BUILDING COASTAL RESILIENCE IN THE FACE OF CLIMATE CHANGE

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TAKE ACTION TODAY TO SAVE THE COAST TOMORROW

Coastal managers know that sea level rise is impacting coastal communities now, and its impacts are predicted to become more severe in the coming decades. Coastal managers and policy makers need to take immediate action to protect their communities and natural resources along the California coastline.

California has been a leader in building coastal resilience concepts into land use planning and other policy arenas. The Nature Conservancy's Coastal Resilience Network Project was initiated to capture and share lessons learned by communities that have already undertaken local and regional initiatives to address sea level rise up and down California's coast. This document reviews these lessons and outlines the steps that successful initiatives have taken to develop local adaptation plans. The information here was gathered by Nature Conservancy staff through consultation with a vast network of adaptation and planning practitioners throughout California.

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Monterey Bay coastline

Projects that participated in the review are:

Humboldt County: Humboldt Bay Sea Level Rise Adaptation Planning Project;

San Francisco Bay & Outer Coast: Our Coast Our Future; Adapting to Rising Tides

Monterey Bay: Adapt Monterey Bay; the Monterey Bay National Marine Sanctuary's & the Center for Ocean Solutions' efforts with the development of Integrated Regional Water Management Plans for Santa Cruz and Monterey Counties

Ventura County: The Nature Conservancy's Coastal Resilience Ventura Project

Los Angeles: AdaptLA

San Diego County: The Port of San Diego's Climate Action Plan; the Tijuana River National Estuarine Research Reserve's (TRNERR) Climate Understanding and Resilience in the River Valley (CURRV) project; and The San Diego Foundation's Sea Level Rise Adaptation Strategy for San Diego Bay

Four kinds of interrelated aspects of adaptation are described and reviewed here: stakeholder engagement, sea level rise modeling, decision support tools, and economic analysis tools. Stakeholder engagement refers to the processes by which local interest groups, decision makers, and land and resource managers are brought into the project. Sea level rise models use either quantitative descriptions of physical processes or semi-empirical methods to project sea level rise and flooding into the future. Decision support tools provide a way to examine those sea level rise predictions visually (e.g., on a map) and simultaneously describe the resources – natural and human – that are put at risk under various scenarios. Economic models provide information on the numerous impacts different climate scenarios and/or decision paths can have on socioeconomic resources. Planning for coastal resilience can involve any combination of these processes.

This guide is a summary of a much more detailed document, California Coastal Resilience Network: A compilation of lessons learned from local experience for stakeholder engagement, sea level rise and coastal flood modeling, decision support tools, and economic analysis in coastal climate change adaptation in California, which can be obtained from The Nature Conservancy by emailing Kelly Leo at kleo@tnc.org.

© Kelly Leo Transportation infrastructure near the coast

© Rebecca Wells Harbor seals at Elkhorn Slough

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Coastal habitat protection in Ventura County

TABLE OF CONTENTS

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Stakeholder engagement in action - Coastal Resilience Ventura

STAKEHOLDER ENGAGEMENT

Stakeholder engagement is a critical step in conducting any kind of environmental planning, including planning to address the challenges of sea level rise. Extensive research has been dedicated to determining and documenting best practices for stakeholder engagement, but the real-world challenges of environmental planning sometimes conflict with implementing best practices as outlined in the literature.

This section presents a revised set of best practices for stakeholder engagement in climate adaptation planning, developed via extensive interviews with practitioners engaged in a range of ongoing adaptation planning projects in California. Taking the time to plan ahead and thoughtfully manage stakeholder engagement can be the key to implementing a successful project.

Table 1: Recommended Best Practices for Stakeholder Engagement in Coastal Climate Change Adaptation

	Recommended Best Practice	Justification Based on Interviews with Practitioners
Identify Mutual Goals	At a project's outset, facilitators and end users should identify mutual and/or compatible goals so that both parties gain from the relationship.	In an ideal world, project facilitators are impartial to the outcome of a stakeholder process; however, in reality, facilitators often have their own agenda, which can affect their subjectivity with respect to the range of possible actions. The range of possibilities should ideally be defined by local managers empowered with the time and resources to proactively plan for adaptation. Project leads will have to balance the needs of the participants and the goals of their own organization. Depending on the mission of the lead organization(s), project leads may be able to rely entirely on the goals of the participants, or they may incorporate the needs of the participants to inform the development of a pre-planned tool or deliverable.
What's in it for Me?	Emphasize knowledge-sharing processes while recognizing that stakeholders are most likely to participate in projects that provide tangible results that they can use.	The collective experience of the projects surveyed suggests that stakeholders are very interested in explicit results. As a result, stakeholders might be less likely to participate in projects that focus solely on sharing knowledge without the possibility of gaining new information (e.g., more advanced or localized modeling) or new, proprietary tools.
Don't Get Lost in the Weeds – Provide Appropriate Level of Detail	Link information producers and users, while understanding that the level of information desired by scientists and by diverse decision-makers may differ dramatically.	In the projects reviewed, project leads made sure to link data generation and modeling outputs to local decision makers. However, they consistently noted that users have different intended applications of the data (for example, planners versus non-profits) and therefore have different requirements for the levels of detail, the choice of layers to include in the visualization and modeling, and sensible strategies. Project leads noted the need to balance quantity, quality, and practicality of data requests.
Go with the Flow – Be Adaptable	Design projects and processes to facilitate learning, knowledge transfer, and stability and continuity, with the understanding that participants may come and go, projects will evolve, and needs will change.	While stability and continuity are important, personnel, political climate, stakeholders, and other factors can change over the lifetime of a project. Stakeholders must understand that the process will be flexible and adaptive. The timeline may change as new directions and opportunities emerge, methodologies may evolve, and involvement of stakeholders may vary.
Know Your Target Audience(s)	It may be necessary to re-evaluate the target audience regularly as the project progresses. Build inter-organizational connections while regularly re-evaluating the target audience as the project progresses, and identify stakeholder values and positions prior to engagement to develop a communication plan that resonates with them.	Projects must carefully determine their target audience, often by considering the policy context in which decision-making and adaptation happen on the ground, but they also must recognize that they may need to reach multiple audiences simultaneously, or shifting audiences as the project takes shape over time.
Support Stakeholder Engagement and Critical Decision Making	Provide regular opportunities for participants to provide input, and be sure to provide adequate decision-making support, recognizing that most stakeholders are not adaptation experts or they wouldn't need your help in the first place.	While stakeholder input is absolutely critical, stakeholders might lack the technical knowledge to offer specific solutions to sea level rise-related problems. Substantial structure and guidance should be provided when asking for stakeholder input, in order to avoid distracting from a project's central goals.
Communicate Clearly, Avoiding Jargon	Avoid jargon and communicate science clearly and concisely, recognizing that stakeholders will have various levels of technical training and scientific expertise.	Invest the necessary time to ensure stakeholders fully understand the adaptation information. Ask reflective questions, conduct usability trainings, and/or interview stakeholders to ensure they are confident in their local adaptation knowledge and they understand project modeling and coastal adaptation terminology.
Carefully Manage Engagement to Avoid Stakeholder Fatigue	Maintain consistent and ongoing communication with participants, while limiting time/money/energy-intensive face-to-face meetings to minimize stakeholder fatigue.	Stakeholders are often overburdened and have limited resources to devote to these efforts; as a result, the appropriate amount and type of stakeholder communication may vary by project. Project leads must be mindful of stakeholder fatigue and walk the delicate line between inundating stakeholders with project-related correspondence and losing momentum and stakeholder enthusiasm with infrequent communication.
Project Planning & Management are Critical	Provide structure and focus for discussions during in-person meetings to maximize their efficiency while providing opportunities for brainstorming and idea sharing.	While stakeholders want to feel that their time is being used efficiently, they also appreciate the opportunity to brainstorm and share their own ideas. Several project leads and participants noted the benefits of having larger, more open-ended discussions to allow brainstorming and facilitate creative thinking.
Where Feasible, Compromise to Find Win-Win Solutions	Provide salient (relevant to the policy context) and credible products, while recognizing that collaboration and full representation of all stakeholder groups may require compromises.	Project leads noted difficulty in meeting all of the information demands for stakeholders within the boundary of an individual project; funding limitations often require a staged approach to analysis and implementation. Additional detail on vulnerability or project-level projections is likely to be a common request from stakeholders, who want that level of detail to support adaptation-related decision making. Consequently, it is critical that project leads work with stakeholders even before the start of a project to set clear expectations for what that particular phase of the project can deliver. Where possible, project leads should work with stakeholders to design project scopes before submitting funding applications to ensure the results provide the level of detail necessary for decision-making stakeholders.

STAKEHOLDER ENGAGEMENT:

EVOLUTION OF TARGET AUDIENCES OVER PROJECT LIFESPAN

Most of the projects studied here have undergone shifts in target audience over the course of the project. Initial stages are often conducted by consulting with a broad stakeholder group, representing coastal managers from the national, state, regional, and local levels. In this manner, an atmosphere of open dialogue is created that establishes trust in the process and among the project participants.

As the projects progress, key stakeholders, often those municipal planners most poised for action, are identified and become strong partners. The ultimate goal is that the project, or some derivative group of stakeholders, takes a more site-specific, on-the-ground approach to implementation. Advocacy groups are key, particularly in implementing site-specific actions. These on-the-ground efforts often involve a marriage of advocacy groups and land owners or managers, working together with planners, engineers, public works staff, and the community to raise awareness and facilitate action.

CASE STUDY: THE NATURE CONSERVANCY'S COASTAL RESILIENCE VENTURA PROJECT

In The Nature Conservancy's Coastal Resilience project in Ventura, initial stakeholder engagement focused most heavily on city and county planners and local resource agency leads. However, as the project progressed, local interest groups and elected and appointed officials became increasingly involved and the group expanded to include over 30 organizations and agencies. In 2014, the City of Oxnard collaborated with community members and local interest groups to block a coastal power plan that was proposed in a highly vulnerable area, referencing the project's sea level rise and flood hazard modeling projections as a main resource.

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Coastal habitats and infrastructure

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Coastal habitat restoration sites at Santa Cruz Island

SEA LEVEL RISE MODELING TECHNIQUES

Sea level rise models project likely inundation and flooding at a variety of scales under a range of sea level rise, tidal, and storm scenarios. There are several existing sea level rise model types, ranging from process-driven models to semi-empirical approaches. For any technique, significant technical expertise is required for developing, parameterizing, and running these models; typically coastal geomorphologists and physical engineers are contracted to construct and run models and then analyze their outputs. The outputs of sea level rise models can be visualized and interpreted using decision support tools (see the next section of this document).

This section presents a comparative analysis of the most commonly used sea level rise modeling techniques in California, which will help coastal managers understand the differences among the models and choose which might be the right approach for their community or question.

The models chosen for comparison have been applied along the open California coast (exposed to significant episodic wave energy) and they have been applied to identify hazards associated with climate change. However, there are additional models that show promise in improving the existing modeling efforts and should be assessed further as they are applied elsewhere.

MODELS VS. DECISION SUPPORT TOOLS

Please Note: This section explores models that show the coastal hazards resulting from the effects of sea level rise and storms, which are distinct from – and frequently, mistakenly made synonymous with – the various web mappers and decision support tools that are utilized to package and display model outputs in a spatial format suitable for analysis by managers and decision makers. For example, NOAA's Coastal Services Center developed a sea level rise and coastal flooding model. The outputs generated by the NOAA model were then made accessible through the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer. Similarly, the ESA PWA model outputs are made accessible through The Nature Conservancy's Coastal Resilience decision support tool. The USGS CoSMoS model outputs are represented through the Our Coast Our Future (OCOF) interactive mapping tool. The associated decision support tools and web mappers are highlighted in the following section.

SEA LEVEL RISE MODELS

NOAA

http://csc.noaa.gov/digitalcoast/tools/slrviewer
This model was developed by NOAA's Coastal Services Center to provide a tool to view the impacts of sea level rise consistently across the country. The tool's viewer maps Mean High Water without any influence of waves or storm surges. Users can select 1-foot sea level rise increments and overlay spatial data on social vulnerability and marsh migration in a simple, representative way.

Pacific Institute (ESA PWA)

http://www.pacinst.org/publication/the-impacts-of-sea-level-rise-on-the-california-coast/
This model, developed by ESA PWA with funding from the California Ocean Protection Council in support of Pacific Institute's study on sea level rise, uses the 2009 downscaled Global Climate Model for California. Multiple scenarios were applied to project erosion and flooding hazards for the entire California coast, using the best statewide data sets for topography and historic trends in coastal erosion available at the time.

The Nature Conservancy Coastal Resilience – Ventura County and Monterey Bay (ESA PWA)

http://coastalresilience.org/california/
This model builds upon the Pacific Institute model (above). It was developed for Ventura with funding from The Nature Conservancy and Ventura County, and was later applied to the Monterey Bay region with funding from the State Coastal Conservancy for a regional sea level rise vulnerability assessment led by the Monterey Bay Sanctuary Foundation. It utilizes FEMA hazard identification methodologies and projects them into the future while combining them with sea level rise and coastal erosion. Five distinct hazards are mapped at a scale suitable for parcel-level planning: coastal erosion, wave velocity, coastal flooding (extent of flooding), depth of flooding (a more intricate analysis useful for economic damage assessments), and fluvial flooding.

CoSMoS 2.0 via Our Coast Our Future (USGS)

http://data.prbo.org/apps/ocof/
This model feeds results of the latest Global Climate Models (GCMs) into a global wave model to develop projections of wave conditions for the U.S. West Coast through 2100. Those offshore wave conditions, combined with tides and storm surge, are modeled at the local level along the shore to determine coastal water levels, which are then used to estimate the extent of flooding. The model projects 40 combinations of sea level rise and storms between 0 and 2 meters, with a 5 meter extreme. Outputs include coastal flooding extents and depths, and uncertainty associated with multiple aspects of the modeling along with projections of wave heights, nearshore current strength, and storm event-based beach changes.

Navy/SPAWAR methodology as tested at Naval Base Coronado and Marine Corps Base Camp Pendleton
https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change/Vulnerability-and-Impact-Assessment/RC-1703
This methodology development and testing was funded by the Strategic Environmental Research and Development Program (SERDP) of the Department of Defense (DoD) as part of a research project aimed at projecting future coastal hazard impacts on coastal DoD installations. The primary goal of this project is to develop methods for assessing impacts of local mean sea level rise and associated phenomena on military infrastructure.

The tables on the following pages compare various aspects of these tools.

SEA LEVEL RISE MODELING TECHNIQUES

Table 2: Model Selection Criteria

	NOAA	Pacific Institute (PWA)	ESA PWA (Ventura County & Monterey Bay)	USGS CoSMoS (Our Coast our Future – SF Outer Coast)	SPAWAR
Cost/km of shoreline	$9,064/km2	$286.36	$1,910.36	$840	~$5700
Time to Complete	4 years	5 months	2 years	2 years	3+ years
Spatial Resolution	Analysis points vary with tide locations, data interpolated at 2m scale	100m alongshore, aggregated at 500m	100m alongshore, aggregated at 500m, interpolated at 2m resolution	10-100m alongshore interpolated at 2m resolution for final flood maps	100m alongshore for forcing, 2m resolution for flooding and inundation
Planning Scale	Statewide/ Regional	Statewide/ Regional	Local Jurisdiction/ Parcel Level	Local Jurisdiction/ Parcel Level	Regional to Component Level/ Engineering
Coastal Erosion - Cliffs	No	Yes	Yes	No	Yes (coupled to beach where appropriate)
Coastal Erosion - Beaches	No	Yes	Yes	Yes (storm only)	Yes (couple to cliff where appropriate)
Coastal Flooding	Yes	Yes	Yes	Yes	Yes
Hydrologic Connectivity	Yes	No	Yes	Yes	Yes
Storm Event Erosion	No	Yes	Yes	Yes	Yes
Fluvial Flood Hazards	No	No	Yes	No	No

Table 3: Model Technical Details

	NOAA	Pacific Institute (PWA)	ESA PWA (Ventura County & Monterey Bay)	USGS CoSMoS (Our Coast our Future – SF Outer Coast)	SPAWAR
Forcing - Coastal Flooding	Mean Higher High Water (from NOAA VDATUM)	Total Water Level	Dynamic Water Level	Dynamic Water Level	Total Water Level
Bathtub	No	Yes	No	No	No
Forcing - Coastal Erosion	No	Total Water Level	Total Water Level	No	Total Water Level & Wave Energy
Erode then Flood	No	No	Yes	No (yes for single storm)	Yes
Geology	No	Yes	Yes	No	Yes
Backshore Classification	No	Yes	Yes	No	Yes
Geomorphology (Beach Slopes, Toe Elevations, Crest Height)	No	Yes	Yes	Yes	Yes
Waves	No	Yes - Cayan	Yes - Synthetic time series	Yes - WW3 from GCM	Yes - WW3 from CCSM3 A2 scenario
Wave Transformation	No	Yes - MOPs CDIP	Yes - SWAN	Yes - SWAN and XBEACH	YES - CDIP
Sea Level Rise Scenarios	1 foot increments up to 6′	0.6m, 1.0m, 1.4m	0.43m, 0.93m, 1.47m	0.25 to 2m at 0.25m increments and 5m	0.0m, 0.5m, 1.0m, 1.5m, 2.0m rise 2000-2100
Alongshore Transport	No	No	No	No	Incorporated on littoral cell scale via estimated sand budget surplus/ deficit
Method of Storm-Induced Erosion/ Accretion	NA	Komar et al. 1999, FEMA 2005	Komar et al. 1999, FEMA 2005	Xbeach (no accretion)	Equilibrium shoreline position (Yates et al. 2009)
Method of Long-term Erosion from MSLR	NA	Revell et al. 2011	Revell et al. 2011	NA	Mass-conserving coupled/decoupled beach & cliff retreat model including regional sand budgets and subaerial erosion processes
Process Time Series or Percent Exceedance	NA	% exceedance	% exceedance	Extreme value analysis (return periods)	Extreme value analysis from time series and associated return periods
Uncertainty Methods	Low lying areas, confidence map	none	Spatial aggregation	Estimated error of DEM and model remapped on topo	Scenario ranges, return period ranges, sensitivity analysis
Incorporation of Armoring	No	No	Yes	Yes, indirectly based on slope	No
Topographic Surface	For California specifically, 2010 OPC LiDAR – 5m and 2m	1998/2002 LiDAR	2010 OPC LiDAR 2005 USGS merged DEM	2010 OPC LiDAR and multibeam bathymetry - 2m	Fused USACE 2002 LiDAR with SIO March 2006 coastal LiDAR; Fused various historical beach profiles to generate best localized data
Hydraulic Connectivity	Yes	No	Yes	Yes	Yes (with adjustable alongshore scale)
Culverts, Ditches, Drainages	No	No	Yes	If captured by DEM	No

Sea level rise models generate a wealth of information for planners and managers, but the models themselves do not typically provide an easy way to communicate the information they generate. Adaptation practitioners have developed a suite of decision support tools to “visualize” model outputs, often on maps, to aid managers. These decision support tools are the subject of the following section.

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Seawalls along Monterey Bay shoreline

DECISION SUPPORT TOOLS

Information produced by the types of models described in the previous section can be visualized on maps and used to help coastal managers choose approaches to coastal resilience. This section presents and compares online decision support tools that illustrate coastal risk and vulnerability for the suite of sea level rise issues that are of concern to coastal managers. Some communities have invested in more localized, detailed data incorporated into customized decision support tools, while many others rely on FEMA flood maps and national-scale tools from NOAA, USGS and the EPA. No matter the scale, decision support tools universally illustrate model outputs, and models are inherently projections - best estimates based on scientific evidence - which are constantly evolving. Decision support tools are only as useful as the modeling information that goes into them and in the way that they communicate the model outputs to the target audience. Therefore the emphasis here is on information delivery for decision support.

The field of climate and sea level rise tool development is in a state of rapid change, so any inventory and report on this subject will inevitably be a snapshot. The tools evaluated here were selected because they represent a broad range of features and geographies. These tools work at different scales (national, state, local), use different modeling assumptions, and represent the work of government, non-profits and academic institutions. As tool and data quality continue to improve, this evaluation process will need to be updated.

DECISION SUPPORT TOOLS

The tools compared in this section are:

Surging Seas Risk Finder

www.sealevel.climatecentral.org
Climate Central's Surging Seas Risk Finder, available for eleven U.S. coastal states (California, Connecticut, Florida, Maine, Massachusetts, New Hampshire, New Jersey, New York, Oregon, Rhode Island, Washington), provides local sea level rise and flood risk projections, interactive maps, and exposure from the scale of zip codes up to more regional levels. Surging Seas is designed to help communities, planners, and leaders better understand sea level rise and coastal flood risks to diverse populations and assets over time.

Sea Level Rise and Coastal Flooding Impacts Viewer

www.csc.noaa.gov/digitalcoast/tools/slrviewer
The purpose of NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer is to provide coastal managers and scientists with a preliminary look at persistent and event-driven coastal inundation across the U.S. The viewer is a visual screening/planning tool that uses nationally consistent data sets and analyses and provides data for download or viewing via web map services. It is designed to allow communities to visualize as well as plan for exposure to sea level rise and more frequent storms and associated flooding.

Coastal Resilience - Ventura County and Monterey Bar

www.maps.coastalresilience.org/ventura
The Nature Conservancy's Coastal Resilience tool is a visualization and decision support platform where ecological, social, and economic information can be viewed alongside sea level rise and storm surge scenarios in order to identify restoration and adaptation solutions. It is available for multiple locations in the U.S., Latin America and the Caribbean. Coastal Resilience applications in CA are designed to inform county coastal and hazard mitigation planning. Coastal Resilience in California is now available statewide, using Pacific Institute data where more detailed examinations of local projects are not available.

Our Coast Our Future

www.pointblue.org/ocof
Our Coast, Our Future is a collaborative, user-driven project focused on providing San Francisco Bay-area coastal resource and land use managers and planners locally relevant, online maps and tools for anticipating vulnerabilities to sea level rise and storms (Half Moon Bay to Bodega Bay).

Protected coastal wetlands at Ormond Beach

Vulnerable coastal infrastructure in Oxnard, CA

Table 4: Decision Support Tool Comparison

	Surging Seas Risk Finder	NOAA SLR and Coastal Flooding Impacts Viewer	Coastal Resilience - Ventura County and Monterey Bay	Our Coast Our Future
Purpose	To provide a multi-part web tool to help communities, planners, and leaders better understand sea level rise and coastal flood risks to diverse populations and assets over time	To provide a visual screening tool and consistent data to help communities visualize and plan for exposure to sea level rise as well as more frequent storms and associated flooding	To compile and deliver web-based planning tools incorporating nature-based solutions to coastal Ventura communities for disaster risk reduction and climate adaptation	A collaborative, user-driven project focused on providing San Francisco Bay Area coastal resource and land use managers and planners locally relevant, online maps and tools
Geographic Coverage	National tool that is currently available for: CA, CT, DE, FL, GA, ME, MD, MA, NH, NJ, NY, NC, OR, RI, SC, TX, VA, WA, DC	National tool that is currently available for: AL, American Samoa, CA, CT, Saipan, DE, DC, FL, GA, Guam, HI, ME, MD, MA, MI, NH, NJ, NY, NC, OR, PA, PR and USVI, RI, SC, TX, VA, WA	• Comprehensive Ventura County and Monterey Bay data on social, economic and ecological information • A statewide application is available with detailed explorations of Monterey Bay, Ventura County, and Santa Barbara County, coming in Fall 2015	San Francisco Bay Area Outer Coast (Half Moon Bay to Bodega Bay)
Key Distinctions	• Takes a screening-level look across coastal areas of contiguous US • Uses consistent methods and data for essentially all locations. Maps are based primarily on elevation data supplied by NOAA and used in NOAA's SLR Viewer. Maps display static water levels up to 10 feet above the local high tide (MHHW) • Local projections combine sea level rise and storm surge to give integrated risk estimates by decade • No physical modeling of waves on top of sea level rise, nor coastal erosion or other coastal processes • Analyses cover 100 demographic, economic, infrastructure, and environmental variables, compiled by zips, cities, counties, states, as well as planning and legislative districts. Socio-economic exposure map based on Social Vulnerability Index (SOVI) data, plus population density, race/ethnicity, per capita income, and property value layers. • Displays levee data from the Midterm Levee Inventory (FEMA/USACE), the best available national levees dataset. Does not provide analysis of marsh or mangrove migration. • User can select among various global sea level rise models and scenarios (NOAA, USACE, IPCC, etc.) when viewing integrated sea level rise and storm surge risk estimates by decade • Provides custom community "fast look" reports, plus extensive data downloads (Excel format) for sea level and flood risk projections, and for any data variable	• Takes a screening-level look across coastal areas of contiguous US and selected islands • Uses consistent methods and data for all locations • Sea level visualizations are provided at one-foot increments (0-6 feet) above mean higher high water irrespective of time • Includes flood frequency information based on local National Weather Service field office thresholds for shallow coastal flood warnings • Storm surge projections not included • Socio-economic exposure map based on Social Vulnerability Index (SOVI) data and block group level economic data from U.S. Census and Bureau of Labor Statistics • Marsh migration analysis available for all geographies based on NOAA coastal land cover data and migration rules modified from the Sea Level Affecting Marshes Model (SLAMM) • Displays simulations of sea level rise at local landmarks • Associated data provided for download or as mapping services for use by communities as a foundation for further local assessment	• Maps selected geographies with a focus on developing nature-based adaptation solutions • LiDAR-based sea level rise scenarios (2030, 2060, 2100) are based on various low, medium and high projection scenarios (A2 and B1 IPCC emission scenarios) • Storm surge scenarios included (tidal inundation, large storm wave impact, flood inundation, and river flooding) • Combines sea level rise and storm surge • Chronic shallow coastal flooding information included (monthly tidal inundation) • Coastal erosion risk layers included based on various large storm wave events • Future land use modeling scenarios (2020-2100) given low and high sea level rise scenarios including future changes to tidally influenced wetlands • Custom apps developed on the data viewing platform for displaying flood and sea level rise scenarios, future marsh migration and land-use patterns, and community planning in specific sub-geographies	• LiDAR-based sea level rise scenarios from 0 to 2 meters with 25 centimeter intervals plus a 5-meter extreme scenario • Three storm scenarios (annual, 20 year, 100 year) • Contains uncertainty analysis for minimum and maximum inundation for a particular scenario • Combines sea level rise and storm surge • Illustrates wave height for each sea level rise and storm scenario • Includes data layers for velocity of ocean waters near shore • Future marsh migration for each scenario will be included for San Francisco Bay

ECONOMIC TOOLS

Decision makers in coastal regions are aware that climate change calls for new planning strategies that address evolving environmental conditions. They need compelling economic information to justify their adaptation actions. A number of different economic tools and approaches have been developed that can provide the analyses needed to make informed decisions

Application of Economic Tools to Sea Level Rise Adaptation Issues

Economic tools are required to help decision makers compare and contrast numerous practical and theoretical adaptation approaches ranging from seawall construction to dune restoration to managed retreat from coastal areas. It is challenging, but critical, for decision makers to understand the economic and socioeconomic consequences of the anticipated changes brought about by sea level rise and coastal change, and of selecting one adaptation strategy over another. In order to make the appropriate choice, decision makers need to consider a full suite of costs and benefits for each strategy. There is currently no single tool that can address all economic effects of sea level rise; tools have been developed for estimating the cost of flood damages, the value of ecosystem services, the changes to economic variables, and the metrics for quantifying social and community impacts. Before selecting a tool, it is important to understand the capabilities and limitations of the tools available, and the goals of the stakeholders involved in a project. For example, do stakeholders want to understand the change in recreational value of a coastal area due to loss of beach from sea level rise? Or, do stakeholders want to know the potential impact on jobs and revenue from reduced tourism stemming from beach loss? While these questions may sound similar, the answers involve different economic metrics and methods, and therefore require different tools to address them.

Four main categories of economic tools are assessed here: 1) flood damage and hazard tools; 2) ecosystem service tools; 3) regional economic impact tools; and 4) social and community impact tools. The appropriate applications of each are described in the following sections.

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Beachfront development at high risk from sea level rise and coastal hazards

ECONOMIC TOOLS

FLOOD DAMAGE AND HAZARD TOOLS

Flood damage tools, developed to analyze the loss of economic value from flooding events, can be used by policy makers to measure changes in economic value such as housing values, market inventories, and other assets with market value. Flood damage tools estimate damages to public infrastructure such as highways, roads, and utilities. These goods often lack measures of market value. In the place of market value, flood damage tools use replacement cost, the cost to reconstruct and repair damaged public infrastructure. There are two primary flood damage economic estimation tools: Hazus and HEC-FDA. Hazus, a composite of multiple tools developed by FEMA to plan for and manage natural disasters, is a nationally applicable standardized methodology for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses GIS technology to estimate physical, economic, and social impacts of disasters. The Flood Damage Reduction Analysis (HEC-FDA) software developed by the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) can perform an integrated hydrologic engineering and economic damage assessment.

Table 5: Summary of Flood Damage Estimation Tools

Selection Criterion / Model	Hazus	HEC-FDA
Economic Metrics	Economic value, economic impacts, and public values	Economic value
Data Requirements	None required, but site-specific data accommodated	• Hydrologic and hydraulic • Structure inventory and values • Damage functions
Technical Expertise	GIS	• Engineering • Economics
Analytical Flexibility	Very flexible, no uncertainty	Very flexible including uncertainty
Spatial Scale	Any	Any
Mapping Capabilities	No	Yes
Budget Considerations	Free	Free

*It should be noted that this analysis does not review the technical difficulties inherent in assessing true property values, which is often one of the most significant technical challenges in applying these tools; accurately applying this information goes well beyond collecting parcel data and manipulating it in GIS.

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A stretch of the Pacific Coast Highway abutting sensitive coastal habitat

© Kelly Leo Coastal resource extraction, Monterey Bay

© Walter Heady California's scenic coastline

ECONOMIC TOOLS

ECOSYSTEM SERVICE TOOLS

Several goods and services that generate benefits lack clear market signals of value because they are public goods (a good consumed in common). Several economic and ecological methods have been developed to estimate the value attributable to functioning natural resources; however, these tools rely on large survey data and are often costly and time consuming. Ecosystem service tools have been developed to assist planners and policy makers in leveraging the body of science that measures changes in the flow of ecosystem services. These tools have been designed to answer questions about which ecosystem services will be affected, how much, and what the economic value of those services is. There are three ecosystem service tools evaluated in this review: (1) Ecosystem Service Review (ESR), (2) Integrated Valuation of Environmental Services and Tradeoffs (InVEST), and (3) Artificial Intelligence for Ecosystem Services (ARIES).

Table 6: Summary of Ecosystem Service Estimation Tools

Selection Criterion / Model	ESR	InVEST	ARIES
Economic Metrics	Qualitative discussion of economic value	Economic value	Economic value
Data Requirements	None	• Data sources are listed online •Web address where data can be accessed is available	• Data sources are listed online • Data not distributed directly to users as part of the system
Technical Expertise	None	GIS, Ecology	GIS
Analytical Flexibility	Very flexible	27 ecosystem services	8 ecosystem services
Spatial Scale	Any	Landscape & Watershed	Landscape & Watershed
Mapping Capabilities	None	GIS	GIS
Budget Considerations	Budget friendly	Budget heavy	Budget heavy

ECONOMIC TOOLS

REGIONAL ECONOMIC IMPACT TOOLS

Regional economic impact tools are used to calculate how changes in one economic sector will impact the total economy in terms of jobs, income, GDP, and revenue. There are two commonly used economic impact models presented below: (1) IMPLAN, and (2) RIMS II. IMPLAN was designed for users of varying skill levels and backgrounds in economics to create economic reports using peer-reviewed methods in a standardized process. RIMS II is an input-output model based on peer-reviewed methods developed by the Bureau of Economic Analysis (BEA). RIMS II is appropriate for all levels of expertise.

Table 7: Summary of Regional Economic Impact Tools

Selection Criterion / Model	IMPLAN	RIMS II
Economic Metrics	• GDP • Income • Jobs • Federal tax revenue • State and local tax revenue	• GDP • Income • Jobs
Data Requirements	Regional datasets used to estimate multipliers are purchased form IMPLAN	Pre-estimated multipliers are purchased from BEA (Bureau of Economic Analysis)
Technical Expertise	Required for more sophisticated uses	Not required
Analytical Flexibility	Unrestricted: Trade-flow data can be adapted to meet specific conditions of study resulting in multipliers that accurately represent inter-industry relationships	Restricted: Multipliers cannot be adjusted by analyst - they are generated by the model
Spatial Scale	• State / County / Zip Code scale • Multi-regional modeling capabilities	• State / County / Zip Code Service
Mapping Capabilities	None	None
Software Requirements	IMPLAN Software	Microsoft Excel
Budget Considerations	Data cost can range from $400 for a state to over $8000 for a state package with all regions by zip code included	Data can be purchased for as low as $75 for an industry and $275 for a region

*Note: The main metric needed is either the number of employees OR gross revenues - or some other proxy for revenues. One typically purchases the data (in the form of an input/output matrix) and the multiplier is generated by the model—it will vary depending upon the distribution of the spending.

Coastal agriculture in Monterey

ECONOMIC TOOLS

SOCIAL AND COMMUNITY IMPACT TOOLS

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Coastal habitats in Ventura

A few economic tools evaluate social and community impacts of sea level rise and climate change. Since the advent of concerns surrounding environmental justice, more tools have been developed to identify how impacts of a project, or an adaptation strategy, may differentially affect sensitive or vulnerable populations or places of elevated community importance.

The Hazus model described previously includes some emergency costs and estimates of the business interruptions associated with natural hazards. In addition, methods are evolving to evaluate the potential for distributional impacts and to identify, evaluate, and preempt distributional impacts of climate change adaptation strategies. One such tool reviewed is the Social Vulnerability Index (SoVI) developed by the Hazards and Vulnerability Research Institute at the University of South Carolina. SoVI measures the social vulnerability of U.S. counties to environmental hazards. The index is a comparative metric that facilitates the examination of the differences in social vulnerability among counties.

The index is pre-calculated and available at the state and county level. It combines several socioeconomic variables in order to represent biophysical vulnerability (physical characteristics of hazards and the environment) and social vulnerability to determine an overall place vulnerability. Social vulnerability is represented as the social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards. The index should be used to understand the comparative risk to a population from natural hazards in terms of resources for relocation, lifelines, and ability to access resources during time of recovery.

Other measures or approaches to evaluating community impacts of climate change include the evolving approaches to "resilience analysis." Resilience analysis focuses on the capacity of a system to withstand changes or shocks and maintain its primary functions. At present, a group of communities and states surrounding the Gulf of Mexico are working with the Environmental Protection Agency (EPA) to develop a draft resilience index that will serve as a self-assessment tool for coastal communities.

ECONOMIC TOOLS
CUSTOM ECONOMIC ANALYSES

Answering specific questions about the economic costs and benefits of coastal climate change adaptation approaches generally requires considering more than one type of impact and use of more than one tool or partial application of multiple concepts described above. Three analyses are briefly described below to provide examples of how analyses can be customized to answer specific questions.

Rocky coastline near Big Sur

Monterey Bay

"Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay" is an analysis carried out by ESA PWA for the Monterey Bay Sanctuary Foundation and The Southern Monterey Bay Coastal Erosion Working Group. This analysis evaluated the benefits of erosion avoidance by comparing loss of ecosystem services (habitat and recreation values) with the costs of the different erosion mitigation alternatives. The authors used a Benefits Transfer approach to estimate the value of lost recreation and habitat, and market values to evaluate losses to property from erosion. Economic impacts were also evaluated, and these results were presented separately (economic impacts are measured differently than benefits and costs in economics. These metrics may not be combined, but should both be presented).

In this analysis, the hazard triggering adaptation was erosion. Hence, only methods to quantify erosion losses were used. In addition, monetary estimates for the value of losses and gains in recreation and habitat were connected to geomorphic models of future losses of beach width. The study used the Coastal Sediments Benefit Analysis Tool (CSBAT) and Benefits Transfer methods for estimating ecosystem services. The CSBAT tool is itself a hybrid economic tool because it aids users in transporting sediment and nourishing beaches in a least-cost fashion. As such it combines the ecosystem service analysis of beach restoration and recreation with the standard economic analysis that endeavors to find the least costly method of achieving a goal. The study provides an analysis for a 100 year time horizon.

Economic Impact of Coastal Adaptation Strategies for Southern Monterey Bay

With funding from the State Coastal Conservancy, The Nature Conservancy is working with a team of scientists, geomorphologists, expert urban and environmental economists, regional conservation partners, and key, local, decision-making stakeholders to pioneer a new way of analyzing the economic impact of climate adaptation strategies in the Southern Monterey Bay area. The analytical approach used for this project estimates recreational value from counts and survey data conducted on-site within the study area. Storm damage prevention benefits are measured by (1) estimating the value of specific parcels (i.e., residences, businesses, etc.), and (2) estimating the loss due to erosion or flood loss under various sea level rise scenarios and adaptation strategies. For all other ecosystem functions, goods and services, the approach involves using offsets in order to preserve critical natural capital (e.g., the total grunion spawning ground is less than one square mile—all in California). This approach is similar to the one applied for wetlands restoration projects. This approach values beach ecosystems at the cost of restoring a similar beach (preferably within the same littoral cell) elsewhere with an appropriate offset ratio (as with wetlands restoration where a 4:1 ratio is common since restoration projects typically have lower ecological value).

ECONOMIC TOOLS
CUSTOM ECONOMIC ANALYSES

Ventura County
As part of The Nature Conservancy's Coastal Resilience project in Ventura, ENVIRON International Corp. was hired to analyze the economic impacts of sea level rise inundation, flood damages, and other hazards (e.g., erosion) for the study area under two broad adaptation strategies, one focusing on armoring solutions, and the other focusing on nature-based solutions. Costs of each were compared with benefits of each, and these results will be available to decision makers, along with estimates of costs and benefits to habitats and recreation, through The Nature Conservancy's online decision support tool for Ventura County.

In this analysis, damages were connected to multiple hazards, including flooding, erosion, and storm surge impacts. As a result, different models were utilized. Hydrologic modeling expertise was available for this analysis, without which the economic analyses would not have been possible. The analysis for Ventura County used the Habitat Equivalency Analysis approach to quantify the relative value of ecosystem services. The analysis incorporated results from SLAMM modeling (Sea Level Affecting Marshes Model), which simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. Distributions of wetlands are predicted under conditions of accelerated sea level rise, and results are summarized in tabular and graphical form. Where SLAMM analyses were not available, results were extrapolated from existing model outputs within the study area.

Coastline view from Ormond Beach, Ventura County

Los Angeles County
AdaptLA included an economic and social vulnerability assessment. The economic assessment was conducted using a combination of Hazus and the I-O model, a modeling approach not discussed in this analysis. The social vulnerability study looked at characteristics associated with higher social vulnerability, as well as well-established indices like SoVi and CA DPH's Community Vulnerability to Climate Change screening tool. The analysis identified particular communities within Los Angeles that are more vulnerable to the impacts of sea level rise (for a suite of reasons such as lower incomes), allowing the city to take that information into consideration when prioritizing adaptation projects. The analysis looked at the cost to the city of doing nothing to adapt to climate change and found that a 10 year flood in 2050 would cost the city $410 million in building losses alone. The City is now armed with physical, social and economic vulnerability information, which will be used to inform adaptation planning and implementation.

PARTING THOUGHTS

After a year of networking with adaptation practitioners and experts throughout California, a number of other important concerns and considerations surfaced that warrant mention.

Designing and Aligning Projects and Policies to Planning Contexts

The political context for climate adaptation is exceedingly complex and, as a result, adaptation planning processes are not necessarily designed around any one specific planning framework. This has the potential to lead to difficulties in translating current planning work into on-the-ground, actionable adaptation. Engaging with stakeholders prior to applying for grants and designing project scopes can help to align project outputs with planning processes, ensuring projects provide greatest value to targeted stakeholders and decision makers. However, this issue will not be solved entirely through stakeholder engagement; there is a need to streamline coastal climate adaptation policy and to improve communication between local and state management entities.

The Future of SLR Modeling in CA

All models inherently contain uncertainties; however, concern over degrees of model accuracy should not inhibit decision makers from taking action to implement informed adaptation measures. Existing modeling and visualization tools are adequate to initiate local planning processes. Future efforts should be dedicated to validating the leading sea level rise and coastal flooding models and to clarifying expressions of model uncertainty to help assuage these concerns. The state's adaptation community is also advocating for the integration of multiple modeling techniques, selecting the most appropriate facets of the models in order to best address specific geographic regions in the state.

Getting the Most out of Decision Support Tools

Decision support tools must be tested by stakeholders to determine their performance and usability. In addition, while inundation scenarios can now be mapped using decision support tools, these tools lack the ability to visualize or characterize the outcomes of various planning decisions, rendering them unable to provide actual recommendations for action to planners and other practitioners. It is important that stakeholders recognize this limitation and that adaptation practitioners work to produce the right data and analyses to help close the gap between the information the decision support tools offer and the recommendations that the decision-makers are seeking.

The Role of Economic Analysis in Coastal Climate Change Adaptation

Although frequently identified as the limiting factor for communities in terms of their ability to adapt to climate change, there are few examples of successful incorporation of economic considerations into adaptation planning and there is little to no consensus about the best way to do so. California can lead the way by exploring how best to consider the economic impact of climate change adaptation in practice. The state's adaptation community acknowledges that there is now an opportunity to infuse adaptation planning with economic analysis that did not exist prior to the development of the suite of tools examined in this project. Aligning practitioners at the outset has the potential to conserve time, money, and energy as the adaptation community considers the economic consequences of adaptation in the coming years.

The Time is Right for Adaptation Networking

The California adaptation community is active and empowered, as reflected in the number and scope of the efforts detailed in this report, ARCCA's (Alliance of Regional Collaboratives for Climate Adaptation) expansion focused on providing an opportunity for dialogue between regional collaboratives working on climate adaptation in urban areas of California, and the deluge of applications for Ocean Protection Council and State Coastal Conservancy funds for local "Climate Ready" and Local Coastal Program update funds. More than 800 participants attended the inaugural California Adaptation Forum in 2014, illustrating the extent of interest and growing expertise statewide in this topic. The California Coastal Resilience Network project built strong connections within the local adaptation planning community throughout coastal California. In particular, leaders of local/regional adaptation efforts helped The Nature Conservancy to identify common challenges at the local scale that highlight the need for ongoing collaboration and coordination among coastal decision makers to focus on large scale, coastal infrastructure adaptation projects.

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A shore bird at Ormond Beach, in Ventura County

NEXT STEPS

The Nature Conservancy, with additional support from Resources Legacy Fund, is leading an expanded California Coastal Resilience Network to:

Strengthen Cross-Geography Connections: Continue and strengthen connections with and among specific coastal counties, building the cross-geography approach to addressing shared nature-based adaptation concerns, particularly with respect to large, coastal infrastructure.

Formalize and Expand the Network's Reach: Include additional geographies that would benefit from this collaborative approach to improving coastal management and enabling local planning and adaptation. In addition to seeking members with traditional concerns about coastal climate change adaptation, we will make a concerted effort to round out the Network's dialogue by cultivating member communities where social equity and vulnerability are explicit priorities.

Identify Common Challenges and Opportunities for Collaborative Action: Continue (through monthly calls and webinars) to identify common challenges at the local scale across the entire Network, focusing on local coastal adaptation planning and collectively identifying where the state can help. Encourage state-wide dialogue and knowledge exchange about how economics can be incorporated into adaptation planning.

Provide Point of Contact with State Agencies to Elevate Issues of Concern: The Coastal Resilience Network will be administered by a project manager who will provide a point of contact with state agencies to elevate issues of concern facing California coastal communities, and leverage our policy influence beyond that of individual sites.

Expand TNC's Coastal Resilience Web Tool to Cover California's Entire Coastline: The California Coastal Resilience web tool (http://maps.coastalresilience.org/california/) is now available for the entire coast of California. Our California Coastal Resilience Network's decision support tools comparison suggested that TNC's Coastal Resilience platform is suitable for statewide expansion, in that it is flexible, fully customizable, and able to support the proliferation of modeled vulnerability projections from diverse sources. Network members will be able to populate local sub-sites with existing high-resolution inundation and flooding scenarios, and other social, economic, and ecological data. California-wide content will also be developed to assist in the analysis of strategic statewide opportunities for adaptation. Specific analytic tools will be developed to support community planning, economic cost/benefit analyses of strategy alternatives, and future habitat projections.

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