Beyond Bathtub:

Modeling and Responding to Sea-Level Rise and Shoreline Change

Workshop Summary Report

Photos Courtesy of California King Tides Initiative

Hosted at Southern California Coastal Water Research Project, Costa Mesa, CA
December 19, 2012

"All models are wrong, but some are useful"

George Box, 1979

Workshop Agenda

Morning Session

10:00 - 10:05 Welcome

- Mary Small, *California Coastal Conservancy*

10:05 - 10:30 Overview on the National Research Council Report Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present, and Future

- Dr. Gary Griggs, *University of California, Santa Cruz*

10:30 - 1:00 Models and Applications to Address Shoreline Change Impacts: Case Studies

- Lily Verdone, *The Nature Conservancy* & Dr. David Revell, *ESA PWA*
- Marina Psaros, *Coravai* & Dr. Patrick Barnard, *U. S. Geological Survey*
- Patrick McCay, *Naval Facilities Engineering Command;* Dr. Reinhard Flick, *Scripps Institution of Oceanography* & Russ Boudreau, *Moffatt and Nichol*

Afternoon Session

1:00 - 2:00 Lunch and Tools Demonstration

- Sea Level Rise Viewer – Becky Lunde, *NOAA Coastal Services Center*
- Our Coast Our Future – Dr. Patrick Barnard, *U. S. Geological Survey*; Marina Psaros, *Coravai* & Kelley Higgason, *Gulf of the Farallones National Marine Sanctuary*
- Coastal Resilience Tool – Lily Verdone, *The Nature Conservancy*

2:00 - 3:30 Holy Grail: Breakout groups with scientists, planners, and managers to guide future model outputs and science efforts

3:30 - 4:15 Sea-Level Rise Guidance Resources

- Lesley Ewing, *California Coastal Commission*
- Tom Kendall, *U. S. Army Corps of Engineers*
- Sarah Flores, *Ocean Protection Council*

4:15 - 4:30 Wrap Up & Next Steps

Presentations available online at the workshop website.

SETTING THE STAGE

Coastal managers in California are faced with the challenge of protecting coastal environments and resources from the impacts of climate change. Shoreline change - resulting from the confluence of sea-level rise (SLR), coastal erosion, storm surge, El Niño, flooding, and inundation - threatens coastal communities, infrastructure, and natural habitats. As more models and tools have become available to aid in the development of vulnerability assessments and adaptation strategies, a need was articulated among coastal managers to better understand the following topics:

CA King Tides Initiative: South Imperial Beach (Tijuana River National Estuarine Research Reserve)

1. The range of impacts associated with shoreline change;
2. How modeling goes "beyond bathtub" by considering the *dynamic* impacts of shoreline change;
3. The purpose and capabilities of existing models and tools that address shoreline change (e.g. some address storm activity impacts at short-time scales, some address long-term erosion impacts); and
4. The data and types of information required to run the models.

In order to develop a better understanding of the above topics, this workshop convened a variety of speakers to help bridge the gap between coastal managers and modelers. Dr. Gary Griggs, scientist and co-author of the National Research Council's report on sea-level rise[1], set the stage by explaining the latest science behind SLR projections. The workshop provided a forum for three pairs of scientist/manager teams to present on three ongoing California-based case studies to illustrate available model approaches and applications. Finally, three resource managers described state and federal guidance on sea-level rise.

In addition to plenary presentations, attendees were given tools demonstrations, introducing coastal managers to the National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center's Sea Level Rise Viewer, the Our Coast Our Future project, and The Nature Conservancy's (TNC) Coastal Resilience Tool. Following the tools demonstration, breakout sessions provided opportunities for scientists and managers to discuss barriers in moving forward. Scientists heard from managers about management needs and tool utility - the "holy grail" of desired modeling - to inform future research and modeling efforts. Likewise, managers heard from scientists about the state-of-the science and application constraints. This workshop served as a venue for this bi-directional information transfer to occur and was sponsored by CA Ocean Protection Council, Tijuana River National Estuarine Research Reserve's Coastal Training Program, USC Sea Grant, and the West Coast Governor's Alliance on Ocean Health.

[1] Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future (2012).

CONTENTS

GLOSSARY

BAECCC Bay Area Ecosystems Climate Change Consortium
BUD Basic Underwater Demolition
CoSMoS Coastal Storm Modeling System
CO-CAT Coastal and Ocean Resources Working Group for the Climate Action Team
CZMA Coastal Zone Management Act
DEM Digital Elevation Model
ENSO El Niño - Southern Oscillation
GCM Global Circulation Model
GHG Greenhouse Gasses
IPCC Intergovernmental Panel on Climate Change
LiDAR Light Detection and Ranging
LCP Local Coastal Plans
MSLR Mean Sea-Level Rise
NOAA National Oceanic and Atmospheric Administration
NRC National Research Council
OCOF Our Coast, Our Future
PDO Pacific Decadal Oscillation
SLR Sea-Level Rise
SPAWAR Space and Naval Warfare
TNC The Nature Conservancy
TWL Total Water Level
USACE U.S. Army Corps of Engineers
USGS U.S. Geological Survey

FIGURES

SUMMARY OF THE NATIONAL RESEARCH COUNCIL REPORT ON SEA-LEVEL RISE FOR CALIFORNIA, OREGON, AND WASHINGTON: PAST, PRESENT, AND FUTURE

Dr. Gary Griggs, *University of California, Santa Cruz*

The workshop commenced with an overview of the National Research Council (NRC) study entitled *Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present and Future*.

Several major findings from the NRC study were highlighted, including:

- Average sea-level rise projections for California: 6 inches by 2030; 12 inches by 2050; and 36 inches by 2100;
- Sea-level rise will cause waves and run-up to reach higher elevations and extend farther inland;
- To prepare for the immediate future, planners and officials should look at impacts of past El Niños (e.g. 1982-83 and 1997-98) and other major storms; and
- Coastal erosion, and flooding and inundation will increase in magnitude and duration over the 21st century, increasing exposure of development and natural features to impacts of waves and high water.

Temporal Differences in Sea-Level Rise

When talking about sea-level rise, it is important to note that sea-levels can change at different scales of time and at different rates. Examples of quick and high rates of change include tsunamis that can raise sea-levels by 50 feet or more over minutes, tides that can raise levels between 5-45 feet over hours, and storm surges that can raise sea-levels 5-25 feet over the course of hours.

Slower, longer-term rates of change include El Niño type events that can raise sea-levels by 1-2 feet over months. Ice melt and thermal expansion (what people generally refer to when speaking of "sea-level rise") can lead to millimeter rises per year that equal hundreds of feet over thousands of years. Similarly, plate tectonics and volumes of ocean basins can change by hundreds of feet over millions of years.

Examining sea-level rise on a glacial/interglacial geologic time scale reveals that sea-levels were lowest ~22,000 years ago and rose at about 1.5 meter/century for ~8,000 years. Compared to this rise, sea-levels have been fairly constant for the last 4,000 years. However, there has been a global acceleration in SLR since the mid-1800s. It is estimated that sea-level rise between 1870 to early 1990s was about 1.70 millimeter/year compared to estimates of 3.17 millimeter/year between early 1990s to present day. Therefore, while sea-level rise is not new, the current rate we are experiencing is.

Several methods have been used to estimate sea-level rise over the years. Between 1800-1900, estimates relied on geological measurements (e.g. examination of tree rings or ice cores). Since 1900 to current day, estimates have relied on tide gauge data and more recently satellite altimetry. Projections into the future are based on models.

Geographic Differences in Sea-Level Rise
Global differences are based on volumes of water in the oceans (i.e. how much is in the ocean vs. how much is trapped in ice sheets and glaciers). These changes are driven primarily by global temperature.

Sea-level rise variations can differ dramatically, at the regional or local level. This is due to differences in plate tectonics causing subsidence or uplift, land subsidence due to fluid withdrawal (e.g. petroleum or water extraction), atmospheric circulation patterns (e.g. El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO)), and storm surges affecting ocean levels over days to months.

Based on the NRC report, ice melting is a dominant factor of sea-level rise, constituting 2/3 of SLR, while density changes account for another third. However, local subsidence and tectonic activity is important to consider as well.

Generally, rates of SLR in Southern California are uniform. Based on local tide gauge data, San Diego and Orange County are experiencing about 2 mm/yr, while Los Angeles is experiencing about 1mm/yr.

Methods for Making Future Projections
Climate models from the 2007 Intergovernmental Panel on Climate Change (IPCC) report are based on what we know about physical processes with different models using different greenhouse gas (GHG) emission assumptions. Unfortunately, these projections underestimate land ice contribution.

Semi-empirical methods used by Vermeer & Rahmstorf (2009), rather than looking at every individual component, demonstrate empirical relationships between global temperatures and global sea-level in the past. These models can reproduce past SLR well, but not changes in ice behavior.

The National Research Council's report (2012) used both approaches previously described resulting in a method that considers climate models and extrapolations of observed trends in ice loss rates (i.e. accounts for rapid changes in ice sheets and glaciers-ice dynamics).

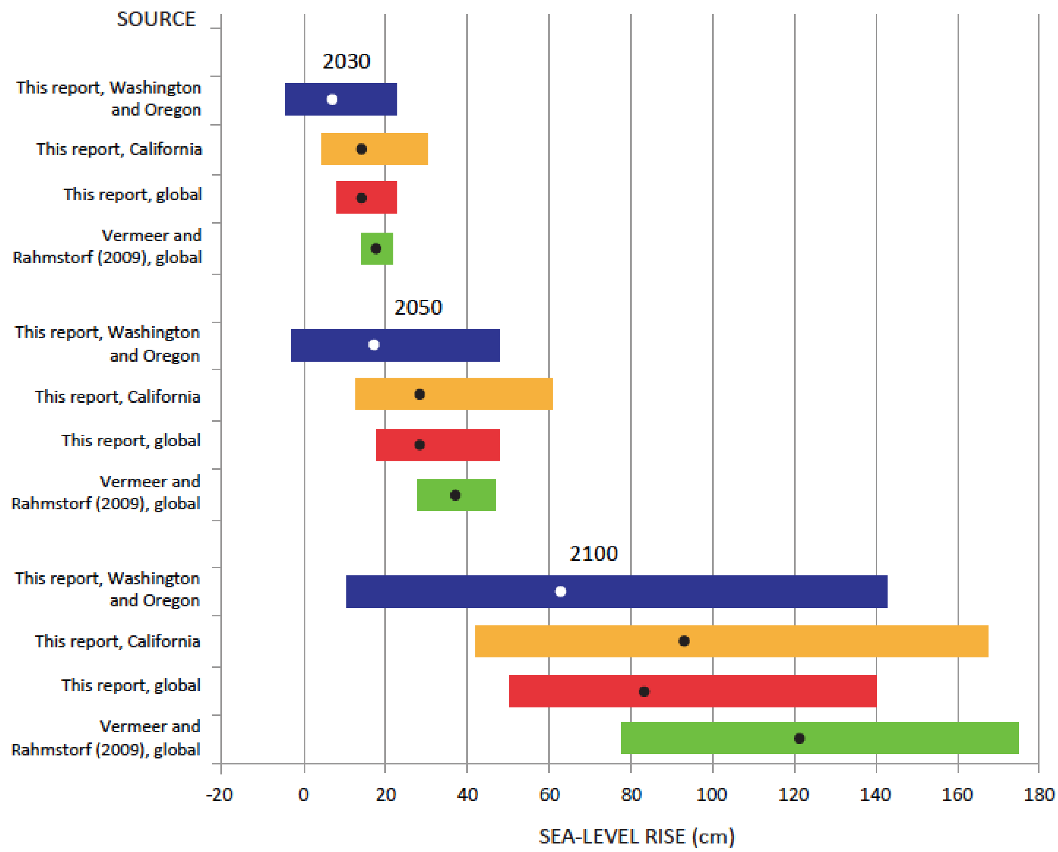


Figure 1: Summary of predicted sea-level rise rates.
(Table adapted from the NRC report (2012) - referred to as "this report" in figure.)

There is high confidence in projections for 2030, but by 2100, it can only be expected that the rate of SLR will fall within uncertainty bounds. Uncertainty in model results is largely based on how much effort is put towards reducing GHG emissions.

Changes in Storm Climate and Catastrophic Coastal Storms

Most historic coastal damage has been caused by the confluence of large waves, storm surges, and high tides during a strong El Niño. Sea-levels during a strong El Niño event can be up to 1 foot higher for several months. Such an event in 1982-83 caused more than $200 million in damage to California. Water-levels during these events can exceed sea-level rise projections for 2030 and possibly 2050. Their additive effects will become more significant as sea-level rises.

The components that contribute to a change in sea-level include ocean warming (thermal expansion of water and ice-melt); multi-decadal circulation shifts (PDO); circulation shifts occurring on shorter timescales (ENSO, $\leq$10 years); and extreme storm events and wave run-up (episodic events in the order of hours and days).

Naturally occurring King Tides (highest spring tides[2]) also contribute to an episodic rise in sea-level. In California, many flood events causing damage to communities have occurred as a result of King Tide events at current sea-level, highlighting the potential damage to coastal communities resulting from a few inches of sea-level rise.

Over the next decades, the confluence of ENSO events, high tides, and storm surge events will become very important, particularly when considering the impacts SLR will have on low-lying communities.

MODELS AND APPLICATIONS TO ADDRESS SHORELINE CHANGE IMPACTS: CASE STUDIES

A number of communities along the coast are beginning to model the impacts of sea-level rise and shoreline change to start to identify location appropriate adaptation strategies. In the morning session, three case studies were presented by managers and scientists who discussed the methodologies utilized in their efforts. Below is a brief overview of these case studies, focusing on the application of the models. A summary table of model inputs, outputs, assumptions, uncertainties, advantages, constraints, and applications are provided in Appendix A.

Case Study #1: **Coastal Resilience Ventura**
Manager: Lily Verdone, *The Nature Conservancy*
Scientist: Dr. Dave Revell, *ESA PWA*

Overview

TNC's Coastal Resilience Ventura project has three major components:

1. Development of the TNC Coastal Resilience Ventura Visualization Tool
2. Identification of key planning and policy decisions
3. Identification of economic benefits of natural solutions

1. TNC's Coastal Resilience Ventura Visualization Tool

In 2006, TNC created a decision-support tool called Coastal Resilience for New York and Connecticut. It used downscaled sea-level rise projections to create interactive web maps that also contained features of the landscape that were relevant to decision-making - habitat features (e.g. wetlands, protected areas), critical infrastructure (e.g. hospitals, water treatment plants), and socially vulnerable communities with little resources to mitigate the impacts of climate change. The Coastal Resilience tool allows managers to pick the SLR scenario and includes some modeled storm inundation projections.

[2] **Spring tide:** a tide of greater-than-average range around the times of new moon and full moon (Merriam-Webster).

Since 2006, this tool has been expanded to other regions across the country, including Ventura. TNC has been working in Ventura since 1999 and has developed diverse partnerships with local, state, and federal agencies as well as farmers, developers, and local organizations. The development of the Coastal Resilience Tool for Ventura was driven by these local stakeholders and decision-makers. The partners in this stakeholder-driven approach helped:

- Choose relevant management contexts;
- Determine variables in decision-making;
- Incorporate the impact of coastal change on variables;
- Create indices reflecting variables, both now and under future conditions; and
- Test indices with specific decision-makers and within specific decisions.

The goal of this tool is to advance social, economic, and environmental solutions to climate change and coastal hazards. This is done by maping risk, identifying vulnerable communities and stakeholder-identified assets, and demonstrating benefits to important natural resources.

2. Identification of key planning and policy decisions

TNC partnered with a planning center to interview local decision-makers and a steering committee. Results from these interviews indicated that sea-level rise fits mostly in five local decision-making contexts:

1. General Plans
2. Local Coastal Plans
3. Zoning regulations
4. Use of sand dune and wetland habitats as barriers and buffer zones
5. Innovative and cost effective tools to manage retreat

3. Identification of economic benefits of natural solutions

TNC is interested in economic analysis of nature-based solutions for natural and human community adaptation to climate change impacts. This is achieved through valuing ecological services, which entails assessing the benefits of "green solutions" such as floodplain and coastal wetland protection as well as conducting economic risk assessments for sectors such as agriculture and tourism.

Summary

Coastal Resilience Ventura provides a collaborative, stakeholder-driven approach that identifies multiple benefits for people and nature with the goal of promoting resilient landscapes for the future.

Modeling

The modeling which supports Coastal Resilience Ventura is provided by the consulting group, ESA PWA. Their model took a hybrid approach, utilizing nine sea-level rise scenarios derived from high- and mid-range projections developed by the National Research Council, which was adjusted based on local tide gauge information; as well as a medium SLR scenario from the 2011 U.S. Army Corps of Engineers (USACE) Sea Level Rise Guidance.

They use a total water level (TWL) methodology that incorporates tides, wave climate based on both existing conditions and a 500-year equivalent storm event, flooding based on historic storm events, and fluvial inputs from a 100-year river discharge event. This TWL model then drives a coastal erosion model such that when the TWL exceeds the elevation of a dune or cliff, it causes an erosion response that is based on geology, geomorphology (e.g. slopes, heights), backshore type (e.g. cliff, dune, inlet, armored), historic erosion rates (e.g. short and long-term), coastal armoring, and topography. In terms of outputs, the model provides coastal hazard zones; essentially stepping through time, eroding the coast at 10-year time steps and flooding through hydraulic connectivity to look at the change in flooding risk. Other outputs include coastal wave run-up zones (e.g. momentum impact), coastal flooding due to extreme events, inundation, and river flooding.

The backshore types and geological units are subdivided into 500-meter spacing so actual to scale analysis and calculations are applicable to 500-meter blocks along the coast, which was done to support planning level decisions.

Case Study #2: **Our Coast, Our Future**
Manager: Marina Psaros, *Coravai*
Scientist: Dr. Patrick Barnard, *U.S. Geological Survey*

Overview

The Bay Area already has in place a consortium of natural resource managers, scientists and stakeholders through the Bay Area Ecosystems Climate Change Consortium (BAECCC). Their goal is to collaboratively understand and reduce the negative impacts of climate change on Bay Area ecosystems and communities.

The inception of the Our Coast, Our Future (OCOF) project emerged from the Gulf of Farallones National Marine Sanctuary's need for downscaled sea-level rise and storm scenario information for planning. Because BAECCC was already in place, important stakeholders were able to quickly mobilize to secure funding though the NOAA's Climate Program Office to begin this type of study.

The goal of OCOF is to create a science-based, decision support tool to help understand, visualize, and anticipate coastal climate change impacts to Bay Area communities and ecosystems. Objectives include:

- Model vulnerabilities to SLR & storm hazards;
- Assess user info needs;
- Map vulnerabilities at appropriate scale for management action; and
- Develop web-based user interface to interpret data in the context of management decisions.

There was significant stakeholder input and essential end user feedback in the development of the OCOF decision support tool development. This included scoping workshops, presentations at regional and local meetings, advisory committee, and focus group testing. The primary need identified was that adaptation must be a part of existing work flows, such as: fitting into regulatory requirements, species protection plans, habitat restoration plans, municipal plans, and infrastructure maintenance plans. The benefits to users include increased buy-in from stakeholders through increased transparency, the use of the best available science, and bringing the capacity in-house.

This tool is primarily about the assessment phase and does not address the planning and implementation phases. It was noted that it is important to set the expectation about what this tool (and the technology and science) can do.

Summary

Three keys to success for the OCOF project include:

- Through BAECCC, a pre-existing venue for information-sharing and idea incubation that allowed the group to respond to funding opportunities;
- Sustained focus on end-user context and real world situations that fit into existing workflow and processes of OCOF users; and
- Being explicit about the limits of modeling and technology.

Modeling

OCOF utilizes the Coastal Storm Modeling System (CoSMoS), developed by Dr. Patrick Barnard and colleagues from U.S. Geological Survey (USGS). CoSMoS is a physics-based numerical modeling system for assessing coastal hazards on the West Coast. It predicts coastal hazards for the full range of sea-level rise and storm possibilities using global climate and ocean modeling tools. Through OCOF, results from CoSMoS are being integrated into a coastal vulnerability tool with guidance from federal (e.g., NOAA, National Parks Service), state (e.g., California State Parks), and city governments (City of San Diego, Los Angeles, and San Francisco) to meet their planning and adaptation needs.

The first iteration of CoSMoS (1.0) hindcast a local storm from January 2010 (~10-year storm intensity) plus two sea-level rise scenarios of 0.5 m by 2050 and 1.4 m by 2100 per California state guidelines[3]. Unlike the other approaches described here, this model explicitly models the waves, currents, and water-levels across the entire study area using a process-based modeling approach. Model inputs include elevation data through digital elevation models (DEMs), waves generated from the output of global circulation models (GCMs), wind and atmospheric pressure from GCMs, and various sea-level rise scenarios. CoSMoS 2.0, which is being utilized by OCOF, expands on these scenarios.

Future shoreline change is not incorporated in this current version of CoSMoS, but is slated to be included in future versions.

[3] State of California Sea-Level Rise Interim Guidance Document

***Case Study #3:* Naval Base Coronado**
Manager: Patrick McCay, *Naval Facilities Engineering Command*
Scientist: Dr. Reinhard Flick, *Scripps Institution of Oceanography*

Overview

Naval Base Coronado has many coastal dependent uses, with many distinct Naval operations housed on the island, including a helicopter base and a Navy SEAL training facility, making the infrastructure at this base extremely vulnerable to sea-level rise. The amphibious base - used for training the Navy Seals and the Basic Underwater Demolition (BUDs) team - has facilities directly adjacent to the ocean that need to be managed so there is a wide enough beach to continue supporting all training missions. Also, there are environmental concerns, as the Navy manages bird habitat for threatened and endangered species (e.g. California Least Tern, Western Snowy Plover), as beaches recede and sea-level rises, intertidal nesting habitat can be lost.

In response to the potential implications of sea-level rise, the 2008 National Defense Authorization Act had a section titled Department of Defense Consideration of Effect of Climate Change on Department Facilities, Capabilities, and Missions. This section has three important components:

1. Assess risks of projected climate change to current and future missions of the armed forces;
2. Update defense plans based on these assessments; and
3. Develop capabilities to reduce future impacts.

The Navy's primary mission is to ensure that the Navy SEALs can continue to be successfully trained at Coronado in spite of the impacts of climate change. However, uncertainties around future projections are a concern. In order to overcome this uncertainty the Navy has put together a working group to consider climate change. In addition, according to the Coastal Zone Management Act (CZMA) the Navy has to be consistent with California coastal policy; therefore, the Naval Base Coronado looks to the California Coastal Commission to help address sea-level rise.

The Navy is trying to balance meeting their immediate needs while developing solutions that address their long-term needs over the next 100 years as sea-level rise occurs. There are many potential responses to SLR that are being considered at Coronado:

- Managed retreat is an important option to keep in mind when looking at future and current development. Environmental Impact Statements will help inform the placement of future development while the usage of some of the older outdated facilities needs to be considered (e.g. do we reuse them or demolish them and consider moving back?).
- Beach nourishment is an option that could be used to address the issue of beach erosion. In the future, sea-level rise might lead the Navy to fund projects that specifically look to beneficial reuse while protecting facilities.
- Hardening the shoreline is an option that is being looked at closely for some portions of the base but is often controversial and can affect the mission of

carrying out Naval trainings. The Navy is looking closely at the cost and feasibility of hard stabilization structures.

Summary

In order to continue to carry out its training missions, the Navy began to consider the long-term and short-term impacts of sea level rise and erosion. Moffatt & Nichol is helping the Naval Base Coronado address the immediate threats that are currently jeopardizing facilities directly on the beach while Dr. Ron Flick is helping the Navy look more closely at the long-term impacts of sea-level rise.

Modeling

Naval Base Coronado and Marine Base Camp Pendleton uses a shoreline change model-developed by a team from Scripps Institution of Oceanography, TerraCosta Consulting, and Space and Naval Warfare (SPAWAR) Systems Center Pacific, which seeks to go beyond flood modeling, to model beach change and cliff retreat. It uses total water level (TWL) and wave attack to show beach erosion. In basic terms, as the shoreline moves back due to rising sea-level, the active beach disappears. This leads to a narrowing of the beach, which then results in erosion taking sand out of the cliff to maintain beach width. The rate of shoreline retreat depends on what is eroding. For example, if a tall 20 meter cliff is being eroded, it takes less retreat to produce a lot of sand out of that tall cliff than it does out of a wetland.

To show shoreline change, the model utilizes beach profile data, which is then used to calculate the beach width, cliff and terrace topography, geology (i.e. how much sand is in the cliff being evaluated), historical and projected rainfall, waves, TWL to get the "active beach" profile, and Mean SLR projections (0.5 m, 1.0 m, 1.5 m, 2.0 m).

This model is being applied at Naval Base Coronado (essentially a barrier island) and at Camp Pendleton (a cliff-backed beach) to see how these training facilities are going to be affected with future SLR. The model was run for every 100 meters along the Camp Pendleton and Coronado shoreline to show future beach and cliff profiles.

SEA-LEVEL RISE GUIDANCE RESOURCES

There are a number of SLR guidance resources available to managers and planners, which can help coastal decision-makers determine what future SLR projections to use when running models or planning for specific coastal projects. Below is a summary of three presentations given at the workshop, providing SLR resources for attendees to use when incorporating SLR into their work.

Beyond Climate Change
Lesley Ewing, *California Coastal Commission*

The CA Coastal Commission is working on producing a new sea-level rise guidance document that should be available for public review in the first half of 2013. The Commission will continue to use the best available science to update forthcoming guidance documents, and will continue to consider how new climate and sea-level rise science fits into the context of the Coastal Commission's work.

In terms of climate change recommendations, one size does not fit all. Different projects have different concerns and expectations associated with them. For example, when considering a coastal trail versus a power plant, each of these has different expectations of performance and longevity, meaning the Commission will continue to treat projects on an individual basis.

Different landscapes require different climate change considerations. For beaches, it is important to consider long-term beach changes (e.g. erosion and seasonal beach profile change), as well as water- and wave-level changes (e.g. high tide, sea-level rise, waves from a 100-yr storm). For bluffs, it is important to consider slope stability (plus a factor of safety), the annual erosion rate, and the life for the structure.

New development should be safe from erosion, flooding, or wave impacts over its life-without shoreline protection. It is important to remember that all of the rates for impacts (e.g. erosion, waves) are expected to change with SLR so it will be important to reassess rates with time.

California King Tides Initiative: High Water in Sausalito and It's a Blast! (Photo by Jay McGill)

After reviewing the process by which the Commission reviews and approves submitted Local Coastal Programs (LCPs), it was noted that most of the currently approved LCPs were completed approximately 15 to 20 years ago, and that many of them did not have clear indications of having incorporated SLR and/or climate change impacts. Despite this gap, many LCPs address hazards (such as flooding and erosion) and have language on resource protection, and thus might have the foundation already established to incorporate climate change impacts.

In March of 2013, the Ocean Protection Council authorized to disburse up to $2,500,000 to fund competitive grants to create vulnerability assessments, data collection and updates to Local Coastal Programs to help local governments plan for adaptation to sea-level rise and associated climate change impacts along the open coast of California. This authorization is subject to the conditions: 1) that the Coastal Conservancy shall coordinate with the Coastal Commission on grant criteria, and 2) that each grant shall be submitted for subsequent review and approval by the OPC prior to the final award of each grant.

Overview of the Army Corps of Engineers SLR Scenarios

Tom Kendall, *U.S. Army Corps of Engineers*

Three scenarios of SLR – historic, intermediate, and high – are considered in the U.S. Army Corps of Engineers' (USACE) planning process. The current projections are largely based on the NRC's 1987 publication but the USACE is considering NRC's 2012 report on SLR in future updates.

The rate for the "USACE Intermediate Curve" is computed from a modified version of the old NRC Curve I considering both the most recent IPCC (2007) projections and the local rate of vertical land movement. Likewise, the rate for the "USACE High Curve" is computed from a modified version of the old NRC Curve III considering both the most recent IPCC (2007) projections and the local rate of vertical land movement. The USACE's sea-level change scenario curves can be found here. Current guidance does not assign a probability to each curve, but rather provides the framework for scenario-based analyses.

CA King Tides Initiative: Humboldt. (Photo by "jlegge" on Flickr, 2012)

Data by Steve Gill (NOAA) highlights that the maximum projection from a number of studies conducted between 1987 and 2012 suggests a reasonable upper limit of eustatic rise to be 2 meters or less by 2100, making the point that the USACE's scenarios well bracket most existing projections. After discussing the USACE's strategy, considerations for understanding the consequences of "wrong" assumptions were highlighted, along with a stakeholders "comfort with risk" Stakeholders must assess their level of comfort with the selected project alternative under a variety of future scenarios. Assessments need to be made by thinking in terms of the lifecycle of a project. The "best" plan is often the one that works well in many scenarios, and this can be judged through the use of tools like a Least Regrets Analysis.

The State of California's Actions to Support Climate Change Readiness

Sarah Flores, *Ocean Protection Council*

California's Coastal and Ocean Resources Working Group for the Climate Action Team (CO-CAT) is a group comprised of 16 state agencies that have jurisdiction over coastal and ocean matters for the state of California. In 2010, CO-CAT developed the Sea-Level Rise Interim Guidance Document that presents a range of recommended SLR rates to use based on the best available science. This was called an "interim" guidance document because it was meant to act as a placeholder until the National Research Council released its report on SLR for the West Coast (2012). An update to this document is underway that will incorporate the SLR projections presented in this NRC report. The document will continue to make the recommendations that are currently outlined, but will emphasize the importance of considering storm impacts (e.g. flooding, erosion) for short-term planning (e.g. 10-40 years), per the findings of the NRC report. The updated Sea-Level Rise Guidance Document was released in March of 2013.

CO-CAT is also working on the Coastal and Ocean Chapter of the Climate Readiness Strategy, 2013 (formerly known as the 2009 California Climate Adaptation Strategy), and that the goal of this document is to coordinate agency policies and frame them under the state priorities. The public version will be available for comment.

Three state resources that are available and forthcoming include the CA Climate Change Adaptation Planning Guide (released mid 2012), which is meant to be a resource for local communities undertaking adaptation; the State Hazard Mitigation Plan update (lead by CalEMA, in progress); and the General Plan Guidance update (lead by the Governor's Office of Planning and Research, in progress).

BREAKOUT SESSIONS: "HOLY GRAIL"

During the morning session, presentations of shoreline change modeling helped attendees gain a better understanding of the constraints of current models and the potential for future model development. Building on this new understanding the "holy grail" session involved breaking out into four separate and diverse groups that were each represented by modelers, city planners, and natural resource managers to discuss what model users need from future models. In this format, modelers got feedback to help steer the future development of models based on the needs identified during the discussion. The two questions that guided the discussions were as follows:

1. What do you need models to consider so you can do your job better?

2. Modelers want guidance to inform the future direction of modeling…What do you want them to know?

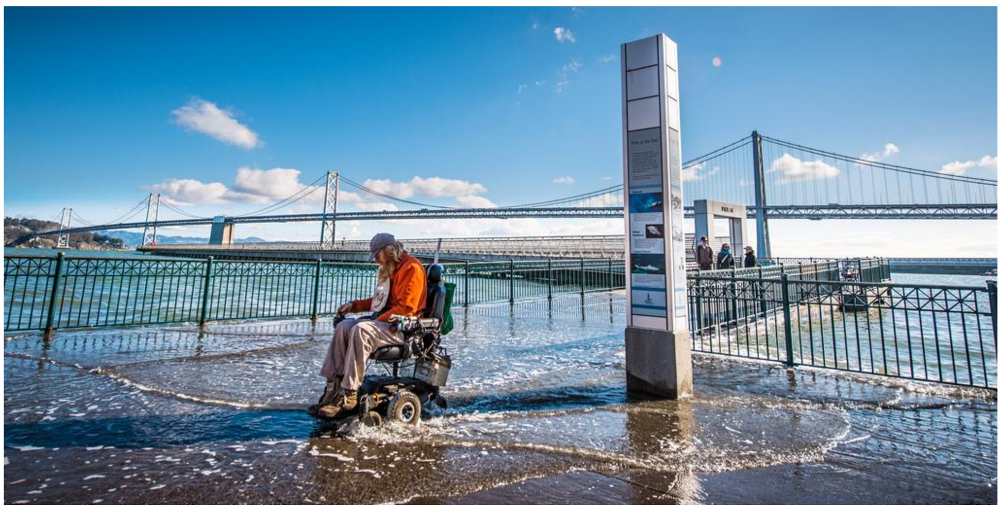
Discussion Findings

Outlined below are suggestions made by planners/managers (users) as to what they would like to see future SLR models incorporate:

1. **Sediment:** Users expressed a need for models to incorporate more detailed sediment budgets, focusing on accretion and erosion rates, and long-shore currents and upstream transportation. During this discussion, model users said that they would like to better understand how important non-linear changes in sediment budgets are when planning for sea-level rise. For instance, is it more important to consider the long-term movement of sediment when managing a particular section of shore or are short-term trends equally as important? In addition, managers/ planners would like to gain a better understanding of trapped sediment behind structures such as dams. If a dam was removed or added, what kinds of impacts would such an action have on regional sediment budgets?
2. **Hydrologic Processes**: There was also an expressed need for modelers to incorporate hydrological processes into sea-level rise models, including fluvial discharge and channel erosion rates. There was great interest in understanding how rivers are going to interact with the rising seas and how upstream hydrologic processes will interact in areas that are projected to be inundated and/or flooded.
3. **Flooding:** Users would like future models to provide a more detailed understanding about how areas will be flooded including extent, depth, risk, and the expected length of flooding during storm events.
4. **Temporal & Spatial Downscaling:** Users would like to see models that provide more fine scale projections and explore sub-decadal timeframes. In addition, planners are hoping to obtain more regionally specific models that focus on a local community's specific needs.
5. **Wetlands:** Users are hoping that future models will consider the impacts of sea-level rise on wetlands more specifically. How effective are wetlands and open spaces at dissipating waves? How does sediment move through wetlands affecting the survivability of surrounding habitats (e.g. elevating land, beach width)? This information can be beneficial to those directly involved in wetland restoration and adjacent coastal communities.
6. **Historical Examples:** Users would like to have models incorporate historical examples into visual maps to represent extreme flooding in the past, and contrast considering implications of SLR.
7. **Real-Time Capability:** City planners have expressed an interest in having maps that have real-time capability to aid in emergency response efforts. If we know a storm is coming, a model that can help project the areas of a community that are at high risk can inform how emergency management agencies delegate their resources, such as sandbag placement and evacuation efforts.
8. **Economics:** Users would also like models to incorporate an economic component considering the financial impact of sea-level rise, including cost of

lost infrastructure, businesses, and habitats. Taking this concept a step further, it would be useful for managers to be able to incorporate specific management actions into a model, weighing the cost of the management decisions or future development against what consequences might be averted by such a decision. For example, users would like to have a model that allows them to visualize the economic impact of putting up a sea wall versus no sea wall, to determine if this specific management action is worth the initial investment and maintenance costs.

9. **Risk:** There is a need for models to provide more insight into the probability of risk. Some users suggested that models provide a visualization of low, medium, and high risk regions of communities. This would help planners to better allocate their resources for areas that are most likely to be affected by SLR.



California King Tides Initiative: San Francisco Bay. (Photo by Mike Filippoff)

10. **Various Management Options:** Users need models to allow them to compare different management decisions. For example, users want to be able to visualize the extent of flooding with a seawall versus no seawall, or different flooding scenarios based on beach width.

Finally, users would like a state guidance document that supports their work – describing best uses for existing models, how to best access these models, and how to finance them.

Below are suggestions made by modelers to planners/managers (users) on what types of data they need in order to improve future models:

1. **Extreme Events or Tides:** Modelers need planners and managers to groundtruth flooding extent during major storm events or extraordinarily high tides. For instance, when an area is flooded it would be useful for public works employees to collect geospatial data as to how far the flooding reached inland. It would be tremendously helpful if local governments could train employees in their public works departments to conduct such groundtruthing exercises. Attendees also thought that there is great potential to tie the California King Tides Initiative into

this work, starting a citizen science initiative in which the public collects GPS data on how far a king tide reaches inland.

2. **Hard Structures:** There is also the need to engage the public or city employees in collecting data on the location of hard structures along the shorelines (e.g. sea walls, piers, jetties). Modelers need a clearer picture of where hard structures are and how far they extend along the shoreline and into the sea.
3. **Historical Data:** Finally, modelers would like to have access to historical flooding extent data. This information will help modelers gain a better understanding of how specific storms in the past caused flooding, and how long that flooding persisted.

FUTURE DIRECTION

As scientific models are refined, this workshop can serve as a model for conducting outreach with managers and planners that are the end users of this information. This type of workshop offers a venue for coastal managers and planners to communicate with sea-level rise modelers, increasing the understanding about what current models are capable of, and how both users and modelers can improve the future of SLR modeling. The case studies are critical for offering examples of how collaboration between managers and scientists can help local communities effectively prepare for future sea-level rise. It is important that bidirectional communication between modelers and model users continues beyond this workshop, in order to ensure that managers are aware of what models are available, and that modelers can develop tools that meet the needs of coastal decision-makers.

Appendix A: Summary of Models Presented

	Case Study #1: **Coastal Resilience Ventura**	**Case Study #2:** **Our Coast, Our Future (CoSMoS)**	**Case Study #3:** **Naval Base Coronado**
Model Inputs	Physical forcings: • Offshore wave/ climate “scenarios • Transformed nearshore waves • Tides • TWLs	Elevation data (DEM)	Beach profile & width data (calibration): • Beach width calculated from profiles
	Backshore characterization (based on using coastal forcing mechanisms and intersect it with the coast): • Geology • Geomorphology (slopes, heights) • Backshore type (cliff, dune, armored) • Historic erosion rates • Coastal armoring • Topography	Waves (from GCMs)	Cliff & terrace topography, geology, rainfall: • Semi-annual LiDAR over-flights (2001-2009) • Rainfall data (2001-2009) and contribution of rain to cliff erosion • Rainfall projections (downscaled 2000-2100)
	Sea-level rise scenarios	Wind and Atmospheric Pressure (from GCMs)	Waves-local energy, run-up & closure depth: • Hourly hindcast (1979-2009, calibration) • WW-III projections (2000-2099)
		Sea-level rise scenarios	TWL Statistics-“active beach” profile: • Tide • Non-tide residual • Wave-driven run-up
			Mean sea-level rise (MSLR) projection scenarios: • 2000-2100 (0.5, 1.0, 1.5, 2.0 m by 2100)

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	Case Study #1: **Coastal Resilience Ventura**	**Case Study #2:** **Our Coast, Our Future (CoSMoS)**	**Case Study #3:** **Naval Base Coronado**
Model Outputs	Erosion hazard zones (integrated with coastal flooding)	Flooding depth, extent and uncertainty	
	Coastal wave run-up hazard zone ("knock you off your feet" waves)	Waves	
	Coastal flooding	Currents	
	Coastal inundation	Shoreline and profile change (based on event)	
	River flooding	Cliff failures	
Model Assumptions	Equilibrium shoreline profile response	GCMs provide the best representation of future wave climate	Beach profile and width model: • Uses Bruun Rule, which assumes the beach profile is maintained; there is upward & landward translation with MSLR, and offshore profile extent is dependent on sand movement from erosion • No hard-rock terrace • No account for structures
	TWL exceedance of toe elevation	DEM is adequate representation of future beach and nearshore elevation and slope (i.e., morphology)	Cliff & terrace model: • Driven by TWL • Slope similarity is maintained
	Relationship between toe elevation and TWL will remain constant in the future	No management action	
	Historic erosion rates indirectly accounts for sediment budget (where you have little sediment, high erosion rates and vice versa)		
	Coastal erosion is driven by marine processes		
	Cliff armoring will eventually be abandoned		

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	Case Study #1: Coastal Resilience Ventura	Case Study #2: Our Coast, Our Future (CoSMoS)	Case Study #3: Naval Base Coronado
Model Uncertainties	Input data sets: • Topographic • Scenarios	DEM is only as good as the elevation data behind it (~ +/- 18 cm): • Model processes and local-scale results limited to resolution and accuracy	Bruun Rule overestimates MSLR erosion (beach width & profile model)
	Address uncertainty: • Sensitivity analysis of inputs • Spatial aggregation approach (e.g. one area is always hazardous, one is sometimes, one is rarely)	Modeling TWLs	Bruun Rule overestimates wave erosion (beach width & profile model)
		Projected forcing (i.e., storm conditions): • Are GCMs giving accurate prediction of future storm conditions	Erodibility limit of cliffs (cliff & terrace model)
		What are the odds of joint occurrence of SLR, storm and spring tide, and even fluvial flooding	
Model Advantages	Geared towards planners (planning scale decisions)	Ideal for planning for full range of potential current and future coastal impacts	
	Includes geology, backshore type	Publicly available data and access to support	
	Scenario approach (waves, SLR)	Active scientific development	
	Integrates erosion and flooding through time		
	Modular so you can update accordingly		
	Not dependent on time series (can pick an elevation)		
	Consistent with FEMA guidance		
	Can address wave overtopping of structures and wave momentum		
	Can include land motion (subsidence)		

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	Case Study #1: Coastal Resilience Ventura	Case Study #2: Our Coast, Our Future (CoSMoS)	Case Study #3: Naval Base Coronado
Model Constraints	Considers potential erosion not actual erosion (project vs. predict)	Does not predict future beach morphology changes (but USGS is actively working on this)	
	No direct sediment budget element (being developed)		
	No accounting of beach width (being developed)		
	No robust statistical analysis of all uncertainties		
Model Applications	Designed to support local decision-making efforts: • Pacific Institute 2009 (used by City of Santa Barbara and City of Capitola for General Plan updates) • Coastal Resilience Ventura (City of Oxnard/County of Ventura interested in using these models to update LCPs; Ventura County will do analysis for its County General Plan) • Monterey Bay (Natural Capital project)	Climate impacts assessments	Beach profile & width model: • Basis for adaptation strategies • Training or recreation area loss projections • Run-up & flooding projections • Facilities vulnerability (undermining) projections • Economic loss estimates • Nourishment cost estimates
		Coastal impacts for range of possible current and future conditions (SLR and storms), ideal for infrastructure and ecosystem vulnerability	Cliff & terrace model: • Basis for adaptation strategies • Training or recreation area loss projections • Facilities or development area loss projections • Facilities vulnerability (undermining) projections • Protection cost estimates
		Web-based coastal planning user-interface	