated waves play a role in providing a source of sand by eroding sea cliffs. However, these weather and climatic events also drive sand movement offshore, narrowing beach widths, and initiating sand transport out of the OLC. Additionally, the effect of coastal storms on sand budgets is perhaps the least understood of all processes (Chenault 2007). In 1997 the US Army Corps of Engineers completed a study of the sand budget including erosion patterns in the OLC and found patterns of sediment moving via longshore littoral transport in a southerly direction (Hales et al. 1997).

Table 1 summarizes a breakdown of natural and actual sand inputs into the OLC and shows that fluvial sediment and bluff erosion inputs have been altered through human modifications, reducing natural inputs by 26% (California Department of Boating and Waterways and State Coastal Conservancy 2002). “Natural” inputs as shown in Table 1 refer to the amount of sediment per year fluvial streams, bluff erosion, and gullies/terraces would contribute if not modified by humans. Fluvial streams have been modified by the building of dams, channels, and diversions, all which alter the “natural” flow of sediment. Bluffs have been modified from their “natural” state by high bluff-top development and cliff stabilization, which also alter the amount of beach sediment created. The decline in natural sand supply has made beach nourishment necessary and has prioritized research toward understanding processes that drive the sand budget, particularly wave climate and high-intensity storms caused by El Niño events.

Table 1 Sediment Inputs into the Oceanside Littoral Cell (California Department of Boating and Waterways and State Coastal Conservancy 2002)

Inputs	**Natural (m3/yr)**	**Actual (m3/yr)**	**Reduction (m3/yr)**
Fluvial Streams	219,045 (44.7%)	101,304 (27.9%)	117,741 (53.8%)
Bluff Erosion	51,455 (10.5%)	41,974 (11.6%)	9,480 (18.4%)
Gullies/Terraces	219,427 (44.8%)	219,427 (60.5%)	0 (0%)
Total Littoral Input	489,927 (100%)	362,705 (100%)	127,222 (26%)

2.1.1. Sand Sinks in the Oceanside Littoral Cell

Sand sinks in the OLC sand budget include the movement of sand into two nearby submarine canyons as well as longshore transport of sediment exiting out of the southern boundary into the adjacent littoral cell and offshore towards deeper ocean. Climatic and weather processes can drive sand movement towards sinks through longshore and offshore transport.

2.1.1.1. Submarine Canyons

Submarine canyons are considered a sink in sand budgets, and in the OLC sand is transported via longshore in a southerly direction until it eventually enters the beginning of the La Jolla submarine canyon (California Department of Boating and Waterways and State Coastal Conservancy 2002). Additionally, the Carlsbad submarine canyon located offshore the city of Carlsbad, in the middle of the OLC, is a sand sink. The location of these canyons is shown in Figure 1.

2.1.2. Sand Sources in the Oceanside Littoral Cell

Sources of sand in the OLC include sediment transported via fluvial streams, sand created by sea cliff erosion, sand transported from gullies and terraces, and beach nourishment projects. The natural processes of sediment creation and transport through fluvial streams and sea cliff erosion has been greatly modified by human-built structures including dams, reservoirs, sea cliff anchoring, sea walls, and rip rap.

2.1.2.1. Fluvial streams

While fluvial rivers and streams are a major source of beach sand for many California beaches, the OLC is an exception. Dam construction inhibits sediment transport from fluvial streams, and dams in the OLC have reduced the fluvial sediment contribution by 54% (California Department of Boating and Waterways and State Coastal Conservancy 2002).

2.1.2.2. Sea cliff erosion

Cliff erosion is a source of sediment in the OLC sand budget, with most of the coastline, 73%, composed of semi-continuous sand or cobble beaches backed by sea cliffs (Masters 2006; California Department of Boating and Waterways and State Coastal Conservancy 2002). While the erosion process can provide valuable sediment to nourish beaches, it is a problem to local property owners, businesses, and government. Sea cliff armoring, which aids to prevent erosion, has reduced the amount of sand supplied to the OLC (Figure 2). Historically sea cliff erosion contributed 11% of sand to the OLC; however, with an estimated 20% of the OLC sea cliffs armored with some form of protection against erosion, sand contribution has been reduced by 18% (California Department of Boating and Waterways and State Coastal Conservancy 2002).

Figure 2 A seawall in Encinitas (California Department of Boating and Waterways and State Coastal Conservancy 2002)

2.1.2.3. Gullies and Terraces

Sand transported onshore into the OLC from gullies and terraces historically accounted for roughly 45% of the sand budget input (California Department of Boating and Waterways and State Coastal Conservancy 2002). The reduction of sand input from the modification of natural cycles associated with fluvial stream and bluff erosion has lowered the estimated annual sediment input into the OLC, and sand input from gullies and terraces now accounts for a higher percentage of total littoral input.

2.1.2.4. Beach Nourishment

Beach nourishment, a common method used in Southern California to restore and maintain sandy beaches, has been conducted in many locations throughout the OLC since the 1940s (Chenault 2007). Previous studies indicate that beach nourishment projects in the OLC have contributed an overall annual average ranging from 85,000 m^3 per year to 350,000 m^3 per year (Chenault 2007; Patsch and Griggs 2006). Large scale beach nourishment projects have been undertaken by the San Diego Association of Governments (SANDAG) including a project in 2001 where approximately 1.4 million cubic meters of sand was placed on ten beaches and another project ten years later, in 2012, where 0.8 million cubic meters of sand was placed on seven beaches (Table 2) (Figure 3) (AMEC Earth & Environmental, Inc. 2005; Coastal Frontiers Corporation 2015).

Table 2 2001/2012 SANDAG Beach Nourishment Sites in the OLC (AMEC Earth & Environmental, Inc. 2005, Coastal Frontiers Corporation 2015)

Beach Nourishment Sites	**Quantity (m^3)**	
	2001	**2012**
Torrey Pines State Beach	187,316	-
Del Mar	139,914	-
Leucadia	100,921	-
Fletcher Cove, Solana Beach	111,625	108,567
South Carlsbad State Beach	120,800	107,802
North Carlsbad	172,025	167,438
Cardiff State Beach, Encinitas	77,220	68,045
Moonlight Beach, Encinitas	80,278	70,339
Batiquitos	89,453	81,043
Oceanside	321,878	224,015
Total	**1,401,429**	**827,248**

Figure 3 SANDAG 2001 Beach Nourishment Project Locations (Patsch and Griggs 2006)

The location and amount of sediment placed on beaches in the OLC provide a baseline comparison for analyzing beach sediment shifts following El Niño events. Beach profile monitoring data, in the form of on-the-ground transect surveys, was collected at all the beach nourishment sites beginning in 1996 and ending in 2003. Profile data collected through November 2003, show that dry beach width receded and the overall profile became flatter, suggesting that nourishment material eroded and moved offshore and towards the downcoast beaches (Coastal Frontiers Corporation 2004).

2.1.3. Wave Climate

Beaches in Southern California experience a highly variable seasonal profile (Figure 4). During the winter sand is eroded from the beach from storm-generated wave events and typically forms an offshore sandbar, which often protects the shore from further events by causing waves to break further offshore (Patsch and Griggs 2004). While winter beach erosion is a normal process for the OLC, frequent high-intensity wave events, coupled with existing sand budget deficiencies, and additional factors like high tides can cause permanent erosion.

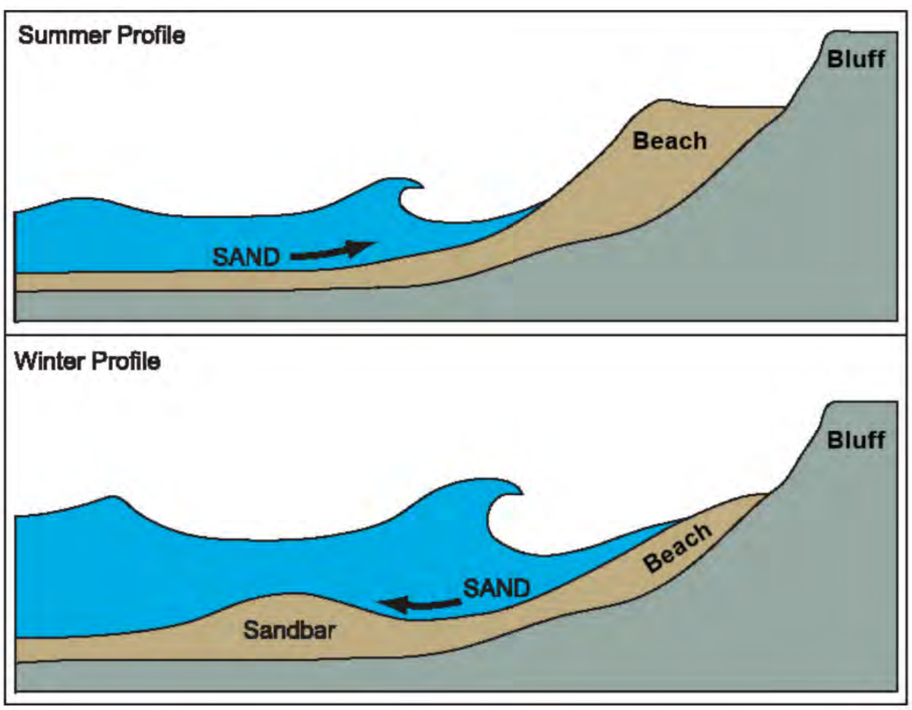

Figure 4 Sand Budgets – Winter versus Summer Profile (Patsch and Griggs 2006)

2.2 El Niño Coastal Storms

During El Niño seasons, California experiences above-average rainfall, warmer sea-surface temperatures, and large waves, resulting in increased coastal erosion. La Niña seasons show the opposite, with colder sea-surface temperatures, drier conditions, and less severe storms (Hapke et al. 2009). Recent research has shown that extreme El Niño events coupled with climate change induced warmer water temperatures have the potential to double the frequency of extreme El Niño events occurring (Cai et al. 2014). Additionally, the elevated water levels and associated powerful waves that drive beach erosion will have a greater impact with sea level rise (Barnard et al. 2014). Tropical storms in Southern California are a rare occurrence, and extreme erosion is dominated by repeated storm events during El Niño (Ludka et al. 2016).

2.2.1. Effects on OLC Sand Budget

El Niño seasons bring increased storm frequency and intensity and a shift of wave climate. These storms affect the OLC sand budget by shifting sediment. Large waves with southerly storm tracks result in more direct wave effects on the coastline and increase sand transport out of the system. In contrast, La Niña seasons are marked by decreased precipitation, decreased sediment production, and a gentle wave climate resulting in less sediment lost from the system.

Quantifying the volume of sediment that is transported out of the system due to El Niño events can provide scientists and planners useful information towards understanding the OLC sand budget as a whole. Comparing El Niño season sediment shifts to La Niña season sediment shifts provides a control to begin to distinguish non-El Niño sediment trends from El Niño sediment trends.

2.3 Remote Sensing to Measure Coastal Change

Remote sensing has been used to measure coastal change using a variety of techniques. Traditionally, high-resolution aerial imagery combined with topographic maps enabled researchers to digitize shorelines and measure change over time. The process of using high-resolution aerial imagery required manual and often tedious digitization, repeated over time, to begin to measure change. LiDAR combined with Global Positioning Systems (GPS) provides the ability to collect large elevation point clouds and using GIS analysis, shoreline and sediment volume can be quantified over a time-series. LiDAR provides the ability to go beyond measuring shoreline shifts in 2-D and provides accurate 3-D elevation data that can be used to calculate sediment volume trends.

2.3.1. High-Resolution Aerial Imagery

Prior to the development and use of GPS and LiDAR, aerial imagery and topographic maps were the primary tool for beach and coastal profiling. Chenault provides an in-depth study on beach-width change in the OLC, utilizing historical aerial photographs and transects (Chenault 2007). Figure 5 shows a map of Chenault's work where transects are used to measure beach width changes over time. While transects have been the norm for coastal scientists monitoring beach width changes, LiDAR data has the ability to calculate elevation changes at a wider coverage. The following additional studies show the use of LiDAR to conduct time-series analysis using a technique called DEM differencing.

Other studies have employed aerial photography as a supplement to LiDAR analysis. A study conducted by Egley, from the Naval Postgraduate School, used LiDAR to examine erosion in the southern Monterey Bay during the 1997-98 El Niño (Egley 2003). Egley used a DEM differencing technique to measure elevation changes as well as transects to create elevation profiles of the results (Figure 6).

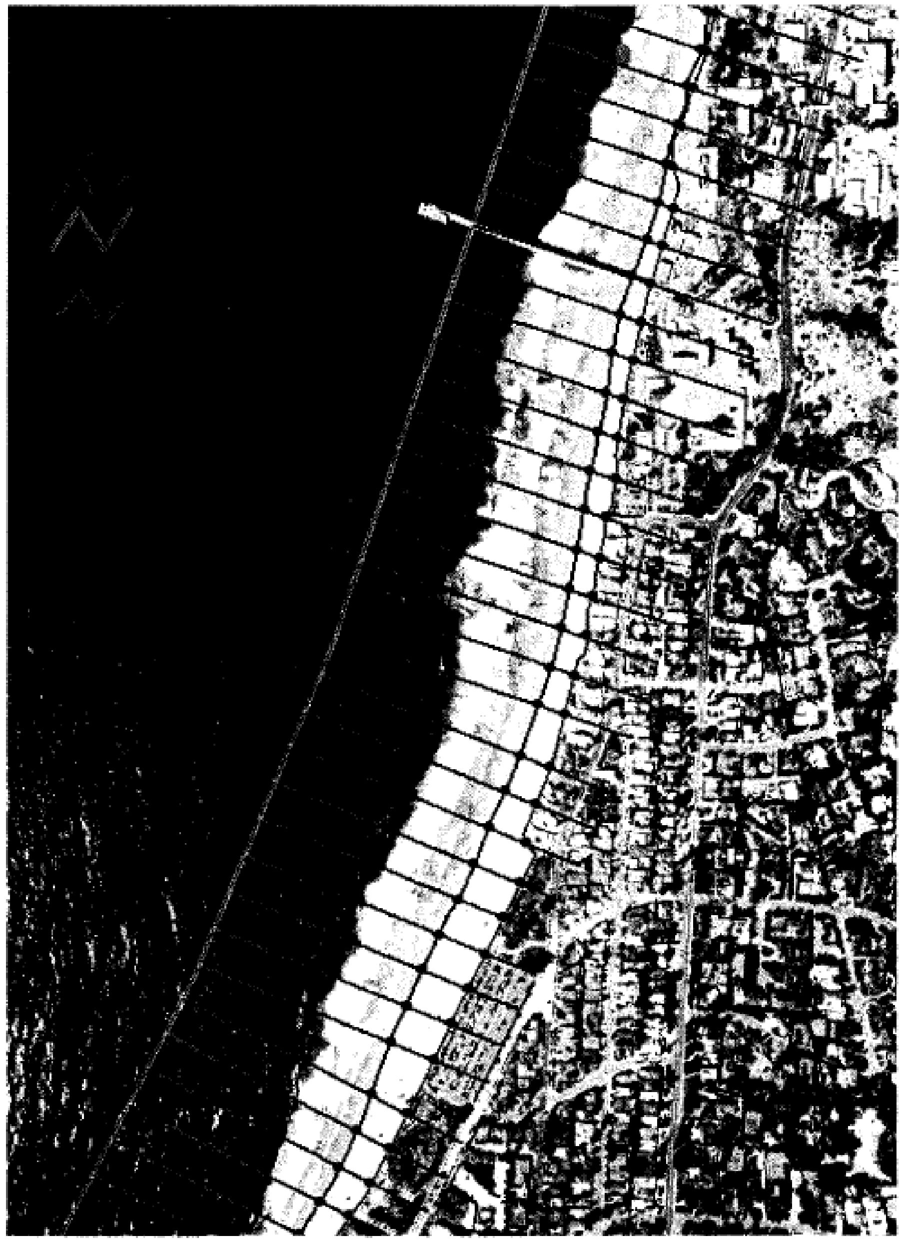

Figure 5 The use of aerial imagery and transects to measure beach width changes over time - La Jolla 2001 (Chenault 2007).

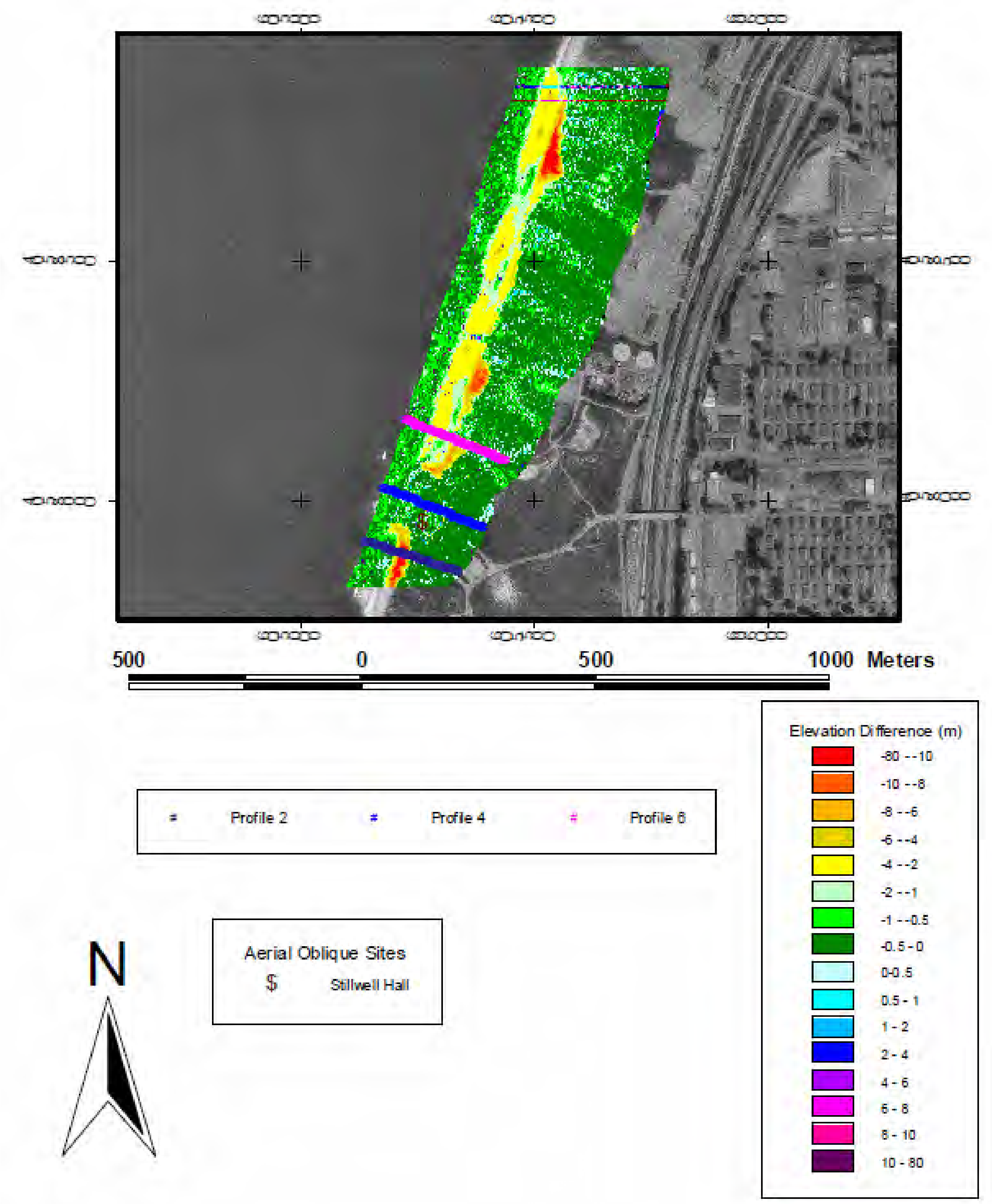

Figure 6 Erosion analysis in southern Monterey Bay, Fort Ord, during the 97-98 El Niño using LiDAR (Egley 2003)

2.3.2. Light Detection and Ranging (LiDAR)

There have been many studies utilizing LiDAR data to measure coastal geomorphologic change. In a thesis research project conducted by Brian Coggan from the University of California – Santa Cruz, shoreline change in Southern California during the 2009-2010 El Niño season was investigated using time-series LiDAR data (Coggan 2014). Using two time-series LiDAR datasets, Coggan measured beach changes, identifying distinct areas of erosion and accretion as well as volumetric beach sediment changes. Using GIS analysis tools and an ArcMap extension called the Digital Shoreline Analysis System (DSAS), shoreline change was calculated using a transect reference system. Figure 7 shows a visual representation of Coggan's work, where larger red circles indicate higher erosion along the corresponding transect and larger green circles indicate higher accretion along the corresponding transect. The use of transects to measure shoreline change is a common denominator in beach geomorphologic investigations.

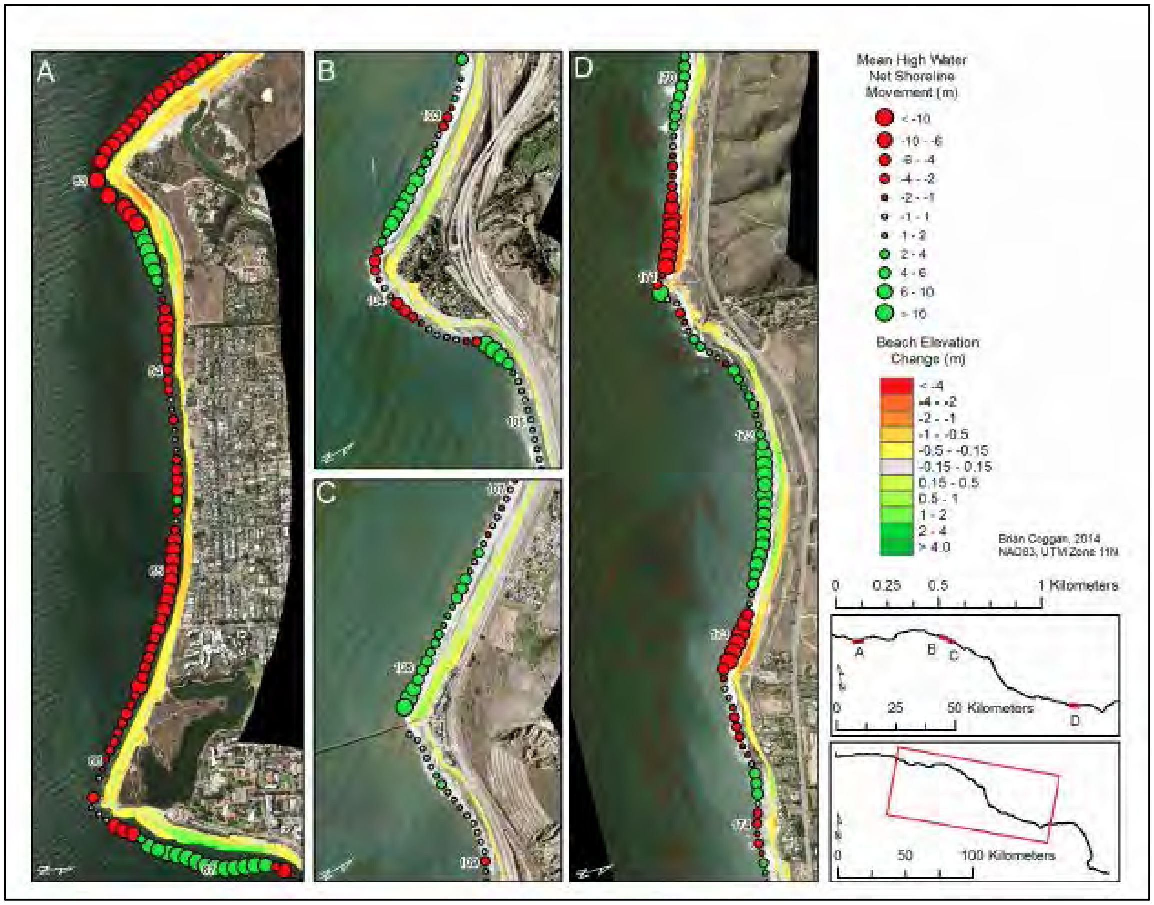

Figure 7 Transect method calculating shoreline change in southern California during the 09-10 El Niño (Coggan 2014).

Quan used LiDAR data collected from an ocean vessel to measure coastal erosion associated with the 2009-2010 El Niño event in Monterey, California (Quan 2013). This project also analyzed 2008-2009 (non-El Niño) data as a control and 1997-1998 (El Niño) as another comparison with a goal of conducting a hotspot analysis to determine location and magnitude of coastal shoreline change. Figure 8 shows results from Quan's study, the dashed line on the plot indicates erosion along the coast during the 1997-1998 El Niño, while the solid line indicates erosion trends during inter-El Niño periods from 1998-2009.

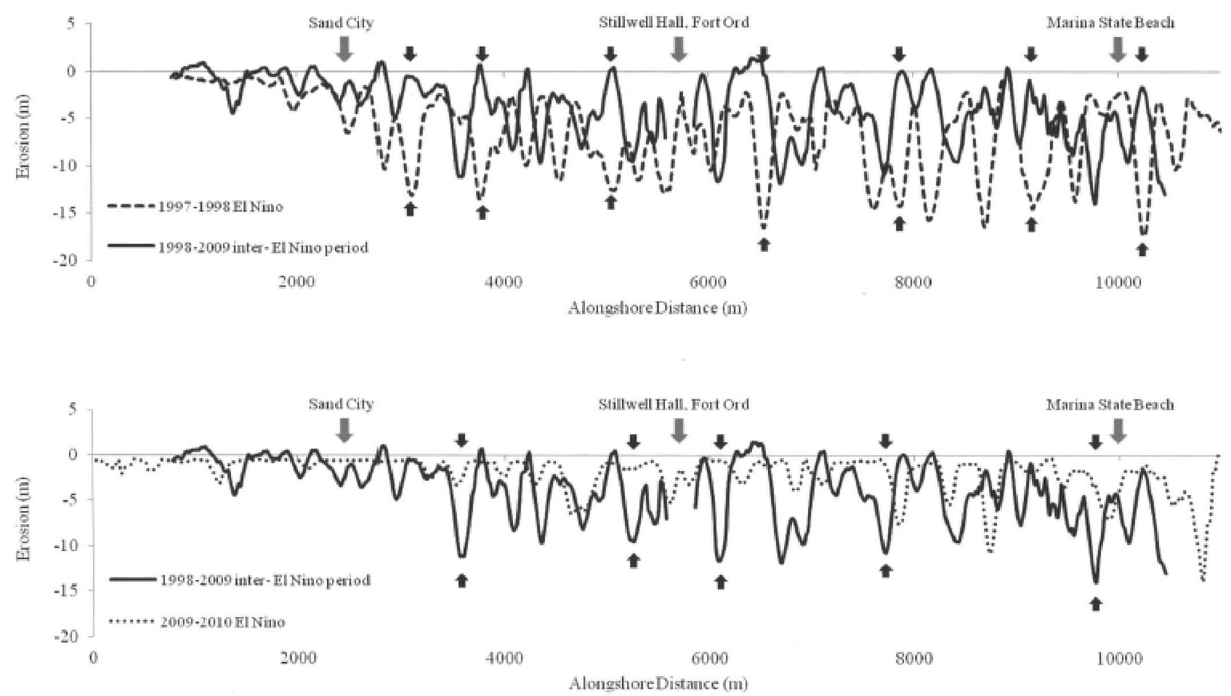

Figure 7. Plots of shoreline recession after consecutive El Niño to inter-El Niño periods (top) and inter-El Niño to El Niño periods (bottom) with a 100 m running average at 10 m elevation (NAVD88) for Southern Monterey Bay. *X* axis represents alongshore distance (m) starting in Sand City and ending at Marina Sate Beach. *Y* axis represents shoreline recession (m). Black arrows indicate some erosion hot spot shift locations. Anomalously high shoreline recession values at Stillwell hall were omitted.

Figure 8 Plot method of visualizing shoreline change during an El Niño and inter-El Niño Period in Monterey Bay, CA (Quan 2013).

In a book titled, *GIS-based Analysis of Coastal LiDAR Time-Series*, sediment volume shifts are measured by time-series LiDAR analysis and represented through defined shoreline segments (Hardin 2014). Hardin also details specific GIS methods to analyze coastal changes through raster-based analysis, shoreline feature extraction and change metrics, volume analysis, and visualization (Hardin 2014). Hardin outlines DEM differencing analysis, a method which was used in this study (Figure 9).

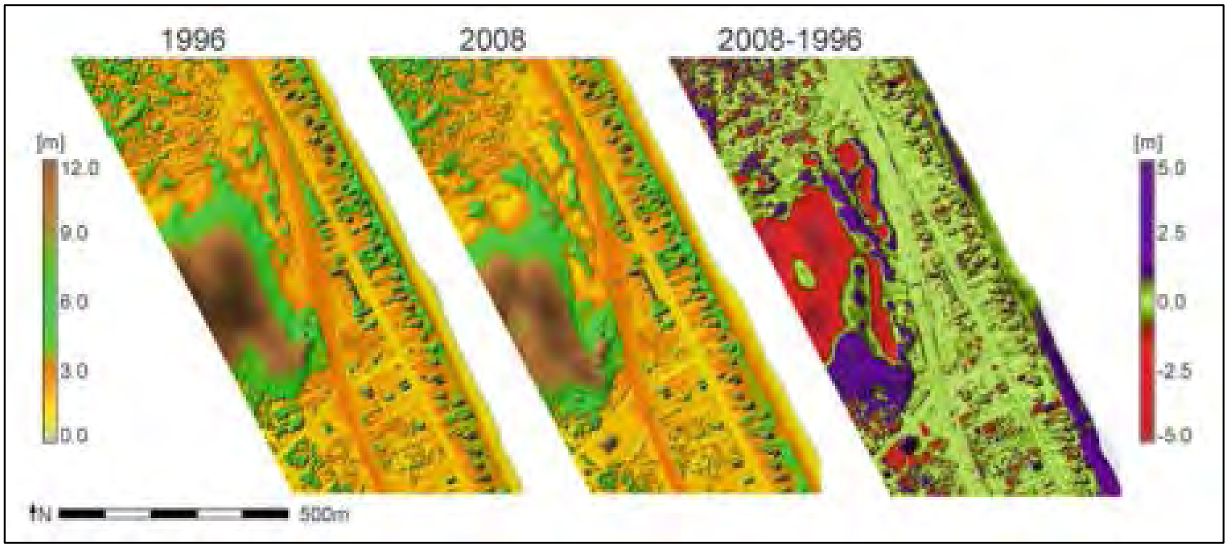

Figure 9 DEM differencing technique to analyze coastal time-series LiDAR data (Hardin 2014)

Another study specific to the OLC was conducted by Young and Ashford, who investigated the application of airborne LiDAR in detecting sea cliff and beach sediment change during a relatively dry season from 1998 to 2004 (Young and Ashford 2006). They were able to measure rates of volumetric sea cliff erosion and found that sea cliffs provided roughly 67% of beach grain sediment through erosion processes. Young and Ashford used LiDAR data to create high-resolution DEM rasters and their analysis included measuring and detecting changes through DEM differencing (Figure 10).

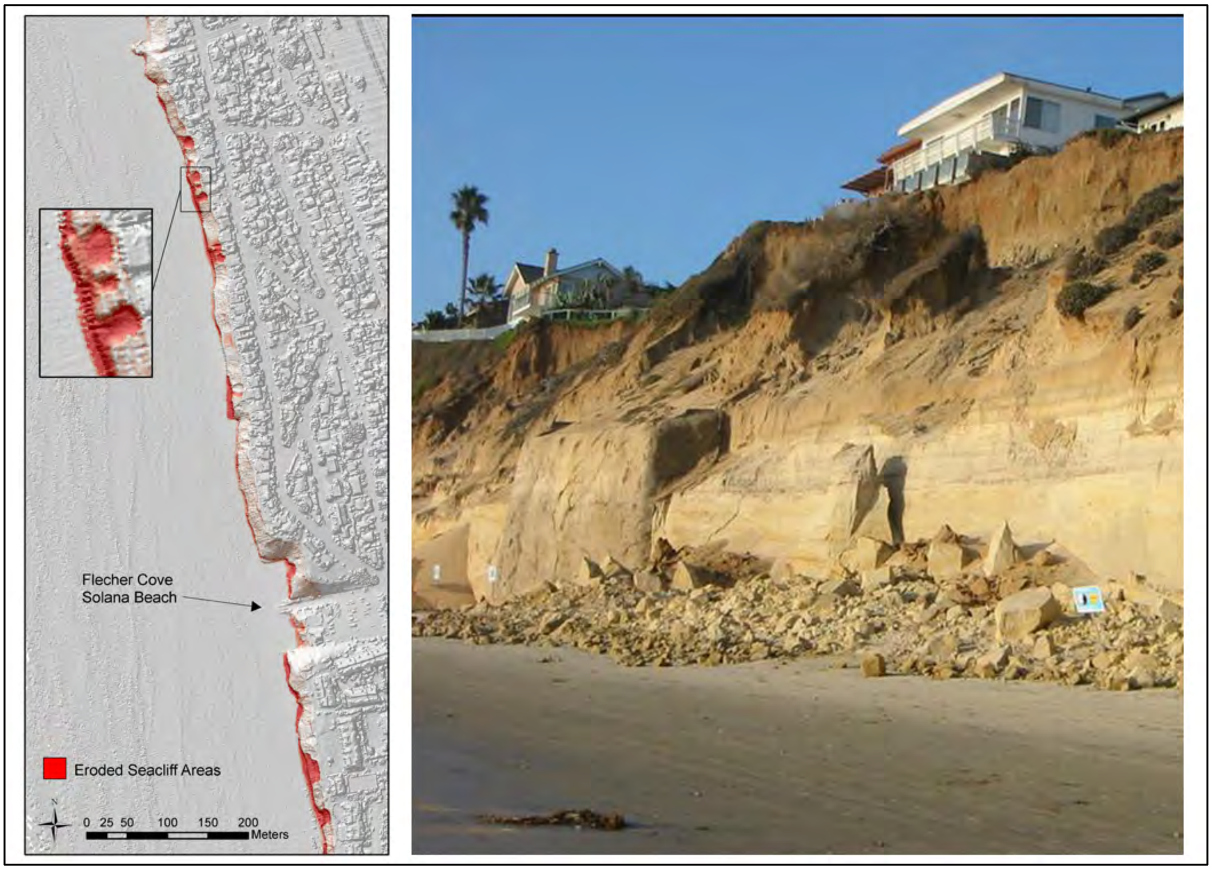

Figure 10 LiDAR time-series analysis to detect cliff failure (Young 2006)

Chapter 3 Methods

This chapter outlines the methods used in this study. The first section discusses the sources of LiDAR datasets used in the analysis and their corresponding metadata. The following sections discuss in detail the methods used in preparing and formatting the LiDAR data, the creation of Digital Elevation Surfaces (DEMs) using the Empirical Bayesian Kriging (EBK) method, and the sediment volume change analysis.

3.1 Data Sources

Data included time-series LiDAR datasets taken from the Fall of 2006 to the Spring of 2008. This time period encompassed an El Niño winter event followed by a La Niña winter event. Figure 10 shows the four individual LiDAR datasets that were used for analysis. For the purpose of a time-series analysis these four datasets were grouped into three sets associated with the following survey events:

Fall 2006 - Spring 2007 – El Niño winter

Spring 2007 – Fall 2007 – Summer of 2007

Fall 2007 - Spring 2008 – La Niña winter (control)

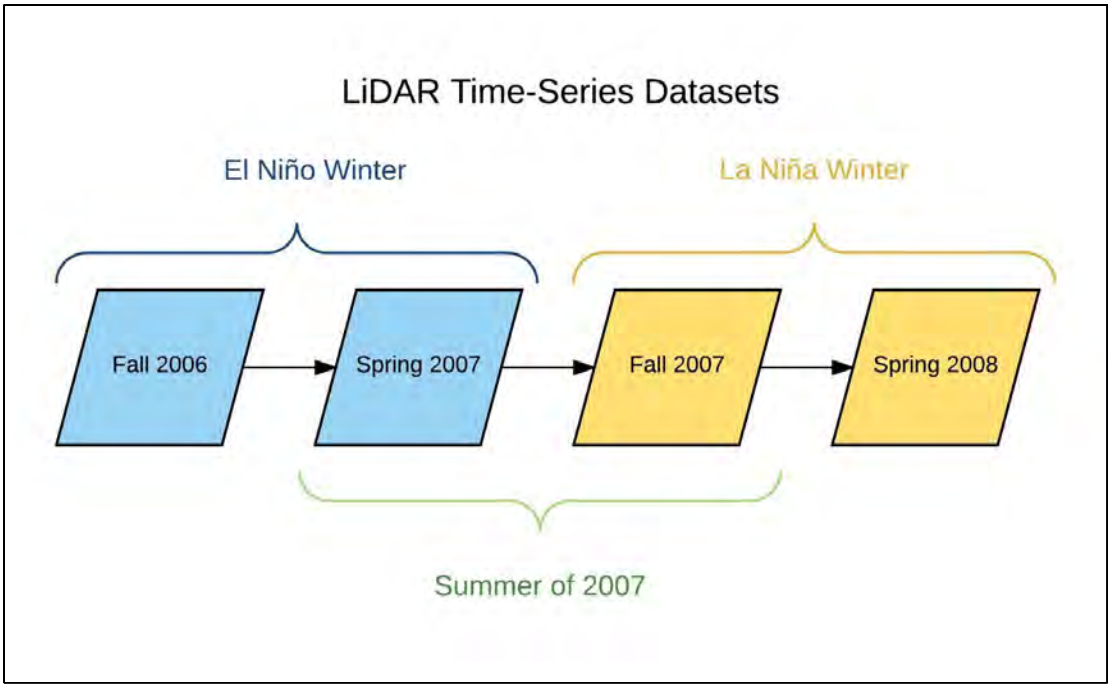

Figure 11 LiDAR time-series datasets.

All LiDAR datasets were derived through flights conducted in association with the Southern California Beach Processes Study (SCBPS)/Coastal Data Information Program (CDIP) as part of Scripps Institution of Oceanography (SIO) in cooperation with the Bureau of Economic Geology, University of Texas at Austin. The SCBPS program is designed to improve the understanding of beach sand transport by waves and currents with the goal of improving local and regional coastal management. The National Oceanic Atmospheric and Administration (NOAA) Office for Coastal Management was also involved, and the datasets are available through a government data portal (www.data.gov) for download in the compressed LiDAR file format (.LAZ) (Table 3).

Table 3 LiDAR Datasets

Year	Season	Event	Name	Extent	Source (URL)
2006	Fall	El Niño	October 2006 LiDAR Point Data of Southern California Coastline – Scripps Institute of Oceanography (SIO)	Long Beach to US/Mexico Border	2006 October LiDAR
2007	Spring		March 2007 LiDAR Point Data of Southern California Coastline – Scripps Institute of Oceanography (SIO)	Long Beach to US/Mexico Border	2007 March LiDAR
2007	Fall	La Niña	March 2007 LiDAR Point Data of Southern California Coastline – Scripps Institute of Oceanography (SIO)	Long Beach to US/Mexico Border	2007 November LiDAR
2008	Spring		November 2007 LiDAR Point Data of Southern California Coastline – Scripps Institute of Oceanography (SIO)	Long Beach to US/Mexico Border	2008 April LiDAR

According to the metadata, datasets were generated by the processing of laser range, scan angle, and aircraft altitude data collected using an Optech Inc. Airborne Laser Terrain Mapper (ALTM) 1225 in combination with geodetic quality Global Positioning System (GPS) airborne and ground-based receivers. Each survey recorded data for an approximate 500 to 700-meter wide strip of coastline during low tide conditions. Instrument settings and parameters as documented by metadata are summarized in Table 4.

Table 4 LiDAR Instrument Settings and Parameters

Setting or Parameter	Details
Laser pulse rate (scanner rate)	25 kHz
Scan angle	+/- 20-degree beam divergence
Narrow altitude	300-600 m
Ground speed	95-120 kts

3.2 Processing Overview

Conducting this analysis required three major stages: data preparation and formatting, DEM creation using Empirical Bayesian Kriging (EBK), and beach sediment volume change analysis. This section provides an overview of the workflow while later sections provide specific details for each. Figure 12 shows the general workflow.

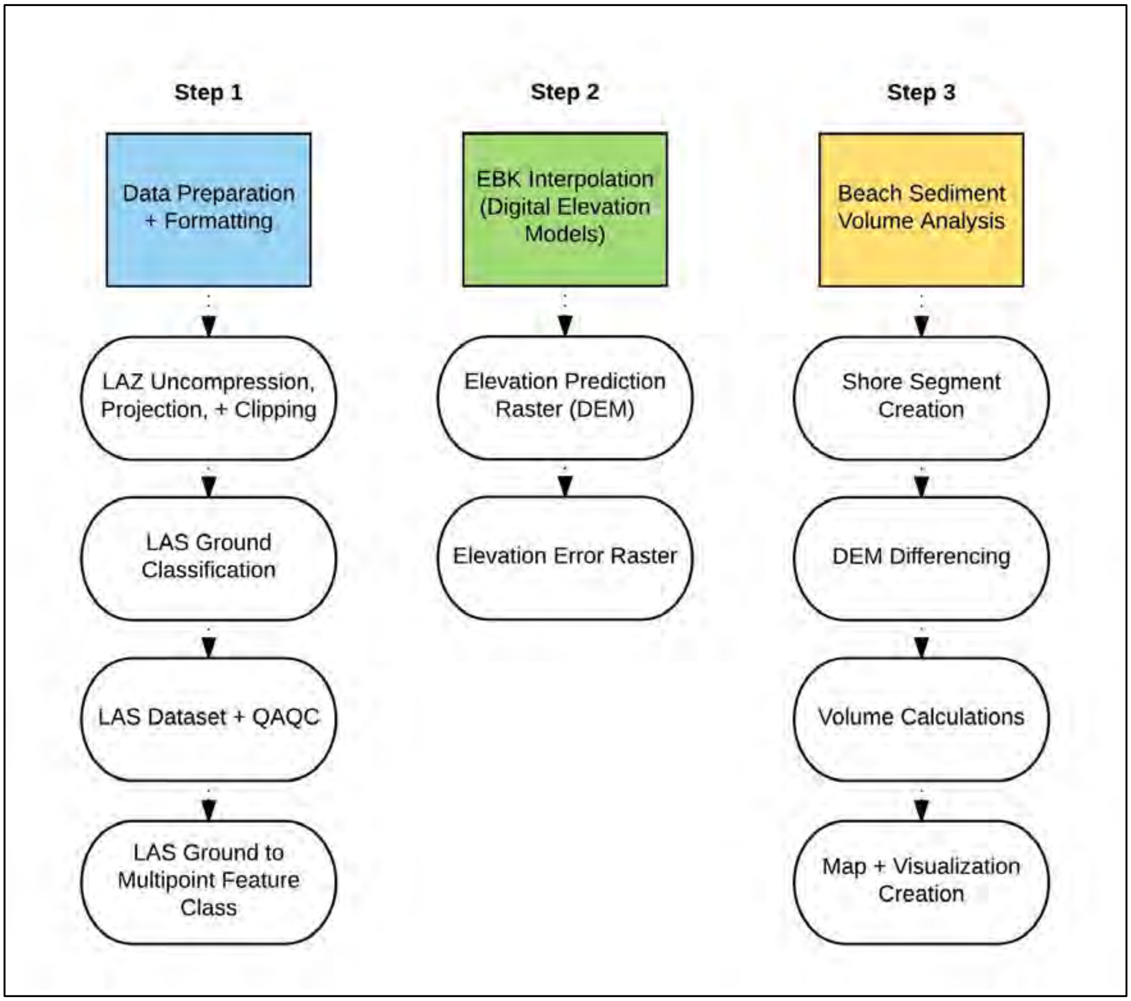

Figure 12 Processing Overview

First, compressed LiDAR datasets, in .LAZ format, were downloaded and extracted using the LAStoZip tool in the LasTool suite. Time series LiDAR datasets comprised of a fall pre-winter storm season and a spring post-winter storm season were analyzed for the 2006-2007 El Niño event and following 2007-2008 La Niña event. Uncompressed .LAS files were then projected from a geographic coordinate system into a projected coordinate system using the LAStoLAS tool in the LasTool suite. Projected .LAS files were ground classified to distinguish bare earth from buildings and infrastructure using the LasGround tool in the LasTool suite.

Transitioning to the ArcMap 10.4 platform, a LAS Dataset for each dataset in the time series (Fall 2006, Spring 2007, Fall 2007, Spring 2008) was created using the Create LAS Dataset tool. The creation of a LAS dataset allowed classified data to be visualized in ArcMap and enabled faster rendering of the LiDAR point cloud by displaying points only when zoomed into a local extent. Additionally, a suite of functions including the ability to filter classifications so that only ground classified points and last returns were visible, as well as calculating point statistics, enabled the ability to quickly conduct visual QA/QC checks against building footprints and further prepare the LiDAR data for Digital Elevation Model (DEM) creation. Following preprocessing, projection, and ground classification of the LiDAR data, final LiDAR points classified as "ground" and "last return" were converted to a multipoint feature class using the LAS to Multipoint tool in ArcMap's 3D Analyst toolset.

An Empirical Bayesian Kriging (EBK) method was used to create an interpolated DEM surface using the EBK tool in ArcMap's Geostatistical Analyst toolset. An EBK interpolation method to create a DEM surface provided the ability to account for error in the LiDAR analysis. Four DEM surfaces were created, corresponding to the four LiDAR datasets in the time-series and included the Fall of 2006 and Spring of 2007 (El Niño event) as well as the Fall of 2007 and Spring of 2008 (La Niña Event).

In order to calculate beach sediment volume shifts a shoreline band partitioned by cross-shore segments was created to delineate the dynamic shore area as well as segment the shore band into manageable segments. A technique to measure coastal elevation change, DEM differencing, was applied using the Raster Calculator tool in ArcMap's Spatial Analysis toolset. DEM differencing was conducted to calculate beach elevation changes that occurred during the 2006-2007 El Niño winter, Summer of 2007, and 2007-2008 La Niña winter. Shore segment volume changes were performed by first calculating the volume of individual raster cells then summing the volume of raster cells over the entire shore segment. The rate of volume change in the shore segment was calculated by dividing the shore segment volume change by the area of the shore segment. Maps and graphs representing the rate of sediment volume change per segment over the time-series were created.

3.3 LiDAR Data Preparation and Formatting

Figure 13 details the workflow involved in preparing LiDAR data for analysis. The goal of this step was to prepare the raw LiDAR datasets for input into the EBK Model to create surface elevation DEMs associated with each of the four survey datasets. Following the download and uncompression of the LiDAR datasets, the files associated with each survey were projected into a NAV 1984 California State Plane coordinate system, clipped to a defined study area, and ground classified according to ASPRS standards. LastoLas tools provided the functionality to perform the majority of LiDAR data preparation and formatting with an advantage of batch processing capability. Following the ground classification process, the resulting LAS files were imported into ArcMap by creating a LAS Dataset associated with each survey. After the LAS dataset for each survey was visually inspected to ensure the ground classification process was accurate, the LAS to Multipoint ArcMap tool was used to create a multipoint feature class of only ground (bare earth) points for each survey.

Infrastructure can affect the output of the DEM interpolation; therefore, it was necessary to classify ground (bare earth) points from all other points. Only last-return ground points were carried on to the DEM interpolation process. After LAS files were projected from a global to projected coordinate system and then clipped to the study area to reduce the file size and processing time, the LAStoGround tool was used to batch process the files and classify ground points. Ground classified LAS files were visualized in ArcMap by creating a LAS dataset associated with each survey time period (i.e. Fall 2006, Spring 2007, Fall 2007, Spring 2008). LAS datasets were visualized in ArcMap and a visual quality assurance control check was performed on the ground classification by overlaying ground only classified points on an Esri imagery basemap.

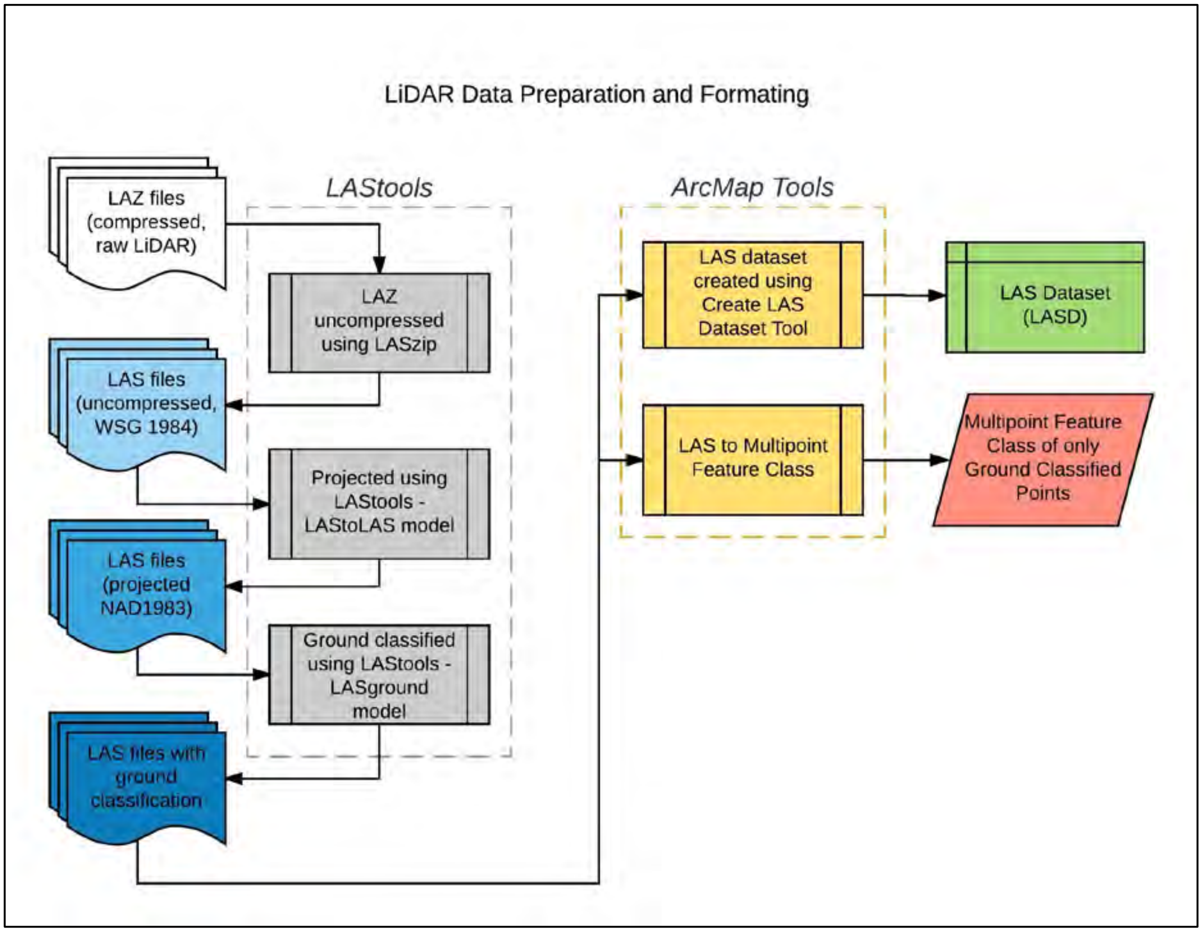

Figure 13 LiDAR to DEM workflow

3.3.1. LAZ Uncompression, Projection, and Clipping

Original LiDAR files were downloaded in a compressed, .LAZ, format specific to LiDAR data and using the open source software, LasZip, created by Martin Isenberg, as part of the LasTools software suite, individual LAZ files were decompressed into .LAS files with attributes of latitude, longitude, and elevation (Isenberg 2016).

Uncompressed .LAS files were then projected from a horizontal coordinate system (WGS84 World Mercator) to a projected coordinate system (NAD88 State Plane CA VI) using the LastoLas tool in the LasTools software suite. The vertical coordinate system of the .LAS files is the North American Vertical Datum of 1988 (NAVD88). Units for both the horizontal and vertical projected coordinate system remained in meters for analysis.

3.3.2. LAS Ground Classification

In order to create a DEM surface interpolated from only ground points within the LiDAR point cloud, it was necessary to undergo the process of classifying ground points (bare earth) from non-ground points (buildings, vegetation). Coastal infrastructure like buildings (i.e. ocean front properties and lifeguard towers) and piers, harbors, other man-made features that extended above the bare earth surface were filtered from the LiDAR point cloud in the ground classification process. Most of the LiDAR datasets had no classification attributes assigned.

Table 5 highlights the LiDAR classifications used for this study, developed by the American Society for Photogrammetry and Remote Sensing (ASPRS), additional classification values for buildings, vegetation, etc. exist but were not necessary for this study.

Table 5 ASPRS standardized LiDAR classifications used

Classification Value	**Meaning**
0	Created, never classified
1	Unclassified
2	Ground

Ground points in the LiDAR datasets were classified using the LasGround tool which is part of the LasTool software suite. LasGround classifies ground points using an automatic classification method which implements a contour/segmentation-based object-oriented approach.

In the background processing, LasGround generates contour lines from the highest elevation in the area down to the lowest elevation in the area using relatively small intervals (0.5m) and through a complex process of grouping and segmenting contours, the model is able to distinguish surface objects from the ground (Hug et al. 2004).

3.3.3. LAS Dataset

Transitioning into the ArcMap interface, ground classified .LAS files were imported into ArcMap using the Create LAS Dataset tool. Four separate LAS datasets were created associated with each time-period in the time-series. The Create LAS Dataset tool, part of the LAS Dataset toolset, allows the rapid read and display of LiDAR data in ArcMap. LiDAR attributes, including classifications and returns, and spatial references are displayed as well. The LAS Dataset tool displays individual .LAS files as tiles until zoomed into a close enough extent that distinguishing individual points is possible, which allows for efficient processing and graphics rendering (Figure 14). Additional tools allowing the removal and addition of individual .LAS files also provide streamlined editing capability.

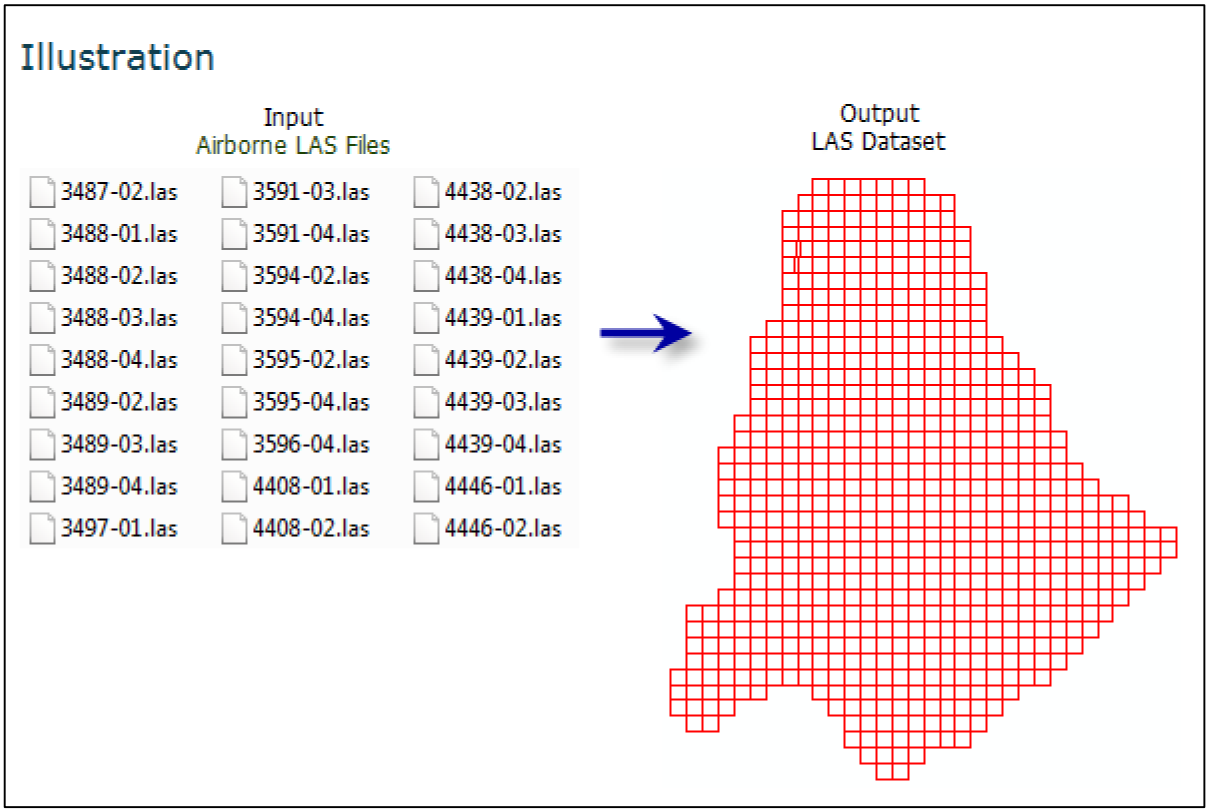

Figure 14 ArcMap tool Create LAS Dataset input and output illustration (Esri 2016)

Once LAS datasets were created, ground classification was verified by visually comparing to background imagery. Point statistics were documented for each LAS Dataset including original # of LiDAR points, # of ground classified points, and # of ground classified plus last return points.

3.3.4. LAS Ground to Multipoint Feature Class

Following the ground classification process and creation of LAS datasets, LAS dataset files were converted into a multipoint feature class. Using the LAS to Multipoint tool, in the LAS Dataset toolset, parameters were set to convert only ground classified and last return points into the multipoint feature class. The laser emitted from LiDAR systems has the capability of measuring multiple elevations as the pulse reflects from high objects in the landscape first (buildings or infrastructure) then lower vegetation, structures until finally, the pulse reflects off bare-earth surfaces (Keranen and Kolvoord 2016). Carrying on points that were ground classified and last returns ensured only bare earth points would be inputted into the next step of creating a DEM.

3.4 LiDAR-derived Digital Elevation Models (DEMs)

Digital elevation models (DEMs) were created for each LiDAR dataset using an Empirical Bayesian Kriging (EBK) interpolation method. While no statistical interpolation process can produce a true elevation surface, the EBK interpolation method provides the ability to incorporate uncertainty when creating DEMs (Krivoruchko and Butler 2013). The ability to measure uncertainty is particularly important in a detailed time-series analysis. Calculating elevation changes and volume changes at a high, 1-meter grid size, resolution requires combining time-series data and error, if present, can persist and possibly increase in subsequent stages of the analysis. Additionally, identifying sources of error in the individual DEMs was necessary to conclude whether or not the next stages in the analysis were feasible in the terms of producing a product that could accurately measure sediment volume changes over time.

Other interpolation methods, including inverse distance weighted (IDW), spline, natural neighbor, and standard kriging were considered, but none provided associated error. Triangulated Irregular Network (TIN) surfaces were also evaluated, as they are commonly used to display elevation surface data. TIN surfaces are convenient for creating surfaces using irregularly spaced known elevation points; however, the LiDAR datasets used for this analysis consisted of dense and fairly uniform spacing of elevation points. Additionally, the TIN surface interpolation methods, like the other interpolation methods discussed, did not offer statistical error outputs.

The EBK interpolation method accounts for error by running multiple simulations on the dataset, estimating error through the underlying semivariogram (Esri 2016). The statistical basis behind the semivariogram concept is rooted in spatial autocorrelation, meaning the closer things are, in this case elevation points, the more similar they will be than points further away (Chilès and Delfiner 1999). The semivariogram defines how the similarity of points diminishes over distance (Krivoruchko 2012). The model repeatedly runs simulations, in the case of this analysis, 100 simulations were specified. The large elevation dataset, made up of millions of points, is automatically broken into a subset for model runs, due to model computational limits. The default subset setting was used, 100 points per subset. After specifying the parameters and desired number of model runs the EBK process uses the following statistical logic outlined in four steps (Esri 2016). Step 1 produces an initial semivariogram, estimated from a subset of known elevation data. Step 2 uses the initial semivariogram as a model, to calculate data and produce predicted elevation points within the subset. Step 3 creates a new semivariogram which is estimated from the predicted elevation points. Then, Step 4 repeats Step 2 and 3 for 100 model runs. The model then moves to another subset of known elevation points and repeats the process in entirety until all subsets have been covered. Understanding how the EBK interpolation method works provides insight into the enormous computational modeling involved, especially when dealing with LiDAR datasets that contain millions of elevation points.

Using the ArcMap EBK tool a 1-meter grid resolution DEM and associated error surface was created for each of the four LiDAR datasets as shown in Figure 15. Each dataset required individual EBK interpolations; therefore, the EBK model was run with the same settings four separate times.

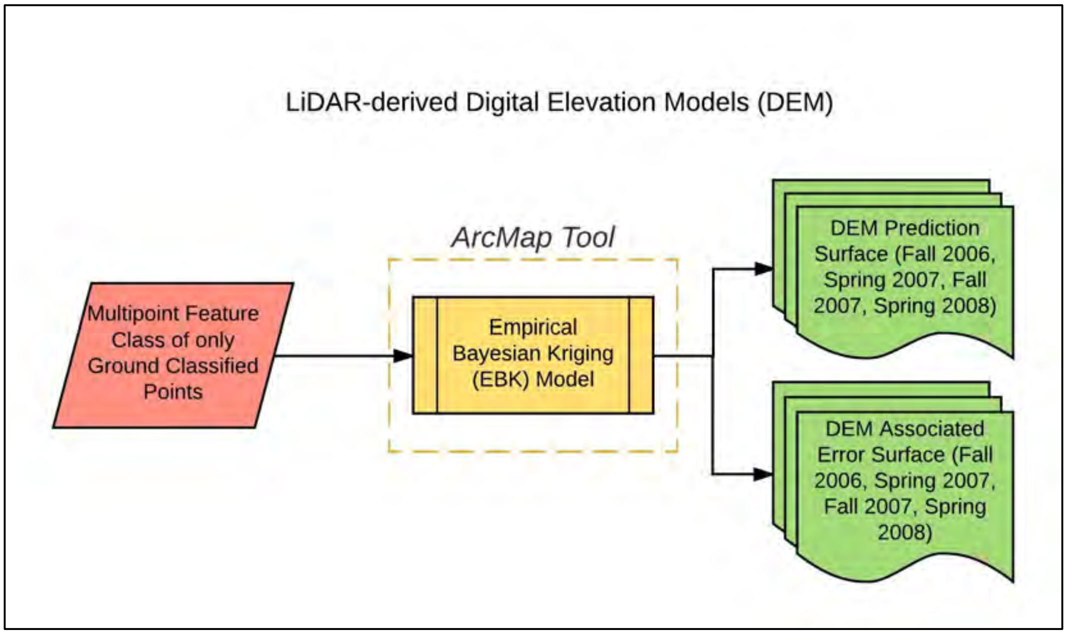

Figure 15 LiDAR-derived Digital Elevation Model (DEM) Workflow

3.4.1. Empirical Bayesian Kriging (EBK) Analysis

The multipoint feature class for each LiDAR dataset, consisting of only ground (bare earth) elevation points, were used to create a digital elevation model (DEM) surface using the Empirical Bayesian Kriging (EBK) tool. The EBK method was chosen because the ArcMap EBK tool automatically calculates and adjusts parameters to receive accurate interpolation results and also estimates the level of error associated with the interpolation. A total of four DEM surfaces corresponding to the following four LiDAR surveys in the time-series were created: 1) Fall of 2006, 2) Spring of 2007, 3) Fall of 2007, 4) Spring of 2008.

Output cell resolution for each DEM was set to a 1-meter grid cell size. The raster grid size to use for DEM creation was chosen based on the criteria of a minimum of one LiDAR data point per grid cell and a low range of elevation variation within each cell. Additional parameters as discussed previously included setting the number of model runs (simulations) to 100 and the subset size to 100 points. Following the creation of the initial Fall 2006 DEM, all other three datasets were set to snap to the Fall 2006 raster. Raster snapping was necessary to ensure that individual raster cells in all datasets aligned for the later DEM differencing process. This snap raster parameter was specified in the EBK tool's Environment Settings under Processing Extent.

In order to minimize processing time, the extent of the Raster Analysis was masked to the Study Area Boundary. Masking the raster analysis avoided a default rectangle raster output and the processing of data outside the study area.

3.4.2. ArcGIS Processing Requirements

Due to the large amount of elevation points in each dataset individual EBK interpolation processes took approximately 3-5 hours to complete. This required high-end processing ability. Standard ArcMap conducts background processing in 32-bit, and in order to improve processing speeds, the 64-bit Background Processing option available through ArcGIS was downloaded and installed. The 64-bit Background Processing option replaced the regular 32-bit, allowing EBK interpolation analysis and DEM grid surface creation to be computed using more system resources. All LiDAR analysis and geoprocessing were conducted on a stand-alone, high performance, desktop with the system specifications listed in Table 6.

Table 6 Desktop system specifications used for LiDAR analysis and geoprocessing

Component	**Detail**
Processor	3.4 GHz Intel Core i7
RAM	64 GB DDR Memory
Hard Drives	128 GB Solid State Drive + 1 TB SATA Drive
Graphics	Dedicated Graphics Card – 2 GB Nvidia GeForce GT 730
Operating System	Windows 10

3.5 Beach Sediment Volume Change Analysis

The beach sediment volume change analysis consisted of three processes including DEM differencing, defining shore segments, and calculating sediment volume change. These processes are shown in Figure 16 and discussed in detail below. The final results consisted of tables of actual sediment volume change in cubic meters and the rate of sediment volume change per square meter for each shore segment. The rate of sediment volume change per square meter during the 2006-2007 El Niño winter was joined to the shore segments and visually displayed in a series of maps. Detailed tables of actual sediment change in each shore segment over the 2006-2007 El Niño winter, Summer of 2007, and 2007-2008 La Niña winter were created and included in this manuscript as Appendix A.

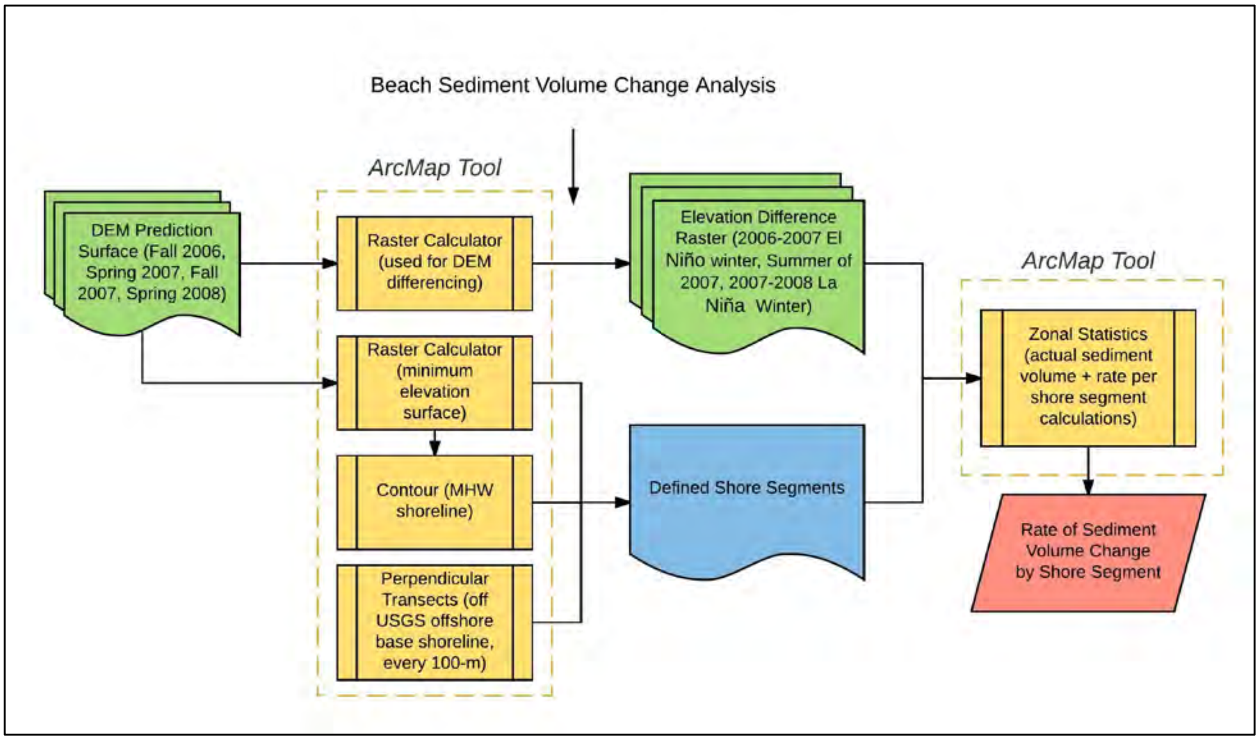

Figure 16 Beach Sediment Volume Change Analysis Workflow

3.5.1. DEM Differencing

The four DEMs created using the EBK process were used to calculate elevation change over the 2006-2007 El Niño winter, summer of 2007, and following 2007-2008 La Niña winter. ArcMap’s Raster Calculator tool was utilized to perform DEM differencing over the datasets and

Table 7 shows the three time-series calculations that were made. Each DEM differencing calculation resulted in a new raster (1-meter cell size resolution) representing elevation change.

Table 7 DEM Differencing to Measure Elevation Change over Time-Series

DEM (time y) (meters)	**minus**	**DEM (time x) (meters)**	**equals**	**DEM difference (time y – time x) [Elevation change in meters]**
Spring 2007	-	Fall 2006	=	2006-2007 El Niño Winter
Fall 2007	-	Spring 2006	=	2007 Summer
Spring 2008	-	Fall 2007	=	2007-2008 La Niña Winter

3.5.2. Shore Segments

In order to compute and visualize volume change for the large study area, the coastal zone was broken up into manageable segments. A shoreline band was created by using a combination of calculating the minimum shoreline based on local tidal datums and manual digitization with the aid of contours. The shoreline band was then broken up into manageable segments which were assigned unique identification numbers. Transects were used to aid in the process of segmentation; however, it is important to note that segmentation was arbitrary and not based on any physical landmarks.

The seaward boundary of the shoreline band was delineated by calculating a minimum Mean High Water (MHW) shoreline. MHW is one of several different tidal datums that are calculated at tidal stations. Figure 17 shows the various elevation and tidal datums associated with the La Jolla tidal station (#9410230). Tidal datums are computed by averaging long-term tidal data (1983 to 2001) collected by the station. Since tidal influences are uniform throughout the OLC, meaning changes in tide observed in La Jolla will be the same in Dana Point, the long-term data from the La Jolla tidal station provided sufficient data to calculate a MHW shoreline.

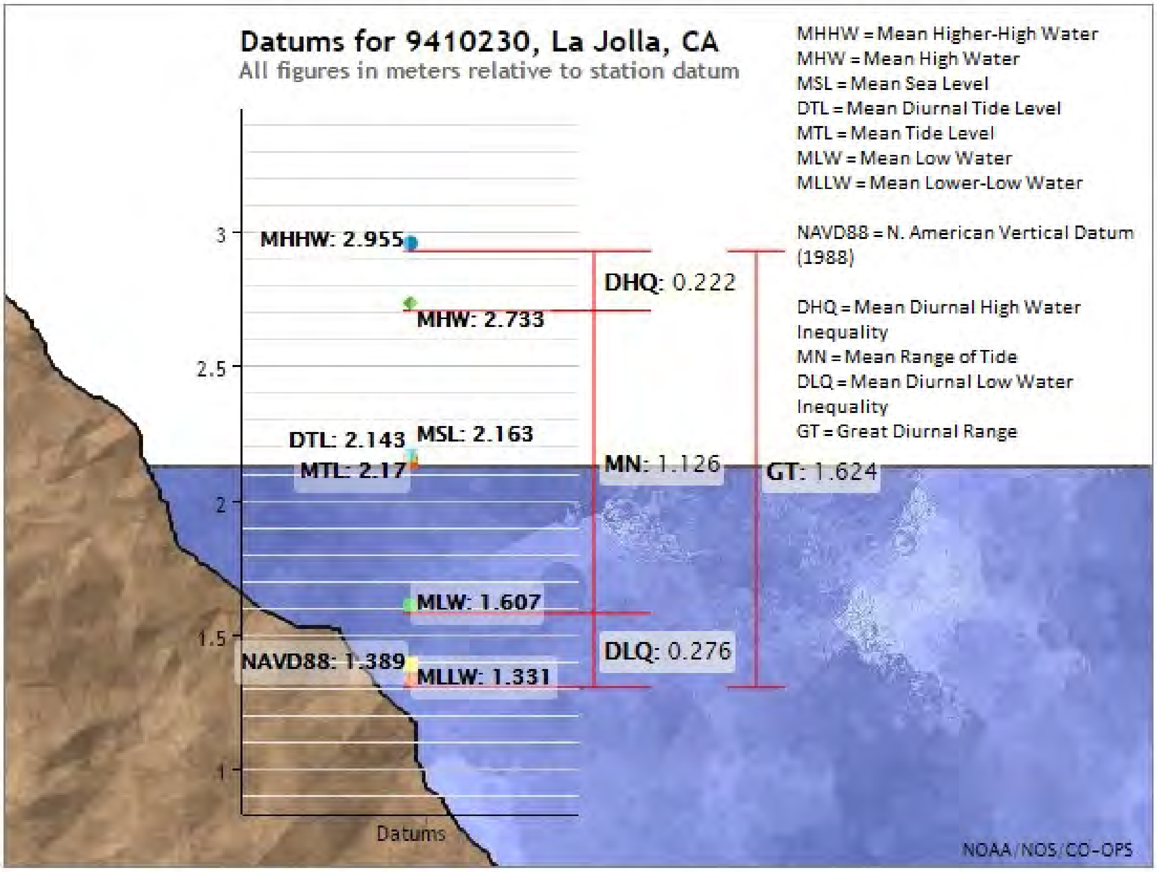

Figure 17 Elevations datums (in meters) for La Jolla, CA (Station #9410230) (NOAA 2016)

In order to calculate the minimum MHW shoreline, all four DEMs were inputted into ArcMap's Cell Statistics Tool, and the minimum elevation for each cell was calculated. This process produced a minimum raster elevation surface. The minimum MHW shoreline was derived by drawing a contour across the minimum raster elevation surface at the Mean High Water (MHW) tidal datum. As Figure 17 shows, the difference between the NAVD88 vertical coordinate system and the various tidal datums for the La Jolla station. In the NAVD88 vertical coordinate system, a contour drawn at zero would actually lay at 1.389 meters in the tidal datum, closer to Mean Lower Low Water. With the assumption that zero meters in the NAVD88 vertical datum equals 1.389 in the tidal datum, the MHW was calculated by drawing a contour at 1.344 meters, the difference between MHW and NAVD88 values in Figure 17.

The shoreline band extends landward to include the sandy beach with the landward boundary defined as the end of sandy beach and the beginning of stabilized dunes, infrastructure, or cliff faces. The landward boundary of the shoreline band was created using a combination of elevation contours created from the DEMs, identifying sharp elevation gradients, and manual digitization using imagery as guides. The landward boundary of the shoreline band was typically between the 4 and 6-meter elevation contours.

Transects were generated by creating transects every 100-meters perpendicular to an offshore shoreline as a base. The offshore shoreline was available through the United States Geological Service shoreline project and is commonly used to generate perpendicular transects (USGS 2005). Using an offshore shoreline as an anchor for transects minimized the occurrence of transects crossing each other. A minimal amount of editing was required to clean up transects that crossed over each other, primarily around coastal areas that had sharp turns in the shoreline direction. Transects were generated off the USGS offshore shoreline in ArcGIS using the Perpendicular Transects tool created by M. Ferreira (M. Ferreira 2014). Figure 18 shows the process of creating shore segments using the Mean High Water (MHW) shoreline, elevation contours, and transects.

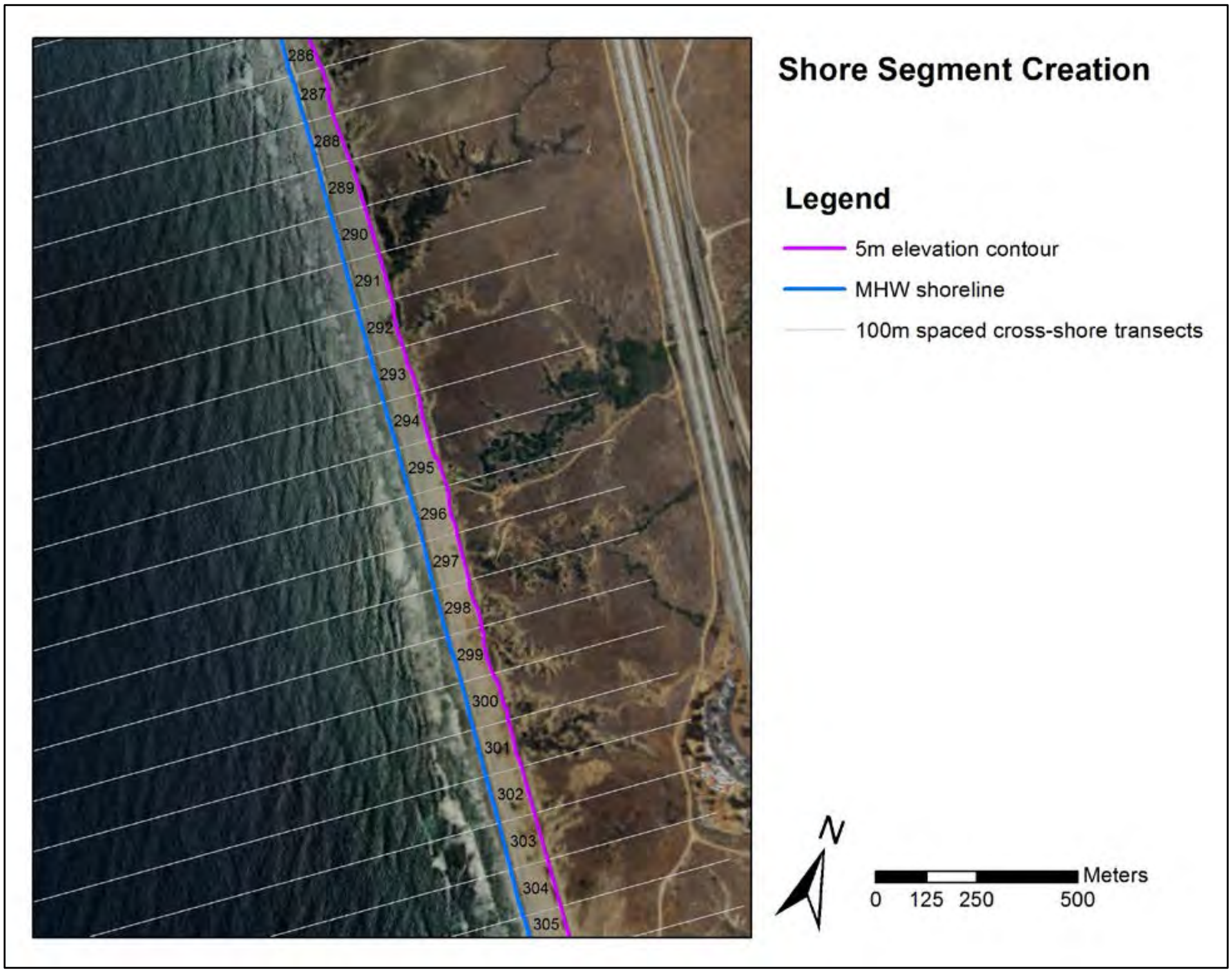

Figure 18 Shore segment creation process

3.5.3. Volume Calculation

Beach sediment volume change between the time-series was calculated using the elevation difference rasters associated with each time-series. The three elevation difference rasters identified in Table 9 were individually inputted into ArcMap's Zonal Statistic as Table tool to calculate statistics per shore segment necessary to derive total volume change per segment and the rate of volume change per segment.

The volume per individual cell (V_{cell}) was calculated by multiplying the area of the cell (A_{cell}) by the elevation difference of the cell (z_{cell}), as shown in Equation 3.1. In the case of this analysis, all grid cell sizes were one meter by one meter, making all A_{cell} values equal $1m^2$.

$V_{cell} = A_{cell} z_{cell}$ where; z_{cell} = elevation difference (m) of cell and $A_{cell} = 1m^2$ (3.1)

To calculate the total change in volume per segment, (V_{cell}) was summed for all the cells within the segment. This calculation is represented by Equation 3.2. $V_{segment}$ represents the total change in sediment volume in cubic meters for a shore segment, and a negative value represents erosion while a positive value represents accretion.

$$V_{segment} = \sum_{segment} V_{cell} \tag{3.2}$$

Individual shore segments had varying areas and to normalize sediment volume changes in both maps and graphs, the rate of sediment volume change in the form of cubic meters per square meter was calculated for each shore segment. In some cases, shore segments with high amounts of sediment volume shift ($V_{segment}$) were associated with large areas of beach; however, these segments did not necessarily have high rates of sediment volume change compared to smaller shore segments. Normalizing data visualized in the graphs and maps allowed for a more accurate representation to use for comparing shore segment volume changes. The rate of sediment volume change ($R_{segment}$) in cubic meters per square meter was calculated by dividing the total sediment volume change of a shore segment ($V_{segment}$) by the total area of the shore segment ($A_{segment}$) as shown in Equation 3.3.

$$R_{segment} = V_{segment} \div A_{segment} \tag{3.3}$$

Detailed graphs of the rate of sediment volume change by shore segment were created for the 2006-2007 El Niño winter and 2007-2008 La Niña winter. Graphs and tables were created to summarize overall actual sediment change and rates of sediment change for the whole study area for the 2006-2007 El Niño winter, Summer of 2007, and 2007-2008 La Niña winter. Additionally, Appendix A was created to include actual sediment changes by shore segment in the form of detailed tables for all time periods.

Chapter 4 Results

Chapter 4 discusses the results of this study. The results from preparing and formatting the LiDAR datasets for analysis focus on the ground classification process and include elevation point statistics, 3D visualization, and the creation of multipoint feature classes. Next, the results from using the EBK interpolation method to create DEMs is discussed. Finally, the results from the beach sediment volume change analysis are presented. The beach sediment volume change analysis includes the final data represented by a series of graphs, tables, and maps along with detailed narratives of erosion and accretion patterns observed along the coast in the OLC.

4.1 LiDAR Preparation and Formatting Results

Figure 19 and Figure 20 show a snapshot of the Fall 2006 LAS dataset with all elevation points and only ground elevation points, respectively. Buildings, tall manmade infrastructure, most roads, lifeguard towers, and piers were filtered out. ArcMap tools also provided the capability to view LAS dataset segments in a 3-D rendering. Figure 21 shows a segment in San Clemente as part of the LAS Fall 2006 dataset with all elevation points while Figure 22 shows the same segment with only ground classified points; elevation points associated with buildings and the pier structure are not displayed. Table 8 shows the point statistics of each LAS dataset including the total number of elevation points in the delineated study area followed by the number and percentage of those points that are ground (bare earth) classified. The percentage of ground classified points ranged from 23.7% to 37.6% of total elevation points. Table 8 also shows the minimum and maximum elevation point of each dataset, which ranged from -8.24 m to 110.12 m. Negative elevations were often associated with intertidal and ocean environments while elevations on the higher end of the range were associated with tall bluffs and cliffs extending from the beach area.

Using the ArcMap LAS to Multipoint tool in the 3D Analyst toolbox, classified LAS files for each survey were exported into a multipoint feature class. Settings for the export filtered out all elevation points except those that met the criteria of ground (bare earth) and last returns. These multipoint feature classes were used as input to create ground (bare earth) digital elevation models using an Empirical Bayesian Kriging interpolation technique.

Table 8 LAS Elevation Point Statistics

LAS Dataset	**All Points in Study Area Boundary**	**Ground (Bare Earth) Classified Points**		**Elevation Range (meters)**	
		# of points	**% of points**	**Min**	**Max**
Fall 2006	100,078,983	23,773,745	23.7%	-8.02	110.14
Spring 2007	79,085,737	28,257,867	35.7%	-8.24	108.32
Fall 2007	103,299,390	38,065,726	36.8%	-5.36	107.00
Spring 2008	120,057,674	45,155,213	37.6%	-5.12	107.13

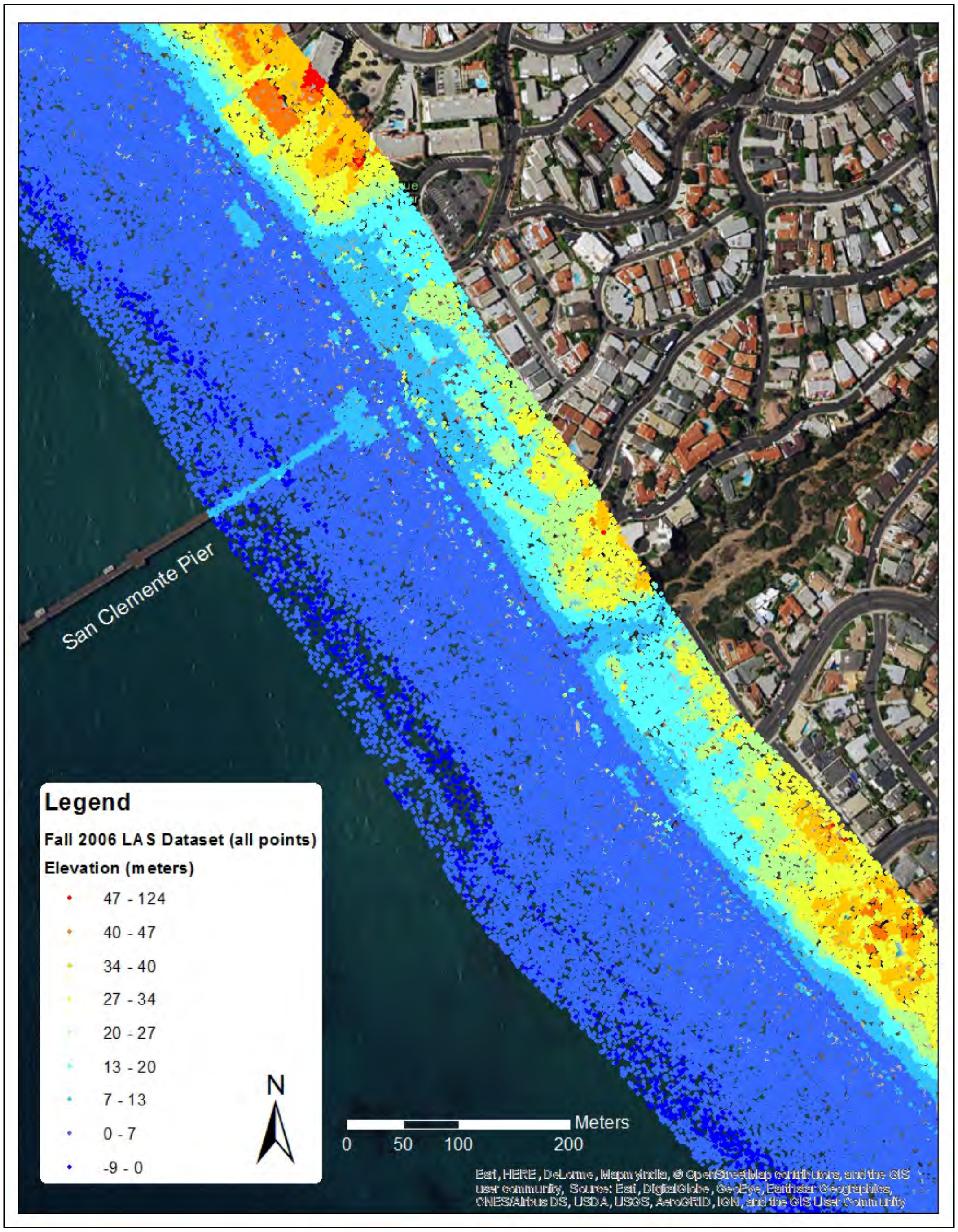

Figure 19 Fall 2006 LAS dataset with all elevation points

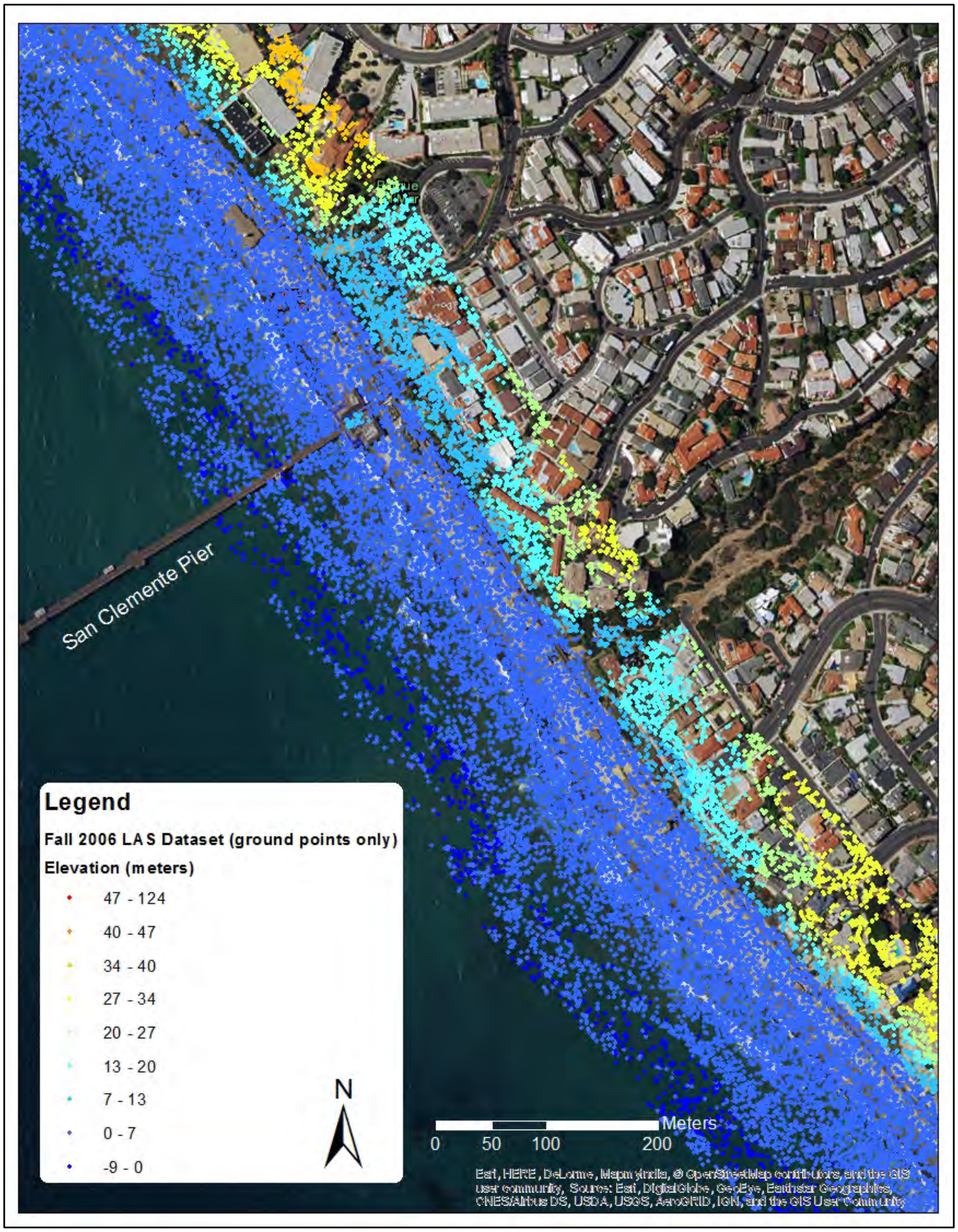

Figure 20 Fall 2006 LAS Dataset with only ground (bare earth) classified points

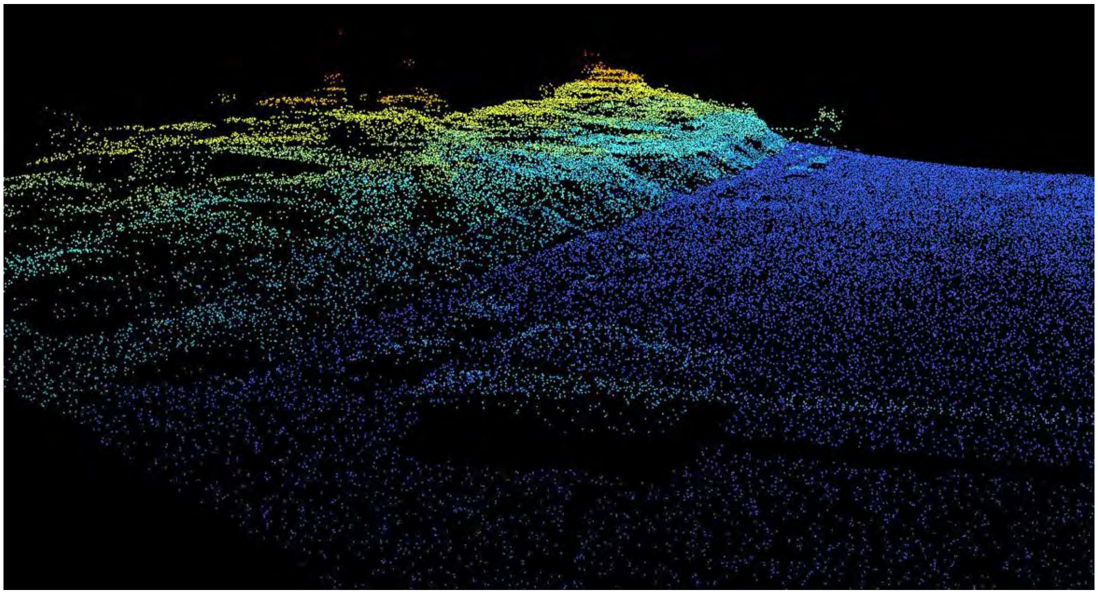

Figure 21 Fall 2006 LAS dataset 3D view with all elevation points

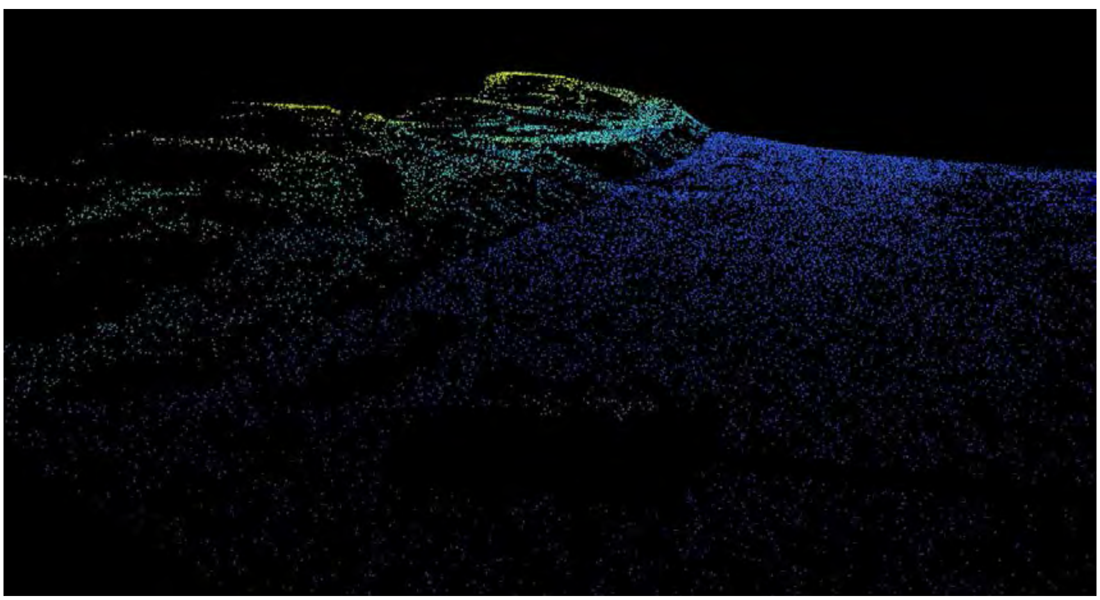

Figure 22 Fall 2006 LAS dataset 3D view will only ground (bare earth) classified points

4.2 EBK Interpolation and DEM Creation Results

The EBK interpolation process was the most time-consuming of all steps in this study. After many failed attempts at running the EBK model, successful model runs were completed using a computing machine with multiple core processors and high memory capacity. The EBK tool took approximately 4 hours to create each of the four DEMs.

The EBK tool also outputted error rasters corresponding to each interpolation elevation raster. These error rasters provided the ability to quantify and spatially reference error associated with the created DEM. As expected due, to the high density of elevation points in the study area, elevation error was found to be minimal. Higher elevation error was typically seen in areas where points corresponding to buildings and infrastructure had been removed during the ground classification process.

4.3 Beach Sediment Volume Change Analysis Results

A total of 792 shore segments were created along the coastline from Dana Point to La Jolla and covered a total area of just under 3.5 million square meters. The following sub-sections describe in detail the results of the beach sediment volume change analysis. Appendix A includes detailed results of sediment volume changes by shore segments during the 2006-2007 El Niño winter, the Summer of 2007, and following 2007-2008 La Niña winter.

4.3.1. Dana Point

Shore segments one through 38 comprise the Dana Point region, the northern most section of the OLC, and include an area of just under 200,000 m^2 (Figure 26). Beach sediment volume change analysis showed overall stability for Dana Point beaches during the 2006-2007 El Niño winter, with a net deposition of 3,682 m^3 of sediment. The harbor jetties and infrastructure likely played a role in protecting Doheny State Beach from southerly storm tracks and associated waves during El Niño storms. The decrease of sediment in Shore Segment 6 can be explained by the San Juan Creek mouth and associated berm shifting from open to closed conditions (Figure 25). The shore segments just south of Doheny State Beach display erosion during all time periods. Overall spatial patterns of erosion and accretion were similar for both the El Niño and La Niña winters; however, the rate of erosion per square meter was significantly greater during the La Niña winter (Figure 23 and Figure 24). Interestingly, the Dana Point region experienced the greatest overall erosion relative to other areas of the OLC during the intermediary summer 2007 period, with a sediment loss of 30,257 m^3, a rate of roughly -0.15 m^3 per square meter.

Table 9 Dana Point Sediment Net Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
1 - 38	199,655	3,682	-30,257	-31,241

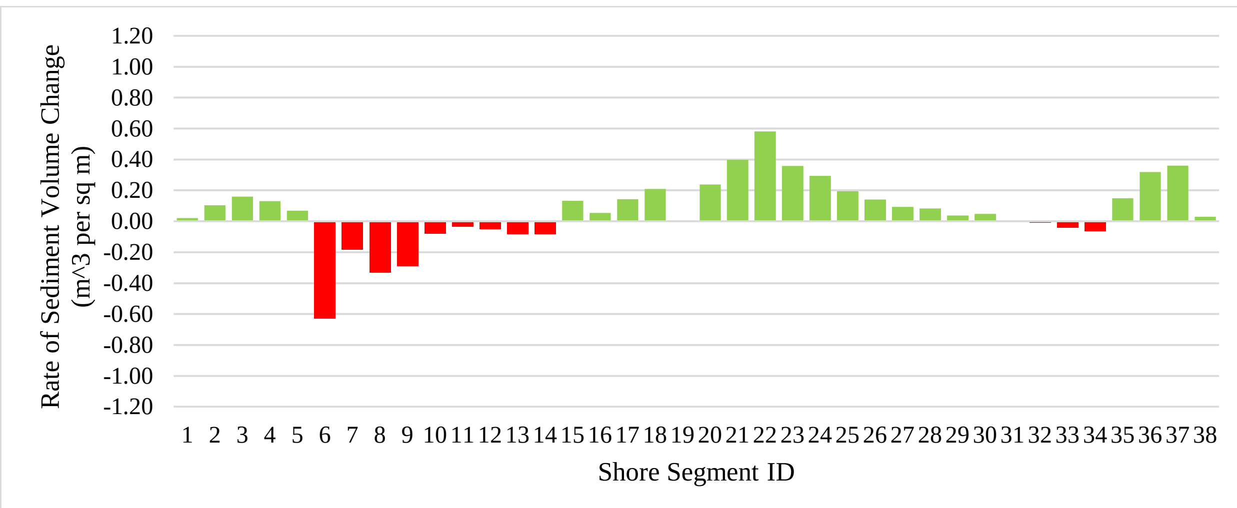

Figure 23 Dana Point – Rate of sediment volume change by shore segment during the 06-07 El Niño

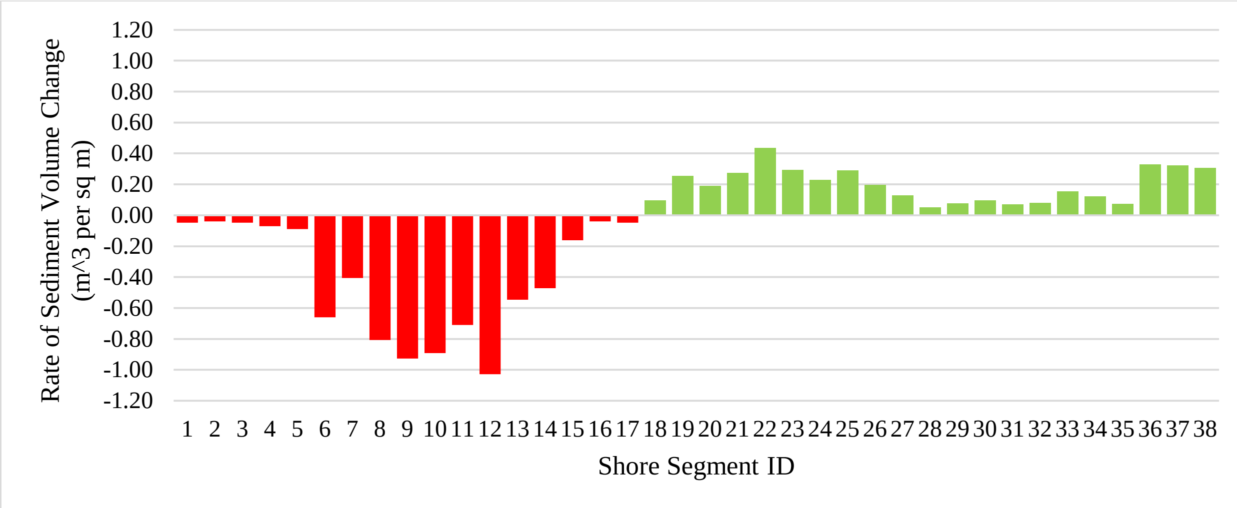

Figure 24 Dana Point – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 25 Historical imagery showing the San Juan Creek mouth shift from open to closed (Left: February 2006, Right: March 2007) (Source: Google Earth)

Figure 26 Dana Point - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.2. San Clemente

For this study, the San Clemente region is divided into a north and south region, arbitrarily separated by the San Clemente pier landmark. San Clemente (north) is defined as shore segments 39 through 75 and San Clemente (south) is defined as shore segments 76 through 113. Collectively, the San Clemente shore segments total area is 235,846 m^2.

4.3.2.1. San Clemente (North)

The San Clemente (North) area, defined by shore segments 39 through 75, represent a total area of 95,593 m^2 (Figure 29). The spatial pattern of erosion and accretion during the 2006-2007 El Niño winter is indicative of longshore sand transport (Figure 27). A spatially similar longshore sand transport pattern is also visible during the 2007-2008 La Niña, only with muted erosion and accretion amounts (Figure 28). During the Summer 2007, longshore sediment deposition and erosion patterns are reversed from both winter observations. During the 2006-2007 El Niño winter the San Clemente (North) area lost 6,608 m^3 of sediment; however, 6,874 m^3 of sediment was deposited back onto the beaches during the Summer 2007 (Table 10). The following La Niña winter showed a total sediment loss of 5,054 m^3, only a slight decrease relative to the previous El Niño winter.

Table 10 San Clemente (North) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
39 - 75	95,593	-6,608	6,874	-5,054

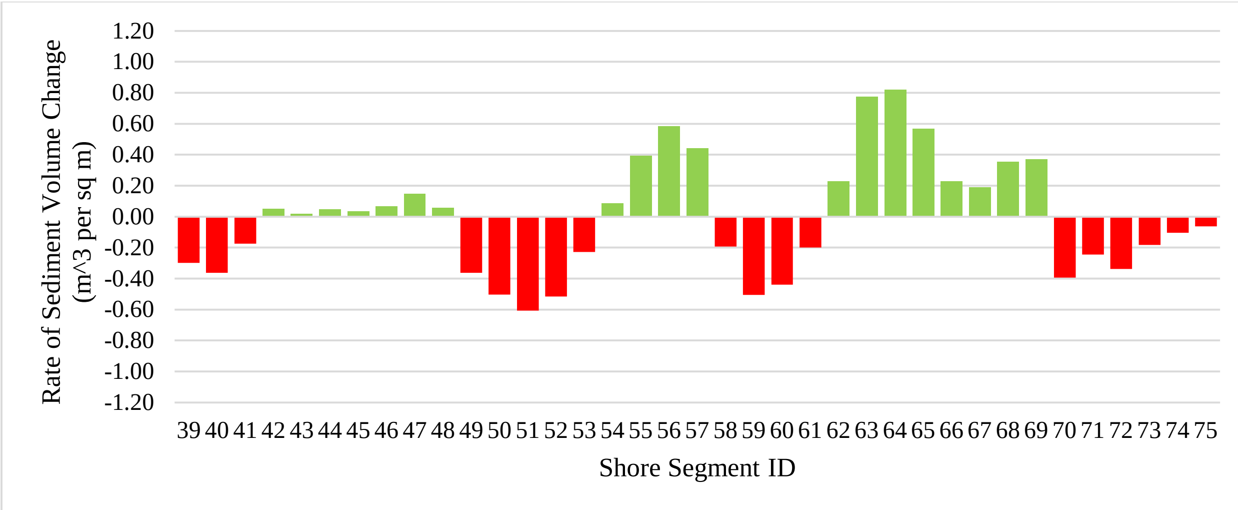

Figure 27 San Clemente (North) – Rate of sediment volume change by shore segment during the 06-07 El Niño

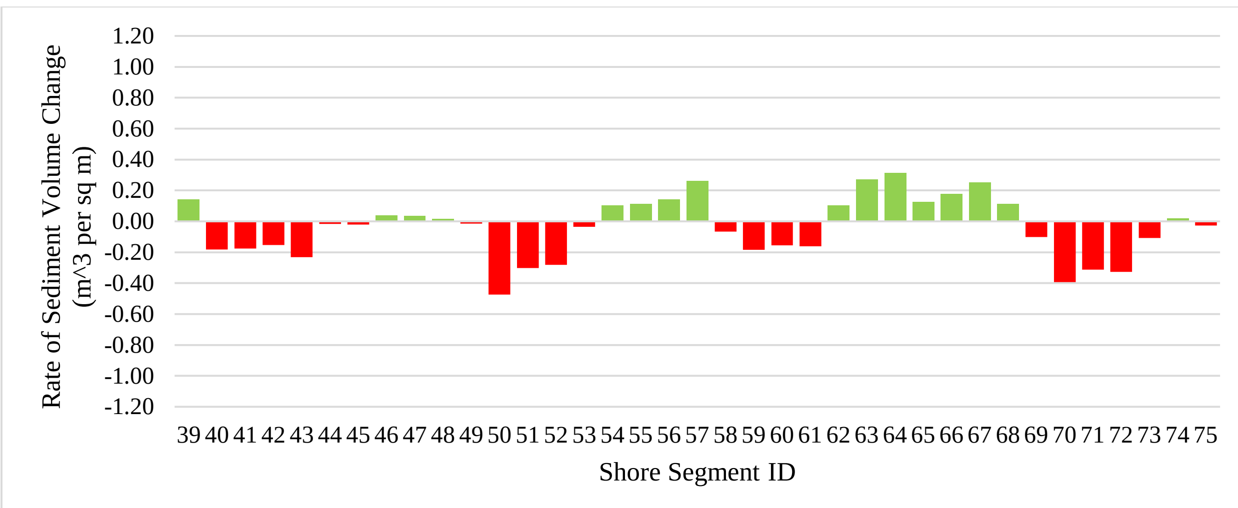

Figure 28 San Clemente (North) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 29 San Clemente (North) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.2.2. San Clemente (South)

San Clemente (South), defined as shore segments 76 through 113, showed overall greater erosion during the 2006-2007 El Niño winter than the 2007-2008 La Niña winter (Figure 30 and Figure 31). During the 2006-2007 El Niño winter 30,875 m^3 of beach sediment was lost, and most shore segments experienced erosion. Shore segment 76, which includes the San Clemente pier showed some accretion and shore segments 111-113 had significant accretion likely due to a combination of increased sediment flow out of Cristianitos Creek and a shift in shoreline direction. During the Summer of 2007, the San Clemente (South) shore segments gained 14,058 m^3 of sediment, almost half of the sediment that was lost during the previous winter (Table 11). The following 2007-2008 La Niña winter showed a net sediment loss of 6,034 m^3 (Table 11).

Table 11 San Clemente (South) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
76 - 113	140,253	-30,875	14,058	-6,034

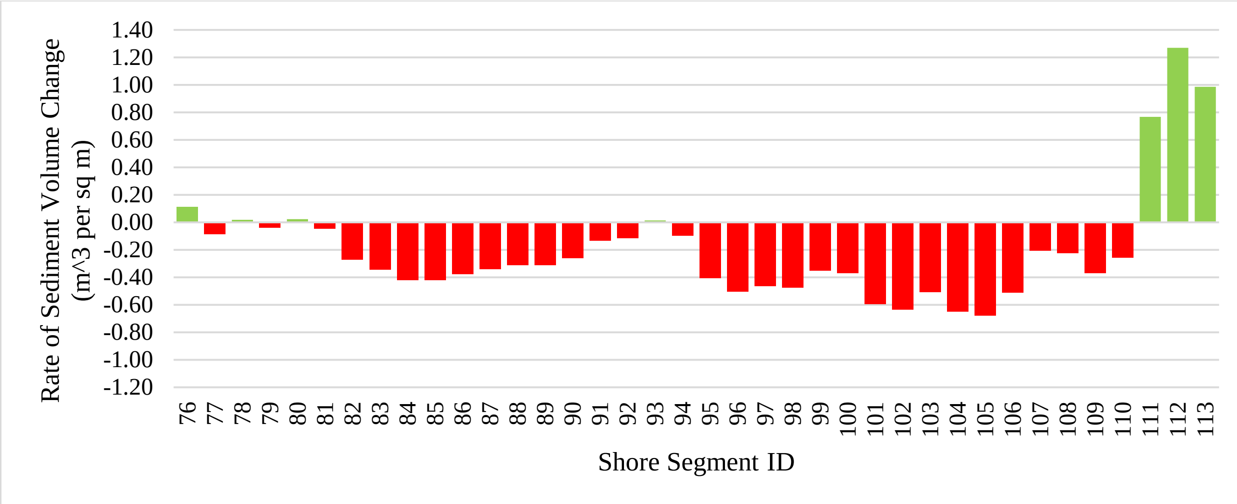

Figure 30 San Clemente (South) – Rate of sediment volume change by shore segment during the 06-07 El Niño

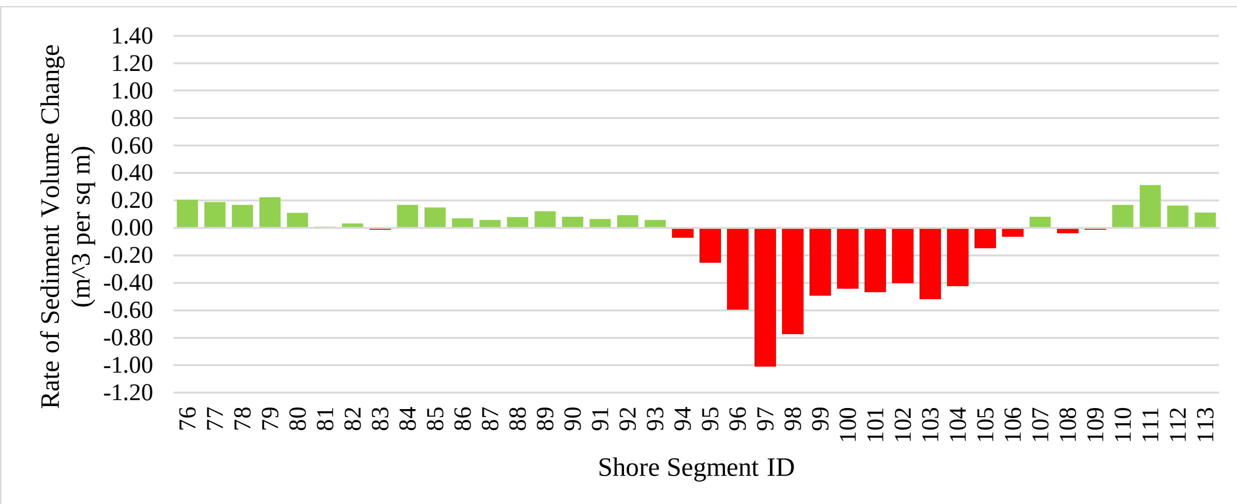

Figure 31 San Clemente (South) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 32 San Clemente (South) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.3. San Diego North

The San Diego North region consists of shore segments 114 through 313. For the purpose of this study, the San Diego North region was arbitrarily defined to span from San Onofre to Camp Pendelton Marine Corps Base (MCB). Higher rates of sediment volume loss during the 2006-2007 El Niño winter were seen in southern portions of San Onofre State Beach and Camp Pendelton MCB. Cliff failure was also observed in the San Onofre State Beach area. Individual sub-regions and results are discussed in the following sections.

4.3.3.1. Trestles Beach to San Onofre State Beach/ Nuclear Generating Station

Shore Segments 114 through 151 represent the area from Trestles Beach to San Onofre State Beach ending adjacent to the decommissioned San Onofre Nuclear Generating Station (SONGS) (Figure 35). Collectively shore segments 114 through 151 represent 173,772 m^2 of coastal beach. Both the El Niño and La Niña winters showed similar distribution trends of accretion and erosion, with the narrow beach area north of San Onofre Creek along the point showing the greatest erosion rate as signified by Shore Segments 121 through 122 (Figure 33 and Figure 34). During the 2006-2007 El Niño winter, this area showed a net loss of 5,568 m^3 of sediment followed by a recovery of 6,479 m^3 sediment during the Summer of 2007. The 2007-2008 La Niña winter showed a greater loss of beach sediment in this area than the preceding El Niño winter with a net loss of 6,479 m^3 (Table 12).

Table 12 Trestles to San Onofre (SONGS) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
114 - 151	173,772	-5,568	6,594	-6,479

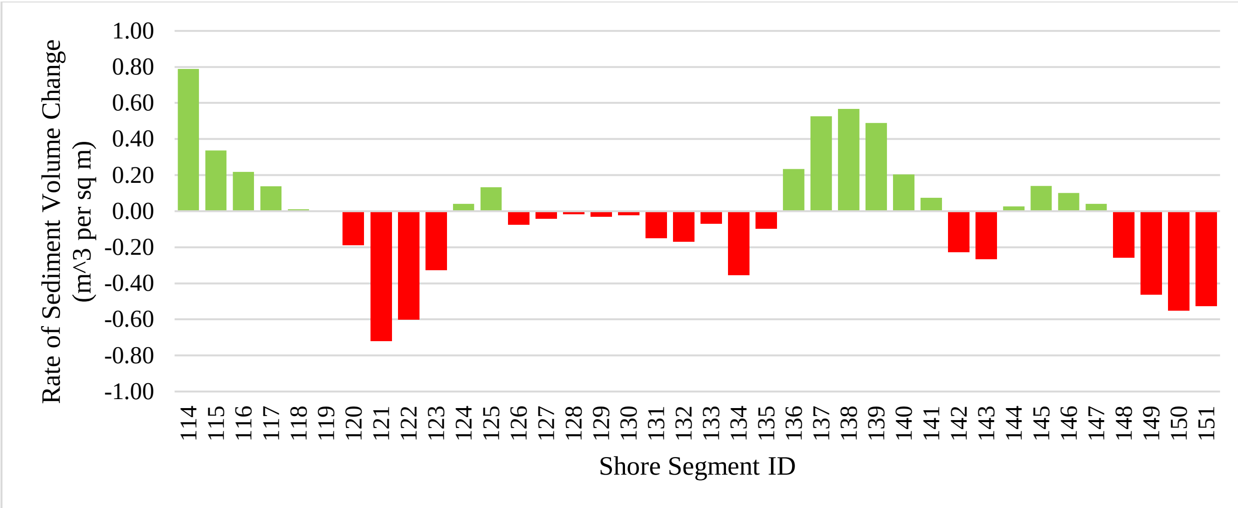

Figure 33 Trestles to San Onofre (SONGS) – Rate of sediment volume change by shore segment during the 06-07 El Niño

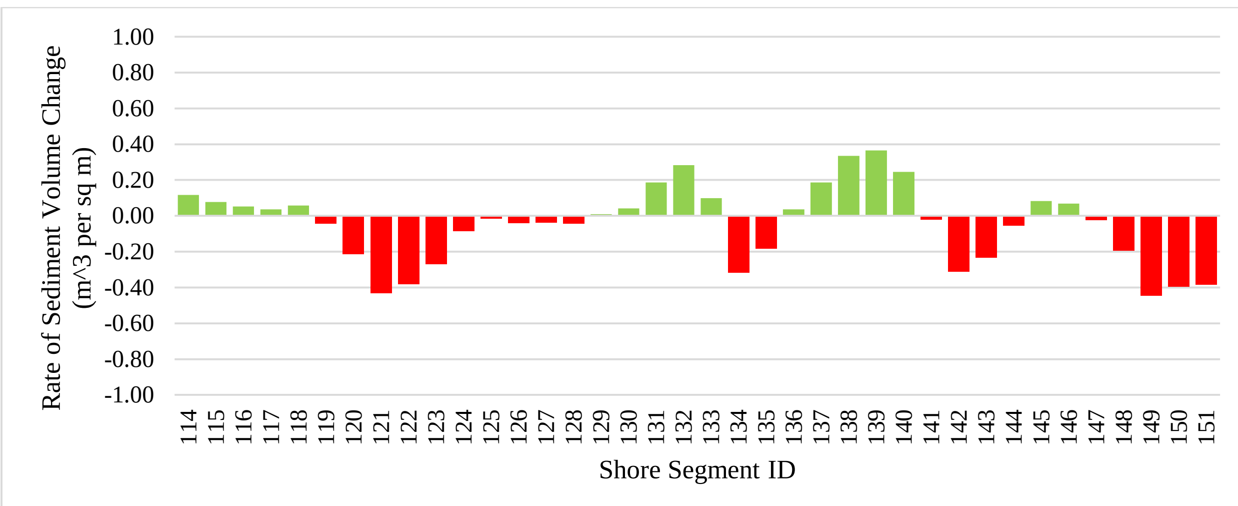

Figure 34 Trestles to San Onofre (SONGS) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 35 Trestles to San Onofre (SONGS) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.3.2. San Onofre State Beach to Camp Pendelton Marine Corps Base (North)

San Onofre State Beach to the northern extent of Camp Pendelton Marine Corps Base (MCB) are identified as shore segments 152 through 191 and cover an area of 88,000 m^2 (Figure 38). Dense nearshore development ends following the San Onofre Nuclear Generating plant, and the physical characteristics of the beach are primarily natural with beach faces transitioning to steep bluffs. Sand transport is visible in both the El Niño and La Niña winters as indicated by alternating erosion and accretion trends as shown in Figure 36 and Figure 37. Unlike most regions within the OLC which showed net sediment accretion over the summer months, this region showed erosion during the Summer of 2007. Rates of sediment volume loss during the 2006-2007 El Niño winter were only slightly higher than the 2007-2008 La Niña winter; however, the rates of sediment volume accretion, specifically at shore segments 168 and 169 were significantly greater during the 2006-2007 El Niño winter. Figure 39 shows a close up of shore segments 168 and 169 that are parallel to unstable cliff bluffs and a tributary/creek outlet, which could explain the increased accretion rate during the 2006-2007 El Niño.

Table 13 San Onofre State Beach to Camp Pendelton MCB (North) Net Sediment Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
152 - 191	88,000	-6,208	-1,762	-8,235

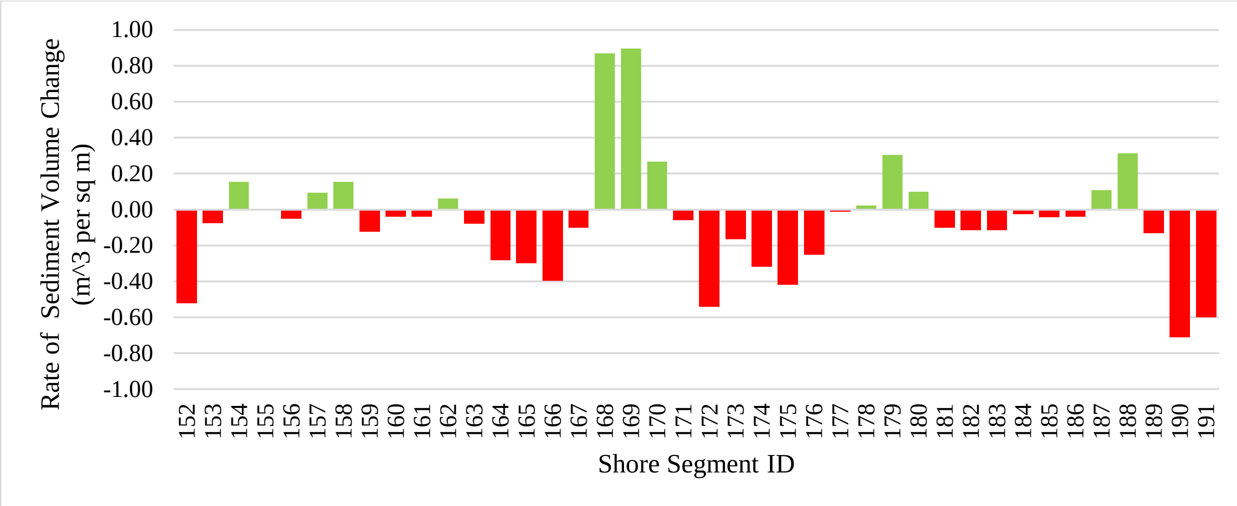

Figure 36 San Onofre State Beach to Camp Pendelton MCB (North) – Rate of sediment volume change by shore segment during the 06-07 El Niño

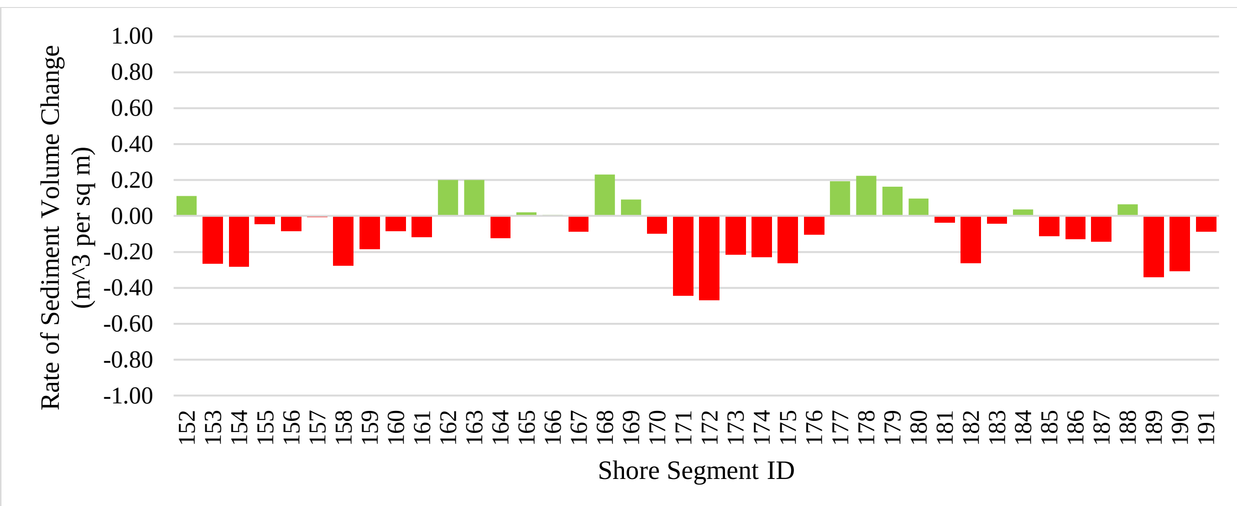

Figure 37 San Onofre State Beach to Camp Pendelton MCB (North) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 38 San Onofre State Beach to Camp Pendelton MCB (North) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

Figure 39 2006-2007 Elevation difference raster highlighting cliff erosion in shore segments 168 and 169

4.3.3.3. San Onofre State Beach/Camp Pendelton MCB (Central)

Continuing down the coast, San Onofre State Beach and Camp Pendelton MCB are identified by shore segments 192 through 231 and represent a collective area of 164,192 m^2 (Figure 42). This section of coastline remains relatively undeveloped, with California Highway 1 offset and adjacent to the coastline and scattered military training facilities present. Overall, the 2006-2007 El Niño winter showed a higher rate of sediment volume loss than the 2007-2008 La Niña winter (Figure 40 and Figure 41). Sediment accretion was visible in segments 229-231 during the 2006-2007 El Niño winter, and further investigation identified a small tributary/creek outflow that likely contributed sediment from increased flow caused by winter storm runoff. During the 2006-2007 El Niño winter 11,032 m^2 of sediment eroded from the beaches, followed by 5,375 m^2 of sediment accreting during the following Summer of 20078 months (Table 14). The net amount of sediment loss during the subsequent 2007-2008 La Niña winter was 2,752 m^2, substantially less than the preceding El Niño winter (Table 14).

Table 14 San Onofre State Beach/Camp Pendelton MCB (Central) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
192 - 231	164,920	-11,032	5,375	-2,752

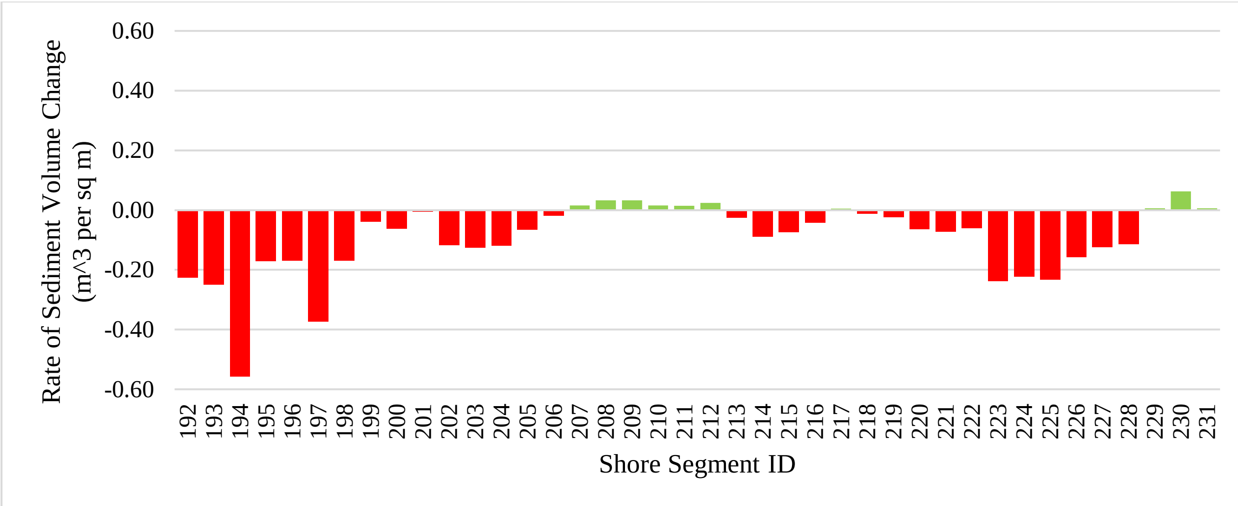

Figure 40 San Onofre State Beach/Camp Pendelton MCB (Central) – Rate of sediment volume change by shore segment during the 06-07 El Niño

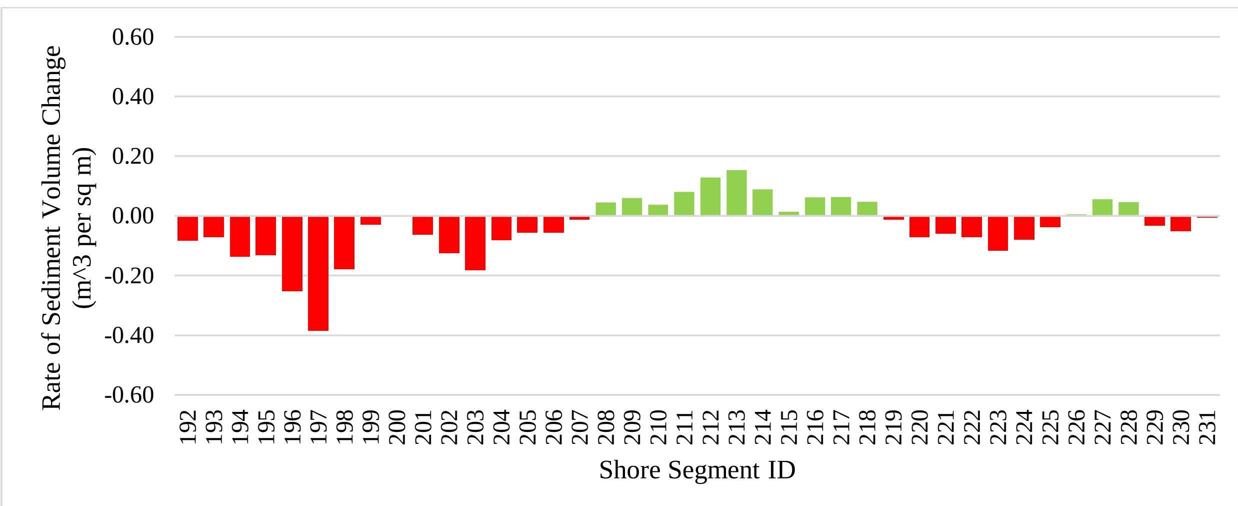

Figure 41 San Onofre State Beach/Camp Pendelton MCB (Central) – Rate of sediment volume change by shore segment during the 07-08 La Niña

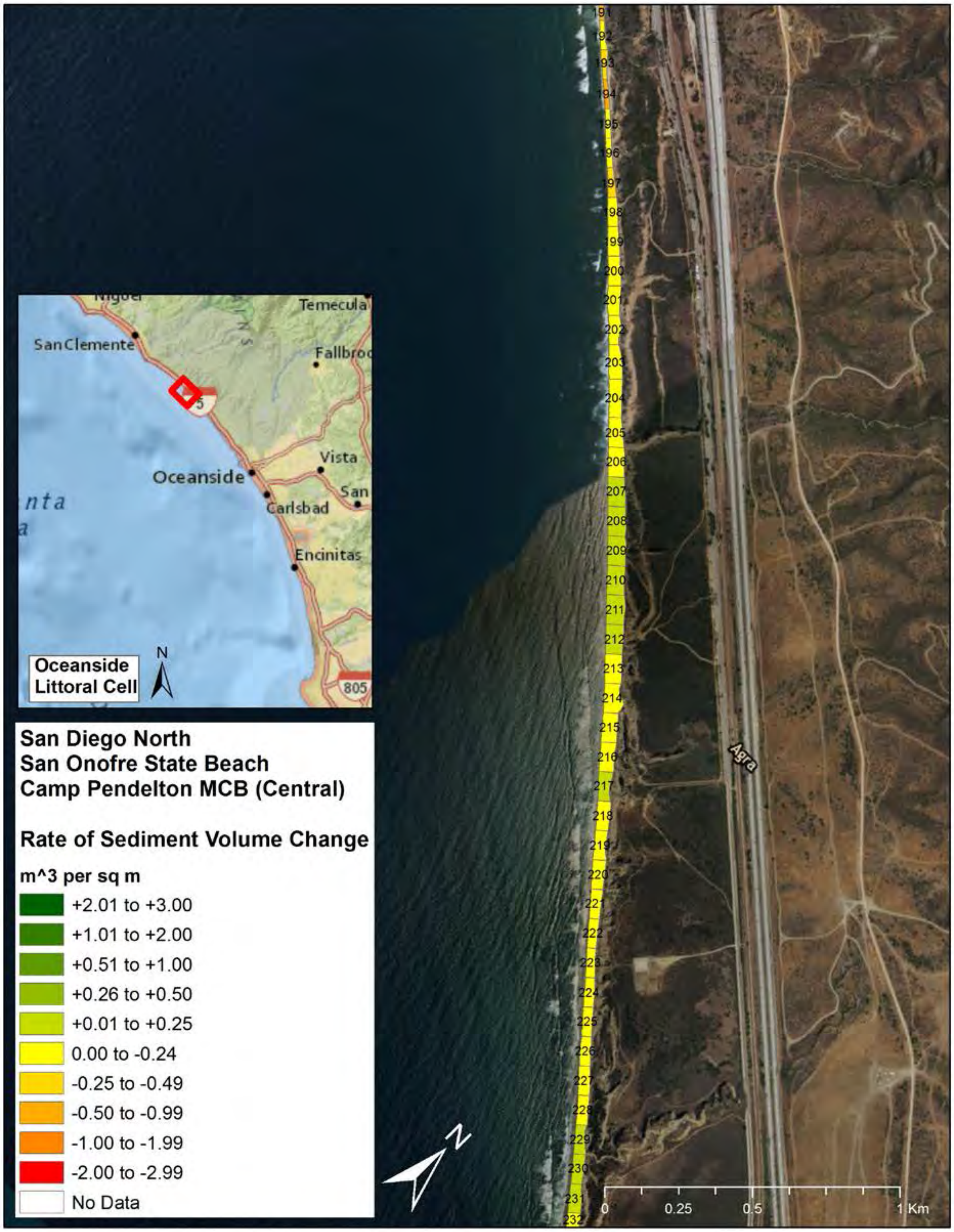

Figure 42 San Onofre State Beach/Camp Pendelton MCB (Central) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.3.4. San Onofre State Beach/Camp Pendelton MCB (South)

The San Onofre State Beach and Camp Pendelton MCB (South) region is represented by shore segments 232 through 272, covering an area of 234,367 m^2 (Figure 45). During the 2006-2007 El Niño winter, all shore segments in this area showed sediment loss, with sediment volume loss rate ranging from 0.01 to 0.21 m^3 per sq m (Figure 43). Overall, this area showed over three times the net loss of sediment during the 2006-2007 El Niño winter compared to the 2007-2008 La Niña winter (Figure 44). Following a net loss of 24,829 m^3 of sediment during the 2006-2007 El Niño winter, nearly half this amount of sediment (12,989 m^3) was deposited back onto the beaches over the Summer of 2007 (Table 15). The large degree of seasonal variability in sediment erosion and accretion points towards a highly dynamic beach system, which could be confirmed by further investigation into long term trends.

Table 15 San Onofre State Beach/Camp Pendelton MCB (South) Net Sediment Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
232 - 272	234,367	-24,829	12,989	-7,373

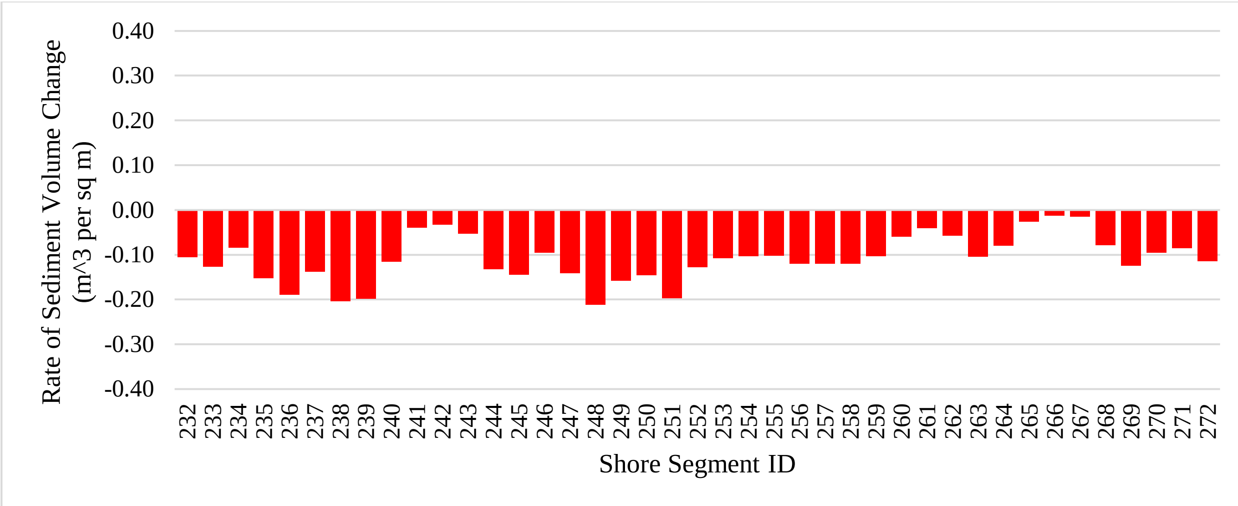

Figure 43 San Onofre State Beach/Camp Pendelton MCB (South) – Rate of sediment volume change by shore segment during the 06-07 El Niño

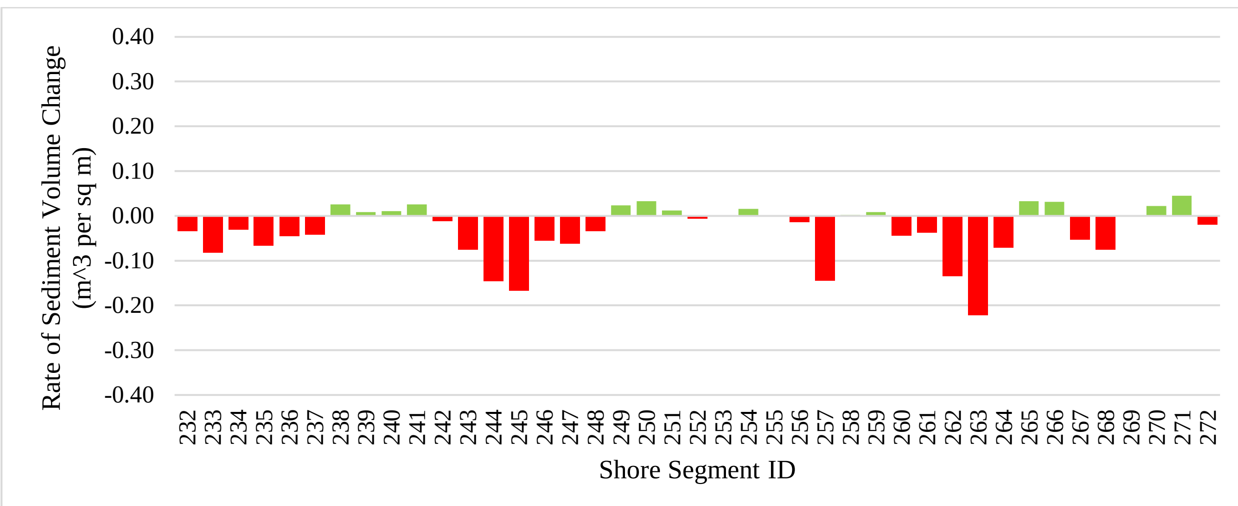

Figure 44 San Onofre State Beach/Camp Pendelton MCB (South) – Rate of sediment volume change by shore segment during the 07-08 La Niña

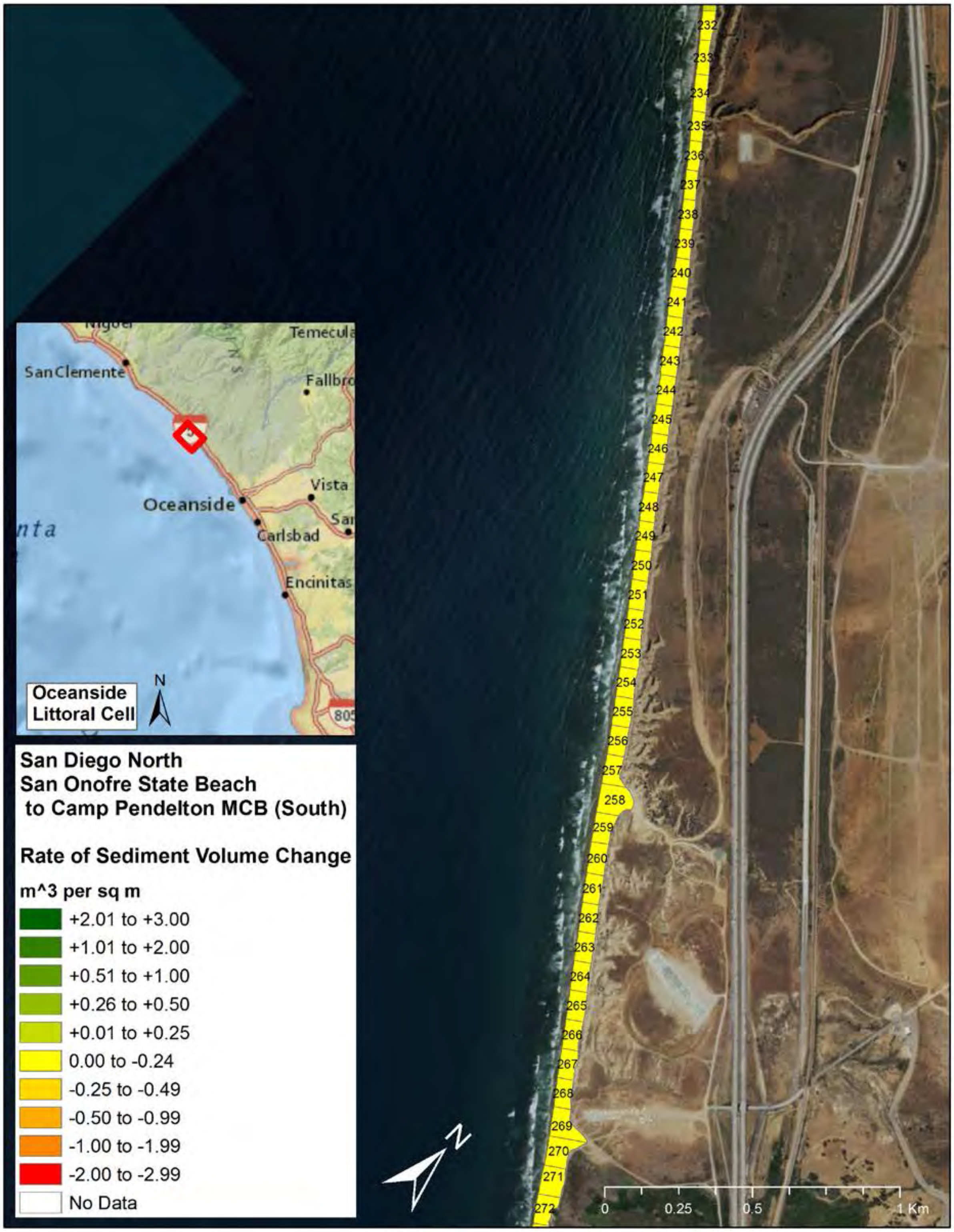

Figure 45 San Onofre State Beach/Camp Pendelton MCB (South) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.3.5. Camp Pendelton MCB (South)

The southernmost extent of Camp Pendelton MCB is identified by shore segments 273 through 313, and also marks the end of the larger San Diego Central region (Figure 48). This area, spanning just over 300,000 m^2 of beach, experienced a high degree of erosion during the 2006-2007 El Niño winter. Even greater than trends seen in shore segments to the north, the erosion rates in this region ranged from 0.06 to 0.20 m^3 per sq m during the 2006-2007 El Niño (Figure 46). A substantial amount of sediment, 12,269 m^3, was deposited onto the coastline during the following Summer of 2007 (Table 16). During the 2007-2008 La Niña winter only 2,279 m^3 of sediment was lost, orders of magnitude less than the preceding El Niño winter (Table 16 and Figure 47).

Table 16 Camp Pendelton MCB (South) Net Sediment Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
273 - 313	304,278	-43,756	12,269	-2,279

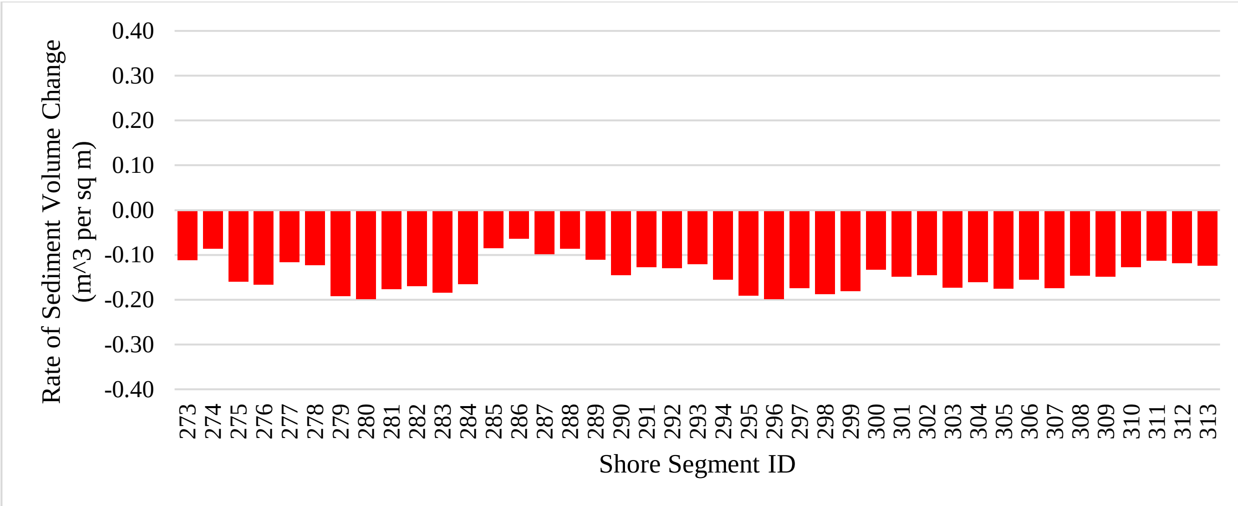

Figure 46 Camp Pendelton MCB (South) – Rate of sediment volume change by shore segment during the 06-07 El Niño

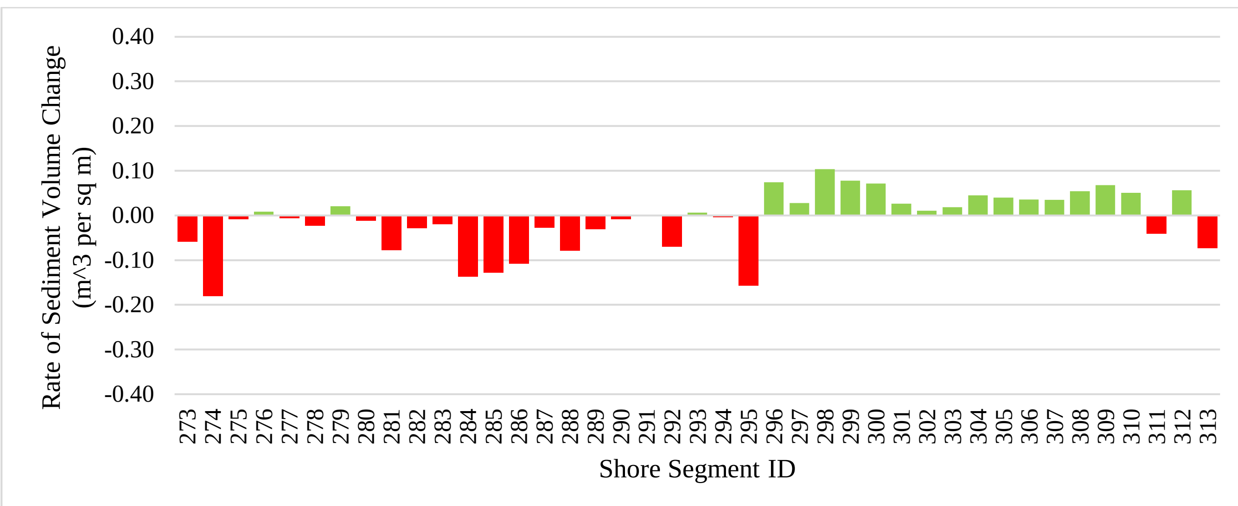

Figure 47 Camp Pendelton MCB (South) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 48 Camp Pendelton MCB (South) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.4. San Diego Central

The San Diego Central region consist of shore segments 314 through 509. This area spans from the southernmost extent of Camp Pendelton MCB to Carlsbad State Beach. Camp Pendelton MCB to the mouth of the Santa Margarita Marsh and Oceanside City Beach showed the highest rates of erosion in this region during the 2006-2007 El Niño winter. Shore segments surrounding the Santa Margarita mouth showed the highest rates of sediment accretion during the Summer of 2007. Individual sub-regions and results are discussed in the following sections.

4.3.4.1. Camp Pendelton MCB (South) to Santa Margarita Marsh

The southernmost sections of Camp Pendelton MCB to the beginning of the Santa Margarita Marsh outflow is designated by shore segments 314 through 354 (Figure 51). This subset of shore segments covers some of the widest beaches in the OLC with an area of 434,560 m^2. This large area of beach was severely impacted during the 2006-2007 El Niño with 112,231 m^3 of sediment lost and sediment loss rates ranging from 0.08 to 0.87 m^3 per sq m (Figure 49). Interestingly, this area also displayed the highest sediment accretion rates compared to the rest of the study area, with 257,176 m^3 deposited back onto the beaches during the Summer of 2007 (Table 17). While sediment loss was high during the 2006-2007 El Niño winter, more than double the sediment amount deposited onto beaches. During the following 2007-2008 La Niña winter a mere 15,952 m^3 of sediment was lost from the shore segments, minimal compared to the previous El Niño winter (Table 17 and Figure 50).

Table 17 Camp Pendelton MCB (South) to Santa Margarita Marsh Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
314 - 354	434,560	-112,231	257,176	-15,952

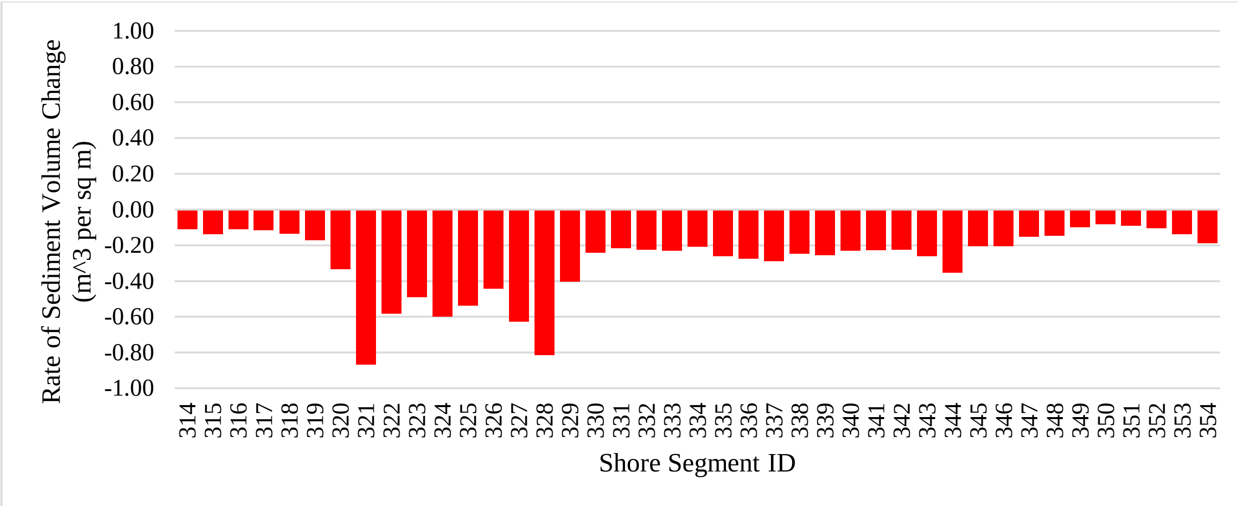

Figure 49 Camp Pendelton MCB (South) to Santa Margarita Marsh – Rate of sediment volume change by shore segment during the 06-07 El Niño

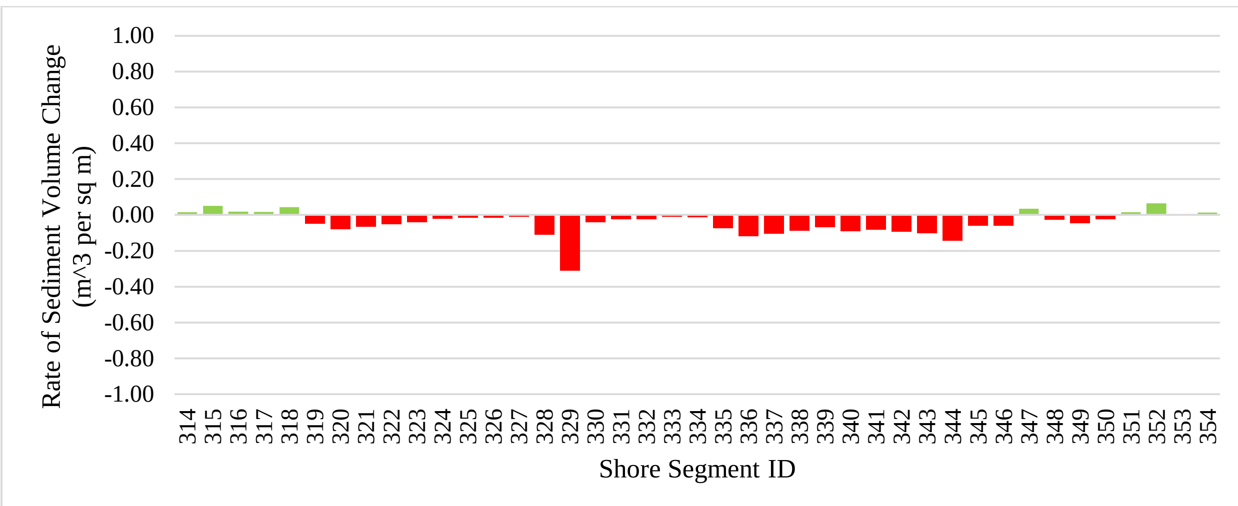

Figure 50 Camp Pendelton MCB (South) to Santa Margarita Marsh – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 51 Camp Pendelton MCB (South) to Santa Margarita Marsh - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.4.2. Santa Margarita Marsh to Oceanside Harbor

Beginning at the Santa Margarita Marsh mouth and including Oceanside Harbor, shore segments 355 through 388 include both natural landform features and highly modified coastal infrastructure (Figure 55). Erosion was visible throughout most of this area during the 2006-2007 El Niño winter, with over 35,000 m^3 lost during this time period (Table 18). The following summer showed a deposition of 11,657 m^3 of sediment (Table 18). The most noticeable change in sediment volume during the 2007-2008 La Niña winter was around the Santa Margarita Creek mouth, where major shifts in the mouth opening and berm morphology occurred. Between the Summer of 2006 and Spring of 2008, the creek mouth shifted southeast from shore segment 355 to 357 causing a major redistribution in sediment. The shift of the Santa Margarita Creek mouth was confirmed in by comparing historical imagery (Figure 54). During both the El Niño and La Niña winter, sediment build up was visible in the shore segments north of the harbor entrance, where a large rock jetty structure is present (Figure 55). Small sections of beach inside the protected harbor showed minor erosion during the 2006-2007 El Niño, but otherwise remained relatively stable.

Table 18 Santa Margarita Marsh to Oceanside Harbor Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
355 - 388	450,785	-35,290	11,657	-1,802

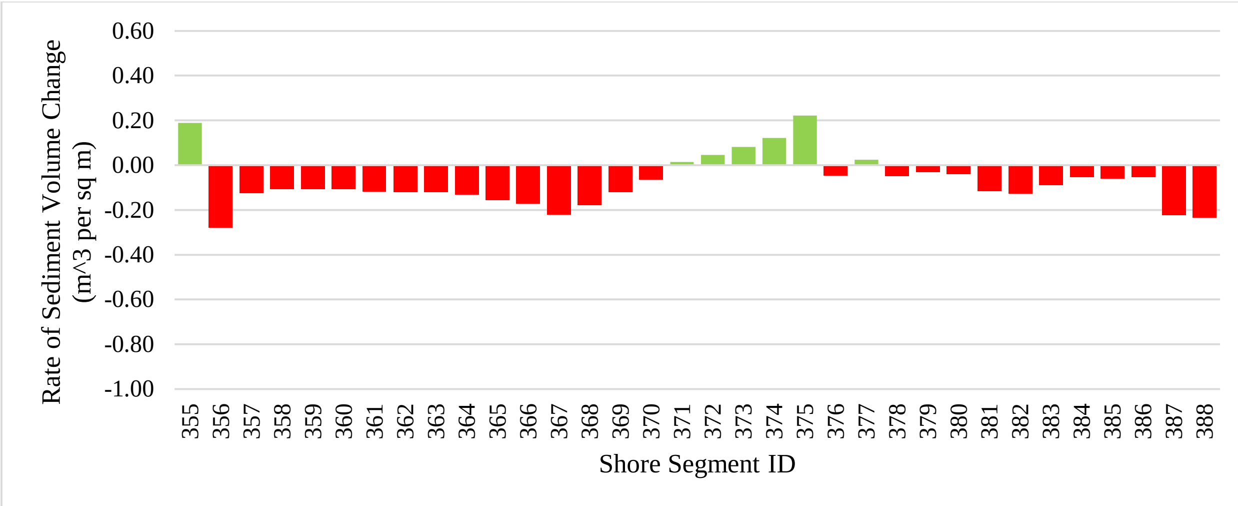

Figure 52 Santa Margarita Marsh to Oceanside Harbor – Rate of sediment volume change by shore segment during the 06-07 El Niño

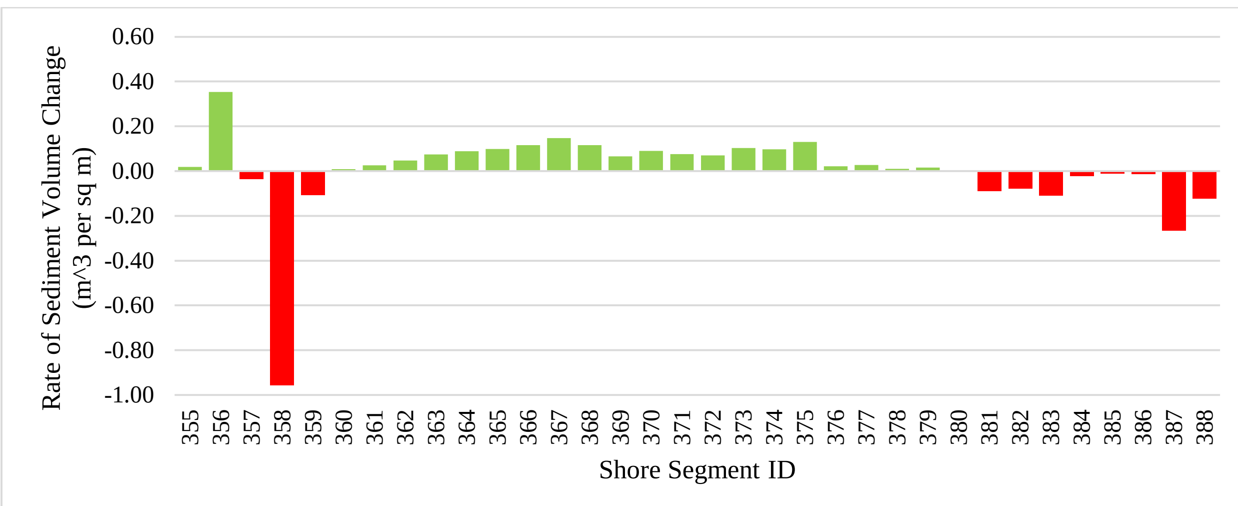

Figure 53 Santa Margarita Marsh to Oceanside Harbor – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 54 Historical imagery showing the shift of the Santa Margarita Creek mouth (Left: June 2006, Right: March 2008) (Source: Google Earth)

Figure 55 Santa Margarita Marsh to Oceanside Harbor - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.4.3. Oceanside City Beach

Oceanside City Beach is designated as shore segments 389 through 429, and make up an area of 128,119 m^2 (Figure 58). This section of beach is a popular recreational destination for both local residents and tourists. Additionally, this subset of shore segments following the Oceanside Harbor marks the beginning of a highly developed San Diego County coastline, with residential and commercial properties. A small data gap in the Spring 2007 and Fall 2007 LiDAR dataset prevented sediment analysis in shore segments 405 through 412. This data gap covered 14,685 m^2 of narrow beach in front of residential properties (Figure 58). During the 2006-2007 El Niño winter nearly 21,399 m^3 of sediment was lost in this region, with 8,564 m^3 sediment gained during the following summer months and 9,805 m^3 sediment lost during the following 2007-2008 La Niña winter (Table 19). Overall, the rate of sediment loss in this region, during the 2006-2007 El Niño winter, was 0.35 m^3 per sq m, higher than the 2007-2008 La Niña sediment loss rate of 0.20 m^3 per sq m (Figure 56 and Figure 57).

Table 19 Oceanside City Beach Sediment Net Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
389 - 429	128,119	-21,399	8,564	-9,805

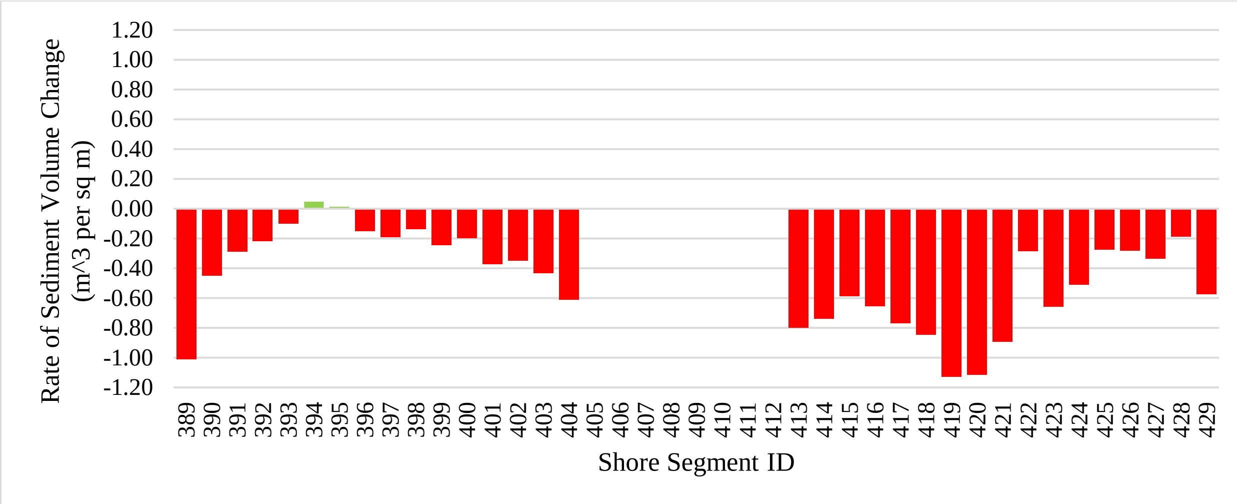

Figure 56 Oceanside City Beach – Rate of sediment volume change by shore segment during the 06-07 El Niño (shore segments 405-412 no data)

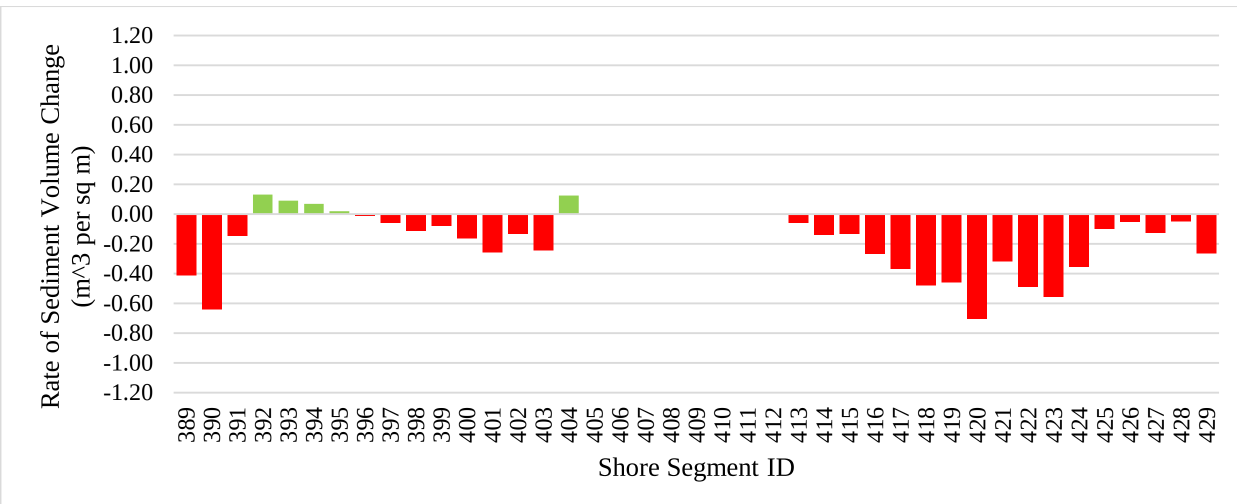

Figure 57 Oceanside City Beach – Rate of sediment volume change by shore segment during the 07-08 La Niña (shore segments 405-412 no data)

Figure 58 Oceanside City Beach - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.4.4. Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon)

Shore segments 430 through 469 represent the area from North Carlsbad to Carlsbad State Beach (Agua Hedionda Lagoon) (Figure 61). These shore segments cover a total area of 124,673 m^2, characterized by high beach front development, publically used beaches and two lagoons. Buena Vista Lagoon to the north is an intermittently open/closed mouthed lagoon, while Agua Hedionda Lagoon to the south has a bridge abutment and rock jetties to keep the mouth open. During the 2006-2007 El Niño, these shore segments collectively lost 23,155 m^3 of sediment from the beaches (Table 20). During the following Summer of 2007, 16,922 m^3 of sediment was regained (Table 20). Overall rates of erosion were less during the 2007-2008 La Niña winter versus the 2006-2007 El Niño winter; however, more shore segments in this region experienced erosion during the 2007-2008 La Niña winter which resulted in a net loss of 24,996 m^3 of sediment (Figure 59 and Figure 60). During the 2006-2007 El Niño winter, the rock jetties near the Agua Hedionda Lagoon played a role in trapping sediment which was likely transported from the nearby shore segments to the north (Figure 61).

Table 20 Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
430 - 469	124,673	-23,155	16,922	-24,996

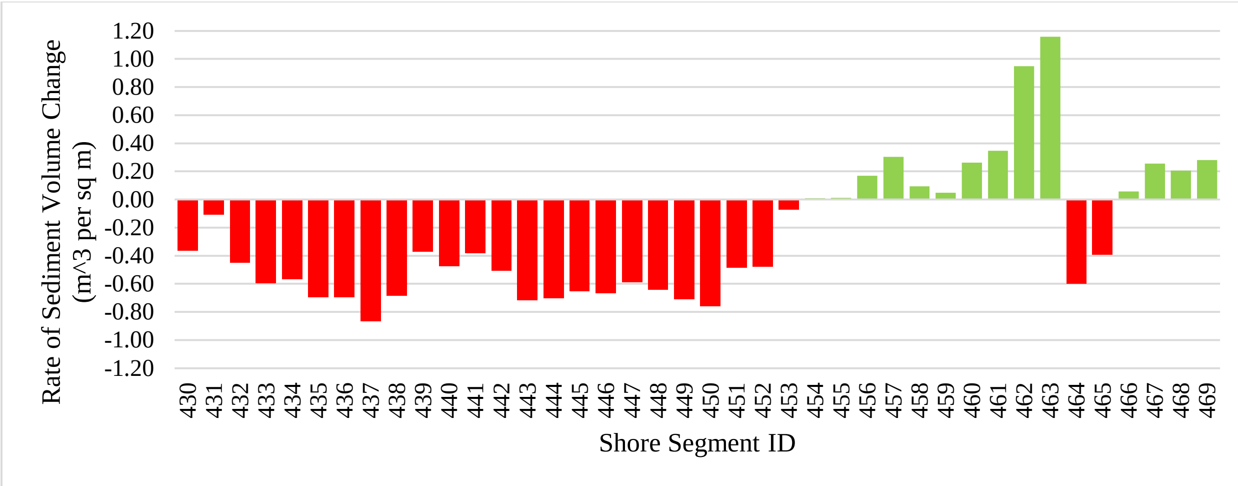

Figure 59 Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon) – Rate of sediment volume change by shore segment during the 06-07 El Niño

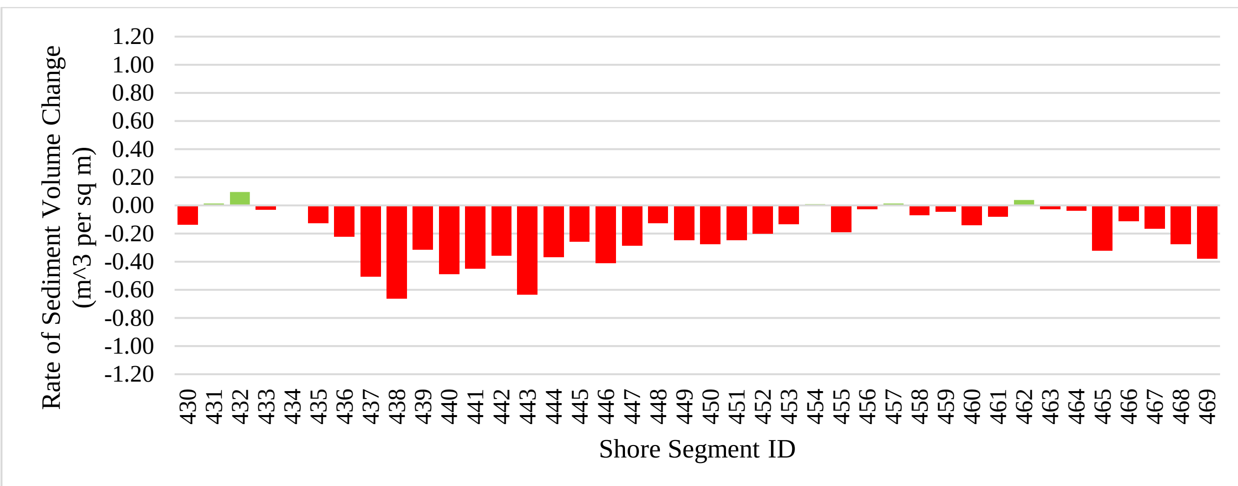

Figure 60 Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon) – Rate of sediment volume change by shore segment during the 07-08 La Niña

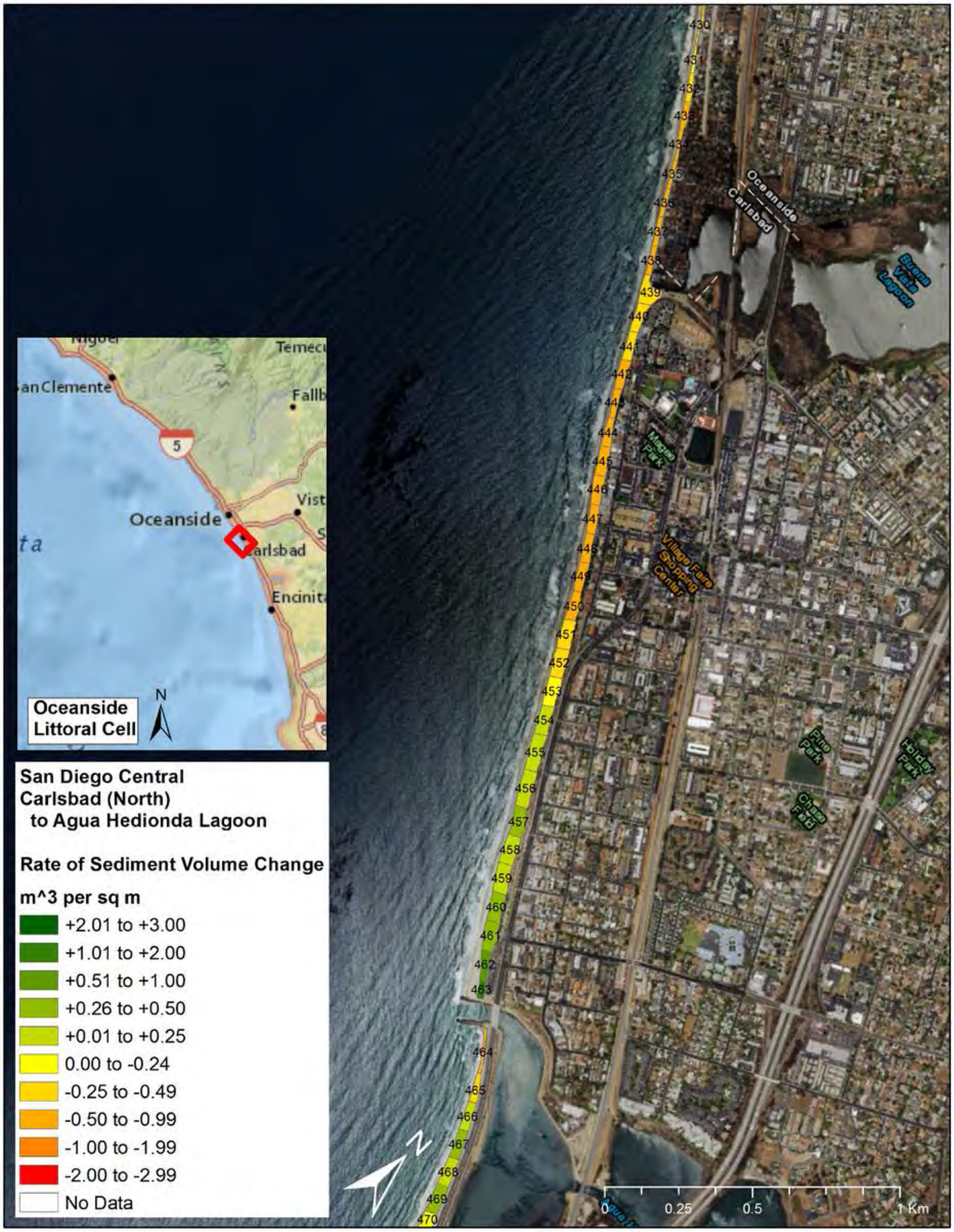

Figure 61 Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.4.5. Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South)

Continuing down the coast, shore segments 470 through 509 represent 85,606 m^2 of beach from Agua Hedionda Lagoon to the north to the southern extent of Carlsbad State Beach (Figure 64). Unlike other regions in the OLC where development hugs the coastline, this region is characterized by narrow beaches bordered by cliffs and bluffs. Parking lots and campground infrastructure line the tops of the bluffs with residential development inland. Shore segments 483 through 486 represent a section of particularly narrow beach lined by bluffs and during the 2006-2007 El Niño winter this area experienced high rate of sediment accretion as shown by Figure 62, likely due to the contribution of sediment from cliff erosion. Even with high sediment accretion rates in some shore segments during the 2006-2007 El Niño winter, this region lost 12,429 m^3 of sediment (Table 21). The Summer of 2007 saw no sediment recovery with a loss of 1,081 m^3 (Table 21). The 2007-2008 La Niña winter resulted in a net loss of 10,934 m^3 of sediment, similar to the 2006-2007 El Niño winter amounts (Table 21).

Table 21 Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
470 - 509	85,606	-12,429	-1,081	-10,934

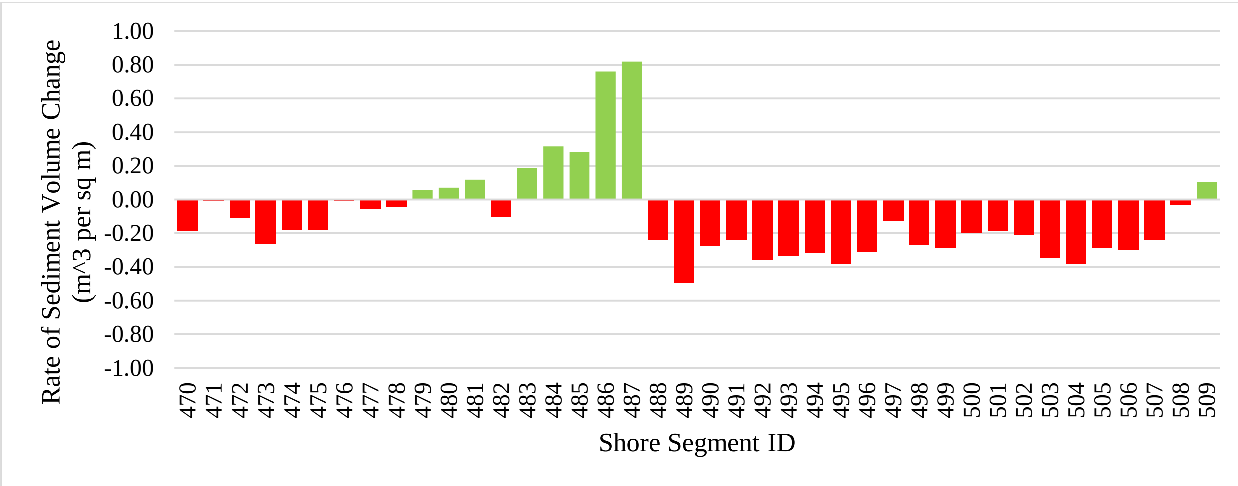

Figure 62 Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South) – Rate of sediment volume change by shore segment during the 06-07 El Niño

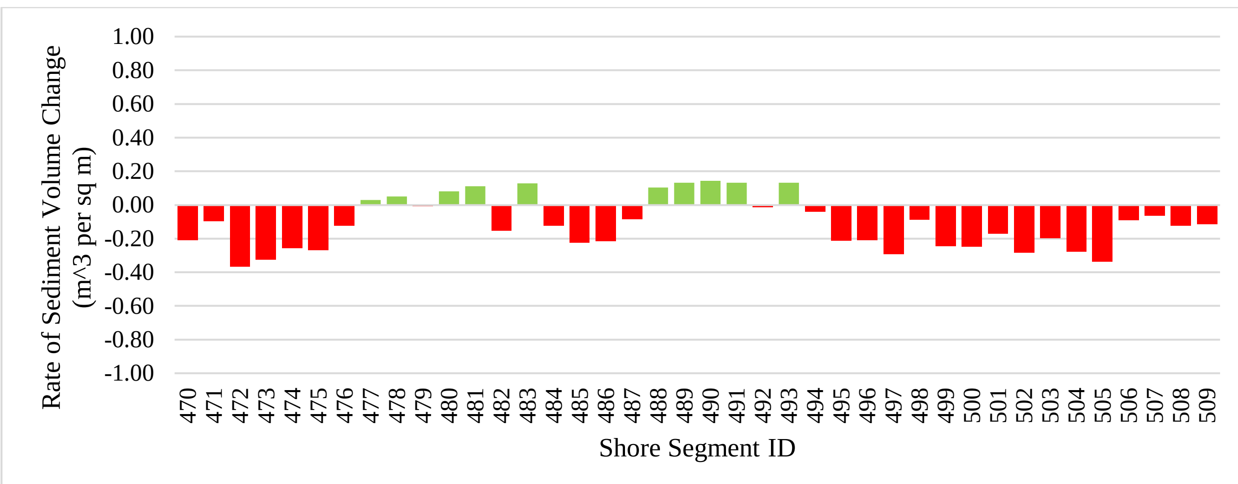

Figure 63 Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South) – Rate of sediment volume change by shore segment during the 07-08 La Niña

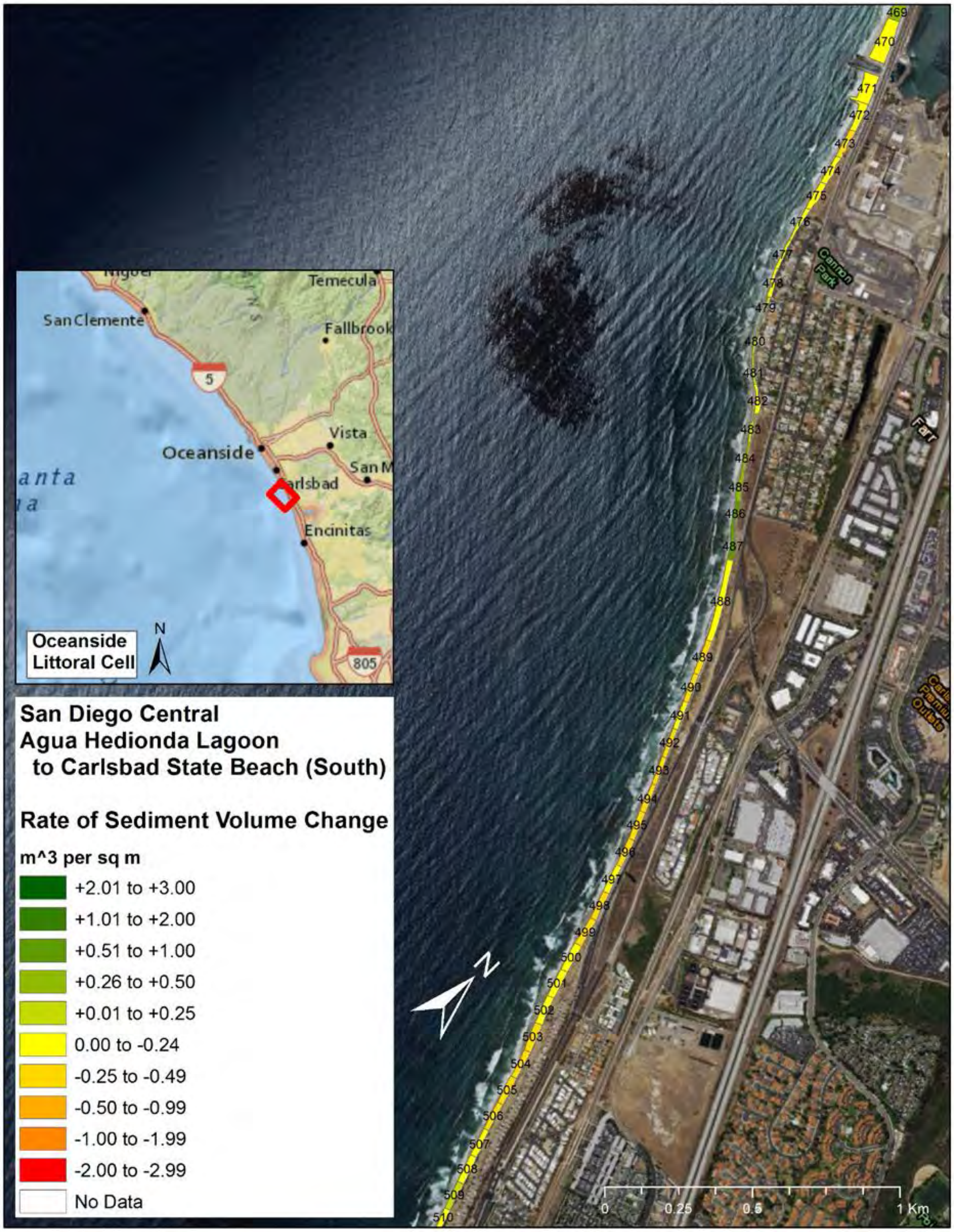

Figure 64 Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5. San Diego South

The San Diego South region consist consists of the southernmost portion of the OLC study area and includes shore segments 510 through 792. This area spans from Carlsbad to La Jolla Shores. High rates of sediment erosion were seen in most of this region during both the 2006-2007 El Niño winter and 2007-2008 La Niña winter. The highest rate of erosion during the 2006-2007 El Niño for the entire OLC study area was observed in the area of Torrey Pines State Reserve, where cliff erosion was present. The rate of sediment accretion during the Summer of 2007 was high.

4.3.5.1. Carlsbad State Beach (South) to Encinitas (North)

Shore segments 510 through 549 represent the coastal area from the southern extent of Carlsbad State Beach to the northern region on Encinitas. Collectively these shore segments cover an area of 118,238 m^2 (Table 22). Wider shore segments are seen in the vicinity of the Batiquitos Lagoon mouth (shore segments 527 to 532) where a bridge abutment and two rock jetties are present (Figure 67). The Batiquitos Lagoon mouth, like Agua Hedionda to the north, is maintained to remain open to the ocean. During the 2006-2007 El Niño winter, the beaches in this region lost a total of 14,230 m^3 of sediment (Table 22). Sediment accretion during the 2006-2007 El Niño was visible in some shore segments, with the highest sediment accretion rate, 0.43 m^3 per sq m, in the two shore segments just north of the jetty lining the Agua Hedionda Lagoon mouth (Figure 65). Moving down the coast past the mouth of Agua Hedionda Lagoon, the beach begins to narrow, and erosion rates up to 0.89 m^3 per sq m are seen (Figure 65 and Figure 67). During the Summer of 2007, most shore segments south of the Agua Hedionda Lagoon mouth showed accretion trends, and overall 3,519 m^3 of sediment was deposited in this region (Table 22). The following 2007-2008 La Niña winter showed greater overall erosion in these shore segments, with 18,549 m^3 of sediment lost; however, the rate of sediment volume change per sq m was less than the previous El Niño winter (Figure 66).

Table 22 Carlsbad State Beach (South) to Encinitas (North) Net Sediment Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
510 - 549	118,238	-14,230	3,519	-18,548

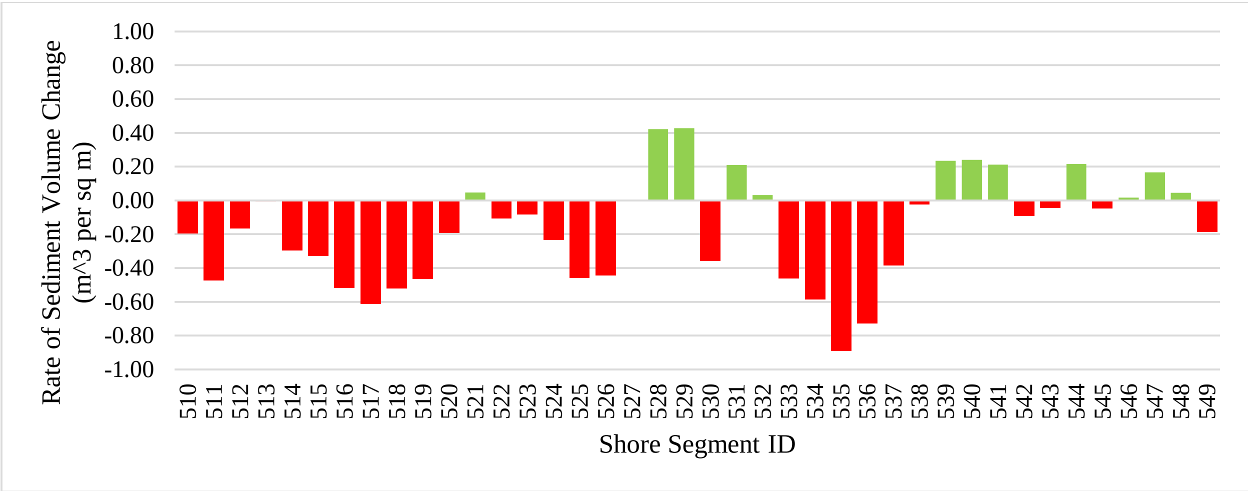

Figure 65 Carlsbad State Beach (South) to Encinitas (North) – Rate of sediment volume change by shore segment during the 06-07 El Niño

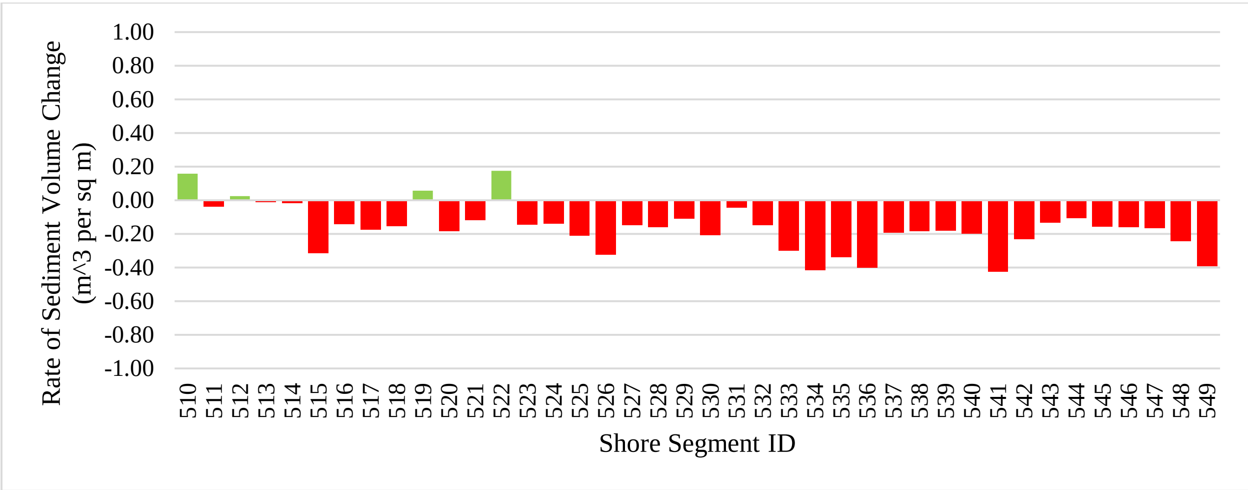

Figure 66 Carlsbad State Beach (South) to Encinitas (North) – Rate of sediment volume change by shore segment during the 07-08 La Niña

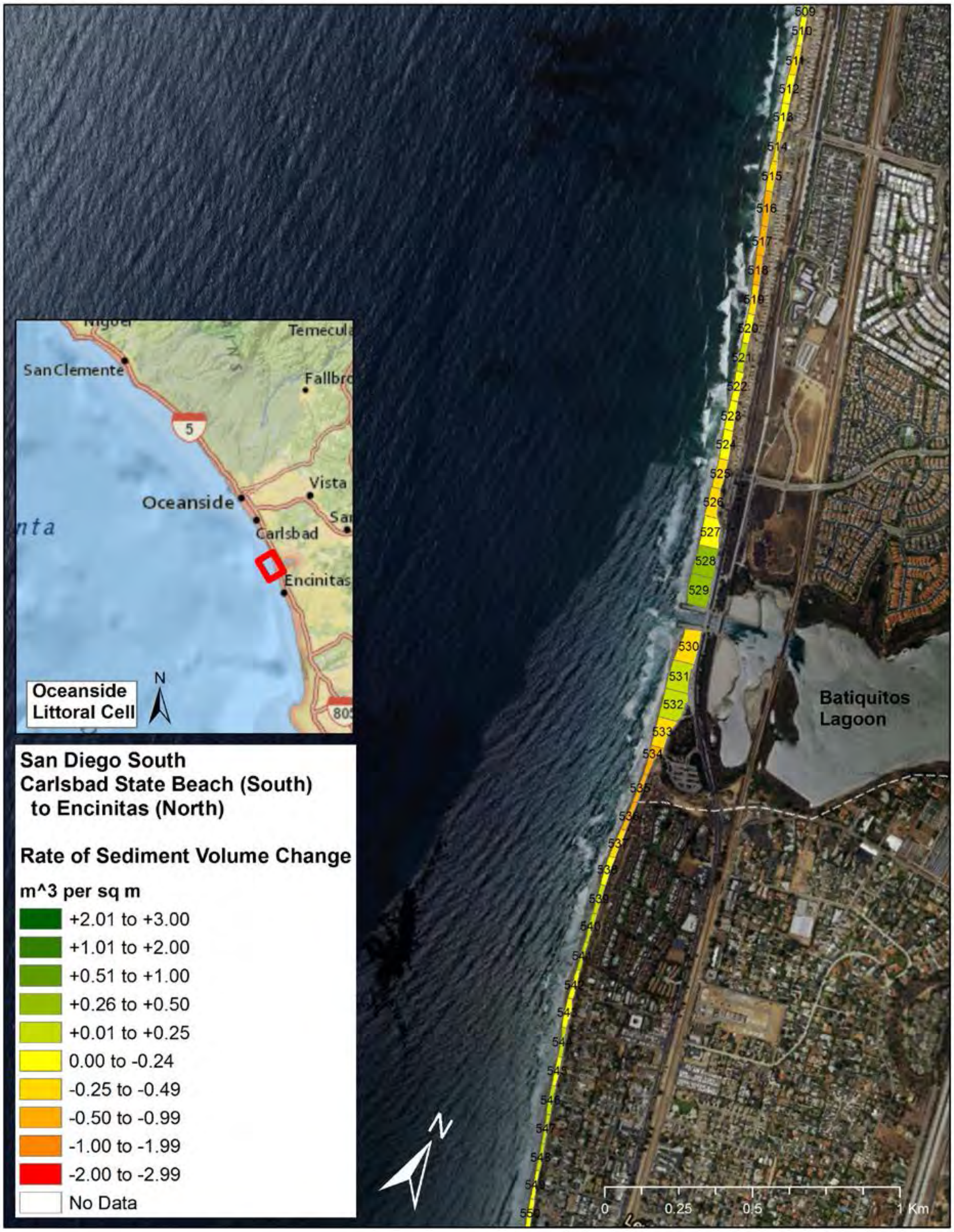

Figure 67 Carlsbad State Beach (South) to Encinitas (North) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.2. Encinitas (North) to Encinitas (South)

Shore segments 550 through 591 represent most of the beaches in the city of Encinitas and cover an area of 98,529 m^2 (Table 23) This region is characterized by narrow beaches, with the exception of Moonlight Beach (Shore Segment 575) and steep eroding bluffs. Cliff failure and landslides sporadically occur on bluffs which become eroded from winter storms and over 30 percent of the City of Encinitas coastline has some form of shoreline armoring to protect development as well as safety among beach goers (City of Encinitas 2010). Erosion rates were similar during both the 2006-2007 El Niño and 2007-2008 La Niña winters; however, accretion rates were substantially higher during the 2006-2007 El Niño winter (Figure 68 and Figure 69). During the 2006-2007 El Niño winter, high accretion rates, up to 1.95 m^3 per sq m, were seen in shore segments 581 through 586 and were likely caused by sediment contribution from cliff erosion (Figure 70).

Table 23 Encinitas (North) to Encinitas (South) Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
550 - 591	98,529	-7,911	7,180	-15,576

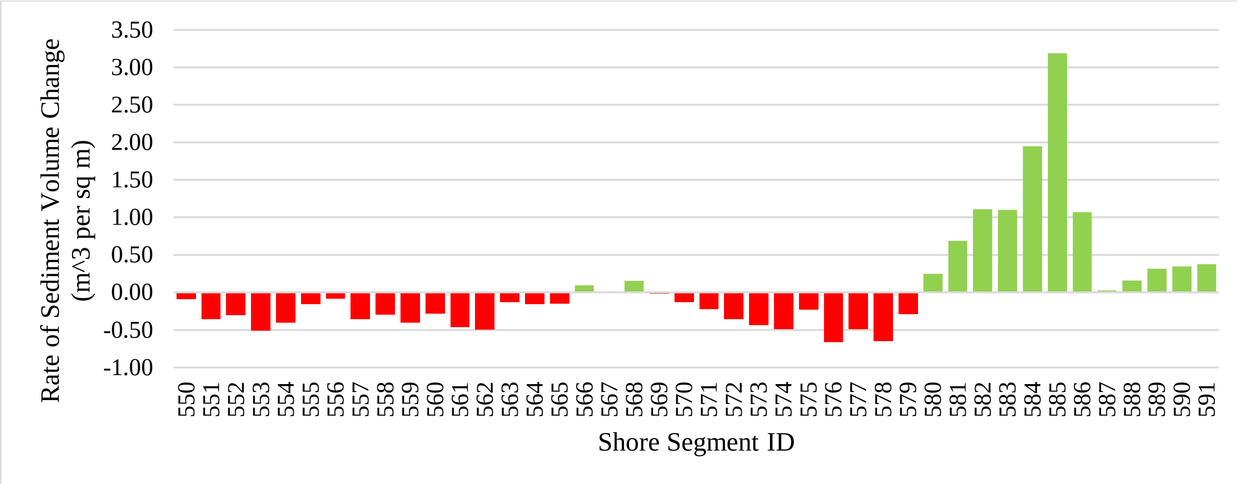

Figure 68 Encinitas (North) to Encinitas (South) – Rate of sediment volume change by shore segment during the 06-07 El Niño

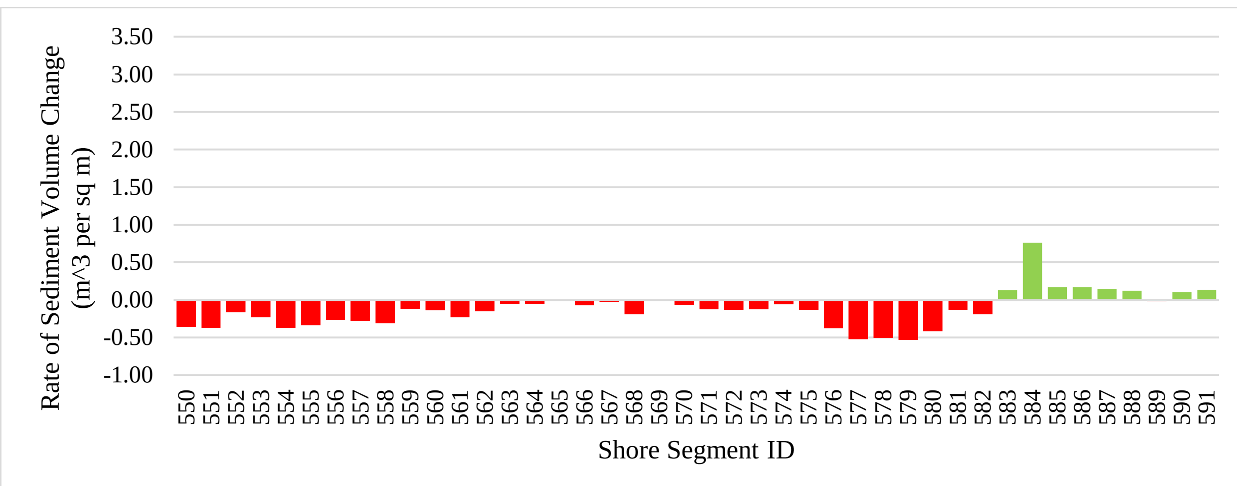

Figure 69 Encinitas (North) to Encinitas (South) – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 70 Encinitas (North) to Encinitas (South) - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.3. Encinitas (South) to Cardiff State Beach

Shore segments 592 through 630 span the southern extent of the City of Encinitas to Cardiff State Beach and San Elijo Lagoon. These shore segments cover an area of 100,196 m^2 and are less developed in terms of bluff-top residential properties compared to the Encinitas (North) region. During the 2006-2007 El Niño winter 29,848 m^3 of sediment was lost in these shore segments, and during the 2007-2008 La Niña winter a comparable amount of sediment, 25,194 m^3, was lost (Table 24). Shore segment 613, which lines the mouth of the San Elijo Lagoon was one of the few segments that showed an increase in sediment during the 2006-2007 El Niño winter (Figure 71 and Figure 73). The Summer of 2007 showed a net gain of 14,374 m^3, however not enough sediment to recover from both the previous and following winter erosion (Table 24).

Table 24 Encinitas (South) to Cardiff State Beach Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
592 - 630	100,196	-29,849	14,374	-25,194

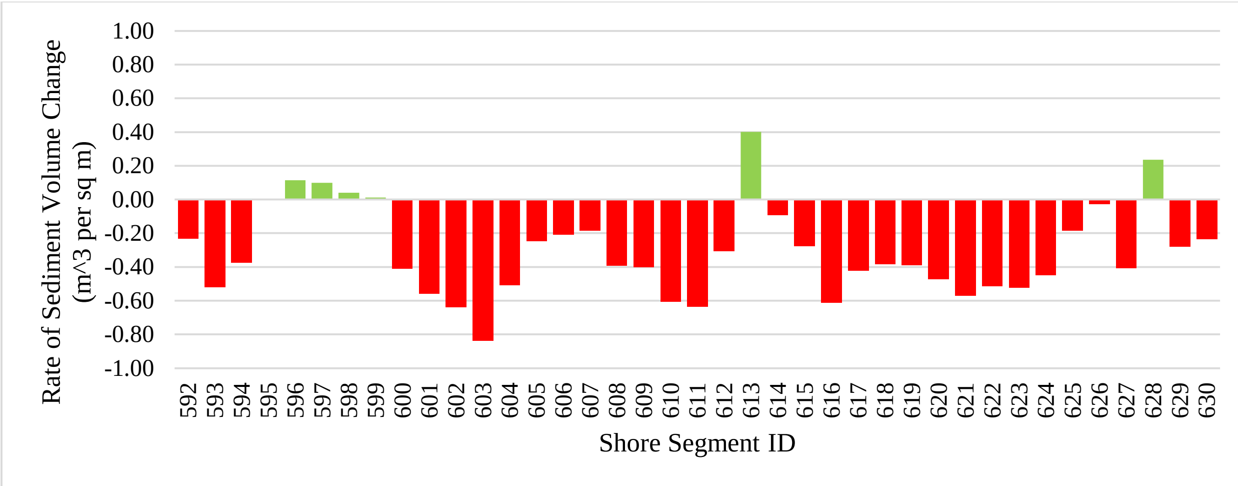

Figure 71 Encinitas (South) to Cardiff State Beach – Rate of sediment volume change by shore segment during the 06-07 El Niño

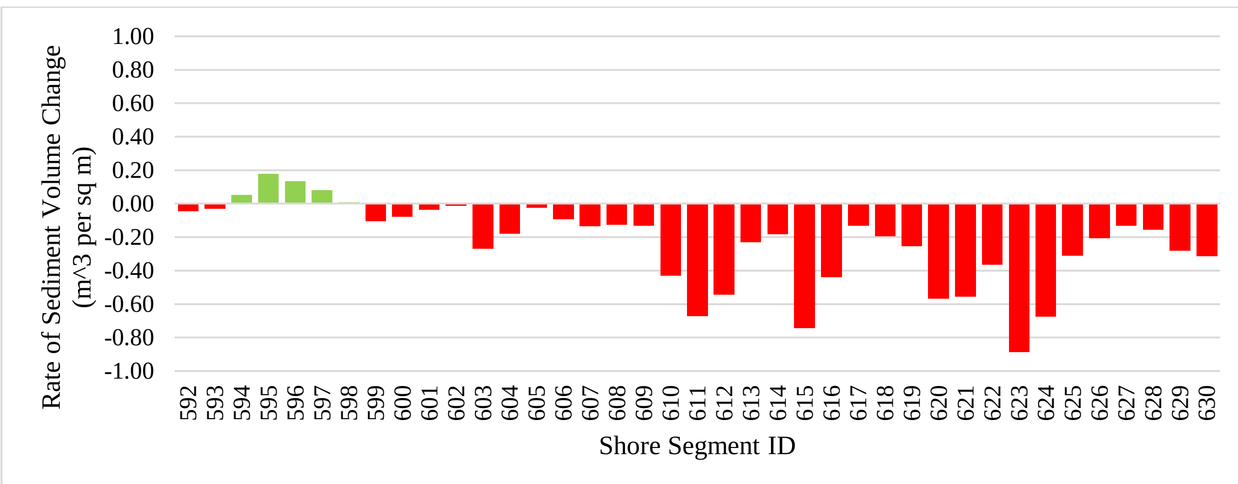

Figure 72 Encinitas (South) to Cardiff State Beach – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 73 Encinitas (South) to Cardiff State Beach - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.4. Cardiff State Beach to Del Mar

Shore segments 631 through 669 represent the coastal area from Cardiff State Beach to the City of Del Mar. The shore segments north of the San Dieguito Lagoon include the relatively narrow beaches of Solana Beach. The majority of shore segments in this area experienced high rates of erosion during both the 2006-2007 El Niño and following 2007-2008 La Niña winters, with slightly more sediment lost during the 2007-2008 La Niña winter (Figure 74 and Figure 75). Eight shore segments saw some form of accretion during the 2006-2007 El Niño winter, while only one shore segment registered accretion during the 2007-2008 La Niña winter. Overall, 25,239 m^3 of sediment was lost from the beaches in this area during the 2006-2007 El Niño. The Summer of 2007 showed only partial recovery of sediment with a 14,583 m^3 gain (Table 25). Sediment accretion was seen in the large shore segment lining the mouth of the San Dieguito Lagoon, which is mechanically maintained to remain open throughout the year (Figure 76). The smaller shore segment (656) just north of the San Dieguito Lagoon experienced a very high rate of erosion (-2.37 m^3 per sq m).

Table 25 Cardiff State Beach to Del Mar Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
631 - 669	73,708	-25,239	14,583	-30,449

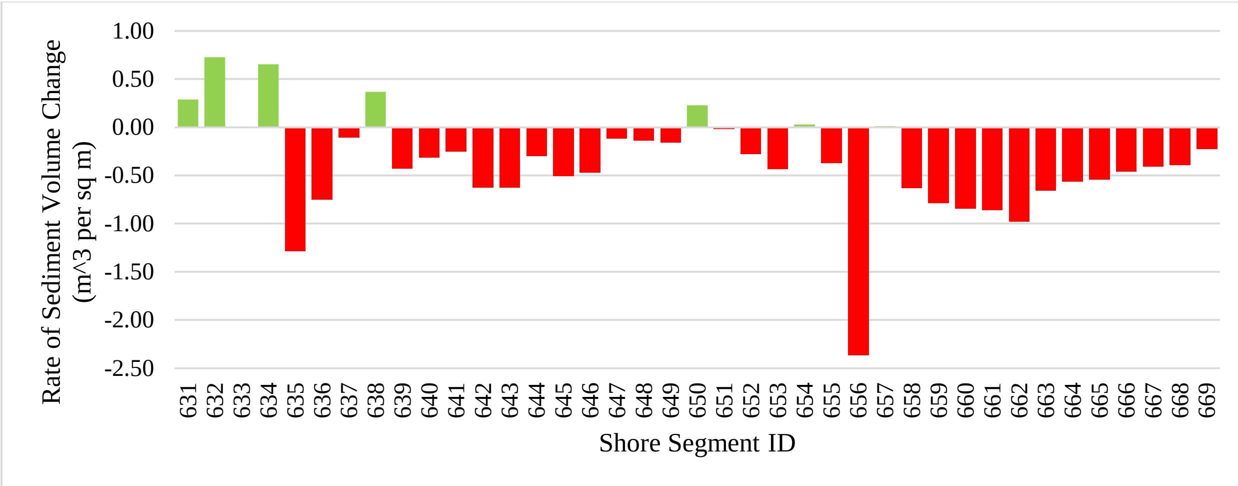

Figure 74 Cardiff State Beach to Del Mar – Rate of sediment volume change by shore segment during the 06-07 El Niño

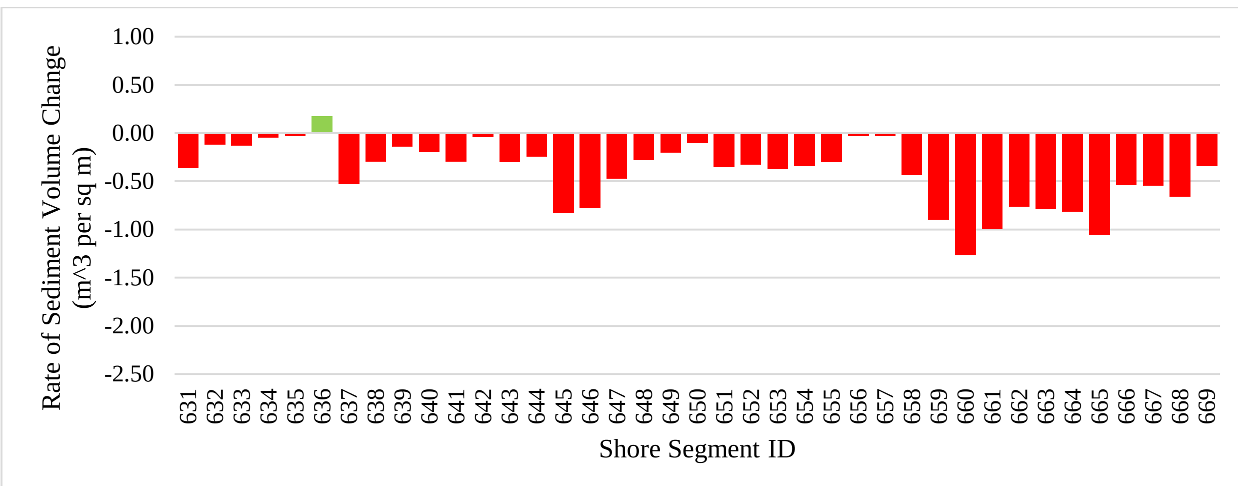

Figure 75 Cardiff State Beach to Del Mar – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 76 Cardiff State Beach to Del Mar - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.5. Del Mar to Los Penasquitos Marsh

Shore segments 670 through 709 cover the area from Del Mar to the Los Penasquitos Marsh. The beaches in this area are generally wider than the neighboring shore segments to the north in the Solana Beach (Figure 79). These shore segments saw an overall trend in erosion during both the 2006-2007 El Niño and 2007-2008 La Niña winters, with more sediment lost during the La Niña winter than the El Niño winter (Figure 77 and Figure 78). Shore segments south of the Los Penasquitos Marsh mouth experienced fairly high rates of erosion during both winter seasons, with opposite high rates of accretion during the intermediary summer season (Table 26). This area south of the Los Penasquitos Marsh mouth was also one of the two receiver sites in Del Mar where sand was replenished during the 2001 SANDAG project. Collectively, sediment recovery during the Summer of 2007 was minimal compared the level of erosion experienced during both the 2006-2007 El Niño winter and following 2007-2008 La Niña winter. This phenomenon warrants the need for further investigation into long term sediment erosion and accretion trends.

Table 26 Del Mar to Los Penasquitos Marsh Sediment Net Volume Change Summary

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
670 - 709	126,799	-28,153	8,253	-38,645

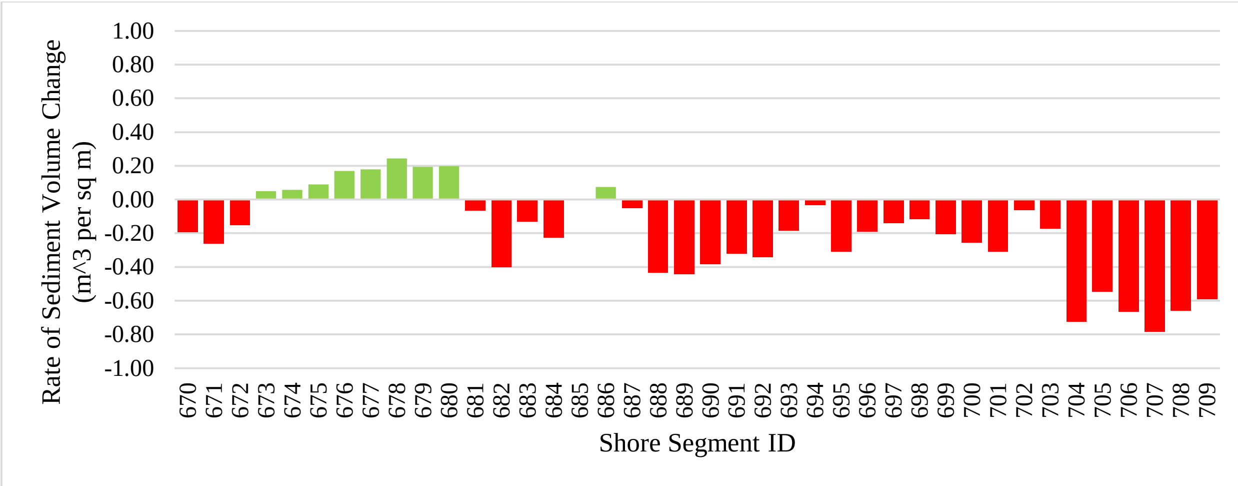

Figure 77 Del Mar to Los Penasquitos Marsh – Rate of sediment volume change by shore segment during the 06-07 El Niño

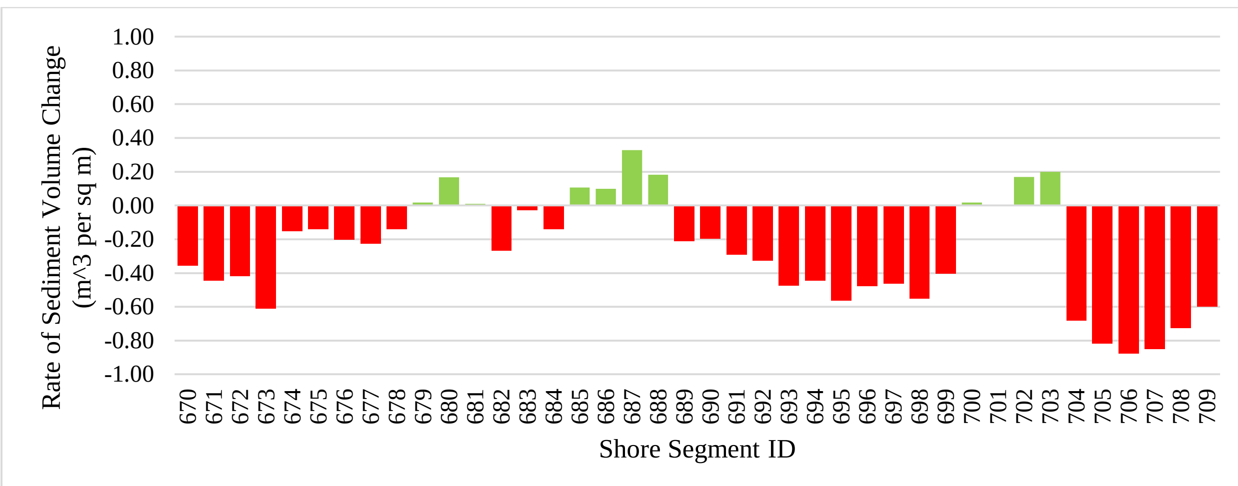

Figure 78 Del Mar to Los Penasquitos Marsh – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 79 Del Mar to Los Penasquitos Marsh - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.6. Los Penasquitos Marsh to Torrey Pines State Reserve

Shore segments 710 to 749 cover the area of the Torrey Pines State Reserve. These shore segments represent 201,499 m^2 of protected beaches lined by coastal bluffs that have minimal development (Table 27 and Figure 82). During storms, small creeks and tributaries cut through the bluffs and form canyons which drain to the ocean. This hydrological interaction with the land can cause cliff erosion, and historically cliff failure and landslides have occurred in this area. Erosion rates were similar during both the 2006-2007 El Niño and 2007-2008 La Niña winters; however, during the 2006-2007 El Niño winter a large amount of sediment accreted on shore segment 727 caused by the nearby cliffs failing and depositing over 7,000 m^3 onto the beach (Figure 80, Figure 81, and Figure 82). Further investigation into the DEM Differencing results clearly shows this cliff failure as well as other nearby areas experiencing cliff erosion (Figure 83). Overall sediment erosion and accretion trends show that the Torrey Pines State Reserve is a highly dynamic area, influenced not only by large seasonal changes in offshore and onshore sand movement but also cliff landforms and hydrology.

Table 27 Los Penasquitos Marsh to Torrey Pines State Reserve Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
710 - 749	201,499	-58,755	49,780	-80,428

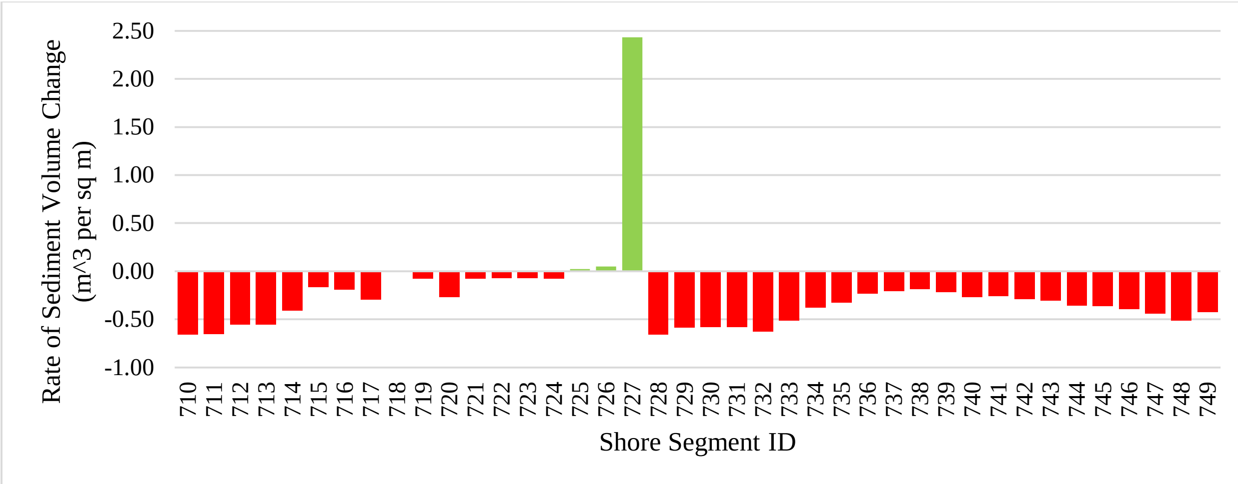

Figure 80 Los Penasquitos Marsh to Torrey Pines State Reserve – Rate of sediment volume change by shore segment during the 06-07 El Niño

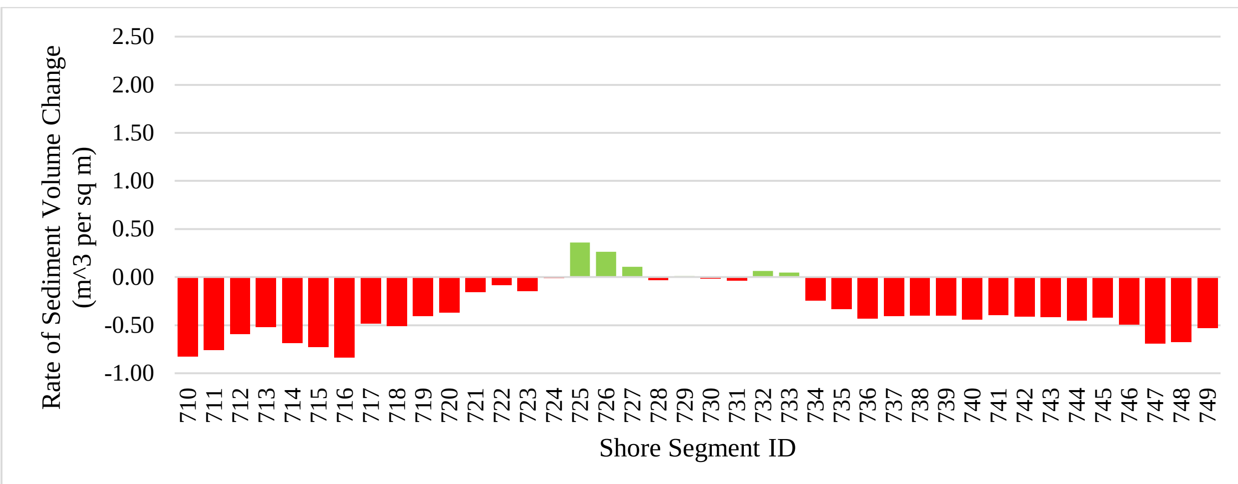

Figure 81 Los Penasquitos Marsh to Torrey Pines State Reserve – Rate of sediment volume change by shore segment during the 07-08 La Niña

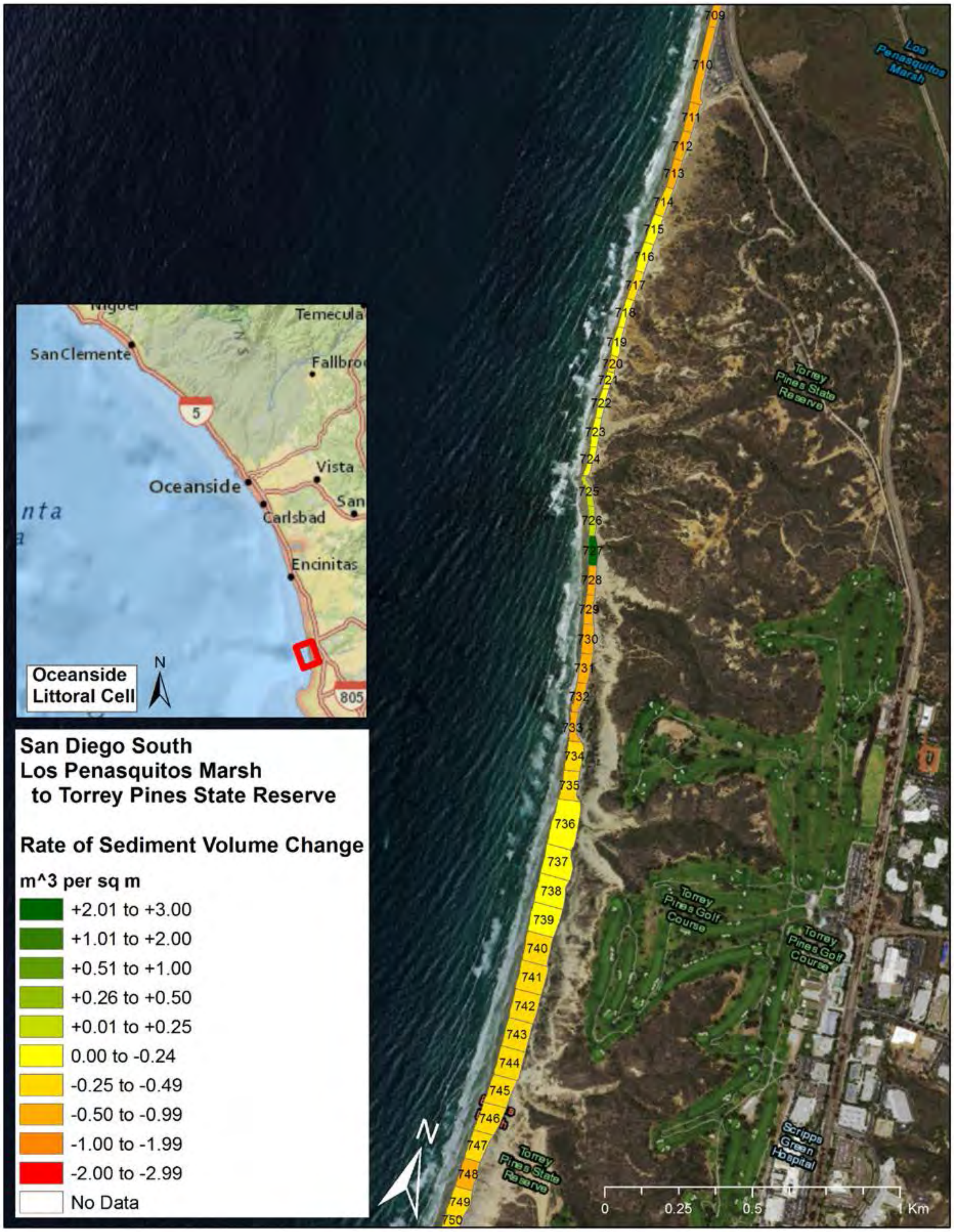

Figure 82 Los Penasquitos Marsh to Torrey Pines State Reserve - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

Figure 83 Torrey Pines State Reserve – Elevation difference raster highlighting cliff erosion

4.3.5.7. Torrey Pines State Reserve to La Jolla Shores Beach

Shore segments 750 through 792 represent the southernmost extent of Torrey Pines State Reserve to the end of the study area at La Jolla Shores Beach. This region experienced consistently high rates of erosion during the 2006-2007 El Niño winter, with the exception of two shore segments at La Jolla Shores Beach, an area where the beach face direction drastically turns towards the north before La Jolla Point (Figure 86 and Figure 87). During the 2006-2007 El Niño winter 72,220 m^3 of sediment was lost from these shore segments versus 37,637 m^3 of sediment lost during the 2007-2008 La Niña winter (Table 28). Overall the rate of sediment loss in this area was higher than any other region in the OLC during the 2006-2007 El Niño winter. A high amount of sediment, 48,611 m^3, was recovered during the intermediary Summer of 2007, however not enough sediment to make up for the previous El Niño winter erosion (Table 28). A small data gap covering shore segments 770 to 773, just north of the Scripps Pier, was due to very minimal if no sandy beach present (Figure 87). Overall, this region like the neighboring Torrey Pines State Reserve to the north exhibits a strong seasonal influence of sediment erosion and accretion.

Table 28 Torrey Pines State Reserve to La Jolla Shores Beach Net Sediment Volume Change Summary

Shore Segment ID	**Area (m^2)**	**Sediment Volume Change (m^3)**		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
750 - 92	**153,028**	**-72,220**	**48,611**	**-37,637**

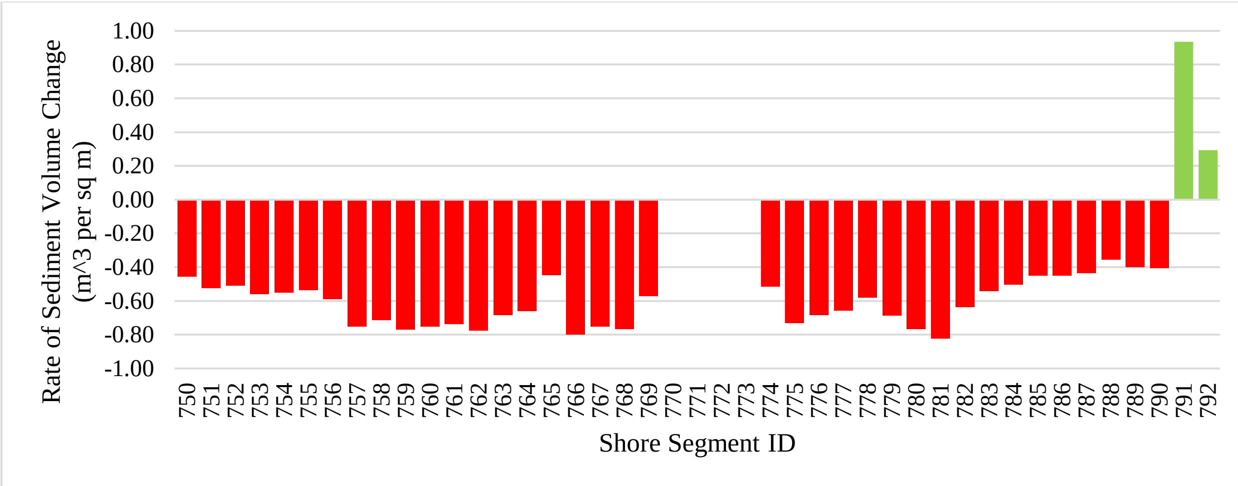

Figure 84 Torrey Pines State Reserve to La Jolla Shores Beach – Rate of sediment volume change by shore segment during the 06-07 El Niño

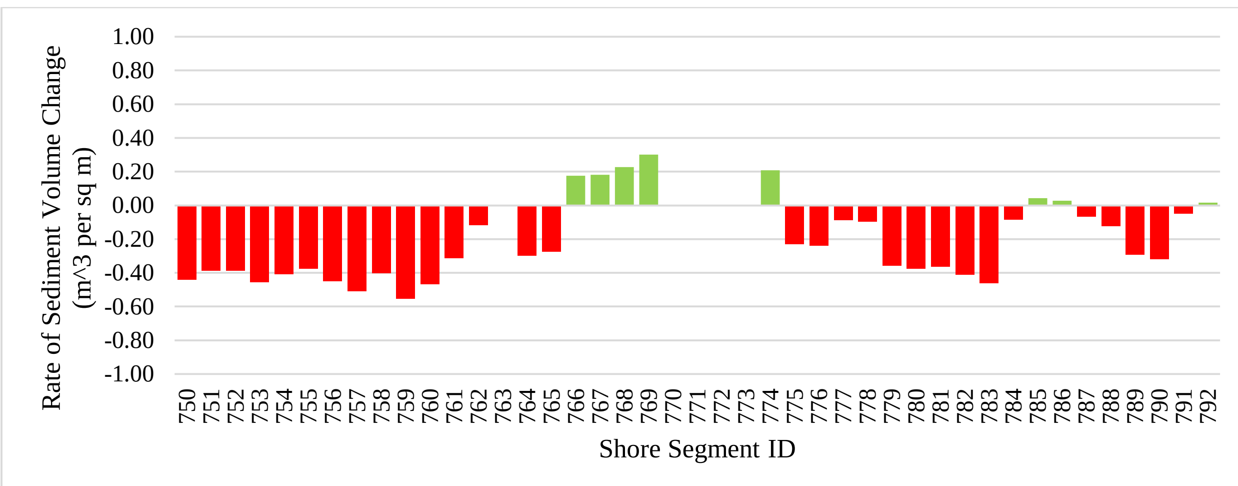

Figure 85 Torrey Pines State Reserve to La Jolla Shores Beach – Rate of sediment volume change by shore segment during the 07-08 La Niña

Figure 86 Torrey Pines State Reserve to La Jolla Shores - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.5.8. La Jolla Shores Beach South

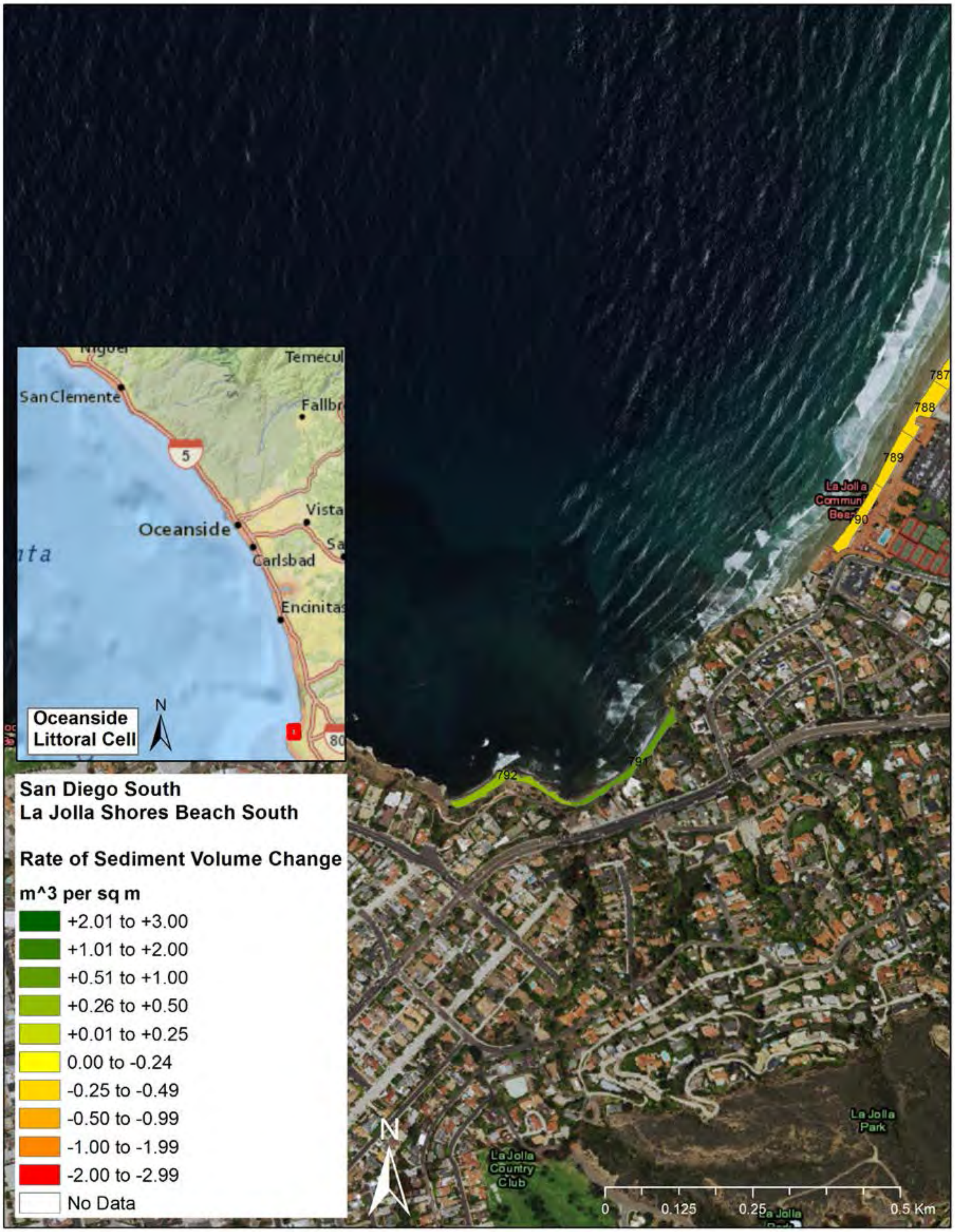

Figure 87 La Jolla Shores Beach South - Map of rate of sediment volume change by shore segments during the 06-07 El Niño

4.3.6. Overarching Results

While sediment change showed local variation in patterns of accretion and erosion, sediment change in the Oceanside Littoral Cell showed greater overall erosion during the 2006-2007 El Niño Winter when compared to the 2007-2008 La Niña Winter. Table 29 and Figure 85 summarize the total sediment volume change in cubic meters during the 2006-2007 El Niño winter, 2007 summer, and 2007-2008 La Niña winter. During the 2006-2007 El Niño winter a total of 584,711 m^3 of sediment was lost from the OLC. Figure 87 shows the average rate of sediment volume change by region during the 2006-2007 El Niño winter. The summer, immediately following the 2006-2007 El Niño Winter showed a significant amount of sediment recovery, with 458,766 m^3 of sediment deposited on beaches. The following 2007-2008 La Niña winter showed a total sediment volume loss of 386,624 m^3. While both the El Niño and La Niña winters showed a net loss of sediment, overall net loss of sediment was nearly twice as greater during the El Niño winter. The net sediment change over the entire time-series (Fall 2006 to Spring 2008) was negative 512,569 m^3.

Table 29 Total Sediment Volume (m^3) change in the OLC

2006-2007 El Niño Winter (m^3)	**2007 Summer (m^3)**	**2007-2008 La Niña Winter (m^3)**	**Net Sediment Change (m^3)**
-584,711	458,766	-386,624	-512,569

Table 30 Overall Rate of Sediment Volume Change (m^3 per sq m) in the OLC

2006-2007 El Niño Winter (m^3/sq m)	**2007 Summer (m^3/sq m)**	**2007-2008 La Niña Winter (m^3/sq m)**	**Net Sediment Change (m^3/sq m)**
-0.19	0.1	-0.12	-0.22

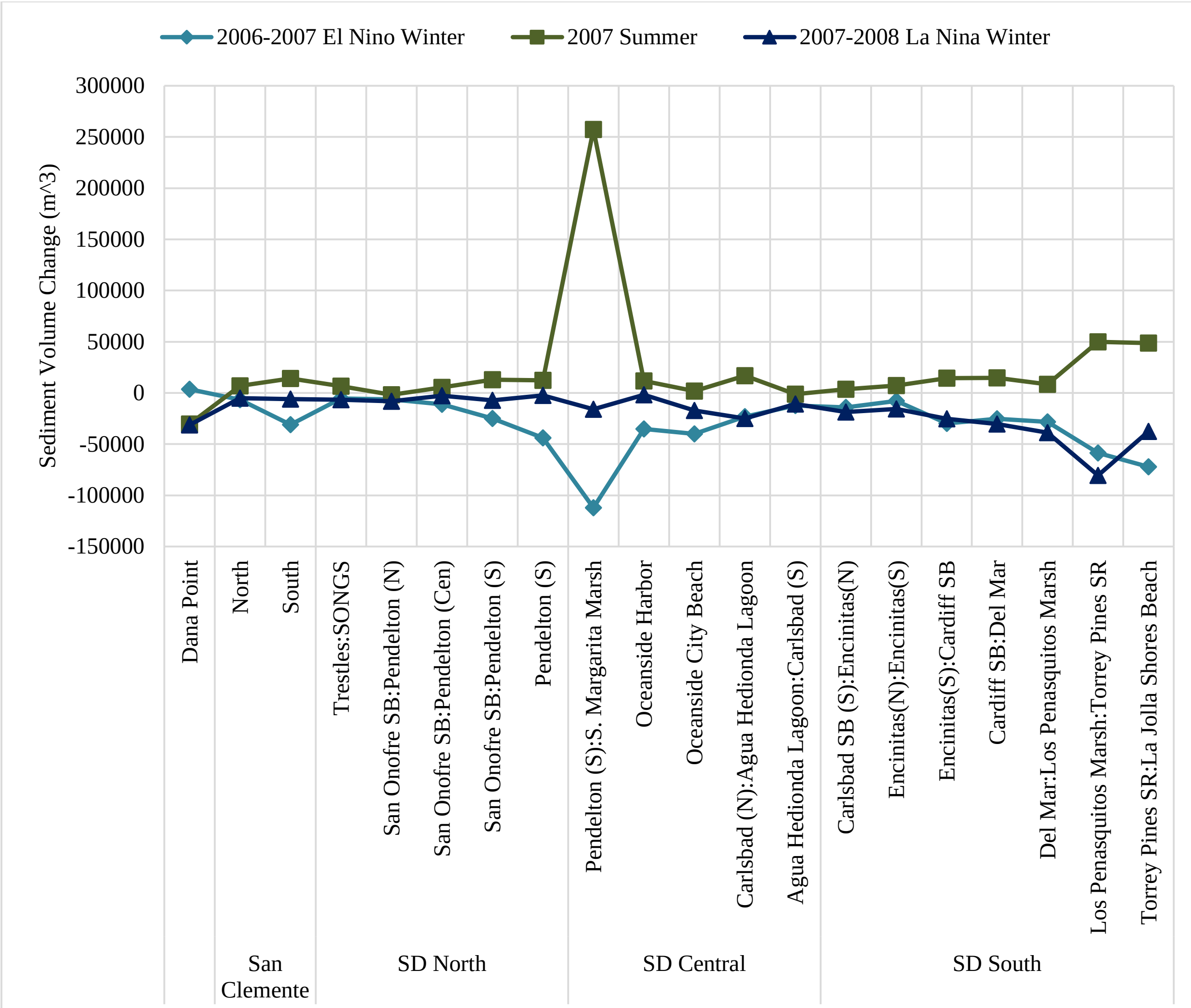

Figure 88 Total sediment volume change (m^3) in the OLC summarized by region

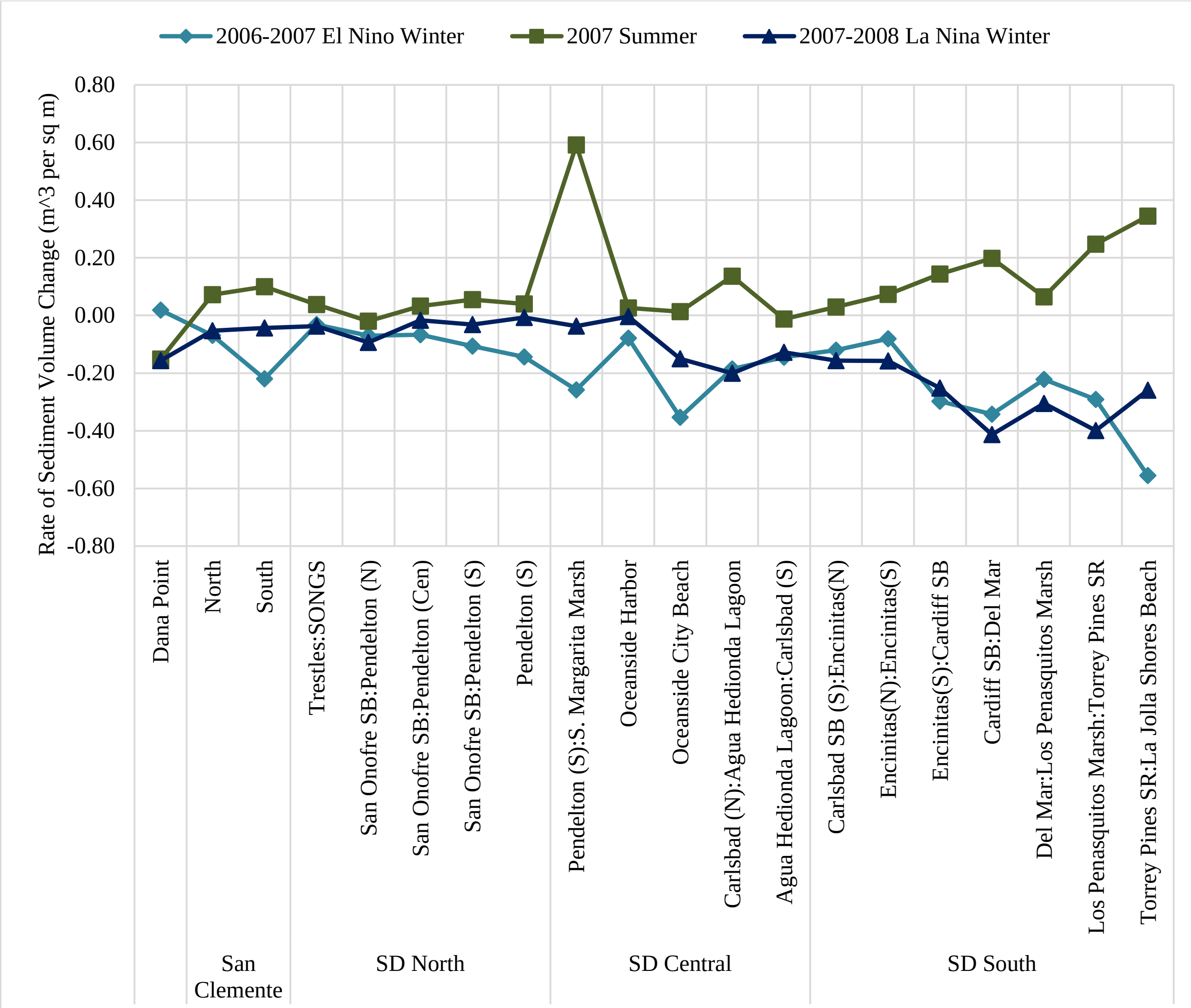

Figure 89 Rate of sediment volume change (m^3 per sq m) in the OLC summarized by region

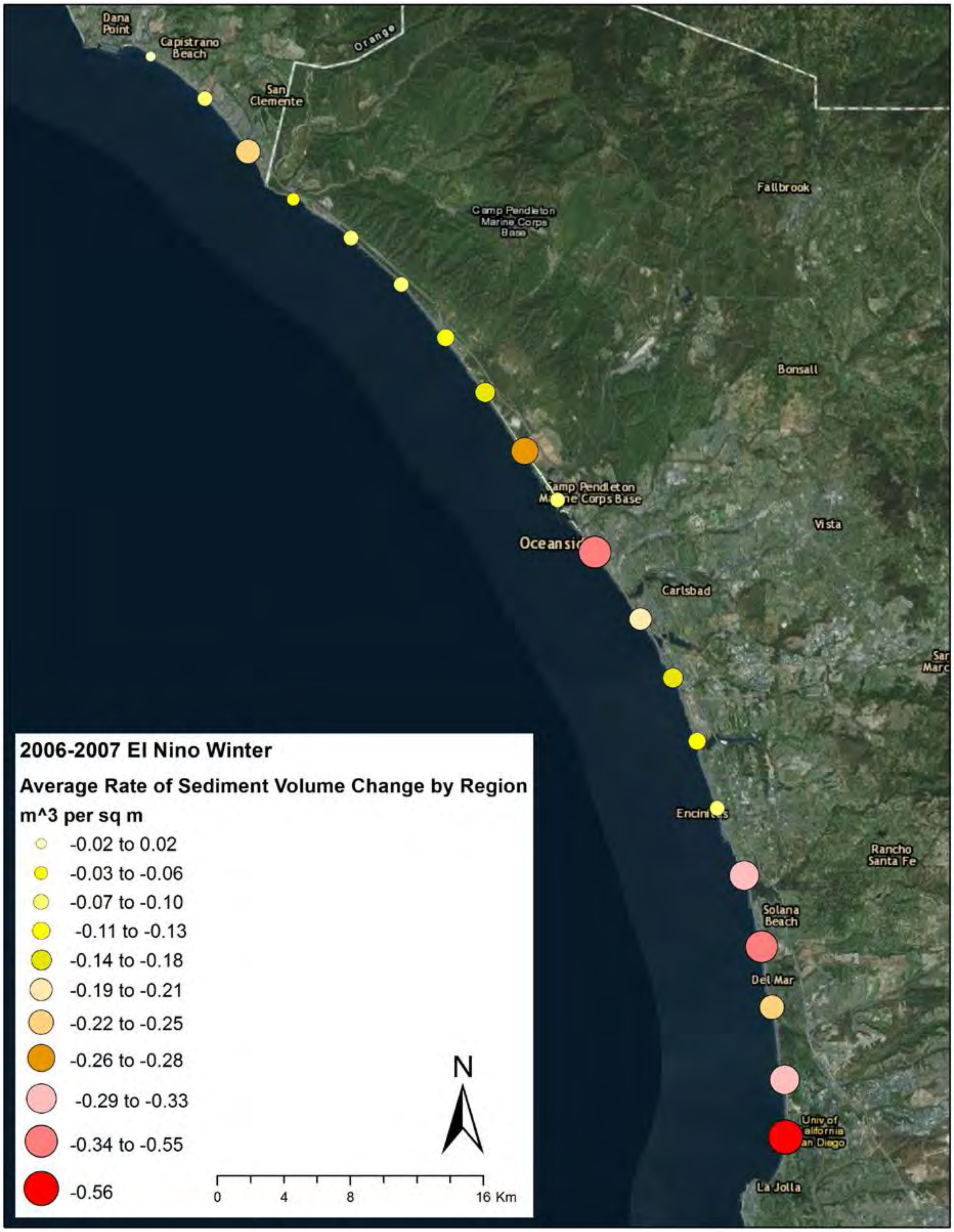

Figure 90 Average rate of sediment volume change by region during the 2006-2007 El Niño winter

Chapter 5 Conclusions

This study provides a method to analyze beach erosion and accretion patterns over time using LiDAR datasets. Beach sediment changes were analyzed for the coastal beach zone in the Oceanside Littoral Cell (OLC), which spans from Dana Point to La Jolla in Southern California. The study time period was from the Fall of 2006 to the Spring of 2008 and included four LiDAR datasets which encompassed the 2006-2007 El Niño and following 2007-2008 La Niña winter events. Beach sediment changes were also analyzed for the intermediary Summer of 2007.

Overall, this study shows that sediment volume loss was higher during the 2006-2007 El Niño winter than the following 2007-2008 La Niña winter. Partial sediment recovery was observed during the summer following the 2006-2007 El Niño winter. Local variation in sediment changes was high during the 2006-2007 El Niño with effects from long-shore current sand transport visible in portions of the study area. Coastal infrastructure, including rock jetties, harbors, and piers, affected sand movement. High rates of sediment volume change were observed at the Santa Margarita Marsh and Agua Hedionda Lagoon mouths. Additionally, sediment accretion from cliff failure was identified at several sites.

The beaches in Southern California are a highly dynamic system, with the winter and summer wave climate continually displacing and depositing sand. El Niño events bring an increase in the frequency and intensity of coastal winter storms which can cause major beach erosion. Erosion is a serious threat to the OLC and the use of LiDAR data to analyze beach sediment volume changes over time can inform beach managers and coastal scientists. These results can be applied to identify coastal areas prone to erosion, evaluate the interaction of coastal infrastructure with sand movement, and identify ideal areas for sand replenishment projects. Using the methodologies in this study, LiDAR data can be used to calculate actual sediment volume change with high resolution. Rates of sediment volume change can be summarized for a given shore segment, allowing beach managers and coastal scientists to visualize the spatial distribution of sediment change over time.

Time-series coastal LiDAR datasets have the ability to go beyond traditional 2-dimensional shoreline analysis and identify 3-dimensional sediment volume shifts; however, the process of analyzing large and complex datasets comes with challenges. Like most LiDAR datasets, the datasets used in this study were made up of elevation point clouds containing millions of points. Working with such large datasets is time consuming, requiring a series of steps to edit, clean, and prepare the data for use. The LastoLas software suite provides batch processing functionality which allows processes to be run with minimal user supervision. The ArcMap EBK interpolation process required heavy computing power and each elevation DEM created took at least four hours to complete. Previous failed attempts in running the ArcMap EBK tool on the LiDAR datasets was resolved by using a computer with multiple-core processors with high memory capability and installing the ArcMap Background Geoprocessing (64-bit) option so that additional system resources could be used for parallel processing.

The methods and results proposed in this study have many applications to future research. Increasing time-series periods on the order of decades and including multiple El Niño winter events may identify long-term trends in sediment erosion and accretion. The data results from long-term time-series can inform prediction models and incorporate future sea level rise and coastal storm scenarios. Future research can also include the incorporation of near shore bathymetric surveys into the time-series analysis. Concurrent bathymetric time-series data would unveil near-shore processes and provide information on the interaction of sediment movement on and off dry beaches as well as offshore sediment loss into deep waters and submarine canyons.

The methods used in this study can also evaluate sediment contribution from cliff erosion and identify cliff failure sites. Finally, this research has the potential to identify beach restoration sites as well as provide information to prioritize shoreline protection.

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Appendix A

Dana Point Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
1	9,624	194	-1,343	-467
2	9,805	1,016	-1,174	-397
3	6,887	1,105	-839	-335
4	6,928	904	-1,091	-483
5	6,866	468	-953	-613
6	5,525	-3,476	-979	-3,642
7	9,472	-1,712	-3,438	-3,842
8	18,528	-6,155	-2,078	-14,965
9	4,691	-1,353	1,021	-4,349
10	4,314	-335	648	-3,851
11	4,273	-149	-378	-3,033
12	4,127	-213	1,033	-4,246
13	4,696	-382	-899	-2,569
14	4,852	-403	-38	-2,288
15	4,967	659	-114	-800
16	3,923	212	195	-154
17	4,779	688	364	-228
18	4,728	985	-650	453
19	3,207	5	-737	815
20	4,155	988	-1,053	780
21	4,466	1,779	-1,385	1,220
22	3,016	1,754	-1,194	1,310
23	4,008	1,440	-1,048	1,169
24	3,938	1,162	-756	900
25	4,300	833	-901	1,244
26	4,874	686	-1,233	943
27	5,299	500	-1,213	673
28	5,176	435	-965	251
29	4,932	184	-1,135	380
30	4,433	211	-1,135	423
31	4,695	0	-1,004	331
32	4,865	-41	-869	392
33	4,490	-187	-924	699
34	4,305	-262	-666	525
35	3,381	503	-624	247
36	2,512	800	-1,210	823
37	2,117	764	-845	681
38	2,501	75	-647	762
Total	**199,655**	**3,682**	**-30,257**	**-31,241**

San Clemente (North) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
39	6,171	-1,843	192	883
40	2,390	-867	530	-434
41	2,800	-492	426	-491
42	2,614	136	479	-401
43	4,704	84	504	-1,092
44	5,288	248	-6	-83
45	5,904	205	-80	-116
46	5,516	377	-437	202
47	4,904	718	-239	177
48	1,544	88	53	25
49	1,229	-446	320	-18
50	1,290	-650	719	-611
51	1,539	-934	774	-466
52	1,744	-899	665	-491
53	2,367	-541	398	-82
54	2,262	191	-324	233
55	1,993	782	-623	222
56	1,377	802	-331	197
57	840	369	-196	221
58	740	-143	140	-48
59	3,706	-1,870	1,595	-679
60	4,740	-2,085	1,073	-731
61	3,753	-745	295	-605
62	2,356	533	-202	242
63	1,272	985	-518	345
64	985	807	-309	308
65	896	509	-90	113
66	904	205	77	160
67	1,020	193	31	257
68	746	263	-174	85
69	1,207	447	-3	-122
70	1,109	-436	957	-436
71	1,705	-419	903	-531
72	2,772	-936	1,086	-904
73	3,169	-583	317	-338
74	3,697	-387	-419	69
75	4,340	-274	-709	-114
Total	**95,593**	**-6,608**	**6,874**	**-5,054**

San Clemente (South) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
76	4,450	496	-479	909
77	4,021	-349	-342	755
78	3,878	74	-354	651
79	4,186	-172	-87	934
80	4,487	99	-220	492
81	4,417	-200	-37	38
82	5,097	-1,384	721	171
83	3,128	-1,074	437	-37
84	2,648	-1,108	69	446
85	2,761	-1,165	-144	410
86	3,030	-1,132	228	214
87	3,801	-1,296	433	223
88	3,798	-1,185	230	297
89	3,110	-962	-10	378
90	3,149	-812	326	253
91	4,476	-598	-231	293
92	4,041	-457	-566	380
93	3,438	47	-162	203
94	3,015	-292	565	-210
95	2,829	-1,143	1,319	-716
96	2,519	-1,270	955	-1,498
97	2,136	-993	716	-2,154
98	2,338	-1,109	218	-1,808
99	3,017	-1,061	118	-1,487
100	2,879	-1,065	203	-1,277
101	2,487	-1,480	811	-1,162
102	2,659	-1,683	1,249	-1,066
103	3,399	-1,726	1,084	-1,768
104	3,432	-2,228	1,179	-1,454
105	3,702	-2,515	1,049	-545
106	9,655	-4,937	1,990	-625
107	9,794	-2,023	1,460	790
108	3,511	-787	1,391	-133
109	3,725	-1,374	1,198	-46
110	4,081	-1,041	-526	686
111	2,650	2,034	-683	824
112	1,961	2,488	-16	321
113	2,548	2,508	-34	284
Total	**140,253**	**-30,875**	**14,058**	**-6,034**

Trestles to San Onofre (SONGS) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	**Summer 07**	**07-08 La Niña winter**
114	4,088	3,222	-231	475
115	5,305	1,789	-328	409
116	4,691	1,020	-110	242
117	7,232	1,000	31	267
118	4,890	50	770	280
119	4,173	-6	1,115	-175
120	3,038	-573	1,139	-646
121	2,224	-1,600	1,555	-961
122	3,010	-1,809	1,604	-1,145
123	4,056	-1,323	1,161	-1,090
124	2,079	86	346	-172
125	3,278	437	226	-50
126	3,633	-269	338	-138
127	4,969	-203	-41	-184
128	4,240	-66	107	-185
129	3,188	-95	146	28
130	3,200	-73	-142	135
131	3,266	-487	-276	610
132	10,830	-1,827	-2,379	3,070
133	5,018	-351	-1,098	496
134	17,711	-6,274	1,731	-5,592
135	4,682	-460	-353	-848
136	3,842	901	-1,760	140
137	2,926	1,537	-1,980	544
138	3,094	1,754	-1,918	1,039
139	3,313	1,618	-1,612	1,209
140	4,111	836	-1,136	1,010
141	3,342	249	-5	-61
142	2,657	-601	771	-825
143	5,559	-1,476	1,682	-1,287
144	6,601	174	672	-361
145	6,523	912	97	542
146	6,829	692	-102	466
147	5,486	223	416	-128
148	3,558	-913	1,051	-692
149	2,244	-1,036	1,597	-1,001
150	2,367	-1,302	1,969	-934
151	2,519	-1,324	1,541	-966
Total	**173,772**	**-5,568**	**6,594**	**-6,479**

San Onofre State Beach to Camp Pendelton MCB (North) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
152	1,713	-889	222	191
153	1,604	-118	553	-423
154	768	119	257	-217
155	575	2	56	-26
156	522	-27	50	-43
157	817	77	-42	-6
158	3,744	575	-1,016	-1,030
159	3,799	-464	-704	-702
160	3,332	-127	-686	-282
161	2,654	-104	143	-308
162	2,324	144	-190	464
163	2,357	-189	-393	471
164	2,493	-706	110	-307
165	2,662	-790	-437	55
166	2,612	-1,034	-233	14
167	3,489	-342	-140	-311
168	2,384	2,070	-1,267	552
169	1,330	1,191	-382	122
170	2,818	750	-215	-279
171	2,814	-166	299	-1,246
172	3,125	-1,693	1,119	-1,464
173	3,156	-520	840	-676
174	2,251	-713	537	-518
175	2,207	-923	447	-577
176	2,193	-549	-158	-224
177	1,887	-19	-906	363
178	1,732	38	-1,039	387
179	1,929	587	-932	315
180	1,985	197	-60	193
181	2,180	-219	215	-81
182	2,352	-270	71	-616
183	2,350	-271	197	-101
184	2,205	-53	54	80
185	2,283	-96	-16	-255
186	2,345	-93	311	-300
187	2,110	228	278	-305
188	1,832	573	-86	120
189	1,800	-237	356	-614
190	1,690	-1,202	611	-516
191	1,577	-945	414	-135
Total	**88,000**	**-6,208**	**-1,762**	**-8,235**

San Onofre State Beach/Camp Pendelton MCB (Central) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
192	1,742	-394	-84	-144
193	1,836	-459	-288	-131
194	1,511	-841	22	-206
195	1,701	-289	-414	-225
196	1,976	-334	-384	-498
197	2,382	-887	160	-917
198	3,310	-560	-149	-590
199	3,737	-140	-702	-109
200	4,103	-255	-370	-13
201	4,149	-21	-256	-261
202	3,794	-443	141	-477
203	4,984	-619	456	-911
204	5,730	-683	86	-469
205	4,752	-315	-180	-267
206	5,415	-98	-263	-304
207	5,803	88	-390	-75
208	6,097	201	-595	276
209	6,106	203	-387	365
210	5,855	93	-42	221
211	6,209	93	83	500
212	5,887	143	65	756
213	5,672	-143	398	867
214	5,738	-507	871	509
215	5,202	-389	716	71
216	4,973	-207	457	307
217	4,127	22	2	262
218	4,376	-52	-160	207
219	4,063	-100	136	-55
220	4,257	-272	456	-308
221	3,669	-261	559	-219
222	3,295	-200	331	-238
223	2,960	-706	782	-343
224	3,289	-734	925	-262
225	3,390	-788	759	-128
226	3,622	-566	438	18
227	3,864	-477	415	214
228	3,721	-425	520	172
229	3,642	20	252	-117
230	3,916	245	416	-201
231	4,065	25	593	-29
Total	**164,920**	**-11,032**	**5,375**	**-2,752**

San Onofre State Beach/Camp Pendelton MCB (South) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
232	4,199	-446	619	-145
233	4,557	-578	552	-376
234	5,556	-469	-92	-172
235	4,317	-658	-36	-288
236	4,146	-785	-87	-191
237	4,043	-557	-307	-167
238	4,129	-844	-564	105
239	4,364	-866	-324	38
240	5,109	-590	-285	55
241	5,442	-216	-717	138
242	5,314	-173	-625	-66
243	5,518	-292	-225	-420
244	5,382	-709	386	-786
245	5,514	-796	722	-924
246	5,502	-525	579	-309
247	5,070	-719	683	-312
248	4,963	-1,051	1,058	-169
249	5,248	-827	825	123
250	5,368	-781	665	177
251	5,380	-1,059	1,055	64
252	5,501	-704	918	-32
253	6,083	-656	767	-12
254	5,950	-612	758	92
255	6,152	-632	673	10
256	5,844	-698	629	-79
257	6,045	-729	557	-877
258	10,342	-1,238	668	18
259	6,433	-663	151	54
260	6,304	-373	185	-278
261	5,744	-232	171	-220
262	5,682	-326	297	-764
263	5,871	-615	825	-1,305
264	5,794	-463	514	-411
265	5,996	-160	-39	198
266	5,585	-69	-187	176
267	5,659	-81	-62	-302
268	5,511	-431	412	-413
269	8,301	-1,033	632	-15
270	8,540	-811	514	189
271	7,701	-654	349	348
272	6,208	-708	375	-125
Total	**234,367**	**-24,829**	**12,989**	**-7,373**

Camp Pendelton MCB (South) to Santa Margarita Marsh Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
314	9,376	-1,047	936	140
315	8,784	-1,205	1,124	448
316	8,686	-945	1,292	159
317	9,470	-1,097	1,335	166
318	9,220	-1,241	1,428	408
319	8,213	-1,407	1,562	-396
320	8,306	-2,767	5,844	-663
321	8,003	-6,948	19,640	-504
322	8,332	-4,867	28,427	-430
323	8,851	-4,341	32,168	-342
324	8,559	-5,120	33,732	-169
325	8,525	-4,578	30,764	-114
326	8,481	-3,758	29,211	-114
327	8,712	-5,473	26,605	-78
328	8,970	-7,298	13,264	-961
329	6,548	-2,634	2,892	-2,038
330	8,286	-1,995	734	-326
331	9,169	-1,970	684	-213
332	9,558	-2,156	792	-206
333	9,933	-2,272	1,037	-72
334	9,938	-2,058	1,099	-119
335	10,228	-2,659	1,834	-748
336	10,102	-2,771	1,192	-1,193
337	9,805	-2,833	968	-999
338	9,394	-2,322	1,237	-827
339	9,658	-2,477	1,317	-659
340	9,765	-2,238	1,016	-873
341	9,956	-2,261	503	-816
342	10,329	-2,303	984	-947
343	10,932	-2,846	1,004	-1,106
344	11,189	-3,953	1,719	-1,577
345	11,382	-2,330	1,492	-666
346	11,790	-2,427	1,159	-703
347	12,320	-1,848	1,047	436
348	13,058	-1,892	874	-336
349	14,414	-1,432	858	-659
350	16,071	-1,302	544	-390
351	17,412	-1,570	866	255
352	17,442	-1,814	964	1,131
353	17,613	-2,439	1,558	-87
354	17,780	-3,337	1,470	236
Total	**434,560**	**-112,231**	**257,176**	**-15,952**

Santa Margarita Marsh to Oceanside Harbor Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
355	17,692	3,355	6,507	336
356	17,551	-4,866	-1,157	6,191
357	17,111	-2,137	-3,893	-588
358	16,578	-1,788	702	-15,868
359	14,666	-1,576	665	-1,570
360	14,433	-1,543	621	123
361	16,364	-1,915	907	429
362	16,421	-1,979	681	777
363	16,131	-1,907	-23	1,194
364	15,298	-2,005	-298	1,362
365	14,647	-2,277	42	1,446
366	13,416	-2,310	275	1,559
367	11,950	-2,629	415	1,755
368	11,438	-2,042	1,466	1,329
369	11,248	-1,334	1,384	743
370	11,098	-711	909	1,002
371	10,374	145	895	793
372	10,170	467	936	713
373	10,177	826	593	1,044
374	10,586	1,290	-41	1,024
375	8,781	1,943	-64	1,147
376	19,867	-917	-767	436
377	18,053	435	-862	496
378	13,933	-655	-24	144
379	14,474	-428	-353	226
380	5,064	-193	-167	-11
381	8,956	-1,019	1,004	-802
382	11,934	-1,504	215	-930
383	11,845	-1,030	-402	-1,302
384	11,403	-593	-1,110	-256
385	10,139	-604	-1,033	-120
386	17,632	-940	-789	-238
387	12,431	-2,774	3,429	-3,298
388	8,924	-2,075	994	-1,088
Total	**450,785**	**-35,290**	**11,657**	**-1,802**

Oceanside City Beach Sediment Net Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
389	1,760	-1,777	857	-726
390	4,537	-2,028	577	-2,904
391	5,571	-1,610	-509	-822
392	5,981	-1,298	-969	785
393	6,248	-622	-1,398	563
394	6,383	300	-2,552	436
395	6,272	72	-1,891	113
396	6,419	-957	-955	-91
397	5,844	-1,122	-284	-356
398	4,738	-642	-610	-545
399	5,700	-1,404	-128	-451
400	5,304	-1,050	-894	-869
401	5,085	-1,897	-1,048	-1,316
402	4,433	-1,548	42	-586
403	3,206	-1,387	672	-790
404	2,765	-1,690	646	343
405	2,885	No data	No data	No data
406	2,364	No data	No data	No data
407	1,635	No data	No data	No data
408	1,588	No data	No data	No data
409	1,824	No data	No data	No data
410	1,066	No data	No data	No data
411	1,455	No data	No data	No data
412	1,868	No data	No data	No data
413	2,693	-2,152	-329	-163
414	2,410	-1,778	217	-340
415	3,129	-1,832	-254	-413
416	2,811	-1,840	430	-750
417	2,620	-2,010	729	-966
418	2,213	-1,869	813	-1,064
419	1,954	-2,205	1,358	-898
420	1,761	-1,961	1,501	-1,245
421	1,176	-1,050	738	-374
422	2,861	-815	1,420	-1,403
423	1,793	-1,179	676	-994
424	1,512	-769	523	-536
425	1,456	-398	197	-145
426	1,539	-435	173	-83
427	1,485	-499	285	-189
428	1,057	-195	-14	-54
429	718	-412	101	-188
Total	**128,119**	**-21,399**	**8,564**	**-9,805**

Carlsbad North to Carlsbad State Beach (Agua Hedionda Lagoon) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
430	717	-261	81	-97
431	869	-93	-122	12
432	1,643	-742	-129	157
433	1,940	-1,154	-206	-58
434	1,069	-606	-33	-3
435	1,256	-872	-250	-158
436	1,490	-1,037	-559	-326
437	1,655	-1,432	8	-839
438	1,832	-1,258	292	-1,212
439	4,734	-1,770	628	-1,484
440	3,386	-1,607	1,212	-1,649
441	2,950	-1,128	748	-1,326
442	2,985	-1,507	1,033	-1,064
443	2,210	-1,586	1,240	-1,398
444	2,633	-1,848	1,384	-961
445	3,488	-2,283	1,629	-901
446	3,433	-2,290	1,441	-1,399
447	2,974	-1,756	1,104	-852
448	2,961	-1,899	1,020	-370
449	3,030	-2,145	1,167	-750
450	3,466	-2,635	1,318	-947
451	4,399	-2,144	905	-1,079
452	4,488	-2,151	1,259	-908
453	4,422	-325	711	-583
454	4,310	42	508	46
455	5,684	71	572	-1,084
456	5,695	968	-437	-135
457	4,431	1,348	95	60
458	4,764	442	54	-335
459	4,856	233	204	-214
460	4,563	1,195	1	-638
461	4,403	1,529	-235	-350
462	2,752	2,611	-281	111
463	1,360	1,575	-146	-35
464	1,308	-784	266	-51
465	2,135	-843	971	-681
466	3,019	172	-60	-332
467	3,424	872	-456	-562
468	3,871	799	-19	-1,066
469	4,068	1,144	4	-1,535
Total	**124,673**	**-23,155**	**16,922**	**-24,996**

Carlsbad State Beach (Agua Hedionda Lagoon) to Carlsbad State Beach (South) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
470	7,297	-1,336	2,219	-1,518
471	4,897	-42	-40	-482
472	2,601	-289	283	-954
473	1,984	-528	364	-643
474	2,042	-366	345	-524
475	2,334	-415	384	-627
476	1,515	-10	70	-189
477	1,120	-61	-172	34
478	1,227	-56	-207	63
479	633	37	-47	-5
480	631	45	-107	51
481	670	78	-185	75
482	1,230	-125	126	-189
483	951	179	-175	123
484	1,188	376	-276	-145
485	1,508	428	-307	-336
486	1,486	1,130	-375	-319
487	1,783	1,459	-425	-151
488	5,865	-1,425	-2,390	607
489	2,385	-1,180	-659	315
490	1,882	-514	-572	270
491	1,699	-411	-384	223
492	1,584	-571	46	-23
493	1,594	-528	-84	210
494	1,855	-583	-55	-73
495	2,073	-793	61	-443
496	2,092	-645	35	-437
497	2,139	-270	94	-628
498	2,051	-552	225	-177
499	2,369	-685	276	-578
500	2,629	-516	239	-652
501	2,504	-459	69	-424
502	2,426	-507	163	-687
503	2,613	-909	266	-520
504	2,111	-805	392	-584
505	2,282	-663	92	-771
506	1,956	-591	-106	-174
507	1,972	-470	-154	-125
508	2,302	-76	-52	-284
509	2,126	220	-58	-243
Total	**85,606**	**-12,429**	**-1,081**	**-10,934**

Carlsbad State Beach (South) to Encinitas (North) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
510	1,824	-355	56	289
511	2,155	-1,018	-202	-84
512	2,523	-414	-367	64
513	2,356	-16	-125	-23
514	1,538	-454	32	-23
515	2,657	-866	51	-834
516	2,892	-1,496	-57	-415
517	2,505	-1,534	25	-435
518	2,364	-1,233	-247	-365
519	2,328	-1,077	-647	134
520	2,358	-450	-639	-430
521	2,254	106	-587	-261
522	2,483	-260	-916	437
523	2,897	-235	-356	-417
524	3,196	-739	165	-437
525	3,370	-1,541	332	-707
526	3,823	-1,690	124	-1,226
527	5,976	-4	-208	-884
528	7,062	2,984	-76	-1,118
529	7,659	3,280	20	-833
530	7,417	-2,651	969	-1,537
531	7,265	1,524	596	-298
532	7,836	254	849	-1,163
533	5,225	-2,406	1,124	-1,560
534	2,601	-1,521	666	-1,077
535	1,605	-1,430	257	-544
536	1,674	-1,217	395	-668
537	2,156	-831	43	-412
538	2,082	-44	-2	-379
539	1,690	395	84	-304
540	1,459	351	236	-288
541	1,252	264	403	-530
542	1,559	-142	345	-359
543	2,013	-88	161	-269
544	1,463	316	93	-154
545	1,536	-70	243	-240
546	1,560	26	84	-248
547	1,254	208	30	-207
548	1,234	55	245	-299
549	1,137	-211	320	-444
Total	**118,238**	**-14,230**	**3,519**	**-18,548**

Encinitas (North) to Encinitas (South) Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
550	1,619	-145	305	-582
551	1,401	-502	284	-523
552	1,789	-539	71	-295
553	975	-498	47	-225
554	2,803	-1,126	-226	-1,038
555	3,114	-480	-116	-1,051
556	2,859	-243	-178	-755
557	2,563	-903	-241	-711
558	2,362	-695	-718	-738
559	2,105	-853	-1,410	-242
560	1,727	-482	-612	-240
561	1,996	-923	-621	-464
562	2,367	-1,168	-488	-354
563	2,151	-272	-532	-114
564	2,184	-344	-651	-104
565	2,185	-322	-863	-22
566	2,614	252	-1,138	-197
567	2,823	-2	-917	-61
568	2,608	400	-352	-496
569	2,746	-45	-16	4
570	2,400	-300	278	-153
571	2,958	-665	247	-365
572	3,452	-1,220	296	-446
573	3,188	-1,399	837	-404
574	3,702	-1,806	1,305	-233
575	7,251	-1,676	772	-950
576	3,370	-2,224	1,889	-1,271
577	2,934	-1,436	1,958	-1,539
578	2,707	-1,763	2,107	-1,360
579	2,565	-745	1,837	-1,361
580	2,220	550	1,472	-922
581	1,892	1,300	1,095	-245
582	1,999	2,212	1,263	-374
583	2,052	2,255	652	265
584	1,071	2,088	-350	815
585	962	3,067	-805	163
586	848	909	251	145
587	1,962	51	464	293
588	1,669	266	64	201
589	1,085	343	-81	-20
590	1,538	531	-185	159
591	1,713	641	186	234
Total	**98,529**	**-7,911**	**7,180**	**-15,576**

Encinitas (South) to Cardiff State Beach Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
592	2,576	-599	1,221	-116
593	2,143	-1,116	1,094	-64
594	1,818	-684	738	96
595	1,388	3	112	248
596	1,165	134	-54	156
597	1,204	120	167	98
598	1,798	71	142	14
599	1,666	20	167	-175
600	2,327	-952	538	-184
601	2,526	-1,415	248	-91
602	2,386	-1,525	229	-31
603	1,922	-1,610	756	-520
604	2,085	-1,060	82	-377
605	2,534	-629	-60	-60
606	2,144	-448	51	-200
607	2,129	-396	289	-286
608	2,132	-837	81	-265
609	2,408	-970	142	-314
610	2,091	-1,265	688	-902
611	1,985	-1,263	1,107	-1,337
612	1,880	-574	637	-1,023
613	4,978	1,995	-1,562	-1,148
614	4,525	-422	-264	-830
615	3,513	-972	237	-2,612
616	2,810	-1,726	-7	-1,237
617	3,668	-1,550	-542	-477
618	3,229	-1,245	-163	-633
619	3,281	-1,276	269	-831
620	3,156	-1,489	869	-1,797
621	3,033	-1,730	1,259	-1,691
622	2,638	-1,358	856	-963
623	2,395	-1,253	964	-2,125
624	2,152	-970	789	-1,454
625	2,852	-525	835	-889
626	5,247	-151	113	-1,092
627	4,060	-1,660	1,293	-538
628	2,296	539	-68	-355
629	2,478	-689	694	-692
630	1,578	-372	427	-497
Total	**100,196**	**-29,849**	**14,374**	**-25,194**

Cardiff State Beach to Del Mar Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
631	1,842	527	130	-668
632	528	384	-79	-62
633	868	-4	380	-109
634	220	144	-13	-10
635	681	-878	380	-20
636	724	-542	80	125
637	440	-47	-16	-231
638	492	180	-21	-145
639	328	-142	34	-44
640	2,101	-664	-41	-404
641	1,571	-398	-103	-459
642	602	-378	-69	-22
643	802	-505	244	-239
644	829	-250	-321	-199
645	1,268	-647	354	-1,054
646	1,651	-784	810	-1,277
647	1,682	-197	601	-789
648	2,179	-304	404	-608
649	2,308	-364	227	-464
650	1,515	347	-109	-157
651	1,800	-31	217	-628
652	1,074	-297	323	-351
653	1,136	-495	534	-419
654	558	16	-25	-190
655	504	-186	19	-151
656	1,436	-3,399	-207	-45
657	14,431	183	-351	-454
658	1,796	-1,140	438	-774
659	1,392	-1,093	636	-1,245
660	1,400	-1,182	1,003	-1,771
661	1,455	-1,248	1,091	-1,444
662	1,500	-1,468	1,207	-1,143
663	2,711	-1,787	804	-2,135
664	3,436	-1,945	690	-2,786
665	3,058	-1,657	988	-3,209
666	3,472	-1,606	1,266	-1,858
667	3,569	-1,463	957	-1,947
668	2,826	-1,115	1,086	-1,861
669	3,523	-804	1,035	-1,202
Total	**73,708**	**-25,239**	**14,583**	**-30,449**

Del Mar to Los Penasquitos Marsh Sediment Net Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
670	3,745	-732	1,265	-1,331
671	3,875	-1,014	1,444	-1,722
672	3,158	-487	1,209	-1,322
673	2,841	143	1,143	-1,737
674	3,254	186	507	-489
675	2,829	252	446	-402
676	1,992	336	396	-402
677	1,581	283	456	-359
678	1,661	404	122	-232
679	1,319	255	76	24
680	1,808	358	75	304
681	1,887	-126	168	20
682	1,637	-655	393	-436
683	1,599	-213	-155	-45
684	1,480	-338	145	-209
685	1,968	4	-454	209
686	2,510	185	-851	250
687	3,168	-162	-1,490	1,042
688	2,748	-1,193	-1,169	501
689	2,979	-1,318	-464	-629
690	3,372	-1,298	-616	-662
691	3,927	-1,258	-770	-1,143
692	3,747	-1,279	149	-1,228
693	4,518	-838	362	-2,141
694	5,102	-175	-252	-2,263
695	4,367	-1,357	500	-2,454
696	4,497	-853	197	-2,153
697	4,591	-641	248	-2,131
698	5,404	-629	-130	-2,981
699	5,739	-1,177	-266	-2,316
700	4,785	-1,224	-1,137	85
701	4,549	-1,413	-605	19
702	4,666	-302	-725	787
703	1,858	-321	-208	372
704	2,663	-1,933	1,263	-1,816
705	3,647	-1,997	1,044	-2,978
706	3,237	-2,156	1,813	-2,843
707	2,542	-1,999	1,640	-2,162
708	2,777	-1,831	1,485	-2,012
709	2,772	-1,640	999	-1,660
Total	**126,799**	**-28,153**	**8,253**	**-38,645**

Los Penasquitos Marsh to Torrey Pines State Reserve Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
710	7,283	-4,780	3,738	-6,028
711	3,161	-2,060	1,548	-2,389
712	3,035	-1,691	1,168	-1,789
713	2,888	-1,607	1,417	-1,508
714	2,964	-1,215	1,470	-2,029
715	3,330	-560	1,261	-2,425
716	3,281	-626	1,438	-2,750
717	2,716	-797	803	-1,304
718	2,289	-16	314	-1,164
719	2,551	-196	477	-1,034
720	1,379	-371	414	-508
721	1,380	-104	221	-213
722	2,235	-154	9	-186
723	2,401	-168	14	-350
724	1,937	-152	262	-18
725	1,967	46	-524	710
726	2,160	103	-453	569
727	2,959	7,194	-46	319
728	2,648	-1,741	1,180	-75
729	2,948	-1,723	398	33
730	3,830	-2,228	370	-67
731	3,769	-2,192	392	-149
732	3,025	-1,897	98	193
733	2,678	-1,370	-204	128
734	5,530	-2,090	417	-1,351
735	5,655	-1,841	847	-1,882
736	14,094	-3,274	1,039	-6,089
737	9,926	-2,051	846	-4,061
738	9,849	-1,842	897	-3,935
739	9,741	-2,108	1,781	-3,893
740	8,785	-2,349	2,334	-3,866
741	9,316	-2,426	2,658	-3,674
742	8,874	-2,539	2,833	-3,646
743	8,516	-2,618	2,828	-3,538
744	8,536	-3,049	2,602	-3,861
745	7,961	-2,902	2,836	-3,344
746	7,539	-2,954	3,102	-3,720
747	6,152	-2,702	3,111	-4,251
748	5,731	-2,947	2,997	-3,866
749	6,480	-2,758	2,887	-3,417
Total	**201,499**	**-58,755**	**49,780**	**-80,428**

Torrey Pines State Reserve to La Jolla Shores Beach Net Sediment Volume Change

Shore Segment ID	Area (m^2)	Sediment Volume Change (m^3)		
		06-07 El Niño winter	Summer 07	07-08 La Niña winter
750	6,499	-2,961	2,784	-2,873
751	6,103	-3,201	2,592	-2,369
752	6,765	-3,439	2,660	-2,614
753	6,557	-3,664	2,796	-2,987
754	6,757	-3,707	2,586	-2,763
755	6,103	-3,277	2,446	-2,295
756	5,014	-2,946	2,105	-2,256
757	4,922	-3,699	1,526	-2,511
758	6,553	-4,679	2,437	-2,646
759	4,330	-3,329	1,813	-2,399
760	4,446	-3,347	2,531	-2,069
761	3,766	-2,779	2,025	-1,174
762	2,906	-2,253	1,439	-345
763	2,526	-1,722	1,289	6
764	2,728	-1,805	1,356	-809
765	2,694	-1,204	928	-740
766	2,618	-2,093	891	460
767	2,533	-1,907	670	462
768	2,281	-1,749	569	519
769	1,496	-856	108	449
770	3,802	-496	-740	572
771	1,272	119	-288	128
772	1,344	879	-886	521
773	1,287	7,994	-2,145	808
774	979	-504	-79	204
775	2,538	-1,853	785	-584
776	2,538	-1,730	687	-605
777	2,952	-1,933	182	-252
778	3,472	-2,011	300	-340
779	2,638	-1,811	1,213	-945
780	2,487	-1,909	1,406	-939
781	2,126	-1,748	1,411	-774
782	2,259	-1,436	1,262	-928
783	7,430	-4,025	2,981	-3,426
784	6,184	-3,114	1,677	-524
785	3,941	-1,774	851	168
786	3,267	-1,467	796	93
787	3,113	-1,348	812	-207
788	2,439	-865	544	-303
789	1,937	-776	618	-564
790	2,237	-906	691	-712
791	2,479	2,319	686	-118
792	2,710	792	296	44
Total	**153,028**	**-72,220**	**48,611**	**-37,637**