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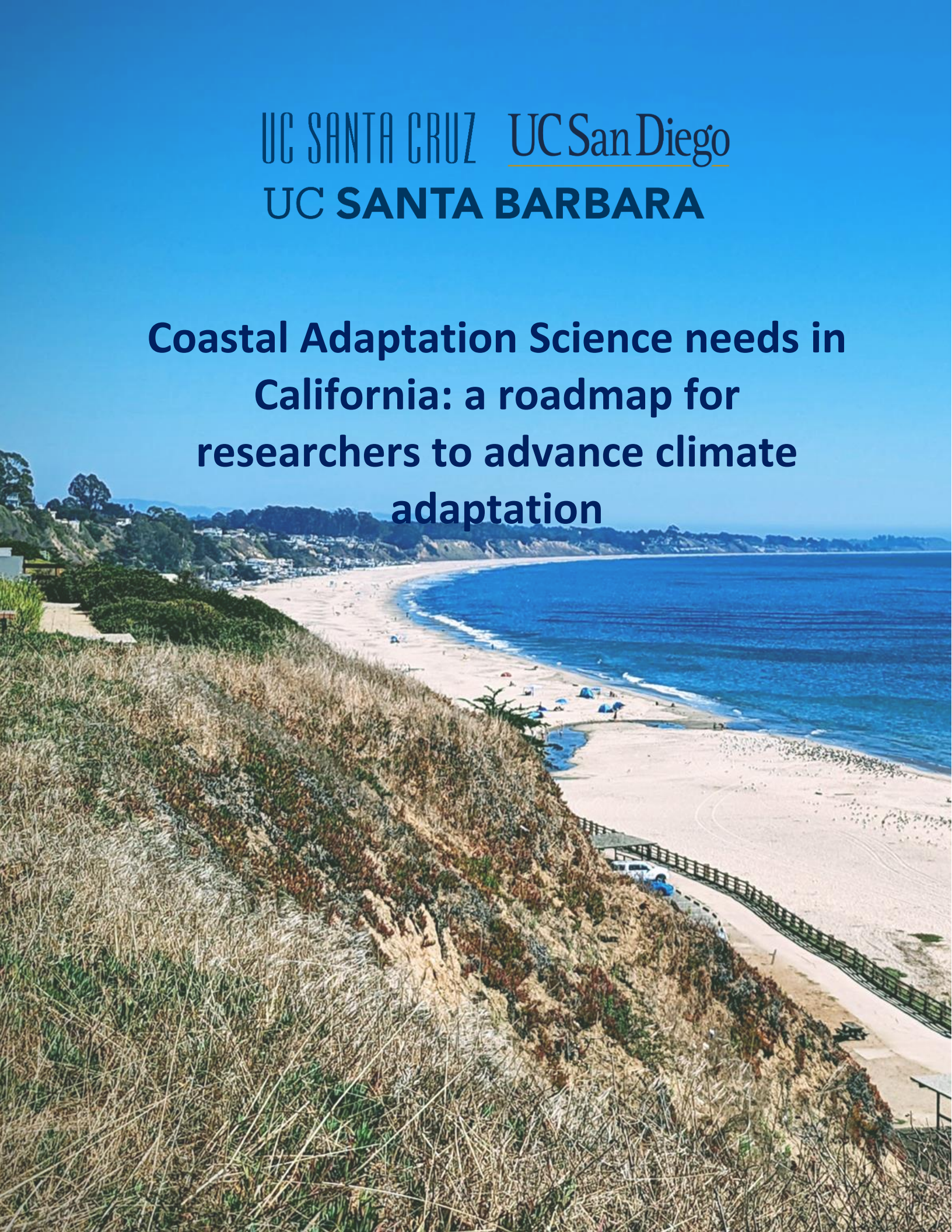
Coastal Adaptation Science needs in California: a roadmap for researchers to advance climate adaptation



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Executive Summary

This report synthesizes critical gaps in coastal adaptation knowledge and technology for California that were identified through a review of the recent literature and policy documents, two workshops (one with adaptation practitioners, and one with scientists from the University of California, UC) and detailed analysis of selected case studies. It focuses on those gaps that if addressed, might best align future research with community coastal adaptation needs.

The analysis is the result of a pilot multicampus collaboration on coastal resilience and adaptation between three UC campuses: Santa Cruz (UCSC), Santa Barbara (UCSB) and San Diego (UCSD). The goal of our collaboration was to generally identify current understandings of coastal hazard impacts and adaptation strategies along California's heterogenous coastline to help address four main questions:

1. What do we know (data, modeling capacities, decision support systems) about historic and future coastal changes (including monitoring technology)?
2. What are some of the main challenges for identifying and evaluating effective adaptation options?
3. How are local communities responding and are these responses informed by science, including socioeconomic and communication sciences?
4. What future research can most effectively help advance coastal adaptation?

Status and trends in coastal adaptation in California

While communities have made significant progress beginning to address coastal vulnerabilities and adaptation strategies, efforts face multiple challenges going forward. These challenges run the gamut from the need to build community and organizational capacity to conduct adaptation planning, to grappling with scientific uncertainty in projections of sea level rise (SLR) but also other coastal hazards determining future coastal change, ecosystem changes and functions, to the evaluation of economics, financing, implementation, regional effects, and monitoring of adaptation strategies and pathways. One challenge becoming increasingly apparent is the need to identify and evaluate the typologies and effectiveness of strategies and the distribution of costs and benefits of adaptation, in an equitable manner. On the outer coast, for example, completed local adaptation strategies range from conceptual identification of adaptation "approaches" to defined strategies that include specific interventions, timing, and necessary capital improvements. In between lie strategies that may identify next steps, studies, or other actions on the way towards a more specific strategy.

This study identified some overall trends in adaptation planning:

1) The need for regional strategies for connected communities. For example, a need for a strengthened regional strategy has been identified for the San Francisco Bay area, where the hydrological connection between communities surrounding the bay is readily apparent.
2) Use of special districts to address coastal hazards and financing challenges, for example, whether "neighborhood scale" planning will enable more effective and successful adaptation strategizing.
3) Increasing focus on social equity, inclusion and community engagement, which are featured in multiple state guidance documents, including the Office of Planning and Research's Adaptation Planning Guide (2020), the California Natural Resources Agency Adaptation Strategy (2022), the Ocean Protection Council's Equity Plan, and different guidance provided by the California Coastal Commission, among others.
4) Dynamic re-visioning of the adaptation planning process and the use of "adaptation pathways", as way to address the future uncertainty in ever-changing socio-ecological coastal systems by linking future actions to potential changes in environmental and social conditions.

Adaptation Science Needs and Gaps

This assessment identified at least 33 key needs and gaps[1] that can be organized into seven major adaptation questions (Figure 1):

1) **What is projected to happen?** Targeted coastal science to (1) support prediction of climate change and related oceanographic forcing (sea level rise, wave energy, extreme conditions, etc.) prediction at the local level; and (2) improve the characterization of climate change impacts on the coastal zone, such as changes in groundwater elevations and cascading impacts.

2) **How can we better communicate this change?** Integrate and convey existing and future sea level rise guidance for practitioners.

3) **How can we center environmental justice, equity, and communities in adaptation investments?** Improve community engagement with adaptation planning, and how to achieve more equitable outcomes in adaptation decisions.

4) **What works?** Evaluate adaptation interventions to inform pathway planning is needed, such as social cost-benefit analysis and cost-effectiveness of different strategies.

5) **How can we effectively implement adaptation pathways, and avoid maladaptation?** Integrate understanding of coastal change and engagement with community values, over different and varied time horizons and geographic scales.

6) **Monitoring and technology: when interventions should be implemented and how to measure their performance?** Integrate monitoring of coastal change and interventions to support improved planning, and address feedback in the adaptation decision process to support connected pathway adaptation and implementation.

7) **How can we better integrate researcher and practitioner objectives to better support actionable adaptation plans?** Align academic incentives and practices with the practical needs and timing of community and governmental decision processes.

The report also includes extended technical annexes with a review of existing data and tools relevant for coastal adaptation, policy, and guidance notes, and details of identified needs and gaps (see organization summary).

Way forward for actionable adaptation science

There are multiple ways to synthesize the wide range of coastal adaptation science needs. This review was a pilot scale opportunity to consider a rapidly expanding universe of coastal scientific undertakings and an increasingly complex set of socio-environmental questions about how communities can effectively and equitably adapt to accelerating climate and coastal changes. The research team's hope is that the identified challenges can inform a more targeted research agenda for University of California scientists and others to help advance the capacity of the state to address coastal adaptation.

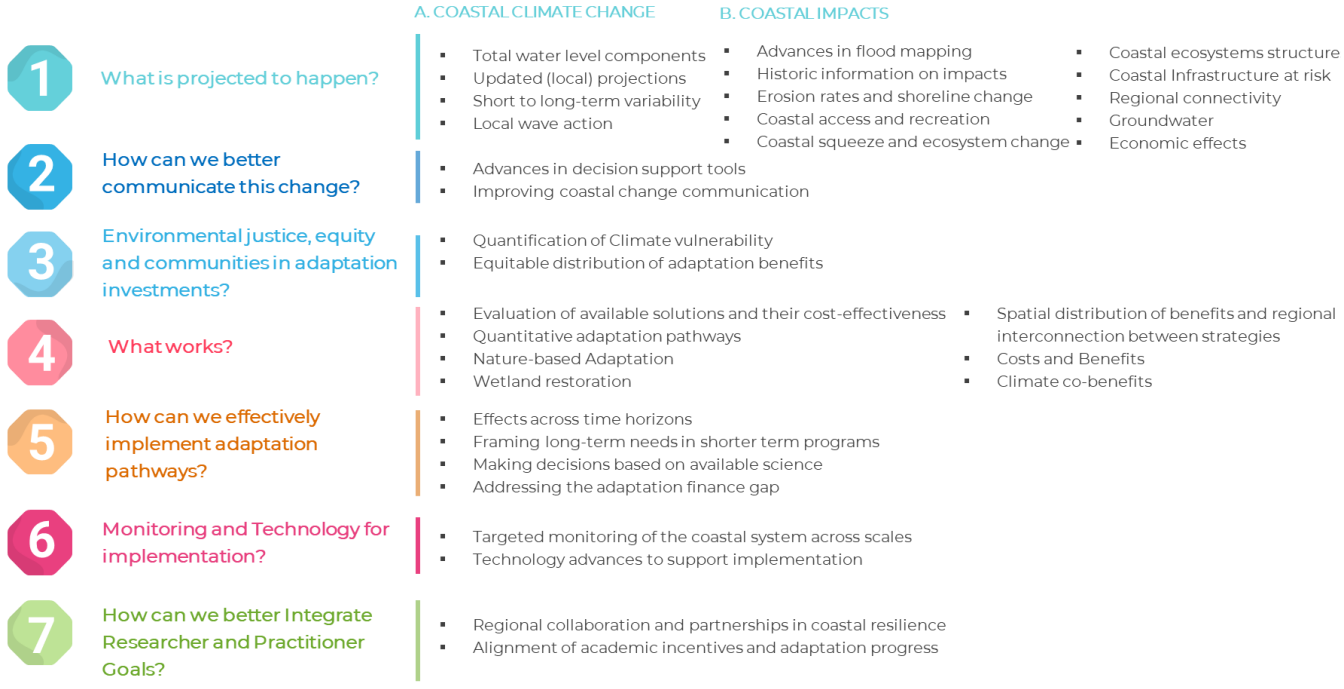
[1] These identified gaps and needs were selected as key challenges based on our analysis and through their consistent detection in revised literature. However, there could be other gaps not listed here. A more comprehensive list can also be found in the Annexes.

In particular, none of the UC campuses alone may bring the expertise, technology, capacity, or relationships to holistically address these 7 questions. Yet, addressing these challenges requires local, regional, and state partnerships with stakeholders and agencies, but also intercampus collaboration. Some of the key topics that UC is well positioned to address are:

- Advance coastal climate impact assessments.
- Applied focus on adaptation science and evaluation of strategies.
- Support regional monitoring and observational capacities.
- Advance economic and finance research on adaptation.
- Provide advisory roles for communities and agencies.

In addition to UC initiatives, California's 5th Climate Change Assessment represents an opportunity to facilitate research across these broad areas of need. The recent UC Climate Resilience research call may also result in projects that directly address some of the specific challenges identified in this pilot review. To increase the potential for UC climate science to directly inform coastal adaptation needs, UC should proactively revisit the connections between the research that is on-going and the needs of practitioners, particularly if additional rounds of state and UC funding will be directed to this specific adaptation challenge. To this end, a UC system-wide coastal resilience hub that can serve as an advisory body to local adaptation could critically support the integration of science with on-going coastal adaptation practice, but also shape UC's research broader impact to confront the climate priorities.

SUMMARY OF COASTAL ADAPTATION SCIENCE NEEDS AND GAPS



I. Introduction

California's coastal communities face increasing challenges to adapt to climate change. Erosion, flooding, and other shoreline impacts are increasingly affecting the coastal system and communities (e.g., atmospheric rivers of January 2023). The Ocean Protection Council, the Coastal Commission and other state agencies have identified coastal hazard adaptation as one of the state's highest priorities [1,2]. The recent California Climate Adaptation Strategy (CAS, hereafter) [3] also reflects the pressing need for solutions to the impacts of climate change across sectors, many in the coastal zones. The strategy synthesizes and builds on previous strategies to protect communities, the economy, and nature from the climate change impacts by defining six outcome-based priorities:

1. Strengthen protections for climate-vulnerable communities.
2. Bolster public health and safety efforts to protect against increasing climate risks.
3. Build a climate-resilient economy.
4. Accelerate nature-based climate solutions and strengthen climate resilience of natural systems.
5. Make decisions based on the best available climate science.
6. Partner and collaborate to leverage resources.

To advance these priorities, the State of California has recently developed several guidance documents and tools to direct the adaptation planning process at the local level (see review of Tools and Guidance in Annex). California's communities have also made significant progress identifying local vulnerabilities, potential options for community response, and projects to address risks in localized areas. However, the challenge is great, the coast is diverse, and while adaptation planning is expanding across jurisdictions, significant work remains, including strategizing, coordinating at regional scales, updating of land use authorities, and implementation of projects.

Advancing coastal adaptation in California can benefit greatly from the leadership, coordination and innovation that can occur between agencies, communities, and academia, through the alignment of efforts, timelines, incentives and goals between policy, implementation and research. In this spirit, this project aimed to identify the *most pressing* research, knowledge, and technology adaptation gaps to focus collective efforts.

In this context, this project had three main objectives:

1. Review our understanding of coastal hazard impacts along California's heterogenous coastline and the strengths of UC campuses to address adaptation challenges.
2. Convene scientific experts to synthesize information and develop findings to address the need to ground policy development in cutting-edge science.
3. Coordinate with communities, agencies, academics, students, and other partners to identify critical data, modeling, technological and other information gaps that UC and other research partners could help address in the future.

Specifically, our focus has been centered on aligning coastal adaptation science and practice in the State along four key questions:

1. What do we know (data, modeling capacities, decision support systems) about historic and future coastal changes (including monitoring technology)?
2. What are some of the main challenges for identifying and evaluating effective adaptation options?
3. How are local communities responding and are these responses informed by science, including socioeconomic and communication sciences?
4. What future research can most effectively help advance coastal adaptation?

To respond to these questions and identify those pressing needs and gaps that should be guiding research efforts to advance adaptation, we organized two workshops; reviewed tools and data; and analyzed selected policy, guidance documents, and other literature. Workshops were organized with adaptation practitioners and with over 30 researchers (mostly from the UC system) with the goals to identify (1) strengths and weaknesses of the adaptation science used thus far in California; and (2) what works, and what is needed to advance adaptation in California counties and cities. In addition, we selected three cities at various planning stages for detailed case study analysis.

For over the last 15 years, advances have been large, but some key challenges remain [4]. Below, we present a summary of (1) the community adaptation planning process, as well as proposed frameworks for the planning process; (2) lay out the main knowledge and technological gaps and needs identified from a review of documents and consultations; and (3) propose a roadmap to help respond to specific questions in the adaptation process and implementation, and to help address the science–practice disconnect [4]. Since this document is the result of analysis of more extended information, we also include technical annexes that contain further detail and information on tools, guidance notes and a more detailed of research, knowledge and technological gaps.

Section and Organization of the Report

Status and Trends of the Adaptation Planning process in California	Knowledge and technological gaps and needs	Conclusions and way forward: roadmap for responding to seven adaptation-centered questions
Annex 1. Review of relevant policy, guidance documents and resources	Annex 2. Review of relevant for coastal adaptation to climate change in California	Annex 3. Summary of workshop consultations

II. Status and trends of the adaptation planning process in California

The adaptation planning process and local community plans

Coastal resilience and climate adaptation occur at the intersection of (Figure 1) climate science and coastal hazards; adaptation processes that include governmental and civic engagement and socioeconomic dimensions; policy, management and regulation of the coastal zones; and observations and factual information on coastal change and their effects. The interplay of these factors and the decision processes to drive local adaptation is therefore complex, multi-sectoral, and short- and long-time ranged.

FIGURE 1 DIMENSIONS OF ADAPTATION AT THE INTERSECTION OF COASTAL CLIMATE SCIENCE, COMMUNITY ADAPTATION PLANNING, POLICY AND MONITORING.

The assessment of the status and trends of sea level rise (SLR) adaptation planning in California is framed by a general policy sciences method using a social decision process model and problem-orientation concerning the challenge of coastal adaptation at the community level [5]. The inquiry into the decision process was informed by a heuristic framework with a simple linear model of decision progression from community goal setting, coastal vulnerability assessment and adaptation strategizing, to plan update, implementation, monitoring, and evaluation, situated in the geophysical and social settings of local context.

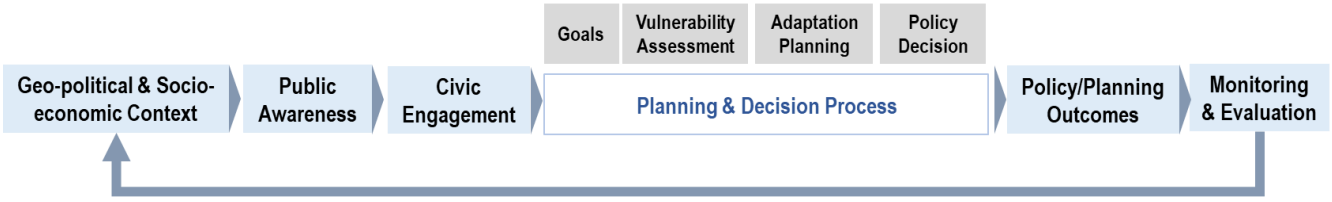


FIGURE 2. DECISION PROCESS HEURISTIC MODEL FOR COASTAL ADAPTATION INQUIRY. [2]

This conceptual model resonates with various conceptual frameworks for the adaptation planning process, including guidance from (see Annex 1): the California Coastal Commission, general planning guidance from the California Office of Planning and Research, and the California Adaptation Planning Guide from the state Office of Emergency Services [6] (Figure 2). Although differing somewhat in

[2] Supported with collaborative research conducted by the California Coastal Adaptation Project by the Ocean and Coastal Policy Center (OCPC) at UCSB and the California Ocean Protection Council [9].

terminology and emphasis, each decision framework highlights the different functional parts or phases of a community decision process in sequence and relation to each other, focused on moving from goal setting, understanding environmental and social change, evaluating alternative intervention or adaptation strategies, implementation, and monitoring, evaluation and feedback. For example, the Cal OES Adaptation Planning Guide describes four major phases of decision process (Figure 2):

- Phase 1: Explore, Define, and Initiate;
- Phase 2: Assess Vulnerability;
- Phase 3: Define Adaptation Framework and Strategies;
- Phase 4: Implement, Monitor, Evaluate, and Adjust.

General Trends in Adaptation Planning

California's coast is highly diverse, with a wide variety of geographic and geophysical land and seascapes,, demographic patterns, and built environments [7,8]. Within this diverse setting, sea level rise (SLR) adaptation planning takes place in unique social and environmental contexts that shape community values, perceptions, decisions, and actions.

In California, all communities on the outer coast are required to prepare local coastal plans (LCPs) pursuant to the California Coastal Act. LCPs must address statewide coastal resource management policies while establishing the kinds, locations and intensities of development that are allowed in the coastal zone [9]. In 2015, the California Coastal Commission (CCC) issued comprehensive SLR guidance to local governments about how to update LCPs for SLR and associated coastal hazards [10]. Communities around San Francisco (SF) Bay are not subject to the Coastal Act, but they do need to follow California's general planning law, including a requirement to update their plans to address community safety, including climate adaptation and flooding hazards. The SF Bay Conservation and Development Commission (BCDC) also exercises regulatory authority over development in the Bay and along the immediate shoreline [11]. BCDC has also been leading the Adapting to Rise Tides Program, including a comprehensive 'roadmap' for building capacity and enabling adaptation planning at the community level [12].

Over the last decade, the CCC, State Coastal Conservancy, and the Ocean Protection Council have invested millions of dollars in local coastal adaptation planning to support communities (e.g., Figure 3). Both the CCC and OPC have substantial additional funding to support continued planning. This funding jump-started planning work in multiple coastal communities. On the outer coast, for example, about 60% (47) of the counties and cities had completed SLR vulnerability assessments by the fall of 2022. Almost a third (22) of the communities had completed adaptation strategies, and a handful (8) had updated their LCPs to implement an adaptation strategy [9] (Figure 3)[3]. Many more communities are actively working on each of these phases of coastal adaptation planning with and without state funding. Around San Francisco Bay dozens of communities have conducted vulnerability assessments and developed adaptation strategies; by 2012 about half of the Bay Area jurisdictions had an adaptation plan in place or underway [13].

[3] Comprehensive review under development, by UCSB, supported by Ocean Protection Council: https://storymaps.arcgis.com/stories/5c3ec4198b564750886cc75b95a8e492

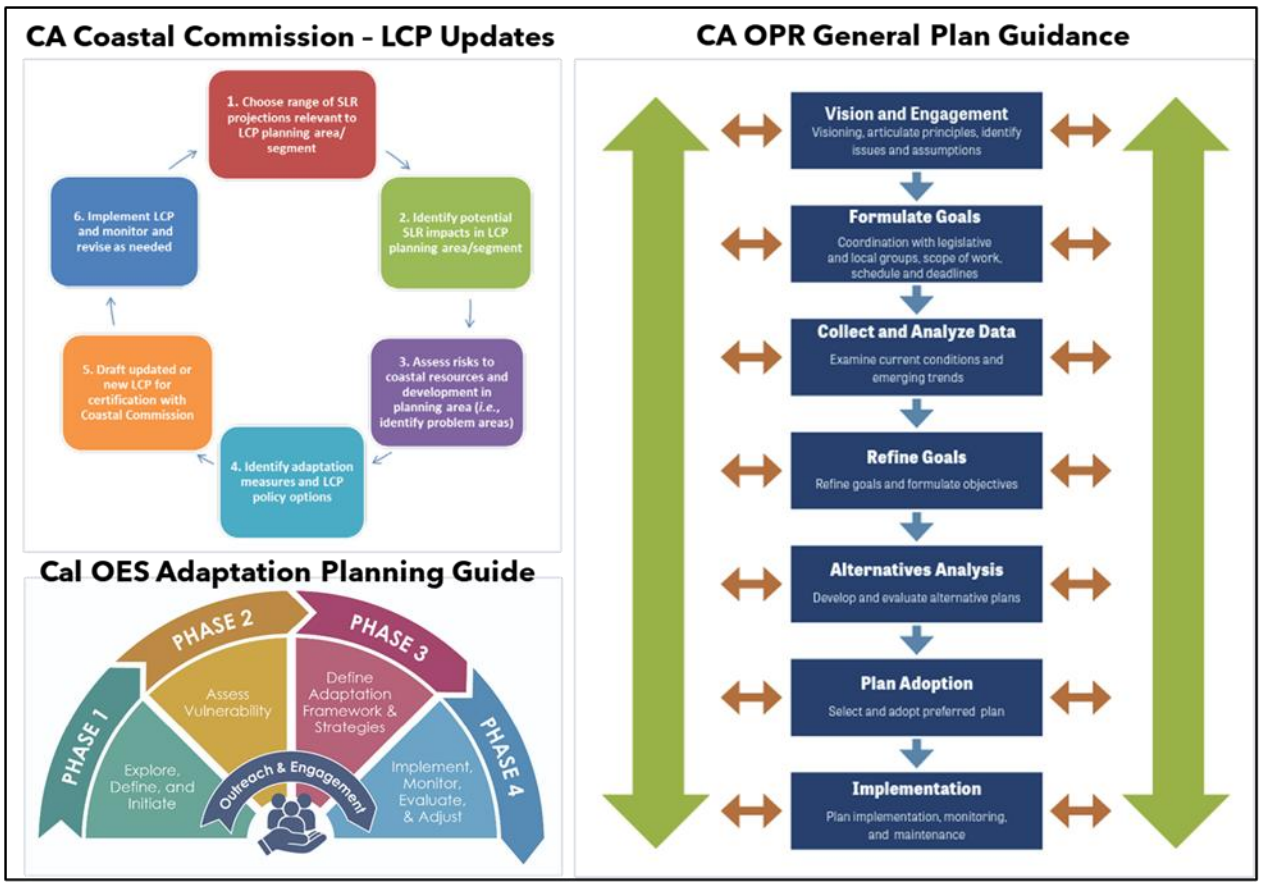


FIGURE 3 EXAMPLES OF CALIFORNIA PLANNING PROCESS MODELS.

Adaptation planning is at various stages across the 125 local government jurisdictions (76 on outer coast, 49 around San Francisco Bay) of counties and cities along the California shoreline. Information gathered from government documents, online sources, and coastal practitioners was generally assessed using the social process mapping questions of *who* was involved, *when* and *where*, and around *what* activities and *how*, across the phases of decision (Figure 1). For example: who were the participants in a community's vulnerability assessment? over what period of time and geography? what tasks were undertaken and how were they completed? Information was developed at a high-level survey for the 125 coastal jurisdictions within the constraints of the pilot-scale project funding.

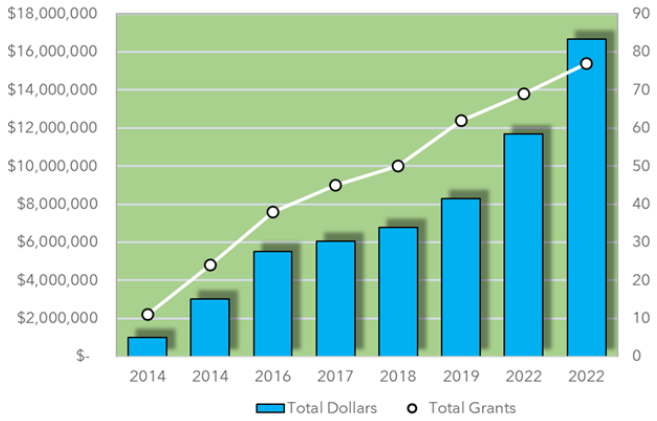


FIGURE 4 STATE GRANT FUNDING FOR LOCAL COASTAL PLANNING UPDATES.

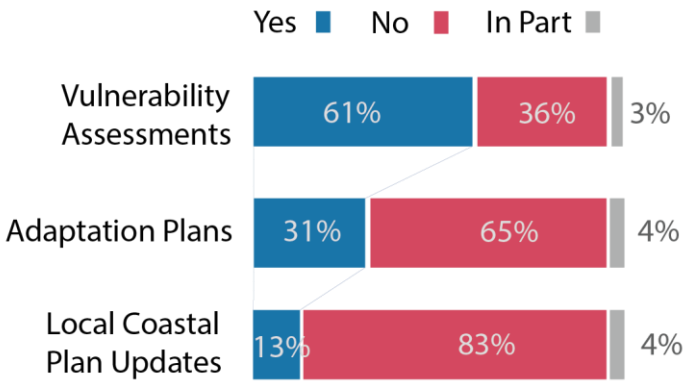


FIGURE 5 PROGRESS IN SEA LEVEL RISE ADAPTATION PLANNING – OUTER COAST. ADAPTED FROM: [9]

Challenges in the Adaptation Planning Process

While communities have made significant progress beginning to address coastal vulnerabilities and adaptation strategies, efforts face multiple challenges going forward. These challenges run the gamut from the need to build community and organizational capacity to conduct adaptation planning, to grappling with scientific uncertainty in SLR projections, to financing adaptation planning, implementation and monitoring. For example, in a recent poll, over 90% of the SF Bay area respondents indicated that inadequate staffing and funding was a key barrier to adaptation planning and implementation. More than half also identified scientific uncertainty as a key barrier [12,14].

One primary challenge becoming increasingly apparent is the identification and implementation of "actionable" strategies. On the outer coast, for example, completed adaptation strategies range from higher-level conceptual identification of what might be termed adaptation "approaches" to more defined strategies that identify specific interventions, timing and capital improvements necessary to make them happen. In between are strategies that identify next steps, studies or other actions on the way towards a more specific strategy [9].

In addition to specific adaptation planning work, some communities have focused on interventions independent of an encompassing adaptation plan. There is also a growing emphasis on nature-based strategies within this group. For example, nature-based interventions have been implemented or are being developed at Cardiff Beach in Encinitas, Manhattan Beach in Los Angeles County, Surfer's Beach in Ventura, Carpinteria in Santa Barbara County, and at Stinson Beach in Marin County [9,15]. In the San Francisco Bay area, significant attention has been directed to "living shoreline" strategies, such as the horizontal levee constructed by the Oro Lomo Sanitary District [16,17]. The California Dune Science Network[4] is also working to expand understanding of coastal dunes and their role in building resilient adaptation responses [15].

The question of geographic scale and sectoral coverage has also become a central part of the adaptation planning discussion. The need for more regional strategies has become clear, particularly in the San Francisco Bay area, where the hydrological connection between communities surrounding the bay is readily apparent [18,19]. A similar dynamic is present in Wigi (Humboldt Bay[5]) and to some extent in San

[4] https://www.resilientcoastlines.com/

[5] https://humboldtslri.org/

Diego Bay[6]. The San Francisco Estuary Institute has produced a comprehensive assessment of the Bay focusing on "operational landscape units", or OLUs [20], to identify geographic and geophysical connections (especially hydrological) that may shape dynamic shoreline changes and adaptation opportunities in any given sub-region. A similar discussion along the outer coast, focused sometimes on littoral cells than can span multiple jurisdictions and necessitate regional sand management [21] (e.g. BEACON: Beach Erosion Authority for Clean Oceans and Nourishment [7]).

Another aspect of the planning scale includes the role that special districts may play, such as legislation for the establishment of special districts to address flooding hazards and financing across legal jurisdictions. SB 852, the Climate Resilience Districts Act, allows local governments to create districts for the purpose of addressing climate change effects and impacts through activities and actions that include mitigation and adaptation. At least one special district, *OneShoreline*, has moved forward with this concept through specific legislation to expand its original flood protection purpose created circa 1958[8]. Somewhat related, but in the direction of narrowing scale, the SLR working group at the CCC recently introduced the "neighborhood scale" concept for adaptation to help move planning forward by focusing on more manageable, smaller sections of coastline[9].

The other major trend in coastal climate adaptation is the increasing focus on equity, inclusion and engagement. This includes attention to the social equity and environmental justice implications of adaptation responses, such as disproportionate impacts from flooding or rising groundwater to disadvantaged communities[10]. Substantial efforts are also being made to engage tribal communities in both decision processes and resource management [e.g., 22]. Questions are also being raised about the trade-offs inherent in different adaptation strategies, including between environmental and economic concerns, and with respect to the distributional equity of different shoreline responses, such as the tension between risk reduction for coastal property owners and the impacts to public beaches from shoreline protection interventions [23].

Finally, one major trend in adaptation plans deserves special mention: the embrace of adaptation pathways as a method for integrating the monitoring of changes in environmental and social conditions with community vision and values that set a course for community adaptation. Several jurisdictions have explored a "pathway" approach that focuses on the identification of environmental and social triggers or thresholds that trigger the need for an adaptation action (e.g., Santa Cruz[11]; Santa Barbara[12]). Adaptation pathway efforts are, however, in the early stages of implementation. The impacts of storms of January 2023 have increased discussions in places like the City of Santa Cruz, where recent storm damage might have triggered the next set of adaptation responses based on the City's adaptation planning documents (City of Santa Cruz, 2021).

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[6] https://www.sandiego.edu/soles/centers-and-institutes/nonprofit-institute/signature-programs/climate-collaborative/

[7] https://beacon.ca.gov/

[8] https://oneshoreline.org/our-history/

[9] California Coastal Commission Sea Level Rise Workshop - https://documents.coastal.ca.gov/assets/press-releases/slr/WebAgenda_LocalGovSLRworkshop_1.27.2023.pdf

[10] Toxic Tides - https://sites.google.com/berkeley.edu/toxictides/home

[11] https://www.cityofsantacruz.com/government/city-departments/city-manager/climate-action-program/resilient-coast-santa-cruz

[12] https://santabarbaraca.gov/sites/default/files/documents/Services/SLR%20Adaptation%20Plan/Sea-Level%20Rise%20Executive%20Summary.pdf

Insights from the analysis of case studies in more advanced stages of adaptation

Within the scope of the pilot project, we selected three case studies at advanced stages of the planning process but with different characteristics and trajectories. The goal of the detailed analysis of these studies was to develop a deeper understanding of the process and lessons learned from each, and to perhaps inform others in earlier stages of the process (see Figure 1). We selected three cities of similar geographic scale: Del Mar, Santa Cruz, and Hayward. The three communities have made significant progress in shoreline adaptation planning and decision-making. The cities also encompass coastal and San Francisco Bay shoreline regions that face a range of challenges related to coastal hazards. The case analyses were constructed from local and regional policy documents (including but not limited to local coastal plans, general plans, and hazard mitigation plans) and interviews with practitioners.

Each case study was analyzed by reviewing the process, organized into the steps in Figure 1, and the primary programs and documents that the cities have developed and employed in their adaptation planning processes. From the analysis, we assessed adaptation challenges at the local level, and some of the pathways employed by regional and local governments in coastal planning. The analyses were supplemented by information gathered in the practitioner workshop. The results are summarized in Table 1. Some of common features identified in the plans included:

1. All plans developed an initial assessment of existing conditions and coastal challenges;
2. Involved significant stakeholder outreach and engagement (although Del Mar lacked targeted communication and engagement that influenced the acceptance of certain adaptation actions like managed retreat discussions);
3. Included SLR modeling and mapping;
4. Identified adaptation strategies by typologies and in a spatial explicit form, along with implementation considerations, timelines and priorities;
5. Implementation of the plans remains limited (although still recent)

Adaptation phases	Hayward	Del Mar	Santa Cruz
Vulnerability Assessment	Preliminary Study of the Effect of Sea Level Rise on the Resources of the Hayward Shoreline Adapting to Rising Tides Shoreline Resilience Study	Coastal Hazards, Vulnerability, and Risk Assessment	Beach Vulnerability and Adaptation Strategy West Cliff Drive Adaptation & Management Plan: Existing Conditions Inventory and Future Vulnerability Assessment
Primary SLR Adaptation Planning Documents	The Hayward Regional Shoreline Adaptation Master Plan	City of Del Mar - Sea Level Rise Adaptation Plan	SLR Policies & Strategies: Beach and Public Access West Cliff Drive Adaptation & Management Plan
General Plan Update	Hayward General Plan 2040, adopted 2014	Del Mar Community Plan, adopted 2019	General Plan 2030; adopted 2012, updated 2019
Last Local Coastal Plan Update	N/A	Ongoing process that began in 2015, most recent update	Currently in process of updating, last adopted LCP

		was withdrawn from consideration in 2021	update was in 1995
Notable Supporting Documents	Technical Memo for Land Development in Areas Subject to Sea Level Rise Sea Level Rise & Land Development in Hayward	Legal Risk Analysis of SLR Adaptation Strategies in San Diego Sediment Management Plan Comparing SLR Adaptation Strategies in San Diego: NOAA Economic Framework	Resilient Coast Santa Cruz Story Map History of Santa Cruz Coastline SC Beaches: Urban Climate Adaptation Policy Implication & Response Strategy Evaluation Technical Report AB 691 Sea Level Rise Assessment: Santa Cruz Municipal Wharf
Related Adaptation Programs / Sites	Adapting to Rising Tides	N/A	Resilient Coast Santa Cruz
Primary Methods Used in Adaptation Planning	Analysis of Existing Conditions Stakeholder outreach Sea level rise modeling and mapping Adaptation strategies research Implementation considerations	Thresholds to guide planning and implementation of adaptation measures Establishment of a technical advisory	Stakeholder engagement Adaptation pathways approach Development of short, medium and long term projects Quantification of assets at risk

TABLE 1 SUMMARY OF CASE STUDIES.

Workshops with Practitioners and Researchers

For further insight into the common features and differences in these advanced cases of adaptation in California, we organized two workshops with practitioners and researchers where we aimed to (1) identify strengths and weaknesses of the coastal adaptation science available for local adaptation plans; (2) assess the challenges and strategies that have worked in practical settings and based on local experience; (3) and consider what will be needed to further advance adaptation across coastal counties and cities of California. The main findings are summarized below.

Workshop 1 – Practitioners

The first workshop with practitioners used the experiences in the case studies in Santa Cruz, Hayward, and Del Mar to identify differences in their respective approach to coastal adaptation planning and challenges and concerns faced, including critical gaps in data, modeling, technology and monitoring. The workshop also included state agencies as well as representatives from each city. The main outputs are summarized below (see extended version of outputs in Annex 3).

The availability and communication of critical information was a major discussion point:

Stakeholders (cities and counties, local consultants; community-based organizations; and regional actors) identified the need for clear guidance on the best available science and methods to *implement* trigger-based communication, monitoring and adaptation.

- Information is abundant and available in a variety of forms including technical documents, models, experts, and various visual representations of proposed solutions.
- Stakeholders highlighted the ease of using information when presented in a non-technical format (e.g., easy-to-interpret visuals) and the importance of access to experts who could offer explanations.
- Understanding, interpreting, and effectively using the resources for adaptation planning can be challenging. Practitioners also found difficulties determining what part of the information is important and relevant for them, and the searching can be very time and resource intensive.
- More standardization and consistency between vulnerability analyses is needed as stakeholders noted difficulty with constantly changing information and guidelines. Additionally, continually evolving science can lead to frustration and mistrust for those without a technical background, and conflicting information can result in confusion indicating a need for explanation of changes.
- There is also a mismatch between long-term adaptation strategies and short-term limiting factors such as funding, timelines, and staff capacity.

The discussion pointed to a need and desire for more effective scientific communication. This is something that researchers at UC and other academic institutions could specifically help address. In particular, multidisciplinary approaches that better integrate science and public planning concerns appear needed. Participants also discussed the general need for science that is transparent and easy to understand/access:

- One of the most important components of adaptation planning is effective *communication and engagement* with community members. In each city, community engagement took place in different forms ranging from general events with 100+ people to individual focus groups to online forums and surveys. Planners noted the large amount of time spent reaching out to community members.
- Education was considered a key component of the adaptation planning process. Many participants noted the necessity of early and continuous engagement in the community.
- Another area of improvement includes effective communication of findings to the community to reduce the potential for friction and conflict; which may include reporting findings at regular intervals, supporting local community groups and using non-partisan entities to communicate information (e.g., University).

Funding was identified as a major challenge to advance the implementation of existing plans:

- Not only the lack of funding for adaptation projects, but a common barrier is the challenge of how to manage and allocate funding properly. This ties into equity concerns as socioeconomic differences influence who gets funding.
- Some workshop participants noted that regional collaboration may serve as an effective strategy for helping individual jurisdictions navigate acquiring knowledge and grants and address this inequality in adaptation investments.

The workshop also discussed communication barriers between science-based tools and potential users:

- While portals, models, and other technical resources are useful tools, they can be confusing to operate for people unfamiliar with science.

- Practitioners asked for trained professionals that can help translate the best and latest science into local adaptation policy, planning, and implementation. An example highlighted in the discussion was the Coastal Resource Center (CRC) at UC Irvine: the CRC works with the University's Sea Grant program and coastal managers to decrease gaps in translational capacity. It was observed that this program could potentially serve as a model for scaling up to a state level by the UC.

Workshop 2 – Research community

The second workshop focused on academic researchers and was centered on science gaps and research needs that UC and partners[13] could help address in the future to facilitate coastal adaptation in California. Participants included scientists from UC campuses working on coastal adaptation but also scientists from the US Geological Survey.

The main observations about the major coastal adaptation science needs included (see Annex 3):

- Better characterization of coastal hazards, impacts, and social vulnerability in California and the importance of characterizing system-wide and cascading effects of impacts, as well as adaptation investments, economic information, and effective communication and collaboration.
- Predicting the trajectory of shoreline change of coastal bluffs, beaches, wetlands, and marshes may help increase scientific consensus on how best to adapt to a shifting coastline. There is also a need to better characterize how variables such as ocean/wave forcing will affect erosion and flood projections.
- Inconsistent data and lack of collaboration amongst researchers has resulted in difficulty translating science into coastal planning and selecting adaptation pathways/methods.
- Better understanding of how humans shape hazards, such as spatial interactions where actions at one location can impact other locations.
- Cost benefit analyses of adaptation strategies, such as nature-based solutions, to assist local and regional jurisdictions in implementing solutions to flooding and erosion.
- Address limitations with scaling of coastal monitoring, as there is often a mismatch between large scale historical profiles of coastal morphology (often obtained through aerial photography) and changes at a local level. There is a greater need for more granular and detailed parcel by parcel data for the shoreline.
- While some coastal areas have extensive datasets (e.g., San Diego and Santa Barbara), there are regions of California where monitoring is largely lacking. Scaling monitoring up is a logical next step, however, barriers to upscaling of coastal monitoring include a lack of resources and political obstacles.
- The development of sound physical impact assessments is becoming more widespread, but translation of this knowledge into understanding ecosystem and community vulnerability remains challenging. The cascading impacts and downstream effects are often poorly understood. In order to effectively address social vulnerability, more publicly available and easily accessible data would be helpful.
- The state faces significant socio-economic challenges related to coastal research, planning, and project implementation. For example, coastal property owners are typically wealthy, but pockets of socially vulnerable communities exist along the coast, and a significant gap in representation exists when it comes to decision making.

[13] This project was funded by UCOP Multicampus Program. Therefore, it has a specific focus on developing capacities and informing needs in adaptation science in the UC system.

- Large funding and capacity disparity among regions for coastal resilience. Potential disinvestment and devaluation in response to SLR has left many communities angry about, and suspicious of change. Human behavior and reactions to threats will affect hazards and impacts, so better understanding these dynamics will aid coastal planning efforts.

In terms of knowledge gaps, workshop participants expressed interests spanning from the development of innovative algorithms for assessing integrally river and coastal systems at community-relevant scales, to the design of new forms of infrastructure based on landscape processes and which foster ecological recovery and social equity. A wide range of physical and social shoreline expertise garnered interdisciplinary debate and potential for collaboration. The main observations included:

- Often incentive systems, particularly grant funding, do not align with practical project timelines.
- Developing research pathways for coastal adaptation planning and implementation are burgeoning as state support has increased; but it requires targeted funding for prolonged research activities, such as monitoring.
- Participants noted the lack of tools and resources that operate at a scale that supports local analytic needs of coastal managers and planners. For example, the Coastal Storm Modeling System (CoSMoS) predicts flooding and coastal erosion, but it may not be useful for assessing local impacts, or specific adaptation questions (e.g., what happens when a single dune is added).
- Another barrier is a lack of information about specific costs:benefits and efficacy of adaptation solutions at a local level. This makes it difficult for coastal managers to effectively communicate adaptation plans to the general public, who often have questions and concerns.
- There is a need to advance the research and knowledge base about nature-based designs and their benefits in terms of potential locations, typologies and effectiveness.
- Effective communication between researchers, coastal managers, and the public can be difficult due to a lack of standardized measurement used for evaluating local hazards and choosing adaptation options. This could indicate a need for capacity building to better understand coastal hazards in local contexts, and a data driven project that standardizes an evaluation framework of coastal adaptation options at the local level.

Finally, many participants were disappointed by what they perceived as a lack of transformative vision for statewide coastal adaptation.

- While addressing local needs is important, identifying what the state is working towards will be crucial.
- Some participants felt that the shift from local to regional planning, such as the use of operational landscape units, has been advantageous for collaboration, information sharing, and addressing flooding at the ecosystem scale.
- However, any major changes will need to be made in cooperation with state agencies, especially the CCC, to avoid conflict and ensure legally defensible solutions.
- Ultimately, California's coastal adaptation would benefit greatly from the coordination of timelines and incentives of academics and state agencies.

III. Coastal Adaptation Knowledge and Technological Needs

This section presents a review of the scientific and governmental literature organized into seven major categories of knowledge and technology needs that broadly align to core questions related to functional steps of the adaptation planning process:

1. **What is projected to happen?** climate changes, coastal hazards and physical changes and impacts in the coastal system.
2. **How can we better communicate these changes?** the process of translating the science basis into actionable guidance and adaptation plans to reduce the impacts.
3. **How can we center environmental justice, equity and communities in adaptation investments?** Community engagement and equity dimensions of impacts and solutions is central to the adaptation planning process and adaptation decisions.
4. **What works? – identifying effective adaptation solutions**. Evaluation of adaptation interventions to inform investments and implementation of adaptation measures.
5. **How can we effectively implement adaptation pathways, and avoid maladaptation?** Alternative decisions occur over time scales at the intersection of physical coastal change, community values, socioeconomic impacts, and financing.
6. **How can we effectively implement adaptation pathways, and avoid maladaptation?** Measuring coastal changes triggers adaptation decisions, but making and informing short term decisions and programs need to align with long-term adaptation needs.
7. **How can we better integrate researcher and practitioner goals and objectives to better support actionable adaptation plans?** Academic incentives and approaches alignment (or lack of) with practical needs and timelines of community and governmental processes.

Under these seven lenses, we organized key scientific, knowledge and technical gaps and needs, which are summarized below. A more extended outline of needs can be consulted in Annex 1.

What is projected to happen? Part A. Changes in the Coastal Climate

Understanding what is projected to happen requires attending to both the physical basis of coastal climate changes as well as the physical impacts that the change in coastal climate dynamics may cause.

BOX 1. SEA LEVEL RISE IN CALIFORNIA

California has been steadily increasing its focus and investment in sea level rise (SLR) science and adaptation planning since the late 2000s, including executive orders by consecutive Governors Schwarznegger, Brown and Newsom. In the last decade, state guidance and funding for local adaptation planning has increased substantially. The State of California Sea-Level Rise Guidance (SLR Guidance, hereafter) and guidance from the BCDC and the California Coastal Commission call for the best available SLR science to be incorporated into planning, permitting, and investment decisions. California promulgated statewide SLR guidance in 2018. Recently, the federal government provided updated SLR estimates for the U.S., including California. (inter-agency SLR Technical Report, 2022). While not differing significantly from the 2018 California guidance in magnitudes and timing, the federal effort does provide improved estimates and reduced uncertainty for the near term (to 2050), and it eliminates a very high end “H++'' projection for 2100 driven by a catastrophic ice melt scenario,

concluding that such an outcome was not likely (though it remains identified as a real possibility in 2150). The guidance also addresses the increased frequency of flooding that will likely accompany SLR. Overall, based on various ranges driven by uncertainty in future emissions pathways and the response of the underlying physical processes, the guidance projects possible SLR along the contiguous U.S. coast of 0.6–2.2 m in 2100 and 0.8–3.9 m in 2150, relative to sea level in 2000. California is currently updating its state-level guidance based in part on this recent federal technical work.

FIGURE 6 IMAGES OF THE JANUARY 2023 COASTAL STORM IMPACTS ALONG WEST CLIFF DRIVE, SANTA CRUZ, CA.

California communities have been using available SLR estimates in dozens of local vulnerability assessments (see Box 1), including through application of the CoSMoS/Our Coast Our Future SLR tool (see Annex of tools) [24]. Many local governments have also used consulting teams to project the SLR estimates onto local landscapes and identify potential impacts. Still, there remains a need to continue refining SLR science in multiple dimensions, particularly concerning the role of wave action and extreme events, consideration of compounding flooding effects (SLR and precipitation) and updating shoreline erosion projections based on the latest scientific understandings and modeling.

The following specific **coastal climate and impact information gaps** were found in the literature:

1. Historic and future sea level components

Existing guidance emphasizes the need to use locally relevant SLR projections that account for regional and local drivers of changes in sea levels, such as tectonic uplift or subsidence, extreme events, wave runup and compound flooding [10]. Many vulnerability assessments conducted to date have relied on downscaled projections from the Coastal Storm Modeling System (CoSMoS) [24,25] or similar modeling from targeted consulting studies as a basis for understanding potential shoreline change and impacts at the local level. Still, there is a need for improved characterization of different flooding drivers and how they may manifest locally, especially in relation to the potential effectiveness of adaptation strategies.

The consideration of such locally-relevant and potentially compounding forces is varied in local assessments. Sometimes, there is little characterization beyond SLR[14] and other factors that influence local

[14] Based on the latest projections, California will face an expected relative SLR, in meters, by mid-century ranging from 0.15 to 0.31, for the intermediate-low to intermediate-high scenarios, respectively. In the long-term (beyond 2050), the differences between scenarios become increasingly larger driven by differences in potential future Green House Gases (GHG) emissions scenarios. By 2100, the expected SLR will be between 0.4 to 1.3 for the intermediate-low to -high scenarios for California (SLR Technical Report, 2022).

total water levels. Total water levels causing coastal flooding can occur from elevated tides, episodic storms, storm surge [26], waves [27,28], river discharge [29], and seasonal variability [30–32]. Flood events are also caused by elevated precipitation events and higher mean sea levels from El Niño and atmospheric rivers (e.g., storms of January 2023). In combination with SLR, these water level components can disproportionately increase flood frequency [33] and volume. Many of these components are often studied independently (e.g., coastal, riverine and pluvial flooding) but local factors alone or in combination can produce significantly higher water levels than estimates of static mean sea levels (SLR alone) by mid-century. Severe future coastal impacts will be driven by changes in all the components.

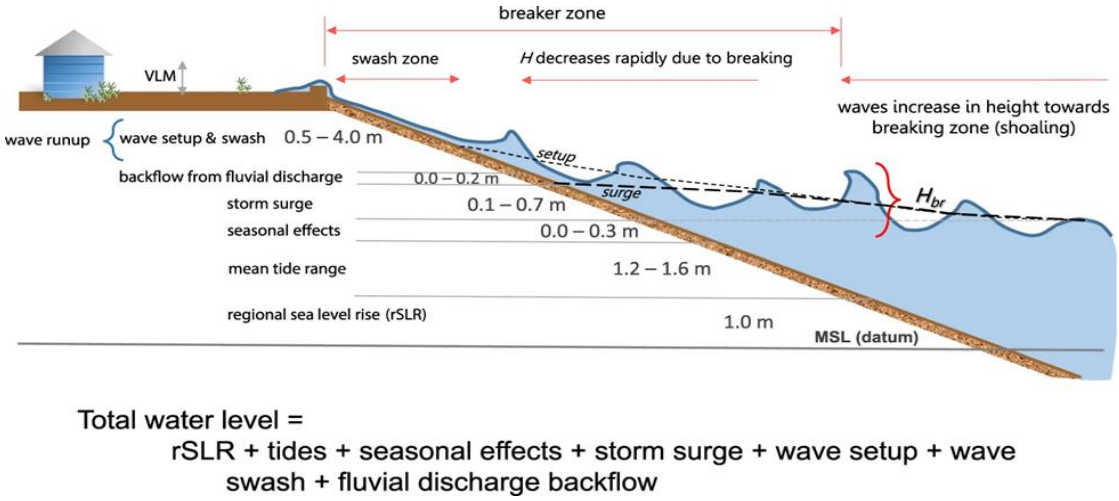

FIGURE 7 TOTAL WATER LEVEL CONCEPT. EXAMPLE FROM CALIFORNIA FOR 1 M OF SEA LEVEL RISE AND WATER LEVEL COMPONENTS RESULTING IN FLOODING. THE RANGE OF VALUES ARE BASED ON OBSERVATIONS AND MODELING CONDUCTED DURING THE DEVELOPMENT OF THE COASTAL STORM MODELING SYSTEM (COSMOS) FOR CALIFORNIA. SOURCE: [34]

State guidance identifies the need to consider all the components of "total water level" when considering potential impacts. Although the CoSMos tool includes storm scenarios and groundwater modeling, literature indicates a need for continued refinement and elaboration to improve flooding factors and timescales including: local granularity, compound effects, a focus on impacts associated with wave-driven flooding and erosion, groundwater infiltration, and effects on sea levels of morphodynamic changes in shoreline and ecosystems (e.g. Climate Adaptation Strategy).

2. Downscaled projections for the Coupled Model Intercomparison Project Phase 6 (CMIP6)

Climate models are constantly being updated, as different modelling groups around the world incorporate higher spatial resolution, new physical processes and biogeochemical cycles. Modelling groups coordinate efforts through the different generations of the Coupled Model Intercomparison Projects (CMIP). The California 5th Climate Assessment is producing new climate data and scenarios with the Coupled Model Intercomparison Project Phase 6 (CMIP6), which will provide higher climate sensitivity and granularity compared to previous versions. These models will improve resolution of climate data and projections across sectors and should include downscaled projections for coastal hazards including extreme sea levels, wave action and interannual events.

3. Short- to long-term variability in coastal hazards

Assessments and planning often focus on SLR as a single component of coastal impacts and may neglect shorter- and long-term effects of storm activity on coastal flooding, beach erosion, and cliff retreat, where the predictive capacity into the future has been more limited [35]. While some vulnerability assessments and adaptation plans may consider coastal erosion, storm waves and extreme flooding events, they largely lack future projections of extreme weather events, the compound effects of short-term events, and interannual variability. For example, El Niño-induced changes in wave intensity, direction, and sea levels and their related impacts are locally critical, but often considered only generally since detailed information on local changes and historic impacts is lacking. Understanding the driving causes of storm impacts and interannual events like El Niño, now and in the future, is critical to inform management responses and would also help inform long-term hazard adaptation responses. Similarly, changes in coastal dynamics at intern-annual scales may influence sediment transport and increase the effect of coastal flooding and erosion individual events, exceeding critical tipping points. Short- and long-term variability in coastal hazards and shoreline change should be a central part of long-term coastal risk management strategies.

4. Local wave action

Among coastal dynamics, wave-driven processes remain poorly characterized and connected to coastal impacts. Many vulnerability assessments in California do conduct at least a basic assessment of wave-driven flooding or hazard impacts; however, others may not critically-examine this component of shoreline change and impact. Wave runup is a major contributor to flooding and analyses are often conducted on a site-by-site basis through the environmental review of proposed developments. Still, there is a need for improved wave modeling and impact analysis at the community scale, particularly as climate changes continue to accelerate. The contribution of wave run-up to flooding may increase nonlinearly with SLR (a 1ft increase in SLR may lead to more than a 1ft increase in wave run-up) as wave action would be able to reach further onshore and produce overwash (e.g. damages from in Santa Cruz from recent storms Images) [36]. Whereas contributions of waves to total water level have been estimated at over 40% in the Northwest of the USA [37], wave-driven contributions to flooding, storm erosion and sediment transport remain poorly characterized locally, but are key to anticipate the coastline in the future and storm induced flooding and erosion events. To date, available wave data includes (see Annex 2) in-situ observations (e.g. Coastal Data Information Program), future projections of wave parameters based on CMIP5 GCM models [38,39] - used by CoSMoS for impact assessment [34] - and recent updates for CMIP6 models up to the mid-century [40]. This information corresponds to results for offshore areas, lacking effects of local coastal features; long-term historic and future time series of wave parameters at local sites (shallow water areas) are not yet available.

1.B. What is Projected to Happen? - Part B. Physical impacts and effects in the coastal system

The characterization of impacts should also continue to move beyond SLR inundation. The impacts considered in vulnerability and local adaptation plans vary in resolution and typologies including, for example, permanent inundation from SLR; extreme episodic flooding; interannual extremes (e.g., ENSO); storm induced shoreline erosion; long-term expected changes in the shoreline; cliff/bluff retreat; groundwater flooding; and ecosystem impacts. The key needs for advancing the characterization of physical impacts, based on the literature and by practitioners, include:

5. Addressing limitations in flood mapping

Vulnerability analyses should consider dynamic flood modeling. Estimates of exposure from dynamic flood modeling show three-fold increases in exposed population compared to SLR and a static coastline (Barnard et al 2017): over $150 billion of property at risk of flooding by 2100 in California, which represents over 6% of the state's GDP, and 600,000 people[15] [34].

Future research should improve: the analysis of frequency of compound events, as high tide flooding increasingly represents a source of nuisance flooding that will increase in the future, assessments should identify map out areas affected by regular flooding [16] [17]; compound effects from other contributors to coastal flooding such as groundwater, tides, and rainfall, but also the effects of land change (subsidence and erosion); be developed at regional scales, as identified by the regional Strategy for a rising Bay (Joint Platform, 2021); and include the effects of coastal defenses.

6. Historic information on impacts and consequences

Historic information provides key data for understanding coastal change and impacts, beyond permanent inundation from SLR (e.g., the King Tides Project for SLR submergence). The planning processes may be as well informed by historic changes in recent impacts, such as cliff erosion events [41], or El Niño events [32,42–45], which may resemble long-term impacts of climate change in some coastal zones of California. Many vulnerability assessments review historical coastal damage events, including from major El Niño years; others also draw on historical records of shoreline change to set the stage for discussion of future change. Yet, the consideration of historic data and effects of historic extreme events could be improved through more systematic assessment. More analysis of historic flood and erosion impacts, the geophysical drivers, their economic effects, and the social impacts, particularly through an environmental justice lens, would improve vulnerability assessments and the evaluation of effective adaptation options, across temporal scales.

7. Erosion rates and shoreline change

Coastal erosion is not only a growing issue for built assets and infrastructure, but also from the point of view of natural lands, public access, and biodiversity. Erosion is one of the major threats to California's coastline from climate change. The long-term impacts of SLR and waves on coastal change were recognized in the Fourth Climate Change Assessment (2018) as a gap for the next cycle (5th Climate Assessment). Continued improvement in the estimation of shoreline change rates across different types of coastlines (e.g. cliffs/bluffs, beaches, estuaries) is needed for climate vulnerability assessment and for defining appropriate setback distances, as stated in the California Coastal Commission Sea Level Rise Policy Guidance [10].

[15] Population at risk of SLR by 2100 has been estimated in California to increase from 95,000 to 216,174 for a 0.3m to a 1.8 SLR scenario; while adding population, the estimate by 2100 would vary between over 222 thousand to over 1 million [69].

[16] By one estimate, annual average event frequencies for minor, moderate, and major high tide flooding heights (NOAA) in the Northwest are expected to be over 10 annually by 2050, compared to 3 in 1990 (Sea Level Rise Technical Report, 2022, section 3).

[17] In California, the King Tides Project aims to visualize future sea level impacts by observing the highest tides of today. The SLR Action Plan suggests expanding the King Tides Project to cover more major high tide flooding events in more locations and information about tidal processes.

Although recent advancements provide decadal to centennial-scale predictions of shoreline evolution [46,47][18] for varied California settings, (beaches backed by dunes, cliffs, estuaries, river mouths, and urban infrastructure), predictive capacity remains limited for storm-induced changes. Other areas for predictive model improvement include theoretical frameworks, quantification of accuracy and uncertainty, computational efficiency, and integration with observed data.

8. Public coastal access and recreation

The California Coastal Commission Sea Level Rise Policy Guidance [10] calls for more information about how climate change could affect public access, recreation (e.g. changes to waves and surfing), and coastal resources. A 2021 study prepared for the Commission provides an evaluation of issues related to SLR and protection of public trust lands [48]. Another study is underway examining the projected impacts of SLR on beach access and social equity [49]. More attention to the social and recreational impacts of SLR, particularly to important sandy beach recreation areas, is needed.

9. Coastal squeeze and ecosystem change

Identifying where coastal squeeze could limit ecosystem migration of has also been identified as a critical gap for understanding future coastal changes (e.g., California 5th Climate Assessment)[50]. Identification of wetland migration pathways is also needed for determining SLR adaptation opportunities in communities that could use wetlands to confront flooding and erosion. For example, highways, railways, and fixed development can act as barriers to the inland migration of wetlands and beaches, which can impede ecological processes critical for functional habitats for rare, protected, and endangered species. Improved characterization of these barriers is needed. Identifying wetland migration pathways is also critical to: (1) locate sites and the extent of the impacts (e.g. future shoreline, flood zones), (2) inform actions to build ecosystem resilience (including areas affected by coastal squeeze), and (3) ensure that restoration actions are successful with climate change. Addressing coastal squeeze and enabling wetland migration pathways is also central to achieving the specific goals and metrics on wetland changes by 2030 (+20%) and 2040 (+50%) set by the California Climate Adaptation Strategy (CAS) [3].

The California Coastal Commission Sea Level Rise Policy Guidance also highlights potential impacts to beach ecology from shoreline protection projects and climate change, including their potential economic costs [10], which calls attention to assessing the effects of coastal management interventions, from a coastal risk perspective, alongside climate-driven hazards.

10. Coastal ecosystem structures, functions, and services

Mechanisms to build ecosystem resilience at regional scales remain poorly understood and unincorporated in adaptation plans. Incorporation of statewide or regional valuations and vulnerability assessments of coastal habitat functions, and their space in coastal resilience, could help align ecosystem resilience and adaptation[19] [51]. In addition to their adaptation benefits (see point on nature-based solutions) the role of restoration of blue carbon habitats (coastal wetlands, eelgrass, tidal marshes) in achieving carbon neutrality and/or climate resilience and adaptation is also receiving attention but remains poorly characterized. Analyses should also prioritize identifying habitats vulnerability to SLR and

[18] For example, CoSMoS-COAST was developed to simulate sandy shoreline evolution along 500 km of coastline in Southern California [47]. CoSMoS-COAST combines process-based models of coastline evolution and features data assimilation to predict that up to 67% of beaches may completely erode by 2100 without large-scale human interventions.

[19] See statewide vulnerability assessment of California 'coastal habitats - https://coastalresilience.org/project/conservation-assessment/

extreme storms and the relationships between natural and social systems in order to develop mechanisms that integrate and account for ecosystem services (including those from freshwater and coastal environments) in conservation, management, and development decisions and in climate change programs (e.g., Research Investment Plan Update, 2021, by the California Strategic Growth Council).

11. Coastal infrastructure and the built environment

To date, there is no comprehensive statewide analysis of the costs associated with addressing vulnerable critical infrastructure, though critical attention is being focused on the need to assess and adapt to projected vulnerabilities of critical infrastructure [52]. Some of the priorities include identifying critical infrastructure assets at risk such as trade seaports operations marinas, power plants, and critical roadways and railways.

12. Regional connectivity and system-wide analysis

Regional interconnections in vulnerability assessments and adaptation solutions remain limited. The interconnections of the watershed, land and coastal waters are key to: understand and counteract the impacts of SLR, for example, on salination of underground aquifers throughout California; understand economic impacts of changes in water supply (in coastal cities and water supply network); study flood and erosion impacts and solutions beyond coastal jurisdictions limits, increase regional coordination for adaptation investments and building ecosystem resilience, especially as species migrate across regions; and manage streamflow, wetlands, and biodiversity estuarine areas and deltas.

13. Seawater intrusion and contamination of groundwater

The California Coastal Commission Sea Level Rise Policy Guidance identified the need to characterize the potential effects of SLR and changes in rainfall on groundwater and coastal aquifers [10]. Specific gaps include: a regional assessment of equitable and effective water resources management under climate change scenarios that includes the effects of groundwater-surface water interactions; identifying the risk of salinization of underground aquifers; determining the socioeconomic and ecological benefits and costs of alternative salinity management scenarios; and pinpointing the communities across California that are most vulnerable and at risk to these impacts. Other gaps identified relate to evaluating the potential incidence and severity of saltwater intrusion in individual aquifers; establishing criteria for deciding whether and when saltwater intrusion requires mitigation or response; and identifying strategies for the agriculture sector.

Seawater intrusion from SLR can also affect flood risks. Critical needs are understanding the effects from SLR on groundwater contamination and inundation of contaminated soils and sites, as well as structural corrosion/foundation failures. The effects of SLR inundation on waste facilities (toxic, solid, recycling) and contaminated sites as well as health (mental and physical) and social impacts of hazardous waste and environmental toxins from flooding, SLR, and other climate related events also remains largely uncharacterized, though the California Department of Toxic Substances Control has launched a new initiative to address more systematically the interaction of SLR and contaminated sites [53].

14. Characterization of economic effects

A consistent gap across the reviewed documents is the need for a deeper understanding of the economic effects of climate change impacts. How climate change affects California's coastal economy across sectors is a specific priority of the CAS [3]. There has been a tendency to project only large-scale impacts, for example, on the state's entire economy and county-level costs based on national/state data, but, just as the physical impacts of climate change vary across the coast, so too do the related economic benefits and burdens, as identified in the Climate Change Research Plan for California [54]. The policy discusses the

need to characterize economic impacts of SLR, extreme flooding, and coastal erosion that can affect public access, private/public property, and infrastructure. This aligns with the State's priority to support adaptation of rural communities and tourism economies (e.g., 5th Climate Assessment).

How can we better Communicate this Change?

15. Advances needed in decision support tools

The number of available tools to help communities assess vulnerability to climate change in coastal areas has grown substantially. However, there are subtle differences among them, which can result in confusion and, in some cases, hinder planning for SLR and other coastal hazards (especially rapid-onset hazards associated with extreme weather events).

As part of this study, we completed a review of tools and decision support systems relevant for coastal adaptation (Box 1 provides a summary and Annex 1 provides extended information). Broadly, the tools classify into three main types (Box 1 and Annex): inundation viewers; impact explorers; and adaptation toolkits. Some tools also allow a comparison of strengths and weaknesses of these flood mappers. For example, '*Sea the Future*' [20](created by the California State Coastal Conservancy) helps identify tools based on location or by distinguishing features, and compares methodologies and features across multiple tools. Psaros et al. 2014 [55] also provide a tool comparison matrix and can be accessed at [56].

Most tools focus on flooding from SLR and extreme sea levels, and rarely consider short and long-term erosion, wave-driven coastal processes contributions to flooding, and compound effects (see previously). Their application locally varies depending on the data sources, data availability, hazard types, and frequency of updates.

Three potential sources of confusion for practitioners using various tools to assess vulnerabilities at the local level include: (1) the focus on long-term (mid- to end-of century) projections instead of short-term extreme-weather events (e.g. El Niño storms); (2) the uncertainty around the expected time of specific inundation levels; and (3) the multiple scenarios and uncertainties associated with them.

BOX 2. SUMMARY OF TOOLS AND DECISION SUPPORT SYSTEMS

Numerous viewers of coastal flooding exist that include three main flood drivers: (1) sea level rise (SLR), (2) extreme water level changes (most often the 100-year flood zone), and (3) combined SLR and extreme sea levels driven by storms. Some examples of flood explorers include national, state and local alternatives such as Climate Central's Surging Seas toolkit, Our Coast Our Future, and the BCDC Adapting to Rising Tides Bay Shoreline Flood Explorer (Table 1). Most previous efforts primarily on long-term SLR with a static tide level, and neglect dynamic physical drivers such as tidal non-linearity; storms (e.g., storm surge, wave run-up, and river discharge); interannual climate variability (e.g., elevated water levels during El Niño events); hydrodynamic processes associated with bathymetry; built environment and the natural coastline configuration; erosion and flooding responses. Most viewers use a "bathtub approach"[21], which is a first approximation passive approach that does not consider local, dynamic processes. Recent publications show that this approach is inadequate for assessing local impacts. To date, CoSMoS, developed by the USGS in California, is the only tool that provides projected changes across storm conditions regionally, including the effects of wave induced processes, groundwater, and shoreline and cliff retreat, as well as

[20] https://www.seathefuture.org/#/

[21] Elevation and tide data is used to produce inundation areas uniformly raising water levels by various selected future sea level values.

marsh migration in the San Francisco Bay, although consultant analyses of specific local vulnerabilities have also done this. The effects of SLR, tides, waves and storms in California will affect over $150 billion of property (+6% of the state's GDP) and 600,000 people by the end of this century (Barnard et al 2018). This is a three-fold increase in exposed population than if only SLR and a static coastline are considered.

Other tools use this hazard information to calculate exposure (assets and/or people exposed in the flood zone), and compute economic metrics or socioeconomic damages (e.g., USGS Hazard Exposure Analytics Reporting, HERA). For example, Surging Seas and the NOAA Coastal flood explorer, provide information on flood exposure to permanent flooding and extreme flooding events. The NOAA coastal flood exposure is one of the most comprehensive national scale flood explorers, and provides hazard layers for high tide flooding, FEMA flood zones, tsunami, SLR, storm surge, and a composite flood layer. The NOAA mapper also allows exploration of infrastructure, ecosystem, and societal exposure overlaid on flood hazard maps. Recently, the Climate Mapping for Resilience and Adaptation (CMRA) Assessment Tool provides information on past, present, and future climate-related hazards and directs users to federal grant funds for climate resilience projects, including those available through the Bipartisan Infrastructure Law. Other tools provide vulnerability and climate justice information, such as the Climate and Economic Justice Screening Tool, which allows users to identify disadvantaged communities exposed to climate hazards by census tracts using environmental or climate indicators.

There are also toolkits and collections of resources such as CalAdapt that provide not only data exploration and visualization, but also include community adaptation guidance (see also Table– guidance review). The most recent toolkit, the Climate Resilience Plan Alignment Toolkit (launched in November 2022), by the Integrated Climate Adaptation and Resiliency Program (ICARP) at the Governor's Office of Planning and Research, provides a suite of collaboration tools for practitioners to coordinate local resilience planning efforts. The toolkit provides a menu of tools and best practices for communities to use while meeting local planning requirements, balancing planning priorities, conducting risk and vulnerability assessments, advancing equitable outcomes and community engagement, and seeking funding to plan and implement solutions. The U.S. Climate Resilience Toolkit is another potential resource for accessing step-by-step guidance on managing climate risks, case studies, and future projections at a national scale.

16. Improving coastal change communication

As discussed above, the most pressing needs in communication and tool development mirror the science needs, including better incorporation of coastal erosion, historic impact data, compound effects analysis, regional scale assessment, and consideration of social and economic effects. All modeling and tool creation would benefit from periodic updating and consistency across platforms. This is perhaps the most pressing need, namely, the confusion that is potentially created through the proliferation of different models and tools, which may end up hindering rather than facilitating local adaptation planning. New advances should also begin to address the role of different adaptation interventions.

Research on climate communications has received increased attention. For example, the Adaptation Planning Guide [6] indicate several guides and resources that include: '15 Steps To Create Effective Climate Communications' [57]. Communicating adaptation needs is challenging because SLR is a phenomenon that is abstract to many people; climate change is a slow and temporally distant process; and the benefits of adaptation will only materialize in the future and may not always be tangible to everyone today. Experiences in local adaptation plans and coastal communities also confirm the need for strategic communication and engagement. For example, managed retreat has often faced steady resistance in many communities and is challenged by societal perceptions and the large cost in terms of private property loss [58].

How can we center environmental justice, equity and communities in adaptation investments?

17. Quantification of climate vulnerability

Climate vulnerability is defined in the Adaptation Strategy as "*the degree to which natural, built, and human systems are at risk of exposure to climate change impacts*" [3]. The 2022 Adaptation strategy, when presenting various climate-focused actions, prioritizes making communities more resilient while also addressing systemic inequalities. However, some observe that this priority is challenged by the lack of quantitative methods and data-based analyses for the identification and traceability of equitable adaptation approaches and locations. Existing information to characterize vulnerable communities is still provided at large scales and as a percentage of vulnerable assets or people; while there is limited information on vulnerable and disadvantaged people at risk with enough spatial granularity to plan adaptation options that may benefit specific, disadvantaged populations. Key needs include the improved identification of vulnerable/at risk underserved communities, including tribal communities, as well as the different drivers (climatic, social, economic, physical) of coastal climate risks and vulnerabilities (Equity priority, Goal A, CAS).

18. Equitable distribution of adaptation benefits

Equity is also rapidly becoming a central part of coastal adaptation. Equity and social justice in coastal resilience efforts, strengthening tribal relations, and increasing support for communities entitled to environmental justice are present in different policy documents, including the State Agency SLR Action Plan [59] and the Climate Adaptation Strategy (CAS) [3]. *Equity*, in this context, is defined as '*the fair and just distribution of financial and institutional resources to address impacts across communities that stand to be adversely affected by those impacts, and commitment to include those communities in the development, prioritization, and implementation of adaptation policies, programs, and services*' (West Oakland Environmental Indicators project).

The Coastal Commission Sea Level Rise Policy Guidance [60] and Environmental Justice Policy (2019) [61], and the State SLR Action Plan [62]also encourage integrating and prioritizing equity and social justice in all SLR adaptation planning and projects. Community-based organizations and California Native American tribes should also be involved throughout the SLR planning process, through meaningful, early, and frequent consultation (SLR Action plan). Adaptation investments should consider impacts on equity by characterizing physical, social, political, and economic inequities in climate risks and historic and future projections, accounting for the effect of adaptation decisions.

The Adaptation Planning Guide [6] suggests that equity should be part of all phases of adaptation planning through a multidimensional approach and having three objectives: 1) procedural, 2) distributional, and 3) structural. Procedural equity should create processes that are transparent, fair and inclusive; distributional equity distributes resources, benefits and burdens fairly, while prioritizing resources for communities that experience the greatest inequities and impacts; Structural equity should address the consequences of past harms, such as redlining, and prevent the future consequences of structural social biases.

Therefore, mainstreaming equity and social justice in adaptation decisions requires a better understanding of how this multidimensional approach can be accomplished through enhanced adaptation planning processes and investments; identifying distributions of benefits and impacts; finding ways to create positive feedback mechanisms to address historic impacts; enhancing co-benefits of adaptation; and providing critical information for local leaders to take action, including communicating how climate

change impacts human communities can influence effective, proactive, and equitable management (California 5th Assessment Report).

What Works? – Identifying effective adaptation solutions

There is a need for more science and evaluation of adaptation strategies and options, their effectiveness, and the comparative evaluation of their social costs and benefits, including the distribution of these from a social equity perspective.

19. Evaluation of available solutions and their cost-effectiveness

One of the largest limitations identified is how to demonstrate the efficacy of adaptation strategies. This requires defining methods and information to evaluate, both quantitatively and qualitatively adaptation options and their effectiveness and costs. The lack of direct ways to account for adaptation options is common across all the documents reviewed in this study. Tools do not yet exist for evaluating: the potential effects of adaptation options in reducing risks and coastal change; where they could be implemented effectively; by when (different climate scenarios); and what would be the shorter-term needs for preventing flooding and erosion from extreme events.

There is also a need to define typologies of solutions for different environments, for example by establishing a taxonomy or recommended interventions with associated information on costs and effectiveness. By coastal typologies, some of the most pressing and demanded solutions regionally and locally include the need to evaluate sediment budgets and solutions to prevent and control erosion; protect civil infrastructure such as roads in a sustainable way; and ways to evaluate, prevent and maintain cliff and beach stability.

20. Adaptation pathways: evaluation of effectiveness across space and time

A critical need exists to evaluate the effectiveness of adaptation interventions in sequential, adaptation pathways approaches. Adaptation pathways are iterative policy roadmaps that help decision-makers plan and implement climate adaptation efforts under uncertainty [63,64] as they provide a route for sequencing actions by monitoring triggers and thresholds to signal when to start a next phase of adaptation [10,64]. They represent an innovative tool for coastal communities to identify community goals and objectives and increase their preparedness and resilience to hazards given uncertainties of specific timing of impacts The use of phased, trigger-based solutions and adaptation pathways is supported by (see Annex 1 for a summary of the policy documents): the SLR Action plan, the Coastal Commission Infrastructure guidance [52], CA Adaptation Clearing House recommendations for adaptation planning from Coastal Plan Alignment Compass and the recent Alignment tool, the Climate Adaptation Strategy [3], the SLR Action Plan [62], and piloted experiences by different communities. However, their implementation faces numerous challenges, including:

- how to evaluate the potential effectiveness of measures and investments in terms of efficacy, economic costs and financing?
- how to characterize the projected changes in the coastline (shoreline retreat, ecosystem migration) and factor them in in sequential trigger-based decisions?
- what are timeframes are needed to take action based on expected changes?
- what technology can be utilized to assess, monitor and replicate implementation?
- How can community values and shared visions for shorelines be integrated with pathway design and implementation?

- What is the role of citizen science and the coproduction of adaptation science in pathway implementation?

21. Nature-based adaptation

Nature-based adaptation measures work with natural processes and landforms to provide protection for ecosystems and the built environment and to support coastal resilience and risk reduction [65]. Along highly modified shorelines, nature-based measures are often hybrid approaches engineered to mimic natural processes and also provide specific services such as coastal risk reduction and critical habitat [20].

Nature-based adaptation has received increased attention in California through expanded research, experience and policy documents that show their effectiveness. In Executive Order N-82-20 [22], Governor Gavin Newsom prioritized the management of California's natural resources and land and called for the accelerated use of nature-based solutions (NBS). The 2022 Climate Adaptation Strategy also commits to implementing multi-benefit, NBS to combat climate change, by continuing to increase the number of projects while also addressing equity and environmental justice issues [3]. The State Agency SLR Action Plan [62] also suggests that adaptation should prioritize the conservation of coastal habitats and associated functions, allow space for upland and inland migration of coastal habitats, and use of NBS when possible. Furthermore, principle 6 of the 7 governing principles for resilience [66] states to (i) protect and enhance public trust in natural and cultural resources, such as beaches, wetlands, other habitats, biodiversity, and culturally important areas, and (ii) prioritize the use of nature-based adaptation where appropriate. NBS is also one of the five considerations under the Coastal Commission infrastructure guidance [52] that recommends local governments and asset managers prioritize nature-based strategies in all new SLR adaptation planning efforts. The OPC Strategic Plan to protect California's Coast and Ocean - goal 1- [2] also calls for innovative and transferable nature-based adaptation of variable size and scale, including living shorelines, eelgrass and oyster beds, wetland and beach restoration, and other adaptation strategies such as managed retreat, where feasible.

Despite this momentum for NBS in California, key gaps remain to help advance their implementation (Annex 1):

- Identify NBS that are appropriate for the different coastal landscapes considering the hydrological, ecological and geomorphological conditions. There is a general lack of tools and methods to assess the availability, viability and effectiveness of NBS (including hybrid options) in heavily urbanized waterfronts (boardwalks) and coastal infrastructure (piers, wharfs, ports), as well as how to integrate NBS into relevant infrastructure and investment. New methods are also needed to measure and assess equity and environmental justice through the investment in NBS, as well as characterizing the multi-benefits provided by NBS in consistent, rigorous ways.
- Economic information and financing of NBS. Characterization of economic impacts and benefits analysis of NBS (5th Assessment) as well as the characterization of market mechanisms, processes and financing mechanisms is hindering implementation. For example, demand exists for approaches that can accelerate wetland and seagrass habitat creation and restoration including developing and/or enhancing wetland and seagrass mitigation banking, blue carbon mitigation banking, and other finance instruments to support more implementation [2].
- Definition and metrics. A clear definition for classifying NBS solutions is currently lacking. However, it is needed to adequately maintain a record of interventions. NBS monitoring parameters need to be clearly identified and defined.

[22] https://www.gov.ca.gov/wp-content/uploads/2020/10/10.07.2020-EO-N-82-20-.pdf

- Future adaptability. Landscape connectivity of ecological and coastal processes that will enable future self-adaptation of ecosystems remains to be characterized. Sustainability and effectiveness over the long-term remain two major factors of uncertainty in these adaptation options.

22. Wetland restoration for coastal adaptation

Goal A of the Adaptation Strategy [3] includes NBS actions to protect, restore, and create coastal wetlands. One metric used to measure these goals in the Adaptation Strategy will be whether the acreage of coastal wetlands increases by 20% by 2030 and by 50% by 2040. Another metric for NBS is the development of a statewide coastal wetland inventory to track protection, restoration, and creation. Gaps and priorities to meet these wetland management goals include:

- Methods to quantify wetland restoration benefits. Quantitative understanding on the role of wetlands as protective assets for urban areas and other infrastructures from coastal and inland flooding is currently lacking. There is also a lack of spatial definition of the coastal wetlands that could be restored for coastal resilience benefits and methods to ensure coastal wetland restoration and management actions are successful against SLR, including opportunities to reuse sediment [14] and guidance for increasing wetland sediment supply and retention, techniques for developing an adaptive wetland restoration plan, and monitoring criteria. The policy documents also highlight the need to quantify the benefits of wetlands for coastal protection, carbon storage, water supply, and water quality.
- Identification of wetlands at risk and migration pathways. There are needs to define and map wetland risk, identify potential wetland migration pathways [10,14], and develop methodologies for establishing buffer widths from natural resource areas for protecting such migration corridors.
- Monitoring of benefits and changes. Monitoring existing multi-benefit wetland projects to document the habitat benefits, flood protection, and ability to adapt to SLR could help inform future multi-benefit projects.

23. Spatial distribution of benefits and regional interconnection between strategies

Regional coordination in the identification and analysis of adaptation actions has been limited. Cities and counties should coordinate plans to identify risks and opportunities regionally to provide integrated management of impacts and solutions. The need for a regional, broader view of impacts, solutions, and adaptation processes is patent in different documents that call for understanding of interconnected systems as vulnerabilities in one place or for one component can potentially cascade throughout the system (e.g. adaptation investments and network effects) [10]. For example, minor flooding that blocks off a portion of a roadway could increase traffic on alternative routes, which over time, could increase maintenance costs. Another example is the need to understand littoral cells and sediment budgets for adaptation along sedimentary shorelines.

One example of a regional planning approach is the San Francisco Bay Shoreline Adaptation Atlas [20] and the use of *Operational Landscape Units* [23] based on natural processes, instead of planning zones based on jurisdiction. This framework helps identify where solutions could help create a resilient shoreline with multiple benefits. Similar shoreline management approaches can potentially be applied on the open coast.

[23] Operational Landscape Units (OLUs) are a practical way to manage the physical and jurisdictional complexity. Baylands OLUs consist of landscape features such as rivers, floodplains, and wetlands, as well as elements of the built environment such as parking lots, landfills, and residential neighborhoods. The connections between the features of the Baylands OLUs are important: altering the movement of sediment or water in one part of an OLU is likely to have an impact elsewhere in the OLU.

The Adaptation Clearing House provides advice for cross-referencing plans by integrating the actions and risk reduction strategies at multiple levels [67].

It is becoming increasingly important to ensure that adaptation projects will not shift hazards and impacts elsewhere along the coast. This requires methods to assess the spatial interconnectivity of adaptation solutions infrastructure, nature, and people [19,68].

24. Costs and benefits of adaptation projects

Information on the costs and benefits of adaptation strategies is one of the largest challenges identified. The need to evaluate the economic and environmental costs and benefits of alternative strategies, the economic opportunities, and their distribution is raised consistently. For example, the Coastal Commission Infrastructure guidance recommends evaluating the costs and benefits of adaptation strategies over the entire life cycle of the infrastructure, assessing both market and non-market values, and pursuing additional federal and state funding for infrastructure adaptation [52]. Yet, there is very limited information for planners on the costs and benefits of adaptation strategies (e.g. Joint Platform in San Francisco Bay [12]). Some jurisdictions, though, such as the City of San Francisco, have developed more detailed capital improvement plans that focus broadly on the social benefits of specific capitol resilience investments[24]. A need exists to document experiences and identity optimal project locations so investment decisions can lead to equitable distribution of adaptation benefits [3]. Access to climate finance should also keep a focus on addressing disparities, including tribal communities' access to adaptation finance.

25. Climate co-benefits of investments in adaptation

California prioritizes implementing adaptation solutions that also support reducing Green House Gas (GHG) emissions. However, it requires more robust tools and techniques to quantify and account for the multiple benefits of adaptation strategies that can be helpful to address a range of future climate concerns, including justice issues. Design-based approaches should identify opportunities to achieve multiple benefits and leverage funding sources, including synergistic opportunities for adaptation and mitigation (e.g., wetlands).

Specifically for wetlands (see also section for wetlands), the Climate Change Research Plan for California [54] identified that wetland restoration can play a critical role in protecting the coast and deltas from flooding while also sequestering carbon and reducing GHG emissions; but would require a *Wetland Carbon Protocol* to better monetize emission reduction benefits from wetland restoration projects.

Other climate co-benefits of adaptation strategies may include effects on human health, recreation and cultural values of coastal zones, impacts on wellbeing, hazardous waste, and environmental pollution (contaminated sites vulnerability), effects on the real estate market, and connections with affordable housing and retrofitting of buildings. Specific methodologies and tools to evaluate these co-benefits in consistent, rigorous ways are needed to report adaptation benefits, inform decisions, and ensure equitable distribution.

[24] City and County of San Francisco Capital Plan Fiscal Years 2020-2029

How can we effectively implement adaptation pathways, and avoid maladaptation?

There is growing interest in adaptation pathways to address scientific and environmental uncertainty and long planning horizons in coastal adaptation. It follows that there is a need to improve our understanding of a variety of aspects that are inherent in adaptation planning, within the framework of pathways thinking.

26. Evaluating effects across time horizons

Long planning horizons in adaptation plans represent a challenge to secure funding for individual projects and to align timelines between science projections (mid to end of century) and city planning horizons. As a result, projects that address shorter-term needs, such as beach nourishment, have been easier to move along and be implemented, making long-term climate change considerations more difficult to implement as part of comprehensive strategies[25]. Coastal adaptation science should focus on providing actionable information across all temporal scales in adaptation pathways, by informing and helping evaluate shorter-term actions, mid-term (e.g., mid-century) targets and long-term goals (e.g., end-of-century).

27. Framing long-term needs within shorter term programs and financing

Successful experiences in communicating climate change have framed adaptation discussions around key aspects such as access points to the coast, beach uses, multi-benefit projects such as living levees, etc. Identifying entry points with community values and needs, creating economic cases for the need to adapt, and considering cross-sectoral, multi-benefit solutions can help communicating and making decisions on long-term planning needs through shorter term interventions and strategies.

28. Making decisions based on the best available climate science

'*Use the Best Available Science*' is one of the 7 Principles for Aligned State Action to create directions for alignment of state actions and decisions around SLR; as it also stated in Priority 5 of the CAS [3]. However, methods to operationalize climate science into decision-making and connect it with local demand varies between locations; as discussed, the *'best available science'* concerning SLR projections and assessment methods has been provided by statewide agency guidance [1,10,52] and, sometimes, locally through local collaboration with campuses in the UC system (and other academic partners) or dedicated staff[26]. One proposed solution has been the creation of scientific advisory boards for adaptation planning and implementation (e.g., in the San Francisco Bay area) [12]. The UC system has the potential to help address this gap by providing targeted support on best available science. The recent Disaster Resilience Network[27], as well as other intercampus advisory initiatives could help connect scientific expertise with local and state needs.

29. Addressing the adaptation finance gap through innovative mechanisms

One of the critical factors hindering implementation is the limited funding available for adaptation projects, relative to the costs of the effects of climate change in the coastal zones and ecosystems of California. This is both a local problem and a global one: adaptation is not receiving finance at the necessary scale. New adaptation funding mechanisms and structures are needed, such as an Adaptation

[25] Statement based on workshop input. See Annex.
[26] Statement based on workshop input. See Annex.
[27] University of California (ucdrn.org)

Fund that would allocate funds, manages cross-sectoral investments, accounting, and financial reporting. Ways to address the adaptation finance gap are: building long-term capacity to mainstream adaptation; support university curriculum, teaching and research on adaptation (as well as mitigation) finance; innovative instruments to mobilize private sector adaptation finance (e.g., Coalition for Climate Resilient Investment, CCRI); and finance and economic research. Scaling up adaptation finance in California will also require actionable ways to track investments. Because adaptation is very context-specific, and unlike mitigation finance that focuses on reducing GHG emissions overall, adaptation requires a broad array of activities tailored to climate risks in specific locations.

Monitoring and Technology for implementation: when interventions should be implemented and how to measure their performance?

30. Targeted monitoring of the coastal system

The available observations and datasets of the coastal system in California broadly cover meteorological and offshore oceanographic conditions. Table 1 in Annex 2 provides an overview of available observations and databases useful for examining coastal hazards and vulnerability in California. Datasets vary from site specific to regional and can include historical, real-time, and forecast model data. Site specific observations include tide, buoy, shore, and weather stations. Regional data sets include broad scale observations (such as satellite-based imagery), and interpolated or modeled observations (such as regional wave models).

One of the detected gaps is that observations of surf zones and swash conditions are relatively limited. High temporal frequency observations at the coastline are needed to capture coastal changes before, during, and after storm events. These datasets needed to develop, calibrate, and validate predictive models on the timing and a magnitude of coastal hazards, to be used to assess coastal vulnerability and address the limitations identified in previous sections.

The Climate Change Research Plan [54], in 2015, specifically included monitoring needs for (1) tracking of shoreline changes and impacts from storms (e.g., beach and cliff erosion) to improve methods for predicting shoreline evolution and (2) measuring land elevation changes such as subsidence and tectonic activity in relation to SLR.

31. Technology advances to support implementation of adaptation pathways

Some other technologies that can support adaptation include: monitoring and tracking the cumulative impacts of projects in the coastal zone, including both new development and any adaptation strategies [10]; methods to measure the spatial distribution of benefits of adaptation; mapping of coastal habitats inventory (i.e., dunes, beaches, wetlands, rocky intertidal, and eelgrass), to evaluate their vulnerability to SLR; and monitoring of changes to trigger adaptation pathways and trigger-based decisions. There are also other specific gaps, some indicated above, which are related to specific adaptation challenges, such as monitoring natural conditions/systems, NBS design and implementation, and consistent and systematic data collection needed to develop time series needed for climate change impact assessment.

Regional monitoring approaches can also be more cost effective than individual programs. This is an area that exceeds the capacity of local communities and where UC and other academic institutions could most critically help support.

How can we better integrate researcher and practitioner goals and objectives to better support actionable adaptation plans?

32. Regional collaboration and partnerships to advance coastal resilience science

Priority 6 of the CAS calls for partnering and collaboration for leveraging resources. In recent years, multiple local and regional climate collaboratives have formed across nearly every geographic region in California, representing over 80 percent of the state's population, such as the North Coast Resource Partnership, the San Francisco Bay Area Collaborative, the Central Coast Climate Collaborative, and the San Diego Regional Climate Collaborative, among others [6]. However, coastal science research (and the UC system) is not yet directly involved beyond individual participations of some researchers and/or local campuses. For the UC system, supporting regional initiatives may require contributing to effective partnerships and coordination for coastal resilience at regional, state, and national scales, through collaboration across sectors and regions, and coordination between communities and Universities to share a joint vision for climate adaptation and resilience research and training opportunities.

Inconsistent and insufficient collaboration between researchers and communities have also resulted in limited translation and advancement of solution-based science in adaptation plans. Effective communication between researchers, coastal managers, and the general public has also been challenged by a lack of standardized measurement for evaluating local hazards and adaptation options. This indicates a need for developing a framework for capacity building, engagement, and communication of more consistent or translatable coastal adaptation options and metrics of success.

33. Alignment of academic incentives and adaptation progress

In addition, incentive systems in academia can be barriers to adaptation progress. The lack of alignment may be produced when grant funding often does not align with practical adaptation planning timelines. Also, traditional research funding is often focused on theory-based research as opposed to applied research. For example, prolonged research activities such as monitoring, which is highly demanded by communities, are difficult to develop, creating a mismatch between distribution of observations and the availability of large-scale (e.g., aerial photography) versus local impacts (e.g., flooding events, shoreline erosion).

Another challenge includes the short-term nature of grants that can preclude developing consistent long term monitoring datasets needed to evaluate climate change impacts, or long-term collaborations between the universities and the communities, which are limited to a project-based basis. More vexing, adaptation planning at the local level operates at varying local times and scales, with no relationship to the timing of academic research work or funding. Academic work typically is not coordinated with the practical demand for scientific input and vice versa. However, important progress on this front is potentially made through the efforts of California's climate assessments. Most recently, for example, the 5th assessment has identified 26 areas of research that will now be developed through a statewide call for research proposals [50].

IV. Conclusions and way forward for advancing coastal adaptation science

The seven adaptation-centered research questions

This pilot-scale project conducted a review of the scientific and governmental literature, evaluated several coastal adaptation case studies, and conducted two workshops from 2021-2023. The results point to **33 key knowledge and technology needs organized into 7 categories to move coastal adaptation planning forward in California**. These categories broadly align to core questions that speak to functional steps of the adaptation planning process and important aspects of understanding coastal adaptation.

8) **What is projected to happen?** Targeted coastal science to (1) support prediction of climate change and related oceanographic forcing (sea level rise, wave energy, extreme conditions, etc.) prediction at the local level; and (2) improve the characterization of climate change impacts on the coastal zone, such as changes in groundwater elevations and cascading impacts.

9) **How can we better communicate this change?** Integrate and convey existing and future sea level rise guidance for practitioners.

10) **How can we center environmental justice, equity, and communities in adaptation investments?** Improve community engagement with adaptation planning, and how to achieve more equitable outcomes in adaptation decisions.

11) **What works?** Evaluate adaptation interventions to inform pathway planning is needed, such as social cost-benefit analysis and cost-effectiveness of different strategies.

12) **How can we effectively implement adaptation pathways, and avoid maladaptation?** Integrate understanding of coastal change and engagement with community values, over different and varied time horizons and geographic scales.

13) **Monitoring and technology: when interventions should be implemented and how to measure their performance?** Integrate monitoring of coastal change and interventions to support improved planning, and address feedback in the adaptation decision process to support connected pathway adaptation and implementation.

14) **How can we better integrate researcher and practitioner objectives to better support actionable adaptation plans?** Align academic incentives and practices with the practical needs and timing of community and governmental decision processes.

Addressing these challenges requires enhanced intercampus collaboration in coastal resilience.

Collectively, UC campuses can bring the expertise, technology, capacity, and relationships to holistically address these 7 questions. Addressing these challenges requires local, regional, and state partnerships with stakeholders and agencies, but also intercampus collaboration. Some of the key topics that UC is well

positioned to address are climate impact assessments; applied focus on adaptation science; regional monitoring and observational capacities; economic and finance research; and advisory roles for communities and agencies.

To increase the potential for UC climate science to directly inform coastal adaptation needs, UC should proactively revisit the connections between the ongoing research and the needs of practitioners, particularly as state and UC funding will likely be directed to climate solutions. To this end, a UC system-wide coastal resilience hub that can serve as an advisory body to local adaptation could critically support the integration of science with on-going coastal adaptation practice, but also shape UC's research broader impact to confront the climate priorities.

V. Annexes

Annex 1. Knowledge and technology needs and gaps based on relevant policy, guidance documents and resources

This Annex provides a synopsis and a list of key points and research gaps and needs in key adaptation documents in California.

Annex 2. Review of relevant resources for coastal adaptation to climate change in California

Summary Table 1. Observations (data archive and real time)

Summary Table 2. Viewers and Tools, Decision Support Systems

Summary Table 3. Guidance documents on adaptation to coastal climate hazards in California

Annex 3. Summary of workshop consultations and case studies

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Annex 1. Knowledge and technology needs and gaps based on relevant policy, guidance documents and resources

Table of Contents

Comparison of flood visualization tools - Table 1 (e.g. Cal-Adapt, Sea The Future, etc.) (2022)

Produced by: review of various sources (see Tables in Annex 2)

Synopsis:

As part of this study, we completed a review of tools and decision support systems relevant for coastal adaptation (see Annex 2). This section provides an overview of the main takeaways from such revision. We conclude that there are many tools available that help communities understand sea level rise and visualize present and future flooding. The number of tools has also grown substantially in recent years. However, the subtle differences among them can be confusing and, in some cases, a barrier to planning for sea level rise and other coastal hazards, especially for rapid-onset hazards associated with extreme weather events. Furthermore, the vast majority of tools are focused on sea level rise and extreme sea levels, but rarely consider short and long-term erosion and wave-driven coastal processes.

Some tools allow a comparison of strengths and weaknesses of these flood mappers. 'Sea the Future', for example, is a resource created by the California State Coastal Conservancy to help identify tools based on location or other features, as well as compare methodologies and features across multiple tools. It provides summary information and presents similarities and differences among tools. A comparison matrix that compares tools and models was also developed by (Psaros et al., 2014) and can be accessed at (Climate Central, n.d.).

In terms of hazards, there is an overwhelming presence of alternative viewers of coastal flooding that include three main flood drivers: (1) sea level rise, (2) flooding from extreme water level changes (most often the 100-year flood zone), and (3) increments of sea level rise or extreme sea levels. Some good examples of flood explorers include national, state and local alternatives such as Climate Central's Surging Seas toolkit, Our Coast Our Future that uses CoSMoS, the BCDC Adapting to Rising Tides Bay Shoreline Flood Explorer (San Francisco Bay) (see Annex 2, Table 2 for the comprehensive review of tools).

Other tools use this hazard information to calculate exposure (assets in the flood zone) or compute economic metrics of damages. For example, Surging Seas and the NOAA Coastal flood explorer, as some selected examples, provide information on flood exposure to permanent flooding and extreme flooding events. CoSMoS results are also used in many tools to calculate socioeconomic damages (e.g., USGS Hazard Exposure Analytics Reporting, HERA). The NOAA coastal flood exposure is one of the most comprehensive flood explorers, and available at a national scale, as it provides hazard layers for high tide flooding, FEMA flood zones, tsunami, sea level rise and storm surge, as well as a composite flood layer . The NOAA mapper also allows exploration of infrastructure, ecosystem and societal exposure that can be overlaid on flood hazard maps. Most recently (September 2022), the Climate Mapping for Resilience and Adaptation (CMRA) integrates information from across the federal government to help people consider their local exposure to climate-related hazards. The CMRA Assessment Tool provides information on past, present, and future climate conditions. The site also points users to federal grant funds for climate resilience projects, including those available through the Bipartisan Infrastructure Law. Some of the tools present vulnerability and climate justice information, such as the Climate and Economic Justice Screening Tool, which allows users to identify disadvantaged communities exposed to climate hazards by census tracts using environmental or climate indicators.

There are also toolkits and collection of resources such as CalAdapt that provide not only data exploration and visualization, but also include important guidance for communities on how to approach the adaptation process (see also Annex 2, Table 3 for a review of guidance documents). The U.S. Climate

Resilience Toolkit is another potential resource for accessing step-by-step guidance on managing climate risks, case studies, and future projections at a national scale.

Key points and research gaps:
From the analyses of tools and toolkits (see Annex 2), the identified gaps include:

- Most of the existing tools focus on coastal flooding, and there is a large gap in the information available for coastal change in estuarine areas (marsh migration), sandy shorelines, and bluff/cliff areas. From the available tools, only two of them provide information on beach erosion (CoSMoS) and cliff retreat. Whereas CoSMoS projects future erosion through modeling; (Swirad & Young 2022) characterized historic bluff and cliff erosion from lidar data.
- There is limited information on historic flood and erosion events, as the tools largely focus on long term (mid- to end-of century) projections of hazards. However, the planning processes may be as well informed by historic changes; cliff erosion from lidar data (Swirad and Young, 2022), or flood and erosion impacts from El Niño (Barnard et al., 2017; Barnard and Hoover, 2011; Young, 2018) are good examples.
- Most existing tools lack compound flooding from other sources including wave action, riverine, and surface water flooding from rainfall-runoff events. They also do not yet consider erosion, subsidence, or local wind and wave effects. To date, CoSMoS is the only tool that provides projected changes across storm conditions regionally, including the effects of wave induced processes, groundwater, and shoreline and cliff retreat, as well as marsh migration in the San Francisco Bay.
- Many tools present no updates or infrequent cycles of updated information.
- Other local applications and mapping tools have been used in local adaptation planning efforts, but they largely vary on the source of data, approaches, information on hazards and rigor. The disparity of approaches in local plans indicates a need for prescriptive recommendations on the best data and tools to use.
- Importantly, the available tools lack a general consideration of adaptation options, their effectiveness, and costs.
- Information on cost-benefits of adaptation solutions is largely lacking.
- Detailed coastal change information is also lacking in many areas (e.g., changes in shoreline position, beach and dunes, marshes, building footprint)
- There is limited information on vulnerable and disadvantaged people at risk with enough spatial granularity to plan adaptation options. The existing information is provided at large scales and as a percentage of vulnerable assets or people.

California's Climate Change Assessments (updated every five years, Fifth Assessment: 2022 - 2025)

Produced by: California Governor's Office of Planning and Research
https://opr.ca.gov/climate/icarp/climate-assessment/

Synopsis:
Building resilience to climate change impacts requires sustained investment in climate science and research. Senate Bill 1320 (Stern, 2020) calls on the State, through the Integrated Climate Adaptation and Resiliency Program, to advance action-based science by developing California Climate Change Assessments at least every five years. California's Climate Change Assessments contribute to the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience

actions, while also directly informing State policies, plans, programs, and guidance, to promote effective and integrated action to safeguard California from climate change.

The Fourth Climate Change Assessment (2018) provides information to build resilience to climate impacts, including temperature, wildfire, water, sea level rise, and governance. It included a Coast and Ocean Summary Report for the first time. The full suite of Fourth Assessment projects and other tools can be found at: www.ClimateAssessment.ca.gov.

The Fifth Assessment is being led by the California Governor's Office of Planning and Research (OPR) from 2022-2026, in partnership with the California Energy Commission, California Natural Resources Agency, and California Strategic Growth Council.

Key points and research gaps:

Main gaps after Fourth Assessment

The Fourth Assessment improved understanding of climate impacts and potential adaptation approaches, but it also revealed areas where additional research and investigation was needed (chapter 4):

- Hazard and impacts
    - Long-term impacts of SLR and waves on coastal change
    - Evaluation of combined impacts of SLR projections and coastal storms
    - Changes in land use, exposure, and vulnerability: land use projections that consider alternative development patterns influenced by climate hazards, exposure, and vulnerability. Development patterns will affect GHG emissions and exposure to climate risk.
    - Water resources: Vulnerability, adaptive capacity, and potential impacts of climate-related hydrological stressors for disadvantaged communities needs significant advancement
    - Improve resolution of climate data and projections: in many sectors, data is needed at a granularity that may extend beyond the resources provided by Cal-Adapt. Local SLR projections are of critical importance, particularly for the inland impacts and the Sacramento–San Joaquin River Delta's vulnerability.

- Improved support for local adaptation and integration of user needs
    - An important finding from several of the Fourth Assessment reports and in recent literature examining adaptation activity is that more information is needed to support local planning through tools that evaluate the economic and environmental costs and benefits of alternative strategies, characterize their extent adaptation measures and the potential reduction in economic costs of climate change
    - Obstacles to adaptation include, not only lack of information but also governance, political attitudes, financing, and leadership (Moser and Ekstrom, 2010). (Moser et al., 2018) shows that funding and financing challenges are among the top barriers to adaptation, but that these are affected by a number of other non-financial factors.
    - Attention to less developed areas: several studies show that less populated and rural institutions generally lag behind actors in larger urbanized areas (Moser et al., 2018).
    - Increased efforts to test and implement models of co-production (Vogel et al., 2016), as well as the use of tools like robust decision making (Sriver et al., 2018) and risk management under high uncertainty (Kunreuther et al., 2013)
    - Experiments and pilots that explore learning by doing.

    - Continued investment and engagement around Cal-Adapt
    - Better understand adaptation approaches (including public-private cooperation) in mitigating the effects of climate change, as well as socio-technological strategies for adaptation.

- Climate justice, tribal communities and engagement
    - Understand the distribution of climate impacts on disadvantaged and vulnerable communities
    - Integrate the needs of these communities and populations into planning; Develop tribal-specific adaptation strategies in the context of the legal, cultural, and political considerations
    - Better understand and account for Traditional Ecological Knowledge in the design of climate solutions. Documentation and case studies of integration of Traditional Ecological Knowledge and collaborative approaches to support climate resilience.

- Improved accounting of climate co-benefits
    - More robust tools and techniques to quantify and account for the multiple benefits of climate actions, as the State has placed a priority on implementing adaptation solutions that also support reducing GHG emissions. In this regard, a guide to some Climate Investments Co-benefit Assessment Methodologies was assembled by the California Air Resources Board [1].
    - Characterize where carbon storage and ocean acidification amelioration potential may be greatest within the variety of physical environments along California's coast.

- Integration of climate change into conservation planning
    - How climate change will affect strategies and investments in conservation
    - Types of landscape connectivity projects will be most effective
    - Better quantification of the value of ecosystem services provided by natural systems, and the potential benefits of improving ecosystem processes such as carbon sequestration on working lands, which could incentivize conservation projects.
    - Oceanic conditions that are affecting individual commercial or recreational fish or shellfish species, to establish harvest quotas.
    - genetic adaptation benefits of California's MPA network and possible changes in configuration
    - 'health' of aquatic ecosystems throughout California, including recommendations for endemic and highly endangered aquatic biota.

- Innovative approaches to building resilience
    - Increasingly, adaptation and resilience solutions are taking a more integrated approach that considers how climate change will affect *systems*, or the networks that connect people, infrastructure, and nature.
    - Design-based approaches to building resilience to better understand and identify opportunities to achieve multiple benefits and leverage funding sources.
    - Interconnections across infrastructure, nature, and people

<u>Update for preparation of Fifth Assessment (as November 2022)</u>

[1] California Climate Investments Co-benefit Assessment Methodologies | California Air Resources Board

- The 5th assessment is producing new climate data and scenarios that portray impacts of climate change on California (the next generation of projections that align with Coupled Model Intercomparison Project Phase 6, or CMIP6).
- Recording of Kick off meeting
- Research priorities are currently being selected from a list of four key research topics. The topics that were considered most relevant to coastal zones are outlined below:

Topic area 1 - **Infrastructure and Built Systems** - *climate impacts on land use, development, transportation and built infrastructure, and how these systems respond to these impacts, including climate-related human migration and displacement.*

- Economic impacts and benefits analysis of nature-based infrastructure and adaptation solutions
- Changes in population distribution and density statewide due to climate change migration patterns. Identification of geographic areas that will be or are especially vulnerable to events precipitating mass displacement. (*with a focus on coastal population and migration towards the coast* [2]*)*
- Urban greening strategies for supporting biodiversity, improving public health, and building resilience to climate change.
- Climate-related risks and impacts on the California real estate market. (*coastal real state*)
- Connections between affordable housing and improving climate resilience (*coastal real state*)
- Carbon sequestration in the built environment.
- Economic impacts of SLR.
- Impacts of SLR on:
    - inland waterways, including saltwater intrusion, groundwater contamination, groundwater inundation, changes in tidal reach, and the combined flood risks from tides, surges, and river discharges.
    - existing and future coastal infrastructure.
    - waste facilities (toxic, solid, recycling) and contaminated sites.
- Potential groundwater and structural corrosion/foundation failures from saltwater intrusion due to sea level rise.
- Cascading impacts of climate change

Topic area 2 - Human Health, Culture, and Wellbeing - *Climate impacts on human health (physical and mental) and emergencies, general safety and wellbeing (including in the workplace), impacts to cultural resources, and resilience to these impacts)*

- How climate change impacts can be communicated and incorporated into effective, proactive, and equitable management (e.*g. managed retreat, adaptation investments*)
- Establish partnerships and lessons learned from tribal expertise, traditional knowledge, and indigenous leadership.
- Impacts of climate change on:
    - California's historical sites and properties. (*in coastal zones*)
    - Persons experiencing homelessness (coastal cities)

[2] Parentheses denote specific aspects that relate to the coastal system.

- Economic disruptions, including emergency response (*extreme weather events, El Nino, tsunamis*)
- Most vulnerable workers
- Impacts to rural communities and tourism economies (*coastal tourism*)
- Health (mental and physical) and social impacts of sea level rise.
- Health (mental and physical) and social impacts of hazardous waste and environmental toxics from flooding, SLR, and other climate related events. This includes developing a statewide contaminated sites vulnerability assessment.

- Economic equity
  - Equity impacts of climate change adaptive strategies
  - Analysis of government recovery assistance for climate-fueled disasters (e.g., wildfire, flood, drought). (*coastal disasters: El Nino, tsunamis, large storms*)
  - Access to climate finance with a focus on disparities and how can those be addressed, including tribal communities' access. (*as it relates to coastal adaptation investments*)

Topic Area 3 - Water Management - *Climate impacts on residential, agricultural, and industrial water use and the physical and social systems that manage ground and surface water supply, as well as water quality*

- Role of wetlands in carbon storage, water supply, and water quality
- Effects on water resources and planning
  - Equitable and effective management under climate change
  - Effects on groundwater basins and groundwater-surface water interactions *(as it relates to seawater intrusion and salinization*)
  - Levels of significant groundwater rise and associated planning *(as it relates to seawater intrusion and salinization*)
  - Impacts of SLR on salination of underground aquifers throughout California. Which areas, structures, and communities are most vulnerable?
  - Socioeconomic and ecological benefits and costs of alternative salinity management scenarios (with consideration for sea level/groundwater rise, changes to water temperature, and droughts of increasing timescales)
  - Geologic impacts and hazards from long-term groundwater withdrawal and subsidence. (*coastal subsidence and low-lying lands in deltas*)
- Water uses:
  - How different water user types respond to moderate increases in salinity at their intakes.
  - Impacts of SLR on inland waterways, including saltwater intrusion, groundwater contamination, groundwater inundation, changes in tidal reach, and the combined flood risks from tides, surges, and river discharges.
  - Which communities across California are most vulnerable and at risk to these impacts?
- Economic impacts of changes in water supply (*coastal cities and water supply network*)

Topic Area 4 – Natural lands and biodiversity - *climate impacts to natural terrestrial ecosystems, habitat, and biodiversity, including forests, deserts, shrublands/chaparral, urban forests/parks, grasslands, wetlands, and coastal lands, and how to respond*

- Impacts of climate change (including extreme events) on:
  - Biodiversity
    - what factors affect vulnerability and resilience,
    - methods to identify the greatest threats to biodiversity caused by climate change

        - species response to climate change,
        - tracking and monitoring the impacts of climate change on biodiversity (*as it applies to coastal ecosystems*)
        - Opportunities for species to adapt or be resilient to climate impacts: climate refugia and connectivity/migration pathways and corridors (*coastal/marine species*)
    - ecosystem structures, functions, and services. (*coastal*)
    - Coastal erosion and landslides:
        - State's coastal sediment budgets, including opportunities to reuse sediment as a SLR adaptation strategy.
        - Climate driven threats from geologic hazards related to SLR and resulting coastal erosion and landslide risks.
- Restoration actions
    - How to ensure restoration actions are successful with climate change, including SLR impacts on coastal wetland restoration
    - Role of restoration of blue carbon habitats (coastal wetlands, eelgrass, tidal marshes), deserts, mountain meadows, and shrublands/chaparral in achieving carbon neutrality and/or climate resilience and adaptation (*blue carbon habitats*)
    - Types of greenspaces in urban communities for supporting biodiversity, achieving carbon neutrality, and building climate resilience (*coastal areas*)
    - Effects of large-scale forest management/treatments on streamflow, wetlands, and biodiversity (deltas)
    - Potential wetland migration pathways to inform actions to build resilience to sea level rise.
- Mechanisms to increase regional coordination for building ecosystem resilience, especially as species migrate across regions (*coastal focus*)

Additional gaps - Other identified gaps related to these topics include:

- Assessment of impacts
    - Coastal squeeze effects on ecosystem change
    - Governance of coastal change impacts.
    - Effects of coastal climate on large coastal infrastructure facilities (trade seaports operations and infrastructure, marinas)
    - Determine safety levels of existing coastal structures by mid- and end-of-century
    - Mechanisms of cliff erosion associated to beach condition and runoff
- Adaptation implementation
    - Effectiveness, feasibility and spatial interconnectivity of adaptation solutions
    - Synergistic opportunities for adaptation and mitigation (e.g. wetlands)
    - Innovation in financing and investments to support adaptation
    - Guidance and case studies of errors and successes for equitable distribution of adaptation investments
    - Determine availability, viability and effectiveness of hybrid and nature-based adaptation in heavily urbanized waterfronts (boardwalks) and coastal infrastructure (piers, wharfs, ports)
- Desalination as an additional source of water supply

Produced by: State of California
Link

Synopsis:
The 2022 California Climate Adaptation Strategy presents six state priorities and relevant actions to increase climate resilience at the state, regional, and local levels. The six outcome-based priorities that must drive all resilience actions in California are:

1. Strengthen protections for climate-vulnerable communities
2. Bolster public health and safety efforts to protect against increasing climate risks
3. Build a climate-resilient economy
4. Accelerate nature-based climate solutions and strengthen climate resilience of natural systems
5. Make decisions based on the best available climate science
6. Partner and collaborate to leverage resources

The Strategy explains the goals, actions to achieve the six priorities and provides a framework that prioritizes the equitable distribution of climate resources. The Strategy builds on the first strategy developed in 2009 as well as lessons learned from recent sector-specific plans (e.g. Natural and Working Lands Climate Smart Strategy and Climate Action Strategy for Transportation Infrastructure).
One of the novelties of this update is that it unifies collective climate adaptation efforts across all sectors and regions, while establishing a nexus with other plans. When presenting various climate-focused actions, the State prioritizes making communities more resilient while also addressing systemic inequalities. The Strategy includes a total of 150 climate adaptation actions, success metrics, and timeframes for each action. Per Assembly Bill 1482, California is statutorily required to release an updated climate adaptation strategy every three years.

Key points and gaps:
Given its relevance, the most relevant points for coastal resilience, grouped by strategic priority, are outlined below as a summary (the research gaps are provided after):

Key points

- **P1 - Strengthen protection for climate-vulnerable communities**
  Climate vulnerability is defined as "the degree to which natural, built, and human systems are at risk of exposure to climate change impacts." The Strategy highlights the importance of increasing the resources available for historically underserved communities. The Strategy commits to supporting the communities that are most vulnerable to climate threats and simultaneously experience physical, social, political, and economic inequalities with three goals:
    - Goal A: Engage with and build capacity in climate-vulnerable communities.
    - Goal B: Improve understanding of climate impacts including the forces that drive vulnerability
    - Goal C: Build resilience through state programs.

  To achieve equity, under Goal A, California will work to engage with and build capacity in climate-vulnerable communities. California aims to partner with underserved communities, including tribal communities, to build coastal climate resilience.

- **P2- Bolster Public Health and Safety**

This priority includes climate change impacts on water supply and sanitation, and environmental hazards such as algae blooms.

- Goal A: Reduce urgent public health and safety risks posed by climate change
- Goal B: Consider future climate impacts in governmental planning and investment decisions
- Goal C: Improve infrastructure's climate resilience to protect public health and safety

- **P3 - Build a Climate-Resilient Economy**
  The Strategy calls for proactive investments to limit the long-term fiscal costs of the climate crisis.
  - Goal A: Expand economic opportunities for California by building climate resilience
  - Goal B: Deepen understanding of how climate change affects California's economy

- **P4- Accelerate Nature-Based Climate Solutions**
  In Executive Order N-82-20[3], Governor Gavin Newsom prioritized the management of California's natural resources and land and called for the accelerated use of nature-based solutions. In the Strategy, California commits to implementing multi-benefit, nature-based solutions to combat climate change, in a way that increases equity and environmental justice, a core theme of the Strategy:
  - Goal A: Increase the pace and scale of nature-based climate solutions
  - Goal B: Increase landscape connectivity and establish climate refugia
  - Goal C: Integrate nature-based solutions into relevant infrastructure and investment
  - Goal D: Accelerate state processes to support the implementation of nature-based climate solutions

- **P5- Make Decisions Based on the Best Available Climate Science**
  To improve its understanding of the impacts of climate change, the state will use the Strategy to aim to invest in actionable science. The Strategy establishes a commitment to new and innovative climate research and its application of research findings for adaptation measures, with two goals:
  - Goal A: Support actionable climate science
  - Goal B: Operationalize climate science into decision-making

- **P6- Partner and Collaborate to Leverage Resources**
  Multiple agencies, governments, and nongovernmental entities must partner, coordinate, and collaborate to build climate resilience both in California and across the country.
  - Goal A: Collaborate to build climate resilience across sectors and regions
  - Goal B: Increase awareness of climate adaptation and resilience issues

Metrics

Metrics are associated with each goal to evaluate progress on climate change by integrating considerations beyond standalone, climate-only considerations. Decision-makers can incorporate California's metrics into adaptation and resilience metrics in their own state, regional, and local plans or use the Strategy as a model to develop their own. Key metrics related to coastal adaptation:

- To engage with and build capacity in climate-vulnerable communities, the state will measure its progress by evaluating the availability and accessibility of multilingual sea-level rise interpretative and educational materials.

[3] 10.07.2020 EO N-82-20 (ca.gov)

- Cultivating effective partnerships with tribal communities will be measured by also evaluating the inclusion of traditional ecological knowledge and tribal expertise into land and resource management decisions.
- As a part of California's pursuit of nature-based climate solutions, under Goal A, California also outlines actions to protect, restore, and create coastal wetlands. One metric used to measure these goals is whether the acreage of coastal wetlands increases by 20 percent by 2030 and by 50 percent by 2040.
- Another metric for nature-based solutions is the development of a statewide coastal wetland inventory to track protection, restoration, and creation.

Key research gaps identified from the Strategy (most pertinent to coastal zones):

- **P1 - Strengthen protection for climate-vulnerable communities**
  - Identification of vulnerable/at risk underserved communities, including tribal communities, and what are the drivers of coastal climate risks and vulnerabilities (Equity priority, Goal A)
  - How to build capacity in local communities (Equity priority, Goal A)
  - Characterize physical, social, political, and economic inequities in climate risks and historic and future projections, accounting for adaptation decisions.
  - As part of this priority (Action 1), a statewide and all-risk, web-based platform that identifies climate vulnerable communities is planned. It should include other coastal hazard information

- **P2- Bolster Public Health and Safety**
  - Climate change impacts on water supply through the effect of salinization of underground sources
  - Characterize algae blooms frequency and future change
  - Public health and safety risks posed by climate change and sea level rise
  - Exposure to erosion of critical health facilities and infrastructure
  - How to adapt and improve infrastructure's climate resilience
  - Record experiences and identity where investments should be located so investment decisions can lead to equitable distribution of adaptation benefits.

- **P3 - Build a Climate-Resilient Economy**
  - Better characterization of fiscal costs of coastal climate impacts.
  - Economic opportunities, distribution of costs and benefits of adaptation investments (e.g. keep a record of projects and projected benefits)
  - How climate change affects California's coastal economy across sectors (flooding, erosion impacts; ecosystem and coastal landscape change; public access and private coastal property).
  - (Action 3) 'Identify and assess sea-level rise impacts and associated financial costs to coastal lands'. This should keep a short-, medium- and long-term view and include most relevant hazards for each impact and timeframes. For example, El Nino events may be driving additional challenges in shorter time frames, in addition to the longer term rise in mean sea levels.
  - Analysis of economics, effectiveness and suitability of adaptation options.

- **P4- Accelerate Nature-Based Climate Solutions**

- What nature-based solutions (NBS) are available and effective in each coastal landscape (from a hydrological, ecological and geomorphological point of view)
- Maintaining a record of NBS investments requires a clear definition for classifying NBS solutions.
- Characterization of multi-benefits provided by NBS
- How to integrate NBS into relevant infrastructure and investment, effectiveness and design aspects.
- How to measure and assess equity and environmental justice through the investment in NBS
- Financing
    - Improve and mainstream state processes and financing mechanisms to support the implementation of NBS
    - Advance market mechanisms and tools to accelerate NBS
- Wetland restoration
    - Identify coastal wetlands that can be restored and with resilience benefits.
    - Estimate total carbon sequestration associated with wetlands creation and restoration
    - Methods and technologies to track restored wetlands and their benefits.
- Pilot projects
    - What NBS demonstration projects in State Parks, wildlife areas, and ecological reserves are most needed. (Metric, Action 7)
    - What parameters to use for monitoring NBS pilot projects
- Characterize landscape connectivity, in ecological and coastal processes terms, and establish conditions for future self-adaptation of ecosystems

- **P5- Make Decisions Based on the Best Available Climate Science**
    - Methods to operationalize climate science into decision-making and connect it with local demands
    - Creation of scientific advisory boards for adaptation planning and implementation
    - Action 6, goal A, calls for incorporating best available science, including the use of adaptation pathways on sea level rise into policies, plans and permits, requires evaluation of timeframes, effectiveness of measures, and economic costs and financing mechanisms. It also requires technology to assess, monitor and replicate adaptation pathways implementation
    - Expand the practice and knowledge base around adaptation pathways, including their evaluation and community involvement.
    - Action 7, goal A, recognizes the need of long-term monitoring/adaptive monitoring, and other efforts to improve nature-based climate solution decision-making.
    - Rapid assessment climate vulnerability index assessment tool that is inclusive of tribal nations' priorities and cultural resources. (Action 8, goal A)

- **P6- Partner and Collaborate to Leverage Resources**
    - Create effective partnerships and coordination for coastal resilience at regional, state, and national scales.
    - Collaboration across sectors and regions
    - Coordinate with Universities to share climate adaptation and resilience research and training opportunities.

Produced by: The California Governor's Office of Emergency Services
Link

Synopsis:
The 2020 update of the Adaptation Planning Guide (APG) is a resource for local governments engaged in adaptation and resiliency planning. It was designed to help local government, regional entities, and climate organizations incorporate best practices and current science and research into their adaptation plans. This updated APG addresses the passing of SB 379, requiring cities and counties to include climate adaptation and resilience in the safety element of their general plan, local hazard mitigation plan, or climate adaptation plan. The Guide defines four main phases for adaptation: 1) Define, explore and initiate; 2) assess vulnerability; and 3) define adaptation framework and strategies; 4) implement, monitor, evaluate, and adjust. It includes a step-wise process to apply each phase. A brochure is also available here.

Key points and gaps:

- The APG presents a step-by-step process to plan for climate change.
- In 2020, the state updated the APG to reflect the latest best practices; to integrate recent updates to state plans, policies, programs, and regulations (see Figure); and to ensure that communities have guidance on using the best available science and information.
- The Phases of the Adaptation Planning Process involve:
    - Phase 1, Explore, Define, and Initiate: This phase includes scoping the process and project, such as identifying the potential climate change effects and important physical, social, and natural assets in the community. It also identifies the key stakeholders in the local government and throughout the community.
    - Phase 2, Assess Vulnerability: This phase includes analysis of potential impacts and adaptive capacity to determine the vulnerability for populations, natural resources, and community assets. The vulnerability assessment identifies how climate change could affect the community.
    - Phase 3, Define Adaptation Framework and Strategies: This phase focuses on creating an adaptation framework and developing adaptation strategies based on the results of the vulnerability assessment. The adaptation strategies are the community's response to the vulnerability assessment—that is, how the community will address the potential for harm identified in the vulnerability assessment, given the community's resources, goals, values, needs, and regional context.
    - Phase 4, Implement, Monitor, Evaluate, and Adjust: In this phase, the adaptation framework is implemented, consistently monitored and evaluated, and adjusted based on continual learning, feedback, and/or triggers.
- The APG applies to 11 sectors. An Appendix provides summaries of each sector and its vulnerabilities.
- It also includes outreach and engagement recommendations, and it recognizes equity as a critical aspect of planning adaptation.
- The guide highlights the need to identify communities feeling the cumulative burden of climate change, environmental pollution and historical socioeconomic disparities, as identified in the 4th Climate Assessment, to leverage an opportunity to address issues in a holistic manner through adaptation planning.
- Page 53 and Appendix C of the guideline outlines resources (as of 2020) in California, at the Federal level, and by nongovernmental parties.

- Appendix D provides examples of local adaptation strategies by sectors.

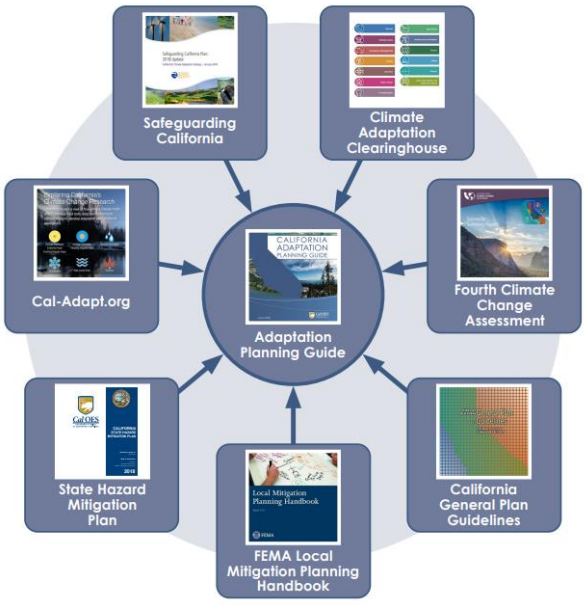

Figure. State and Federal Resources Related to the APG

Climate Resilience Plan Alignment Toolkit (2022)

Produced by: The California Governor's Office of Planning and Research
Link

Synopsis:
The Climate Resilience Plan Alignment Toolkit, released in November 2022, aims to support local and regional climate resilience planning efforts. The Toolkit is a suite of collaboration tools for local government staff and decision-makers, tribes and tribal-serving organizations, community members and non-profits, regional entities, and others to coordinate and align local and regional resilience planning efforts. The toolkit is designed to accelerate local climate action, and provides a menu of tools and best practices for communities to use while meeting local planning requirements, balancing multiple planning priorities, conducting risk and vulnerability assessments, advancing equitable outcomes and community engagement, and seeking funding to plan and implement solutions.

Key points and gaps:
- The toolkit includes a Plan Alignment tool and an interactive version of coastal hazard plan alignment.
- It includes case studies and examples of how different types of communities across California have integrated plans and processes.
- It also includes Community and Stakeholder Engagement tips and resources.

Cal-Adapt (2022)

Produced by: California Governor's Office of Planning and Research
Link

Synopsis:

Cal-Adapt is the State's open-source web platform for accessing high-quality, peer-reviewed downscaled climate data and projections from California's Climate Change Assessments. Cal-Adapt supports climate adaptation and decision-making through a variety of tools and features to help users understand, visualize, and use future climate impact data such as projected changes in sea level rise, wildfire, temperature, precipitation, and more.

Key points and gaps:

- All the tools for coastal areas are based on SLR, high tide flooding, and extreme flooding estimates and flood mapping.
- Information on groundwater flooding, erosion, and other impacts is missing.
- Limited information on historic shoreline changes, interannual events, and short-term events
- The toolkit includes webinars and tutorials (on the use of the site, and integration with gis and other software). No specific guidance is provided, however, on how to use the tools in adaptation processes or what data is most relevant for coastal vulnerability assessment.
- Limited or no information on[4]:
    - adaptation solutions (cost-effectiveness, enabling conditions)
    - financial costs, economic impacts or replicable solutions.
    - governance aspects,
    - effective communication techniques and strategies
    - best approaches for community-based decisions (e.g. adaptation pathways).
    - successful examples and replication conditions.

State Agency Sea-Level Rise Action Plan for California (2022)

Produced by: Sea-Level Rise Leadership Team, led by Ocean Protection Council (OPC)
Link

Synopsis:

The SLR Action Plan is a first-of-its-kind, coordinated effort to outline a roadmap toward coastal resiliency for California. Developed through collaboration and partnership with the 17 state agencies that make up the State Sea-Level Rise Leadership Team, the SLR Action Plan serves to guide the state in planning and implementing sea-level rise adaptation over the next five years. It builds on Senator Atkins' landmark legislation, Senate Bill 1, which drives California's efforts to achieve coastal resilience in the face of rising seas.

The Plan contains approximately 80 agency-specific actions that are tied to outcomes and deadlines. It also includes a section on equity and social justice in coastal resilience efforts, strengthening tribal relations, and increasing support for communities entitled to environmental justice. It is structured around the seven Principles for Aligned State Action (PDF) (see next section): Best Available Science, Partnerships, Alignment, Communications, Local Support, Coastal Resilience Projects, Equity; which create a direction for how to align state actions and decision points around SLR. The Ocean Protection Council (OPC) was charged with working with agency partners to create the Plan.

[4] Although the scope of this tool may not be specifically some of these gaps and the Adaptation clearing house partly covers these points, it is here deemed beneficial to cover these gaps.

Key points and gaps:

Through the process of collecting, analyzing, and synthesizing hundreds of actions contributed by California agencies, a few key themes arose as long-term goals:

- The entire coast of California should be prepared and planning for SLR and adaptation plans should:
    - Highlight the vulnerabilities of natural and human resources and the impacts of SLR.
    - Identify short-, medium-, and long-term solution sets.
    - Adequately consider the priority and phasing of actions and strategies.
    - Develop project implementation strategies and ensure active community engagement processes that strive for equity across racial/social lines by implementing appropriate, targeted strategies.
- SLR adaptation planning should include pathways to resiliency to SLR of 3.5' by 2050 and 6.0' by 2100
    - These planning targets represent a standard approach for SLR planning and preparation to better promote resilient planning when more locally specific or varied risk scenario planning is less feasible.
    - However, best available science (e.g., State Sea-Level Rise Guidance, 2018; Interagency SLR Technical Report 2022), should be consulted to determine which SLR scenarios are most appropriate, which is context dependent.
    - New and redevelopment in the coastal zone should utilize these targets as consistent minimum criteria for planning for the impacts of SLR.
    - The Sacramento–San Joaquin River Delta was not considered part of the coastal zone for this Action Plan because it is inland, and the hydrology is extremely complex.
- Integrate and prioritize equity and social justice in all SLR adaptation planning and projects.
    - Community-based organizations and California Native American tribes should be highly involved throughout the SLR planning process, through meaningful, early, and frequent consultation.
- Adaptation strategies
    - Nature-based solutions should be pursued when possible. These include vegetated dunes, living shorelines, wetlands and marsh restoration. Gray infrastructure such as seawalls should be avoided when possible.
    - Adaptation planning and implementation should prioritize the conservation of coastal habitats and maintaining biodiversity and associated functions, including allowing space for upland and inland migration of coastal habitats. Coastal habitats including wetlands, beaches, and dunes should be protected and conserved.
    - SLR adaptation plans should lead to project implementation**.** Adaptation plans should be specific and actionable, leading to decisions and implementation projects that prepare communities along coast, bays, and estuaries for adaptation.
    - Adaptation plans should guide a governing entity to action that achieves resilience. This may occur through integration with other required planning documents such as Local Coastal Programs, General Plans, and Local Hazard Mitigation Plans
    - Managed retreat, as feasible, should be implemented where needed.

Key actions identified (*most relevant to this study*)

- Governance and coordination
    - Coordinate with FEMA to update Advisory Coastal Hazard Maps with SLR, coastal erosion, and other necessary impacts.

    - In coordination with federal partners, tribes, academic institutions, and non-profit organizations, update current statewide SLR models (see review of tools in Annex 2).
    - Methods and guidance for Stakeholder Engagement, as it relates to SLR.
- New data and tools
    - Develop an inventory of coastal habitats (i.e., dunes, beaches, wetlands, rocky intertidal, and eelgrass) and assess their vulnerability to SLR.
    - Expand the King Tides Project to cover more major high tide flooding events in more locations and information about tidal processes.
    - Public tool that highlights community risk solutions to SLR and other climate hazards and allows consumers to better access insurance pricing information.
- Methods and modeling
    - Improve understanding and mapping of how SLR will impact critical infrastructure.
    - Determine SLR related risks to biodiversity.
    - Analyze the current and expected future location of the mean high tide line or zone at a variety of locations, and the implications to public trust lands, uses, resources, and assets.
    - Address rocky intertidal and beach habitat loss due to SLR.
    - Inform decisions that protect and adapt public trust lands, assets, and uses, from the impacts of SLR.
- Adaptation science and implementation
    - Provide local adaptation and planning guidance, including use of adaptation pathway approaches, reducing common obstacles, and community engagement and outreach best practices.
    - Provide multilingual adaptation strategies.
    - Best practices and recommendations for multi-benefit wetland restoration, indicators of resilience, and criteria for prioritization and funding of restoration
- Water resources
    - Determine Water quality threats from SLR.

Principles for aligned State action (SLR Action plan 2022)

Produced by: various agencies

(note: although this entry does not point out research gaps, it is hereby included as it is relevant for coastal applications and State context as it relates to coastal resilience initiatives at the State level)
Link

Synopsis:
These Principles are aimed to guide unified, effective action toward sea-level rise resilience for California's coastal communities, ecosystems, and economies around: Best Available Science, Partnerships, Alignment, Communications, Local Support, Coastal Resilience Projects, and Equity.

Key points and gaps:
The Principles are summarized below.
1. Develop and Utilize Best Available Science
    - Apply best available science to planning, decision-making, project design, and implementation. Prioritize frequent engagement with stakeholders to ensure the science is actionable.

- Utilize SLR targets based on the best available science and a minimum of 3.5 feet of SLR by 2050. Develop and utilize more protective baseline 2050 and 2100 targets for road, rail, port, power plants, water and waste systems, and other critical infrastructure.

2. Build Coastal Resilience Partnerships
   - Partner and coordinate regularly on SLR resilience issues, policies, planning, processes, mandates, permitting, information, funding, and projects, including with federal and local government bodies and tribes, and across issue areas and mandates.
   - Regularly and collaboratively collect, share, and publicize the latest information on SLR and how agencies are using SLR projections to reduce risks to safety, property, infrastructure, natural ecosystems, and native species.
   - Build strong relationships with all partners at all levels of government, and with the public, nonprofits, businesses, and other stakeholders.
   - Consult, learn from, and coordinate and partner with tribes to ensure inclusive and multicultural stewardship of lands and waters subject to SLR.

3. Improve Coastal Resilience Communications
   - Enhance SLR and coastal resilience communications and engagement, including alignment on SLR messaging and implementation of a coordinated public awareness and education campaign.
   - Increase transparency, efficiency, and alignment of state and local coastal resilience processes, policymaking, and decision-making.

4. Support Local Leadership and Address Local Conditions
   - Support local planning and adaptation policies and projects that address local and regional conditions, meet baseline standards for climate impacts, and consider acute increases in SLR caused by storm surges, El Niños, and other events.
   - Evaluate and learn from local conditions, including community priorities, health and safety, critical infrastructure, housing, culture, economies, patterns of development, local environment, and other characteristics, to inform risk tolerance and adaptation.
   - Prioritize the early protection of and capacity building for the most under-resourced and vulnerable frontline communities in developing and implementing adaptation plans, projects, and strategies.

5. Strengthen Alignment around Coastal Resilience
   - Develop and apply baseline, administration-wide SLR assumptions, projections, targets, terms, and standards into coastal projects, retrofits, planning, funding, regulatory, and permitting initiatives. Consider statewide decision-making guidelines to help identify the strongest solutions, establish priorities, and ensure baseline success. Prioritize avoidance of initiatives that shift hazards and impacts elsewhere along the coast or shoreline.
   - Ensure that up to date SLR resilience planning is in place coastwide and includes alignment on: minimum baseline targets; vulnerability assessments for communities, infrastructure, property, and natural ecosystems and native species; SLR economic impact assessments, including the cost of resiliency projects and the potential cost of no action; and identification of multi-benefit SLR resiliency strategies.
   - Collaboratively work to pursue and develop specific funding sources for state, regional, and local coastal resilience planning, projects, and public outreach.
   - Where possible, avoid creating unnecessary duplication of existing state agency authority.

6. Implement and Learn from Coastal Resilience Projects
    - Protect and enhance public trust in natural and cultural resources, such as beaches, wetlands, other habitats, biodiversity, and culturally important areas.
    - Protect critical public water-dependent infrastructure, ports, harbor districts, and other evolving public trust needs and uses, given the unique characteristics, significance, constraints, and values of these public trust uses.
    - Prioritize the use of nature-based adaptation measures where appropriate.
    - Build coastal resilience by increasing the number of restoration and adaptation projects, such as wetland restoration; ensure that adaptation projects do not shift hazards and impacts elsewhere along the coast or shoreline. Streamline permitting for high-need coastal restoration projects.
    - Realize multiple benefits from coastal resilience projects where feasible.
    - Take action to prevent impacts from SLR to public access as feasible, toward the continued protection and enhancement of public coastal access for all.

7. Integrate and Prioritize Equity and Social Justice
    - Integrate and prioritize equity and social justice, including Tribal justice, in all aspects of state actions focused on building SLR adaptation and resilience.
    - Develop and prioritize SLR projects that ensure benefits to vulnerable communities, meaningfully involve residents in the decision-making process, address environmental justice and systemic inequities, and implement relevant state agency equity and environmental justice plans and policies.

CA Adaptation Clearing House (accessed November 2022)

Produced by: California Governor's Office of Planning and Research
Link

Synopsis:
The Adaptation Clearinghouse aims to support a community of practice across the state through knowledge exchange between communities, businesses, and across levels of government. The Adaptation Clearinghouse allows users to navigate a searchable database of adaptation and resilience resources that have been organized by climate impact, topic, and region. It provides a platform for sharing case studies of how communities, businesses, and organizations are responding to climate change impacts.

Key points and gaps:
- Types of resources provided:
    - Assessments, plans or strategies
    - Communication or educational materials
    - Planning and/or policy guidance
    - Data, tools, and research
    - Case studies, projects, or examples
- Integrated Climate Adaptation and Resiliency Program (ICARP)
    - In 2015, Governor Brown signed Senate Bill 246 (Wieckowski), which directed the Governor's Office of Planning and Research (OPR) to form the ICARP.
    - The Program is designed to develop a cohesive and coordinated response to the impacts of climate change across State, local, and regional levels. One main component of the Program is this State Climate Adaptation Clearinghouse, which serves as a centralized source of information.

- The Clearing House includes case studies and examples of projects, and the 'Coastal Plan Alignment Compass', that discusses different plans and how to consider SLR: Local Hazard Mitigation Plan; Adaptation Plan; General Plan; Local Coastal Program.
- The *ResilientCA Adaptation Planning Map* (RAP-Map) is a statewide inventory of local government adaptation and resiliency planning efforts. Users can quickly access, analyze, or download the planning details of local jurisdictions, including links to vulnerability assessments; adaptation goals, strategies and implementation measures; and updated and adopted General Plan Safety Elements, Local Hazard Mitigation Plans, or other stand-alone adaptation or resilience plans.

Some of the recommendations for adaptation planning from Coastal Plan Alignment Compass include:

- Use of the best available science and existing planning initiatives.
- Before starting
    - Use consistent community goals and objectives to coordinate strategies and policies among the various plans.
    - Develop a standing team of diverse representatives from various planning efforts. Meet regularly to keep coordination consistent and ongoing. This helps to build understanding of each plan, overcome sector silos, gain buy-in from multiple agencies, and transfer knowledge.
    - Become familiar with other planning processes and plan requirements. More investment at the onset may yield bigger returns later.
- Coordinate plans
    - Integrate the same actions and risk reduction strategies in multiple plans. For example, adaptation strategies from local planning documents can also be used as mitigation actions in a local hazard mitigation plan. At a minimum, cross-reference plans.
    - Coordinate between cities and counties, and regionally, to identify risks and opportunities for integrated management.
    - Ensure consistency among other local plans and legislation, including State Lands Commission assessments (Assembly Bill 691), comprehensive plans, integrated regional water management plans, and transportation plans. Capital improvement plans are an important implementation tool.
    - A stand-alone adaptation strategy, with actions at multiple planning horizons and developed with cross-sector buy-in, can be a reference document when updating multiple plans.
- Hazard guidance
    - Consult the State of California Sea-Level Rise Guidance for the most current SLR projections, and the California Coastal Commission SLR Policy Guidance for planning approaches consistent with the Coastal Act.
    - If multiple modeling information sources are available, consider using them all to get a more robust assessment of the hazards. Modeling results that overlap are a good indication that a particular area is especially vulnerable.
    - Ensure that planning accounts for the useful life of critical infrastructure, not just design life. Planning that responds to observed triggers (e.g., flood frequency, erosion, etc.) helps accomplish this in a fiscally and politically pragmatic manner.

The Coastal Compass also provides the following suggestions to avoid common barriers and pitfalls:

- Timing for each plan's development, updates, and approvals may differ significantly. Be aware of time frames so that funding and staff resources for one plan can assist elsewhere as needed.

- Different levels of specificity are needed for various risk and vulnerability assessments. Determine which plan needs the most specificity and develop an assessment at that level so all plans can benefit. If this isn't feasible, design the assessment so other components can be added as needed or as funding becomes available.
- Plan Coordination
    - Ensure that a strategy, policy, or action in one plan does not contradict another plan. Comparing plan goals at the outset will help identify potential conflicts.
    - Check with neighboring jurisdictions to see if policy implementation can be coordinated, and that inconsistency will not create issues between jurisdictional boundaries.
    - Plan components can inform other plans, but entire plans generally are not interchangeable. For example, while parts of a local hazard mitigation plan and a general plan's safety element might overlap, the plans are not interchangeable because FEMA requirements differ from safety element requirements.
- There is no perfect science. Develop an adaptive process that allows modification as science advances. New information or legislative amendments may also trigger planning updates.

Sea Level Rise Technical Report (2022)

Produced by: The National Oceanic and Atmospheric Administration (NOAA)
Link

Synopsis:
The SLR Technical Report provides the most up-to-date SLR projections available for all U.S. states and territories.

Key points and gaps:

- Multiple lines of evidence provide increased confidence, regardless of the emissions pathway, in a narrower range of projected global, national, and regional sea level rise at 2050 than previously reported (Sweet et al., 2017).
    - Relative sea level along the contiguous U.S. (CONUS) coastline is expected to rise on average as much over the next 30 years (0.25–0.30 m over 2020–2050) as it has over the last 100 years (1920–2020).
    - The projections do not include natural year-to-year sea level variability that occurs along U.S. coastlines in response to climatic modes such as the El Niño–Southern Oscillation.
- By 2050, the expected relative sea level (RSL) will cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes, with major and moderate high tide flood events occurring as frequently as moderate and minor high tide flood events occur today.
    - Without additional risk-reduction measures, U.S. coastal infrastructure, communities, and ecosystems will face significant consequences.
    - Across all severities (minor, moderate, major), high tide flooding along the U.S. East and Gulf Coasts will largely continue to occur at or above the national average frequency.
- Higher global temperatures increase the chances of higher sea level by the end of the century and beyond.
    - The scenario projections of relative sea level along the contiguous U.S. (CONUS) coastline are about 0.6–2.2 m in 2100 and 0.8–3.9 m in 2150 (relative to sea level in 2000); these ranges are driven by uncertainty in future emissions pathways and the response of the underlying physical processes.

- As a result of improved understanding of the timing of possible large future contributions from ice-sheet loss, the "Extreme" scenario from the 2017 report (2.5 m global mean sea level rise by 2100) is now viewed as less plausible and has been removed.
    - Nevertheless, the potential for increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that could reach this threshold in the decades immediately following 2100 (and continue rising).
- Regionally, the projections are near or higher than the global average in 2100 and 2150 for almost all U.S. coastlines due to the effects from vertical land motion (VLM); gravitational, rotational, and deformational effects due to land ice loss; and ocean circulation changes.
    - Largely due to VLM, relative sea level projections are lower than the global amounts along the southern Alaska coast and are higher along the Eastern and Western Gulf coastlines. These variations need to be further studied.
- Monitoring the sources of ongoing SLR and the processes driving changes in sea level is critical for assessing scenario divergence and tracking the trajectory of observed SLR, particularly during the time period when future emissions pathways lead to increased ranges in projected SLR.
    - Efforts are under way to narrow the uncertainties in ice-sheet dynamics and future SLR amounts in response to increasing greenhouse gas forcing and associated global warming.
- Early indicators of changes in SLR trajectories can serve to trigger adaptive management plans and are identified through continuous monitoring and assessment of changes in sea level (on global and local scales) and of the key drivers of sea level change that most affect U.S. coastlines, such as ocean heat content, ice-mass loss from Greenland and Antarctica, vertical land motion, and Gulf Stream system changes.

Regional Strategy for A Rising Bay: Joint Platform (2021)

Produced by: Bay Adapt
Link

Synopsis:
The Bay Adapt regional strategy is a plan for the Bay Area to make it resilient and adaptive into the future. As the region grows and changes, coastal resilience can be achieved by supporting collaborative action, fostering greater equity among residents, and sustaining the unique ecosystems residents rely upon and thrive within. The Bay Adapt Program Strategy for a Rising Bay contains an introduction to challenges and opportunities in the region and all 9 actions and 21 tasks.

Key points and gaps:
- The Plan advocates for partnerships between academics, scientists, and communities to fill information gaps through original research, data collection, analysis, and monitoring.
- The interpretation of science should be tailored to the audience or user, ranging from the general public to academics.
- SLR is as an equity challenge given by its disproportionate impacts on vulnerable communities, lack of equitable community engagement, and the cumulative impact of underinvestment and lack of government accountability over decades. Equity in this context was defined as '*the fair and just distribution of financial and institutional resources to address impacts across communities that stand to be adversely affected by those impacts, and commitment to include those communities in the development, prioritization, and implementation of adaptation policies, programs, and services*' (West Oakland Environmental Indicators project)

- Engaging the entire region in collective action requires clear agreement on the path forward and checks and balances. Rather than specifying individual projects, the Joint Platform lays out guiding principles for region-wide actions, goals and tasks. Its aim is to overcome barriers, accelerate keys to success, and share targets to achieve: Flood protection and reduced flood risk; Robust integration of adaptation into community-focused local plans; Recognition, elevation, and support for frontline communities; Accelerated permitting and faster project construction for priority adaptation projects; Technical assistance for local governments to plan and implement projects faster; More funding for adaptation; Metrics for deciding what makes the best kind of adaptation plan or project (equitable, efficient, multi-benefit, nature-based, and coordinated with others) and for tracking local and regional progress.

- Under task 4.1., 'Align research and monitoring with information gaps', the Strategy identifies, from a technical perspective, key information needs that include:
    - Enhance regional flood modeling related to multiple hazards (such as groundwater, watershed, riverine/tidal, subsidence, erosion)
    - Expand networks of water elevation monitoring stations for real-time updates to the rate and timing of sea level rise in the Bay
    - Expand open data initiatives to facilitate sharing.
    - Standard operating procedures for validating and nominating data for common use
    - Information on cost and suitability of adaptation strategies for different Bay conditions
    - Identification of potential wetland migration pathways
    - Tracking, sharing, and integrating data from various sectors to spotlight opportunities to reuse sediment.
    - Equitable distribution of burdens and benefits of adaptation.
    - Impacts and consequences of contaminated sites as they intersect with flooding and/or rising groundwater and strategies for mitigating these impacts.
- It aims to establish an independent *Climate Science Consortium*, to provide high-quality science translation, under Task 4.2: 'Make scientific data, information, and guidance easier to access and use' aims to help users create adaptation plans and projects by improving and facilitating easy access to the most relevant information.
- The Strategy also calls for a separate technical assistance "storefront" to support plans and projects to provide users with:
    - Standardized, up-to-date scientific data, such as common flood models and SLR projections, as created by the Climate Science Consortium.
    - Best available science white papers on specific issues, as curated or developed by the Climate Science Consortium.
    - Individualized consultations via a professional help desk network.
    - How-to guidance on the steps of assessing vulnerability and developing adaptation plans.
    - Adaptation plan and project examples and case studies.
    - Tools for evaluating adaptation options.
    - Funding and financing assistance.
    - Lecture series, conferences, training, working groups, and/or workshops.
    - Access to a technical consultant bench (Task 4.3).
- Action 5 calls for a unified adaptation approach that aligns local and regional plans and requires:
    - Guidance and best practices for community engagement and community-led adaptation planning processes
    - Common minimum short and long-term SLR climate projections for planning.

- Standard flood data sets.
- Regionally appropriate strategies for protecting natural areas, frontline communities, public access, regional transportation links, and other critical regional assets.
- Guidance on how and where to prioritize nature-based solutions along the shoreline where feasible and appropriate.
- Land use guidance, such as how to plan for habitat migration with SLR.
- Guidance on how to plan for long-term implications of SLR beyond current planning horizons.
- Guidance on how to connect SLR planning to other critical topics, including public and environmental health, emergency response, and housing considerations.

Research Strategy and Framework: Research Investment Plan Update (2021)

Produced by: the California Strategic Growth Council (SGC)
Link

Synopsis:
Through consultation with State agencies and other State climate change research programs, the SGC has identified five priority research areas for investment in its Climate Change Research Program (outlined below).

Key points and gaps:

- Supporting and Protecting Vulnerable Communities from the Impacts of Climate Change
  - Identify the impacts of climate change on vulnerable groups, which may negatively impact their health and livelihoods.
  - More holistic adaptation requires adopting policies that allow vulnerable communities to withstand the impacts of climate change while simultaneously addressing existing inequities as evidence shows that climate impacts have disproportionate effects in the State's most vulnerable communities and populations.
  - Identify effects of policies intended to adapt and strengthen resilience as they may exacerbate existing inequities and vulnerabilities if they are not designed from the outset to address, rather than further entrench these patterns.
- Integrating Land Use, Conservation, and Management into California's Climate Change Programs
  - Additional research is needed to understand the relationships between natural and social systems, and to develop mechanisms that integrate and account for ecosystem services (including those from freshwater and coastal environments) in conservation, management, and development decisions and in the State's climate change programs.
  - Research results can include tools and methodologies to assess and advance State and local planning decisions.
- Increasing Data Accessibility and Planning Support for Local and Regional Climate Change Planning
  - Broaden the scope and data available in Cal-Adapt so that it can effectively support resilience initiatives beyond the energy sector.
  - Tools that integrate community adaptive capacity with climate hazard information, as well as assessments of user needs and identification of approaches for the long-term sustainability of planning support tools like CalAdapt or other resources for planning.
- Accelerating and Supporting Transitions to Climate Smart Communities

    - Increasing the development and implementation of climate-informed planning and policies at the local and regional level will be critical to the State's climate success.
    - Understand the barriers and challenges to community transformation and its just and equitable distribution.
- Low-GHG Transformative Technology Development and Deployment
    - Identify promising technologies or tools that would achieve significant GHG emission reductions through widespread deployment over the next two decades.
    - Transformative technologies that are envisioned as needed to achieve the 2030 and 2050 GHG reduction targets but require significant technological breakthroughs to achieve significant market penetration.

Rising Seas in California: An Update on Sea-Level Rise Science (2017)

Produced by: Ocean Protection Council (OPC)
Link

Synopsis:
The report provides guidance to state agencies for incorporating sea-level rise projections into planning, design, permitting, construction, investment and other decisions. This document, requested by the California Ocean Protection Council and guided by a set of questions from the state Sea Level Rise Policy Advisory Committee, provided a synthesis of the state of the science on sea-level rise.

Key points and gaps:
- Scientific understanding of SLR is advancing at a very rapid pace.
    - SLR projections will continue to change as the impacts of local, regional, national and global policy choices are manifest.
    - Given this dynamic environment, OPC encourages the creation of science-policy processes that are flexible, iterative and adaptive. At minimum, OPC recommends that SLR projections be updated every 5 years.
- Probabilities of specific sea-level increases can inform decisions. A probabilistic approach to SLR projections, combined with a clear articulation of the implications of uncertainty and the decision-support needs of affected stakeholders, is the most appropriate approach for use in a policy setting.
    - This report employs the framework of Kopp et al. (2014) to project SLR for three representative tide gauge locations along the Pacific coastline. These projections may underestimate the likelihood of extreme sea-level rise, particularly under high emissions scenarios
- SLR timelines: Before 2050, differences in SLR projections under different emissions scenarios are minor but they diverge significantly past mid-century; after 2050, SLR projections increasingly depend on the trajectory of greenhouse gas emissions.
- Updating the science underpinning California's statewide guidance will be important as understanding of ice-sheet contributions to SLR increases, and/or the range of likely future emissions scenarios begins to narrow.
    - Of the major contributors to global SLR , the loss of ice from the Greenland and Antarctic Ice Sheets has the greatest potential to increase sea levels.
    - Contributions from ice sheet losses also present the greatest uncertainty in the rate and amount of SLR at time horizons beyond the next few decades.

- Characterize regional short-term increases in sea level from El Niño associated flooding, king tides, storm surges, wave-driven water level increases, as these will continue to be the driver of most of the strongest impacts to infrastructure and coastal development.
- There are several different sea-level rise visualization tools available; the NOAA SLR Viewer and Climate Central's Surging Seas are the two most commonly used examples.
    - These allow a user to develop an inundation map for virtually any coastal area in California that will project a range of future sea levels onto the specific area.
    - These viewers have been referred to as a "bathtub approach" simply because, while they use accurate elevation and tide data, inundation is determined by uniformly raising water levels by various selected future sea level values in combination with the average daily high tide.
    - This passive approach is a reasonable approximation of the future everyday impacts of SLR. However, it does not consider potential flooding driven by the dynamic processes that affect coastal water levels daily (e.g., tidal variability, waves), seasonally (e.g., elevated water levels during El Niño events) or during storm events (e.g., storm surge, wave run-up, and river discharge) and the hydrodynamic complexity associated with bathymetry, built structures and the natural coastline configuration.
- These projections of future sea level and changing coastal hazards can and should be used along with a comprehensive assessment of what is at risk (i.e., exposed to future coastal hazards) and what is at stake (i.e., the monetized and non-monetary values attached to what is exposed) to weigh the different types of costs, and potential losses and benefits of taking action now to prevent future harm against the wide-ranging risks of inaction
- Uncertainty about the exact amount of future SLR should not be a deterrent to taking action now.

California Coastal Commission Sea Level Rise Policy Guidance (2018)

Produced by: California Coastal Commission (CCC)
Link

Synopsis:
The report lays out interpretive guidelines for addressing sea level rise in local coastal programs and coastal development permits. Since the original Policy Guidance from 2015, the Ocean Protection Council released two reports that updated the understanding of sea level rise science and best practices for planning for and addressing anticipated impacts:

- *Rising Seas in California: An Update on Sea-Level Rise Science*, synthesizes recent evolving research on sea level rise science, and forms the foundation for the second report,
- *The State of California Sea-Level Rise Guidance*: *2018 Update*. The 2018 OPC State SLR Guidance provides higher level recommendations for how to plan for and address sea level rise impacts, notably including a set of projections recommended for use in planning, permitting, investment, and other decisions.

Key points and gaps:
The CCC identified 10 key research needs:

- Modeling
    - Fluvial dynamics should be included in flood assessments as they relate to and interact with rising sea levels, habitat evolution models (e.g., SLAMM) that project future locations of wetlands and other coastal habitats.

    - Advance the interaction of other climate change-related impacts with the impacts of sea level rise (e.g., changing precipitation patterns, increased frequency and/or intensity of storms).
- Improved estimates of local vertical land motion
    - Especially instances when it will be important to modify the regional SLR projections for local vertical land motion, types of existing information on land motion (e.g., tide gauge records, satellite data, land-based GPS stations) that provide the best estimates of local land trends.
    - Procedures for adjusting state or regional SLR projections for subregional or local conditions, and additional data that are needed to implement this procedure.
- Baseline data and monitoring systems
    - Data are needed for coastal and nearshore waters, beaches, bluffs, dune systems, nearshore reefs, tide pools, wetlands, and other habitat areas to better understand these systems, monitor trends, and detect significant deviations from historic conditions that may be related to sea level rise and other aspects of climate change.
    - A system for monitoring and tracking the cumulative impacts of projects in the coastal zone, including both new development and any adaptation strategies, is needed to better understand the impacts of development in the face of sea level rise and the efficacy of various adaptation methods.
- Methods for estimating change in erosion rates and shoreline change due to future sea level rise
    - There is a need for a peer-reviewed methodology for estimating change in erosion rates due to sea level rise for bluffs, beaches, and other shorelines exposed to erosion.
    - An improved understanding of future erosion rates is necessary to better evaluate projects affected by such erosion, including in terms of calculating an appropriate setback distance.
- Analysis of SLR impacts to coastal access and recreation
    - More information is needed about how sea level rise could affect public access areas and recreation throughout the state, including changes to waves and surfing, and the potential economic costs of these impacts.
    - Additional information about how these changes will affect lower-income populations and underserved communities is particularly important.
- Analysis of SLR impacts to wetlands and strategies for preserving wetlands throughout the state
    - methodologies for establishing natural resource area buffer widths in light of SLR
    - Approaches for identifying and protecting migration corridors
    - Guidance for increasing wetland sediment supply and retention, techniques for developing an adaptive wetland restoration plan, and monitoring criteria.
- Methods to evaluate impacts to coastal resources from shoreline protection
    - Methods to evaluate and mitigate for the adverse impacts to recreation, public access and beach ecology from shoreline armoring projects.
- Assessment of coastal habitat functions with SLR and other climate change impacts
    - Understanding of the value and benefits that intact natural habitats provide, especially as they relate to increasing coastal resiliency to SLR.
    - Identify the coastal habitats that are most likely to experience adverse impacts from SLR and extreme storms, and what the associated loss of ecosystem services will mean for coastal populations.
- Potential effects of SLR on groundwater and coastal aquifers
    - Evaluation of the potential incidence and severity of saltwater intrusion at the scale of individual aquifers, under various SLR scenarios

    - Criteria to use when deciding if saltwater intrusion requires mitigation or response
    - Identification of strategies to address the impacts rising groundwater and saltwater intrusion have on agriculture.
- Analysis of non-environmental factors that influence SLR adaptation
    - How environmental justice/social equity, economic, and legal considerations, among other factors, interact with environmental vulnerabilities will be important when assessing adaptation planning opportunities and challenges.

The Guidance also provides the following recommendations:

- Developing Local Hazard Conditions Based on Regional or Local SLR Using Best Available Science
- Describes General LCP Amendment Processing Steps and Best Practices
- Describes funding Opportunities for LCP Planning and Implementation
- Identifies the Primary Coastal Act Policies Related to SLR and Coastal Hazards
- Provides SLR Projections for 12 California Tide Gauges

Coastal Commission infrastructure guidance (2021)

Produced by: California Coastal Commission (CCC)
Link

Synopsis:
The goal of the Commission's draft document (the Guidance), Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone, is to promote resilient coastal infrastructure and protection of coastal resources by providing local governments, asset managers, and other stakeholders with policy and planning information to help inform sea level rise adaptation decisions that are consistent with the California Coastal Act.
The Guidance addresses two main types of infrastructure – transportation and water – and presents six key considerations for successful adaptation planning. These considerations are accompanied by recommendations for stakeholders on how to plan effectively for the impacts of sea level rise on coastal infrastructure, a description of the regulatory framework that applies to adaptation planning for infrastructure, and model policies that can be used by local governments as a tool for updating Local Coastal Program (LCPs).

Key points and gaps:
There are five key considerations emphasized throughout this Guidance that represent significant challenges and opportunities within the critical infrastructure planning process:

(1) Coordinated Planning: coordinating with neighboring jurisdictions, including through regional climate collaboratives; utilizing Local Coastal Program (LCP) planning, Public Works Plans (PWP), and other vulnerability and planning efforts to plan infrastructure improvements at a regional scale
(2) Environmental Justice: Due to discriminatory land use policies and systemic racism, environmental justice communities often experience disproportionate environmental burdens and are more vulnerable to adverse impacts from a project. The guide recommends considering the equitable distribution of burdens and benefits to environmental justice communities at all stages of adaptation planning
(3) Phased Adaptation: Phased adaptation is the incremental implementation of adaptation and resilience strategies over time as sea level rises. One method, which has been used in several important cases in California, is to allow temporary armoring to protect threatened structures

for a short period of time until relocation of the structures can be completed, after which the temporary armoring is removed to restore coastal processes and habitats along the shore.

(4) Adaptation Costs and Funding: evaluating the costs and benefits of adaptation strategies over the entire life cycle of the infrastructure, assessing both market and non-market values, and pursuing additional federal and state funding for infrastructure adaptation

(5) Nature-Based Adaptation Strategies: recommends local governments and asset managers prioritize nature-based adaptation strategies in all new sea level rise adaptation planning efforts.

The Guidance provides example model policies that local governments may choose to work from to help promote critical infrastructure adaptation (in Appendix B) as starting points to develop policies appropriate for local conditions. The policies cover a spectrum of potential adaptation strategies. However, all communities and asset managers should consider the following principles in infrastructure planning:

- Use the best available science and higher sea level rise projections (scenarios associated with medium-high and extreme risk aversion) to evaluate critical infrastructure in vulnerability assessments.
- Approach SLR adaptation planning for infrastructure through collaborative regional planning processes that bring together all relevant jurisdictions, agencies, and stakeholders. Maximize public participation.
- Consider planning tools such as Public Works Plans (PWPs) to coordinate cross-jurisdictional projects necessary to implement a sea level rise adaptation plan.
- Address disproportionate burdens and benefits to environmental justice communities and incorporate meaningful engagement practices and equitable public participation processes throughout the entire planning process.
- Consider phased, trigger-based solutions and adaptation pathways.
- Conduct long-term vulnerability assessments and adaptation planning to assess potential impacts of coastal hazards; the social, environmental, and economic costs and benefits of adaptation strategy alternatives over time; and triggers for phased adaptation.
- Initiate adaptation planning efforts before impacts from coastal hazards begin to occur.
- Plan infrastructure in sites that avoid hazards. Where hazard avoidance is not feasible, prioritize nature-based adaptation strategies over hard shoreline armoring. When armoring is used, mitigate adverse coastal resource impacts and require planning to identify a long-term solution that is most protective of coastal resources.
- Pursue potential funding and investment opportunities at federal, state, regional, and local levels.

Other gaps identified:

- There is no comprehensive analysis of the costs associated with addressing vulnerable critical infrastructure in the state.
- Understand the probabilities of SLR scenarios for planning.
    - The best available science currently offers probabilities of specific sea level projections at tide gauges to be used to inform decisions; however, the probabilities stem from a set of SLR projections derived from global climate models; thus, they are not true probabilities in the traditional sense of the word, they reflect the probability that a group of climate models will predict a certain amount of SLR, given the range of parameters used in the climate models.

- Improve understanding of interconnected systems as vulnerabilities in one place or for one component can potentially cascade throughout the system (e.g. adaptation investments).
    - For example, minor flooding that blocks off a portion of a roadway for even a short amount of time could increase traffic on alternative routes. Over time, this type of nuisance flooding could increase repair and maintenance costs.
- Identify impacts to critical transportation assets and adaptation measures.
- Coastal squeeze
    - Identify segments of highways and railways located near the shoreline and, like other types of fixed development that can act as barriers to the inland migration of wetlands, beaches, and other coastal resources as sea levels rise. Such barriers impede ecological processes critical for functional habitats for rare, protected, and endangered species.
- Identify areas where highways and railways adjacent to the shoreline may lead to increased inland development that relies on the de-facto protection provided by these assets.

OPC Strategic Plan to protect California's Coast and Ocean (2020-2025)

Produced by: Ocean Protection Council (OPC)
Link

Synopsis:

The "Strategic Plan to Protect California's Coast and Ocean: 2020-2025" provides a roadmap for protecting the ocean and coast. It envisions all California communities enjoying thriving ecosystems, clean water, healthy food, secure infrastructure, ready public access to the coast and ocean, and an inclusive blue economy that advances ecosystem health, offers meaningful work, and reverses past injustices. the Plan offers four Goals to guide California's efforts from 2020 to 2025 in addressing challenges to coasts and the ocean (with objectives, targets, and actions in each goal area):

- GOAL 1: Safeguard Coastal and Marine Ecosystems and Communities in the Face of Climate Change
- GOAL 2: Advance Equity Across Ocean and Coastal Policies and Actions
- GOAL 3: Enhance Coastal and Marine Biodiversity
- GOAL 4: Support Ocean Health through a Sustainable Blue Economy

Key points and gaps:
(*research gaps are identified based on the actions for each goal*)

GOAL 1. Safeguard Coastal and Marine Ecosystems and Communities

- Methods and modeling
    - Identify and characterize impacts of SLR on contaminated sites.
    - How to demonstrate the efficacy of various SLR and extreme event adaptation strategies
    - Approaches to accelerate wetland and seagrass habitat creation and restoration including, but not limited to, developing and/or enhancing wetland and seagrass mitigation banking, blue carbon mitigation banking, cutting the green tape to accelerate habitat restoration and creation projects, green infrastructure projects, creative finance instruments, and other possible solutions.
    - Assess current and future impacts to California's ecosystems, species, communities, cultural resources, and economies due to climate change and changing ocean conditions.

    - Better understand how climate change will impact or alter sediment pathways and budgets across watersheds.
- Adaptation projects and pilots
    - Innovative and transferable nature-based infrastructure adaptation measures and projects of variable size and scale, including living shorelines, eelgrass and oyster beds, wetland and beach restoration, and other adaptation strategies such as managed retreat, where feasible
    - Regional coordination in adaptation solutions, including natural infrastructure solutions.
    - Pilot projects across the state that represent a diversity of locations, with variable size and scale.
- Coastal ecosystems
    - Optimizing coastal wetland climate resilience, carbon sequestration, flood control, and biodiversity benefits
    - Understand the evolving role of aquatic vegetation (including submerged aquatic vegetation) in mitigating ocean acidification and storing carbon.
    - Future habitat space for seagrass meadows and kelp forests along the California coast.
    - Better understand the role of California's MPAs in providing climate change resilience
- Ocean impacts
    - Scientific guidance to inform new nutrient loading standards that minimize biological and chemical impacts including ocean acidification, hypoxia, and harmful algal blooms
    - Development of ocean acidification and hypoxia monitoring and observation system
    - Advance the science on ocean acidification and hypoxia vulnerability and identify risks to California's biological resources, communities, and economies, within the context of other ongoing environmental changes.
- Water uses and resources
    - Water reuse technology
    - Methods to reduce nutrient loading and/or phasing out coastal wastewater discharge into the ocean.
- Technology and observations
    - Long-term climate monitoring, modeling, and mapping of data, at both the statewide and regional scales

<u>GOAL 2. Equity across ocean and coastal policies and actions</u>

- Sea-level rise vulnerability assessments of tribal resources
- Effective beach management and public health notification approaches
- Meaningful and equitable collaboration with California's tribal governments and tribal communities on coastal and ocean issues
- Shared state definition of "healthy oceans" grounded in ecosystem-based science.

<u>GOAL 3. Enhance coastal and marine biodiversity</u>

- Methods and modeling
    - Methods and tools to track implementation progress and critical issues
    - Innovative, and advanced technologies and methods to support MPA monitoring for statewide ecological and socioeconomic monitoring of the MPA network, environmental DNA
- Coastal ecosystems
    - Identify endangered rocky intertidal habitats and beaches, statewide mapping.

    - approach for predicting multi-scale climate-driven changes in rocky intertidal and beach ecosystems, including species range shifts.
    - Measures for addressing rocky intertidal and beach habitat loss due to SLR.
    - Kelp forest ecosystem protection and recovery; improve management approaches
- Sediment management efforts
    - Support the federal-state Coastal Sediment Management Workgroup efforts to implement the California Sediment Master Plan and regional approaches to coastal sediment management, including regional sediment coordination committees.
    - Beach Resiliency and beach replenishment as part of sediment management efforts
    - Identify opportunities for the beneficial reuse of sediment along the coast and in the San Francisco Bay and Estuary
- Adaptation projects and pilots
    - Increase the scale of coastal habitat restoration and conservation, including ecosystems across the land-sea interface, such as estuaries, dunes, and coastal bluffs.
    - Adaptation of restoration projects to SLR through natural sediment accretion processes
    - Address causes of health and habitat destruction, such as those affecting the Tijuana River, that have widespread impacts on public trust lands, resources, access, and beneficial uses
- Fisheries (in relation to coastal activities)
    - The effects of changing ocean conditions and impacts on forage and predator species, and socioeconomic considerations.
    - Science-based innovative tools and approaches to advance the Marine Life Management Act (MLMA) Master Plan
    - Research on the ecological and socioeconomic impacts of climate change on priority state-managed fisheries
    - Innovative approaches to fishery management (e.g., box crab emerging fishery).
    - Impacts of whale strikes from the shipping industry and other sources of whale and turtle mortality
- Ocean impacts
    - Advance development of a baseline of plastic pollution monitoring data for coastal and marine waters and a standardized approach to track the state's progress in reducing plastic pollution
    - Assess microplastics risks, sources, and pathways and to develop standardized monitoring method
    - Impacts of harmful algal blooms on estuarine, coastal, and marine ecosystems and improve the state's ability to prevent, predict and respond to events
    - Systems to communicate harmful algal bloom conditions to the public in real time.
    - Identify sources, pathways, composition, ambient concentrations, and potential human and ecological health impacts of emerging contaminants in marine, coastal, and estuarine waters
    - Strategies that minimize introduction, improve detection, increase effectiveness in combating marine invasive species, and eradicate marine invasive species where possible

<u>GOAL 4. Sustainable blue economy</u>

- Coastal infrastructure
    - Project climate change impacts on working harbors and fisheries-dependent infrastructure statewide

    - Innovative financing for ports and fishing communities to impacts from changing ocean conditions
    - Identify air pollution sources that contribute to greenhouse gas hot spots in and around ports
- Adaptation implementation
    - Pilot projects that minimize negative impacts on the marine environment and ecosystems, such as new gear types or technologies.
    - Adaption of shoreside fisheries infrastructure
- Aquaculture
    - Understanding of the impacts of, and opportunities for, aquaculture in state marine waters.
    - Innovative tools and approaches to inform sustainable aquaculture management
- Offshore industry
    - Investigate the effect of decommissioning and reuse of oil and gas platforms on the marine environment
    - Lessons learned and recommendations from ongoing decommissioning efforts related to Platform Holly and Lease 421 facilities
    - Criteria that will ensure responsible evaluation and potential implementation of offshore wind projects, consistent with state law.
    - Characterize environmental and socioeconomic impacts of potential offshore wind projects.
- Assess sustainable coastal tourism and provide recommendations on how to grow and enhance the industry consistent with coastal and marine conservation law and policy

Coastal Conservancy Strategic Plan (2018-2022)

Produced by: Coastal Conservancy
Link

Synopsis:
The Plan presents how the Coastal Conservancy accomplishes the work, key drivers shaping the coastal landscape, accomplishments, and view of the future of the California coast and its watersheds (from 2018-2022) - including the steps needed to respond to climate change and promote environmental equity and justice. The Plan also provides a policy reference, an overview of our priorities, a delineation of coastal issues by region, and a summary of our financial status and needs. The plan suggests 4 principles that could guide planning and investment decisions:

(1) Priority should be given to actions that both build climate preparedness and reduce greenhouse gas emissions;
(2) Where possible, flexible and adaptive approaches should be taken to prepare for uncertain climate impacts;
(3) Actions should protect the state's most vulnerable populations; and
(4) Natural infrastructure should be prioritized.

Key points and gaps:
- Coastal infrastructure
    - Coastal development, including overnight accommodations, are central aspects of public access to the coast. Improve information about visitor-serving amenities on the coast (i.e. better characterization of uses and values of the coastal zone)

    - Adapt antiquated infrastructure to incorporate more environmentally sustainable designs,
    - Develop more efficient and sustainable methods in engineering
    - Barriers to coastal access disproportionately impact low-income populations and people who live further from the coast.
- Adaptation implementation and projects
    - Advance solutions for adaptation along urban waterfronts
    - Develop multi-objective, multi-habitat projects, such as Living Shorelines,
    - Development and implementation of multi-benefit Green Infrastructure and Stormwater Resource Plans
    - Develop programs that provide coastal access, environmental education, and habitat restoration and stewardship opportunities
    - Assist local communities to implement adaptation projects
    - Restoration and enhancement of wetlands and other regionally-important habitat
- Water resources and uses
    - Managed Aquifer Recharge and other water supply projects to enhance streamflow for salmonids, support coastal agriculture and increase climate resiliency
- Methods and modeling
    - Identify coastal squeeze areas, where wetlands, beaches, and dunes will be threatened with rising sea levels and limited opportunities for landward migration.
    - Identify impacts and adaptation projects that directly benefit disadvantaged communities

Coastal Hazard Modeling Systems (CoSMoS)

Produced by: US Geological Survey

Synopsis:
The Coastal Storm Modeling System (CoSMoS) is a modeling approach developed by the U.S. Geological Survey designed to understand the present-day and future vulnerability of the coast in support of federal and state climate change guidance, local planning, and emergency response[5]. CoSMoS projects coastal flooding and shoreline change (sandy beach change and cliff retreat) due to both sea level rise and coastal storms driven by climate change. It also includes c groundwater flooding. Compared to other regional hazard information, the CoSMoS modeling is unique in that it accounts for all the dynamic components of water level. CoSMoS has been used in other flood mappers (Our Coast Our Future, n.d.) and in the Hazard Exposure and Reporting Analytics (HERA) website, which examines community hazard exposure, compares the exposure of multiple communities, and explores changes in hazard exposure through interactive maps and graphics, and tables. The CoSMoS tools have informed most recent State vulnerability and adaptation planning

Key points and gaps:
Despite being one of the most comprehensive tools for understanding future coastal impacts, the CoSMoS environment still presents some limitations for local adaptation planning that represent gaps in technology and knowledge:

[5] This tool is included individually in this annex as many projects have relied on it. Since it is also considered one of the most advanced and complete tools in terms of coastal hazards and impacts, it is used here to identify main limitations in state of the art coastal hazard projections.

- Coastal storm scenarios are not currently included in model projections of shoreline change or groundwater rise (only available for SLR scenarios);
- The hazards are projected for the long-term (end of the century), but the models do not allow forecasting shorter term effects that are critical for coastal management, e.g., flooding and erosion from extreme events (e.g. El Nino years), as this information is not incorporated in the modeling or the online tools.
- However, one of the largest limitations to date is that there is no direct way to account for adaptation options. This is common across all the tools revised in this study. CoSMoS projects hazards into the century, but equivalent tools do not yet exist for evaluating the effects of adaptation options to remediate these projected changes, where they could be implemented, by when depending on the ongoing changes, and forecast shorter term effects on flooding and erosion from extreme events (e.g., El Nino years).
- Coastal protection infrastructure:
    - The modeling approach assumes that existing coastal protection infrastructure (e.g., levees, revetment, sea walls) is structurally sound and will never fail, which is unlikely given they will be stressed by future flooding events.
    - There are also other flood protection structures and flow conduits important to local coastal flooding patterns that are typically beyond the resolution of this modeling approach, such as tide gates, culverts, sewage outflows, and narrow sea walls.
- Groundwater modeling currently shows long-term, steady-state equilibrium conditions.
    - Seasonal and tidal fluctuations are not yet considered, nor are any human activities (e.g. pumping, drains, augmentation), instead the model is forecasting shifts in the baseline (i.e., average) water table conditions.
- Shoreline change and erosion
    - Long-term shoreline projections are not included for sandy environments, statewide.
    - The projections of cliff erosion present large uncertainties, compared to other impact modeling.

State of California Sea-Level Rise Guidance (2018 update)

Produced by: Ocean Protection Council (OPC)
Link

Synopsis:
Catalyzed by direction from Governor Brown in 2016, the update to the State of California Sea-Level Rise Guidance (Guidance) reflects advances in sea-level rise science and addresses the needs of state agencies and local governments as they incorporate sea-level rise into their planning, permitting, and investment decisions. The updated Guidance provides: 1) a synthesis of the best available science on sea-level rise projections and rates for California; 2) a stepwise approach for state agencies and local governments to evaluate those projections and related hazard information in decision-making; and 3) preferred coastal adaptation approaches.

Key points and gaps:
- Probabilistic projections need to be taken as an evolving representation of the scientific field, open to updates and modifications.
    - In this context of continued and unquantifiable uncertainties, incorporating long-range planning for SLR in decisions is increasingly urgent.

    - A challenge that remains is determining when SLR thresholds will occur and with what level of confidence it will occur in the given timeframe.
- Future SLR projections presented in the Guidance do not include acute increases in water level associated with El Niño events, king tides, storm surges or large waves.
    - Alone or in combination, these events will produce significantly higher water levels than SLR alone, and will likely be the drivers of the strongest impacts
- Critical to consider inland impacts of SLR
    - The Guidance currently pertains mostly to the coast, inland areas should follow the same set of recommendations and principles beyond the immediate coastal zone.
    - Incorporate inland SLR modeling and projections to the extent they are available and based on rigorous and peer-reviewed science.

Climate Change Research Plan for California (2015)

Produced by: the California Environmental Protection Agency
Link

Synopsis:
California's innovative climate policies are built on a strong base of research about the impacts of climate change. The Research Plan delineates California's most critical climate-related research needs over the next three to five years.

Key points and gaps:
The Research Plan identifies critical areas of research that must be supported in order to inform climate-related policy.

- Monitoring
    - How is climate changing in California?
    - What monitoring strategies and capabilities will be necessary to track variations and changes in climate, including extreme events?
    - What improvements in climate modeling are needed to support vulnerability assessments that lead to better adaptation planning at multiple levels and across sectors?
- GHG Accounting
    - What new emissions accounting methods can help validate estimates of GHG emissions, especially for non-CO2 gasses such as short-lived climate pollutants and in difficult-to quantify sectors such as agriculture, waste, and forestry?
    - What are the areas of greatest uncertainty?
- Reducing GHG Emissions
    - What are the most effective strategies and technological innovations to significantly reduce GHG emissions in all sectors of the economy?
    - What are their economic, public health, and environmental impacts and co-benefits?
- Addressing Climate Change Risks
    - How vulnerable are the people, resources, and infrastructure of California to climate change impacts?
    - How is this vulnerability distributed among groups and geography?
    - What are the most effective strategies and technological innovations to safeguard California from these impacts?

The Research Plan also identifies several cross cutting areas of research that involve multiple sectors or would benefit from strong interdisciplinary approaches:

- Social science research
    - How to address social, regulatory, institutional, and legal barriers that may impede or delay the implementation of technically sound adaptation options.
    - Identify barriers across sectors and to understand, in practical terms, how to overcome those barriers across multiple regions and economic sectors.
    - Non-economic costs and benefits of integrated mitigation and adaptation strategies must be supported for the well-being of California.
- The economics of climate change
    - Economic impact of climate change. There has been a tendency to project only large-scale impacts, for example, on the state's entire economy but, just as the physical impacts of climate change vary across the state, so too do the related economic benefits and burdens.
    - "On the ground" interdisciplinary studies are needed to allow in-depth estimation of economic costs and benefits related to the implementation of risk management strategies.
- Environmental justice
    - Identify disadvantaged communities and certain racial/ethnic groups that could experience disproportionate public health risks and economic burdens.
- Extreme events
    - Cascading and exacerbated impacts.
    - Integrated assessment of best options to prepare for, respond to, and recover from these events.

The Plan identifies specific research needs for wetlands because restoration of California's wetlands could play a critical role in protecting the coast and delta from flooding due to high waves and SLR while also sequestering carbon and reducing GHG emissions. These needs include:

- Wetland Carbon Protocol
    - Develop the scientific foundation to understand the potential for reducing emissions through wetland projects. This could allow wetland restoration projects to better monetize emission reduction benefits.
- Restored wetlands as carbon sinks
    - Continue to construct and assess large-scale pilot projects on Twitchell and Sherman Islands while continuing to monitor GHG flux, methyl mercury, subsidence reversal, and general habitat effects in both baseline environments (corn, alfalfa, and irrigated pasture environments) and constructed wetlands.
    - Quantify spatial variability of impacts on these measures by constructing and monitoring additional sites throughout the Sacramento–San Joaquin River Delta, estuaries, and along the coast.
- Wetlands as protective assets for flood protection
    - Develop a quantitative understanding on the role of wetlands as protective assets for urban areas and other infrastructures from coastal and inland flooding.
    - Monitor existing multi-benefit wetland projects in California to document the habitat benefits, flood protection, and ability to adapt to sea-level rise to learn from current projects and help inform future multi-benefit wetland projects.
    - Support implementation of multi-benefit restoration projects.

- Wetlands at risk from climate change
    - Support ongoing science-based regional planning (e.g., San Francisco Bay Ecosystem Habitat Goals Report, Southern California Wetland Recovery Project Regional Strategy) that are identifying wetlands at risk from climate change and strategies to increase resilience.
    - Monitor the effectiveness of these enhancement strategies to increase resilience.

Protection of ocean and coastal ecosystem will require further research related to:

- Monitoring and modeling ocean acidification and hypoxia and their impacts
    - Develop a regional approach for monitoring spatial and temporal variation of ocean acidification and hypoxia.
    - Improve ability to model pH, oxygen, and nutrients in the near-shore environment to determine contributions of local nutrient inputs to acidification and hypoxia and identify geographic locations most susceptible to acidification and hypoxia.
    - Determine key marine species that should be targeted for impact analyses and perform modeling studies to assess food web responses under future climate scenarios and evaluate appropriate management strategies (e.g., marine protected areas).
- Coastal ecosystem and fisheries management
    - Evaluate approaches to developing climate-ready fisheries and management actions within marine protected areas to improve resilience to climate.
- Monitoring impacts on the shoreline
    - Collect data to track shoreline changes and impacts from storms (e.g., beach and cliff erosion) to improve methods for predicting shoreline evolution.
    - Measure land elevation changes such as subsidence and tectonic activity in relation to SLR.
- Forecasting and climate impact scenario information
    - Develop updated methods for predicting flood frequency under changing climate,
    - Improve forecasting of extreme events such as extreme precipitation associated with atmospheric rivers (as described in Chapter 3).
- Role of marine protected areas in resilience
    - Investigate how, and the extent to which, marine protected areas contribute to the resilience of coastal and marine ecosystems, coastal communities and the broader economy
- Tools and approaches to prepare for climate risk to ocean and coast
    - Compile improved social and economic data, including the quantification of ecosystem services, to enable the evaluation of different approaches to prepare for climate risk (e.g., seawalls, managed retreat, living shorelines, artificial reefs, and no action/business as usual).
    - Evaluate innovative adaptation approaches such as green infrastructure (e.g., tidal wetlands, eelgrass, and native oysters) to help reduce vulnerability to climate-related hazards.
    - Capitalize on the opportunity of a statewide network of marine protected areas as a living laboratory, where considerable research and monitoring is already under way, for understanding the effects of climate change on California's ocean resources.
    - Conduct multidisciplinary and integrated analyses to understand the costs, benefits, feasibility, and acceptability of alternative strategies

- Incorporation of ecosystem services and green infrastructure into policy will require further research on:
    - Methods for modeling ecosystem services and their value in assessing climate risks and climate-related projects or policies.
    - Identify where and how to best deploy adaptation strategies

The following regional research needs were also identified:

- Monitoring
    - Monitoring information is needed to understand ongoing changes and trends in the natural and built environments and to help evaluate planning decisions that have been made. This information is needed from a steady, reliable source.
- Forecasting and Climate Projections
    - Information on the potential impacts of climate change is needed at a scale that is relevant and actionable by the regions, including an improved understanding of the risks of extreme events.
- Vulnerability Assessment
    - Regions need tools and information to identify what is at risk under a changing climate, including infrastructure, population, natural systems, and the economy.
- Adaptation Tools and Approaches
    - Research needs to identify the appropriate scale for action designed to address climate risks. When is the regional scale the appropriate scale for action?
- Partnerships
    - How can we best leverage work being completed at the regional level to support adaptation?
    - How can State-sponsored research best support regional efforts?
    - What governance mechanisms best support regional adaptation efforts?
    - How can climate risks and response options be effectively communicated at the local to regional level?
- Case studies
    - At the local level, decision makers need to know what works and how to act on it. This is particularly true with the economics, barriers, and disturbance topics.
    - Positive feedbacks, co-benefits, and replicable outcomes are critical information for engaging local leaders to take action

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Annex 2. Review of relevant resources for coastal adaptation to climate change in California

This document includes three tables that collect, list and review different resources available to date (as of October 2022) to guide adaptation to climate change in coastal areas of California.

- Table 1 outlines datasets, observations and other relevant data related to climate hazards in coastal zones.
- Table 2 focuses on tools, decisions support systems, toolkits (defined as repository of resources and guidance documents), and other online resources available for communities.
- Table 3 deals with guidance documents available to date and includes a brief description of scope and goals.

The review has been developed to facilitate an overview of resources, tools and guidelines and main policy documents. It may not be comprehensive, but it represents an updated repository of resources that were considered relevant by the authors.

The review included resources at different scales: global, national, state-wide and regional (including different jurisdictions). Specific resources for local sites are not included.

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T1. Datasets and Observations (data archive and real time)

Data / Tool	Description	Data type	Tool type	Source	Scope	Link
2022 Sea Level Rise & Extreme water level projections	Up-to-date sea level rise and extreme water level projections available for all U.S. states and territories. This multi-agency effort represents the first update since 2017, offers projections out to the year 2150 and information to help communities assess potential changes in average tide heights and height-specific threshold frequencies. The data are provided along with the '2022 Sea Level Rise Technical Report'. It also provides an *API (Application Programming Interface)* URL Builder allows an advanced user to access and interact with the data.	Future Extreme Water Levels (EWL) (at tidal gauges and 1-degree grid for the U.S.A.).	Dataset	NOAA	National	Sea Level Rise Technical Report: Download and FAQs (noaa.gov) **NOAA API URL Builder**
NOAA Tides & Currents Products – Water Levels	Data and products from tidal gauges across the U.S. including observed, predicated water levels, and long term sea level trends.	Water levels (benchmark data sheets relative to a Datum, 1 minute water level data, tide predictions, harmonic constituents, datums) Sea level trends	Dataset Data download Data exploration Data visualization	NOAA	National	CO-OPS Products - NOAA Tides & Currents
NOAA Tides & Currents – Extreme Water Levels	Annual and monthly exceedance probability levels for select CO-OPS water level stations with at least 30 years of data.	Exceedance probability statistics and extreme water levels	Dataset Data download Data exploration Data visualization	NOAA	National	Extreme Water Levels - NOAA Tides & Currents
Coastal Data Information Program	The Coastal Data Information Program (CDIP) provides access to coastal environment observations (current and historical), access to a wave forecast for California, and a map with stations with meteorological and oceanographic data along the East Coast, US Gulf Coast, Hawaii, Alaska, US territories in the Pacific, and Puerto Rico.	Ocean buoy wave data Meteorological variables	Dataset Data download Data exploration Data visualization	UC San Diego	State & National	http://cdip.ucsd.edu/m/
The California Coastal Geoportal	The California Coastal Geoportal makes it easy to discover, use and distribute geospatial data layers that are relevant to the state's coastal and marine environment. Designed for state analysts and accessible to the public, the Coastal Geoportal features an index of select data layers, a desktop viewer, and links to other online tools and resources.		Dataset Data download Data exploration Data visualization	State of California	State	California Coastal Geoportal | California Natural Resources Agency
The California Ocean Uses Atlas	Public-private partnership between NOAA's Marine Protected Areas Center and Marine Conservation Institute, which provides information for ocean management by mapping. The Atlas provides access to data of significant human uses of the ocean in state and federal waters of the coast of California. Spatial data for nearly 30 ocean uses. were gathered through a series of participatory mapping	Human uses of the ocean	Dataset Data download Data exploration Data visualization	NOAA	State	https://marineprotectedareas.noaa.gov/dataanalysis/atlas_ca/viewer/

	workshops convened with regional ocean use experts throughout the state.					
California Seafloor Mapping Program	The California Seafloor Mapping Program (CSMP) is a cooperative program to create a comprehensive coastal and marine geologic and habitat base map series for all of California's State waters.	Bathymetry	Dataset Data download	USGS	State	https://www.usgs.gov/centers/pcmsc/science/california-seafloor-mapping-program
U.S. Integrated Ocean Observing System	Network of coastal ocean observing systems (SCOOS, *CeNCOOS for California*)	Various oceanic and meteorological data	Dataset Data download Data exploration Data visualization	NOAA	National Regional	https://ioos.noaa.gov/
NOAA Data Access Viewer	Search for and download elevation (lidar), imagery, and land cover data for the coastal U.S. and its territories.	Elevation Imagery Land Cover	Dataset Data download Data exploration	NOAA	National	https://coast.noaa.gov/dataviewer/#/
National Weather Service	Real time, archived, and short term weather data.	Meteorological data	Dataset Data download Data exploration Data visualization	NOAA	National	https://www.weather.gov/
National Water Dashboard	Current and historical stream flow, groundwater, and surface water data	Stream flow Groundwater Surface water	Dataset Data download Data exploration Data visualization	USGS	National	https://dashboard.waterdata.usgs.gov/app/nwd/?region=lower48&aoi=default
Earth Resources Observation and Science (EROS) Center	EROS maps, monitors, and analyzes land change. Provide aerial imagery, satellite data, digital elevation, radar, etc.	Imagery Elevation Radar	Dataset Data download Data exploration Data visualization	USGS	National	https://www.usgs.gov/centers/eros
National Data Buoy Center	Real time and historical observation of buoy data	Offshore Waves	Dataset Data download Data exploration Data visualization	NOAA	National	https://www.ndbc.noaa.gov/
CoastSat	Satellite based shoreline mapping and beach slopes	Shoreline position Beach change trends Beach slope	Dataset Data download Data exploration Data visualization	UNSW	State	http://coastsat.wrl.unsw.edu.au/

T2. Viewers and Tools, Decision Support Systems

(*) 'Toolkit' denomination is given to websites/platforms that not only include mapping and tools, but also case studies, reports and other resources.

Data / Tool	Description	Hazard	Tool type	Source	Scope	Link
A. COASTAL HAZARD VIEWERS/MAPPERS (only Sea Level Rise and extreme flooding)						
NASA Interagency Sea Level Rise Scenario Tool	The tool provides access and visualization of sea level scenarios and information contained in the 2022 technical report produced by the Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force. It also provides access to global projections	Sea Level Rise (regional and global)	Dataset Data exploration Visualization & Mapping	NASA	National & Global	Interagency Sea Level Rise Scenario Tool – NASA Sea Level Change Portal
Coastal Hazards System 2.0 (CHS)	The CHS is a national coastal storm hazard data resource for probabilistic coastal hazard assessment (PCHA) results and statistics, storing numerical and probabilistic modeling results including storm surge, astronomical tide, waves, currents, and wind. It provides storm probability for different regions, based on a joint probability model. CHS is an up-to-date and easily accessible environment for development, storage, and rapid access to PCHA hazard results, additional information such as tides, wind and rainfall, and documentation of the results.	Storm probability Extreme Water Level	Data download Data exploration	USACE CHS (Coastal Hydraulics Laboratory)	National	CHS (dren.mil)
FEMA National Flood hazard layer	The National Flood Hazard Layer (NFHL) is a geospatial database that contains current effective flood hazard data. FEMA provides the flood hazard data to support the National Flood Insurance Program. NFHL data covers over 90% of the U.S. population. New and revised data is being added continuously. The regional data on extreme water levels uses a combination of NOAA storm-tide observations, historical high-water marks,17 synthetic storm simulations (e.g., Nadal-Caraballo et al., 2020; ERDC Coastal Hazards System18), and wave effects to estimate the regulatory floodplain and its exposure to the rarest of events (e.g., 1% and 0.2% annual chance events). FEMA provides this information for national flood insurance purposes19 but does not consider future sea levels	Extreme Water Level	Screening tool Data download Data exploration Visualization & mapping	FEMA	National	National Flood Hazard Layer | FEMA.gov Viewer: Draft National Flood Hazard Viewer (arcgis.com)
NOAA Tides & Currents Products – Coastal Inundation Dashboard	Dashboard that provides access to real-time and historical coastal flood information at select locations, real-time water levels, 48-hour forecasts of water levels and historic flooding information at a majority of coastal water level stations operated by the National Ocean Service (NOS) Center for Operational Oceanographic Products & Services (CO-OPS). The product features both a map-based view where users can see which stations across the U.S. may be flooding, and a more detailed station view where real-time water levels and historical data for a specific location are highlighted.	Water levels (historic) Extreme Water Levels	Data download Data exploration Data visualization	NOAA	National	Coastal Inundation Dashboard Coastal Inundation Dashboard - NOAA Tides & Currents

Climate Central Surging Seas Toolkit	This website, developed by Climate Central, provides access to different research, maps and tools, and examples Sea level rise analysis, including the Risk Zone Map and other visualization tools and custom coastal flood risk analysis for the US. It also includes flood mapping capabilities globally.	Sea Level Rise Extreme Water Levels	Screening tool Data download Data exploration Visualization & mapping Repository of resources	Climate Central	Global / National	Map by year Map by flood level Map by elevation data (compares two global elevation models)
CalFloD-3D Sea Level Rise Viewer	This online viewer explores modeled inundation locations and depths for three areas: San Francisco Bay, the Sacramento-San Joaquin River Delta, and the entire California coast; for increments of sea level rise under a 100-year flood event. CalFloD-3D model is unique and innovative in dynamic spatial detail and the fact that it incorporates real time series water level data from a past storm event to capture the dynamic effect of storm surges in modeling inundation using 3Di, a three dimensional hydrodynamic model along with high resolution earth surface models. The source data and interactive, easy-to-use visualizations are available at a high spatial resolution (3m) for the San Francisco Bay Area and the Sacramento-San Joaquin Delta, with coverage for the entire California Coast available at 50m resolution.	SLR and ESL flooding	Screening tool Data exploration	State of California (CalAdapt)	State / Regional	https://cal-adapt.org/tools/slr-calflod-3d/
Hourly Projections of Sea Level	This app allows exploring hourly sea level projections at selected Tide Gauge Locations along the California coast.	Sea Level Rise Extreme Water Level	Screening tool	*State of California / Cal-Adapt*	State	Hourly Projections of Sea Level (cal-adapt.org)
Sea Level Rise - Coastal Inundation Scenarios (SLR-CIS)	The Sea Level Rise - Coastal Inundation Scenarios tool explores projected water levels associated with Sea Level Rise (SLR) and a near 100-year storm scenario along the California coast and San Francisco Bay from two different models - CalFloD3D-TFS and CoSMoS. The tool allows a comparison of flood results from these two models using the provided map viewer.	Sea Level Rise Extreme Water Level	Screening tool Data exploration	*State of California / Cal-Adapt*	State	https://cal-adapt.org/tools/slr-coastal-inundation
B. OTHER VIEWERS (other hazards, multihazards)						
Digital Coast Sea Level Rise Viewer tool	This web mapping tool can be used to visualize community-level impacts from coastal flooding and sea level rise.	Sea Level Rise (regional sea level rise from 2022 and 2017 studies) High tide flooding (EWL) Marsh migration potential	Dataset Screening tool Data exploration Visualization & Mapping	NOAA	National	Sea Level Rise and Coastal Flooding Impacts (noaa.gov)

Our Coast, Our Future 3.0	OCOF is a collaborative, user-driven tool providing coastal California Resource managers and land use planners with resources to understand, visualize and adapt to sea level rise and coastal storms. The platform helps visualize, synthesize and download outputs from the USGS Coastal Storm Modeling System (CoSMoS). It also includes hazard maps, case studies, and science and modeling details, including sea level rise projections. Flooding accounts for sea level rise and storm frequency.	SLR and ESL flooding (extent and duration) Current velocity Cliff retreat Shoreline erosion Groundwater static flooding	Screening tool Data download Data exploration	Point Blue Conservation Science & USGS	State	https://ourcoastourfuture.org/
California Coastal Cliff Erosion Viewer	Tool that provides access to information on California's coastal cliff retreat statewide using recent Lidar data. Users can browse any cliff in the state to see its past rate of erosion and related retreat statistics. The website is designed for coastal planning and development decision-makers, but the information may also be of interest to members of the research community, and the general public.	Cliff erosion rates (historic)	Data exploration Data download	Scripps Coastal Processes Group UC San Diego	State	https://siocpg.ucsd.edu/data-products/ca-cliff-viewer/
CalOES MyHazards	MyHazards is a tool for the general public to discover hazards in their area (earthquake, flood, fire, and tsunami) and learn steps to reduce personal risk. Using the MyHazards tool, users may enter an address, city, zip code, or may select a location from a map. The map targets the location, and allows users to zoom and scroll to their desired view. The screen then presents information on the risks identified within the search radius, and recommended actions.	Flooding, earthquakes, fire risk	Screening tool	Governors office of Emergency Services	State	Home Page - Cal MyHazards
Climate Explorer	This tool accompanies the US Climate Resilience Toolkit. The Climate Explorer gives users a way to check how climate conditions in the United States are projected to change over the coming decades. This information—derived from global climate models—is available for counties and county-equivalents for all 50 states and U.S. territories in the United States.	Meteorological data (Temperature, precipitation, durations and threshold analyses) High tide flooding	Data exploration Data download	NOAA	National / at County level	Climate Explorer (nemac.org)
C. OTHER VIEWERS (Exposure, effects on infrastructure)						
NOAA Coastal County Snapshots - Sea Level Rise	Online tool with county resilience data for current and future flood hazards, critical facilities, jobs, businesses, etc. The tool provides print and electronic options (the print version can be used as a handout and for general awareness). The electronic version allows users to see the data superimposed on a map or through a graphic interface, provides access to the data used to make each snapshot.	Flood exposure for each county, with data on: Marine economy; Total coastal economy; land affected by SLR and Extreme Water Level (100-year floodplain)	Screening tool Data exploration Data download Visualization & Mapping	NOAA	National (county-based)	NOAA | Coastal County Snapshots
NOAA Coastal Flood Exposure Mapper	Online mapper to visualize hazard layers (high tide, FEMA flood zones, tsunami, storm surge, sea level rise), societal exposure (population density, poverty, elderly and employees), infrastructure exposure (development, critical	infrastructure and ecosystem exposure to floods (Extreme Water Level)	Screening tool Data download Data exploration Visualization & mapping	NOAA	National	Coastal Flood Exposure Mapper (noaa.gov)

	facilities) , and ecosystem exposure (natural areas, natural protection, wetland potential and pollution sources).					
Coastal Resilience Evaluation and Siting Tool (CREST)	The online tool projects impact of sea level rise on social vulnerability, critical infrastructure, and priority species to modeled Resilience Hubs, as well as priority areas identified by level of protection, flood vulnerability, socioeconomic impact, and effect on wildlife. This tool is primarily for siting resilience projects at a national level but includes regional Targeted Watershed Assessments for certain sites including the San Francisco Bay Area. The tool also identifies Resilience Hubs, based on the combination of a community exposure index and a fish and wildlife index.	Sitting threats (impermeable soils, soil erodibility, SLR and ESL, areas of low slope)	Screening tool Data exploration	NFWF	National / State / regional	https://resilientcoasts.org/Home CA Regional assessment (page 55)
USGS | Hazards Exposure and Reporting Analysis (HERA)	The Hazard Exposure and Reporting Analytics (HERA) website combines coastal flooding from projected storm and sea level rise scenarios with estimates of community level exposure to populations, economic assets, land cover, critical facilities, and infrastructure. Hazards are provided by the USGS Coastal Storm Modeling System (CoSMoS).	SLR and ESL Socioeconomic Exposure to flooding	Screening tool Data exploration	USGS	State	https://www.usgs.gov/apps/hera/
Point Blue Conservation Science's Climate-Smart Restoration Toolkit	The Climate-Smart Restoration Toolkit provides a checklist and resources for restoration practitioners interested in designing their projects in a way that prepares them for climate change.	Restoration projects		*Point Blue Conservation Science*	State	Climate-smart Restoration Toolkit - Point Blue
Adapting to Rising Tides (ART) Program – inundation maps (* regional)	The Adapting to Rising Tides (ART) Program was originated in 2010 by the San Francisco Bay Conservation and Development Commission (BCDC) and NOAA's Office for Coastal Management in a collaborative planning with local, regional, state and federal agencies and organizations, as well as non-profit and private associations, along the Alameda County shoreline - the ART Subregional Project – to identify how current and future flooding will affect communities, infrastructure, ecosystems and economy. Since then, the ART Program has continued to lead and support multi-sector, cross-jurisdictional projects that build local and regional capacity in the San Francisco Bay Area to plan for and implement adaptation responses. The website provides access to data and maps, but also step-by-step guidance, projects, and findings.	(Regional and local maps) SLR and ESL flooding Social vulnerability	Screening tool Data exploration	San Francisco Bay Conservation and Development Commission (BCDC)	Local (SF Bay)	https://www.adaptingtorisingtides.org/ Regional and local maps: https://www.adaptingtorisingtides.org/maps-and-data/
Adapting to rising tides – Bay shoreline flood explorer	Flood data of areas and sectors exposed to current and future flooding from sea level rise and storms.	Sea Level Rise Extreme Water Level Flood Exposure	Data exploration Data download	San Francisco Bay Conservation and Development Commission (BCDC)	Local (SF Bay)	https://explorer.adaptingtorisingtides.org/explorer

Risk zone map & Risk finder	This global interactive map — searchable by city or postal code — shows areas vulnerable to permanent submergence from sea level rise, or to flooding from sea level rise, storm surge, tides, and tsunamis, in different combinations. For the U.S., the Risk Finder includes flood exposure based on social vulnerability, population distribution, ethnicity, income, property value and landmarks. The tool also integrates interactive reporting for localities and counties. The Risk Zone Map shows areas vulnerable to near-term flooding from different combinations of sea level rise, storm surge, tides, and tsunamis, or to permanent submersion by long-term sea level rise.	Sea Level Rise Extreme Water Levels Social and property exposure	Screening tool Data download Data exploration Visualization & mapping	Climate Central	National	Risk zone maps Risk estimates
Affordable housing at risk	Based on the Surging Seas toolbox, this app by Climate Central combines physical vulnerability and coastal flooding data to estimate exposure for affordable housing units	Sea Level Rise Extreme Water Levels Affordable housing exposure	Screening tool Data download Data exploration Visualization & mapping	Climate Central	National	Affordable housing at risk
Ocean at the Door	With similar information to the risk finder and zone map, this version of the tool integrates building and property value information from Zillow.	Sea Level Rise Extreme Water Levels Building exposure	Screening tool Data download Data exploration Visualization & mapping	Climate Central	National	Ocean at the door map
San Francisco Bay Eelgrass Impact Assessment Tool	This web-based application was created by BCDC to support the Long Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region (LTMS) program and the National Marine Fisheries Service's 2011 LTMS Programmatic Essential Fish Habitat (EFH) consultation. The web assist project planners in identifying potential impacts of dredging projects in San Francisco Bay to eelgrass.	Habitat exposure	Screening tool Data download Data exploration Data visualization	San Francisco Bay Conservation and Development Commission (BCDC)	Regional	https://data.cnra.ca.gov/dataset/san-francisco-bay-eelgrass-impact-assessment-tool1
Community Vulnerability (BCDC 2020)	The San Francisco Bay Conservation and Development Commission Adapting to Rising Tides Program developed a dataset to better understand community vulnerability to current and future flooding due to sea level rise and storm surges. This data has been used in the Adapting to Rising Tides Bay Area Sea Level Rise Vulnerability and Assessment project as well as helping inform the implementation of the BCDC Environmental Justice and Social Equity Bay Plan amendment.	Social vulnerability to SLR and ESL flooding	Screening tool Data download Data exploration	BCDC	Regional	https://data-bcdc.opendata.arcgis.com/datasets/community-vulnerability-bcdc-2020
NOAA Stormwater Tool	This tool allows communities to determine how present and future flooding can affect stormwater systems. It uses information on sea levels, high tide flooding and sea level rise projections to generate reports that can display information about current and future flooding impacts and inform planning efforts.	Sea Level Rise High tide flooding Extreme Water Level Impacts to Infrastructure	Screening tool Data exploration Visualization & Mapping	NOAA	National	Adapting Stormwater Management for Coastal Floods (noaa.gov)

D. COMPARISON OF TOOLS, PLANNING AND TOOLKITS						
US Climate Resilience Toolkit	Toolkit with a catalog of more than 500 digital tools can help you take steps to build resilience, from engaging a community to developing a climate action plan. It also includes a collection of case studies, guidelines and a proposed framework for developing a resilience plan (i.e., 'steps to resilience')	SLR and ESL flooding Tools and case studies	Comparison of tools Case studies Repository of resources	NOAA	National	U.S. Climate Resilience Toolkit | U.S. Climate Resilience Toolkit
California "Sea the Future" Tool	The Sea the Future (STF) tool was developed to help users understand the differences among 12 sea-level rise and coastal inundation information and mapping tools applicable to California. Sea the Future provides summaries and information on tool features, similarities and differences across tools, and advantages and disadvantages of each.	SLR and ESL flooding	Comparison of tools Screening tool Repository of resources	State of California	State	https://www.adaptationclearinghouse.org/resources/california-e-sea-the-future-e-tool.html
Adaptation Clearinghouse	The Adaptation Clearinghouse is the State of California's consolidated searchable database of resources for local, regional and statewide climate adaptation planning and decision-making. Search and explore resources for adaptation and resiliency efforts in California. The Adaptation Clearinghouse allows to navigate a searchable database of adaptation and resilience resources that have been organized by climate impact, topic, and region. Importantly, the Adaptation Clearinghouse also provides a platform to share and access case studies and stories about how and why communities, businesses, and organizations are responding to climate change impacts. One of the topics is 'ocean and coast'.	Sea Level Rise Extreme Water Level Erosion Planning, guidance	Data exploration Data download Case studies, projects, and examples Repository of resources (assessments, plans or strategies; communication or educational materials; planning and/or policy guidance)	Governor's Office of Planning and Research, State of California.	State	https://resilientca.org/
ResilientCA Toolkit	This section of the Adaptation Clearing house website (ResilientCA.org) provides key state resources and allows exploring the database of all Tools, Data, and Scientific Studies on the Adaptation Clearinghouse	Sea Level Rise Extreme Water Level Erosion Planning, guidance	Repository of resources Comparison of tools	Governor's Office of Planning and Research, State of California	State	Tools | ResilientCA
Cal-Adapt Toolkit	Drawing on the wealth of California's peer-reviewed, State-sponsored climate change research, Cal-Adapt is an interactive website that enables exploration of climate risks associated with low- and high-emission scenarios. Custom visualizations allow users to explore projected temperature changes, wildfire risks, sea level rise, and snow pack at the local level. All data presented on the site are freely available for download to support further analysis. The California's recently released Adaptation Planning Guide directs users to Cal-Adapt, which has established itself as a primary tool enabling resource managers; city, county, and	Sea Level Rise Extreme water levels Temperature Snowpack Heavy precipitation events Drought Wildfire	Data exploration Data download Repository of resources	California Energy Commission, State of California	State	https://cal-adapt.org/

	tribal governments; and other public and private decision-makers to find locally relevant information to facilitate planning for climate risks.					
The ResilientCA Adaptation Planning Map (RAP-Map)	The RAP map is a statewide inventory of local government adaptation and resiliency planning efforts. Users can quickly access, analyze, or download the planning details of local jurisdictions, including links to vulnerability assessments; adaptation goals, strategies and implementation measures; and updated and adopted General Plan Safety Elements, Local Hazard Mitigation Plans, or other stand-alone adaptation or resilience plans. Originally developed in 2021, the most recent August 2022 update shows the results of OPR's annual inventory review of all California counties.	SLR (planning implementation)	Mapper with status of adaptation planning	Governor's Office of Planning and Research	State	Rap Map | ResilientCA
Adaptation Capability Advancement Toolkit (Adapt-CA)	This toolkit, developed by the Local Government Commission in coordination with the California 4th Climate Assessment reports, helps participants to assess their leadership and organizational culture, staffing and technical capability, stakeholder engagement and partnerships, and operations and institutionalized processes. Capacity is measured on a four-point scale, from Initiation (the lowest level of capacity) to Optimization (the highest level).	SLR (governance)	Matrix, checklist and roadmap for self-assessment of capabilities for adaptation planning	Local Government Commission	State	Adaptation Capability Advancement Toolkit – ARCCA California

T3. Guidance documents on adaptation to coastal climate hazards in California

Report	Organization	Description	Regional Scope	Year	Link
State Agency Sea-Level Rise Action Plan for California	Ocean Protection Council	Seven principles (Best Available Science, Partnerships, Alignment, Communications, Local Support, Coastal Resilience Projects, Equity) create a direction for how to align state actions and decision points around SLR. The Ocean Protection Council (OPC) was charged with working with agency partners to create a statewide, collaborative Action Plan that would carry out these principles. The result is this document, the SLR Action Plan, a five-year plan to make advances toward coastal resilience through comprehensive, coordinated, and collaborative work.	California	2022	https://www.opc.ca.gov/webmaster/_media_library/2022/02/Item-7_Exhibit-A_SLR-Action-Plan-Final.pdf
Sea Level Rise Technical Report	National Oceanic and Atmospheric Administration	The Sea Level Rise Technical Report provides the most up-to-date sea level rise projections available for all U.S. states and territories; decision-makers will look to it for information.	United States	2022	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
Regional Strategy for A Rising Bay: Joint Platform	Bay Adapt	A plan for the Bay Area that is resilient and adaptive far into the future. As the region grows and changes, coastal resilience can be achieved by supporting collaborative action, fostering greater equity among residents, and sustaining the unique ecosystems residents rely upon and thrive within.	San Francisco Bay Area	2021	https://www.bayadapt.org/wp-content/uploads/2022/01/BayAdapt_JointPlaform_Final_Oct2021.pdf
Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone	California Coastal Commission	The goal of this Guidance is to promote resilient coastal infrastructure and protection of coastal resources by providing local governments, asset managers, and other stakeholders with policy and planning information to help inform sea level rise adaptation decisions that are consistent with the California Coastal Act. The Guidance addresses specific assets that fall within two main types of critical infrastructure: transportation and water.	California	2021	https://documents.coastal.ca.gov/assets/slr/SLR%20Guidance_Critical%20Infrastructure_12.6.2021.pdf
State Parks Sea Level Rise Adaptation Strategy	California Department of Parks and Recreation (State Parks)	In response to sea level rise, associated changes to the coastal landscape, as well as evolving science and state policy, California State Parks developed a Sea Level Rise Adaptation Strategy to provide a framework to address the impacts of sea level rise in coastal state park units. The Strategy is designed to address the unique resources and needs of State Parks in a holistic manner.	California	2021	http://parks.ca.gov/?page_id=30540
Strategic Plan to Protect California's Coast and Ocean	Ocean Protection Council	In the face of major challenges to California's coast and ocean, this Strategic Plan offers four Goals to guide California's efforts over the next five years. The California Ocean Protection Council developed this strategic plan to advance focused, high-value interagency collaboration that is needed to meet these goals and achieve the collective vision. This document is comprised of objectives, targets, and actions in each goal area.	California	2020	http://www.opc.ca.gov/webmaster/ftp/pdf/2020-2025-strategic-plan/OPC-2020-2025-Strategic-Plan-FINAL-20200228.pdf
Making California's Coast Resilient to Sea	California Natural Resources Agency,	The document is intended to unify state agencies in effective, coordinated action toward climate resilience grounded in science, partnership, communication, and local support. The SLR Principles will guide state agencies' sea level rise initiatives with a common, clear, and foundational	California	2020	https://www.opc.ca.gov/webmaster/_media_library/2021/01/Sta

Level Rise: Principles for Aligned State Action	Environmental Protection Agency	vision. They describe six thematic areas: best available science, partnerships, communications, local support, alignment, and coastal resilience projects. The Principles will anchor collaboration across state agencies to effectively build California's resilience to sea level rise.			te-SLR-Principles-Doc_Oct2020.pdf
Coastal Plan Alignment Compass	California Governor's Office of Planning and Research	The document supports California's coastal communities as they develop and coordinate local plans. The Compass provides an overview of the required elements and best practices for each plan, discusses concrete strategies to leverage vulnerability assessments to help make them usable and applicable to all plans, and identifies crosswalk opportunities and tricky spots to avoid. It also illustrates tools and state guidance documents that support the incorporation of hazards into planning.	California	2019	https://resilientca.org/topics/plan-alignment/compass/
California's Fourth Climate Change Assessment- Statewide Summary Report	California Natural Resources Agency	California's Fourth Climate Change Assessment provides information to build resilience to climate impacts, including temperature, wildfire, water, sea level rise, and governance. California's Climate Change Assessments contribute to the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions, while also directly informing State policies, plans, programs, and guidance, to promote effective and integrated action to safeguard California from climate change.	California	2018	www.ClimateAssessment.ca.gov
State of California Sea-Level Rise Guidance Document	Ocean Protection Council	The update to the guidance reflects advances in sea-level rise science and addresses the needs of state agencies and local governments as they incorporate sea-level rise into their planning, permitting, and investment decisions. The report provides: 1) a synthesis of the best available science on sea-level rise projections and rates for California; 2) a stepwise approach for state agencies and local governments to evaluate those projections and related hazard information in decision-making; and 3) preferred coastal adaptation approaches.	California	2018	https://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/
Sea Level Rise Policy Guidance	California Coastal Commission	The report lays out interpretive guidelines for addressing sea level rise in local coastal programs and coastal development permits.	California	2018	https://www.coastal.ca.gov/climate/slrguidance.html
Case Studies of Natural Shoreline Infrastructure in Coastal California	The Nature Conservancy	Review of five projects that spanned the California coast and represented different coastal settings and corresponding approaches were selected for the purposes of this report: Seal Beach National Wildlife Refuge Thin-layer Salt Marsh Sediment Augmentation Pilot Project, Surfers' Point Managed Shoreline Retreat Project, San Francisco Bay Living Shorelines: Nearshore Linkages Project, Hamilton Wetland Restoration Project, Humboldt Coastal Dune Vulnerability and Adaptation Climate Ready Project.	California	2017	https://coastalresilience.org/case-studies-of-natural-shoreline-infrastructure-in-coastal-california/
Rising Seas in California An Update on Sea-Level Rise Science	California Ocean Protection Council Science Advisory Team	The report provides guidance to state agencies for incorporating sea-level rise projections into planning, design, permitting, construction, investment and other decisions. This document, requested by the California Ocean Protection Council and guided by a set of questions from the state Sea Level Rise Policy Advisory Committee, provides a synthesis of the state of the science on sea-level rise.	California	2017	https://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf

Statewide Sea Level Rise Vulnerability Synthesis	California Coastal Commission	This statewide vulnerability synthesis presents important findings about California's coastal resources at risk to sea level rise and how the Commission can address these risks. County-level snapshots and four Local Coastal Program (LCP) case studies provide more location-specific detail and examples of recent sea level rise planning efforts.	California	2016	https://www.coastal.ca.gov/climate/slr/vulnerability-adaptation/vulnerability/#/map
Adapting to Sea-Level Rise: A Guide for California's Coastal Communities	California Energy Commission Public Interest Environmental Research Program (Russell, N. and Griggs, G.)	This guidebook assists managers and planners in California in developing sea level rise adaptation plans. It begins with an introduction that provides background information about climate change and sea level rise and an explanation of why planners in coastal communities should begin to plan for sea level rise and the associated coastal hazards. The remaining sections walk users through the processes of performing sea level rise vulnerability assessments and risk analyses for the development of adaptation plans that can be tailored specifically to their individual communities.	California	2012	https://caseagrant.ucsd.edu/sites/default/files/Russell-Adapting-to-Sea-Level-Rise.pdf
Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present and Future	Committee on Sea Level Rise in California, Oregon and Washington, Division of Earth and Life Studies, National Research Council	As more and more states are incorporating projections of sea-level rise into coastal planning efforts, the states of California, Oregon, and Washington asked the National Research Council to project sea-level rise along their coasts for the years 2030, 2050, and 2100, taking into account the many factors that affect sea-level rise on a local scale. The projections show a sharp distinction at Cape Mendocino in northern California. South of that point, sea-level rise is expected to be very close to global projections; north of that point, sea-level rise is projected to be less than global projections because seismic strain is pushing the land upward.	United States West Coast	2012	https://nap.nationalacademies.org/resource/13389/sea-level-rise-brief-final.pdf
The Impacts of Sea-Level Rise on the California Coast	California Climate Change Center	This study includes a detailed analysis of the current population, infrastructure, and property at risk from projected sea-level rise if no actions are taken to protect the coast. The sea-level rise scenario was developed by the State of California from medium to high greenhouse gas emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) but does not reflect the worst-case sea-level rise that could occur. The report also evaluates the cost of building structural measures to reduce that risk. If development continues in the areas at risk, all of these estimates will rise.	California	2009	https://pacinst.org/wp-content/uploads/2014/04/sea-level-rise.pdf

Annex 3. Summary of workshop consultations and case studies

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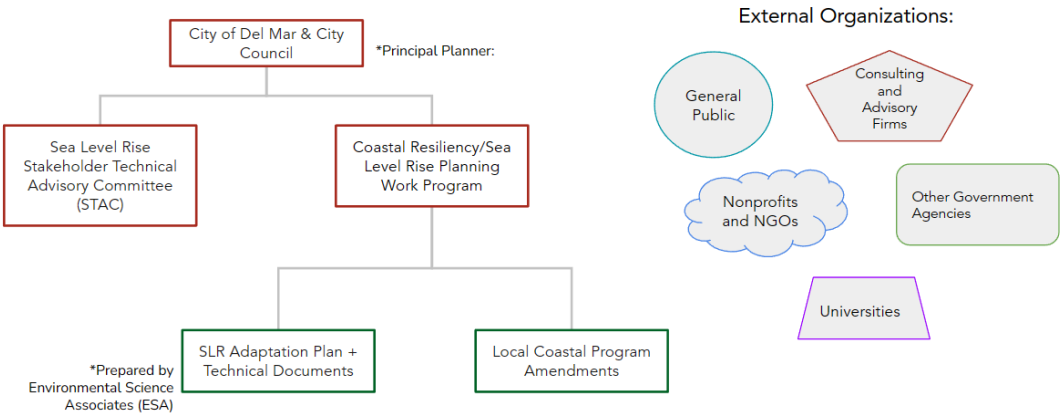
I. Analysis of case studies

This project developed an in-depth review of three city-scale case studies- Santa Cruz, Hayward, and Del Mar. These case studies were chosen after a landscape assessment of sea level rise adaptation plans throughout the state of California. All three selected cities have significant amounts of sea level rise adaptation preparation along with accessible, comprehensive information on these adaptation plans. For each city, local coastal plans, general plans, hazard mitigation plans, and any other publicly available relevant coastal resilience plans were collected and studied to characterize common adaptation pathways that are employed by regional and local governments in coastal planning. While the analysis identified effective practices and strategies to successfully develop coastal adaptation plans, it also revealed as well as common barriers to implementation of the plans. The analysis of the case studies, along with insights from coastal managers, practitioners, and stakeholders were used to identify the current needs of coastal communities and configure a targeted research agenda (main report). The case studies are briefly described below and the process summarized by timelines with the main steps.

Del Mar

Del Mar is a small coastal town located in Southern California with a population of approximately 4,200 people. The city is located in San Diego County approximately 20 miles north of the City of San Diego. This coastal town sports close to 2.5 miles of coastline of continuous beaches separated into three sections that are catered to a variety of recreational activities including swimming and surfing. Under the California Coastal Act, the coastline of the City of Del Mar is under the jurisdiction of the California Coastal Commission, indicating that the city is required to develop and submit a Local Coastal Plan outlining the city's plans for development in the coastal zone. The most recent update to the City's Local Coastal Plan began in 2015 and is ongoing.

DEL MAR'S ADAPTATION PLANNING ORGANIZATION AND STEPS



2014
City receives funding from Ocean Protection Council for adaptation planning

2015 — LCP Update process begins and is ongoing

2015–2018
City's Sea Level Rise Stakeholder Advisory Committee (STAC) was active from July 2015 - September 2018

2016 — Coastal Hazards, Vulnerability, and Risk Assessment planning document is adopted (Updated 2018)

2016
Sea Level Rise Adaptation Plan was adopted (Updated 2018)

2018 — San Dieguito Lagoon Wetland Habitat Migration Assessment Plan adopted

2018
- Sediment Management Plan adapted
- LCP Land Use and Zoning Code Amendments introduced

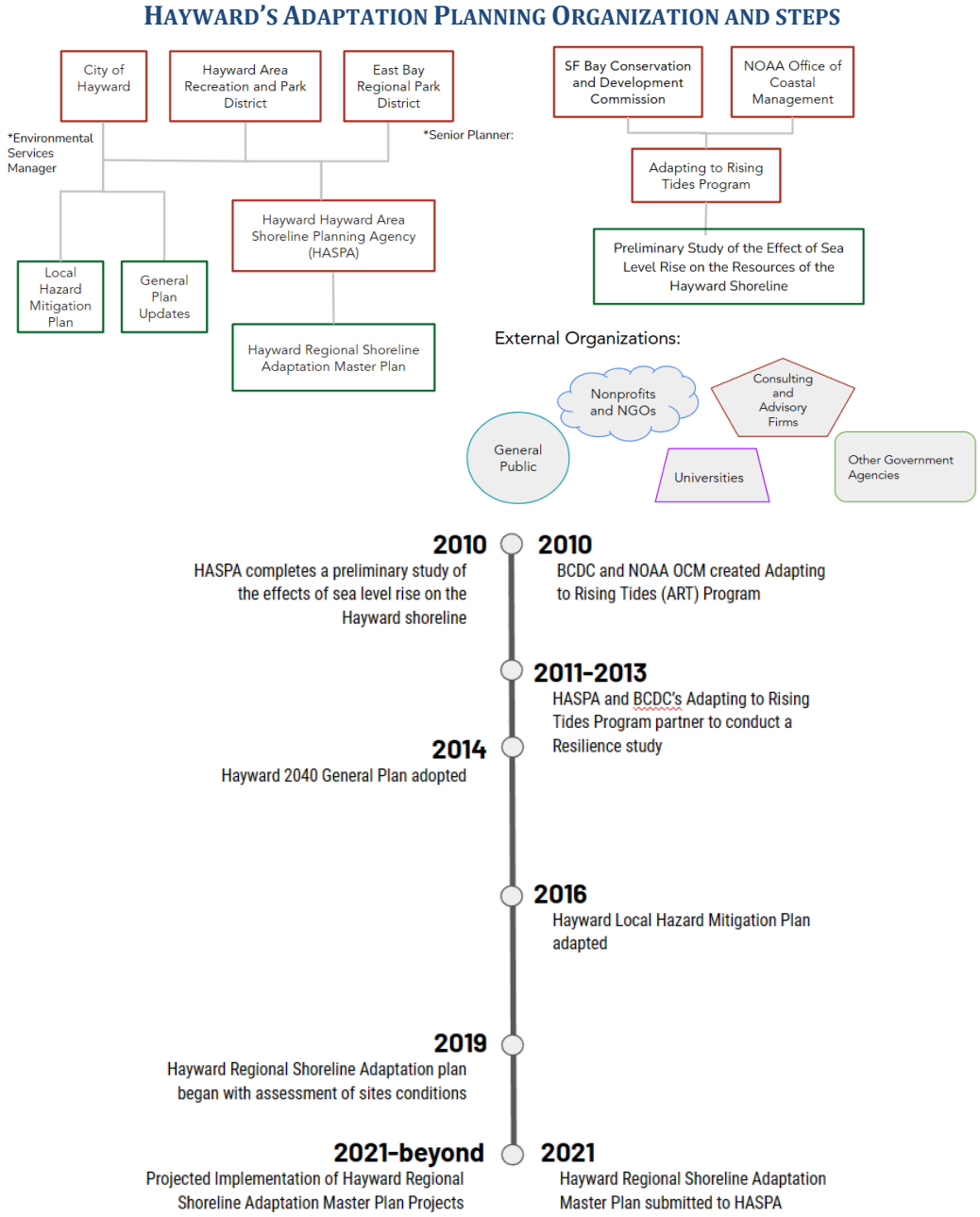
2019
City partnered with Moffatt & Nichol for a multi-year shoreline adaptation program over a period of 3-5 years

2020
Del Mar City Council adopted a Sand Compatibility Opportunistic Use Program (SCOUP)

2025
City has launched a multi-year project to replace the Camino Del Mar bridge. Expected to begin in 2025

Hayward

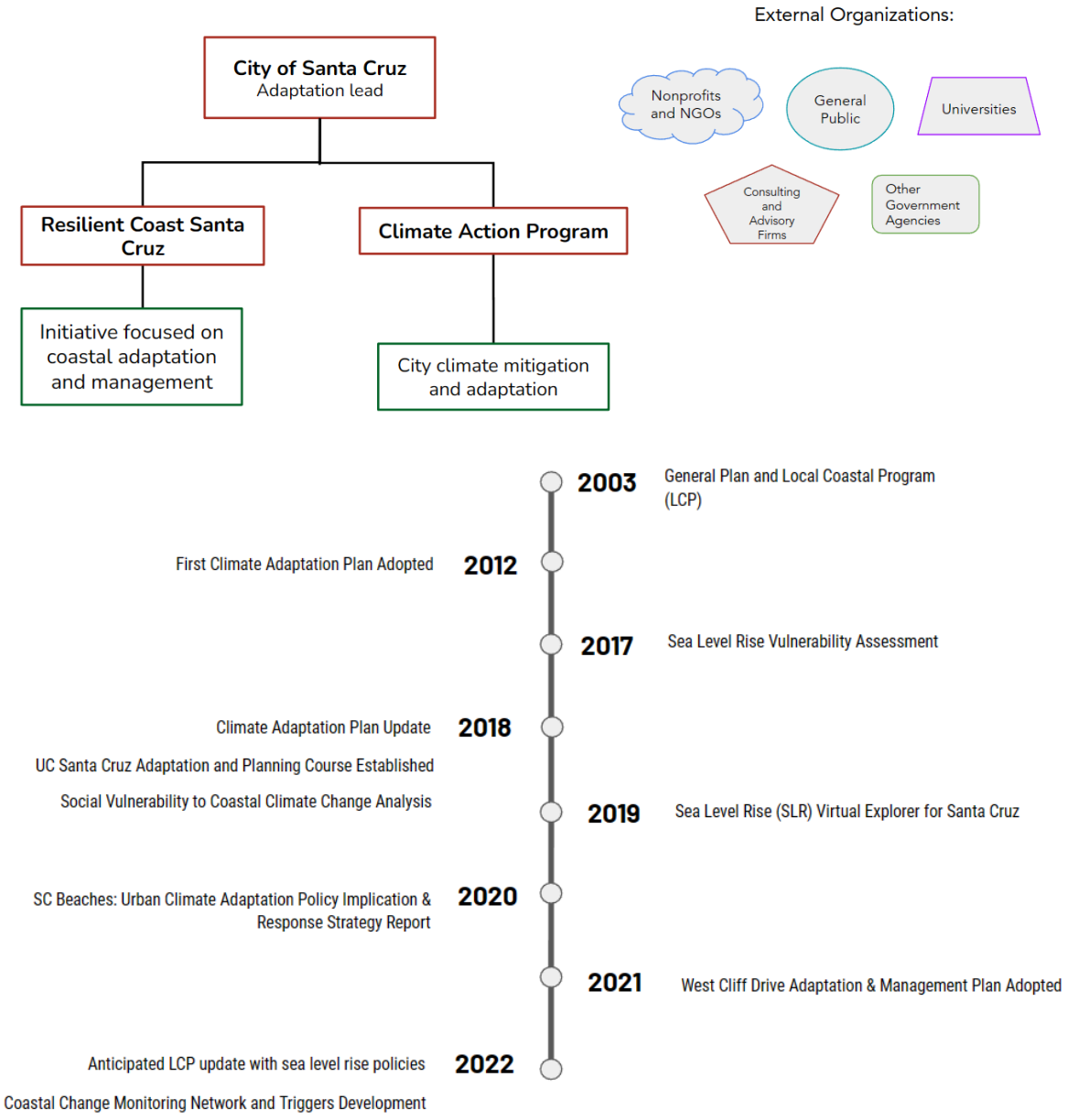
Hayward is a city located in the East Bay of the San Francisco Bay Area with a population of approximately 162,954 people. It is a part of Alameda County which is located on the east portion of the San Francisco Bay. There are many different resources and assets along the Hayward shoreline including ecologically important landscapes such as marsh habitats and wetlands. There are also many urban assets such as transmission lines and utility corridors, wastewater treatment plans and pump stations, solar fields, pipelines, as well as recreational assets such as the Bay trail and the Hayward shoreline interpretive center. Because the city of Hayward borders the San Francisco Bay, its coastal area is under the jurisdiction of the San Francisco Bay Conservation and Development Commission (BCDC), which is in contrast to the other two case studies whose coastline are under the jurisdiction of the California Coastal Commission.



Santa Cruz

Santa Cruz is a medium sized city located in Central California with a population of approximately 62,000 people. Spatially the city covers approximately 15.8 square miles. Santa Cruz is located along the northern edge of the Monterey Bay peninsula and borders the Pacific Ocean. As such, Santa Cruz's coastline is under the jurisdiction of the California Coastal commission. The primary coastal adaptation plan that has been developed in Santa Cruz is the West Cliff Drive Adaptation and Management plan, which was adopted April 27, 2021. This project is a part of Santa Cruz's Resilient Coast Initiative, a two-project initiative that has developed the West Cliff Drive Adaptation and Management Plan and the development of LCP sea level rise strategies and policies to support beach and public access protection.

SANTA CRUZ'S ADAPTATION PLANNING ORGANIZATION AND STEPS



II. Workshop 1. Stakeholders and adaptation planners

Session 1. Coastal adaptation science needs

The focus of this session was on the strengths and weaknesses of science in the coastal adaptation planning process, including: the scientific information, modeling, and available data along with considering the future needs and approaches that are needed to address concerns.

Strengths of the current coastal science in the planning process

A major strength that many of the workshop participants noted (or agreed with) is there is a large amount of information available to help guide the adaptation planning process. This information comes in a wide variety of forms including technical documents, models, experts, and various other visual representations of solutions being proposed. It is considered especially helpful when this information is presented in a non-technical format (for example including easy-to-interpret visuals) as it makes the information easier to distill and there is often a range of levels of technical expertise amongst stakeholders and planners involved in the planning process. It was also considered very helpful to have access to experts who could explain concepts in a non-technical manner. This indicates a need for more multidisciplinary scientific communication.

Weaknesses of coastal science in the planning process

A weakness that exists within the adaptation planning process is related to one of the strengths associated with it: the large amount of information available. While the large amount of information means that planners and stakeholders have access to what they need to make decisions, it can be very difficult to determine exactly what part of the information is important and sorting through the information can be very time and resource intensive. Additionally, some of the workshop participants noted difficulty with constantly changing information, as this constant turnover can lead to frustration and mistrust for those without a technical background. In addition, the quick turnover time for new information sometimes leads to there being more conflicting information, which leads to more confusion. Therefore, there is a need for help explaining why changes happen. Another weakness that was discussed was the gap between adaptation strategies and practical logistics. Planning horizons are often long, in part due to funding challenges (which are another area of concern) and thus the timelines of science projections and city planning are not always aligned.

Changes wanted and coastal science needs for future planning

Integrated, multidisciplinary approaches that integrate science and public planning are needed. There was a recurring concept brought up throughout the workshop of needing science that is transparent and easy to understand/ access. To do this coastal communities and/or agencies may need to collaborate more (potentially by grouping together) so as to avoid confusion that incurs from information overload.

Session 2. Adaptation Planning

The focus of the second session was on adaptation planning. This session focused more on the planning processes themselves (as opposed to the science that informed the planning processes- the focus of the first session), including: the decision-making process behind which shoreline concerns were addressed in each of the jurisdiction's planning processes, community engagement, and what the needs are for successful implementation of adaptation plans.

Strengths of the current planning process (i.e. what planners liked about the planning process in each of their communities)

There was a general consensus amongst the workshop participants that one of the most important aspects to have in the planning process was effective communication and engagement with the community. In each of the cities, community engagement took place in several forms ranging from general events with 100+ people to individual focus groups to online forums and surveys. It was noted that the planners for the adaptation plans often spent a lot of time actively reaching out to the community. Education was considered a key component of the adaptation planning process. Therefore, having resources that were accessible (i.e. lots of visual representation, multi-language story maps, etc.)

Potential areas of improvement for future planning

While there was a consensus that community outreach and engagement was an important part of the planning process, workshops discussions also revealed areas within this realm that may be improved upon. For example, many workshop participants noted the necessity of standing and continuous engagement in the community, and not a "one and done" scenario that is project specific. The concept of equitable community engagement was also discussed. There seemed to be a strong desire among many of the workshop participants to focus on equitable engagement in the future. This type of engagement includes understanding that although the "loudest" voices are the ones that get heard, they may not represent the entire community. While this speaks to larger issues of disproportionate representation, one methodology for ensuring more equitable engagement includes compensation for those participating in focus groups or creating resources that are available in multiple leagues.

Another area of potential improvement is related to exactly *how* findings are communicated to the community. An example of this is in the Del Mar, where many planners noted that there were "unintended consequences" of the messaging. While the science was sound and the planning started well, the vulnerability assessment showed much land was at risk and the Del Mar residents were resistant to any amount of managed retreat. The LCP process in Del Mar essentially got "derailed" in part due to issues that arose due to messaging. A potential way to mitigate this is to make sure that messaging to people who are going to be affected is targeted and directed toward their concerns. Furthermore, it is extremely important to begin outreach and engagement in the process early on and continue lines of contact with the community. This may include reporting findings at regular intervals and supporting local community groups. There will always be a public vs private land right challenge, so getting information from a less political entity may be helpful in avoiding conflict.

What is needed to successfully implement adaptation plans?

A primary need for successful implementation that was discussed by many of the workshop participants was funding. Beyond the process of obtaining funding (which is a well-noted barrier to implementation) there is also the challenge of how to manage and allocate funding properly. This ties heavily into equity concerns- are the projects that go through or gaining priority really the ones that are most needed by the people who will most feel the impact of climate change or are they the projects of the "loudest" constituents? However, as a potential solution for some of the difficulties surrounding funding, some workshop participants noted that regional collaboration may serve as an effective strategy for helping individual jurisdictions navigate acquiring and allocating funding.

Monitoring needed for successful implementation

Monitoring is a major area where the UC system may be able to help local jurisdictions on their paths to implementation of coastal adaptation plans. Many small coastal cities don't have the means to monitor

and having independent scientific monitoring reports released to the cities would be extremely helpful. Whilst there are some multi-sensor networks to monitor coastal change, there is currently a gap in looking at social and ecological triggers, as there are not many examples of this being done.

III. Workshop 2. Scientists

Session 1. Knowledge gaps

In the first session we addressed knowledge gaps related to physical and social coastal science. Participants discussed the need to better understand coastal hazards, impact assessments, and social vulnerability in California.

Knowledge Gaps: Coastal Hazards, Impact Assessments, & Social Vulnerability

More research on the trajectory of shoreline function and change of coastal bluffs, beaches, wetlands, and marshes may help increase scientific consensus on how best to adapt to a shifting coastline. Inconsistent data and lack of collaboration amongst researchers results in difficulty translating science into coastal planning and selecting adaptation pathways/methods. Participants noted the need for more studies on how humans will shape hazards and affect projections, spatial interactions such as how actions at one location can impact other locations, and how certain variables such as ocean/wave forcing will affect flood projections. Additionally, cost benefit analyses of adaptation strategies will aid local and regional jurisdictions in implementing solutions to flooding and erosion. For example, California lags behind on assessing and quantifying the effects of nature-based solutions relative to other parts of the world. This has slowed the application of nature-based solutions along the state's coast.

Participants expressed concern about coastal monitoring scaling issues. There is often a mismatch between large scale historical profiles of coastal morphology (often obtained through aerial photography) and what is occurring at a local level. There is a greater need for more detailed parcel by parcel data for the shoreline. Furthermore, while some coastal areas have extensive data sets (i.e. San Diego and Santa Barbara), there are regions of California where monitoring has been lacking thus far and scaling monitoring up is a logical next step. However, there are several barriers that have prevented the upscaling of coastal monitoring including a lack of resources and political obstacles.

The development of sound physical impact assessments is becoming more widespread, but translation of this knowledge into understanding ecosystem vulnerability and community vulnerability has proven to be difficult. The cascading impacts and downstream effects of coastal risk are often poorly understood. In order to effectively address social vulnerability, more publicly available and easily accessible data would be helpful. The state faces significant socio-economic challenges related to coastal research, planning, and project implementation. For example, outer coast property owners are typically wealthy, but there are pockets of socially vulnerable communities along the coast, and there is a significant gap in representation when it comes to decision making. There is also a large funding and capacity disparity among regions for coastal resilience. Potential disinvestment and devaluation in response to sea level rise has left many communities angry about, and suspicious of change. Human behavior and reactions to threats will affect hazards and impacts, so better understanding these dynamics will aid coastal planning efforts.

How can UC experts help address these gaps?

About 30 researchers discussed the ways in which their labs and projects could fill knowledge gaps related to coastal resilience. Their research interests spanned from the development of innovative algorithms for flow and transport in river and coastal systems and the integration of information technologies to create more accurate and efficient simulation tools to the design of new forms of infrastructure that are based

on landscape processes and which foster ecological recovery and social equity. A wide range of physical and social shoreline expertise garnered interdisciplinary debate and potential for collaboration.

Session 2. Successes and challenges informing adaptation plans

In the second session we addressed successes and challenges associated with adaptation planning and implementation. Drawing from their research experience, participants identified the main scientific gaps or barriers to implementing adaptation pathways more effectively. We also discussed the process of deciding upon thresholds and timelines for action.

Adaptation Planning and Implementation

Often incentive systems, particularly grant funding, do not align with practical project timelines. Historically, research funding has been focused more on theory-based research as opposed to applied research. Developing research pathways for coastal adaptation planning and implementation are burgeoning as state support has increased. However, more funds are needed for prolonged research activities such as monitoring.

Participants noted the lack of tools and resources that operate at a scale that is consistent with the needs of coastal managers and planners. For example, the Coastal Storm Modeling System (CoSMoS) is used to predict sea level rise, flooding, and coastal erosion, but it operates on a broad regional scale. In many cases it does not have the capacity to answer local, specific adaptation questions (i.e., what happens when a single dune is added). Another barrier that has slowed progress is a lack of information on the specific costs/benefits and efficacy of adaptation solutions at a local level. This makes it difficult for coastal managers to effectively communicate adaptation plans to the general public, who often have questions and concerns. Effective communication between researchers, coastal managers, and the general public can be difficult due to a lack of standardized measurement that can be used for evaluating local hazards and choosing adaptation options. This indicates the need for capacity building to better understand coastal hazards, and potentially a data driven project that standardizes a framework of coastal adaptation options and metrics of success.

Another communication barrier that is a result of mismatched needs and tools relates to the translational capacity of coastal adaptation research at large. While portals, models, and other technical resources are useful tools, they are often confusing to operate for people unfamiliar with science. Practitioners have asked for trained professionals that can serve as experts in how to translate science into local adaptation policy, planning, and implementation. A successful example of this is the Coastal Resource Center (CRC) at UC Irvine. The CRC works with the University's Sea Grant program and coastal managers to decrease gaps in translational capacity. This program serves as a model that could be scaled up to a state level and be led by the UC.

Many participants were disappointed by the lack of transformative vision for statewide coastal adaptation. While addressing local needs is important, identifying what the state is working towards will be crucial. The shift from local planning to more regional planning, such as the use of operational landscape units, has been advantageous. But any major changes will need to be made in cooperation with state agencies, especially the Coastal Commission, to avoid conflict and ensure legally defensible solutions. Also, state agencies may have identified key research questions that can drive UC research. Ultimately, California’s coastal adaptation would benefit greatly from the coordination of timelines and incentives of academics and agencies.