California Sea Grant
Final Project Progress Report
R/OE-39
Relationship Between Bluff Erosion
and Beach Sand Supply for the Oceanside Littoral Cell

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Scott A Ashford
Oregon State University
School of Civil and Construction Engineering
scott.ashford@oregonstate.edu

Neal W. Driscoll
Scripps Institution of Oceanography
Geosciences Research Division
ndriscoll@ucsd.edu

Project Hypotheses
Ongoing research by Ashford and Driscoll suggests that erosion of the sea cliffs is an important source of sand to the beaches (50%) in the Oceanside Littoral Cell. This hypothesis is in marked contrast to the established paradigm that rivers supply the majority of sand (up to 85%) to the beaches in the Oceanside Littoral Cell and the cliffs are an unimportant source of sand.

Project Goals and Objectives
The overarching goal of the proposed work was to develop quantitative methods to document the amount of cliff erosion and assess its contribution to the beach sand budget.

Briefly describe project methodology
High resolution, ground-based 3D laser scanning (using LIDAR) was employed to quantify accurately the changes in bluff and beach volumes through time in the study area. The LIDAR models together with sediment grain size analysis of the failures will define the volume of sand liberated by cliff erosion that remains on the beach (e.g., cut-off diameter for retention). High precision elevation mapping and concomitant photographic surveys were combined with these techniques. Using 3D visualization resources available at CALIT2 to link these datasets together allowed us to gain additional insights into the operative processes.

Describe progress and accomplishments toward meeting goals and objectives
To date, we have acquired continuous scans between La Jolla and Encinitas over a three-year period to establish a baseline from which future change can be assessed. One of the main objectives

of the previous proposal was to establish this baseline, develop a surveying approach, and accurately co-registering adjacent scans to minimize the RMS errors in the data. We have continuous seasonal scans for Encinitas, Solana Beach, Del Mar, Torrey Pines, Blacks Beach and Scripps Beach along with repeat surveys to examine style and volume of cliff failures as well as define the rate at which failures are reworked by wave erosion. In addition, we have developed new survey approaches and algorithms for aligning LIDAR scans to minimize uncertainty for sea cliff erosion studies. We have pioneered these new approaches that increase the resolution and reliability of such surveys, which allows quantitative mapping of cliff failures with centimeter accuracy in all azimuths. We also acquired grain size data from the failures to determine what percentage of the failure may remain on the beach. In addition, we collected grain size data for the formations exposed in the cliffs to establish a regional database.

Project modifications
The largest problem encountered was surveying in a dynamic environment that is the beach, where gaining access was difficult and changing as a result of tides and ongoing erosion.

Project outcomes
We are just starting to gain insights from our intensive surveying efforts and have also developed robust surveying approach and alignment software to minimize the uncertainty in LIDAR surveys. The new software and experimental design are open source and can be downloaded by the public. By quantitative mapping of sea cliff erosion as well as measuring the grain size of the failures, we are able to examine the style of cliff failure (subaerial triggers or wave notching) and compare it to wave climate (CDIP) and precipitation in the region. Systematic mapping of the sea cliffs and calculated rates of erosion are critical to understand the importance of the sea cliffs as a sediment source to the beach. Preliminary analysis of the data reveals that sea cliffs represent a much more important sediment source to the beaches than previously thought. The sediment samples acquired from the sea cliffs and the beach are stored in the Scripps Core Repository and the data tables are publicly available and are being used by other researchers at Scripps.

Impacts of project
Coordination is already taking place with local governmental agencies. We have working relationships with the Cities of Encinitas and Del Mar, and the Town of Solana Beach. All three municipalities have readily committed their Lifeguards to work with our team on ground-based LIDAR, and have been doing so for

three years. We have a similar offer of assistance from the Lifeguards in the City of San Diego. We have also collaborated with the town of Solana Beach on a Public Service Announcement for television on bluff erosion. We have interacted with San Diego Association of Governments (SANDAG) and informed them of our ongoing efforts and results (e.g., Shelby Tucker, stu@sandag.org; Rob, Rundle, rru@sandag.org). SANDAG is the San Diego areas' regional planning entity, and plays a key role in the implementation of beach sand replenishment projects.

Benefits, commercialization and application of project results
Beaches in San Diego County are an important natural resource. Economic studies reveal that beach related tourism and associated services contribute more than $200 million a year to the local economy. However, there is growing concern that this resource is at risk. The damming of local rivers, urbanization, and armoring of the bluffs are reducing the natural sand supply to the beach. This reduction in sand supply, along with the documented seal-level rise (2-3 mm/yr), is forcing local municipalities to carry out beach sand nourishment projects at the cost of $10's millions. At the same time, our understanding of the beach sand budget and the relative importance of the different sources are changing. Ongoing research suggests that bluff erosion currently contributes more to the beach sand supply than previously thought. Our research is providing an improved framework for the region as we try to understand the relationship between bluff erosion and beach sand supply in the Oceanside Littoral Cell.

Issue-based forecast capabilities to predict the impacts of a single ecosystem stressor, developed and used for management (i.e., climate change, extreme natural events, pollution, invasive species, and land resource use).

It is extremely difficult to predict how cliff erosion will respond to the documented seal-level rise and predicted increased storminess associated with global warming. Nevertheless, it is quite clear we require a baseline from which future change in erosion rates can be assessed. Our LIDAR surveys yield a quantitative snapshot of the sea cliffs together with the repeat surveys allows us to understand how erosion rates and distribution change through time. Such observations are critical inputs and constraints for any modeling effort of sea cliff erosion.

Tools, technologies and information services developed.
We have generated quantitative maps of the sea cliffs in the southern Oceanside Littoral cell. In addition, we have repeat surveys of large regions documenting how failures are reworked by wave erosion. We have also developed new software and survey designs to improve alignment of adjacent scans.

Publications
Technical reports
Title: Rapid Response to Seacliff Erosion in San Diego County using Terrestrial LIDAR
ASCE Solution to Coastal Disasters Conference, Oahu, Hawaii
Authors: Michael J. Olsen, Liz Johnstone, Adam Young, Tung Ju Hsieh, Scott Ashford, Neal Driscoll, and Falko Kuester
Date: 2008

Title: VR-Based Visual Analytics of LIDAR Data for Cliff Erosion Assessment Proceedings of the 2007 ACM Symposium on Virtual Reality Software and Technology p. 249-250.
Authors: Tung-Ju Hsieh, Michael J. Olsen, Elizabeth Johnstone, Adam P. Young, Neal Driscoll, Scott A. Ashford, Falko Kuester
Date: 2007

Conference papers, proceedings, symposia
Title: Rapid Response to Seacliff Erosion in San Diego County using Terrestrial LIDAR
Authors: Michael J. Olsen, Elizabeth Johnstone, Neal Driscoll, Scott A. Ashford, and Falko Kuester
Date: April 13-16, 2008
Conference Title: ASCE Solution to Coastal Disasters Conference,
Location: Oahu, Hawaii

Title: VR-Based Visual Analytics of LIDAR Data for Cliff Erosion Assessment
Authors: Michael J. Olsen, Elizabeth Johnstone, Falko Kuester, Scott A. Ashford, and Neal Driscoll
Date: Nov 5-7, 2007
Conference Title: ACM Symposium on Virtual Reality Software and Technology
Location: Newport Beach, CA

Title: Georeferencing LIDAR scans for high resolution coastal mapping and quantifying uncertainty
Authors: Michael J. Olsen, Elizabeth Johnstone, Falko Kuester, Scott A. Ashford, and Neal Driscoll
Date: Oct 23-25, 2007
Conference Title: H20 Headwaters to Oceans Conference
Location: Long Beach, CA

Peer-reviewed journal articles or book chapters
Title: New terrestrial LIDAR survey methods for quantitative seacliff erosion analysis in San Diego County
Authors: Michael J. Olsen, Elizabeth Johnstone, Neal Driscoll, Scott A. Ashford, and Falko Kuester,
Date: accepted - 2008
Journal Name: ASCE Journal of Computing in Civil Engineering

Title: Automated regional terrestrial LIDAR point cloud alignment to map topography in dynamic environments
Authors: Michael J. Olsen, Elizabeth Johnstone, Falko Kuester, Scott A. Ashford, and Neal Driscoll
Date: in review - 2008
Journal Name: ASCE Journal of Computing in Civil Engineering

Media coverage
Name of publication/radio station, etc:
Channel 8 News City: San Diego State: CA
Date of publication/broadcast: Fall 2008
Headline or topic: Source of beach sands and cliff failure

Name of publication/radio station, etc: *Union-Tribune* City: San Diego State: CA
Date of publication/broadcast: Spring 2007
Headline or topic: Source of beach sands called into question

Workshops and presentations
Unified San Diego Unified School District - High School Earth Science Teachers Workshop at Scripps
Date: August, 2007

Dissemination of results
Meetings with the San Diego Association of Governments (SANDAG) - Spring 2008
Meetings with consultants working for SANDAG - Summer 2008

Cooperating organizations
Academic Institutions
Scripps Institution of Oceanography; Jacob's School of Engineering

Awards
Driscoll - National Science Foundations MARGINS Distinguished Lecturer 2006

Keywords
Bluff erosion, source of beach sand, LIDAR