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

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Acknowledgements

Funding for this project was provided by a grant from the Resources Legacy Fund Foundation. The partners listed below made significant contributions of their time and detailed, local knowledge of climate change adaptation; they are the Network that made this project possible – thank you.

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Executive Summary

California's coastal planners and decision makers are increasingly aware of the serious risks posed by sea level rise and climate-driven extreme events. Many are undertaking adaptation planning processes to address these risks by integrating hazard mitigation strategies into their land use and natural resource management plans. However, there are multiple obstacles to adaptation at every step of the process, from understanding the issues to the range of challenges associated with appropriate planning and project implementation and management.

Multiple organizations – in consultation with key stakeholders – have initiated projects designed to assist local communities with overcoming their adaptation challenges using a variety of tools, including sea level rise and coastal flooding models, economic analyses, and decision support tools for visualization of this analytical information. Because of the local orientation of these projects, however, it has been difficult to distill a suite of lessons learned from the overall body of work. Other coastal communities who wish to undertake adaptation planning projects of their own – as well as funders and state agencies – could benefit from understanding common obstacles to identifying and executing adaptation strategies, as well as key differences that would inform various approaches to adaptation. The time is ripe and momentum is building for collaboration throughout California.

It was this timing and momentum that inspired the launch of the California Coastal Resilience Network project. The project has focused on distilling lessons learned and best practices from adaptation efforts already in progress throughout California. By identifying what has worked and what is missing from previous or ongoing adaptation efforts, we can help communities that are just beginning to think about adaptation to maximize their efficiency and prioritize approaches that are highly likely to work. The lessons captured in this report will allow state and local adaptation communities to learn from other local efforts and create bottom-up recommendations to best support local climate change adaptation along California's coast.

The California Coastal Resilience Network is led by The Nature Conservancy who has sought advice and lessons learned from from distinct planning projects underway along California's coast. For each geography (San Diego County; Los Angeles County; Ventura County; Monterey Bay; San Francisco Bay; and Humboldt Bay), The Nature Conservancy (TNC) worked with local project lead(s) to identify best practices for stakeholder engagement, and to review the range of sea level rise modeling techniques, decision support tools, and economic models that have already been developed for adaptation planning. Wherever possible, additional input was sought from local project stakeholders. Experts were convened to help draft and review each section.

Because economic impacts of coastal hazards are on the rise, local, state, and federal planners in the United States are starting to see land-use planning as a viable tool for risk reduction. California is at the frontier of this changing attitude. While substantial progress is being made, much more needs to be done. There are still significant gaps in the availability and accessibility of local sea level rise information for California, understanding of the impacts of various adaptation strategies, communication with critical stakeholders, and the translation of plans into action. It is hoped that this analysis will be useful for practitioners at various stages of planning and adaptation and that the Coastal Resilience Network will carry this information forward to the adaptation community throughout California. Below are descriptions of the analyses undertaken by TNC and its partners as a part of this project.

Stakeholder Engagement

While there is a body of literature focused on developing best practices for managing stakeholder engagement in sea level rise decision-making, the practical experiences of managers and planners is often that real-world processes prohibit deployment of those practices exactly as written. TNC reviewed the most-cited best practices and revised them, based on the experiences of California practitioners, as follows:

1. *Communicate the extent to which the project leads' goals can be met with a suite of options and adaptation strategies that would produce acceptable outcomes.*
2. *Begin by identifying mutual and/or compatible goals so that users and facilitators both gain from the relationship.*
3. *Emphasize knowledge sharing processes while recognizing that localized analysis and tools appeal to stakeholders and can facilitate greater knowledge transfer.*
4. *Link information producers and users while understanding that the level of information desired by scientists and by diverse decision-makers may differ dramatically.*
5. *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.*
6. *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.*
7. *Provide opportunities for participants to regularly provide input, while recognizing that they may not have extensive experience with adaptation strategies or be able to play a decision-making role.*
8. *Avoid jargon and communicate science clearly and concisely, recognizing that stakeholders will have various levels of technical training and scientific expertise.*
9. *Maintain consistent and ongoing communication with participants, while limiting time/money/energy-intensive face-to-face meetings to minimize stakeholder fatigue.*
10. *Provide structure and focus for discussions during meetings to maximize value of in-person interactions amongst participants while providing opportunities for brainstorming and idea sharing.*

11. *Provide salient (relevant to the policy context) and credible information through a collaborative process, while recognizing that collaboration and representativeness may require compromises.*

Sea Level Rise Modeling Techniques

TNC hired expert consultants and worked with comprehensive panels of leading sea level rise modelers and California-based adaptation policy experts and coastal managers to review the range of sea level rise modeling approaches that various projects have employed to predict future flooding scenarios that might accompany sea level rise or storm events. The tools reviewed are:

- Sea Level Rise and Coastal Flooding Impacts Viewer (NOAA)
- Pacific Institute (PWA)
- The Nature Conservancy Coastal Resilience - Ventura (ESA PWA)
- CoSMoS 2.0 as applied to Our Coast Our Future (USGS)
- Navy/Scripps model as applied to Naval Base Coronado

The strengths and limitations of each are outlined as well as the development history and technical details of each, which are compared in tables. Another table depicts the differences among models with respect to a range of selection criteria.

Decision Support Tools

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.

Decision support tool developers designed and populated a comparative matrix reviewing a suite of relevant tools for adaptation in California that address coastal flooding risk and community vulnerability. The accompanying analysis also addresses growing confusion among tools. The following online mapping decision support tools were included in this comparative analysis: Sea Level Rise and Coastal Flooding Impacts Viewer; Surging Seas; Coastal Resilience; and Our Coast Our Future. Each tool is described and then compared in tables with respect to key attributes.

All tools shared two basic characteristics. First, the common purpose or objective of all tools is to compile and deliver web-based spatial information that assesses risk and helps communities plan for exposure to sea level rise and more frequent tidal flooding. Second, whether statewide or local in scope, the flooding data in each tool is of high enough spatial resolution to be used for making local planning decisions. The analysis found a number of key distinctions among the tools, which are relevant to deciding which tool might be right for use in a new project. The distinctions are:

- Sea level rise is the focus of most flooding scenarios with half of the tools incorporating storm surge scenarios and combining them with sea level rise

- While some tools provide sea level rise scenarios based on emissions projected at a particular time horizon to increase compatibility with planning time horizons, others provide the scenarios mapped at height or depth intervals without respect to projected time horizons; few of the tools provide uncertainty analyses or mapping confidence

- All tools focus on risk and vulnerability information in association with sea level rise and, to a lesser degree, storm surge; there are only limited examples focused directly on supporting specific adaptation options

- Most tools address marsh migration and future land use patterns but methods of analysis vary

- All tools deliver resources to either state or local planning processes

- Most tools are built and managed centrally and require continued upkeep in order to maintain relevance as best available science constantly improves; few of the tools are open source and/or allow partners to build components of the tool itself

- Although all the tools are capable of exchanging web mapping services, few of them provide mechanisms for transferring data from one tool to another

Economic Modeling Tools

Decision makers in coastal regions are aware that climate change calls for new planning strategies adapted to evolving environmental conditions. Numerous practical and theoretical approaches ranging from seawall construction to dune restoration to managed retreat from coastal areas have been suggested as ways to adapt to these shifts. One of the outstanding challenges for decision makers is to understand the economic and socioeconomic consequences of selecting one adaptation strategy over another. In order to do this, decision makers need to consider a full suite of costs and benefits for each strategy. In response to the critical need to examine a wide range of impacts, a number of different tools and approaches have been developed that can help provide the needed analyses and data to make informed decisions. The purpose of this chapter is to provide an overview of the different analytic tools available and guidance on their appropriate use so that decision makers can get the socioeconomic information they need to select an appropriate adaptation strategy.

There are four main categories of economic tools that are assessed in this review:

- Flood damage and hazard tools
- Social and community impact tools
- Ecosystem service tools
- Regional economic impact tools

For each, the report reviews the economic metrics employed by the tool, its data requirements, the level of technical expertise required to operate it, its analytical flexibility, its mapping capabilities, and budget considerations. The striking few case studies of projects that have successfully integrated multiple economic tools are also presented.

This research effort illuminates several examples of regional-scale adaptation planning efforts which are constrained by time and funding. With additional resources, The Nature Conservancy could lead an expanded California Coastal Resilience Network to:

- Continue and strengthen engagements in, 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 to include additional geographies that did not participate in Phase I but would benefit from this collaborative approach to thinking about improving coastal management and enabling local planning and adaptation;
- Offer collaboration with the existing Alliance of Regional Collaboratives for Climate Adaptation (ARCCA[1]) to provide participating entities with more information about nature-based coastal adaptation approaches and to increase the exchange of information about the suite of shared adaptation concerns unique to coastal California;
- Continue 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 intervene to help;
- Encourage state-wide dialogue and knowledge exchange about how economics can be incorporated into adaptation planning;
- Work collectively to identify challenges shared by experienced local practitioners as well as the most readily-leveraged California-specific adaptation strategies;
- Enable conditions that empower both a state-wide approach to large-scale coastal climate change adaptation and local action; and
- Support existing training programs to collaboratively develop and deliver information and technical tools based on articulated needs.

Conclusions

A number of overall conclusions can be drawn from the suite of analyses presented in this report:

- Stakeholder engagement in adaptation planning processes is critical and must be facilitated thoughtfully in order to ensure that communication with stakeholders

[1] The Alliance of Regional Collaboratives for Climate Adaptation is an umbrella organization, founded in 2012, that brings together the four regional urban climate adaptation collaboratives in California for coordinated dialogue and preparedness planning.

encourages meaningful balance between encouraging active participation and avoiding stakeholder fatigue.

- 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 context. This has the potential to lead to difficulties in translating the current planning work occurring throughout the state into on-the-ground, actionable adaptation. There is a need to streamline coastal climate adaptation policy and for improved communication between local and state management entities.
- Future efforts should be dedicated to validating the leading sea level rise and coastal flooding models and to clarifying expressions of model uncertainty.
- The state's adaptation community is advocating for the integration of multiple modeling techniques, selecting the most appropriate facets of the various models in order to best address specific geographic regions in the state.
- Existing modeling and visualization tools are adequate to initiate local planning processes.
- Decision support tools must be tested by stakeholders to determine their performance and usability. In addition, while inundation scenarios can now be mapped using multiple 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 to planners and other practitioners. It is important that this shortcoming be addressed in order to effectively support and inform future local adaptation efforts.
- Adaptation planners in the state must arrive at consensus around best practices for incorporating economic considerations into adaptation planning. Successfully doing so will support efforts to adapt to climate change.
- Although frequently identified as the most limiting factor for communities in terms of their ability to adapt to climate change, there are few applied examples that incorporate economic considerations into adaptation planning and there is little to no consensus about the best practice for doing so. California can lead the way by exploring how best to consider the economic impact of climate change adaptation in practice.

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Introduction

The Need

Sea level rise and climate-driven extreme events pose serious risks for California's coastal communities. Decision makers and planners in these communities are increasingly aware of the risks and the need to plan for sea level rise by integrating hazard mitigation strategies into their land use and natural resource management plans. Local action is essential: the degree to which communities are vulnerable to climate change is influenced by local conditions, including cultural and community priorities, economic base, ecological setting, and local resources. However, there are multiple obstacles to adaptation at every step of the process, from understanding the issues to the range of challenges associated with appropriate planning and project implementation and management.

Multiple organizations have initiated projects designed to assist local communities with overcoming their adaptation challenges using a variety of types of tools, including sea level rise models, economic analyses, stakeholder engagement processes, and others. Because of the local orientation of these projects, however, it has been difficult to distill a suite of lessons learned from the overall body of work. Other coastal communities beginning to undertake adaptation planning projects of their own – as well as funders and state agencies – could benefit from understanding common obstacles to identifying and executing adaptation strategies, as well as key differences that would inform various approaches to adaptation.

The time is ripe and momentum is building for collaboration throughout California. ARCCA – the Alliance of Regional Collaboratives for Climate Adaptation – is an umbrella organization, founded in 2012, that brings together the four regional urban climate adaptation collaboratives in California for coordinated dialogue and preparedness planning. The California Coastal Conservancy and the Ocean Protection Council have recently offered grant funding for vulnerability studies and Local Coastal Program updates to encourage communities to plan for sea level rise. The California Coastal Commission also recently released a draft guidance document outlining its expectations for incorporating sea level rise into Local Coastal Program updates. Now more than ever, local planning projects are getting underway that could benefit from the experience of earlier on-the-ground efforts.

Thanks to these developments, the time was right to launch the California Coastal Resilience Network project. The project has focused on distilling lessons learned and best practices from coastal adaptation efforts already in progress throughout California. By identifying what has worked and what is missing from previous or ongoing adaptation efforts, we can help communities that are just beginning to think about adaptation to maximize their efficiency and prioritize approaches that are highly likely to work. The lessons captured in this report will allow state and local adaptation communities to learn from other local efforts and create bottom-up recommendations to best support local climate change adaptation along California's coast.

The California Coastal Resilience Network is a project led by The Nature Conservancy to:

- establish a California-wide network for collaborative learning among existing local sea level rise and coastal change adaptation efforts;

- develop guidance on best practices for local communities that are now initiating planning, based on lessons learned from local experts and informed stakeholders;
- work with recognized experts to compare and contrast approaches to modeling, mapping and decision-support tools, and adaptation economics; and
- develop recommendations from The Nature Conservancy to state and federal agencies on “road tested” ways to help local communities implement adaptation strategies.

The Approach

The Nature Conservancy sought advice and lessons learned from distinct planning projects underway along California’s coast. For each region, The Conservancy worked with local project lead(s) to identify best practices for stakeholder engagement. Wherever possible, additional input was sought from local project stakeholders. Expert panels were convened to help draft and review each section. These panels included technical and policy experts from a range of stakeholder groups, including state and local agencies, NGOs, and academia.

The Geographies

TNC consulted multiple ongoing projects up and down California’s coast in San Diego County; Los Angeles County; Ventura County; Monterey Bay; San Francisco Bay and Outer Coast; and Humboldt Bay.

The majority of the research was done through phone interviews with local geographic leads. In two of the geographies, Humboldt Bay and Ventura County – where stakeholder fatigue was a less significant concern compared with some of the other geographies – in-person meetings with stakeholders helped to provide feedback from additional perspectives.

In addition to working with ongoing local adaptation efforts, leading experts conducted comparative analyses of three key aspects of coastal climate change adaptation work: the sea level rise modeling techniques available for use in California; decision support tools most commonly used to assist with sea level rise adaptation and associated coastal management in California; and the suite of analytical tools for considering the economic impacts of climate change adaptation. The Network Project research confirmed the need for the community of adaptation practitioners in California to come together to continue to exchange information across geographies, to share lessons learned, to increase understanding of the highly technical aspects of adaptation, and to identify areas where interests and challenges align well for collaboration on adaptation efforts ranging from local/regional planning to on-the-ground adaptation.

The Projects

<u>Humboldt Bay</u>

The *Humboldt Bay Sea Level Rise Adaptation Planning Project* is a multi-phase assessment funded by the State Coastal Conservancy through the Coastal Ecosystems Institute of Northern California. Phase I included a shoreline inventory and sea level rise vulnerability assessment for the Bay area. Phase II is the Adaptation Planning Project, which has seen the development of inundation mapping and modeling specific to the project area, by Northern Hydrology and Engineering, and will culminate in the development of an adaptation plan co-led by the Humboldt Bay Harbor, Recreation and Conservation District and Humboldt County Public Works. The leading agencies have convened an Adaptation Planning Working Group, led by Aldaron Laird, adaptation planner of Trinity Associates, which represents stakeholder interests in the project area.

San Francisco Outer Coast & Bay

The *Our Coast Our Future* project demonstrates vulnerability to sea level rise and storms to coastal managers and planners in the San Francisco Bay and Outer Coast area. The project is the result of a collaborative effort on the part of the Gulf of the Farallones National Marine Sanctuary, Point Blue Conservation Science (PRBO), the U.S. Geological Survey, the San Francisco Bay National Estuarine Research Reserve, the National Park Service, and NOAA Coastal Services Center. The project was largely user-driven, through an extensive stakeholder engagement process, and closed with a series of training workshops to make ensure that local managers understand how to use the project's decision support tool to gather the information they need to make informed coastal management decisions.

The *Adapting to Rising Tides* project is working with communities in the Bay Area, starting with a portion of the Alameda County shoreline, to understand vulnerabilities and then increase resilience of coastal ecosystems and community services to sea level rise and storms. The ART project represents a partnership between the San Francisco Bay Conservation and Development Commission (BCDC) and NOAA Coastal Services Center (NOAA CSC), with support from ICLEI Local Governments for Sustainability, the Metropolitan Transportation Commission (MTC) and the California Department of Transportation (Caltrans). Phase I of the project convened a Subregional Working Group that identified important assets within the study area, set goals and objectives for the project, determined parameters for the vulnerability assessment, and developed a communications strategy. Phase II of the project consisted of an assessment of the project area's vulnerability to and risk from sea level rise and storms. Working closely with the Subregional Working Group, the ART project then identified a suite of possible adaptation responses. The project is now working with partners in the Bay Area to implement the lessons learned from the project as well as the suite of adaptation responses at both the asset and regional levels.

Monterey Bay

There are a number of disparate adaptation efforts happening within the Monterey Bay area, which could benefit from more structured coordination. The Monterey Bay National Marine Sanctuary and the Center for Ocean Solutions have initiated efforts to bring these diverse efforts together for focused conversations about coordinated adaptation efforts throughout the region.

As part of the development of *Integrated Regional Water Management Plans* for Santa Cruz and Monterey Counties, the Center for Ocean Solutions used the InVEST coastal vulnerability model to show where coastal habitats might be critical in protecting key assets from sea level rise and storms. This process helped to inform aspects of the IWRM plans for the two regions with respect to conservation, restoration and sustainable water management.

The Nature Conservancy's *Adapt Monterey Bay* project, partly funded by a State Coastal Conservancy Climate Ready grant, is analyzing the physical and economic impact of a series of stakeholder identified coastal climate change adaptation strategies for the Southern Monterey Bay area. The Nature Conservancy is working in partnership with a team of geomorphologists and engineers at ESA PWA and Revell Coastal, and a team of environmental economists (Dr. Ryan Vaugh, Dr. Philip King, Aaron McGregor, & Dr. Fernando DePaolis,) to conduct the analysis, as well as partners at the Central Coast Wetlands Group and a Steering Committee of local stakeholders and coastal managers in the region. The project convened its first Stakeholder Workshop in summer 2014 to identify critical assets and issues of concern within the project area and to identify realistic and appropriate adaptation strategies to be modeled and analyzed for the region. The Adapt Monterey Bay project is incorporating lessons learned from the California Coastal Resilience Network assessment and is working closely with the other ongoing adaptation projects throughout the region to coordinate efforts and streamline demands on stakeholder time.

Ventura County

The Nature Conservancy's *Coastal Resilience project in Ventura County* is designed to identify solutions to the social, economic and environmental disruptions brought about by climate change and coastal hazards. The goal is to use science, decision support tools, partnerships, and policy to create strategies that are cost efficient and effective for both people and nature. The project is driven by input from a comprehensive stakeholder Steering Committee and has worked with geomorphologists at ESA PWA to produce sea level rise and coastal flood modeling, visualized through TNC's Coastal Resilience decision support tool specific to Ventura County (soon to be part of a greater effort throughout the entire state of California – coming summer 2015!). The Steering Committee identified critical assets of concern which have been incorporated into the decision support tool in order to allow tool users to do their vulnerability assessments for key coastal features. The project conducted usability testing for its decision support tool to ensure that key users are familiar with the tool and can readily use it to generate the maps they need to inform coastal management decisions in the project area. As part of the project, The Nature Conservancy hired The Planning Center to identify and evaluate existing and potential planning tools that are critical to planning and adapting to sea level rise in Ventura County. The project is in the process of assessing the economic impact of nature-based versus engineered adaptation strategies across the County's coastline and is also identifying opportunities for pilot projects with key partners from the stakeholder Steering Committee.

Los Angeles Area

In Los Angeles, sea level rise adaptation planning began with the evaluation of vulnerabilities within the City of Los Angeles. The City of Los Angeles engaged the University of Southern California (USC) Sea Grant Program to lead *AdaptLA,* a sea level rise vulnerability study and adaptation planning process aimed at evaluating the impacts of coastal climate change within City boundaries, promoting regional partnerships across agencies, and increasing public awareness and input in climate adaptation. The study released in January 2014, assessed the physical, social, economic and ecological vulnerabilities of City assets, resources and communities. For this project, USC Sea Grant and leaders from City agencies partnered with the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC), ICLEI-Local Governments for Sustainability, the U.S. Geological Survey, leading academic researchers, and a broad team of regional stakeholders to develop and review the study. *AdaptLA* has since been expanded to a regional project including 11 cities in Coastal Los Angeles, the County, and a number of other supporting organizations to evaluate coastal climate change impacts within County boundaries, promote regional planning, and build capacity in local departments and agencies.

San Diego County

In 2012, ICLEI-Local Governments for Sustainability released a *Sea Level Rise Adaptation Strategy for San Diego Bay*, which was funded by The San Diego Foundation's Climate Initiative, and developed with oversight of a Public Agency Steering Committee including the Port of San Diego, its five member cities and the San Diego Regional Airport Authority. Additionally, a large group of regional and technical experts as well as bay-front stakeholders were engaged to provide advice, community input and technical analysis in the 18-month long process. The group conducted a vulnerability assessment to determine the impact of sea level rise on 12 sectors of valued community assets and then used that information to develop recommendations to improve the resiliency of those assets.

The *Port of San Diego* adopted a *Climate Action Plan* in 2013*,* which is focused on greenhouse gas emissions reductions. Concurrent with the development of the Climate Action Plan, the Port has also begun planning for climate change adaptation. The Port has begun to incorporate adaptation into various design and planning efforts, including the Integrated Natural Resource Management Plan, which is likely to address climate change adaptation through protection of critical coastal habitats.

Climate Understanding and Resilience in the River Valley (CURRV) is a collaborative effort led by the Tijuana River National Estuarine Research Reserve (TRNERR), assessing local vulnerabilities to inform the development of climate adaptation strategies that jointly address the climate change impacts of sea level rise and riverine flooding. A Steering Committee, comprised of representatives from public agencies that manage the natural and built resources throughout the Tijuana River Valley, is actively collaborating on the project, under the guidance of science and technical advisors and with input from a Stakeholder Working Group that includes public agencies, academia, nonprofits, and a diverse stakeholder base invested in the future of the River Valley. The project was convened in 2013, and aims to finalize planning and shift its focus to implementation in 2015. This project is funded by a grant from the Coastal and Ocean Climate Applications Program of the National Oceanic and Atmospheric Administration (NOAA)'s Climate Program Office, and supported by a grant from the National Estuarine Research Reserve System (NERRS) Science Collaborative.

Stakeholder Engagement

Stakeholder engagement is a critical step in conducting any kind of 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 reality check on the theories and putative best practices of stakeholder engagement in climate adaptation planning by comparing them to the experiences of practitioners engaged in adaptation planning projects in California.

Through in-person and phone interviews, TNC's Coastal Resilience team gathered lessons learned from multiple geographies along California's coast that are undertaking adaptation planning projects. These geographies and projects include:

- Humboldt Bay
    - Humboldt Bay Sea Level Rise Adaptation Planning Project (Trinity Associates)
- San Francisco Bay & Outer Coast
    - Our Coast Our Future (OCOF; multiple Bay Area partners)
    - Adapting to Rising Tides (ART; San Francisco Bay Conservation and Development Commission)
- Monterey Bay
    - Integrated Regional Water Management Plan (IRWN; Center for Ocean Solutions)
    - Adapt Monterey Bay project
    - Multiple bay-wide coastal hazard and sea level rise vulnerability assessments and Local Hazard Mitigation Plan updates
- Los Angeles
    - AdaptLA (USC Sea Grant)
- Ventura County
    - Coastal Resilience – Ventura Project (TNC)
- San Diego County
    - Climate Mitigation and Adaptation (Port of San Diego)
    - Sea Level Rise Adaptation Strategy for San Diego Bay (The San Diego Foundation)
    - Climate Understanding and Resilience in the River Valley (CURRV) (Tijuana River National Estuarine Research Reserve)

The following discussion provides a "reality check," comparing the practical lessons from these projects to the theoretical best practices for stakeholder engagement identified in a review of key literature. This section aims to provide a clear picture of how the process of working with multiple partners and participants in a climate adaptation planning project may differ from what the literature emphasizes, and adjusts each best practice accordingly. In the projects reviewed, the reality of successfully engaging with stakeholders often differs in key ways from the theory. For communities that have not completed an adaptation planning process, this section highlights the key principles they should follow. A timeline of Coastal Resilience Ventura follows, highlighting salient comparisons or contrasts with the theories of stakeholder engagement.

Best Practices Reality Check

Best Practice #1: Present a range of possibilities and acceptable outcomes when facilitating a decision-making process.

Reality: In reality, facilitators often have their own agenda, which can affect their subjectivity with respect to the range of possibilities for action; the range of possibilities should ideally be defined by local managers empowered with the time and resources to proactively plan for adaptation.

In Ventura, and elsewhere, The Nature Conservancy's Coastal Resilience (TNC CR) project does not present all possibilities as equally tenable and agreeable: The Nature Conservancy is an environmental conservation organization with an undeniable mission of protecting nature, habitat, and ecological systems. Consequently, TNC CR project leads have made this goal explicit in the assessment of coastal climate change adaptation scenarios in Ventura. In stakeholder meetings alternative methods for adaptation were identified, including a traditional engineered approach described as "armor in place" and an ecosystem-based approach that emphasized conservation of wetlands and other coastal habitats. Project leads had to present ecosystem-based adaptation, their preferred outcome, as one component of a larger suite of adaptation strategies. TNC will continue to work with stakeholders to discuss a suite of adaptation options that protects critical infrastructure and community assets while also prioritizing conservation of coastal habitat.

In San Francisco, ART project leads noted that an "open house" style workshop can also be effective. This collaborative approach facilitates communication among the stakeholders without direct guidance by project leads. In the context of designing adaptation strategies, this means emphasizing the potential synergies among multiple outcomes of a decision. Project leads also noted that it can be difficult to set expectations for what the project lead or lead agency might be able to deliver if the discussion is too open-ended at the outset.

In Humboldt Bay, the Adaptation Planning Working Group that represents the region's stakeholders also took a more collaborative approach, focusing on understanding the issues first and then stakeholder-driven adaptation planning second. The group helped to inform the vulnerability and risk assessments, collectively educating themselves about the area's vulnerabilities. Now that the group understands current and future threats, they are working to develop stakeholder-driven adaptation strategies.

Revised Best Practice #1: Communicate the extent to which the project leads' goals can be met with a suite of options and adaptation strategies that would produce acceptable outcomes. Begin by identifying mutual and/or compatible goals so that users and facilitators both gain from the relationship.

Best Practice #2: Begin with the participants' needs and goals in mind to understand what motivates them.

Reality: 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. In Ventura, TNC CR project (CRV) leads recognized the need to communicate in a way that resonates with their partners and stakeholders. Consequently, they have worked with participants to identify the relevant vulnerable infrastructure and properties and develop appropriate alternative adaptation strategies. CRV stakeholders noted that the project team listens well and incorporates stakeholder input. In San Francisco, OCOF asked participants how the management community would use the decision-support tool in the Bay Area and what their needs were for the tool in terms of technical capabilities and the user interface. In Humboldt, project leads identified early on the need to work with representatives of the agricultural and ranching industries to identify appropriate strategies to generate community buy-in. Early incorporation of their priorities may lead to agriculture-focused strategies that compromise conservation outcomes for greater political and social feasibility.

Some stakeholder groups might be more vocal in expressing their needs and goals than others. For example, Port of San Diego project leads observed that certain stakeholders were active in engaging the project's board, while the other stakeholders did not express themselves as well, reinforcing the need to provide each participant with varied opportunities to give input. Project leaders must continually balance the stakeholders' needs with the desired outcome of the project, recognizing that compromises are inherent to achieving mutual gain.

Revised Best Practice #2: Begin by identifying mutual and/or compatible goals, so that users and facilitators both gain from the relationship.

Best Practice #3: Prioritize knowledge sharing processes over delivering explicit results.

Reality: The collective experience of the projects polled here suggests that stakeholders are very interested in explicit results. Localized modeling outputs and new tools play a significant role in today's climate change planning environment. Ongoing uncertainty about local impacts makes planning and implementation difficult. Planners want more accurate predictions of sea level rise impacts to guide their work. As a result, stakeholders might be less likely to participate in projects without the possibility of gaining new information (e.g., more advanced or localized modeling) or new, proprietary tools. It may be harder to get stakeholders involved by suggesting, for example, a collaborative effort to identify the most useful existing tools and apply them to a new geography. Coastal Resilience Ventura may have succeeded in attracting stakeholders to participate by virtue of the innovative modeling techniques it offered. ART participants wanted to see the specific actions that might be taken to address each vulnerability.

Stakeholders want to identify implementable actions and barriers to said actions. However, this demand for localized data is not mutually exclusive of knowledge-sharing. Project leads in Humboldt have brought together participants from a diverse assortment of agencies and organizations specifically to facilitate knowledge exchange. This process will not only support the development of actionable adaptation strategies, but has already improved understanding of jurisdictional responsibilities, areas of management overlap, and inter-organizational communication. Ongoing projects demonstrate how knowledge-sharing can occur not in spite of the need for tangible outcomes, but rather through their development.

Revised Best Practice #3: Emphasize knowledge-sharing processes while recognizing that localized analysis and tools appeal to stakeholders and can facilitate greater knowledge transfer.

Best Practice #4: Link information producers, such as scientists or modelers, with information users, such as policy or decision makers.

Reality: This is a widespread strategy utilized by climate adaptation planning projects, but it is important for all participants to understand the types and scale of information needed by various stakeholders. The Coastal Resilience Network has identified several geographies in which local and regional agencies are collaborating with NGOs, working together to provide scientific and technical guidance for planning. CRV provides technical modeling support to stakeholders, including city and county staff, who may be able to utilize the CRV tool in long-range planning decisions and to guide development in and around the coastal zone. The OCOF project sought to engage the management community in the Bay Area directly in the design of the OCOF decision-support tool through extensive breakout groups and detailed exercises. The Humboldt Bay project has engaged with local decision makers at the city and county level, as well as key stakeholders like the Farm Bureau. The Center for Ocean Solutions (COS) led the Monterey IRWM process and facilitated a collaborative vulnerability assessment using the InVEST tool.

In all of these projects, project leads connected data generation and modeling to local decision makers. However, they have 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 note the need to balance quantity, quality, and practicality of data requests.

Revised Best Practice #4: Link information producers and users, while understanding that the level of information desired by scientists and by diverse decision-makers may differ dramatically.

Best Practice #5: Design projects and processes to facilitate learning, knowledge transfer, stability and continuity.

Reality:

This best practice is a valid goal, but one that may have to be adjusted as personnel, political climate, stakeholders, and other factors change. CRV seeks to achieve this goal by developing a tool based on the best available science and modeling techniques. CRV project leads hope to work with higher level stakeholders, including the State Coastal Commission, to receive formal recognition of the validity of Coastal Resilience as a planning tool, which would provide added consistency for local decision makers. Stakeholders have expressed interest in developing a Memorandum of Understanding with The Nature Conservancy to provide additional stability, ensuring the continuity, longevity, and ultimate success of the CRV project. Stakeholders also noted the importance of maintaining the CRV tool as a living resource and providing additional opportunities for training and outreach. Humboldt project leads have encouraged increased communication among participating agencies, encouraging knowledge exchange both during the project and after its completion. The CURRV Project anticipates that the general collaborative nature among the public agencies that manage the Tijuana River Valley's resources will support implementation of the strategies decided upon, thus ensuring continued and consistent engagement in the project.

Project leads also noted that 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. For example, in nearly all of the projects reviewed, there was some turnover among stakeholders over the course of the project. The AdaptLA project was perhaps the most significant example of this, as the project itself was initiated by the then-Mayor. A change in office necessitated that the project leads wait out the transition, bring new officials up to speed, and include the new leadership in the process to ensure the results were acceptable and useful in the new political climate.

Each of the projects reviewed also noted that stakeholder groups can shift over time – with job turnover either at the managerial or political level – and that as projects mature, they can shift from a regional focus to a more site-specific level. At the outset, adaptation planning processes often cast a wide net and include a variety of stakeholders at the table; as the processes continue, the strategies and projects often become more targeted and site-specific. At this point, the focus often turns to more one-on-one work with land owners and managers. It is often at the more detailed or site-specific level that advocacy groups also become key partners. Projects need to find the balance between providing continuity, stability, and continued engagement to active stakeholders, and responding to changing stakeholder group composition; they must support a learning process in an atmosphere that challenges the traditional understanding of stability and continuity.

Revised Best Practice #5: 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.

Best Practice #6: Build connections across disciplines and organizations while targeting the right audience.

Reality: 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. Projects led by agencies with a specific agenda or interest at stake will likely target specific constituencies (e.g., planning officials/agencies) and will choose to communicate their science and goals using language and strategies that resonate more with their target audience than with others. For many projects, the right audience for converting information into action might be an isolated few actors (e.g., planners). However, with the aim of facilitating a truly collaborative and participatory project, many projects might involve a more diverse population of stakeholders. For example, ART project leads identified the need to include more than what they describe as the "usual suspects."

The target audience may also change as the project evolves or progresses through phases. For CRV, the NGO CAUSE (Central Coast Alliance United for A Sustainable Economy), which focuses on social, economic, and environmental justice advocacy, expressed that they do not consider SLR to be of major concern given the temporal scale and the immediacy of other social stressors in the Ventura area. Consequently, it appears that the communication and engagement tactics of CR Ventura did not effectively reach this audience, an outcome that is not unexpected given the project's emphasis on engaging planners. In addition, the right audience might vary for different components of the project. For example, the Steering Committee for the CURRV Project includes the public agencies that own and manage land in the river valley, with each member agency playing a critical role in implementing adaptation strategies. The Stakeholder Working Group includes a broader assortment of regional stakeholders to ensure that the project incorporates multiple perspectives and expertise. Finally, the CURRV Project's technical and science advisors change based on the process, adapting to a flexible methodology as needed. The right audience depends not only on the project context, but on the stages of the project and the support needed.

Revised Best Practice #6: 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.

Best Practice #7: Provide opportunities for active involvement in decision-making and offer opportunities for iterative input to adaptation alternatives.

Reality: Real-world timetables, deadlines, and the limited number of iterations through which a process should proceed in order to maintain momentum might restrict stakeholder input to one or a few sessions. In addition, while stakeholder input is critical, sometimes stakeholders lack the technical knowledge to offer green solutions to sea level rise-related problems, even if they support a natural approach. Substantial structure and guidance should be provided when asking for stakeholder input, in order to avoid distracting from a project's central goals.

CRV stakeholders consistently noted they received appropriate opportunities to provide input and feedback into the CRV process, and that CRV project leads incorporated this input into the project. However, the relationship between project leads and stakeholders is not always so easy. Project leads for ART in San Francisco Bay noted that stakeholders offered a substantial array of concerns when given the opportunity to provide input, complicating the goal of addressing all of their needs. This issue will likely remain a challenge for future projects.

Coastal Resilience Ventura has erred on the side of fewer meetings, to ensure that stakeholders invest in these meetings sufficient enthusiasm and motivation when called upon to do so. As a result, some stakeholders have even expressed a desire for additional communication opportunities, highlighting the need to continually strive for an appropriate balance. Participants may also be less knowledgeable about the issues at hand than the project leads. Local decision makers in the Bay Area and Ventura did not have previous knowledge of various adaptation strategies and thus could not provide significant input until the project leads had suggested options.

Other projects also emphasized the role of stakeholders in providing input. A standing SF Bay Advisory Committee assisted in making critical decisions for the OCOF project. The CURRV Project recognized early in the project cycle that technical and science advisors had a significant role to play in providing input, leading to targeted engagement as part expert workshops, in addition to engagement with the larger Stakeholder Working Group. Overall, broader Stakeholder Working Group meetings were needed to engage a more extensive stakeholder community, but the process allowed for these larger gatherings to occur less frequently than targeted expert meetings and interviews. The planning process for the Port of San Diego also emphasized frequent engagement to encourage buy-in and provided stakeholders with significant decision-making responsibilities. In each geography, stakeholders were provided opportunities to give input. However, project leads consistently identified the need to provide participants with sufficient background knowledge and guidance before decisions could be made.

Revised Best Practice #7: Provide opportunities for participants to regularly provide input, while recognizing that they may not have extensive experience with adaptation strategies or be able to play a decision-making role.

Best Practice #8: Avoid jargon; find clear and concise ways to communicate science and frame the project.

<u>Reality</u>: The projects reviewed as part of this effort have all adhered closely to this principle. Despite efforts to maintain clarity, challenges do remain, particularly when stakeholders with diverse backgrounds and training participate. CRV stakeholders have noted the effectiveness of project leads and contractors in communicating technical information in an easy to understand way. However, they

have consistently identified the terms “green infrastructure” and “nature-based adaptation” as vague terms with the potential for misinterpretation. ART stakeholders required clarification on the technologies and metrics being used. For example, rating systems like "high, medium, and low" may appear straightforward, but likely require additional definition for certain stakeholders. OCOF stakeholders experienced confusion about the various sea level rise tools already available (ART, NOAA SLR Viewer) and how the new tool would differ. Project leads communicated with personnel from NOAA and BCDC about how to present these tools in a coordinated fashion.

To facilitate the transfer of knowledge, the Coastal Resilience Ventura project uses the sea level rise and coastal hazard modeling conducted by ESA PWA to frame the project, connecting users to the producers of information and increasing the salience, credibility, and legitimacy of the information produced. The COS IRWM project focused information exchange through the InVEST model, which was used to communicate climate change vulnerability science and economic information. The CURRV project has chosen to work with existing modeling and maps. In Humboldt Bay, Trinity Associates and Northern Hydrology conducted a vulnerability assessment in coordination with the project’s Adaptation Planning Working Group to develop new maps of vulnerability for the project area. Project leads must be willing and able to communicate at various levels of technical complexity to effectively reach and engage representative and diverse stakeholder groups.

Revised Best Practice #8: Avoid jargon and communicate science clearly and concisely, recognizing that stakeholders will have various levels of technical training and scientific expertise.

Best Practice #9: Maintain consistent and ongoing communication with participants.

Reality: Although it is essential to maintain continued communication with participants to ensure stakeholders are informed and engaged throughout the life of the project, a consistent finding across CA was that stakeholders are 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. Many stakeholders in these projects have busy schedules and numerous other commitments. Sea level rise presents significant temporal scale challenges, demanding that stakeholders have the motivation to address longer term planning horizons. Stakeholders’ vision and motivation may be strained if they are continually tapped for participation in meetings and workshops. In addition, many stakeholders participate in more than one committee or working group, and thus stakeholder fatigue is a valid concern. ART project leads noted the importance of a clear communications strategy. They emphasized that projects should streamline ongoing communication and use follow-up tools such as interviews and surveys to maximize efficiency and participation. OCOF project leads outlined the differing strategies for the San Francisco Bay component of their project, which involved a standing committee that met quarterly, and the outer coast component, which held initial workshops and several focus groups at the end, but not ongoing meetings. Humboldt project leads have noted the ease with which they can bring everyone to the table, as their smaller community size facilitates more communication. Building upon experience convening stakeholder meetings for the *Sea Level Rise Adaptation Strategy for San Diego Bay,* and recognizing the potential for stakeholder fatigue, CURRV embarked upon an approach that combined expert workshops focusing on specific stakeholder interests, one-on-one informational interviews, and email updates. It was found that this was more desired than numerous broader stakeholder meetings for the Tijuana River Valley.

Alternatively, the Port of San Diego's planning process engaged its stakeholders frequently. When the project was in its active stages, the team reached out to stakeholders at least once a month. The team would also check in with stakeholders during longer gaps between meetings to provide project updates. In general, according to the projects consulted as part of this review, participants appreciated regular, concise updates on projects and fewer, efficiently run in-person meetings.

Revised Best Practice #9: Maintain consistent and ongoing communication with participants, while limiting time/money/energy-intensive face-to-face meetings to minimize stakeholder fatigue.

Best Practice #10: Provide structured, focused discussions during meetings to maximize efficiency of in-person meetings.

<u>Reality</u>: While stakeholders want to feel that their time is being used efficiently, they also appreciate the opportunity to brainstorm and share their own ideas. Ventura stakeholders noted that the project leads provided opportunities for them to drive discussions and influence key decision points; they mentioned that agendas were organized such that working group participation was easy. Some representatives of public agencies noted that the time needed to participate presented a major challenge, reinforcing the need for efficient work sessions. ART project leads noted the importance of conducting due diligence prior to making group calls, planning ahead and being realistic about timing and space required for meetings. The smaller community of planners and relevant stakeholders in Humboldt facilitated more face-to-face conversations. Everyone involved can be seated at the same table and communicate directly with each other, encouraging relationship-building and collaboration. The CURRV Project identified the importance of being upfront about the time commitment required on the part of stakeholders, recognizing the need for flexibility as the methodology evolved. Additionally, the team identified the most critical factors for making informed decisions prior to convening their expert workshop, allowing them to maximize the time they had with the participating expert stakeholders. Several project leads and participants noted the benefits of having larger, more open-ended discussions to allow brainstorming and facilitate creative thinking. In general, it is critical to prepare carefully for in-person meetings to maximize efficiency. Efficient meetings will more easily allow for brainstorming and knowledge sharing.

Revised Best Practice #10: Provide structure and focus for discussions during meetings value of in-person interactions amongst participants while providing opportunities for brainstorming and idea sharing.

Best Practice #11: Provide salient (relevant to the policy context), credible, and legitimate information produced using a collaborative process.

Reality: Implementation of this best practice requires a truly participatory engagement process that involves a representative selection of community members. CRV has strived to achieve this by engaging with stakeholders from public and non-profit interests. One stakeholder observed that a good sample of the community had participated on the steering committee. Some notable challenges remain. Agricultural interests have not been involved in the CRV process. Project leads have also noted challenges in communicating the urgency of climate change adaptation planning to the constituency of the advocacy group CAUSE. In San Francisco, ART participants wanted to completely understand the vulnerability and associated risks before undertaking any decision-making. Project leads noted the difficulty in providing all of the desired information to stakeholders; complete information sharing may require compromise and may not achieve an ideal level of "salience." On the other hand, additional detail on vulnerability or project-level projections is likely to be a common request. Consequently, the ability to compromise and provide the level of detail necessary for decision-making is critical to any successful adaptation planning process.

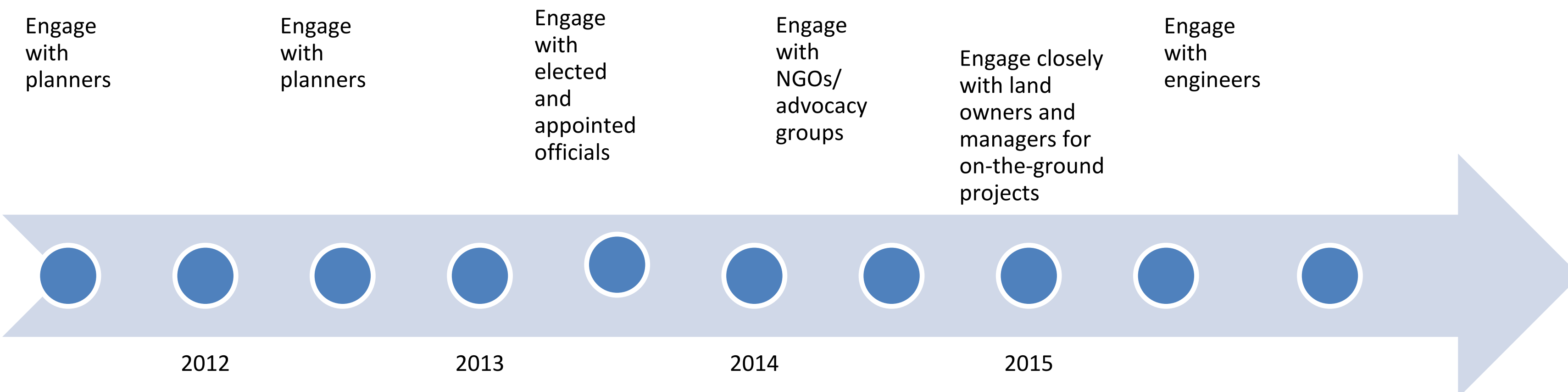
Another example of a successful collaborative process is OCOF, which engaged over 140 attendees in three workshops and asked the appropriate questions to ensure the relevance of their tool. OCOF also divided its project into the SF Bay and the outer coast to ensure that the tools were sensitive to varying geographical contexts.

In Humboldt, project leads are working collaboratively with representatives of public, private, and non-profit interests. The Port of San Diego project brought together a stakeholder working group and provided the group with decision-making responsibility, ensuring collaboration. Stakeholders helped to define risks and provide input to the analyses. The CURRV Project facilitated a collaborative process by forming two groups: a Steering Committee and a Stakeholder Working Group, both of which included technical and science advisors. Project leads learned from other projects, including those of TRNERR's partners, and incorporated a collaborative charter co-developed with the Steering Committee to ensure everyone was in agreement regarding roles and timelines. This living document built an established and agreed-upon partnership and collaboration, while remaining flexible and responsive to ongoing project needs.

Revised Best Practice #11: Provide salient (relevant to the policy context) and credible information through a collaborative process, while recognizing that collaboration and representativeness may require compromises.

Coastal Adaptation Projects – Timeline & Target Audience

Most of the projects studied here have experienced dramatic shifts in their target audience throughout the life of the project. Initial stages are often conducted with a comprehensive stakeholder group, representing municipalities and coastal managers from the national, state, regional, and local levels. Generally speaking, projects kick off by casting a sweeping net out for stakeholders, bringing anyone with interest in the issues to the table to voice all concerns. In this manner, an atmosphere of open dialogue is created that establishes trust in the process and among the project proponents and the managers and stakeholders. As the projects progress, key stakeholders, often those municipal planners most poised for action, are identified and become strong partners. The projects can linger in the planning stages for any length of time, depending on the local political climate and timing of the engagement. However, the complexity of these issues, political will, and financial resources place upper limits on the ability of planners alone to take the drastic action necessary to protect the coastline. Eventually, the ultimate goal is that the project, or some derivative group of stakeholders, takes a more site-specific, on-the-ground focus on implementation. Advocacy groups are key to these efforts, 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.



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Sea Level Rise Modeling Techniques

Multiple initiatives in California are working to model the impacts of climate change, including sea level rise (SLR) and storms, on the California Coast. In December 2012, a collaboration among the Ocean Protection Council, the Tijuana River NERR, USC Sea Grant and the West Coast Governor's Alliance on Ocean Health brought together coastal managers and numerical modelers for a workshop entitled *Beyond Bathtub* to improve managers' understanding of the various models and tools available to help analyze the impact of climate change and coastal hazards in California. The workshop highlighted the fact that cutting edge modeling techniques now go "beyond bathtub"[2] to consider dynamic, storm-driven coastal flooding and shoreline changes. Workshop attendees identified the need for a summary of each relevant model to help coastal managers identify the applicability of each and interoperability between them. That summary of models is provided here, with an additional discussion of the potential for collaboration among the existing models.

> 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 (referred to in this report as the NOAA 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 a subsequent section of this report.

The Nature Conservancy, with support from Resources Legacy Fund, contracted with ESA PWA to summarize the modeling efforts to date and to solicit peer review from key modelers associated with each initiative as well as from coastal policy specialists in California who will utilize this report. Once the initial analysis was completed, technical and policy experts were contacted to review the document and provide key feedback, as well as staff members of the State Coastal Conservancy and the California Coastal Commission.

The purpose of this summary is to compare and contrast the various models in an effort to provide coastal managers with the information necessary to begin answering the following questions:

1. What differentiates the models and how do I select which models to apply?
2. Why, and for what conditions, were each of these models developed?
3. What are the technical differences among models?

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[2] A bathtub model shows inundation solely based on an elevation contour and does not consider possible pathways for water flow. For example, in a bathtub model, everything below a given number of feet is flooded, which can include ponds or other low lying areas that are not hydrologically connected. Newer models incorporate consideration of hydraulic connectivity.

In outlining the differences among models, we assume that readers do not intend to actually operate the models themselves. For each model, users will require specialized software (GIS, MATLAB, Delft3D, SWAN, etc.), technical skills to acquire and pre-process data and manipulate the models, and professional judgment to evaluate the model results. While several of the models are proprietary (Pacific Institute, Scripps, ESA PWA), even the open source models (NOAA, USGS) have these requirements. Even simple “tweaks” might involve weeks of rerunning models or reprocessing large data sets, which is why, although open source models exist, no outside entity has attempted to run them to-date, even with the guarantee of complimentary USGS or NOAA guidance. Because running these models is so technically demanding, and the output data are so complex, agencies have worked closely with stakeholders to identify modeling needs and then hired the model creators to run the models. They typically then work with web specialists to incorporate the modeling results into either web mappers or decision support tools that display the information in a format suitable for use by managers and decision makers.

Additionally, while the tables below indicate the outputs and types of projections each model provides, there is no direct measure of how well the models perform against observations or how they compare with other models. While each model can predict a number of impacts (e.g., waves, flooding, shoreline change), there is no way to evaluate the relative skill of each model, or to be able to truly compare among models without a consistent measure of model accuracy. Part of this difficulty lies in the absence of robust data sets for model testing (e.g., measurements of water levels, waves, flooding extents, etc.) and also in the fact that each model is usually applied in a different geographic setting, making inter-model comparisons impossible. That being said, it is standard practice to calibrate and validate these types of models by comparing results during historical storms to observations at tide gauges and wave buoys.

Even without specific quantification of model accuracy, the models reviewed here use of state-of-the-art approaches, and the results they produce are believed to be adequate to guide land use planning at parcel, site, and regional scales. Many of the models do find ways to describe the uncertainty in their projections. For example, although there are uncertainties inherent in flood modeling, some of the models have incorporated methods of calculating the level of certainty that particular areas will be at risk. Many of the models are run using numerous sea level rise projections and for multiple time series to capture and account for some of the variability associated with modeling coastal flooding. If a parcel is deemed to be at high risk by nine out of ten model runs, it would be unwise for decision makers to grant or reissue permits for critical infrastructure in that place. The trust in the reliability of these models is illustrated by the fact that in July 2014, the City Council in Oxnard approved a moratorium on proposed plans to build a new power plant along the city’s shoreline. The mayor cited maps, produced by The Nature Conservancy from the ESA PWA modeling and illustrated through TNC’s CoastalResilience.org decision support tool, as proof that the coastal flooding risks related to sea level rise were too high in that area to allow for such development.

A more detailed level of engineering vulnerability analysis beyond what these models provide can further assess the potential failures of critical infrastructure components on a site, parcel, or structural level. For example, a pipe in a wastewater treatment plant can be flooded and not necessarily fail. However, if an air vent is underwater or if buoyancy forces on a pipe move or break it, then the plant as a whole can malfunction. At present, this complex and detailed site-level engineering analysis is not included in this model comparison, nor do the models evaluated here produce outputs that allow consideration of these structure-level specifics.

The Sea Level Rise Models

The five models listed below were selected for comparison; a brief discussion of each model is provided below, with links to each web-based tool or viewer, followed by a series of tables that compare various key aspects of the models.

- Sea Level Rise and Coastal Flooding Impacts Viewer (NOAA)
- Pacific Institute (PWA)
- The Nature Conservancy Coastal Resilience - Ventura (ESA PWA)
- CoSMoS as applied to Our Coast Our Future (USGS)
- Navy/Scripps model as applied to Naval Base Coronado

In addition, three other models, the Scripps -Yates model, the BreZo model, and the Humboldt Bay model, are also mentioned briefly in this report but have not been included in the tabular comparison because their application is either not along the open California coast (exposed to significant episodic wave energy) or they have not yet been applied to identifying hazards associated with climate change. However, these models show promise in improving the existing modeling efforts and should be assessed further as they are applied elsewhere

CoSMoS 3.0

At the time of this report, a modeling effort regionally known as CoSMoS 3.0, incorporating several strengths of other models, is modeling the impact of sea level rise and coastal storms for Southern California from Pt. Conception to the Mexican border. This project is significant in that the newest CoSMoS methodology incorporates long-term coastal change and fluvial inputs, improving upon the previous CoSMoS modeling methodology utilized previously throughout the state. This effort represents a significant attempt at integrating the strongest aspects of each modeling technique from ESA PWA, Scripps, and other groups. Although this would be a creditable example of how a "super model" – a fusion of the strongest aspects of each of the individual models consider here – might be applied, this effort is still under development and, at present, has not released a sufficiently detailed scope to be included in this analysis.

NOAA

http://csc.noaa.gov/digitalcoast/tools/slrviewer

This model was developed by NOAA's Coastal Service Center to provide a tool to view the impacts of sea level rise consistently across the country by raising awareness of changes to future high tides. 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. The process used to map sea level rise inundation can be described as a linear transgression approach (tidal waters are projected inland based on limited hydraulic connectivity) that attempts to account for local and regional tidal variability around the country. The model includes hydrological connectivity[3] and represents uncertainty in two ways: the first is a confidence layer that incorporates errors from the LiDAR topography and the vertical datum adjustments; the second is identification of a low lying areas adjacent to the inundated areas for which hydraulic connectivity is unknown, erring on the side of caution with respect to what areas will flood. Other impact interpretation layers are available, including the Social Vulnerability Index (SVI) and a Coastal Land Cover data set.

Strengths – Easy to use, interactive tool. Results are available for the broadest range of geographies of any of the models in this comparison. Good communication of uncertainty and links to potential societal and wetland impacts at a statewide/regional level.

Limitations – Does not address coastal hazards associated with erosion, waves, or storms, and has limited resolution of hydraulic connectivity.

Pacific Institute (ESA PWA)

http://www.pacinst.org/publication/the-impacts-of-sea-level-rise-on-the-california-coast/

This model was developed by ESA PWA with funding from the Ocean Protection Council in support of Pacific Institute work on sea level rise. The model utilized the 2009 downscaled Global Climate Model for California and applied multiple scenarios to project erosion and flooding hazards for the entire California coast, using the best statewide data sets of topography and historic trends in coastal erosion available at the time. The erosion model was driven by a backshore classification that considered geomorphology (slopes, elevations) and geology, important physical properties of the coast that affect erosion processes. Coastal flood mapping was based on bathtub inundation without hydraulic connectivity. The project underwent extensive technical review by researchers at USGS, UCSC, Scripps, Oregon State University, and the California Coastal Commission. Data were utilized by the Pacific Institute to evaluate socio-economic and environmental justice impacts and changes in habitat across the state.

[3] Hydrologic connectivity is the possible flow pathway of water. Considering hydrologic connectivity in a model will illustrate where water can and cannot flow due to armoring, dams, walls, and other flood control infrastructure. A model that incorporates hydraulic connectivity is in direct contrast to a bathtub model, which shows inundation solely based on an elevation contour and does not consider possible pathways for water flow.

Strengths – Systematic approach to mapping future coastal hazards across the state (did not include erosion for southern California) utilizing the best available information at the time. Included geology and geomorphology at a planning level and the best available wave transformation and downscaled climate model data produced during the California Energy Commission 2008 Impact Assessment.

Limitations – No integration of coastal erosion and flooding; no fluvial flood hazard analyses. Did not include erosion for Southern California. No analysis of uncertainties. Backshore characterization layer used to drive GIS modeling and mapping was not included in deliverables. Improved LiDAR data is available now.

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

http://coastalresilience.org/geographies/ventura-county

This Ventura County-wide model builds upon the Pacific Institute model (above) with funding from TNC and Ventura County (ESA PWA 2.0). The coastal hazard modeling included in this effort utilizes FEMA hazard identification methodologies and projects them into the future while combining them with sea level rise and coastal erosion. The project and deliverables were guided by a steering committee representing all of the municipalities in the study area, as well as federal and state agencies and several NGOs in the county. Five distinct hazards were 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. The model included consideration of changes to precipitation, coastal armoring, and wave phase. Management scenarios were incorporated into the modeling to assess the physical impacts of nature-based versus engineered adaptation strategies as part of an economic analysis aimed at providing the costs and benefits of the two adaptation approaches for the Ventura County coastline.

Strengths – Integrated process-based coastal hazards assessment, including time-stepped coastal erosion leading to hydraulically connected coastal flooding. Also included climate effects of precipitation on sea level rise and river flood extents. Uncertainty addressed through a spatial aggregation method to represent relative risk. All data to be made publicly available through an interactive web-based decision support tool.

Limitations – Limited spatial extent. Coastal hazard models based on equilibrium response (assumes the beach remains the same shape into the future as opposed to morphological evolution, which could be caused by changes in sediment grain size, management responses, etc.. CoSMoS does a morphological analysis for storm impacts but does not combine with SLR). Model not calibrated with hindcast data. Coastal flooding hazards not based on statistical recurrence intervals but rather on historic events. Alongshore sediment transport not included. Sediment budget only included indirectly through historic trends of coastal change.

CoSMoS 2.0 via Our Coast Our Future (USGS)

http://data.prbo.org/apps/ocof/

This model utilizes results of the latest Global Climate Models (GCMs), feeding the GCM results into a global wave model to develop 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 projected onto a 2-meter Digital Elevation Model (DEM) 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 (e.g., DEM, model skill) along with projections of wave heights, nearshore current strength, and storm event-based beach changes.

Strengths — Use of latest global climate models to predict the future wave climate along the California coast. Extensive evaluation of model skill in predicting flood extents, waves, and water levels using historical observations. Includes wave transformation modeling across the shelf and surf zone. Models wave-current interactions. Good representation of uncertainties in hazard mapping. Shows storm event-caused beach erosion and coastal flooding. Model outputs available through an interactive web-based decision support tool.

Limitations – Does not evaluate future long term coastal evolution. Storm scenarios/recurrence intervals are determined regionally by the future wave climatology offshore in deep water, not by total water levels at the coast. Alongshore sediment transport and sediment budget not included.

Navy/SPAWAR methodology as tested at Naval Base Coronado and Marine Corps Base Camp Pendleton

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 developing a method of projecting future coastal hazard impacts on coastal DoD installations. Full release of the technical documentation is awaiting final revisions and review. Based on the executive summary, the primary goal of this project was to develop methods for assessing impacts of local mean sea level rise and associated phenomena on military infrastructure with a focus on conditions representative of Southwestern United States coastal military installations such as Naval Base Coronado and Marine Corps Base Camp Pendleton. A key aspect of the work is that the wave-driven runup component of the projections was based on using linkages between GCM outputs and coastal wave models to identify wave energy along a specific segment of coast. Using the downscaled physical wave forcing, a broad range of SLR scenarios was developed to map future erosion and flooding extents.

One unique aspect of this project was the creation of a high resolution DEM based on best available data sources and including beach dynamics and geomorphology by interpolating sparsely available beach profiles. These baseline and future condition elevation models formed the basis for detailed assessment of erosion and flooding footprints for a broad range of future sea level rise scenarios.

Strengths – Robust integrated short- and long-term shoreline response models for both beach and beach-cliff systems incorporating hindcasts and a strong calibration data set applicable to the Southwest U.S.

Limitations –Project focus was on methodology development; full scale application is still limited. The method of developing scenarios has not addressed the joint probability of a coincident occurrence of high tide, storm events, and sea level rise, which requires more pre- and post-storm monitoring data to hindcast storm impacts and better predict future impacts. Elevation model development utilized multiple data sets, collected at different times by different agencies, with varying methods and levels of resolution and accuracy. Absence of short-term shoreline response monitoring during and following extreme events, and absence of long-term shoreline response monitoring during periods of active wave attack on the cliffs limits model validation. In general, data and outputs not yet publicly available.

Other Coastal Hazard Models

Scripps – Yates model (also known as YGOR after authors Yates, Guza, and O'Reilly)

This shoreline response model relatively accurately reproduces measured changes to the beach on annual time scales. The beach response is based on a relationship between the rate of shoreline change and hourly wave energy above a seasonal normal energy level. The model was applied to modeling of SLR and future shoreline changes in the Navy/SPAWAR methodology. The shoreline response works both ways: as the wave energy falls below the mean seasonal average, the shoreline is expected to accrete . The model has been calibrated with measured observations and field data collection in San Diego and Ocean Beach, San Francisco, showing an ability to perform adequately with a larger beach sand grain size and higher wave energy (Yates et al. 2009, Yates et al. 2011).

BreZo

This model uses a Godunov 2D hydrodynamic flow model that predicts both inundation and drainage. The model has been applied to Newport Bay and has yet to include open coast wave processes. High resolution topography was developed using GPS field surveys and validated with documented flood events and high water marks. Research focused on the model application at a relatively small scale examined what improvements to the flood mapping resulted from improvements in topographic resolution. Key findings were the importance of high resolution (cm accuracy) mapping of coastal armoring structures and an understanding of the hydraulic connectivity through storm drains to best calibrate model results to documented real world flooding at a very fine scale (Gallien et al. 2011, Gallien et al. 2013).

Humboldt Bay

As part of the Humboldt Bay Sea Level Rise Vulnerability Assessment Project, Northern Hydrology and Engineering (NHE) developed and applied a two-dimensional hydrodynamic model of Humboldt Bay to assess extreme water levels in the bay under various sea level rise scenarios. The hydrodynamic model was configured within the existing shoreline of Humboldt Bay, and driven by a 100-year hourly sea level height series at the ocean boundary. Also as part of the Vulnerability Assessment Project, Pacific Watershed Associates developed a seamless topographic/bathymetric 1-meter digital elevation model (Project DEM) of Humboldt Bay and surrounding upland areas based on the 2009-2011 California Coastal LiDAR data and various subtidal bathymetric data sets. The Project DEM provided the hydrodynamic model grid elevations and was the base topography for the inundation mapping. Five sea level rise scenarios were assessed with the hydrodynamic model: 2012 (existing conditions), and half-meter increments of 50 cm, 100 cm, 150 cm, and 200 cm of sea level rise above the 2000 year levels. NHE used predicted water levels from the hydrodynamic model to develop inundation maps of the areas surrounding Humboldt Bay vulnerable to flooding from existing sea levels and future sea level rise. For each of the five sea level rise scenarios, inundation maps were produced for mean higher high water, mean monthly maximum water, mean annual maximum water, and the 10- and 100-year recurrence interval water levels. The inundation maps are available as both kmz files and shapefiles. NHE also generated estimates of relative sea level rise from 2000 through 2100 (at North Spit tide gauge), for the Humboldt Bay Sea Level Rise Adaptation Planning Project. This information is crucial to developing regional adaptation strategies for 2030, 2050 and 2100 timeframes.

Focus Question: In what key aspects do the ESA PWA & CoSMoS models differ and how can they best be integrated to form the "super model"?

Multiple shoreline response models are currently being evaluated in multiple geographies using historical data in Southern California and beyond. Based on the results of this analysis, the strongest aspects of each model will be determined, which may result in recommendations to use or integrate multiple models, or particular aspects of a range of models, in a given geomorphic setting.

The ESA PWA and CoSMoS models both operate based on scenarios that include future waves and sea level. Data that describe offshore waves are then used to predict the variability of wave energy based on shoreline orientation, bathymetry and wave exposure. These nearshore waves are then run up the beach to identify various elevations that are at risk from coastal hazards. How are these two models different, and can they be combined?

CoSMoS utilizes global climate model wind fields to drive future projections of waves and then transforms those future waves across the deep continental shelf to the coast and across the surf zone, and finally looks at changes to the beach from storms. CoSMoS uses WAVEWATCH III, a NOAA model, which uses pressure and wind fields to model the generation of waves across the ocean, from globally to regionally. From these results at a regional scale, a suite of storm events are established (i.e., average, annual, 20- and 100-year wave return interval) and the offshore waves are transformed to the coast and across the surf zone using SWAN, a model that simulates waves from deep continental shelf and models their transformation into the surf zone. The final step is to model the transformed waves as they run up the beach, using XBeach, a model which generates changes to the beach profile from a storm event. The outputs of the CoSMoS model are the water level time series during each scenario, flooding extents, depths, current velocities, and wave heights.

The initial model construction funded by the Pacific Institute and carried out by ESA PWA (at the time known as PWA) was completed with involvement from Scripps and USGS, both of which supplied data and provided technical review of the overall methodology. ESA PWA's implementation of the Pacific Institute coastal hazard model takes into account the geology and geomorphology of the backshore, allowing a more complete prediction of erosion response.

The ESA PWA coastal hazards modeling efforts have utilized projections of future waves from downscaled global climate models and extrapolation of waves from existing buoy data (wave height, period & direction. Flood hazards have been identified based on 100 year recurrence intervals and on historic events on top of sea level rise. The use of historic event magnitudes at future sea levels has been shown to be easily communicated with local jurisdictions. In short, the ESA PWA model is more of a shore response model, as opposed to a storm impact and sea level rise flooding model, which can be driven with the top caliber statistical scenarios or a simple 2, 3, or 4 foot sea level rise scenario.

Initial efforts to integrate CoSMoS and ESA PWA modeling on a project funded by the State Coastal Conservancy to assess sea level rise vulnerability in the Monterey Bay region demonstrated that more collaboration between the two entities and modeling methodologies was necessary. Initial collaborative efforts found that the USGS wave output did not include the directional wave spectra (distribution of wave height and period for each direction) necessary to transform the waves from deepwater (at the buoy) to the coast, thus the variety of north and south facing shoreline orientations found in the Monterey Bay were not represented. This is a key area of integration needed in future collaborations. These collaborations will be happening in Los Angeles County & Santa Barbara County as part of the larger CoSMoS 3.0 Southern California initiative.

Detailed SLR Modeling Matrix

TABLE 1: MODEL SELECTION CRITERIA

	NOAA	Pacific Institute (PWA)	ESA PWA (Ventura County & Monterey Bay)	USGS CoSMoS (Our Coast our Future – SF Outer Coast)	SPAWAR
Cost/length of shoreline (km)	$9,064/km^2$	$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 (coupled 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 2: MODEL DEVELOPMENT HISTORY

	NOAA	Pacific Institute (PWA)	ESA PWA (Ventura County & Monterey Bay)	USGS CoSMoS (Our Coast our Future – SF Outer Coast)	SPAWAR
First application	Houston/Galveston, TX; Has subsequently been used in various areas of CA, including San Francisco Bay and Long Beach	Entire State	Entire State (Pacific Institute work is the original version)	1.0 in Southern California; 2.0 in San Francisco Bay & Outer Coast	Southern California
Locations of Applications	Nationwide	All of California, excluding Scripps	Capitola, Ventura, Monterey Bay, Goleta Beach, Mission Creek	Southern California, North Central Coast, San Francisco Bay	Naval Base Coronado, Marine Corps Base Camp Pendleton
Geographic Range of Application	Coastal Counties in CA	Flooding: Oregon Border to Mexico, Erosion: from Oregon to Santa Barbara Harbor	Ventura County Boundaries, Wharf2 in Monterey to Ano Nuevo in Santa Cruz	Bodega Head to Half Moon Bay; Point Conception to Mexico	NBC: Imperial Beach to San Diego Bay entrance including both exposed and protected shorelines MCBCP: Oceanside to San Onofre
Peer Reviewed Publications	Marcy et al. 2010	Revell et al. 2011	TNC Technical Report, MB Technical Report	Barnard et al. 2014	Chadwick et al, 2014.
Technical Report	NOAA Technical Report	PWA 2009	TNC Technical Report	OFR 2009	SPAWAR Technical Report, Chadwick et al. 2014
Mapping tool	Yes	Yes	Yes	Yes	GIS Layers available on request subject to approval
Data Download	Yes	Yes	Yes	Yes	Available on request subject to approval

TABLE 3: COMPARISON OF 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 times 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	Scenario ranges, return period ranges, sensitivity analysis

				remapped on topo	
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

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Decisions Support Tools

Remember when communities did not think about sea level rise at all? They did not have downscaled climate models, inundation projections, community leaders that cared, or money to deal with the issue even if they did. The situation is evolving, however: a growing number of coastal communities have access to locally-relevant vulnerability information, the California Coastal Commission has provided very specific guidance on how communities should plan and adapt, and community leaders are increasingly willing to do the work. Because economic impacts of coastal hazards are on the rise, local, state, and federal planners in the United States are starting to see land-use planning as a viable tool for risk reduction. California is at the frontier of this changing attitude.

While substantial progress is being made, much more needs to be done. There are still significant gaps in the availability and accessibility of local sea level rise information for California, understanding of the impacts of various adaptation strategies, communication with critical stakeholders, and the translation of plans into action. This section presents and compares online decision support tools that illustrate coastal risk and vulnerability and identify adaptation solutions for the suite of sea level rise issues that are of concern to coastal managers. Some communities are lucky enough to have more localized and detailed data incorporated into customized decision support tools, while others rely on FEMA flood maps and national-scale tools from NOAA, USGS and the EPA. This comparative exercise is not meant to advise coastal communities on choosing the ideal tool or information; models are inherently projections, best estimates based on scientific evidence, which are constantly evolving. Therefore the emphasis here is on decision support, not decision-making. Data quality and availability are constantly improving, so the information developed using the decision support tools needs to be updated as new and improved data sources become available. The same can be said of web-based tools. They require ongoing maintenance and support to continue to be a viable mechanism for understanding risk and identifying solutions.

The purpose of this document is to leverage the collective knowledge and experience of the projects consulted by The Nature Conservancy as part of the California Coastal Resilience Network project to evaluate relevant online sea level rise decision support tools for California. As part of project, The Nature Conservancy consulted sea level rise adaptation project leaders in multiple coastal communities throughout California: San Diego, Los Angeles, Ventura, Monterey, San Francisco, and Humboldt. For each community, TNC and its partners consulted with project proponents to describe and compare adaptation planning projects on the basis of geographic scale, the type of planning supported, science and stakeholder engagement approaches, and status. Starting with the dissemination of this paper, The Nature Conservancy hopes to promote and enable ongoing communication among existing local adaptation efforts.

This report reviews a number of tools that address coastal flooding risk, community vulnerability, and adaptation solutions. It also tries to address growing confusion among tools. Planners, managers and stakeholders are inundated by the number of seemingly redundant tools now available on the web; it is increasingly difficult to distinguish among them and to decipher their intended purpose. Conversely, despite awareness of growing coastal hazards, in particular sea level rise and storm surge, many local governments and decision makers still do not have the capacity to map and plan for future climate projections, let alone identify coastal management scenarios to address these threats. Decision makers often have only limited time and resources to devote to accessing critical information that supports management choices. As a consequence, they are unable to integrate coastal hazard risk and sea level rise into their decision-making in order to increase the resilience of human and natural communities. Clearly there is work to be done in communicating precisely how web-based tools can help support specific planning processes. With this in mind, this report addresses three objectives:

- Describe the purpose and intended uses of relevant decision support tools in California
- Compare the tools to give users an understanding of their similarities and differences
- Present the major findings in order to help managers decide on the right tool(s) for hazard mitigation and adaptation planning in their locale.

The intent of this evaluation is to assist decision makers in selecting the most appropriate tool for their specific planning processes. A tool matrix can be found at the end of this report that provides detailed information on each tool.

Tools Reviewed

This report covers the following online mapping decision support tools: Sea Level Rise and Coastal Flooding Impacts Viewer; Surging Seas; Coastal Resilience; & Our Coast Our Future. We initially intended to include the CalAdapt and Pacific Institute tools in this report, and have done so in the tool matrix. However, since the Pacific Institute tool is no longer being actively supported, and CalAdapt is currently more focused on climate impacts other than sea level rise, they are not compared with the other tools in this report.

Why these tools in particular? The field of climate and sea level rise tools is one that 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 so that planners and land managers may best determine which tool is right for their planning objectives.

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 across the U.S. at persistent and event-driven coastal inundation. The viewer is a screening-level planning tool that uses nationally consistent data sets and analyses and provides data for download or consumption via web map services. Most of the data sets visible in the viewer are available for use in other applications. The digital elevation models (DEMs) that form the base maps are conditioned specifically for mapping inundation and have been used in selected coastal resilience efforts and for storm surge modeling and mapping by the National

Hurricane Center. NOAA's primary objectives for this tool are to provide a consistent, national viewer and open access to the data that local communities need to address their needs. The tool covers the contiguous United States coastline as well as Hawaii, the Pacific territories, Puerto Rico and the U.S. Virgin Islands (not yet available in Louisiana and Alaska).

Surging Seas

www.sealevel.climatecentral.org

Climate Central's Surging Seas Risk Finder, available across 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 scales. Surging Seas is designed to provide decision makers, planners, coastal managers, emergency managers, federal and state agencies, journalists, and the general public with information that can be easily summarized to inform their understanding of and response to the risks of sea level rise and coastal flooding. Maps are based on the same 5-meter horizontal grid digital elevation model (DEM) used by NOAA's viewer and consider static sea level rise up to 10 feet above mean higher high water (MHHW). The viewer is a screening-level planning tool that uses data drawn mainly from federal sources, including NOAA, USGS, FEMA, DOT, DOE, DOI, EPA, FCC and the U.S. Census and includes layers for population, social vulnerability, property value, point features and more. It is the intention that all U.S. coastal states will be included in Surging Seas.

Coastal Resilience - Ventura

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 intended to identify restoration and adaptation solutions. The Coastal Resilience tool was first created in 2008 and used on the southern shores of Suffolk County, Long Island, New York. The tool now covers regions within: ten U.S. coastal states (Alabama, California, Connecticut, Florida, Louisiana, Mississippi, New Jersey, New York, Texas, Washington), four countries in Latin America (Mexico, Belize, Guatemala, Honduras), and three island nations in the Caribbean (Grenada, St. Vincent and the Grenadines, U.S Virgin Islands). There is also a U.S. national and global application. Coastal Resilience 2.0 was released in the fall of 2013 to better enable decision-makers to assess risk and identify nature-based solutions to reduce socio-economic vulnerability to coastal hazards. Coastal Resilience in Ventura County is a local application of Coastal Resilience positioned to support governments and institutions that are either responding to disasters or preparing and planning for current and future climate conditions. The purpose of the Ventura tool is to inform county hazard mitigation planning, with intended uses including raising awareness of coastal hazards issues, examining local flood risk, and identifying viable adaptation solutions. By summer of 2015 Coastal Resilience in California will become statewide with detailed examinations of local projections for - and adaptation projects in - Ventura, Monterey, and Humboldt counties.

Our Coast Our Future

www.pointblue.org/ocof

Our Coast, Our Future is a collaborative, user-driven project providing decision support tools to help understand, visualize, and anticipate the effects of sea level rise and storms on the North-central California coast, from Half Moon Bay to Bodega Head, and San Francisco Bay shorelines and baylands. The tool provides maps that use a 2-meter horizontal grid resolution DEM and considers static sea level rise on top of MHHW for 0, 25, 50, 75, 100, 125, 150, 175, 200 and 500 centimeters. The inundation maps also consider 1-year, 20-year and 100-year storm events and their corresponding wave hazards. The water level data were produced using the USGS's Coastal Storm Modeling System (CoSMoS).

LIFTING THE FOG WORKSHOP: THE CA COASTAL RESILIENCE NETWORK IN ACTION

The California Coastal Resilience Network has taken multiple approaches to reviewing adaptation planning tools. For example, in May 2014, many of the Network partners collaborated to convene a targeted group of sea level rise and shoreline change modelers, tool developers, and end-users to discuss the application of these tools in on-the-ground planning processes. Foundational to the discussions were The Nature Conservancy's model and this tool comparison report and associated matrices, developed in collaboration with NOAA and Climate Central. The group identified and explored strategies to ensure future communication of the various tools and models is clear, accurate, and beneficial to intended users. The results from this workshop formed much of the foundation of this report and will be shared with coastal managers and decision-makers statewide.

Tool Comparison Tables

The following pages include quick-reference summary tables of the tools described above. Tools are compared based on the scale at which they operate: Coastal Resilience-Ventura and Our Coast Our Future have been applied to specific regions of CA, while Surging Seas and NOAA's SLR Viewer are national in scope.

TABLE 4: SURGING SEAS & NOAA SEA LEVEL RISE AND COASTAL FLOODING IMPACTS VIEWER

Quick Reference for Using Complementary Decision Support Tools	
Surging Seas	**Sea Level Rise and Coastal Flooding Impacts Viewer**
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 and more frequent storms and associated flooding
Geographic Coverage	
National tool that is complete for the following regions: • Gulf of Mexico: FL to date (TX, MS, AL to be released by end of summer 2014) • West Coast: CA, OR, WA • East Coast: FL, NJ, NY, New England states (GA, SC, NC, VA, DE, MD, PA to be released by end of summer 2014) • Pacific: (HI to be released by end of summer 2014) • Alaska and Louisiana: Timeline TBD due to data availability and quality issues	National tool that is complete for the following regions: • Gulf of Mexico: (TX, MS, AL, FL • West Coast: CA, OR, WA • East Coast: (all states • Pacific: HI, CNMI, Guam, American Samoa • Caribbean: (PR, USVI • Alaska and Louisiana: Timeline TBD due to data availability and quality issues
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 storm surge or 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 on 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 data 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

TABLE 5: COASTAL RESILIENCE VENTURA AND OUR COAST OUR FUTURE

<table>
<tr><th colspan="2">Quick Reference for Using These Complementary Tools</th></tr>
<tr><th>Coastal Resilience Ventura</th><th>Our Coast Our Future</th></tr>
<tr><th colspan="2">Purpose</th></tr>
<tr><td>• To compile and deliver web-based planning tools incorporating nature-based solutions to coastal Ventura communities for disaster risk reduction and climate adaptation</td><td>• 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</td></tr>
<tr><th colspan="2">Geographic Coverage</th></tr>
<tr><td>• Comprehensive Ventura County data on social, economic and ecological information
• A statewide application will be completed summer 2014 with three additional sub-geographies (Monterey, and Humboldt counties)</td><td>• San Francisco Bay Area online maps and tools for anticipating vulnerabilities to sea level rise and storms (Half Moon Bay to Bodega Bay)</td></tr>
<tr><th colspan="2">Key Distinctions</th></tr>
<tr><td>• Maps selected geographies with a focus on determining 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</td><td>• 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</td></tr>
</table>

Major Commonalities and Distinctions among Tools

This analysis revealed some commonalities among tools, and a number of key distinctions.

All tools shared two basic characteristics. First, the common purpose or objective of all tools is to compile and deliver web-based spatial information that assesses risk and helps communities plan for exposure to sea level rise and more frequent tidal flooding. Second, whether statewide or local in scope, the flooding data in each tool is of high enough spatial resolution to be used for making local planning decisions.

The analysis found a number of key distinctions among the tools which are relevant to deciding which tool might be right for use in a new project. The distinctions are:

- Sea level rise is the focus of most flooding scenarios with half of the tools incorporating storm surge scenarios and combining them with sea level rise
- While some tools provide sea level rise scenarios based on emissions at a particular time, others provide more generic interval mapping; few of the tools provide uncertainty analyses or mapping confidence
- All tools focus on risk and vulnerability information in association with sea level rise and, to a lesser degree, storm surge; there are only limited examples focused directly on supporting adaptation options
- Most tools address marsh migration and future land use patterns but methods of analysis vary
- All tools deliver resources to either state or local planning processes; none have yet incorporated both state and local planning scale information
- Most tools are built and managed centrally; few of the tools are open source and/or allow partners to build components of the tool itself
- Although all the tools are capable of exchanging web mapping services, few of them provide mechanisms for transferring data from one tool to another

Conclusion

Only a few years ago the idea of mapping sea level rise in the U.S. was considered highly unconventional. Great strides have been taken to accurately model and visualize coastal hazards, advances which are clearly reflected in the number of decision support tools that have been developed to provide detailed inundation scenarios to coastal managers across the country and specifically in California.

The intent of this report is to highlight the principle objectives and uses of the tools in order to clearly communicate their similarities and differences as well as how they can complement each other. Whether examining the threat of coastal inundation across the state or locally, the elevation data provided in each tool is of high enough spatial resolution to be used for a range of planning processes. This tool comparison has revealed that inundation scenarios are readily available across all tools, although more strides need to be made to explicitly illustrate uncertainty and mapping confidence of future sea level scenarios.

Another distinction is that these tools directly address sea level rise but not necessarily risk reduction planning. Without adequate storm surge scenarios coupled with sea level rise, encompassing both high recurrence flooding and catastrophic events, the picture of risk is incomplete. Tools need to support both short and long term adaptation planning, and therefore a wide range of inundation scenarios is needed – both persistent and episodic events.

Further, most of these tools provide socioeconomic information alongside coastal hazards in order to assess the risk to social and economic assets, and determine community vulnerability. However, few address vulnerability of natural resources in the same light.

The most conspicuous distinction among tools is their ability to support adaptation options. Most provide a canvas for assessing risk and vulnerability, but stop at making any particular recommendation or providing tool functionality that identifies options (i.e., planned retreat, elevation, coastal habitat restoration, reinforcement of built infrastructure). Given these are decision support and not decision-making tools, this omission makes some sense. However, more work can be done to help planners and managers determine appropriate choices in the built and natural environment. Another clear area of tool development is in illustrating the social, economic and environmental benefits of different coastal defenses.

Finally, while substantial investment has been made in most of the tools evaluated in this report in order to streamline their development and release into the public domain, few have been adequately tested with stakeholders for performance, intuitive design, and usability. This user engagement is an essential component of any decision support tool; we recommend more investment be made on outreach and communications to ensure tools are indeed supporting adaptation planning.

Planners and managers with access to detailed, local sea level rise and coastal hazard modeling data available in customized decision support tools repeatedly express the desire for parcel level hazard and vulnerability analyses to justify planning- and permitting-level adaptation responses. The tools here are meant to facilitate decision support at a variety of jurisdictional levels but users must remember that they are tools – they do not have the solutions. Solutions come from a combination of thoughtful planning and decision-making that prioritizes future land uses based on local community values.

Economics of Coastal Climate Change Adaptation

Decision makers in coastal regions are aware that climate change calls for new planning strategies adapted to evolving environmental conditions. Numerous practical and theoretical approaches ranging from seawall construction to dune restoration to managed retreat from coastal areas have been suggested as ways to adapt to these shifts. One of the outstanding challenges for decision makers is to understand the economic and socioeconomic consequences of selecting one adaptation strategy over another. In order to do this, decision makers need to consider a full suite of costs and benefits for each strategy. In response to the critical need to examine a wide range of impacts, a number of different tools and approaches have been developed that can help provide the needed analyses and data to make informed decisions. The purpose of this chapter is to provide an overview of the different analytic tools available and guidance on their appropriate use so that decision makers can get the socioeconomic information they need to select an appropriate adaptation strategy.

To develop better resiliency to coastal inundation, storms, and other climate change impacts, coastal communities will face some fundamental choices. The different measurement approaches or tools for evaluating the environmental, economic, and social tradeoffs of alternative adaptation strategies will be more or less well-suited to the choices faced by a particular community depending on a number of economic and socioeconomic factors, including:

The scale or magnitude of the adaptation strategy – does the question deal with a 50- meter seawall, or a five mile-long dike? Should the evaluation address potential impacts to ten coastal homes, or an entire county or state?

The economic effect that is to be measured – Does the greatest concern surround infrastructure damage? Flood damage repair costs? Loss of ecosystem services? Crowding out of coastal industries? Risks to disadvantaged communities?

Availability of economic baseline data – are there good forecasts of what is expected to occur in the future with climate change? Can these be developed? Without a solid baseline forecast for climate change impacts, the benefits of adaptation strategies can't be evaluated.

Schedule and budget – If a decision needs to be made quickly, then there is a limit to the level of detailed information that will be useful in making a decision. Similarly, the available research budget may determine the level of complexity or the scope of study that is feasible.

The process of selecting an appropriate tool can, in effect, also help to define and refine the specific research question to be examined. The objectives of this chapter are two-fold:

1) To outline the kinds of economic measurements for consideration when evaluating climate change adaptation strategies, and

2) To provide an objective assessment of which tools are best suited to different adaptation decision research tasks and why.

There are four main categories of economic tools that are assessed in this review:

1) Flood damage and hazard tools;
2) Social and community impact tools;
3) Ecosystem service tools; and
4) Regional economic impact tools.

The most well-known and frequently used tools in each category have been selected for review here, focusing on theoretical consistency with widespread disciplinary research, existence of peer-reviewed supporting literature, and applicability to the needs of coastal resource managers and decision-makers at the state and local level. In addition to these categories of tools, examples are provided that show how a mix of models may be used to answer the most important questions for a community making decisions about adaptation strategies.

Basic Framework for Economic Analysis

Economic decision making begins when there is a choice to be made about a particular course of action, such as an investment of some kind, a new program, a project, or selection among a host of alternative ways to solve a problem. Regardless of the specific question, the analysis will evaluate a series of gains, benefits, or improvements that are expected to occur over time, and compare these with a series of losses or costs over the same relevant time period based on stakeholder input, expert opinions, and policy factors. Results are calculated and an adjustment factor known as a discount rate is applied.[4] The discount rate uniformly discounts all benefits and costs depending on how far they occur in the future, thus accounting for uncertainty about future events, the opportunity cost of investment, and the fact that most people prefer benefits now to benefits later (and costs later to costs now). In the context of climate change adaptation decisions, the economic analyses associated with different strategies will often include a "do nothing" strategy, involving no modifications to planning, and one or more adaptation strategies designed to mitigate the impacts seen in the "do nothing" scenario.

As different measurement tools have been designed to measure different types of gain and loss, it is important to consider which types of gains and losses are the most important to the decision at hand. The categories of gain and loss are not independent and may overlap, but usually every effort must be made to reduce the overlap and thereby avoid double counting. For the purpose of this assessment of tools, several key types of economic gains/losses potentially affected by climate change have been identified:

Changes in cost or value of the built environment. These include the kinds of damages that will occur to buildings and infrastructure with rising seas and increased storm activity. Flood damages are

[4] For a good discussion of how discount rates are used to make public decisions, and what different values might be used, see Circular A-94, Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs, available at http://www.whitehouse.gov/sites/default/files/omb/assets/a94/a094.pdf; or Discounting and Time Preference, Coastal Ecosystem Restoration, National Oceanographic and Atmospheric Administration, available at: http://www.csc.noaa.gov/archived/coastal/economics/discounting.htm

included in this category. Gains in this category include the reduction in otherwise anticipated damages.

Effects on the natural environment, or on ecosystem services. This includes increased or decreased rates of erosion caused from rising tides, loss of habitat due to increased flooding and erosion, reduced beach width, sand retention, and any other environmental impacts. Gains in this category could be associated with increases in access to natural amenities, reductions in the loss of habitat, wetland restoration, and carbon sequestration.

Regional economic impacts. This type of impact relates to the vitality of a regional economy. For example, climate change could affect the tourism sector by placing beaches or coastal scenery at risk. Rising seas might also have an effect on activities at ports as port facilities begin to experience increased inundation. Similarly, any commercial sector of the economy might experience business interruptions and damage repair costs that limit the economic feasibility of the sector. In either case, the change in the level of activity in the sector (total revenue, jobs) will have a ripple effect throughout the region and reduce the overall numbers of jobs and income.

Social impacts. Social impacts are more difficult to quantify, but relate to community cohesion and the distribution of effects across different groups of people. In particular, low income or disadvantaged groups might be more affected than wealthier groups.

Other monetary or non-monetary costs stemming from adaptation strategies. Costs associated with investing in wetland preservation or restoration, construction of seawalls and other defensive infrastructure, and long term maintenance programs are all considered losses or costs, and are typically measured in dollar values. Other types of costs might also be considered, such as the costs associated with delaying an action or a loss of economic activity within the region such as when population moves away or jobs are lost.

Application of Economic Tools to Sea Level Rise Adaptation Issues

There is currently no single tool that can address all economic effects of SLR; therefore, this document will review the current suite of commonly used tools and the questions the tools can help analyze. Tools have been developed for estimating the value of flood damages, the value of ecosystem services, estimated changes to economic variables known as economic impacts, and metrics for estimating social and community impacts. Before selecting which tool to use, it is important to understand the capabilities and limitations of the tools available. For example, do stakeholders want to understand the change in recreational value due to loss of beach width from sea level rise? Or, do stakeholders want to know the potential impact on jobs and revenue from reduced tourism stemming from reduction in beaches? While these questions may sound similar, the answers involve different economic metrics and methods, and therefore require different application tools to address them. A list of the types of questions answered by the different tool applications is shown in Table 1. Each type of tool application covered in this assessment is briefly reviewed.

Table 1: Examples of Questions that Types of Tools are Designed to Answer	
Application Tool	**Type of Question**
Flood Damage Tools	• What is the value of damage to buildings and infrastructure due to SLR? • Where will the most physical damage likely occur?
Ecosystem Service Tools	• What is the value of reduced recreation, reduced fresh water, and habitat loss due to sea level rise?
Economic Impact Tools	• How will jobs, income, and revenue be impacted by sea level rise?
Social and Community Impact Tools	• What areas will be disproportionately impacted? • Which areas have fewer resources and require more assistance in order to adapt to sea level rise?

Each type of tool covered in this assessment is reviewed in the sections below in terms of how that tool will inform climate change adaptation decisions for coastal managers. The criteria selected to compare the different economic application tools are based on a review of criteria used in other similar analyses (e.g., see Table 2-1 NCHRP 2004) and discussions with local stakeholder groups. For each application tool, the economic metrics measured, data requirements, level of technical expertise needed, flexibility of the analytical capacity, appropriate geographic scale, necessity for special operating software, and a comparison of relative costs are reviewed. A summary and description of the criteria is listed in Table 2.

Table 2: Application Tool Selection Criteria	
Criteria	**Description**
Economic Metrics	Does the application tool estimate economic values or economic variables?
Data Requirements	What data come with the application tool? What data are required to operate the tool?
Technical Expertise	What type of expertise is required to operate the tool?
Analytical Flexibility	To what degree can the analyst adapt the underlying model parameters to reflect specific conditions/characteristics of the study site location
Scale of Analysis	What geographic delineation is possible?
Software Requirements	What software is needed to operate the tool?
Budget Considerations	Analysis time, data costs, software costs, etc…

Flood Damage 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 containing market values. Another goal of flood damage tools is to 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 (or the cost to reconstruct and repair damaged public infrastructure).

There are two primary flood damage economic estimation tools: (1) Hazus, and (2) HEC-FDA. Hazus, developed by FEMA to plan for and manage natural disasters, is a nationally applicable standardized methodology (actually a composite of multiple tools) that contains models 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 US Army Corps of Engineers' (USACE) Hydrologic Engineering Center (HEC) provides the capability to perform an integrated hydrologic engineering and economic damage assessment. The software integrates a graphical user interface, hydrologic engineering and economics input components, database and management capabilities, and graphics and reporting facilities (USACE 2008).

A brief comparison of the two models is presented in Table 3 and in the sections below.

Economic Metrics

Although the Hazus model is classified here as a flood damage tool, it is the most comprehensive economic analysis tool available, in that it also measures some social impacts, impacts to the regional economy, ecosystem services losses, and emergency costs. In addition to producing value estimates of economic damage to general building stock, Hazus includes built-in methods for estimating social impacts and regional economic impacts. Demographic data that are part of the default database assist analysts and planners in understanding which neighborhoods could be more vulnerable to flooding, and whether specific neighborhoods are more vulnerable due to limited resources for relocation. Hazus is also able to estimate regional economic impacts using the number of businesses impacted, the estimated output per establishment, and the degree of damage and loss of inventory.

The underlying economic methodology in Hazus is damage functions. Damage functions are used to estimate economic losses from flooding by relating the depth of the flood with property, contents of structures, and other economic assets. The default proxy for economic value in Hazus is replacement cost. The damage functions, therefore, relate depth of flooding (in feet), as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost (FEMAb 2012). Hazus also produces useful information about emergency costs and infrastructure damage.

In comparison, the HEC-FDA model produces only damage estimates for various flooding scenarios. These estimates of value are suitable for inclusion in benefit-cost analyses – and are used for decision making by the USACE – and are specifically related to flooding. As with the Hazus model, damages are estimated using depth-damage functions which impact inventories of structures within a floodplain.

Data Requirements

Data availability also differs for the two tools. The Hazus tool comes complete with extensive embedded default databases for the national, state, and county levels. The databases contain information such as demographics of the population in a study region, square footage for different occupancies of buildings, and numbers and locations of bridges (FEMAb 2012). Datasets that are not part of the default package include the hydrologic model and regional trade flow data. All input data can be fairly easily updated to more accurately represent the study region should more specific data become available.

The HEC-FDA tool does not come with default datasets. All data for model and estimation need to be collected by an analyst. This means that hydrologic, hydraulic, and economic input data need to be developed and uploaded before the model can be run. An interdisciplinary team should be deployed to develop data that are internally consistent.

Technical Expertise

The degree of technical expertise required to operate the two models also differs. At the most basic level, the Hazus model requires only that an analyst have a GIS background. The Hazus default data allow for a reconnaissance-level analysis, in which estimates are largely based on national and regional averages (FEMAb 2012). More advanced and complicated analyses require more technical expertise. For example, users with the technical expertise can determine parameters from published reports or maps and incorporate these into the model in a meaningful way. Even more complex analyses can be conducted, should more information be available about the flood hazards and/or measure of exposure (FEMAb 2012). The model even could incorporate results from engineering and economic studies carried out using methods and software not included in the methodology.

In general, the HEC-FDA requires more technical expertise and is recommended to be operated with a qualified, interdisciplinary team. A hydrologic engineer will be required for modeling flooding, similar to Hazus. In addition, an economist will be required to collect and analyze regional assets, values, and damages from flooding.

Hazus does not incorporate risk or uncertainty methods; estimates are based on the probability of an event occurring but do not present a range of expected damages. HEC-FDA model accounts for risk using Monte Carlo simulation. Monte Carlo simulation is a probabilistic statistical method which simulates repeated random sampling in order to obtain numerical results. In order to effectively communicate the comprehensive flood risks communities face over a year, a decade, or through time, the approach used in the HEC-FDA is more technically accurate. Results from the Hazus could also be used to communicate similar analyses (e.g., the probability that a certain flood will occur within a 20 year period, or the expected damage expected in any given year) but this would have to be developed by an analyst outside of the Hazus model itself.

Analytical Flexibility

Both of the flood damage models reviewed here are very flexible. The HEC – FDA is flexible in terms of the value of structures and other assets in the floodplain, the actual damage functions used, and the types of hydrologic and hydraulic results. Everything can be tailored to the situation as needed. Further, the HEC-FDA can accommodate and present results that incorporate uncertainty about flows, damage calculations, and values, as well as uncertainty about the structural integrity of containment features. While this does provide significant flexibility, a fairly significant amount of technical expertise is required to develop model inputs.

As described in the section above on technical expertise, the Hazus model has some flexibility in the level of sophistication of the result, allowing the model to be used for a detailed and rigorous study, or for a briefing-level exercise. Also, there is flexibility in that all default values may be replaced with exact values when evaluating all damage estimates. Finally, when discussing climate change in general and not just sea-level rise, Hazus can be used to examine a variety of natural hazards including earthquakes and hurricanes. Once the model is developed for flooding, it would be a small step to explore whether SLR also aggravates damages associated with other types of disaster. Hazus was developed for floods on the East Coast which have different properties (i.e., wave velocity) than on the West Coast, which might present some issues for West Coast application.

Mapping Capabilities

As mentioned in the opening description of the Hazus and HEC-FDA models, Hazus is completely contained by a GIS environment and the HEC-FDA is conducted outside the GIS environment. Still, the inputs to the HEC-FDA are most conveniently developed through a GIS system. Outputs from the HEC-FDA are not easily inputted into a mapping system for display.

Table 3: Summary of Flood Damage Estimation Tools

Model Selection Criterion	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 [5]
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*

Regional Economic Impact Tools

Regional economic impact tools have been developed to assist planners and policy makers with measuring changes to local economic variables when there is a significant shift in the economy (natural disaster, new regulations, or loss of a productive sector). Planners and policy makers are often faced with deciding among different projects or levels of funding, or understanding how many jobs were impacted by a natural disaster. These tools utilize input-output models that have been developed to

[5] http://www.hec.usace.army.mil/software/hec-fda/documentation/CPD-72_V1.2.4.pdf

trace changes in supply and demand through a regional economy. Input-output models are generally not part of a benefit cost analysis but local decision makers favor them because they estimate the factors that they care about, such as jobs, spending, taxes, etc.

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. When faced with choosing a regional economic impact model, RIMS II and IMPLAN differ in the level of expertise required, data requirements, software knowledge, and budget considerations. In addition, there are subtle differences in the underlying economic models and the number of economic variables reported. IMPLAN, updated and maintained by IMPLAN, LLC, 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 (USDOC BEA 2012). Estimated multipliers for location and industry are supplied to the analyst. RIMS II is appropriate for all levels of expertise.

Economic Metrics

RIMS II and IMPLAN were developed to provide estimates of changes in economic variables due to a policy, project, or change in funding. Both models provide information on total economic output, GDP, labor income, and jobs. However, only IMPLAN provides an estimate of total tax revenues to state/local and federal governments. IMPLAN estimates tax revenue based on real data on tax revenue flows to regional and federal governments generated from employee compensation, proprietor income, taxes on production and imports, household consumption, and corporations, and reflects all regional exemptions, sales, and property tax rates.

Data Requirements

As stated, economic impact studies examine how a change in one sector ultimately affects the entire economy through supply and demand relationships. In order to conduct an economic impact study, information about what the direct impact is or how the change will affect a specific sector or group of sectors is required. Specifically, data required includes what economic sector is impacted, changes to annual revenues, changes to number of employees, and location of impacted facilities or businesses. A summary of direct economic data required is summarized below in Table 4. Data on baseline industry information can be collected through the US Census Bureau[6] and through County Business Pattern data.[7] To understand the specific changes, data is gathered through stakeholder meetings, surveys, interviews with operations management, or literature review on consumer price response such as price elasticities.[8] These data requirements apply to both RIMS II and IMPLAN.

[6] http://www.census.gov/econ/

[7] http://www.census.gov/econ/cbp/index.html

[8] An elasticity is the percent change in one variable divided by the percent change in another. The elasticity of demand with respect to price is the percent change in quantities sold divided by the percent change in price. For

RIMS II only supplies multipliers based on geographic delineation provided to BEA, and the analysis will be based on industrial sector codes used by BEA. Due to proprietary information restrictions, regional trade flow datasets maintained by BEA are not made available to the analyst. In comparison, IMPLAN provides full access to regional datasets and allows analysts to customize industry information to match purchasing patterns, employment patterns, and other known information about the specific project being analyzed. For example, as long as a specific industry exists in IMPLAN data, analysts may modify the data to match the sales and employment information for the study case, while still maintaining the integrity of the model and preserving the ability to estimate Indirect and Induced impacts (Day 2011).

IMPLAN protects the use and distribution of their data by limiting the number of times and computers that purchased data can be downloaded on. Data can only be downloaded and stored on a computer up to 5 times. Therefore, only a limited number of analysts will be able to use the data on their computers. RIMS II, once the multipliers are supplied, they are available to as many analysts as needed to be on the project.

Analytical Flexibility

The two models differ greatly in the degree to which an analyst can modify the underlying model to reflect study site characteristics. Both models use industry averages at the regional level; therefore, multipliers are a function of this aggregated picture of an industry. This approach may not accurately reflect a specific study situation. For example, a new facility is planning to purchase 100% of all resources locally. However, the underlying parameters in the input-output model might indicate that, on average, the industry to which the new facility belongs generally purchases 45% of its inputs locally. Therefore, relying on the model parameters would underestimate total economic impacts because it would assume 55% of the facility's demand for materials occurs outside of the study region (known as "leakages"). IMPLAN allows for this type of information to be modified without altering the integrity of the underlying input-output model. In comparison, the underlying model for RIMS II cannot be adjusted by an analyst. Multipliers are pre-estimated by BEA and supplied to the analyst as fixed values.

Spatial Scale

RIMS II and IMPLAN both supply multipliers at various regional scales including national, state, county, and statistical metropolitan area, and zip code. However, the two models differ in their capability of modeling impacts across multiple regions. Multiregional analysis allows the analyst to examine how a direct impact in one region (e.g., a new facility) will impact the economy in another region. This analysis requires region-to-region trade-flow data. IMPLAN allows for an unlimited number of linked regions to be created in the system, allowing for "leakages," or those impacts that are captured outside of the affected region, to be included in the analysis. These impacts occur when employees live and spend money in a different county, purchasers buy supplies in different counties, or other indirect and induced

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more information refer to the following books: Varian (1992). pp.16–17, and Samuelson, W. & Marks, S. (2003). p.233.

impacts that are not captured by the county/region affected. RIMS II does not offer this type of spatial analysis.

Technical Expertise

Both RIMS II and IMPLAN can be used accurately without requiring an extremely high level of technical understanding of input-output models. As previously discussed, the input-output models are already built and the analyst then needs only to supply data points on changes to a local industry. However, IMPLAN can accommodate more complex modeling, including modification of regional model parameters and multi-regional impact analysis that examines how economic impacts ripple throughout neighboring regions (MRIO analysis). Therefore, a more sophisticated analysis can be conducted using IMPLAN by an analyst who has a more technical background and understanding of the underlying input-output model. It should be noted that this does not imply that the analyst does not need at least a broad understanding of how these models work. Understanding the limitations of the data is necessary to conduct a creditable professional analysis.

Software Requirements

IMPLAN data and impact modeling requires the IMPLAN software available for download online for free.[9] RIMS II does not require software additional to Microsoft Office. The maximum software required is Microsoft Excel.

Budget Considerations

RIMS II is much more cost effective and does not require software to implement. IMPLAN data varies depending up on the overall complexity of the dataset. As the level of the geographic scale of analysis grows more specific (to county and zip code levels), the dataset becomes more complex and costly. Therefore, if the analyst is examining a single state, or county, or zip code, then the analysis can be conducted at a lower cost than an MRIO analysis requiring several counties or zip codes. However, although data from IMPLAN is more expensive than RIMS II, IMPLAN's software is available online at no additional cost.

Table 4: Summary of Regional Economic Impact Tools

Criteria	RIMS II	IMPLAN
Economic Metrics*	economic variables • GDP • Income • Jobs	economic variables • GDP • Income • Jobs • State and local tax revenue

[9] http://implan.com/

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

**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.*

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), creating a significant challenge for policy makers faced with decisions that require understanding how changes in the natural environment will affect the community's overall well-being. A large body of literature has been developed to understand the different types of goods and services provided by nature and methods for valuing ecosystem services. Services may be grouped by the type of benefits to humans: direct or indirect. For example, direct benefits may include opportunities for recreation, such as nature viewing, trails for walking, biking, and horseback riding, as well as opportunities for hunting and fishing. The natural environment also provides many indirect benefits, such as spiritual well-being provided by natural habitats, water and air purification, noise abatement, erosion control, and climate regulation (e.g., avoidance of the heat island effect of developed urban areas).

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. It is important to note that there are no standard or generally accepted techniques for estimating ecosystem services; the tools that have been developed –

and reviewed here – each have limitations and oftentimes require specific data that are not universally available for every jurisdiction.

In 1997, Costanza et al. made waves in the economic community with their controversial attempt to value the world's ecosystem services; their methodology valued one unit of habitat type as of equivalent value wherever it was in the world, as they were focused on providing a big picture estimate to start the conversation around ecosystem valuation (Costanza et al. 1997). This paper sparked an interesting and important debate in the economic community about whether it is even appropriate to value ecosystem services. Despite the continued ethical debate over valuing ecosystems, reality often presents situations in which such action is necessary. The U.S. government uses a standard tool for this type of valuation called Habitat Equivalency Analysis (HEA), specifically to identify the total value of damages to an ecosystem from a pollutant as well as the cost to fix the damages through restoration. There are three ecosystem service tools evaluated in this review: (1) Ecosystem Service Review (ESR), Integrated Valuation of Environmental Services and Tradeoffs (InVEST), and (3) Artificial Intelligence for Ecosystem Services (ARIES). These tools were selected as most appropriate for application to coastal climate adaptation efforts in Califorina.

The ESR, a screening tool developed by the World Resources Institute, includes documents and spreadsheet tools that together provide a low-cost scoping assessment to assist users in identifying ecosystem services at risk (Bagstad et al. 2013).

InVEST is a suite of software models used to map and estimate the value of ecosystem services. InVEST enables decision makers to quantify tradeoffs associated with alternative management choices and to identify areas where investment in natural capital can improve ecosystem service levels for the habitat types currently available in the toolkit. The toolset currently includes sixteen distinct models suited to terrestrial, freshwater, and marine ecosystems. InVEST's current models, which run within ArcGIS or as a stand-alone executable programs, use land cover and other spatial data to quantify service provision for each land-cover type (Bagstad et al. 2013).

ARIES uses modeling techniques that pair locally appropriate ecosystem service models with spatial data based on a set of encoded decision rules. The tool quantifies ecosystem service flows and their uncertainty within a web browser or using a stand-alone software tool. The underlying model uses probabilistic models to quantify the flow of ecosystem services between ecosystems providing the services and their human beneficiaries, enabling estimation of service provision and service use (Bagstad et al. 2013).

Economic Metrics

InVEST and ARIES are both capable of estimating economic value of ecosystem services with both market and non-market values. For example, shellfish contain market values when harvested and sold, as well as non-market values such as water purification. Both tools provide estimates of market and non-market costs where available in the literature. ESR is not capable of providing a quantitative measure of value; however, the analysis is designed to elicit qualitative information about the value of ecosystem services to the community and stakeholders.

Data Requirements

Data collection required for running ESR will include stakeholder meetings, review of survey data, and literature review. The qualitative data collected will be collated by ecosystem services that are likely to be impacted. Data collected from stakeholders, interviews, and literature should also examine which groups are likely to be affected from changes in ecosystem services.

Because both ARIES and InVEST use underlying ecological relationships and functions to calculate ecosystem services in terms of biophysical quantities, both models rely on spatial data that can characterize the natural environment from which ecosystem services flow. InVEST has a database of over 60 data sources where spatial data required for analysis can be located and downloaded.[10] In addition to the data sources provided by InVEST, federal and local agencies, universities, and researchers also have datasets that can be accessed online or through requests. Data that can be gathered from offices local to the study area can often be identified during stakeholder processes. Data required will depend upon the ecosystem services being analyzed, location, and stakeholder needs. ARIES requires less data due to its underlying BN models and is more appropriate under conditions of data scarcity (Bagstad et al. 2013). InVEST's underlying deterministic models are more appropriate for use in contexts where ecological processes are well understood and all input variables are available in data sources (Bagstad et al. 2013). Type of data requirements are summarized in Table 5.

Table 5: Data Requirements for InVEST and ARIES

Data	Example of Variables
Climate	Average temperature, precipitation, aridity index, sea surface temperature
Carbon	Carbon biomass
Land Use/Land Cover Data	Normalized Difference Vegetation Index (NDVI), Net Primary Production (NPP), vegetation canopy cover by type
Biodiversity	Species distribution
Hydrology	Rivers, river basins, river discharges, watersheds
Soil	Topsoil and subsoil texture and chemistry, depth, bedrock, sand, silt, clay, rock
Topography	Digital elevation model data (DEM)
Built Environment Information	Spatial data that characterize the built environment that can obstruct and influence ecosystem services such as the general building stock, dams, levees, transportation, and other sources of built elements

10 http://www.naturalcapitalproject.org/database.html

Analytical Flexibility

All three models allow for analytical flexibility to a varying degree. ESR can arguably provide the most analytical flexibility because the analysis is essentially conducted at the screening level. Therefore, there are no limitations on the number of services, drivers of change, and beneficiaries that can be reviewed. ARIES and InVEST are GIS tools with underlying functions, parameters, and assumptions. While data collected will be specific to study and stakeholder needs, allowing for analytical flexibility at this level, the ability to adapt the underlying parameters and assumptions differ between the two tools.

ARIES allows some user friendly model adaptation abilities. Users can modify variables of interest (either under policy control, such as elevation or land cover, or external, such as annual mean temperature or rainfall) and study their comparative effects (Villa et al. 2009). In addition, users can modify default assumptions in order to compare scenarios and can select the amount of uncertainty they are willing to accept in the probabilistic model (Villa et al. 2009). However, a limitation of ARIES is the lack of transparency of the model code due to its complexity (Vigerstol 2011). While users can change key model parameters in the Java and Clojure code, the BN framework is not intuitive to many users and the complexity of the code may limit analytical flexibility depending upon the analyst's technical background (Vigerstol 2011).

InVEST also allows for some analytical flexibility. The underlying deterministic production functions contain default parameters. All documentation on underlying deterministic production functions and default parameters is available online for free.[11] Default variables can be changed through the property menus in GIS. When an InVEST model is opened in GIS, the user can use interface menus to select and change default parameter values.

Types of Ecosystem Services that can be Analyzed

ESR allows for an unlimited number of services. The spreadsheet tools provide definitions and information for the 27 ecosystem services outlined in the Millennium Assessment (MA 2005) as well as space for the user to include other services identified by stakeholders.

ARIES is currently capable of modeling eight ecosystem services: carbon sequestration and storage, flood regulation, coastal flood regulation, aesthetic views and open space proximity, freshwater supply, sediment regulation, subsistence fisheries, and recreation.

InVEST currently has 16 models in which ecosystem services can be estimated. Models range from Aesthetic Quality to Offshore Wind Energy and each model is able to quantify the ecosystem services specific to those models. For example, the Coastal Protection Model estimates the role habitat plays in

[11] http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/3_0_0/index.html

erosion and flood mitigation. Multiple InVEST models can be operated in a single study. The following is a list of models currently available on InVEST.[12]

- Carbon Storage and Sequestration: The amount and value of carbon stored and sequestered naturally in five carbon pools: above ground biomass, belowground biomass, soil, harvested wood products, and dead organic matter. ($)[13]
- Crop Pollination: The abundance of pollinators in an area of interest and the number of pollinators likely visiting crops on a landscape. ($)
- Timber Production: The amount and value of timber harvest. ($)
- Water Purification: Nutrient Retention: The amount and value of nutrient retention by vegetation for water purification (includes phosphorus and nitrogen). ($)
- Erosion Control: The amount and value of sediment retention by vegetation for erosion control. ($)
- Reservoir Hydropower Production: The amount of water yielded from each unit of the landscape and its annual value to hydropower production. ($)
- Biodiversity: The location and rating of habitat quality and rarity.
- Habitat Risk in Marine and Coastal Habitats: The regions in a landscape or seascape where human impacts on habitat are highest.
- Fisheries and Recreation: The location and amount of ocean fishing and recreational uses.
- Marine Aquaculture Harvest: The amount and value of Atlantic salmon aquaculture based on farming practices, the water temperature, and economic factors. ($)
- Coastal Vulnerability: The location of populations near the coastal region of interest and the relative exposure of those regions to erosion and inundation caused by large storms.
- Wave Energy Conversion: The potential value of energy capture from ocean waves. ($)
- Aesthetic Quality: The visibility of offshore objects from the surrounding landscape or seascape providing information on the aesthetic effects of offshore development.

Spatial Scale

ESR can be performed at any spatial scale. The scale will be determined based on stakeholder needs. InVEST and ARIES can both conduct analyses at the landscape and watershed level.

Technical Expertise

The amount of technical expertise required varies among the three models. ESR requires the least technical expertise. The framework is designed to elicit information and feedback from stakeholders about the source, supply, distribution, and significance of ecosystem services within a defined region.

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[12] Please visit the following website for a description of the different ecosystem service models currently available in InVEST and their user manuals: http://www.naturalcapitalproject.org/models/models.html

[13] ($) indicates that the model is capable of estimating economic values.

InVEST and ARIES both require more technical background, including knowledge of spatial analysis and data as well as an ability to operate GIS. There are conflicting views on which tool requires more time and expertise. Nemec (2013) and Bagstad (2013) both argue that ARIES requires more time and expertise than InVEST. However, Vigerstol (2011) concluded that ARIES is more user-friendly for policy makers and non-technical users and requires much less data and expertise. It is recommended that the choice between ARIES and InVEST be left to a technical expert and the analysis conducted by someone who has a background in GIS and spatial analysis.

Software Requirements

InVEST requires GIS in order to operate. The tool can be downloaded online for free and can be opened and operated within ARC GIS.[14] ARIES can be operated through an online platform. It is recommended that potential users contact the ARIES team[15] to inquire about online tools and products available for use. Results from ARIES can be exported as GIS layers that can be opened and viewed with ARC GIS. ESR does not require any software besides to Microsoft Office. All guidance documents and spreadsheets that walk users through a process of identifying dependencies, risks, and opportunities related to ecosystem services are available online for free[16] (Bagstad et al. 2013).

Mapping Capabilities

InVEST and ARIES are capable of mapping services; however, ESR does not have mapping capabilities. In order to map ecosystem services estimated using ESR, a GIS analyst will need to be included in the team and land cover datasets and recreational data will be need to collected for the study location.

Budget Considerations

All three tools are available online for free and most data are publically available as well (unless study-specific propriety data are required, such as proposed facility locations). However, the three tools differ in the time required to conduct an analysis. ESR requires the least technical expertise and time to review potentially affected ecosystem services. Therefore, ESR is the most budget friendly approach. Both InVEST and ARIES will require more budget and time. While there are conflicting views on which of the two tools require more time and expertise, both tools will require considerably more time and expertise than ESR and, therefore, will require a larger budget to operate.

Table 6: Summary of Ecosystem Service Estimation Tools

Model Selection Criterion	ESR	InVEST	ARIES
Economic Metrics	Qualitative discussion of	Economic value	Economic value

14 http://www.naturalcapitalproject.org/download.html
15 info@ariesonline.org
16 http://www.wri.org/publication/ecosystem-services-review-impact-assessment & http://www.wri.org/publication/corporate-ecosystem-services-review

	economic value		
Data Requirements	None	• Data sources are listed online • Web address where data can be accessed are available[17]	• 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

Social and Community Impact Tools

A few tools have been developed that evaluate social and community impacts of sea level rise and climate change, which provide the indices and threshold analyses that accompany an evaluation of distributional impacts of climate change.. Since the advent of concerns surrounding environmental justice, more tools have been developed to identify how impacts of a project, or in this case an adaptation strategy, may differentially affect sensitive or vulnerable populations, or places of elevated community importance.

The Hazus model described above 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 pre-empt 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 (USC 2014). 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 (Cutter 2003). 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 (Cutter 2003). 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.

[17] http://www.naturalcapitalproject.org/InVEST.html

Other measures or approaches to evaluating distributional or community-based 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.[18] 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.[19] The types of characteristics important to include in a resilience index are shown in Table 7.

More tools for this purpose are needed (Karfakis et al. 2012) and the two primary approaches appear to be vulnerability analysis and resilience analysis. Both have evolved somewhat through the channels of food security research and climate change research in the international environment.

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[18] For more information on Resilience Analysis, see the EPA website, http://www.epa.gov/sustainability/analytics/resilience.htm

[19] Information about this program, Coastal Community Resilience, may be found at http://www.epa.gov/gmpo/coastalresil.html

Table 7: Characteristics of a Resilient System	
Characteristic	**Description**
Diversity	The existence of multiple resources and behaviors within the system
Adaptability	The capacity of the system to change in response to new pressures
Cohesion	The strength of unifying forces, linkages, or feedback loops
Latitude	The maximum amount of change the system can absorb while still functioning
Resistance	The capacity of the system to maintain its state in the face of disruptions

Source: http://www.epa.gov/sustainability/analytics/resilience.htm

Integrating Application Tools for Analysis

To demonstrate how answering research questions might involve considering more than one type of impact and use of more than one tool, some applications are reviewed. These applications not only provide examples of how some of the economic modeling work but also show how tools can be combined to answer specific questions. One of the challenges with reviewing this kind of decision making is that few formal economic decision-making processes surrounding climate change have yet been completed, though many are underway.

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 (2012). 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 cost method of achieving a goal. The study provides an analysis for a 100 year time horizon, and it is not clear the extent to which uncertainty has been incorporated into the benefit cost results.

Ventura County

A similar mixed approach is currently under construction and is anticipated to be completed in the fall of 2014. This effort is sponsored by The Nature Conservancy and is part of an ongoing collaborative effort called Coastal Resilience Ventura (CRV). In this analysis, the economic impacts of sea level rise inundation, flood damages, and other hazards (e.g., erosion) will be measured under two broad adaptation strategies, one focusing on armored solutions, and the other focusing on more nature-based solutions. Costs of each will be compared with benefits of each, and these results will be presented along with estimates of costs and benefits to habitats and recreation.

In the Ventura model, damages will need to be connected to multiple hazards: depth of flooding as well as erosion and storm surge impacts. As a result, different models are being used. Hydrologic modeling expertise is available in both efforts, without which the economic analyses would not be of use.

Ventura County will use Benefits Transfer to evaluate impacts to habitat. Also, in the Ventura project, results from Sea Level Affecting Marshes Model (SLAMM) will be incorporated into the analysis of habitats. SLAMM 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. Within the CRV project, the technical criteria continue to be discussed, and decisions regarding model selection and execution have not been finalized. It is anticipated that the CRV project will also incorporate an analysis of regional economic impacts using the IMPLAN input-output model. Both approaches also depend heavily upon a GIS interface.

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. The social vulnerability study was conducted by Drs. Julie Ekstrom and Susi Moser and looked at individual 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.

Summary

The information presented here is meant to assist decision makers in making sound economic investments in climate change adaptation strategies. The types of economic information needed by decision makers will depend to a great extent on the nature of the economic question posed by the decision maker. It might be that damages to the built environment are of greatest concern, or risk to ecosystem services, or resilience of the local population, or threats to the regional economy, or all of the above. In many cases, the quality of the results will depend on the quality of input data, the commitment of adequate resources to conduct the analysis, and the process of including stakeholders and stakeholder values into the process. This report has assumed that a collection of appropriate adaptation strategies are already known to decision makers and the question is merely to determine which approach or approaches will be the most effective at preventing structural damage, preserving ecosystem services, and protecting vulnerable populations.

Other considerations not analyzed in this review could be important to decision makers when attempting to select an appropriate model. For example, the degree of transparency in the tool might be important and as well the accessibility of results for stakeholders to review on multiple levels such as in a GIS environment with a platform for queries.

As many more communities begin to learn about climate change impacts, they will begin planning adaptation strategies. As this emphasis on adaptation strategies grows, there will be an increasing need to thoughtfully analyze economic, environmental, and social implications of these strategies. Going forward it will be important that decision makers thoroughly understand which tools measure which values and impacts. Furthermore, as more tools are applied to those adaptation decisions, more integrated and flexible tools are likely to evolve.

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Conclusion

Over the past year, The Nature Conservancy's Coastal Resilience Team worked with leads from multiple projects along California's coast to think about the coastal climate change adaptation planning process in California. This report presents some of the highlights of this ongoing conversation. The Nature Conservancy and its partners contemplated best practices in coastal climate change adaptation planning with respect to stakeholder engagement, sea level rise and coastal hazard modeling, decision support tools for adaptation planning, and tools for incorporating economic considerations into adaptation planning. It is hoped that this analysis will be useful for practitioners at various stages of planning and implementation and The Nature Conservancy aims to disseminate this information to the adaptation community throughout California through a continuation and expansion of the California Coastal Resilience Network.

Through conversations with partners and project leads, combined with its own experiences in Monterey and Ventura Counties, TNC identified real world constraints on best practices for stakeholder engagement for adaptation planning, proposing revised best practices based on lessons learned from the network of adaptation projects throughout California. The revisions recognize that adaptation planning does not happen in an analytical vacuum but instead faces very real and tangible limitations, including funding, stakeholder time, and political will. Although no two projects or adaptation communities are the same, the basic principles of stakeholder engagement for adaptation are widely applicable. The improvements suggested here are direct reflections of on-the-ground experience in California, and are intended to serve as guidance for future adaptation efforts as they embark on a stakeholder engagement process. The lessons learned from this leading-edge network of projects and practitioners might save others significant investments in a variety of resources, including time and money, as well as help garner critical intangibles like stakeholder buy-in and political will.

This project also undertook a detailed, peer-reviewed comparison of five sea level rise and coastal flooding modeling techniques. Although the analysis is quite nuanced and complex, at a bird's-eye view the modeling techniques differ with respect to:

- Scale and coverage
- Resolution
- Whether they were developed by modeling the influence of coastal processes or based on statistical data from historical events
- Cost.

The review also touched briefly on three new modeling initiatives that show promise in terms of shaping future modeling applications across the region. Despite the abundance of modeling techniques, none of the models have yet been validated. A comparative analysis is currently underway examining how several of the models perform in multiple geographies using historical data; results of this analysis should be available to the adaptation community in spring/summer 2015 and should demonstrate which models – or aspects of the models – are most accurate in a particular geomorphic setting (i.e., sandy embayment, open coastline, urban armored shoreline, etc.). This analysis is likely to result in recommendations to use models in geomorphically-specific projects, or to integrate the strongest aspects of each model for application in specific geomorphic settings, creating geomorphically distinct "super models." Modelers generally agree that the suite of techniques reviewed produce results that are adequate to inform adaptation planning anywhere from the regional to local level (limited only by each model's current extent of application). Almost any engineer will want as much information as possible before making a decision; The Nature Conservancy had exactly that experience with even its most enthusiastic stakeholders in Ventura County. However, in the absence of additional detail, the Oxnard City Council successfully passed a coastal power plant moratorium referencing the results of The Nature Conservancy's Coastal Resilience Project work conducted in the area. This example indicates that although coastal managers frequently request increasingly detailed analyses to support their adaptation-related actions, at present there is enough high quality modeling available for nearly the entire California coastline; perfection of technique should not be the enemy of progress with respect to taking action now to protect coastal California.

Like the abundance of sea level rise and coastal flood modeling, there has also been a proliferation of online, interactive, decision-support tools in California. The year of interviews, workshops and discussions illustrated that there is a great deal of confusion, even among the community-of-practice, with respect to where modeling ends and visualization through tools begins. Although the two are obviously intimately connected, modeling work is only as useful to adaptation planners as the tools that deliver and present the information. Tools need to be updated to maintain relevance and the most versatile tools can incorporate the results of various models - so it is important to make clear the distinction between tools and models. Even the most user-friendly tools can confound their target audience, illustrating the need for usability testing and training. Although the tools differ in approach, scale, and capabilities, they are all fundamentally trying to provide the illustration of the information necessary to make adaptation decisions. While all the tools reviewed do this well, few of the tools do a great job of illustrating uncertainty, ecological assets, and economic information.

One of the key services that decision-support tools generally do not provide, as a matter of definition, is presentation of recommendations. Many of the tools highlight some very general options: armor or retreat; elevate or undevelop; nourish the beach or restore natural processes. However, in no case do the tools allow visualization of the physical impact of different options, which is ultimately what managers want and need in the absence of an outright list of recommendations for their jurisdiction from "adaptation experts."

Analyzing economic impacts is a critical step in bridging the gap between displaying modeling results and weighing the impact of different adaptation options. This analysis also includes a review of the tools available for critically analyzing the economic impact of climate change adaptation. Although most practitioners agree that economic factors are critical in driving current and future climate change adaptation, this is also the area of adaptation planning that is most obscure. A wide variety of economic tools and assessment approaches exist, mostly designed to assess the impact of a flooding or storm event. The tools are very versatile – they can demonstrate the real estate impact, the social impact, the economic impact, the impact to the regional economy, and a variety of other socioeconomic outcomes of flooding and storm events. For adaptation, however, practitioners need tools that can evaluate costs and benefits of *adaptation solutions* – information crucial to assist decision makers in choosing adaptation strategies; there are very few examples to-date of on-the-ground projects utilize these tools. Among economists, there is no standard, universally agreed-upon methodology for incorporating ecosystem service valuation into such analyses, although there are a variety of ways in which this gap might begin to be addressed. Even as methodologies are identified, data gaps still present challenges. Economic considerations will begin to play a much more significant role in adaptation as planning turns into action. The Nature Conservancy, through its California Coastal Resilience Network, can play a pivotal role in adaptation planning by encouraging state-wide dialogue and knowledge exchange about how economics can be incorporated into adaptation planning.

The California adaptation community is active and empowered, as reflected at the state-wide level by those efforts detailed in this report, the Lifting the Fog workshop in Oakland, 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, as well as the deluge of applications for Ocean Protection Council and State Coastal Conservancy funds for local "Climate Ready" adaptation. More than 800 participants attended the inaugural California Adaptation Forum, illustrating the extent of interest and growing expertise statewide in this topic. The Nature Conservancy's research has reinforced the need for state intervention in California's local adaptation efforts, which could benefit from streamlining and state support through policy, finance, and guidance on technical aspects of adaptation.

The first phase of the California Coastal Resilience Network project built strong connections within the local adaptation planning community of practice 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.

Lessons Learned

A number of overall conclusions can be drawn from the suite of analyses presented in this report:

- Stakeholder engagement in adaptation planning processes is critical and must be facilitated thoughtfully in order to ensure that communication with stakeholders encourages meaningful balance between encouraging active participation and avoiding stakeholder fatigue.
- 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 context. This has the potential to lead to difficulties in translating the current planning work occurring throughout the state into on-the-ground, actionable adaptation. There is a need to streamline coastal climate adaptation policy and for improved communication between local and state management entities.

- Future efforts should be dedicated to validating the leading sea level rise and coastal flooding models and to clarifying expressions of model uncertainty.
- The state's adaptation community is advocating for the integration of multiple modeling techniques, selecting the most appropriate facets of the various models in order to best address specific geographic regions in the state.
- Existing modeling and visualization tools are adequate to initiate local planning processes.
- Decision support tools must be tested by stakeholders to determine their performance and usability. In addition, while inundation scenarios can now be mapped using multiple 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 to planners and other practitioners. It is important that this shortcoming be addressed in order to effectively support and inform future local adaptation efforts.
- Adaptation planners in the state must arrive at consensus around best practices for incorporating economic considerations into adaptation planning. Successfully doing so will support efforts to adapt to climate change.
- Although frequently identified as the most limiting factor for communities in terms of their ability to adapt to climate change, there are few applied examples that incorporate economic considerations into adaptation planning and there is little to no consensus about the best practice for doing so. California can lead the way by exploring how best to consider the economic impact of climate change adaptation in practice.

Future California Coastal Resilience Network

This research effort illuminates several examples of regional-scale adaptation planning efforts which are constrained by time and funding. With additional resources, The Nature Conservancy could lead an expanded and formalized California Coastal Resilience Network to:

- Continue and strengthen engagements in, 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 to include additional geographies that did not participate in Phase I but would benefit from this collaborative approach to thinking about improving coastal management and enabling local planning and adaptation.
- Offer collaboration with the existing Alliance of Regional Collaboratives for Climate Adaptation (ARCCA[20]) to provide participating entities with more information about nature-based coastal adaptation approaches and to increase the exchange of information about the suite of shared adaptation concerns unique to coastal California

[20] The Alliance of Regional Collaboratives for Climate Adaptation is an umbrella organization, founded in 2012, that brings together the four regional urban climate adaptation collaboratives in California for coordinated dialogue and preparedness planning.

- Continue 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 intervene to help.
- Encourage state-wide dialogue and knowledge exchange about how economics can be incorporated into adaptation planning.
- Work collectively to identify challenges shared by experienced local practitioners as well as the most easily-leveraged California-specific adaptation strategies.
- Enable conditions that empower both a state-wide approach to large-scale coastal climate change adaptation and local action.
- Support existing training programs to collaboratively develop and deliver information and technical tools based on articulated needs.