Addressing Sea Level Rise and Floodplain Management in California with the National Flood Insurance Program

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About this Document

This report was developed as part of a collaborative project funded by the NOAA Coastal and Ocean Climate Applications program to address sea level rise in floodplain management. Led by the California Department of Water Resources (DWR), the Scripps Institution of Oceanography (SIO), and the California Ocean Science Trust, this project produced actionable sea level rise and zone of flooding information for coastal decision-makers, with specific consideration of communities that participate in the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP). This report is one of three complementary products that were developed by project partners, with input from external collaborators and consultants. It was developed to function as a comprehensive narrative or summary of the project's components. The report also provides relevant and contextual information on FEMA's NFIP, as well as other sea level rise policies and resources in California and beyond that can inform community efforts to account for rising sea levels in their land use planning and management activities.

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1.0 Background: Planning and Managing for Sea Level Rise in California

Storms introduce risks to coastal communities in California in the form of flooding, erosion, and shoreline retreat. Rising sea levels and altered seasonal wave conditions due to climate change will continue to alter California's shorelines over the coming decades and beyond. As sea level continues to rise, shoreline exposure will increase for any given wave, storm surge, and high tide combination. Adaptation to sea level rise in the coming decades will require existing and future coastal planning and policies to be adaptive and flexible.

California has shown leadership in prioritizing climate change adaptation policy and research (e.g., Assembly Bill 32, Executive Order S-13-08, Safeguarding California, Climate Change Research Plan). These efforts have made California's coastal decision-makers aware of the general effects of climate change and sea level rise, in particular. In addition, the State has invested in a range of data, tools, and guidance products (e.g., statewide seafloor mapping, the *State of California Sea-Level Rise Guidance Document*) in recent years, to promote statewide consistency in planning for sea level rise and more effective responses to related coastal impacts like flooding and erosion.

These investments are advancing knowledge of climate change and its consequences for the state's coastal communities. But, advancing knowledge is not the same as increasing a local community's capacity and ability to deal with sea level rise and other climate impacts. Bringing new knowledge to bear on coastal adaptation and planning requires consideration of what new policies and institutions are needed, as well as how existing policies and institutions can change to be more effective and better coordinated. Leveraging this new knowledge towards coastal adaption planning also requires thoughtful engagement and negotiation among producers and users of knowledge (Dilling & Lemos, 2011; Jacobs, Garfin, & Lenart, 2005; Sarewitz & Pielke Jr., 2007).

The translation of sea level rise information into products and services that adequately support California's broad State mandate is necessary but often, these products are not automatically taken up or used by managers and planners. There is a need for training, technical support, and information tailored to a variety of management, planning and regulatory contexts (Finzi Hart et al., 2012). Continued work to link evolving knowledge of sea level rise dynamics to institutional mechanisms for addressing these risks can help communities adapt to a changing climate in a cost-effective and efficient manner.

2.0 Linking Sea Level Rise Planning to Federal Policies and Programs.

The California Department of Water Resources (DWR) is the designated State-level agency with flood management jurisdiction. DWR coordinates with federal, State, and local agencies and provides planning assistance to agencies to help minimize the risk of flood loss and damage. In addition, DWR is

responsible for coordinating all activities related to California's participation and compliance in the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP), and receives funds from FEMA to supplement DWR's regional office staff.

DWR conducts Community Assistance Contacts and Community Assistance Visits on behalf of FEMA to inspect structures in the floodplain, and review building permits and local floodplain ordinances to confirm NFIP compliance. These interactions provide DWR an opportunity to encourage local land use authorities (i.e., cities and counties) to properly administer their local floodplain management ordinances and develop community flood hazard mitigation plans.

DWR works to support local communities in developing sound management practices to address both current and future flood risks. To this end, DWR saw an opportunity to incorporate new information about sea level rise science and policy into guidance and trainings DWR conducts as part of their visits to NFIP participating communities.

2.1 Project Overview – Linking Sea Level Rise to the National Flood Insurance Program

At the outset of this project FEMA did not formally address climate change impacts in the NFIP although there was a general provision allowing program applicants to consider "expected future conditions" from flooding in the context of program compliance. HR 4348[1] was enacted in June 2012 to reauthorize the NFIP. Among other things, HR 4348 called for the establishment of a Technical Mapping Advisory Council to provide FEMA guidance on how to consider sea level rise in Flood Insurance Rate Maps (FIRMs). Even though this guidance would not be available for some time, local agencies could choose to address sea level rise and related flooding risk in the interim under the rubric of FEMA's "expected future conditions" provision. California's existing State-level guidance requiring local agencies to consider sea level rise in planning decisions and the State's continued investments in sea level rise science provides a foundation for developing information that local agencies can use in compliance with both existing mandates and future regulatory directives from FEMA.

With funding from a NOAA Coastal and Ocean Climate Applications grant program, DWR, the California Ocean Science Trust and Scripps Institution of Oceanography (SIO) collaborated on a project to develop useful information products to support and better prepare local communities to plan and adapt to sea level rise and coastal flooding. DWR provided additional funding through the Division of Flood Management and the Climate Change Program. The primary goal of this project is to take new information on regional-scale sea level rise, wave runup and tides, and translate it into products that are directly relevant to coastal planners and the communities they serve, with a direct focus on communities participating in FEMA's NFIP. In addition to producing discrete informational products, the broader objectives of this project were:

- Fulfilling a California mandate that sea level rise be considered in all planning activities;

[1] H.R. 4348 - Surface Transportation Extension Act of 2012 (https://www.gpo.gov/fdsys/pkg/BILLS-112hr4348enr/pdf/BILLS-

- Understanding the science needs of managers at multiple levels of governance and improving access to the latest sea level rise information;
- Crafting a constructive ongoing role for science in evolving regulations concerned with coastal hazards; and
- Promoting partnerships that strengthen the network of institutions focused on addressing coastal vulnerability, and climate adaptation.

To achieve these objectives the project was organized into several components:

- **Science Needs Assessment**: Ocean Science Trust conducted interviews with coastal planners, engineers, and other decision-makers about the challenges, barriers, and opportunities for developing effective informational products and engagement processes related to sea level rise.

- **Focus Group**: A panel of floodplain managers and coastal decision-makers helped to shape the outputs of this project by providing guidance and input at project milestones. Members of the Focus Group also served as conduits to their broader communities, promoting partnerships and strengthening the network of institutions focused on addressing coastal vulnerability and climate adaptation (See Appendix D for a list of participating agencies and organizations).

- **Sea level Rise Modeling**: Scripps Institution of Oceanography developed indices of potential coastal flooding at six sites within five representative locations across California. These indices were translated into maps depicting the zone of expected flooding in a manner consistent to FEMA guidelines (See Appendix A for more detailed information on SIO's modeling methods and approach).

- **Non-regulatory Guidance Products**: Using the findings from the Science Needs Assessment, and guidance from the Focus Group, three non-regulatory guidance and informational products were developed to support coastal planning and management: 1) An appendix to DWR's *The National Flood Insurance Program in California: Quick Guide* (DWR, 2007) focusing on opportunities to address future conditions like sea level rise flooding and inundation, 2) a Technical Methods Manual that connects SIO modeling outputs to FEMA hazard mapping guidelines, and 3) this report, which provides additional context about this project and additional relevant information.

- **Sharing and distributing project results and products:** The products from this project have already been introduced to audiences at flood management and coastal management conferences beginning in 2014. The project partners, in collaboration with the Focus Group, are continuing to identify opportunities for sharing the products and educating potential end users on their content and application.

2.2 Science Needs Assessment – Understanding Information Needs, Challenges and Opportunities in Using Sea Level Rise Science and Guidance

Developing useful guidance and information requires insight into the science and information needs of decision-makers. This means understanding how decision-makers use and access scientific information, what constraints and opportunities they face in implementing their mandates and policies, and the broader political and institutional contexts in which decisions are being made. Ocean Science Trust conducted a Science Needs Assessment to help guide decisions about the framing, structure, and delivery of this project's information and guidance products.

Building off of existing studies that address and explore the needs of coastal managers (DWR, 2013; DWR, 2014; Finzi Hart et al., 2012; NOAA, 2011; Tribbia & Moser, 2008), this needs assessment involved interviews with key stakeholders (e.g., local floodplain managers, city planners, coastal policy/decision-makers, engineers, and scientists) to:

1. Develop insights on the various challenges, barriers and opportunities for developing and implementing effective information and guidance products that address sea level rise and associated responses (e.g., flooding, erosion);
2. Advance understanding of the processes through which sea level rise information is developed and used; and
3. Evaluate the utility of existing sea level rise information for varying decision-making contexts.

The findings from this Science Needs Assessment were broad, and varied across organizations, offices, cities, and counties. Common themes among the findings did emerge, however. In general, many local decision makers are working to address sea level rise and related coastal impacts such as coastal flooding. These coastal professionals are leveraging a range of policy, regulatory, and management mechanisms and a growing suite of data, tools, and guidance products to meet the challenges posed by a changing climate. However, available resources to support planning and adaptation to sea level rise do not always contain information that is useful and/or relevant in a local context, and there is often a lack of training and technical support to effectively use these resources at the local level. Additionally there are a multitude of information needs around sea level rise, and these needs are complex, nuanced, and are often department-, site-, or project-specific. Interviews also revealed that those working on the ground are more likely to address sea level rise in the context of existing regulatory and planning activities, like an update to a local hazard mitigation plan, and/or if there are readily available incentive structures (e.g., grant programs) to support this work.

The breadth of these findings was helpful to identify general desired characteristics of information products and common information needs. However, the scope and focus of this project are much narrower. The findings below are considered most directly relevant to developing products that support the objectives of this project:

1. **Modeling results and technical information should be relevant to management decision-making frameworks**: While the flood indices developed by SIO are illustrative of future flooding

trends, they fall short of information that can be used in on-the-ground coastal adaptation planning. Products that help translate these indices into zones of future expected flooding, or potential map products are more useful in identifying and visualizing site-specific areas at risk to future flooding.

2. **Include information on shoreline erosion and geomorphic responses, in the context of sea level rise:** Geomorphic response, such as beach, dune, and bluff erosion, is inextricably linked to changing water levels (e.g., sea level rise). Knowledge of the relationships among sea level rise, shoreline change, and coastal flooding is critical for both near-term and long-term planning.
3. **Balance sophistication with simplicity by developing tiered guidance and information products:** Project partners were encouraged to develop a "multi-dimensional" information product that is organized, or tiered, to provide different levels of information for different audiences.
4. **Co-produce products with potential users:** Products are more useful when they are developed, informed, and tested by potential users, practitioners, and other relevant stakeholders. The co-production of products can also ensure that developers can engage with users throughout the lifecycle of the project, which in turn can support the uptake and continued use of products.
5. **Identify incentives that can support the development and use of information:** Communities that are incorporating sea level rise information into their planning and regulatory mechanisms are often harnessing incentive structures, such as State and federal grant programs, to support such work. Within the context of the National Flood Insurance Program, the Community Rating System Program provides a potential incentive for communities to use the information and approaches developed as part of this project.

2.3 Developing a Series of Complementary Products to Address Information Needs

The findings from the Science Needs Assessment helped shape the content, scope, and purpose of a series of three products that were developed from this project. This approach addresses the complex and varied needs of California's coastal managers, as well as their capacity to make use of new information. More specifically, these products were conceptualized as a series to address findings 2, 3 and 4 from the Science Needs Assessment: the need to acknowledge and recognize the impacts of shoreline erosion and geomorphic responses in the context of sea level rise; a need to balance sophistication with simplicity in regards to developing useful products for sea level rise planning and management; and a need to help translate flood indices into mapping products, as flood indices alone, are not as useful as mapping products from a local management and planning perspective. As a result, the two products in addition to this report represent two very different types of resources for planning and adapting to sea level rise. These two additional products are summarized below.

A Sea level Rise Appendix to the NFIP California Quick Guide: DWR developed an appendix to its existing publication *The National Flood Insurance Program in California: Quick Guide* (DWR, 2007). The Quick Guide is a resource for floodplain managers, which contains simplified guidance on how to comply with FEMA's NFIP. The Appendix provides a high-level overview on sea level rise and floodplain management in the context of the NFIP, and provides additional resources that communities can use to

bring explicit consideration of sea level rise into their planning, local floodplain ordinances and other relevant programs. Also included in this document are widely-used and accepted methods to map sea level rise.

Relating Future Coastal Conditions to FEMA Flood Hazard Maps - Technical Methods Manual: The *Technical Methods Manual - Relating Future Coastal Conditions to Existing FEMA Flood Hazard Maps*, builds on the Quick Guide Appendix to provide additional technical information to local floodplain managers, coastal engineers, and contractors who conduct flooding analyses in support of the NFIP and other regulatory and non-regulatory directives. The Manual relates future coastal conditions from modeling conducted by the SIO to existing conditions coastal flood maps from FEMA with the intent to facilitate approximate mapping of future coastal hazards for local planning. This Manual also provides methods for relating future coastal conditions projected through other modeling and research efforts, to FEMA Flood Hazard Maps in addition to the SIO projections. Environmental Science Associates (ESA) developed the Manual, with input from SIO, Ocean Science Trust, and DWR, and broad participation by professionals active in coastal planning (see Acknowledgements). A Focus Group guided the content development of this manual, and a Technical Methods Manual Committee (TMMC) provided more detailed review and input.

3.0 California's Efforts to Address Sea Level Rise

California has simultaneously focused on developing scientific understanding of sea level rise impacts, and on laying the groundwork for both State and non-State entities to consider sea level rise in their activities and operations. In November of 2008, Governor Arnold Schwarzenegger signed Executive Order S-13-08: The Climate Adaptation and Sea level Rise Directive. This Executive Order directed State agencies to prepare for climate change impacts, particularly sea level rise, and called for: 1) Statewide guidance on how to plan for sea level rise in coastal and floodplain areas; 2) a Statewide Climate Adaptation Strategy to assess climate change impacts, and identify vulnerability in the states; 3) studies on critical infrastructure and land use policies vulnerable to sea level rise; and 4) the National Academy of Sciences (NAS) to establish an expert panel to report on sea level rise impacts in California in order to inform State planning and development efforts;

The National Research Council (NRC) convened an independent panel to complete the *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* report (2012). Prior to the release of the NRC report, the State undertook a collaborative effort to provide interim land-use planning guidance related to sea level rise, and begin the process of focusing decision makers on the need to consider sea level rise in their operations. Led by the California Ocean Protection Council (OPC), a Sea level Rise Task Force comprising members of the Coastal and Ocean Working Group of the California Climate Action Team (CAT) was organized. The Sea Level Rise Task Force worked with Ocean Science Trust and the OPC Science Advisory Team (OPC-SAT) to produce the *State of California Sea-Level Rise Interim Guidance Document* (2010).

The final NRC Report was released in 2012, and in 2013, the *State of California Sea-Level Rise Guidance Document* (2013) was finalized with updated California-specific sea level rise projections from the NRC report. While the *Guidance Document* is intended to increase consistency across agency planning efforts, it does not prescribe that all agencies use identical sea level rise values. Because agency mandates and decision-making processes vary considerably, it was anticipated that agency interpretation and use of the *Guidance Document* would vary and that State agencies incorporate these projections "where appropriate and feasible."

The NRC report demonstrates that a one-size-fits all solution is insufficient for coastal adaptation to sea level rise. Beyond including regionally specific projections that can more effectively support coastal planning, it also calls attention to some other important dynamics of the general problem. Chiefly, that the major impacts of sea level rise in the coming decades will be experienced during winter storm conditions, especially when those storms occur during El Niño years when sea levels are higher due to warmer water temperature, and high tides. The report also notes that whether or not storminess increases in the future, sea level rise will increase the incidence and duration of extreme high water events, amplifying storm surge and large waves impacts to the coast (see Appendix A for more detailed information on the science of sea level rise processes).

The newly released NRC Study includes a wealth of information, most notably regional sea level rise scenarios and information on the relative contribution of factors such as tectonics. This information is relevant to local land use planning (e.g. zoning requirements), floodplain management, and infrastructure design. However, additional translation of this scientific knowledge can help to ensure its practical relevance for local decision-makers. *A core focus of this project is to build upon the sea level rise projections of the NRC report, by accounting for local wave effects/storm surges and tides. Collectively, this information is needed to identify the zone of expected flooding in a manner consistent with the NFIP.*

4.0 Sea Level Rise and the National Flood Insurance Program

The NFIP is administered through contracts between local agencies and FEMA. Communities that participate in the NFIP agree to regulate floodplain development according to certain criteria and standards. The NFIP consists of three central, interconnected activities:

1. Flood insurance – Making flood insurance available to help property owners recover following a flood;
2. Floodplain management – Minimizing the physical and economic impacts of flood events using a combination of mitigation efforts and community-adopted floodplain ordinances; and
3. Floodplain identification and mapping – Identifying and mapping community areas that are subject to flooding.

Communities are eligible to receive federal flood insurance if they adopt and enforce floodplain management ordinances to reduce future flood risks according to FEMA standards. Flood Insurance Rate Maps (FIRMs)[2] are the official map on which FEMA has delineated both the special flood hazard areas and the risk premium zones applicable to the community. Property owners and renters can use the FIRM to get a reliable indication of what flood zone their property is located in.

FIRMS are regulatory products that show areas of high flood hazard. They are based on *existing* conditions. FEMA has recognized for some time the importance of addressing *expected future conditions* from climate change related phenomena such as sea level rise, but progress in this area has been slow (FEMA, 2001).

While NFIP regulations do not explicitly require communities to address climate change impacts, local communities can choose to adopt future conditions hydrology for floodplain management purposes, and can work with FEMA to identify those floodplains on their FIRMS. The floodplains that result from future conditions hydrology can be for non-regulatory (informational) or regulatory purposes, depending on the community's preference and it's consistency with FEMA guidelines.

4.1 Addressing Future Conditions - Incentive Programs and Policy Reform

FEMA provides financial incentives for NFIP participating communities to consider future flood risks from a changing climate. The Community Rating System (CRS) is a voluntary program that encourages and rewards community floodplain management activities that exceed the minimum NFIP requirements (FEMA TMAC, 2015). In this program communities can accrue points to improve their CRS rating, which can then result in reductions in insurance premiums[3].

The 2013 CRS Coordinator's Manual (FEMA, 2013), for the first time, includes measures by which communities can earn CRS credits for their efforts to anticipate future risks of flooding due to climate change; thus, establishing an explicit incentive for local communities to address sea level rise within the context of the NFIP. The manual notes that coastal communities may be eligible for CRS credits if, among other things, they have flood hazard assessment and problem analyses made available to the public that address areas likely to flood, and flood problems that are likely to get worse in the future; or have their regulatory maps based on future conditions hydrology.

The *Biggert-Waters Flood Insurance Reform Act of 2012* called for a federal advisory committee comprised of representatives from federal, state, local and private sector organizations, to provide guidance to FEMA on how to account for impacts of climate change and future conditions and how they may be incorporated into the national flood mapping program. This advisory committee, known as the Technical Mapping Advisory Council (TMAC) released a report in December 2015, that includes a set of recommendations for FEMA on the utilization and incorporation of best available climate science and methodologies to assess possible future flood risk.

[2] Digital versions of these maps are called DFIRMS.
[3] Communities are awarded credit points (between 0 and 4,500+) for up to 18 activities across 4 categories: public information, mapping and regulations, flood damage reduction, and flood preparedness

The report also champions the development of future conditions flood risk products, tools, and information for coastal, Great Lakes, and riverine areas. Further, it calls for demonstration or pilot projects to develop future conditions data for representative sites across the Nation. These pilot studies are intended to evaluate the costs and benefits of different methodologies and/or address methodological gaps that affect the development of future conditions data and information products (TMAC, 2015).

To date, two sea level rise pilot studies have been conducted in San Francisco, CA and Puerto Rico. These projects, which were initiated concurrently to the development of the TMAC report, were initiated under FEMA's Risk Mapping, Assessment and Planning (Risk MAP) program. This program works with federal, state, tribal and local partners across the nation to provide high quality flood maps and tools to better assess flood risk as well as outreach and planning support to help communities reduce these risks. Each Risk MAP flood project is tailored to the needs of each community.

The Puerto Rico pilot study assessed the feasibility of different modeling methodologies for producing a sea level rise prototype advisory layer that could be added to a FIRM. It included "proof of concept" non-regulatory maps that could be developed at a fairly low additional cost to help guide long-term planning and adaptation (FEMA TMAC, 2015).

The San Francisco sea level rise pilot project (BakerAECOM & FEMA, 2016) was developed as part of the FEMA Region IX California Coastal Analysis and Mapping Project (CCAMP) Open Pacific Coast (OPC) Study. The CCAMP OPC Study is a larger effort to map FIRMs for 15 coastal counties in California in accordance with FEMA's 2005 Pacific guidelines for new coastal studies. The pilot project resulted in a report (FEMA 2016) that documents the technical methods and results of the future conditions mapping and their potential application to other future conditions studies along the Pacific coast, geospatial data layers that illustrate future conditions flood hazard areas, and non-regulatory flood risk information and maps.

5.0 Linking Sea Level Rise to the National Flood Insurance Program in California

Since this project was first proposed in 2012, there have been many efforts to advance sea level rise planning and adaptation at the Federal, State and local level. The Federal government has signaled strong support for accounting for sea level rise in flood risk management, as evidenced by President Obama's signing of Executive Order 13690 in 2014. This executive order directs federal agencies to take the appropriate actions to reduce risk to federal investments by "updat(ing) their flood-risk reduction standards." Specifically, federal agencies are now required to consider current and future sea level rise risk when taxpayer dollars are used to build or rebuild on floodplains. In California, agencies with coastal management and regulatory responsibilities such as the Coastal Commission, Coastal Conservancy, and DWR have made increased investments in staff support and grant programs, to support local governments in their planning and adaptation to sea level rise. With this support, a number of communities in California are formally addressing the risks posed by a changing climate in their Local

Coastal Plans and Hazard Mitigation Plans (See Appendix B for a list of guidance documents, tools, and examples of local sea level rise planning efforts).

FEMA in particular has made significant progress in addressing future conditions mapping of sea level rise and related coastal processes through proof of concept pilot studies in the San Francisco Bay Area and Puerto Rico. Because of the direct link to the NFIP, FEMA Region IX, along with their consultants, was an active participant in this project, to ensure that the modeling outputs and products generated were consistent and relevant to NFIP and FEMA guidelines and policies. The SIO modeling of future flood conditions, and ESAs work on the Technical Methods Manual to relate SIO modeling outputs to existing conditions coastal flood maps from FEMA, has resulted in additional future flood risk products at six locations in California.[4] This work and the resulting products build on FEMA's sea level pilot projects, and community engagement efforts, to collectively advance public awareness of increasing risks from a rapidly changing climate and inform local land use planning in California.

6.0 Looking Forward

This project has helped to demonstrate the importance of crafting a constructive ongoing role for science in evolving regulations concerned with coastal flooding from rising seas and changing shorelines. It has also helped to promote partnerships that strengthen the network of institutions focused on addressing coastal vulnerability, and climate adaptation in California. The products from this report have already been introduced to audiences at flood and coastal management conferences, and project participants are continuing to identify opportunities for sharing the products and educating potential end users on their content and application. Looking forward, it will be critical to continue to work in close collaboration with regional FEMA leads, NFIP support staff, and other coastal flood management agencies, to apply these products to flood management efforts on the ground. More specifically, these groups could work directly with the communities at the five locations where SIO sea level rise modeling was conducted using the Technical Methods Manual to translate SIO flood indices into mapping products consistent with FEMA's FIRM mapping guidelines. Finally, working with FEMA and NFIP support staff to continue to identify opportunities for sharing these resources with on-the-ground decision makers and the broader public, could help support the integration and application of sea level rise science and flood information into the local land use plans and other regulatory programs such as the NFIP.

[4] SIO future conditions modeling was conducted for the following locations: 1) A portion of Silver Strand Beach north of the Mexican border; 2) La Jolla Shores in the northern part of the City of San Diego; 3) Santa Cruz Boardwalk in central California; 4) Ocean Beach in San Francisco; 5) Crescent City beach; and 6) Crescent City harbor. A more detailed description of the methodology used to generate these outputs can be found in Bromirski et al. 2012, as well as the Technical Methods Manual (TMM).

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Appendix A: Scripps Institution of Oceanography Modeling Future Conditions: Waves and Water Levels

Scientists from the Scripps Institution of Oceanography (SIO) provided future conditions based on outputs from selected global circulation models (GCMs). These outputs consisted of future waves and water levels for three offshore locations and associated wave runup and total water levels for six near shore locations along the California coast.

The SIO future conditions "outputs" consist of future ocean water levels (including non-tidal constituents that affect flood levels) and wave-induced runup, and the summation of water level and runup called Total Water Level (TWL). Flooding is caused by short-term processes superimposed on RSL (Relative Sea Level Rise) and results from storm waves impacting the coast during the co-occurrence of high tides and storm surges, with El Niño–related interannual sea level increases augmenting RSL.

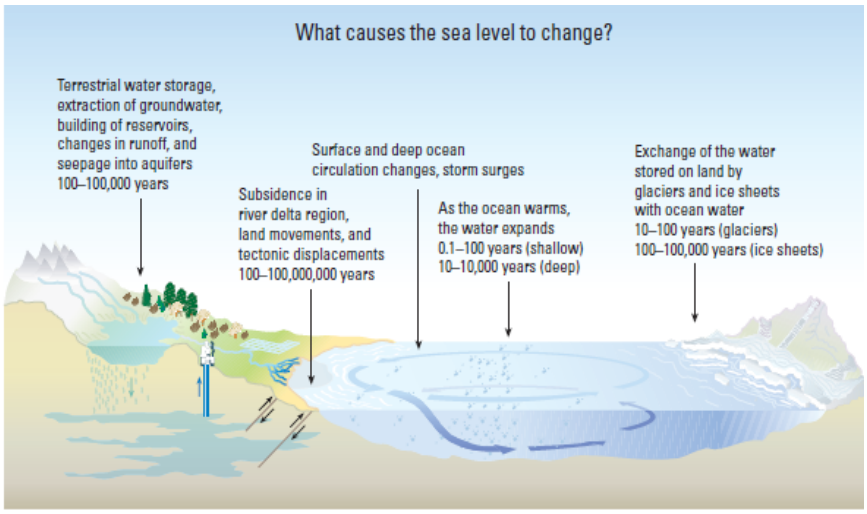
For this project, the outputs were computed for three offshore and six nearshore locations (FigureB.1) SIO used Global Climate Models (GCMs) and secular sea level rise projections (following California guidelines) to compute future water levels and waves. Waves were transformed (refracted) to the following nearshore locations (in order from south to north):

1. A portion of Silver Strand Beach north of the Mexican border;
2. La Jolla Shores in the northern part of the City of San Diego;
3. Santa Cruz Boardwalk in central California;
4. Ocean Beach in San Francisco;
5. Crescent City beach; and
6. Crescent City harbor.

A more detailed description of the methodology used to generate these outputs can be found in Bromirski et al. 2012. The SIO methodology is consistent with FEMA's methods for existing flood hazard mapping, however, rather than using historical data to compute wave runup, SIO methods use forecasted data. Additionally, SIO methods have been applied to a selected number of locations, and have not been used to create hazard maps, limiting their ability to be directly comparable and used for FEMA flood mapping purposes. The goal and purpose of developing the Technical Methods Manual was to facilitate the comparison and application of the SIO results to inform planning for future conditions.

Appendix B: The Science of Sea Level Rise and Related Coastal Processes

The primary factors that create sea level rise include warming of the oceans, which causes sea water to expand, and by melting land ice (glaciers and ice sheets). It is estimated that 90% of the excess heat in the earth system due to global warming and other human activity has accumulated in the oceans (Rhein et al. 2013). Studies using historical tide gage records have documented global sea level rise at approximately +190mm from 1900-2005 (Church et al. 2013). The rate of global sea level rise during the 20th Century has increased during the 19th Century, and satellite altimeter and tide gage observations indicate that sea level rise since ~2000 has increased from about 2mm/yr to nearly 3mm/yr (Church and White 2011; Watson et al. 2015) with ocean thermal expansion and added water from melting glaciers and ice sheets being the primary contributors.



The major factors affecting sea level rise (Source: USGS, 2015)

Because the earth is warming, global sea level rise will continue, and the rate of global sea level rise will likely increase during, and beyond the 21st Century. Outstanding issues regarding sea level rise that have important implications on planning and adaptation measures globally and in California, including 1) the uncertain rate of future sea level rise, which amongst other factors, is highly dependent on the rate of mass loss to the oceans from the Greenland and especially Antarctic ice sheets; 2) how sea level rise varies and will vary spatially; 3) how sea levels will vary over time, across a range of time scales, including storm-driven high-frequency high sea level extremes.

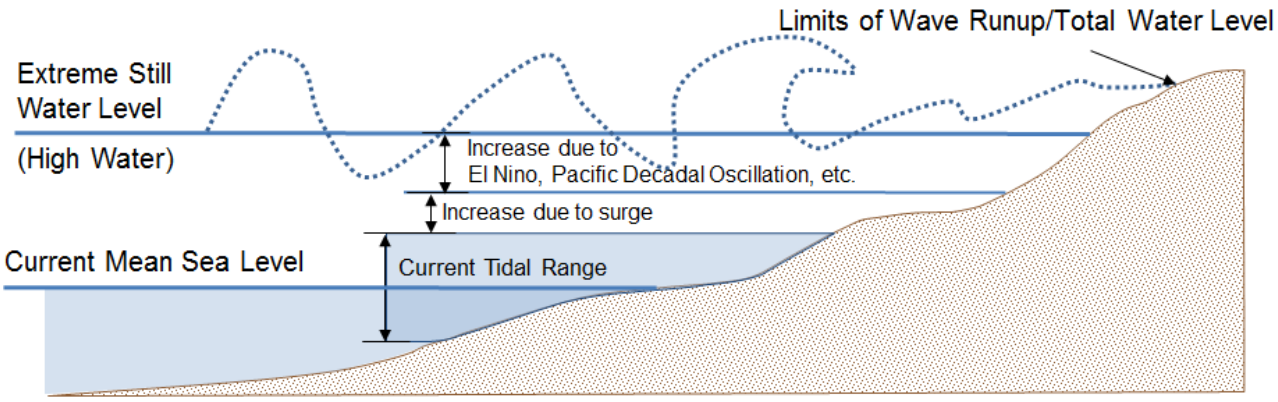
Regional Variations in Sea Level

Over many decades, the amount of sea level rise along the California coast, south of Cape Mendocino, is nearly the same as the global estimated sea level rise (Cayan et al. 2008, National Research Council 2012). However, regionally, such as along the California coast, sea levels have variations that are not in sync with global averages. Winds and currents move water laterally in the ocean, creating anomalous spatial patterns of sea level that can persist for a decade or longer. For example, the altered Pacific basin winds and low atmospheric pressures associated with El Niños and other climate patterns can significantly elevate sea level along the west coast of the United States for several months (Bromirski et al. 2003; Hamlington et al. 2015). On land, geologic processes (e.g., glacial isostatic adjustment, tectonics, compaction) and human activities (e.g., withdrawal of groundwater or hydrocarbons that produces subsidence) raise or lower the coastal land surface, increasing variability in local sea level (e.g.

NRC 2014). Because both the land and ocean surface are commonly moving vertically, local sea level along the coast is often referred to as RSL.

Extreme High Sea Level Events

Most coastal damage in California occurs during periods when both extreme sea levels and extreme wave heights occur concurrently (Flick 1998).



Additive effects of high tides, storm surge, atmospheric patterns (e.g., El Nino) and large waves can result in coastal flooding (Source: adapted from California Coastal Commission, 2015)

The greatest coastal impacts occur when elevated storm surge coincides with high tides near peaks of longer period sea level height fluctuations, all of which are superimposed on mean sea level rise. Most of the "spread" in the distribution of sea levels is caused by tides, which are almost always the largest components of daily sea level fluctuations. Tides are the only component of sea level variability that is accurately predictable. Extreme wave heights and extreme non-tide sea level fluctuations tend to increase from the south to the north along the California coast. Coastal sea level extremes are also exacerbated by other storm effects, such as heavy surf from wind-driven waves (Bromirski et al. 2005). Wave activity provides the primary driving force for coastal erosion and flooding, and when combined with high tides, the chances for coastal damage are greatly heightened.

It is very likely that the frequency and amplitude of high sea level extremes will increase over the 21st Century, due largely to the fact that global sea level will rise.

In addition to rising mean RSL, coastal impacts from sea level fluctuations will also be affected by storm surges and wave runup, especially during severe storms. The TWL at any instant results from the superposition of regional or mean relative sea level, the tide, and non-tide sea level fluctuations, which include ocean thermal expansion, and storm surge. Along the California coast, storm surge is primarily driven by the inverse barometer effect caused by low-pressure storm systems approaching the coast, with a lesser contribution from winds (Chelton and Davis, 1981; Bromirski et al., 2003). The vertical height wave-driven water levels reach is called wave runup. Runup depends on the instantaneous TWL, beach slope, and wave height and wave period. The potential for greatest coastal flooding occurs when

extremes in waves and TWL occur nearly simultaneously. Projections of storm surge and waves indicate that their variability and extremes are not expected to change appreciably over the 21st Century (Bromirski et al., 2012). However, rising global and RSL will greatly aggravate coastal impacts, with the potential for moderate storms at the end of the century producing impacts equivalent to or greater than the most severe storms during previous great El Niños.

Catastrophic Tectonic Events

Finally, extreme and rare events can raise sea level much faster than long-term changes in mean sea levels, including temporary changes caused by earthquake-induced tsunamis and immediate and permanent changes in land subsidence and/or uplift caused by a great earthquake (National Research Council 2012).

Appendix C: Additional Tools, Resources & Guidance for Addressing Sea Level Rise

State Guidance Documents & Studies

- Coastal and Ocean Working Group of the California Climate Action Team (2013). State of California Sea-Level Rise Guidance Document. Provides guidance for agencies in California as they develop approaches for incorporating sea level rise into planning decisions. Provides sea level rise projections from the 2012 National Research Council report *Sea level Rise for the Coasts of California, Oregon, and Washington*. Specifically, this document provides information and recommendations to enhance consistency across agencies in their development of approaches to sea level rise.

- California Coastal Commission (2015). Sea level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits. Provides an overview of sea level rise projections for California from the 2012 National Research Council report *Sea Level Rise for the Coasts of California, Oregon, and Washington,* and recommended methodology for addressing sea level rise in Coastal Commission planning and regulatory actions. It is intended to serve as a multi-purpose resource for a variety of audiences and includes a high level of detail on many subjects.

- Russell, Nicole, and Gary Griggs (2012). Adapting to Sea Level Rise: A Guide for California's Coastal Communities. This guidebook is intended to assist managers and planners in California's coastal cities and counties in developing sea level rise adaptation plans for their communities. It walks through processes of performing sea level rise vulnerability assessments and risk analyses for adaptation plans. It has been informed by several existing but broader climate change adaptation guides and strategies.

- California Emergency Management Agency, California Natural Resources Agency (2012) California Adaptation Planning Guide: This guide is a set of four complementary documents that provides guidance to support communities in addressing the consequences of climate change. The Guide introduces the basis for climate change adaptation planning and details a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development.

- NOAA Office of Ocean and Coastal Resource Management (2010) Adapting to Climate Change: A Planning Guide for State Coastal Managers. This report is designed to help coastal managers develop and implement adaptation plans to reduce the risks associated with climate change impacts affecting their coasts. The guide was written in response to a request from State coastal managers for guidance from NOAA on adaptation planning in the coastal zone.

- The Public Policy Institute of California (2008) Preparing California for a Changing Climate. A suite of studies assessing the State's preparedness for climate change, including analyses of water management, electricity, ecosystem management, coastal management, air quality and public health.

- The Pacific Institute (2009) The Impacts of Sea Level Rise on the California Coast. A study funded by the Energy Commission, CalTrans, the Metropolitan Transportation Commission, the California Environmental Protection Agency, and more, about the economic impacts of sea level rise.

- Bay Conservation Development Commission (2009) Living with a Rising Bay. Describes sea level rise in the Bay Area, including maps showing inundation areas for rises projected at 16 inches and 55 inches.

- The Department of Water Resources (2016) The National Flood Insurance Program in California Quick Guide Coastal Appendix: Planning for Sea-Level Rise. An appendix to the 2007 The National Flood Insurance Program in California: Quick Guide. This appendix provides high-level information on sea-level rise, intended for floodplain managers, planners, and community leaders who need to understand the effects of future sea-level rise in order to enhance their communities' mitigation plans and take action to better protect their citizens.

Mapping Products and Tools

- USGS Coastal Storm Modeling System (CoSMoS): The Coastal Storm Modeling System (CoSMoS) makes detailed predictions (meter-scale) of storm-induced coastal flooding, erosion and cliff failures over large geographic scales (100s of kilometers).

- Technical Methods Manual - Relating Future Conditions to Existing FEMA Flood Hazard Maps: Product developed by Environmental Science Associates on behalf of this project, to link sea level rise modeling conducted by Scripps Institution of Oceanography, to FEMA floodplain maps.

- FEMA Risk Mapping, Assessment and Planning (Risk MAP): Risk MAP provides high quality flood maps and information, tools to better assess the risk from flooding, and planning and outreach support to communities to help them take action to reduce (or mitigate) flood risk. Each Risk MAP flood risk project is tailored to the needs of each community and may involve different products and services.

- Climate Central Surging Seas: An interactive online mapping tool of areas below different amounts of sea level rise and flooding, down to neighborhood scale, matched with area timelines of risk. The tool also provides statistics of population, homes and land affected by city, county and State, plus links to factsheets, data downloads, action plans, embeddable widgets, and more.

- The Nature Conservancy Coastal Resilience Mapping Portal: This online, interactive tool helps users visualize future flood risks from sea level rise and storm surge. The tool identifies areas and populations at risk and provides a better understanding of potential ecological, social, and economic impacts.

- NOAA Sea Level Rise Viewer: A web-mapping tool to visualize community-level impacts from coastal flooding or sea level rise. Photo simulations of how future flooding might impact local landmarks are also provided, as well as data related to water depth, connectivity, flood frequency, socio-economic vulnerability, wetland loss and migration, and mapping confidence.

- Georgetown Climate Center Adaptation Tool Kit - Sea Level Rise and Coastal Land Use: Explores 18 different land-use tools that can be used to preemptively respond to the threats posed by sea level rise to both public and private coastal development and infrastructure. Also provides guidance to help governments in determining which tools to employ to meet their unique socio-economic and political contexts.

- Climate Central Repository - Plans, Actions and Resources: A collection of case studies, tools, plans, and actions for adapting and preparing for sea level rise.

Other Efforts to Address Sea Level Rise in California

- California Climate Change Assessments
- Humboldt Bay - Humboldt Bay Sea level Rise Adaptation Planning Project
- Los Angeles - Sea Level Rise Vulnerability Study for the City of Los Angeles
- Marin County – CSMART: Sea Level Rise and Marin's Ocean Coast
- San Francisco – Our Coast Our Future
- San Francisco - Ocean Beach Master Plan.
- San Francisco - San Francisco Guidance for Incorporating Sea level Rise into Capital Planning.
- San Diego Bay - Sea Level Rise Adaptation Strategy for San Diego Bay
- Santa Cruz - City of Santa Cruz Climate Adaptation Plan
- Santa Barbara City - City of Santa Barbara Sea level Rise Vulnerability Study
- Ventura County - Ventura Coastal Resilience Project
- Tijuana River and Newport Bay – UC Irvine FloodRISE Project

- UCLA - Developing a model ordinance for California local governments to integrate sea level rise adaptation into existing land use plan.

Appendix D: Acknowledgements

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San Francisco Bay Development and Conservation Commission
San Francisco Public Utilities Commission
Scripps Institution of Oceanography
State Coastal Conservancy
United States Army Corps of Engineers
United States Geological Survey