DRAFT: State of California Sea Level Rise Guidance: 2024 Science and Policy Update

January 2024

About this Report

This report was produced by the California Ocean Protection Council (OPC), in partnership with the California Ocean Science Trust (OST) and a scientific Task Force (Task Force). This report updates and replaces the previous 2018 'State of California Sea-Level Rise Guidance', and marks the fourth iteration of statewide guidance since 2010 for state and local decision-makers to incorporate best available science on sea level rise into planning, design, permitting, investments, and other decisions. To support science-based decision-making, this report consists of syntheses of the best available science on sea level rise and coastal impacts (e.g., flooding and erosion) with pragmatic and practical approaches for using this new scientific information (Chapters 2.0 and 4.0), primarily led and authored by the Task Force, as well as specific policy recommendations for incorporating this information into decision-making (Chapter 3.0), led and authored by OPC. To ensure this report meets the diversity of needs and interests for sea level rise decision-making and planning across California, state and local decision-makers, California Native American tribes, planners, and other practitioners were consulted throughout to provide input and feedback into the process and content of this report. An external scientific panel of peer reviewers provided critical review of the sea level rise science synthesis. To keep pace with future advancements in scientific understanding of sea level rise, OPC will continue to uphold its commitment to update this statewide guidance approximately every five years.

California Ocean Protection Council

OPC is a Cabinet-level state body that works jointly with state and federal agencies, non-governmental organizations (NGOs), tribes and the public to ensure that California maintains healthy, resilient, and productive ocean and coastal ecosystems. They do so by advancing innovative science-based policy and management, making strategic investments and catalyzing action through partnerships and collaboration. OPC commissioned the science update and authored the policy guidance (Chapter 3.0) for application in planning and project decisions.

California Ocean Science Trust

OST is an independent non-profit created by the California Legislature to bring cutting edge science to the decisions shaping the future of the California coast and ocean. OST led the delivery of sound, policy-relevant scientific advice to support the development of this report and meet the needs of state and local decision-makers. This included establishing the vision for this effort with the OPC, designing the collaborative science-policy process, and convening the Task Force.

Sea Level Rise Science Task Force

The Sea Level Rise Task Force is an interdisciplinary and multi-institutional collaborative of scientific experts convened beginning in June 2022 by OST to update California's sea level rise guidance based on recent scientific advancements. Members of the Task Force contributed their scientific expertise and perspectives throughout the process to author the technical scientific chapters of this report (Chapters 2.0 and 4.0) but did not provide policy direction.

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Executive Summary

Climate change is altering California's coastline. Rising seas, colliding with more frequent and extreme storms, are drowning beaches, eroding bluffs, flooding homes and businesses, and damaging roads and other essential public infrastructure. Close to 70% of California's residents live along the shore, and millions more visit every year, driving the state's $45 billion-dollar coastal economy as people come to the coast for recreation, cultural and spiritual well-being, a connection to nature, and to support their livelihoods.

To ensure that people, the environment, and the economy can continue to thrive, California must take bold and swift action to help prepare communities for the impacts we are starting to see now and that are projected to worsen in the years ahead. The Newsom Administration and the State Legislature have taken this responsibility seriously, demonstrating leadership by passing landmark legislation, providing unprecedented funding for coastal resilience planning and adaptation projects, including large-scale restoration efforts, and creating a State Sea Level Rise Action Plan to align agency priorities and decisions and leverage expertise and resources across California.

Failure to adequately prepare now will have significant cost implications in the future and consequences to public health and safety, wildlife and habitats, private property, and infrastructure necessary to maintain daily living in California. It will also have impacts on communities burdened by social and environmental injustice who are already disproportionately impacted by climate change, industrialization, and pollution. **To build resilience for coastal communities and ecosystems, thoughtful science-based planning and adaptation actions need to happen now.** This updated State of California Sea Level Rise Guidance provides the best available science and policy recommendations from which to make these decisions. California's enduring connection to the coast demands that we acknowledge the threats on the horizon and innovate to adapt to the changes ahead.

Why Are We Updating the Guidance

The previous State of California Sea-Level Rise Guidance was issued in 2018 (referred to hereafter as the 2018 California Sea-Level Rise Guidance) and was based on a synthesis of best available science at that time. Since then, there have been significant advancements in scientific understanding and ability to project future sea level rise. In February 2022 a national report entitled Global and Regional Sea Level Rise Scenarios for the United States (referred to hereafter as the 2022 Federal Sea Level Rise Technical Report) was released updating sea level scenarios for the United States based on global projections in the latest Intergovernmental Panel on Climate Change report. This national update presented an opportunity to update

California's sea level rise guidance with best available science and align the state's approach with national coastal adaptation efforts.

This report, which includes updated sea level scenarios and policy recommendations, serves as the 2024 update to the 2018 California Sea-Level Rise Guidance. It will support state and local action to assess vulnerability to rising seas and climate-driven flooding and the creation of adaptation plans and projects that build resilience into the future.

California Sea Level Scenarios

Five Sea Level Scenarios are constructed and presented for California. Adopting the scientific framework and approach used in the 2022 Federal Sea Level Rise Technical Report and creating consistency between state and federal planning, each scenario is defined and labeled according to a target value of global mean sea level rise in 2100. The Sea Level Scenarios are derived from the sets of probabilistic projections developed in the Intergovernmental Panel on Climate Change Sixth Assessment report (IPCC AR6), and reflect the most up to date scientific understanding of the physical drivers of sea level rise. The Sea Level Scenarios for California span the plausible range of future sea level rise under all emissions and global development futures and enable users to consider sea level rise without first selecting a single emissions future on which to base planning and projects.

Low: 0.3m (1.0ft) by 2100 - The target of 1 foot of increase in global sea level rise by 2100 is set under the assumption of the current rate of sea level rise continuing on into the future. This assumption is inconsistent with current observations of an acceleration in sea level rise, but could still be considered plausible under the most aggressive emission reduction scenarios. This scenario is on the lower bounding edge of plausibility given current warming and sea level trajectories.

Intermediate-Low: 0.5m (1.6ft) by 2100 - This scenario arises under a range of future emissions pathways, associated with a range of future warming levels and socioeconomic development pathways. Given current sea level observations and estimates of future warming, this scenario provides a reasonable estimate of the lower bound for the most likely sea level rise by 2100. Since low confidence processes (e.g., rapid ice sheet melt) are not important to this scenario, the range of possible sea level rise after 2100 does not expand significantly.

Intermediate: 1.0m (3.3ft) by 2100 - This scenario is driven dominantly by high emissions scenarios, and thus higher warming levels. Projections including contributions from low confidence processes provide about 25% of the pathways for reaching the scenario target by 2100. This scenario provides a reasonable upper bound for the most likely range of sea level rise by 2100.

Intermediate-High: 1.5m (4.9ft) by 2100 - This scenario is heavily reflective of a world where rapid ice sheet loss processes are contributing to sea level rise, associated with intermediate to high future emissions, and high warming. The amount of sea level rise by 2100 corresponds to other scientific estimates of plausible high-end projections.

High: 2.0m (6.6ft) by 2100 - This scenario only arises with high future emissions and high warming with large potential contributions from rapid ice sheet loss processes. Deep uncertainties and ambiguity embedded in this scenario frame a worst case beyond 2100 as we currently understand it, and a statement about the likelihood of reaching this scenario is not possible. It should be used with caution and consideration of the underlying assumptions.

Statewide Averages for Five California Sea Level Scenarios

Median values for California Sea Level Scenarios, in feet, relative to a 2000 baseline. These statewide values all incorporate an average value of vertical land motion corresponding to a negligible rate of 0.1 mm (0.0003 ft) per year uplift. The California Sea Level Scenarios track closely with global mean sea level (GMSL), with differences of only 2 to 3 inches between GMSL and the California Sea Level Scenarios in 2100. Evaluation of the Intermediate, Intermediate-High, and High scenarios (outlined in red below) is recommended to inform appropriate sea level rise planning and project decisions.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.2	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.2
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	3.0
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.9	5.4
2100	1.0	1.6	3.1	4.9	6.6
2110	1.1	1.8	3.8	5.7	8.0
2120	1.1	2.0	4.5	6.4	9.1

2130	1.2	2.2	5.0	7.1	10.0
2140	1.3	2.4	5.6	7.7	11.0
2150	1.3	2.6	6.1	8.3	11.9

Key Takeaways

The California Sea Level Scenarios show greater certainty in the amount of sea level rise expected in the next 30 years than previous reports, and demonstrate a narrow range across all possible emissions scenarios. Statewide, sea levels are most likely to rise 0.8 ft (Intermediate Scenario) by 2050.

In the mid-term (2050-2100), the range of possible sea level rise expands due to more uncertainty in projected future warming from different emissions pathways and certain physical processes (i.e. rapid ice sheet melt). By 2100, statewide averaged sea levels are expected to rise between 1.6 ft and 3.1 ft (Intermediate-Low to Intermediate Scenarios), although higher amounts are possible.

Over the long-term (towards 2100 and beyond), the range of sea level rise becomes increasingly large due to uncertainties associated with physical processes, such as earlier-than-expected ice sheet loss and resulting future sea level rise. Sea levels may rise from 2.6 ft to 11.9 ft (Intermediate-Low to High Scenarios) by 2150, and even higher amounts cannot be ruled out.

Vertical land motion is the primary driver of local variations in sea level rise across the state, driven by a combination of tectonics, sediment compaction, and groundwater and hydrocarbon withdrawal. Vertical land motion is incorporated into the sea level scenarios for each National Oceanic and Atmospheric Administration (NOAA) tide gauge and illuminates locations experiencing subsidence or uplift.

The extreme sea level rise scenario (i.e. H++) from Rising Seas 2017 is much higher than best available science suggests and has not been included in the 2024 update.

Today's coastal storms provide a glimpse into our future in which storm events will become more damaging and dangerous as climate change and sea level rise continue. Coastal storms coinciding with high tides under future sea level scenarios will cause accelerated cliff and bluff erosion, coastal flooding and beach loss, and mobilization of subsurface contaminants. Sea level rise will increase the exposure of communities, assets, services and culturally important areas to significant impacts from coastal storms.

Sea level rise will increase the frequency of coastal flooding events, which occur when sea level rise amplifies short-term elevated water levels associated with higher tides, large storms, El Niño events, or when large waves coincide with high tides. California communities need to be aware of and prepared for a likely rapid increase in the frequency of coastal flooding beginning in the 2030s.

Groundwater rise poses a threat to below-ground infrastructure and freshwater aquifers under future sea level scenarios. In coastal areas with shallow unconfined groundwater, the water table will generally rise with sea level, depending on local geomorphology. This can mobilize soil contaminants, expose underground infrastructure to corrosive saltwater, and put freshwater aquifers at risk of saltwater intrusion.

Guidance on Planning for Sea Level Rise Using the California Sea Level Scenarios

This stepwise process recommends a precautionary approach for incorporating Sea Level Scenarios into planning and projects that includes adaptation pathways to phase actions over time. These steps complement other State guidance documents that also provide stepwise approaches to conducting analyses that inform sea level rise planning and decision making.

STEP 1: Identify the nearest tide gauge
The report’s appendices provide a map of the 13 tide gauges in California for which localized Sea Level Scenarios are presented that incorporate the localized effects of vertical land motion.

STEP 2: Evaluate planning and/or project time horizon(s)
Determine how long a given planning effort or project is intended to function. If it is not possible to plan or adapt for the entire time horizon from the outset, a phased adaptation approach can be taken that provides earlier time horizons for interim adaptation steps.

STEP 3: Choose Sea Level Scenarios and storm conditions for vulnerability assessment
It is recommended to evaluate the vulnerability of people, natural resources and infrastructure under the Intermediate, Intermediate-High, and High scenarios. Analysis of storm conditions under Sea Level Scenarios is also recommended.

STEP 4: Conduct vulnerability assessment
Conducting a vulnerability assessment begins with creating exposure maps of sea level rise-induced inundation and flooding, which can also incorporate coastal erosion and groundwater rise. Once the physical extent of exposure is determined, a sensitivity analysis will provide information on the potential impacts of that exposure. The final step in a vulnerability assessment is for a community to determine its adaptive capacity to the determined impacts.

STEP 5: Explore adaptation options and feasibility
A collaborative process including affected communities, stakeholders, and relevant regulatory bodies should explore feasible adaptation options.

STEP 6: Select phased adaptation approach and/or implement project
Following an assessment of adaptation options, a specific project or adaptation pathway must be selected and implemented.

As the stepwise approach to applying Sea Level Scenarios is undertaken, general recommendations and principles to incorporate include: prioritization of social equity, environmental justice and the needs of underserved and vulnerable communities; protection of coastal habitats and public access; consideration of water-dependent infrastructure and uses; consideration of episodic increases in sea level rise caused by storms and other extreme events; coordination and collaboration with local, state and federal governments; consideration of local conditions; inclusion of adaptive capacity in design and planning; and assessment of risk and adaptation planning should be conducted at community and regional levels when possible.

1.0 Introduction

Earth's climate is changing, ice sheets and glaciers are melting, ocean water is warming and expanding, and sea levels are rising in response. The continuing and increasing emission of greenhouse gasses, particularly carbon dioxide, from the burning of fossil fuels (i.e., coal, oil, and natural gas) are the primary drivers of a warming planet. The more greenhouse gasses that we emit, the warmer the atmosphere and ocean become, and the higher and more rapidly sea level will rise in response.

The potential loss or damage to public infrastructure, health and safety, private developments, and natural habitats due to sea level rise is significant and urgent. Approximately 700,000 residents and $250 billion in property across California could be exposed to the combination of storms and sea level rise-driven flooding during the 21st century.[1] Importantly, adverse impacts from sea level rise are not distributed equitably among vulnerable populations. Sea level rise hazards will have disproportionate impacts on communities with the least capacity to adapt and may exacerbate existing environmental injustices. As we better understand the influence of climate change on the melting of glaciers and ice sheets, ocean warming, and their potential impact on future sea levels and associated coastal hazard risk, the better we can predict and estimate future sea level rise and inform adaptation planning.

As sea level rise accelerates, risks from other coastal processes are expected to increase. For example, rising sea levels will lead to more episodic flooding and permanent inundation of low-lying areas that are exposed to high tides, and erode important habitats such as beaches, coastal wetlands, cliffs, and dunes. Higher sea levels will also contribute to rising groundwater tables that will bring saltwater intrusion into freshwater aquifers, increase corrosion of underground infrastructure, mobilize subsurface contaminants, and lead to surface pooling of water.

Elevated sea levels can exacerbate the damaging effects of coastal storms. On January 5, 2023, wave heights reached 28 feet offshore from Monterey Bay, and arrived simultaneously with spring high tides. Strong onshore winds, which drive and add force to local storm waves and swells from distant storms, further elevated wave heights. Waves eroded the 20-30 foot high bluffs along West Cliff Drive in Santa Cruz, destroying sections of the heavily used roadway and pedestrian path. These co-occurring wave, storm surge, and high tide conditions also destroyed the historic wooden pier at Seacliff State Beach, flooded coastal streets and roads, and damaged both private development and public infrastructure along the northern Monterey Bay shoreline. Such extreme storms are anticipated to increase in frequency and intensity due to

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[1] Barnard et al., 2019.

climate change[2]. The cumulative impact of these storm impacts, combined with accelerating sea level rise, will result in even more significant damage along California's coast.

1.1. Existing state policy guidance and sea level rise planning

Over the past five years, sea level rise planning in California has been guided by the 2018 State of California Sea-Level Rise Guidance. In that guidance, OPC committed to updates approximately every five years to ensure that adaptation planning and projects are based on the best available science.

Since 2018, state agencies and departments have advanced sea level rise adaptation through the development, uptake, and implementation of multiple sea level rise policies, programs, and actions. For example, in 2020 the California Natural Resources Agency and California Environmental Protection Agency released a set of Sea-Level Rise Principles with the purpose of aligning state planning, policy setting, project development, collaboration, and decision-making around sea level rise.[3] These principles were co-developed with the State Sea-Level Rise Collaborative, which is a group of 17 state agencies[4] that meet quarterly to discuss coastal resilience issues at the state level, including emerging science, policy, and projects. Previously named the Sea-Level Rise Leadership Team, the State Sea-Level Rise Collaborative is also synonymous with the California Sea-Level Rise State and Regional Support Collaborative, as referenced in Senate Bill 1 (Atkins, 2021). Facilitated by OPC, the Collaborative co-produced the State Agency Sea-Level Rise Action Plan for California in 2022, which provides a roadmap for coordinated and aligned state agency efforts to build resilience.[5]

Since 2018, sea level rise planning efforts across the state have advanced in number, scale, and sophistication. Many coastal cities and counties have completed vulnerability assessments,

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[2] Bromirski, 2023.

[3] California Natural Resources Agency, 2020. http://www.opc.ca.gov/webmaster/_media_library/2020/05/State-SLR-Principles_FINAL_April-2020.pdf

[4] State Sea-Level Rise Collaborative members: California Natural Resources Agency, California Environmental Protection Agency, San Francisco Bay Conservation and Development Commission, California Coastal Commission, California Energy Commission, California Department of Fish and Wildlife, Caltrans, Delta Stewardship Council, Department of Water Resources, Ocean Protection Council, Governor's Office of Planning and Research, Office of Emergency Services, State Coastal Conservancy, State Lands Commission, State Parks, State Water Resources Control Board, Strategic Growth Council, Department of Insurance.

[5] Sea-Level Rise Collaborative, 2022. https://www.opc.ca.gov/webmaster/_media_library/2022/08/SLR-Action-Plan-2022-508.pdf

which estimate the threat that sea level rise poses to public utility infrastructure, private homes, businesses, recreation areas, community centers, coastal habitats, and more.[6] Most of this planning has not yet considered the potential for impacts from rising groundwater or compound flooding. Sea level rise projections have been incorporated into local and regional planning and decision frameworks including Local Coastal Programs (LCPs), hazard mitigation plans, and the Delta Stewardship Council Delta Plan and Delta Adapts, among others.

1.2. Purpose & Intended Use

This report, and the accompanying data sets and links to tools and resources, serves as the 2024 update to the previous 2018 guidance. This report aims to: (1) synthesize and provide updated science of sea level rise and coastal hazards; and (2) provide practical and pragmatic guidance for applying this updated science across planning efforts and decision-making contexts.

This report provides guidance for a broad range of audiences including state agencies, tribes, regional and local governments, and climate adaptation planners. It is intended to foster coordinated and consistent statewide planning and decision-making based on science, and to enable the incorporation of sea level rise into the full suite of relevant sectors, policy decisions, adaptation plans, project designs, and investments.

1.3. How this report was developed

In June 2022, OPC and OST convened an interdisciplinary Sea Level Rise Science Task Force (hereafter referred to as the Task Force) to update the science foundation for state sea level rise policy. Task Force members contributed their technical expertise in meetings and discussions. OPC and OST collaborated to update the policy guidance as needed to incorporate this new science. OPC and OST consulted and gained input from state agency staff and local and regional planners, via multiple meetings and workshops, to align the updated science and guidance with their needs, interests, and opportunities for planning and preparing for sea level rise. The updated sea level rise science for California in Chapter 2.0 of this report was peer reviewed by three independent experts to ensure technical rigor, and was revised in response to reviewer comments.

Feedback from the State Sea-Level Rise Collaborative was incorporated prior to a public comment period. OPC conducted initial listening sessions and formal consultation with California Native American tribes to ensure that the guidance reflects tribal priorities and meets the needs of tribal governments and tribal communities.

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[6] Lester et al., 2023.

1.4. Updating the science foundation for statewide policy guidance

The 2018 California Sea-Level Rise Guidance was based on a science synthesis, the Rising Seas in California report (hereafter referred to as Rising Seas 2017), developed by an expert panel and released the previous year. Rising Seas 2017 provided sea level projections for specific locations along the California coastline, covering the time period from 2020 to 2150. Three different probabilistic projections tied to "Representative Concentration Pathways", or RCPs, were provided alongside an extreme sea level rise scenario with unknown probability referred to as H++.

Since the release of Rising Seas 2017, the scientific community has made significant improvements in its ability to understand and project future sea level rise, offering a timely opportunity to update California's sea level rise projections and align state guidance with this new science. In particular, observational and modeling studies have provided more clarity on when and how much ice sheet and glacial melt will contribute to future sea level rise. This improved scientific understanding has been reflected in updated global probabilistic sea level rise projections provided by the Intergovernmental Panel on Climate Change 6th Assessment Report (IPCC AR6).[7] In February 2022, a multi-agency federal group delivered the 2022 Federal Sea-Level Rise Technical Report[8], which integrated this best available science from IPCC AR6 into five sea level scenarios that span the plausible range of sea level rise from 2020 to 2150 for all U.S. states and territories.

Representative Concentration Pathways (RCPs)

Future greenhouse gas emissions and concentrations are difficult to predict and depend on future developments such as future population growth, economic growth, energy use, uptake of renewable energy, technological change, deforestation and land use. The climate-modeling community developed four RCPs that span a large range of future global warming scenarios. RCPs are space and time dependent trajectories of future greenhouse gas concentrations and different pollutants caused by different human activities. RCPs quantify future greenhouse gas concentrations and the radiative forcing (additional energy taken up by the Earth system), due to increases in greenhouse gas emissions.

Shared Socioeconomic Pathways (SSPs)

Developed more recently, the SSPs are a collection of narrative descriptions of alternative futures of socio-economic development in the absence of climate policy intervention. Five SSPs describe five different pathways that the world could take, drawing on data including

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[7] Masson-Delmotte et al., 2021.

[8] Sweet et al., 2022.

population, economic growth, education, urbanization, and the rate of technological development. The SSPs are important inputs into the IPCC sixth assessment, and are used to explore how societal choices will affect greenhouse gas emissions.

1.4.1 Framing potential sea level rise futures through scenarios

In Chapter 2.0 of this report, the Task Force adopted the scenarios framework in the 2022 Federal Sea-Level Rise Technical Report to provide Sea Level Scenarios for California, bringing consistency to state and federal sea level rise planning. These scenarios are derived from the sets of probabilistic projections developed in the IPCC AR6, and reflect the most up to date understanding of the physical drivers of sea level rise. As such, the information about the likelihood of meeting or exceeding a specific Sea Level Scenario is embedded in the scenarios themselves (e.g., the High Scenario is less likely than the Intermediate Scenario, as described in more detail in Chapter 2).

The Sea Level Scenarios for California span the plausible range of future sea level rise under all of the possible emissions and global development futures, or SSPs, defined by the IPCC AR6. While Rising Seas 2017 provided probabilistic projections under three IPCC emissions scenarios termed RCPs, the Scenarios in this report span all SSPs and enable users to consider sea level rise without first selecting a single emissions future on which to base planning.

1.5. Translating science into policy guidance

California has a strong existing foundation for developing science-based, pragmatic policy guidance, even in the face of uncertainties about the future. Chapter 3.0 of this report applies the newest science to update policy guidance, as appropriate. These updates do not represent new or significantly changed state policy direction. Consistent with the 2018 California Sea-Level Rise Guidance, this 2024 update recommends a stepwise process for incorporating Sea Level Scenarios into planning and decisions that is still precautionary in nature. This report describes considerations for adaptation and planning that match the advancing sophistication of adaptation planning across the state, and upholds California’s values and priorities that are as relevant today as five years ago when the 2018 California Sea-Level Rise Guidance was released.

Rising Seas 2017 provided a rigorous treatment of scientific uncertainties associated with the physical processes of sea level rise by providing probabilistic projections. The 2018 California Sea-Level Rise Guidance then created decision-ready sea level scenarios by selecting certain projections and assigning levels of risk aversion associated with each (see Table 1 in the 2018 California Sea-Level Rise Guidance). Like the 2018 sea level projections, the California Sea Level Scenarios in Chapter 2.0 incorporate a risk-based framing by addressing uncertainties in the physical processes causing sea level rise, and in the ability to model and project future timing and magnitudes of sea level rise. Chapter 2.0 differs from the 2018 California Sea-Level Rise Guidance in that it provides Sea Level Scenarios spanning a range of emissions pathways, rather than several sets of probabilistic projections each linked to a different emissions pathway (RCP). Like the 2018 California Sea-Level Rise Guidance, the stepwise process for incorporating sea level rise into planning and decisions still includes consideration of other important elements of risk, qualitative and quantitative social and economic impacts, and adaptive capacity.

Chapter 4.0 of this report describes how sea level rise intersects with multiple coastal hazards including flooding, groundwater rise, and shoreline change. Application and use of Sea Level Scenarios and the accompanying guidance is not a single step but should be invoked at multiple stages of climate adaptation planning and implementation. To that end, several data visualization and decision-support tools have been developed, and continue to be refined, to support local, regional, and statewide adaptation planning, which are summarized in Appendix 3. OPC, working with local, tribal, state and federal partners, will continue to support and advance uptake and use of this policy guidance in the full breadth of adaptation planning and implementation that intersects with sea level rise.

Causes of Sea Level Rise in California

Sea level rise along the coast of California is driven by a combination of processes. These processes operate on different spatial scales – from global to local – and affect the California coastline in different ways.

Global Sea Level Rise

The primary causes of sea level rise on global scales are thermal expansion due to ocean warming and the input of freshwater from melting ice sheets and glaciers on land. Both of these processes result from ongoing warming of the planet due to greenhouse gas emissions from human activities. Tide gauge measurements show roughly 5 inches of GMSL rise during the 20th century.[9] Since 1993, satellite altimeters have provided continuous near-global measurements of sea level, showing an additional 4 inches of GMSL rise just in the past 30 years.[10] From these observations, it is clear that sea level rise is accelerating,[11] and the current rate of GMSL rise (1.7 inches/decade) is triple the 20th century rate.

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[9] Frederikse et al., 2020.

[10] Willis, Hamlington, Fournier, 2023.

[11] Dangendorf et al., 2019; Nerem et al., 2018.

Regional Relative Sea Level Rise

Sea level rise is not uniform across the globe. Relative sea level rise (the rise of seas relative to land) at any specific location is driven by a combination of the global processes described above plus three primary local and regional processes:

1) **Sterodynamic Sea Level Change:** Sterodynamic sea level change describes the combined effect of steric (temperature and salinity) changes and changes in ocean dynamics (i.e. winds, currents). Sea level rise caused by large-scale persistent changes in ocean dynamics is not currently expected to be consequential for the California coast.[12] During the satellite altimeter era (1993-present), the combination of shorter-term El Niño-Southern Oscillation (ENSO, or El Niño) and decadal variability led to a dramatic shift in the rates of sea level rise during the satellite record, which have now evened out over the full 30-year record. These shifts will continue to happen in the future, but persistent sterodynamic sea level rise along the California coast is expected to be primarily driven by ongoing thermal expansion of the ocean and, therefore, will track closely with the global average into the future.[13]

2) **Gravitational, Rotational, and Deformational:** The impact of ice-mass loss is expected to be larger for the California coast than the global average.[14] As an ice sheet loses mass to the ocean, its gravitational pull on the surrounding ocean is reduced. In the vicinity of the ice sheet, the reduced gravitational pull on the ocean causes the sea level to decrease, but as distance from the ice sheet increases, the change in local relative sea level becomes greater than the global average[15] (see Rising Seas 2017 or Hamlington et al., 2020 for detailed explanation). As a result, California is heavily impacted by ice loss from the West Antarctic Ice Sheet, and for every foot of global sea level rise caused by ice loss in West Antarctica, California sea level will rise about 1.25 feet. The Greenland Ice Sheet, on the other hand, contributes about 0.75 feet of sea level rise to California for every foot of global sea level rise. Due to its larger-scale regional impact, GRD effects do not lead to large differences in sea level rise between locations along the California coast.

3) **Vertical Land Motion:** Vertical land motion is the result of a combination of processes acting together on different temporal and spatial scales. On the largest scales, Earth's surface is still rising and falling after the retreat of large ice sheets that covered the Northern Hemisphere about 18,000 years ago, a process referred to as glacial isostatic

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[12] Fox-Kemper et al., 2021.

[13] Hamlington et al., 2021.

[14] Griggs et al., 2017.

[15] Mitrovica et al., 2011.

adjustment.[16] Given the distance of California from these past ice sheets, the impact of these land adjustments is small, but detectable. On a local scale, tectonics, sediment compaction, and groundwater and hydrocarbon withdrawal play a role in vertical land motion in California. Records of vertical land motion observation are short, and a complete understanding of vertical land motion at any particular location generally requires considerations of local land-use alongside available measurements. When compared to sterodynamic and gravitational, rotational, and deformation-related changes in sea level rise along the California Coast, the impact of vertical land motion on relative sea level rise is much more localized and can lead to significant differences from one location to the next.

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[16] Peltier et al., 2004.

2.0 California Sea Level Scenarios

Lead Author: Dr. Benjamin Hamlington

Key Takeaways

- Since Rising Seas 2017, the scientific community has made significant improvements in its ability to understand and project future sea level rise and this best available science was incorporated, in this report, into a set of five California Sea Level Scenarios from 2020 to 2150.
- The California Sea Level Scenarios show greater certainty in the amount of sea level rise expected in the next 30 years than previous reports, and demonstrate a narrow range across all possible emissions scenarios. Statewide, sea levels are most likely to rise 0.8 ft (Intermediate Scenario) by 2050.
- In the mid-term (2050-2100), the range of possible sea level rise expands due to more uncertainty in projected future warming from different emissions pathways and certain physical processes (i.e. rapid ice sheet melt). By 2100, statewide averaged sea levels are expected to rise between 1.6 ft (Intermediate Low) and 3.1 ft (Intermediate-Low to Intermediate Scenarios), although higher amounts are possible. cannot be ruled out.
- Over the long-term (towards 2100 and beyond), the range of sea level rise becomes increasingly large due to uncertainties associated with physical processes, such as earlier-than-expected ice sheet loss and resulting future sea level rise. Sea levels may rise from 2.6 ft to 11.9 ft (Intermediate-Low to High Scenarios) by 2150, and even higher amounts cannot be ruled out.
- Vertical land motion is the primary driver of local variations in sea level rise across the state, driven by a combination of tectonics, sediment compaction, and groundwater and hydrocarbon withdrawal. Vertical land motion is incorporated into the sea level scenarios for each National Oceanic and Atmospheric Administration (NOAA) tide gauge and illuminates locations experiencing subsidence or uplift.
- The extreme sea level rise scenario (i.e. H++) from Rising Seas 2017 is much higher than best available science suggests and has not been included in the 2024 update.

In August 2021, the Working Group I contribution to the IPCC AR6 was released.[17] This contribution provides the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science. Chapter 9 of that contribution provides the latest scientific understanding of the physical processes underlying global and regional changes in the ocean, cryosphere and sea level[18] and forms the scientific foundation for developing California Sea Level Scenarios.

The 2022 Federal Sea Level Rise Technical Report includes a set of five sea level scenarios for the U.S., providing a range of plausible changes through 2150. The scenarios were developed from the suite of modeled projections in the IPCC AR6 that include new advancements in the understanding of when and how various global and regional processes may occur (e.g., ocean dynamics, glacier and ice sheet melt, mass redistribution). The five scenarios (Low, Intermediate-Low, Intermediate, Intermediate-High, and High) correspond to average global sea level rise magnitudes in the year 2100. Here, the same framework and approach is adopted for consistency, and the scenarios are regionalized to develop California-specific scenarios.

2.1. Updated Scientific Understanding

Since Rising Seas 2017 was developed, scientific understanding of both present and future sea level has evolved. Recent observations of sea level change have advanced the scientific understanding of present sea level rise, and advances in the projection of future sea level rise reflect a deeper understanding of possible high end estimates of future sea level rise.

2.1.1. Observed sea level change

The rate of sea level rise along California's shoreline during the satellite altimeter era (1993-present) has been less than the global average for much of that record[19] due primarily to the influence of natural variability temporarily obscuring the background, climate-driven rate. The combination of El Niño and decadal variability associated with the Pacific Decadal Oscillation has led to dramatic shifts in the rate of sea level rise across the 30 years of the satellite record, wherein sea level rise was essentially absent during the first half and was substantial during the second half of the record (Figure 2.1, top). These shifts will likely continue in the future, but longer tide gauge records together with recent observations suggest that sea level rise along the California coast should resemble the global average.[20] The time series of average California sea level change from both tide gauges and satellite altimetry is shown in Figure 2.1 (bottom).

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[17] Masson-Delmotte et al., 2021.

[18] Fox-Kemper et al., 2021.

[19] Bromirski et al., 2011; Thompson et al., 2014; Moon et al., 2015; Hamlington et al., 2021.

[20] Hamlington et al., 2021.

Over the complete record from 1993 to 2023, the rate of sea level rise for California, on average, is 0.9 inches/decade.

2.1.2. Advances in projecting future sea level rise

The current consensus understanding on sea level rise was described in the IPCC AR6, which used this knowledge to create new projections of future sea level rise. The updated IPCC AR6 sea level projections are formed by integrating different projections of individual processes that cause sea level change within a consistent framework.[21] The latest generation of global climate models from the Coupled Model Intercomparison Program's sixth phase (CMIP6) are used to account for the ocean dynamic regional sea level rise and similar methods are used for assessing vertical land motion contributions as in past reports. For the coast of California, the updates do not lead to significant changes for these contributions relative to past reports.

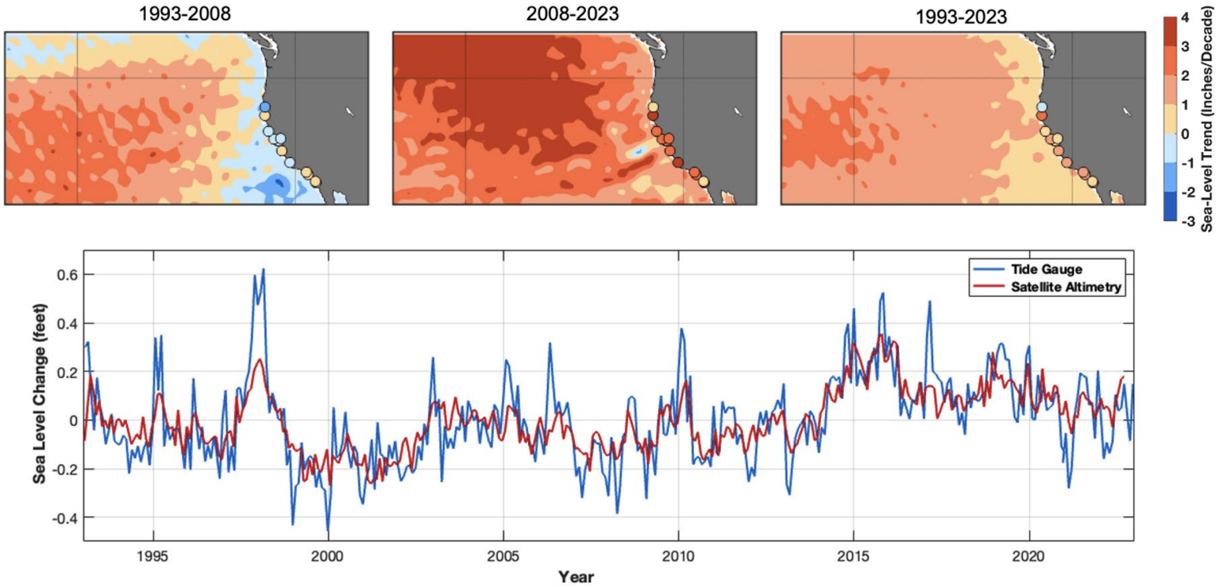

Figure 2.1. Top: The rate of sea level rise, in inches per decade, for California estimated from both tide gauges and satellite altimetry over three different time periods: 1993-2008, 2008-2023, and 1993-2023. Bottom: Sea level variations in feet averaged along the California coastline from both tide gauges and altimetry.

By comparison, the IPCC AR6 reflects a step forward in scientific understanding of the ice sheet contributions to sea level rise, and in how this understanding should be incorporated into projections. This has altered projections of sea level rise relative to past reports (e.g., Rising Seas 2017). In addition to being important sources of future sea level rise, projections of future

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[21] See Table 9.7; Fox-Kemper et al., 2021.

ice sheet change represent the largest sources of uncertainty in estimating sea level rise towards the end of this century and beyond, even with this new understanding.

Within the AR6 framework, a set of SSP scenarios that project global socioeconomic changes to 2100 are used to drive models of the physical processes causing sea level rise to generate sea level projections. Five SSP-based projections included only physical processes in which there is at least medium confidence in the current scientific understanding, and two additional scenarios (one low emissions, one high emissions) included ice sheet processes in which there is currently low confidence among scientists (see below for a description of 'confidence'). These low confidence processes include earlier-than-projected ice-shelf disintegration in Antarctica, abrupt and widespread onset of marine ice-sheet instability and/or marine ice-cliff instability in Antarctica, and faster-than-projected changes in surface-mass balance on Greenland. Low confidence as applied to these processes reflects an incomplete scientific understanding of the physics underlying these processes, and associated gaps in representing these processes in the current generation of models that are used for projections. This leads to low confidence in the ability to quantify the sea level rise that will result if any of these processes were to be triggered. As a result of the low confidence in these processes, the two scenarios in which they appear are considered of unknown likelihood.

2.1.3. Timing of high-end sea level rise

Although the IPCC AR6 assigned low confidence in the role these processes will play in the future, they do play an important role in determining the full range of possible sea level rise at any time in the future. An important change in the IPCC AR6 projections resulted from an update in the understanding of when these low confidence processes could come into play. The physical processes that could lead to much higher increases in sea level are now viewed by the scientific community as less plausible in the coming decades before potentially becoming a factor towards the end of the 21st century and beyond.[22] Additionally, at lower future warming levels (less than 2°C by 2100), significant contributions from these processes are not expected until beyond 2100, if at all.

As a result, when compared to past reports such as Rising Seas 2017, there is less acceleration of sea level before 2050, and the possibility of greater acceleration only towards the end of the 21st century and beyond. This has two primary implications when compared to the projections in the 2018 California Sea-Level Rise Guidance. First, there is now a narrower range of plausible sea level rise prior to 2050. Second, new scientific consensus represented in the IPCC AR6 is that the H++ scenario, in Rising Seas 2017, is not physically plausible as it incorporates too

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[22] DeConto et al., 2021; DeConto & Pollard, 2016.

much sea level rise in the near-term and a consequent ongoing high rate of sea level rise throughout the rest of the 21st century.

Confidence

Confidence, in IPCC terms, measures a combination of available evidence and agreement among scientists. Evidence assesses the amount, quality and consistency of lines of evidence agreeing with a conclusion, while agreement evaluates the breadth of support for conclusions among experts. The IPCC AR6 uses a range of qualifiers to express this assessment, and therefore, confidence: Very Low, Low, Medium, High, and Very High.

In this report, two types of confidence are used:

1) **Medium Confidence**: used to denote moderate agreement among experts on the model treatment of key processes (e.g. those used in the IPCC AR6 SSPs) and moderate lines of evidence supporting model outputs.

2) **Low Confidence**: used to denote a low level of agreement on how models represent key processes (e.g. partial, rapid ice sheet disintegration) and limited evidence supporting model outputs.

2.2. Steps to Build California Sea Level Scenarios

Five Sea Level Scenarios have been developed for the California coast using the following process, also depicted in schematic form in Figure 2.2. This process is consistent with the approach in the 2022 Federal Sea Level Rise Technical Report but is regionalized to produce California-specific scenarios:

1. A front-end assessment of the IPCC AR6 is used to determine a plausible range of global mean sea level rise of between 0.3 and 2.0 m in 2100. Plausible does not simply mean “possible” but is instead used here to mean credible, with the support of published, peer-reviewed projections in addition to the consensus assessment of the IPCC AR6. Further support for the selection of the plausible range is provided in Figure 2.4 through analysis of the ranges of the AR6 scenarios at different time horizons.
2. The IPCC AR6 created sea level projections for multiple SSPs. In addition, projections allowing for potential contributions from rapid ice-sheet loss processes with unknown likelihood were also created for the SSP1-2.6 and SSP5-8.5 scenarios. For each SSP, an ensemble of thousands of “samples” of the trajectory of sea level rise from 2020 to 2150 was produced. The distribution of these samples for each SSP is shown on the left of Figure 2.2.

3. Five GMSL targets or “gates” in 2100 that span the plausible range from 0.3 to 2.0 m are defined. The full set of samples is filtered to find the ones that fit through each of these five gates +/- 2 cm. As shown in Figure 2.2, the SSPs with the lowest emissions primarily build the lowest sea level scenarios. The SSPs with the highest emissions plus the scenario that takes into account rapid ice sheet loss primarily build the higher scenarios. These GMSL targets used to define the California Sea Level Scenarios are consistent with the national report.
4. Finally, five time-varying Sea Level Scenarios of GMSL and associated local relative sea level rise are constructed by collecting all the samples from across SSPs that fit through the defined gates. Logically, the Intermediate Low and Intermediate scenarios will include the highest number of samples, while the other sea level scenarios will have comparatively less. The individual samples of sea level projections provide important contextual information for each of the Sea Level Scenarios, carrying with them a range of warming levels and emissions pathways. While it is not possible to directly assign probabilities to each of the sea level scenarios, additional assumptions about the future (e.g. warming level) allow for the assignment of a probability of exceeding a particular Sea Level Scenario in that assumed future (see Chapter 2.4).

The contributions from sterodynamic sea level rise and from ice mass loss are similar across all of California, varying by less than 1.2 inches from the southern to northern extents at all time periods and all scenarios prior to 2100; vertical land motion is the primary driver of variations among different locations across the state. A single average value of vertical land motion (corresponding to a negligible rate of 0.10 mm/year uplift) is used for this chapter where statewide values of the Sea Level Scenarios are provided. Sea Level Scenarios for individual NOAA tide gauge locations that incorporate site-specific vertical land motion projections can be found in Appendix 2.

The scenarios show the rise in mean relative sea level over time and represent only the relative sea level rise happening on long timescales. Shorter period sea level change associated with El Niño, tides, storm conditions, or other natural ocean variability is not included in the scenarios themselves and does not contribute to the likely range of the scenarios. Including additional sea level rise on top of these scenarios (i.e., a buffer) to account for this natural variability is not recommended. Adding a buffer on top of the scenarios to generate new target values can lead to misleading interpretations and conclusions, and could even lead to double-counting of natural sea level variability when subsequently projecting flood frequency and severity. Rather, the contributions from these temporary fluctuations can be considered related to coastal hazards that contribute to sea levels or when end users are required to use an online tool with limited sea level rise value options (see Chapter 4.0 for more detail).

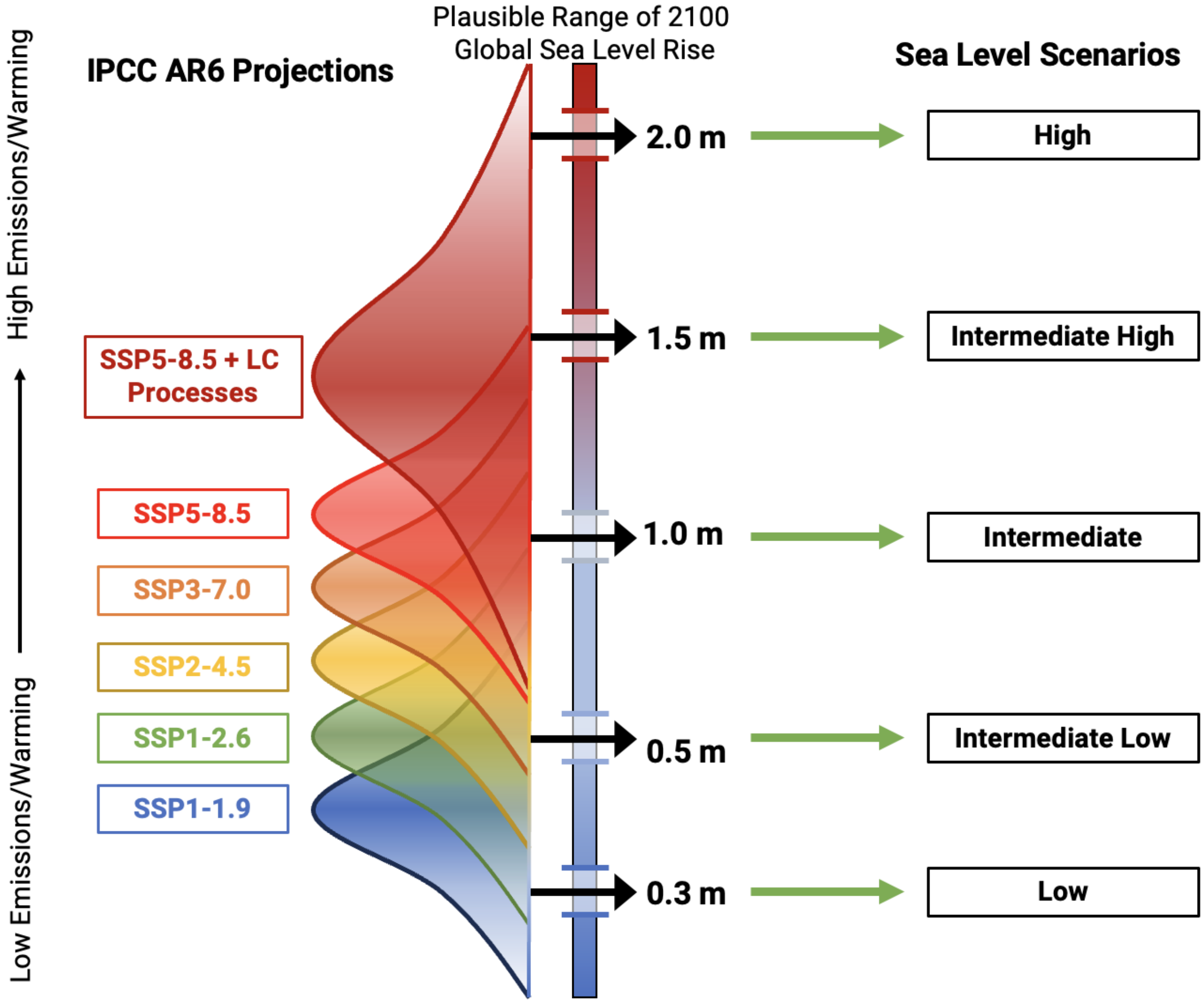

Figure 2.2. Schematic showing that the construction of the sea level scenarios is based on SSPs, which inform a range of plausible future sea level rise. The full range of plausible global sea level rise in 2100 is then divided into sea level scenarios ranging from low to high. The final scenarios cover the time period from 2020 to 2150.

2.2.1 Evolving understanding of ice sheet instability

Some studies published after the release of the IPCC AR6, and garnering significant media attention, suggest that the onset of rapid ice sheet loss may happen in the coming decades.[23] Even if this does occur, there is large uncertainty as to the total extent of the ice sheet loss that would occur as a result and – more importantly – there is large uncertainty as to how quickly sea levels would rise in response, with most timelines beyond the end of the 21st century. Other recent studies have further assessed these low confidence processes to obtain a practical

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[23] E.g., Box et al., 2022; Stokes et al., 2022.

high-end estimate of future sea level, obtaining estimates within the range of the IPCC AR6 projections.[24] Thus, the scenarios developed here for California represent the best available scientific understanding as described both in the IPCC AR6 and in the studies released subsequently.

2.2.2. Measuring vertical land motion

Satellite radar observations from 2014 to present have recorded land movement ranging from 2 inches of sinking or lowering to 2 inches of uplift, with some locations exceeding this typical range.[25] In this chapter of the report, a statewide average rate of vertical land motion was estimated using a statistical model that incorporated observational data from individual tide gauges. Across all locations, the long-term rate of past vertical land motion is assumed to persist into the future, and future relative sea level rise is adjusted accordingly. This average rate of vertical land motion is near zero (0.1mm or 0.003ft uplift per year). Furthermore, the effect of vertical land motion is considered equal across each of the five California sea level scenarios; there is no difference between the vertical land motion contribution for the Low and High scenarios.

Scenarios for individual NOAA tide gauge locations that include local estimates of vertical land motion from nearby global positioning system (GPS) stations are provided in Appendix 2. Alternatively, where very localized GPS data is available allowing more resolved estimates of vertical land motion, these can be added to the statewide average scenario values provided in this chapter.

2.3. Sea Level Scenarios 2020-2150

Five Sea Level Scenarios are constructed and presented for California. Each scenario is defined according to the target value of GMSL rise in 2100:

- Low (0.3m or 1.0ft by 2100)
- Intermediate-Low (0.5m or 1.6ft by 2100)
- Intermediate (1.0m or 3.3ft by 2100)
- Intermediate-High (1.5m or 4.9ft by 2100)
- High (2.0m or 6.6ft by 2100)

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[24] van de Wal, 2022.

[25] Govorcin et al., 2022

Table 2.1

(A) Median values for Sea Level Scenarios for California, in feet, relative to a 2000 baseline. These statewide values all incorporate an average value of vertical land motion corresponding to a negligible rate of 0.1 mm (0.0003 ft) per year uplift.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.2	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.2
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	3.0
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.9	5.4
2100	1.0	1.6	3.1	4.9	6.6
2110	1.1	1.8	3.8	5.7	8.0
2120	1.1	2.0	4.5	6.4	9.1
2130	1.2	2.2	5.0	7.1	10.0
2140	1.3	2.4	5.6	7.7	11.0
2150	1.3	2.6	6.1	8.3	11.9

(B) Rates of sea level rise (inches/year) in 2050 and 2100.

Scenario	Rate in 2050 (inches/year)	Rate in 2100 (inches/year)
Low	0.1	0.1
Intermediate-Low	0.2	0.2
Intermediate	0.3	0.8
Intermediate-High	0.5	1.1
High	0.7	1.3

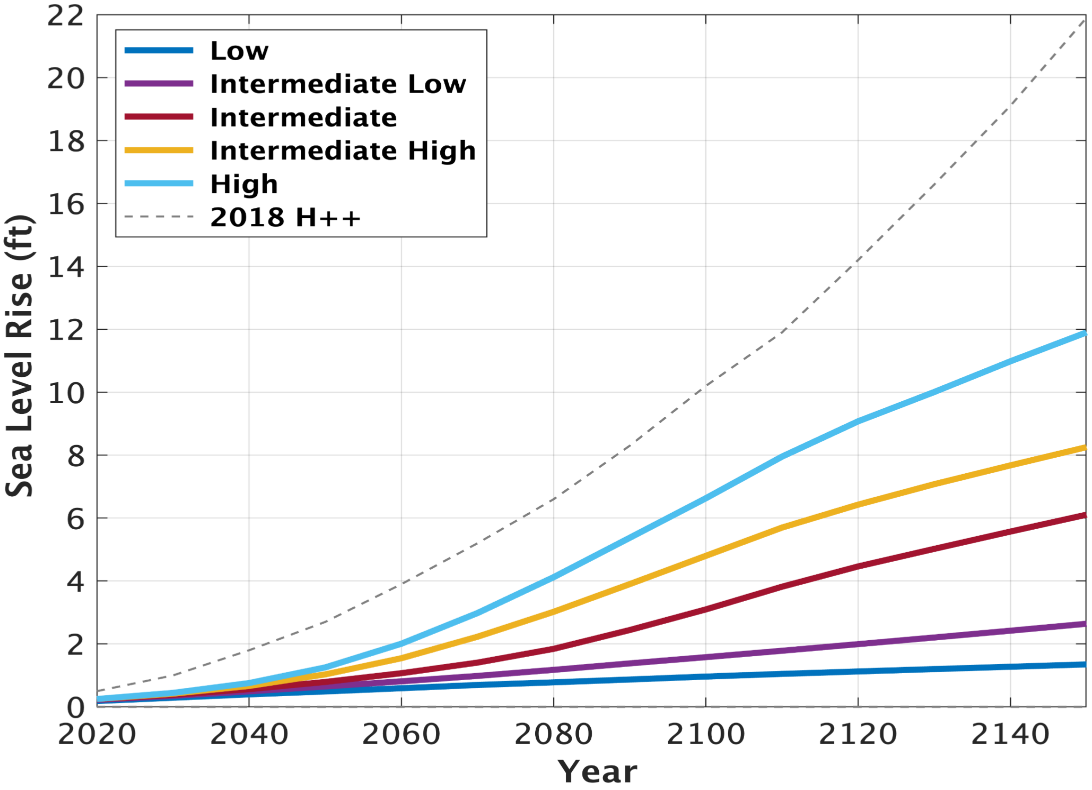

Figure 2.3. Sea Level Scenarios from 2020 to 2150, in feet, with a baseline of 2000. For comparison, the H++ from the 2018 California Sea-Level Guidance is included illustrating that this scenario is above scientifically plausible sea level rise for all dates.

The sea level rise values associated with five Sea Level Scenarios for California are shown in Table 2.1 and Figure 2.3. The key features of these five scenarios for California are noted here and discussed in more detail in the subchapters that follow:

- Through 2100, the scenarios for California track closely with global mean sea level (GMSL), with differences of only 2 to 3 inches between GMSL and the California Sea Level Scenarios in 2100.
- Taken together, the median values of the Sea Level Scenarios capture the plausible range of sea level rise for all time periods prior to 2100.
- Beyond 2100, the range of plausible sea level rise increases significantly and extends beyond that captured by the Low to High Scenarios, as the potential for low confidence processes to contribute to sea level increases.
- The rate of sea level rise in 2050 and 2100 associated with each of these scenarios is also shown in Table 2.1(B). To reach the higher scenarios by 2050, the rate of sea level rise along the California coast would have to increase dramatically from the rate of ~0.1 inches/year over the past 30 years. In 2100, the implied rate of sea level rise is greater than 1 inch/year for the higher-end scenarios.

Understanding Sea Level Scenarios likelihoods

The terms "most likely" and "plausible" have been used in recent assessment reports and are again used here. To date, a definition for these terms and how they have been applied to assess likelihoods of sea level scenarios has not been provided. To assist in their interpretation and application, the terms are defined here.

Most Likely

The phrase "most likely" is used when a scientific assessment of multiple lines of evidence collectively and consistently points towards a single sea level scenario or range across multiple sea level scenarios. These lines of evidence include: a) the projected global surface temperature based on current emissions policy and commitments; b) the current trajectory of globally averaged sea level rise; c) the current trajectory of regionally averaged sea level rise; d) the range across the five sea level scenarios; e) the likely ranges covered by the medium confidence projections in the IPCC AR6. Based on these lines of evidence, the most likely sea level rise will be narrow in the near-term (2050), and they support the selection of a single sea-level scenario. Towards the end of the 21st century, the criteria indicate that the most likely sea level rise is best represented by the range across two sea level scenarios. Beyond 2100, based on current scientific understanding, lack of suitable lines of evidence for support, the possible contribution of low confidence processes, and general level of deep uncertainty, an assessment of the most likely range is not advised. Where the term expected is used, this refers to the amount or range of sea level rise that has been evaluated to be most likely.

Plausible

The plausible range of sea-level rise is the credible and reasonable range of future sea level rise supported by published, peer-reviewed publications and the consensus assessment of the IPCC AR6. Plausible does not mean "possible", which instead has particular meaning for the evaluation of the upper and lower ends of the plausible range. The Sea Level Scenarios are intended to have similar plausibility at the upper and lower ends of the full range (i.e., the Low and High scenarios). However, there is still disagreement within the scientific community about the plausible high-end estimate of sea-level rise between now and 2150. The upper-end of the plausible range is thus defined such that it is supported by scientific consensus and areas of overlap in published studies to the greatest degree possible; given ongoing scientific research, this may be further refined in future assessments.

2.3.1 Comparison of California Scenarios, IPCC AR6 Sea Level Projections, and California 2018 Guidance Scenarios

The goal in defining Sea Level Scenarios for California is for the five scenarios to span the full plausible range of sea level rise at any time from 2020 to 2150 (see the definition of plausible above). As opposed to constructing a projection around a particular emissions pathway, the scenarios specify a targeted amount of global mean sea level rise at a time (2100) in the future. The trajectory for getting to that target value relies on the same science and projection framework from the IPCC AR6. In other words, while the values of the Sea Level Scenarios are fixed to span the plausible range of GMSL rise in 2100, the trajectory of the Sea Level Scenarios before and after that time is set by the underlying AR6 projections.

For example, in 2050 and 2100, the median values of the five California Sea Level Scenarios encompass the 17th to 83rd interval from the AR6 projections (Figure 2.4 A and B). In 2150, however, the range expands due to the potential contributions of the low confidence processes. In particular, the 83rd percentile of the range for the AR6 SSP5-8.5 Low Confidence projection increases significantly. After 2100, the Sea Level Scenarios do have an associated range due to the spread of pathways after reaching their target values in 2100. The upper end (83rd percentile) of the range for the High Scenario encompasses the 83rd percentile of the SSP5-8.5 Low Confidence scenario. Rather than indicating a flaw in the Sea Level Scenario framing, this exemplifies the increasing disagreement among scientists regarding how sea level rise and the important physical processes may evolve further in the future under continuing warming.

Due to the rapid near-term increase in sea level rise that is required, the Extreme Risk Aversion scenario from the 2018 California Sea-Level Rise Guidance, based on H++, is no longer physically realistic. However, there is consistency between the other risk aversion scenarios from the 2018 California Sea-Level Rise Guidance and those presented here. For example, across all three time periods, the Low Risk Aversion scenario closely tracks the range covered by Low and Intermediate Scenarios in this report. The Medium-to-High Risk Aversion scenarios correspond closely to the Intermediate-High and High Scenarios in 2100 and 2150, although are substantially higher in 2050. This difference reflects the narrower and lower range across the more recent IPCC AR6 projections until 2050.

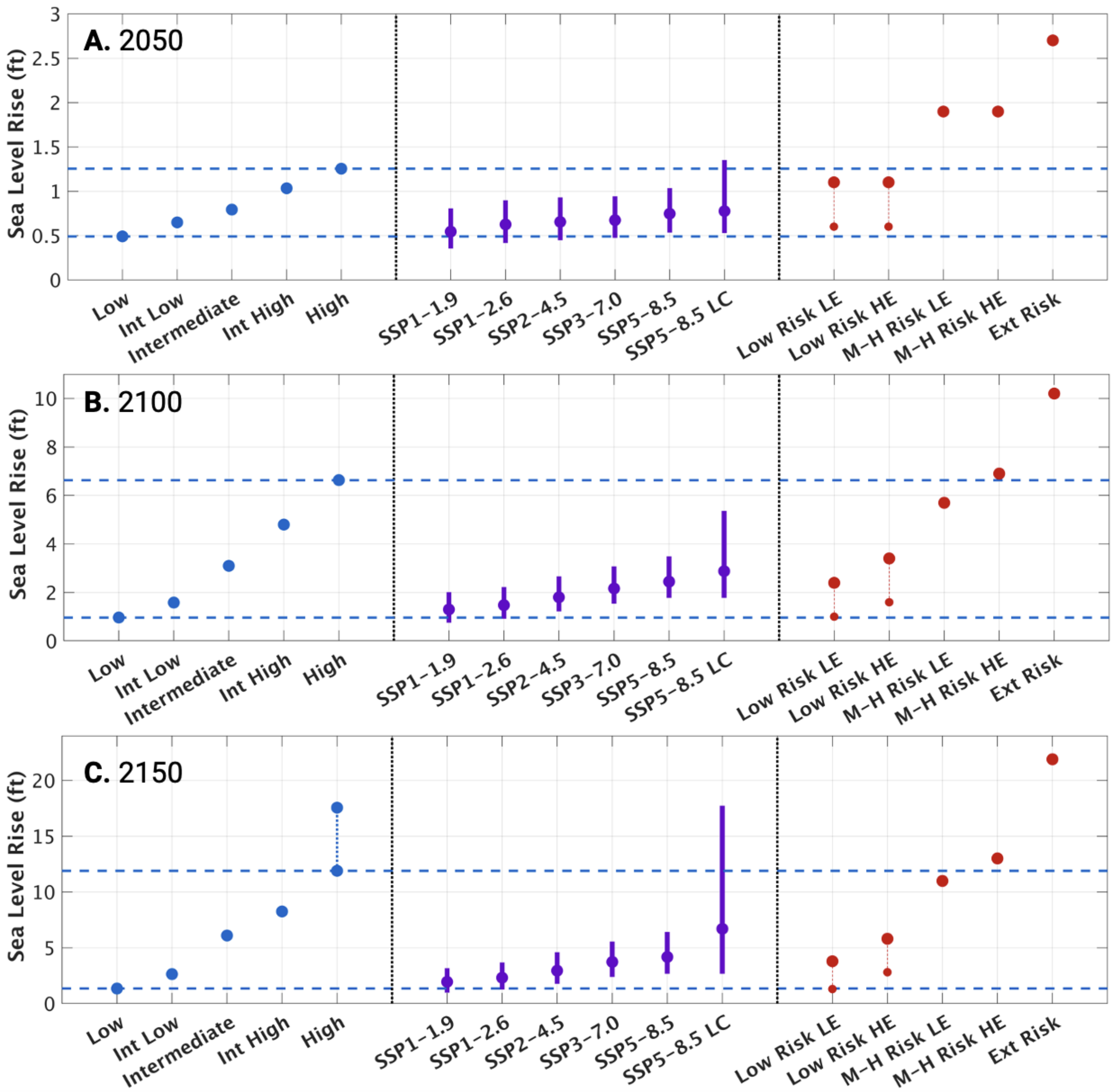

Figure 2.4. Comparison between the sea level scenarios in this report (blue), the sea level projections from the IPCC AR6 (purple),[26] and the values from the 2018 California Sea-Level Rise Guidance (red) in 2050 (A), 2100 (B) and 2150 (C). The horizontal dashed lines indicate the range covered between the median values of the Low and High Scenarios. The vertical lines extending from the median values represent the likely ranges (17th-83rd percentiles) for each projection. Note, the sea level scenarios are defined based on the plausible range in 2100, and the values in 2050 and 2150 are determined by the pathways and time evolutions of the AR6 projections.

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[26] Fox-Kemper et al., 2021.

2.3.3. Sea level scenario changes through time

Near-Term (2020-2050)

The California Sea Level Scenarios in this report show much greater certainty in the amount of sea level rise expected in the next 30 years compared to the previous report. This demonstrates that there is little difference in the amount of sea level rise expected across all foreseeable emissions pathways over the next three decades. In the 2018 California Sea-Level Rise Guidance, the risk aversion scenarios covered a range of 1.1 to 2.7 feet in 2050 relative to 2000. As a result of the updated science in the IPCC AR6, the Low and High Scenarios provide bounds in 2050 of 0.5 ft and 1.2 ft, a range of only 8 inches. This narrowing is driven primarily by a reduction in the upper-end scenario, and sea level rise of 2.7 feet by 2050 is now considered physically unrealistic. In other words, the increase in the rate of sea level rise that is needed to reach this target is not possible based on the current understanding of the processes driving sea level rise.

Furthermore, the 2050 Sea Level Scenarios can be informed by the trajectory of current observed sea level rise for California. In the 2022 Federal Sea Level Rise Technical Report, the sea level rise trend derived from observations over a minimum of 50 years, was extrapolated as an additional line of evidence during this near-term time period. Figure 2.5 shows an observation extrapolation using the tide gauge data from 1970 to 2022 to estimate a rate and acceleration. To the extent possible, the influence of natural variability, like that associated with El Niño, is removed to provide a more direct comparison to the Scenarios. The observation extrapolation tracks on top of the Intermediate Scenario, and the associated range lies between the Intermediate-Low and Intermediate-High Scenarios. In short, it is reasonable to view the Intermediate Scenario as most representative of the sea level rise that is expected to occur between now and 2050, and small deviations of 4 inches either side of this scenario can represent the full plausible range.

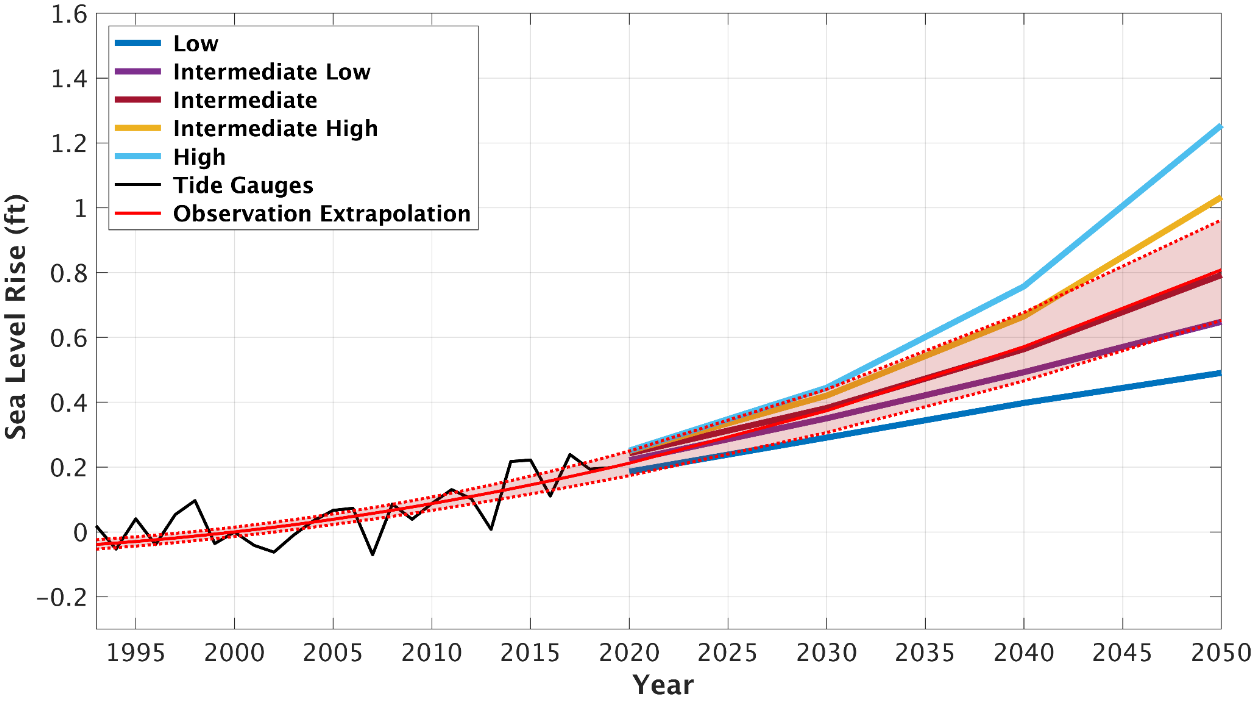

Figure 2.5. Sea Level Scenarios for California, in feet, from 2020 to 2050 relative to a baseline of 2000. The past statewide average tide gauge record is used to assess the trajectory of near-term sea level rise and create an observation extrapolation for comparison to the scenarios. The shaded region, bounded by the red dotted line, represents the likely range for the observation-based extrapolation.[27]

Mid-Term (2050-2100)

Beyond the middle of this century, the differences between the Sea Level Scenarios become increasingly large and more closely associated with both differences in potential future greenhouse gas emissions and possible contributions from low confidence ice sheet processes. The Low and High Scenarios have values of 1.0 ft and 6.6 ft, respectively, in 2100.

The value of the High Scenario is substantially lower than the H++ scenario in 2100 (10.2 ft), and the High Scenario is itself very high relative to the IPCC AR6 medium confidence projections, which include all AR6 projections except the AR6 SSP5-8.5 Low Confidence projections (Figure 2.4B). The H++ value in 2100 would not be reached even when considering the high end (95th percentile) of the AR6 SSP5-8.5 Low Confidence scenario (7.5 ft in 2100).

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[27] Nerem et al., 2022; Hamlington et al., 2022.

Extending the observational extrapolation in Figure 2.5 to 2100 would give an increase of 2.5 ft relative to 2000, which would fall in the middle of the Intermediate-Low and Intermediate Scenarios, but with a much larger likely range than in 2050.

Long-Term (2100-2150)

Beyond 2100, the range across the five Sea Level Scenarios increases significantly, going from 1.4 ft to 11.9 ft between the Low and High Scenarios. The upper end of the range of the AR6 SSP5-8.5 Low Confidence scenario expands to almost 18 ft. This reflects the rapid acceleration in sea level rise that may occur should the low confidence processes become an important factor. Unlike the other time periods, the median values of the Sea Level Scenarios do not fully encompass the 17th-83rd percentiles of the AR6 projections. Specifically, the 83rd percentile of the High Scenario is required to encompass the 83rd percentile of the SSP5-8.5 Low Confidence scenario (Figure 2.4C), although it should be noted that plausibility in this case is supported by a limited set of scientific studies and is a result of the SSP5-8.5 Low Confidence scenario alone.

In a future where the low confidence processes are not considered to be a factor, the range between the Intermediate-Low and Intermediate Scenarios represents the plausible sea level rise. The Intermediate through High Scenarios then represent the range of possibilities should the low confidence processes come into play. Towards 2100 and beyond, ambiguity arising from these low confidence processes and socioeconomic factors plays a major role and drives the wide range across scenarios.[28] Ambiguity arising from the low confidence ice-sheet processes is not just in regards to *whether* and *when* these processes will develop, but also in *how* they will contribute to sea level rise should they develop. This should be considered when applying the scenarios beyond 2100 as decisions must be made with awareness of the assumptions about the future being made. These include the level of warming that is assumed and the degree to which low confidence processes are to occur and additionally drive high amounts of future sea level rise.

These ranges in 2150 are among the most likely values to be revised in future updates as scientific understanding and ice-sheet modeling continues to evolve. In sum, deep uncertainties and ambiguity embedded in the High Scenario frame a worst case as we currently understand it and should be used with caution and consideration of the underlying assumptions in planning adaptation.

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[28] Kopp et al., 2023.

2.4. Sea Level Scenario Storylines

2.4.1 Scenario exceedance probabilities

Given that sea level rise is highly dependent on if and how fast the world's nations reduce global emissions and mitigate warming trends, there are no probabilities that can be assigned directly to each of the Sea Level Scenarios. Instead each scenario integrates information on a potential future pathway for warming levels and emissions. By extension, assumptions about future warming levels can be translated into the probability of exceeding a particular Sea Level Scenario in that assumed future (Table 2.2).

The IPCC AR6 Working Group III (IPCC, WGIII, 2022) assessed that, extrapolating current policies for greenhouse gas emissions warming in 2100, global surface temperature warming is projected to be roughly 3°C above pre-industrial levels. This contextual information can be used to construct "storylines" for each scenario, describing what the future will look like in each case. The storylines for Low, Intermediate Low, Intermediate, Intermediate High and High Scenarios are described in more detail below.

Table 2.2 (next page). Exceedance probabilities for the Sea Level Scenarios based on IPCC warming level–based GMSL projections. Global mean surface air temperature anomalies are projected for years 2081–2100 relative to the 1850–1900 climatology. Global surface temperatures are currently on track to reach 3.0°C above pre-industrial levels by 2100, assuming current rates of emissions-driven warming. Therefore, any temperature anomalies less than (e.g., 1.5 or 2.0°C) or greater than (e.g., 4.0 or 5.0°C) the current trajectory implies lower or greater rates of warming by 2100, respectively. Low warming in the sixth column broadly refers to temperature anomalies less than 2.0°C, and high warming refers to temperature anomalies greater than 4.0°C. The probabilities shown here are imprecise probabilities, representing a consensus among all projection methods applied by the IPCC AR6. As an example of how this table can be read, the third row could be used to produce the following two sentences: "Assuming 3°C of warming in 2100, there is a 5% chance of exceeding the Intermediate Scenario in 2100" and "Assuming high levels of warming in 2100 and contributions from the low confidence processes, there is a 49% chance of exceeding the Intermediate Scenario in 2100."

Global Mean Surface Air Temperature 2081-2100	**1.5°C**	**2.0°C**	**3.0°C**	**4.0°C**	**5.0°C**	Low Confidence Processes, Low Warming	Low Confidence Processes, High Warming
Low Scenario	92%	98%	>99%	>99%	>99%	90%	>99%
Intermediate-Low Scenario	37%	50%	82%	97%	>99%	49%	96%
Intermediate Scenario	<1%	2%	5%	10%	23%	7%	49%
Intermediate-High Scenario	<1%	<1%	<1%	1%	2%	1%	20%
High Scenario	<1%	<1%	<1%	<1%	<1%	<1%	8%

2.4.2. Low Scenario

The target of 1 foot of increase in global sea level rise by 2100 is set under the assumption of the current rate of sea level rise continuing on into the future. This assumption is inconsistent with current observations of an acceleration in sea level rise, but could still be considered plausible under the most aggressive emission reduction scenarios. As a result, the Low Scenario provides the lower bound for plausible sea level rise in 2100 and sits below the median value for all AR6 scenarios at all times between 2020 to 2150. The likelihood of exceeding this Sea Level Scenario in 2050 is greater than 95% and greater than 90% in 2100.

Summary: Aggressive emissions reductions leading to very low future emissions; the scenario is on the lower bounding edge of plausibility given current warming and sea level trajectories, and current societal and policy momentum.

2.4.3. Intermediate-Low Scenario

This scenario arises under a range of both future warming levels and possible SSPs, spanning low, intermediate and high emissions pathways, and integrates many of the AR6 SSP pathways as a result (see Figure 2.2) This scenario is consistent with the median projected sea level rise in a 2°C world, which means there is a 50% probability of exceeding this scenario with 2°C of additional warming by 2100. At a warming level of 3°C in 2100, the probability of exceeding this scenario is 82%. Given the extrapolation of GMSL to 2100 (approximately 2.2 feet[29]), the current projection of future warming of 3°C, and the range of sea level rise across the IPCC AR6

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[29] Nerem et al., 2022

scenarios (Figure 2.4), the Intermediate Low Scenario provides a reasonable lower bound for the most likely range of sea level rise by 2100. Since the low confidence processes are not important to this scenario, the range of possible sea level rise after 2100 does not expand significantly.

Summary: A range of future emissions pathways; a reasonable estimate of the lower bound of most likely sea level rise in 2100 based on support from sea level observations and current estimates of future warming.

2.4.4. Intermediate Scenario

The Intermediate Scenario is driven dominantly by high emissions scenarios, and thus higher warming levels. For the first time in the scenarios, the low confidence projections from the IPCC AR6 contribute significantly and provide about 25% of the pathways for reaching the Intermediate Scenario target by 2100. Given the extrapolation of GMSL to 2100 and the range of sea level rise across the IPCC AR6 scenarios (Figure 2.4), the Intermediate Scenario provides a reasonable upper bound for the most likely range of sea level rise by 2100. At a warming level of 3℃ in 2100, the probability of exceeding this scenario is 5%. In a very-high emissions future with low confidence processes, there is about a 50% chance of exceeding the Intermediate scenario in 2100.

Summary: A range of future emissions pathways; could include contribution from low confidence processes. Based on sea level observations and current estimates of future warming, a reasonable estimate of the upper bound of most likely sea level rise in 2100.

2.4.5. Intermediate-High Scenario

Pathways combining both higher emissions and low confidence processes become the majority, with over 50% of the samples used to construct this scenario coming from the SSP5-8.5 scenario. At all times from 2020 to 2150, the Intermediate High Scenario exceeds the median value of the AR6 scenarios. This scenario is similar to the high-end estimate from van de Wal et al. (2022) under the assumption of high levels of warming in 2100. At a warming level of 3℃ in 2100, the probability of exceeding this scenario is <1% when not considering the low confidence processes, emphasizing the degree to which these processes are needed to get to this scenario. With the low confidence processes, the probability of exceeding this scenario is approximately 20% for very high warming levels.

Summary: Intermediate-to-high future emissions and high warming; this scenario is heavily reflective of a world where rapid ice sheet loss processes are contributing to sea level rise.

2.4.6. High Scenario

Pathways combining both high emissions and low confidence processes are dominant, providing over 80% of the samples to construct the scenario. Low emissions pathways are not plausible under this scenario, and intermediate emissions pathways require a significant contribution from rapid ice sheet loss processes. Before 2100, the High Scenario is significantly above the range of SSP AR6 scenarios, although the range of plausible sea level expands beyond 2150. The probability of exceeding the High Scenario in 2100 is less than 1% for all warming levels without considering low confidence processes. With very high emissions and warming and contributions from the low confidence processes, this probability increases to 8%.

Summary: High future emissions and high warming with large potential contributions from rapid ice-sheet loss processes; given the reliance on sea level contributions for processes in which there is currently low confidence in their understanding, a statement on the likelihood of reaching this scenario is not possible.

3.0 California Sea Level Rise Policy Guidance

Author: OPC

3.1. Summary

In this update, which replaces the 2018 California Sea-Level Rise Guidance, California continues its commitment to science-based policy and decision making. This revised policy guidance incorporates the science update presented in chapter 2.0 to ensure that state, regional, and local sea level rise adaptation planning and project decisions are consistent and grounded in the best available science. As in 2018, this guidance is deliberately structured to be both precautionary and flexible to accommodate local and regional priorities and the broad array of decision-making contexts in which planning for sea level rise is relevant.

In chapter 2.0, five Sea Level Scenarios are constructed and presented for the California coast. Table 3.1 shows the statewide average values for these five scenarios which use a single average value of vertical land motion corresponding to a negligible rate of 0.10 mm/year uplift. Scenarios are also presented for the 13 tide gauges in Appendix 2 and deviations from the statewide average are due entirely to differences in localized vertical land motion (uplift or subsidence).

The scenarios show greater certainty in the amount of sea level rise expected in the next 30 years than previous reports and demonstrate a narrow range across all possible emissions scenarios. Statewide, sea levels are most likely to rise 0.8 ft (Intermediate Scenario) by 2050. In the mid-term (2050-2100), the range of possible sea level rise expands due to more uncertainty in projected future warming from different emissions pathways and certain physical processes. By 2100, sea levels are expected to rise between 1.6 ft (Intermediate-Low) and 3.1 ft (Intermediate Scenario), although higher amounts cannot be ruled out. Beyond 2100, the range of possible sea level rise becomes increasingly large due to uncertainties associated with physical processes, such as earlier-than-expected ice sheet loss and resulting future sea level rise. Statewide, sea levels may rise from 2.6 ft to 11.9 ft (Intermediate-Low to High Scenarios) by 2150, and even higher amounts are possible.

Table 3.1. Median values for Sea Level Scenarios for California, in feet, relative to a 2000 baseline. These statewide values all incorporate an average value of vertical land motion corresponding to a negligible rate of 0.1 mm (0.0003 ft) per year uplift. Evaluation of the Intermediate, Intermediate-High and High Scenarios (outlined in red below) is recommended to inform appropriate sea level rise planning and project decisions.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.2	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.2
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	3.0
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.9	5.4
2100	1.0	1.6	3.1	4.9	6.6
2110	1.1	1.8	3.8	5.7	8.0
2120	1.1	2.0	4.5	6.4	9.1
2130	1.2	2.2	5.0	7.1	10.0
2140	1.3	2.4	5.6	7.7	11.0
2150	1.3	2.6	6.1	8.3	11.9

The stepwise process outlined below recommends a precautionary approach for incorporating Sea Level Scenarios into planning and projects that includes adaptation pathways to phase actions over time. These steps complement other State guidance documents that provide a stepwise approach to the analysis needed to incorporate sea level rise into planning and decision making.

3.2. Stepwise Process to Apply Sea Level Scenarios in Planning and Projects

The following steps provide a decision framework that can be used to guide selection of appropriate sea level scenarios for specific planning and project application. **For the purposes of this guidance, planning refers to local and regional land-use and community planning efforts and projects refer to site-specific siting, conceptional and engineering design, permitting, or construction related to coastal habitats, development, access, or infrastructure. A vulnerability assessment (or similar hazard analysis) is considered to be a step in a planning effort or project rather than a standalone effort**.

Existing Vulnerability Assessments

If a vulnerability assessment has already been completed, an update using the new Sea Level Scenarios may not be necessary. Existing vulnerability assessments should be evaluated to determine whether appropriate sea level rise was included (as compared with the new Sea Level Scenarios). Values will likely not match exactly, but the range of new Sea Level Scenarios should be captured. Anticipated impacts will likely remain the same when using existing vulnerability assessments; however, the time horizon at which impacts are expected to occur may shift farther into the future. Adaptation planning using existing vulnerability assessments should adequately reflect that shift.

It is important to note that existing community-level vulnerability assessments may not be sufficient to characterize site-specific vulnerability; in such cases, a site-specific vulnerability assessment should be conducted using the new sea level rise scenarios included in this guidance. All vulnerability assessments should be considered living documents that may merit updates based on evolving scientific understanding of the drivers and pace of sea level rise.

If you have an existing vulnerability assessment that does not require updating, skip to Step 5 below.

>> STEP 1: *Identify the nearest tide gauge.*

>> **STEP 2:** *Evaluate planning and/or project time horizon.*

>> **STEP 3:** *Choose multiple sea level rise scenarios and storm conditions for vulnerability assessment.*

>> **STEP 4:** *Conduct vulnerability assessment.*

>> **STEP 5:** *Explore adaptation options and feasibility.*

>> **STEP 6:** *Select phased adaptation approach and/or implement project.*

Figure 3.1. The following steps, outlined in the figure and in more detail below, provide a decision framework to guide selection of appropriate Sea Level Scenarios for specific planning and project application.

STEP 1: Identify the nearest tide gauge

In California, differences in relative, local sea level rise values (i.e. at tide gauge locations) are due to differences in vertical land motion resulting from local factors such as tectonic uplift and subsidence. A location experiencing tectonic uplift will experience lower observed rates of sea level rise than a location experiencing subsidence.

Appendix 2 provides local sea level projections, which incorporate estimates of local vertical land motion from nearby GPS stations, for each of the 13 NOAA coastal tide gauges, including a tide gauge in Alameda that was not included in the 2018 California Sea-Level Rise Guidance, thus providing more locally relevant information for planning in San Francisco Bay. If the project is nearly equidistant between two tide gauges, it is appropriate to interpolate between or average the two tide gauges.

Alternatively, when technical capacity and available data allows, jurisdictions that have more localized or site-specific data on vertical land motion can choose to combine the statewide average scenarios in Table 3.1 with their local measurements of vertical land motion for any location on the California coast and San Francisco Bay.

STEP 2: Evaluate planning and/or project time horizon(s)

The time horizon refers to how long a given planning effort or project is intended to function. Many of the planning and projects utilizing this guidance will have time horizons beyond 2100, though some projects may be for shorter-term or temporary development, or planning efforts may consider both long-term goals and the shorter-term actions necessary to achieve them. For instance, community visioning and planning (such as for an LCP) often considers long-term horizons along with the near-term priority actions the community will take. When practical, it is recommended to plan and adapt for the entire time horizon. However, it is not always possible or practical to do this, and so earlier time horizons are relevant when included in a phased adaptation approach, such as adaptation pathways. Phased adaptation for planning and projects can be the most practical and economical approach in many situations, and ensures appropriate actions are taken as sea levels rise over time. In particular, phased adaptation planning should be considered for adaptation of coastal habitats, which are expected to migrate in response to changing conditions. Evaluating the number and timing of adaptation phases within a longer-term timeline will depend on the specifics of the planning or project effort.

Alternatively, rather than using time to identify adaptation phases, it is equally valid to choose sea level rise values (step 3) to correspond to adaptation phases so long as those values roughly capture the time horizon in question. For instance, a community planning effort might choose to develop adaptation pathways for 0.8 foot, 3.3 feet and 5.7 feet water levels which roughly correspond to time horizons of 2050, 2100, and 2150, if using the Intermediate Scenario and depending on location. Since phased adaptation, such as adaptation pathways, is often dictated by thresholds and triggers related to water levels and not time, this can be a more practical approach. In this situation, it is necessary to identify the time frames at which water levels are likely to be reached and prepare accordingly, including what would need to be done if sea levels rise faster than anticipated.

Adaptation Pathways

Adaptation pathways allow decision makers to phase short and long-term adaptation strategies over time to build resilience in the face of uncertainty. Adaptation pathways, which involves sequencing adaptation actions throughout the lifespan of a project, can facilitate cost-effective near-term implementation while planning for future needs that will be triggered by predetermined thresholds or tipping points. Thresholds, or triggers, may be defined by observed sea level rise or other impacts such as flooding extent and frequency or cost to repair/replace damaged built or natural assets. Actions are typically agreed in advance, for example through collaborative community co-design.

Adaptation pathways provide greater flexibility and opportunities to implement no-regrets actions (e.g. habitat restoration or mitigation) to address near-term impacts, while planning for more costly efforts to address and avoid greater damages in the future.

STEP 3: Choose multiple Sea Level Scenarios and storm conditions for vulnerability assessment

A vulnerability assessment is a key step in building coastal resilience and allows decision makers to evaluate the vulnerability of people, natural resources and infrastructure under various future conditions, as well as their level of comfort with over or underestimating sea level rise. Given the uncertainty in the amount of future sea level rise, it is critical to consider a range of scenarios to understand the consequences of various decisions, determine the tolerance for risk associated with those decisions, and to inform adaptation strategies. **For most planning and projects, it is recommended to evaluate Intermediate, Intermediate-High, and High Scenarios to assess a spectrum of potential impacts, consequences, and responses.** In limited circumstances, it may be appropriate to evaluate fewer scenarios based on risk tolerance.

The Low Scenario is scientifically plausible but only with accelerated development of carbon capture technologies and global policy and socioeconomic changes that significantly reduce greenhouse gas emissions. The Intermediate-Low Scenario provides a reasonable estimate of the lower bound for the most likely sea level rise by 2100. California is taking significant action to achieve the state’s ambitious clean energy goals and is committed to addressing and mitigating the impacts of climate change. However, to ensure precautionary sea level rise planning and projects that protect public health and safety, the environment, critical infrastructure, and public access, for the purposes of this guidance, the Low and Intermediate-Low Scenarios are not recommended for planning or projects. The High Scenario is considered to be sufficiently precautionary, even for the most risk averse applications; assuming global surface temperatures reach 3.0°C above pre-industrial levels by 2100, there is less than a 1% chance of exceeding the Intermediate-High or High Scenarios in 2100 (Table 2.2).

Consideration of storm conditions such as annual, 20-year, or 100-year storms in combination with Sea Level Scenarios is also recommended to evaluate extreme coastal water levels, as appropriate. This will provide information on areas that could temporarily flood during extreme coastal water level events before those areas permanently inundate. Wave-driven water levels and storm surge are the two components of storm conditions that typically contribute the most to storm-induced extreme water levels. To evaluate the most accurate assessment of extreme total water levels, other drivers such as tides (e.g., King tides), seasonal effects (e.g., El Niño), and river runoff from heavy precipitation, in addition to the shoreline characteristics of a given location would also need to be accounted for. This level of detail may not be necessary for all applications, but could be relevant for situations that are very risk averse to even a single flooding event (e.g., emergency services).

For most applications, consideration of 100-year storm conditions is recommended. However, certain combinations of sea level rise and storm scenarios may be similar to others, and therefore they need not all be thoroughly evaluated. For instance, the Intermediate Scenario with 100-year storm conditions, might be very similar to the exposure created by the Intermediate-High Scenario alone in a given location. It is therefore recommended to consider the consequences of storm-induced extreme water levels on a project by project basis. Our Coast, Our Future (OCOF) is a sea level rise visualization tool that allows users to visualize sea level rise values with and without storm conditions and can be used as a screening tool to help determine what water levels are appropriate for analysis in a vulnerability assessment.

Ultimately, the project team, with input from relevant stakeholders, should choose sea level rise and storm scenarios for vulnerability assessments that are appropriate for a specific project and can be accomplished within the project budget and are adequately precautionary. Depending on the type of vulnerability assessment pursued, evaluation of each additional scenario may have an associated cost.

Coastal Storm Modeling System (CoSMoS) - Sea Level Rise Visualization Tool

CoSMoS is a dynamic modeling approach developed by the United States Geological Survey and accessed through the OCOF web interface.[30] Its Flooding layer allows users to select different values of sea level rise (in meters and feet) and storm frequency (none [i.e., daily conditions], annual, 20-year, or 100-year) to visualize flooding at a 1-meter resolution across California's outer coast and estuaries (the North Coast is planned for release in 2024), including San Francisco Bay. Because CoSMoS is a comprehensive modeling tool, it incorporates all the key drivers of coastal flooding, including sea level rise, tides, seasonal effects, storm surge,waves, and river flows to produce location specific maps showing total water levels and the associated flooding. It can be used both as a screening tool to examine the flooding from different combinations of sea level rise and storm conditions to help inform selection of the most appropriate sea level rise and storm scenarios for a vulnerability assessment (Step 3) and/or to support the exposure analysis of a vulnerability assessment (Step 4). For most planning and projects, OCOF is well-suited to conduct the exposure analysis portion of a vulnerability assessment.

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[30] https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos#overview

More specifically, to support screening and/or exposure analysis, users can:

- View locally relevant online maps and tools to understand vulnerabilities to sea level rise, storms, and shoreline change
- Interact with a map that includes flood extent, depth, duration, wave heights, current velocity, cliff retreat, shoreline change, and groundwater emergence
- View and download CoSMoS information through the OCOF[31] flood mapper, which provides a user-friendly web-based tool for viewing all model results;
- Download modeling results as GIS shapefiles with accompanying metadata at USGS ScienceBase-Catalog;[32] or
- View and interact with estimates of residents, businesses, and infrastructure that could be exposed to CoSMoS flooding projections from each coastal storm and sea level scenario through the Hazards Exposure Reporting and Analytics (HERA)[33] application.

OCOF allows users to select from a limited number of sea level rise values (i.e., 0.8, 1.6, 2.5, 3.3, 4.1, 4.9, 5.7, 6.6, 8.2, 9.8, and 16.4 feet). Depending on what water levels are identified for analysis, there might not be an option that is an exact match. For instance, the Humboldt Bay Intermediate scenario at 2100 is 3.9 feet, which is between the available selections of 3.3 and 4.1 feet in OCOF. For these situations, it is not always necessary to analyze the exact numerical values; it is more important that the full range of values from Intermediate to High scenarios, with consideration of storm conditions, is evaluated.

STEP 4: Conduct vulnerability assessment

A vulnerability assessment that evaluates impacts from potential sea level rise-induced inundation and flooding includes three key components: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which habitats, people, private property, critical infrastructure, and public access will be affected by sea level rise. Sensitivity is the extent to which these natural and built assets will be damaged or destroyed by that exposure. And adaptive capacity is the ability of natural systems and infrastructure to respond or adapt to rising sea levels to minimize harm.

The first step in a vulnerability assessment is to create exposure maps of sea level rise induced inundation and flooding. This can be accomplished by using a sea level rise visualization tool, such as OCOF which provides visualizations of future flooding and inundation under different sea level rise projections using the CoSMoS model (see box for more detail on CoSMoS).

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[31] http://ourcoastourfuture.org/

[32] https://www.sciencebase.gov/catalog/item/5633fea2e4b048076347f1cf

[33] https://www.usgs.gov/apps/hera/

However, their level of complexity, methodologies, and underlying assumptions differ and it is important to identify an appropriate visualization tool. Alternatively, a tailored made-to-order exposure mapping effort can be performed with more local considerations. These hyper-local and technologically advanced assessments can be time intensive and costly but can provide much greater detail and accuracy than the visualization tools available online. Additionally, aspects of sensitivity can be integrated into project-specific exposure mapping, for example pairing sea level rise exposure with habitat sensitivity information.

Erosion and groundwater are unique considerations because they both can contribute to exposure and are also systems that will be impacted. Erosion of beaches, cliffs, bluffs, dunes, and other landforms is an important component of a vulnerability assessment and should be included as it relates to both exposure and impacts. Similarly, groundwater can be integrated into an exposure analysis, however this requires local water table and geologic information that might not be readily attainable or might add significantly to the expense. For locations with shallow water tables, it is recommended that impacts to groundwater and saltwater intrusion be assessed since rising groundwater may pose a greater flood risk than tidal flooding in some areas.[34] Loss and destruction of other habitats/ecosystems (such as wetlands or submerged aquatic vegetation) can also contribute to exposure as well as being an impacted system. These ecosystem-level dynamics can be very difficult to capture unless an advanced tailor-made assessment is pursued.

Sensitivity is the degree to which a place or asset is affected by sea level rise inundation and flooding. A sensitivity (or impact) analysis will provide information on the potential impacts of exposure to inundation and flooding. For community planning, this should include analysis of erosion, coastal habitats and wildlife, saltwater intrusion and groundwater, recreational areas and access, energy infrastructure, transportation systems, flood protection infrastructure, wastewater systems, stormwater systems, community services and critical facilities, toxic sites, and landfills and waste facilities. Additional analysis of impacts to environmental justice communities is also recommended. For a site-specific project, the analysis would be limited and appropriate to the project scope and location.

The final step in a vulnerability assessment encourages the community to measure the degree to which it is equipped to adapt to sea level rise (i.e., adaptive capacity) through the existence of policies, structures, finances, and human resources that can assist, or already are assisting, adaptation to potential changes.

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[34] Befus et al., 2020.

Adaptive Capacity

Adaptive capacity is the ability of a system or community to evolve in response to, or cope with the impacts of sea level rise. Assets or natural resources with high adaptive capacity will likely have greater flexibility and potential to withstand rising sea levels. Adaptive capacity may be inherent to the asset or can be improved through forward-looking planning or design (for example, including sufficient physical space to allow for buffering effects or inland migration of habitats, or designing a structure that can be easily relocated). Adaptive capacity is also a function of the innate characteristics of a system, e.g., a community that is chronically under-resourced may develop effective adaptation strategies but will likely still be at a disadvantage compared to communities with more resources for advanced planning and implementation.

STEP 5: Explore adaptation options and feasibility

The results of the vulnerability assessment should highlight what is most vulnerable and allow identification of adaptation priorities. This should be done in close coordination with the community, stakeholders, and relevant regulatory bodies. Typically, the next step is to explore site-specific adaptation options and the feasibility of these options, either through an adaptation pathways approach or as a standalone project. This could include discussion of all available adaptation strategies and selection of a limited number that are brought to conceptual design stage or conducting a formal alternatives analysis. A cost-benefit analysis could also be conducted at this stage.

Often the suite of adaptation options is limited by legal, physical, economic, or social constraints. Evaluating adaptation options available will be a highly local process and include the values and priorities of a particular community.

STEP 6: Select phased adaptation approach and/or implement project

Following a thorough assessment of adaptation options, a specific project or adaptation pathway must ultimately be selected. The process of selecting an implementation project or adaptation pathway with an associated water level will include consideration of risk, budget, regulatory constraints, and stakeholder input, in addition to other factors. Selection can often be a negotiation and assessment of trade-offs.

For low risk averse projects, it is recommended that water levels corresponding to the Intermediate scenario be applied, at a minimum. For medium-high risk averse applications, the Intermediate-High Scenario is recommended, and for extreme risk aversion applications, the High Scenario should be applied. Storm surge values can be added to the scenario value as appropriate.

However, in a real-world situation, there might be a maximum level of sea level rise that can be incorporated into a project. Rather than selecting a sea level rise value to design to, a project's design is evaluated to assess if it is sufficiently protective of sea level rise over the lifespan of the project. It is important to maintain a transparent process, guided by the scientific recommendations, when making a final selection.

How to Evaluate Risk for a Project

Risk aversion is the strong inclination to avoid taking risks in the face of uncertainty. State and local governments should consider the risks associated with various sea level rise scenarios and determine their tolerance for, or aversion to, those risks. There is no quantitative calculation to determine a project's risk level, however the general guidance can be provided:

Low risk aversion: Adaptative, lower consequence situations that are fairly risk tolerant, for instance a public bench or unpaved coastal trail. Additionally, low risk should be considered for managing or restoring natural infrastructure, such as tidal wetland management and restoration, creating living shorelines, estimation of saltwater intrusion and coastal landscape migration, or protecting estuarine water quality. When an action has the capacity to be adapted in the future, it is often more important to know the most likely sea level rise rather than the maximum plausible sea level rise.

Medium-high risk aversion: Appropriate for less adaptive, more vulnerable projects that will experience medium to high consequences if impacted because of underestimating sea level rise, such as new or redevelopment of a public campground. These efforts should be more resilient to higher-end sea level rise scenarios.

Extreme risk aversion: For high consequence projects that have little to no adaptive capacity, would be irreversibly destroyed or significantly costly to relocate/repair or would have considerable public health, public safety, or environmental impacts. For instance, critical infrastructure should be considered as extremely risk averse. Extreme risk aversion projects should be resilient to high end sea level scenarios, when feasible.

3.3. General recommendations for Sea level Rise Planning and Adaptation

The 2018 California Sea-Level Rise Guidance provided a set of recommendations to encourage sea level rise planning in alignment with state policy goals and priorities. These recommendations are carried forward in this 2024 Guidance Update below and provide guidance on preferred sea level rise planning and adaptation approaches, with an understanding that the diversity of communities, uses, and natural resources along California's coastline, as well as planning for new development versus existing structures, may merit different approaches to building resilience.

1. **Adaptation planning and strategies should prioritize social equity, environmental justice and the needs of underserved and vulnerable communities.**

   Communities of color, low-income communities, and California Native American tribes have been, and will continue to be, disproportionately overburdened by pollution and climate change. Sea level rise will add to those burdens. Impacts such as increased flooding, damage to homes and roads, disruption to public transportation, elevated exposure to toxic materials, and destruction of coastal sacred places and cultural sites will unduly affect vulnerable communities. These impacts can manifest as complete community displacement, loss of areas with cultural and/or historic significance, loss of personal property, worsened health, reduced or lost wages, and loss of free or affordable public access to the coast. Vulnerable communities may lack financial or other resources to plan for sea level rise as well as the ability to adequately respond to impacts once they occur.

   Sea level rise planning that prioritizes social equity, environmental justice and protection of the lives and property of underserved and vulnerable communities should include early public engagement of those who will be directly or indirectly affected by rising sea levels, a focused characterization of impacts on exposed populations and communities dependent on critical assets threatened by sea level rise, and identification of specific adaptation strategies to minimize or mitigate these impacts. Engaging communities that face existing inequalities already (or will face unequal distribution of sea level rise impacts) early in the planning process will ensure that vulnerability assessments and adaptation strategies accurately reflect their risk, needs and priorities. State and local governments should also prioritize technical support and funding opportunities for planning and adaptation efforts of vulnerable, underserved, and tribal communities. Incorporating social equity and environmental justice in sea level rise planning and adaptation strategies should:

   - ***Address environmental contamination risks for coastal communities adjacent to industry or toxic sites***. Coastal environmental justice communities tend to have fewer beachfront homes at risk of inundation but are often separated from the coast by strips of industrial facilities, ports and military installations. Sea level rise threatens job sites for local residents, risks spreading contamination from cleanup sites, and can damage critical energy, transportation or other infrastructure. Prioritizing cleanup of sites threatened by sea level rise and rising groundwater can prevent toxic contamination from spreading into nearby communities.

- ***Preserve access to and along the beach***. Protecting natural coastlines preserves affordable outdoor recreation access for communities that often lack parks or other sources of green space and face existing health disparities. While many coastal cities in California include expensive beachfront homes, the coast is used regularly for recreation by thousands of working-class residents who are visiting or live nearby. Sea level rise planning and adaptation strategies should protect public access to and along the beach to maximize free or affordable use of the coast for the benefit of all people.

- ***Prevent displacement by ensuring that investments in coastal resilience protect local jobs and housing costs***. In climate adaptation policies, it is important to understand the economic ties between vulnerable communities and polluting industries along their coasts, and how to build environmentally healthy and economically vibrant communities. Deindustrialization of coastal areas and restoration of natural coastal habitats can result in major environmental benefits, but also job losses and rent increases for the very same communities who are intended to be protected by these natural buffers. Coastal resilience investments should provide economic benefits for adjacent working-class communities, including anti-displacement housing policies and local jobs programs.

- ***Address economic impacts on agriculture***. California has major agricultural regions along the Central Coast - such as the Oxnard Plain, Santa Maria Valley and Salinas Valley- where tens of thousands of farmworkers are employed in the fields and whose livelihoods are threatened by seawater intrusion into groundwater aquifers. Focused monitoring of seawater intrusion in coastal agricultural areas, restoration of coastal wetlands buffers, and effective groundwater management to prevent excessive pumping and restore fresh groundwater could help prevent major long-term economic damage to agriculture and farmworkers.

- ***Address emergency services and response to natural disasters***. Vulnerable populations including low-income, unhoused, elderly, disabled and immigrant communities, are often left behind in access to information and resources in the chaos of disaster response. Proactive, deliberate planning in partnership with marginalized communities can prevent this type of systemic failure in the event of a flooding disaster. Emergency services agencies should be prepared to translate print and online communications and create a more comprehensive vulnerable communities emergency response plan through stakeholder engagement. Known information about future flooding risks should be made easily available in all commonly spoken local languages and in visual form.

- ***Evaluate the social and economic implications of various adaptation strategies***. Planning and investment decisions that will increase risk to vulnerable communities should be avoided, and actions to bolster resilience and social equity should be prioritized.

2. **Adaptation strategies should prioritize protection of coastal habitats and public access.**

    - ***Implement natural solutions for shoreline protection.*** Strategies to protect shoreline development from sea level rise impacts should prioritize the use of nature-based solutions where feasible or appropriate and minimize shoreline armoring and flood barriers where possible. While hard structures or gray solutions provide temporary protection against the threat of sea level rise, they disrupt natural shoreline processes, accelerate long-term erosion, and can prevent coastal habitats from migrating with sea level rise, causing loss of beaches and other critical habitats that provide ecosystem benefits for both wildlife and people; therefore, they should only be used in appropriate locations and situations.

      Natural shoreline infrastructure means utilizing the natural function of ecological systems or processes to reduce vulnerability to specific environmental hazards and increase resilience of the shoreline in order to perpetuate or restore its ecosystem services.[35] Natural infrastructure includes preservation or restoration of dunes, wetlands and other coastal habitats and leverages natural processes to reduce risk to human lives, property and infrastructure by providing a buffer against storm surge and increased wave action, thus reducing shoreline impacts and coastal erosion. These solutions have been shown in many cases to be low maintenance, cost-effective and adaptive to changing conditions. Additionally, natural infrastructure provides multiple benefits beyond flood protection including public access, habitat for wildlife and improved water quality, thereby building resilience while improving the overall ecological function of coastal systems.

      In addition to prioritizing natural infrastructure, strategic relocation should be considered as a possible adaptation strategy to address rising sea levels. This can result in a landward redevelopment pattern and thoughtful realignment of development along the coast so that natural erosion and other coastal processes, including beach formation, can continue. This approach also allows shorelines to migrate naturally, rather than using seawalls, flood barriers, or rock revetments to anchor them in a specific location and may involve changing patterns of residential, commercial, or industrial development and restoration of natural areas to enhance ecosystem services,

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[35] Newkirk et al, 2018.

make sound infrastructure investments, and provide additional protection and safety against flooding through buffering effects, as described above.

Strategic relocation will also provide added protection for wetlands, marshes and other important coastal habitats that will face inundation or erosion if restricted from moving landward by existing development or shoreline armoring. Decision makers should prioritize conservation, restoration and land acquisition of properties that can provide needed open space to accommodate inland migration in order to preserve the natural function of wetlands and other coastal ecosystems.

Restoration of wetlands and other coastal habitats should remain a priority in California even in the face of rising seas; even if present-day restored wetlands transition to subtidal habitat sometime in the future, there will still be continued ecosystem benefits for wildlife and people over the long term. In addition, wetland restoration and other adaptation strategies that provide greenhouse gas reduction benefits by storing and sequestering carbon should be prioritized.

- ***Preserve public access, including beaches and coastal parks, while protecting natural resources***. Public access along California's coast is already being affected by sea level rise, coastal flooding, and erosion. Coastal trails, public beaches, park infrastructure, and other state and public assets that are of high value to Californians will increasingly be under threat from higher sea levels, intensified wave action, and accelerated coastal erosion.

  Decision makers, including state and local agencies that manage state or locally owned coastal assets, should assess the vulnerability of public access and prioritize its protection for the invaluable benefits it provides to residents and visitors. Every effort should be made to ensure that protection of public access or park infrastructure does not degrade coastal habitats. Beaches backed by development or shoreline armoring will not be able to migrate inland as sea levels rise, resulting in permanent inundation over time and loss of public access. Consideration should be given to allowing for natural shoreline movement and relocation of public access and park infrastructure to preserve beach access and protect wetlands, dunes and other coastal habitats. Using natural infrastructure to safeguard public access facilities, parks, and trails or planning ahead to relocate these resources will help ensure that both public access and coastal habitats are preserved for the long-term.

3. **Adaptation strategies should consider the unique characteristics, constraints and values of existing water-dependent infrastructure, ports and Public Trust uses.**

Existing water-dependent infrastructure and ports support Public Trust uses vital to the State (such as commerce, navigation, fisheries, and recreation) and have unique characteristics and constraints for adaptation to sea level rise. They are often located in densely developed coastal areas where asset relocation, natural infrastructure solutions, and other space-dependent strategies may not be feasible. Planners should continue to collaborate regionally and with the State to develop adaptation strategies for water-dependent infrastructure that will be protected in place, as well as address strategies to adapt existing infrastructure into the future. Existing shoreline protective structures may need to be repaired and retrofitted to adapt to rising sea levels. Negative impacts to other Public Trust values, including coastal habitats and public access, should be minimized in all existing and future use of shoreline protective structures. Innovative and resilient design alternatives to conventional gray infrastructure should be explored when retrofitting existing protective structures or contemplating future protective structures.

4. **Consider episodic increases in sea level rise caused by storms and other extreme events.**

   As described in more detail in Chapter 4 below, individually or in combination, these events will produce significantly higher water levels than sea level rise alone, and will likely be the drivers of the strongest impacts to coastal ecosystems, development and public access over the next several decades. Water levels reached during these large, acute events have already caused significant damage along California's coast. For example, a strong El Niño combined with a series of storms during high-tide events caused more than $200 million in damage (in 2010 dollars) to the California coast during the winter of 1982--83. Additionally, in areas where rivers meet the ocean, the combined effects of sea level rise, storm conditions and higher riverine water levels could further exacerbate flooding conditions in these locations.

   Furthermore, climate change may result in increased frequency or intensity of coastal storms and extreme events, posing even greater risks for California's coastline from flooding, erosion and wave damage. To adequately protect coastal communities, infrastructure and natural resources, decision makers should consider extreme oceanographic conditions in conjunction with sea level rise over the expected life of a project. A range of existing mapping tools is available to help evaluate storm-related coastal flooding, sea- level rise and shoreline change and to evaluate impacts and change into the future; these mapping tools are described in detail below. In addition to these tools, the San Francisco Bay Conservation and Development Commission's (BCDC) Adapting to Rising Tides (ART) Program has developed robust and locally-relevant resources for the San Francisco

Bay to understand current and future flood risk.[36] It is important to note that current Federal Emergency Management Agency (FEMA) flood maps are based on existing shoreline characteristics and wave and storm climatology at the time of the flood study and historic storm data; therefore, these maps will not reflect flood hazards based on anticipated future sea levels or increased storms associated with climate change.[37]

5. **Coordinate and collaborate with local, state and federal agencies when selecting sea level rise scenarios; where feasible, use consistent sea- level rise scenarios across multi-agency planning and regulatory decisions.**

   Project planning and design along the coast often requires approval by multiple agencies across local, regional, state and federal levels. To increase efficiency and standardize risk evaluation, efforts led by or under the regulatory authority of multiple agencies should use the same sea level rise scenarios to achieve consistency across specific projects and regions. Cross-jurisdictional decisions should also prioritize implementation of consistent or complementary adaptation strategies.

6. **Consider local conditions to inform decision making.**

   Local circumstances and associated sea level rise impacts should be assessed to inform adaptation decisions that will protect communities and the environment. The interplay between sea level rise and conditions such as contaminated soil, groundwater, or stormwater systems as well as beach and cliff erosion can vary significantly along the coast and should be evaluated at a local level. The diversity of shoreline types, natural conditions, community characteristics, services, assets, land ownership, and local priorities may warrant different approaches to planning and adaptation, particularly when making decisions for new development versus maintenance or replacement of existing assets necessary for public health and safety. Adaptation pathways with a phased approach can invoke the precautionary principle while maintaining protection of community well--being, the environment, and critical assets.

7. **Assessment of risk and adaptation planning should be conducted at community and regional levels, when possible.**

   Sea level rise planning decisions made for one municipality, or even one landowner, have the potential to impact the resiliency of nearby properties and coastal habitats. A jurisdiction that chooses to implement natural infrastructure may lose some of the benefits and protection from this adaptation strategy if an adjacent community decides to construct

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[36] www.adaptingtorisingtides.org

[37] https://www.fema.gov/flood-maps/coastal#How

a seawall. Decision makers should identify opportunities to coordinate regional adaptation planning efforts by: conducting regional vulnerability assessments to evaluate common risks; leveraging technical and financial resources; and implementing consistent regional adaptation strategies. BCDC’s ART Program and the San Diego Regional Climate Collaborative[38] are examples of regional planning efforts that can serve as models for other regional planning efforts throughout the state.

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[38] https://www.sdclimatecollaborative.org

4.0 Combined Impacts of Sea Level Rise and Other Coastal Hazards

Lead Authors: Dr. Patrick Barnard and Dr. Gary Griggs

Key Takeaways

- Rising seas will exacerbate coastal hazards such as flooding, coastal erosion, and groundwater rise, which will impact public infrastructure, private development, livelihoods, public health and safety, and natural systems. In the coming decades, these hazards and their associated social and economic impacts will be the most evident manifestation of future climate change in coastal communities.
- Over time, sea level rise will increase the frequency of coastal flooding events, which occur when sea level rise amplifies short-term elevated water levels associated with higher tides, large storms, El Niño events, or when large waves coincide with high tides. California coastal communities need to be aware of and prepared for a likely rapid increase in the overall frequency of high-tide flooding beginning in the 2030s.
- Sea level rise will increase rates of retreat of coastal cliffs and bluffs, the erosion and/or landward migration of beaches, and the loss of coastal wetlands, tidal marshes and sand dunes where barriers exist to their landward migration. Without intervention, approximately 20 to 60% of California's sandy beaches could be seasonally or permanently lost due to sea level rise.
- In coastal areas with shallow unconfined groundwater, the water table will rise as sea level rises. This groundwater rise can mobilize soil contaminants, compromise below-ground infrastructure, and may result in saltwater intrusion into freshwater aquifers. The societal impacts of shallow and emerging groundwater are projected to be comparable to overland flooding impacts during the 21st century.
- Storm events will become more damaging and dangerous as climate change and sea level rise continue. Impacts from high-intensity coastal storms in combination with sea level rise and high tides include accelerated cliff and bluff erosion, coastal flooding and beach loss, and subsurface contaminant mobilization. Sea level rise will increase the exposure of communities, assets, services and culturally important areas to significant impacts from coastal storms.

In the near term, the most obvious demonstrations of sea level rise are likely to be increased coastal flooding, shoreline retreat, groundwater rise, and habitat migration or loss. These coastal processes will be exacerbated by rising seas and will threaten and damage infrastructure and development, impact livelihoods and public health and safety, and jeopardize natural systems.

This chapter provides an overview of coastal hazards that will increase in frequency and/or intensity with rising sea levels. The information in this chapter and resources included in Appendix 3 are intended to inform steps 3 and 4 of the stepwise planning process described in chapter 3. Steps 3 and 4 recommend selection and analysis of storm surge conditions to understand vulnerability to coastal and inland flooding under Sea Level Scenarios for all projects. The stepwise process also recommends consideration of total water levels, coastal erosion, and groundwater hazards on a case-by-base basis. This chapter describes how rising sea levels are expected to affect these coastal processes so that vulnerability assessments can be conducted with awareness of relevant coastal hazards.

OPC, working in partnership with other state and federal agencies, is committed to continuing research, investments and actions that support and increase the use of sea level rise guidance across the full range of coastal decisions that are impacted by sea level rise and associated impacts.

4.1. Increased Coastal Flood Frequency

Of California's 1,100 miles of outer coast, approximately 28% is of low relief, often backed by beaches and dunes, wetlands and lagoons, estuaries, and coastal floodplains. These low-lying areas, which are often heavily populated, are the most affected by coastal flooding at present during extreme high tides and storm conditions, and will be increasingly impacted as sea level rise continues to accelerate. As seen in January 2023, intense storms can cause extreme coastal water levels, which result in coastal and inland flooding. Increasingly frequent flooding events routinely affect transportation corridors and impact coastal recreational facilities and other infrastructure, and cause recurring damage to private and public structures. To date, frequent locations of coastal flooding include the shorelines of Humboldt and San Francisco Bays, Capitola and Rio del Mar on the Central Coast, and Huntington Beach, Newport Beach, and Imperial Beach in southern California.

Imperial Beach with King Tide flooding.

High-tide flooding at Balboa Saloon, Newport Beach.

The continuing rise in sea level across California is predicted to lead to an exponential increase in the frequency of coastal flooding events, doubling with approximately every 2-4 inches of sea level rise.[39] This translates to flooding that will also last longer, extend further inland and to greater depths. Today's once-in-a-lifetime coastal flood could occur annually by 2050 and daily by 2100.[40] Disruption of highway and rail traffic, and other transportation corridors will be among the most significant impacts affecting the largest number of people.

High-tide flooding occurs when high tides, often coupled with other factors that raise the local or regional water level, cause flooding. The frequency and severity of high-tide flooding is projected to increase as sea levels rise. At present, we can get a glimpse into the future when king tides – extreme high tides that occur several times a year – occur, as higher water levels will occur more frequently in the future as sea level continues to rise.

High-tide flooding can vary across locations – even from one community to the next – depending primarily on coastal topography. A statistical model developed by Thompson et al. (2021) projects how the frequency of high-tide flooding might increase during the 21st century at thirteen NOAA tide gauges in California under the different Sea Level Scenarios (see High-Tide Flooding call out box below for more information on this tool). Using the definition of minor high-tide flooding established by NOAA,[41] the frequency of high-tide flooding in California is expected to increase significantly during and after the 2030s. Under the Intermediate Scenario, the frequency of minor high-tide flooding is projected to increase by a factor of three to four depending on location from 2030 to 2050.

In addition, California coastal communities will also be exposed to more frequent high-tide flooding events due to occurrences of the El Niño phase of the El Niño Southern Oscillation and other oceanic events. Under the Intermediate Scenario, Southern California coastlines have a greater than 30% chance of experiencing at least 20 minor high-tide flooding days during a single year by 2030, with San Diego having the highest probability at almost 60%.

High-Tide Flooding

The NASA Sea Level Change Team, in partnership with the University of Hawaiʻi Sea Level Center, developed a Flooding Analysis Tool that provides projections and analysis of high-tide flooding days for 13 tide gauge locations in California to help understand and determine the impacts of future high-tide flooding. The high-tide flooding projections in the Flooding Analysis Tool incorporate the same sea level scenarios that were downscaled for this report, so the tool

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[39] Vitousek et al., 2017.

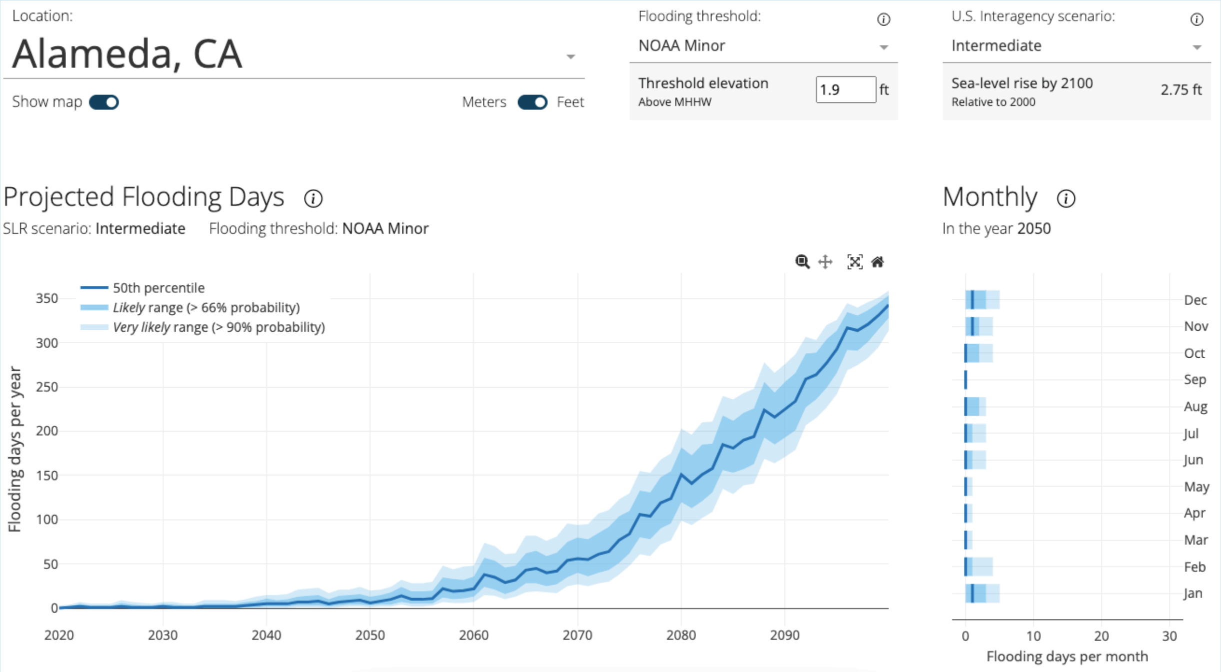
[40] Taherkhani et al., 2020.

[41] https://oceanservice.noaa.gov/facts/high-tide-flooding.html

can be used to determine how high-tide flooding may increase by location during the 21st century under the different Sea Level Scenarios.

The information provided by the Flooding Analysis Tool is site-specific for each tide gauge, and is not extrapolated for areas beyond the tide gauges. If a tide gauge does not exist at the desired location, analysis from the closest tide gauge can provide useful information, but it is important to consider the potential impact of local factors that can differ over short distances that may impact high-tide flooding. The information provided by the Flooding Analysis Tool may be helpful in determining local and regional vulnerability to high-tide flooding into the future, informed by past experiences with high-tide flooding events and projected sea level rise. While evaluation of projected high-tide flooding days is not included as part of the stepwise process in Chapter 3, it may be important to include in vulnerability assessments on a case-by-case basis, particularly for locations that have previously been impacted by high-tide flooding.

The Flooding Analysis Tool[42] website can be used to view high-tide flooding projections. The About tab provides instructions for how to use the tool, including selection of location, flood threshold, and sea level scenario. The Observed Flooding tab allows users to determine relevant flood thresholds based on the known impacts of past high sea level events. Based on the selected combination of location, threshold, and scenario, the Projected Flooding tab will show the expected number of flooding days per year during the 21st century.



Location: Alameda, CA

Flooding threshold: NOAA Minor

Threshold elevation Above MHHW: 1.9 ft

U.S. Interagency scenario: Intermediate

Sea-level rise by 2100 Relative to 2000: 2.75 ft

Projected Flooding Days

SLR scenario: Intermediate Flooding threshold: NOAA Minor

Monthly

In the year 2050

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[42] https://sealevel.nasa.gov/flooding-analysis-tool/about/instructions?station-id=9414290

Figure 4.1 (on previous page). Table produced through the Flooding Analysis Tool showing how the frequency of flooding will evolve during the 21st century for Alameda based on NOAA's Minor flooding threshold under the Intermediate Sea Level Scenario. Projected high-tide flooding days and analyses for the other California tide gauges can be found through the Flooding Analysis Tool.

By 2050, almost every California tide gauge location has a greater than 50% chance – and most have a greater than 75% chance – of experiencing at least one year with 30 minor high-tide flooding days and at least a single month with 10 minor high-tide flooding days. Impacts associated with these minor but increasingly frequent flooding events, such as a brief disruption to transportation systems and economic activity, will have cumulative impacts that can be greater than infrequent extreme events.[43]

California coastal communities need to be aware of and prepared for a likely rapid increase in the overall frequency of high-tide flooding beginning in the 2030s, as well as a continuing increase in flood occurrence. Statewide population exposure to daily coastal flooding varies by a factor of 12 from the low SLR scenario (i.e., 0.25 m SLR = 38,000 residents, expected around 2050 for other SLR scenarios) to the high SLR scenario (i.e., 2.0 m SLR = 440,000 residents, high scenario at 2100) for everyday (no-storm) conditions.[44]

New research underway to understand coastal flooding and extreme water levels

As already experienced in California, heavy rainfall events can coincide with ocean-driven coastal waves and storm surge leading to a compound flooding hazard. These co-occurrences of wave overtopping and heavy runoff often lead to significantly more damages from flooding and shoreline erosion. With research funding from the California Energy Commission (CEC), researchers from Scripps Institute of Oceanography are advancing our understanding of, and ability to project, extreme high water events.

Using historic sea level heights and the maximum sea level heights (99.9 percentile) seen at specific tide gauges in California, often during El Niño seasons, this research will provide hourly projections of how often these maximum sea level records are expected to be reached and exceeded in the future. These projections are consistent with the scenarios included in this report, but provide a different framing to emphasize the expected increase in frequency of today's extreme sea level events as we reach higher levels of sea level rise.

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[43] Moftakhari et al., 2017; Ghanbari et al., 2021.

[44] Barnard et al., 2019.

In addition, the development of a combined model projecting the likelihood of extreme sea level events co-occurring with extreme precipitation storms is underway. Here, researchers will produce high-resolution climate models to identify unusually high precipitation that additionally contributes to coastal flooding. This research is expected to help inform the state's understanding of how compound storm events are expected to drive significant coastal runoff and coastal wave overtopping leading to greater flooding extent, depth, and magnitude of damages.

4.2. Groundwater Rise and Seawater Intrusion

Freshwater aquifers in coastal areas are commonly in contact with the ocean and are therefore susceptible to seawater intrusion. Further, this connection to the ocean will also force shallow groundwater to rise as sea level continues to rise. Low-lying coastal areas of California where unconfined aquifers occur along the shoreline, such as the margins of Humboldt Bay, San Francisco Bay, Monterey Bay and Santa Monica Bay, are particularly vulnerable to these groundwater hazards. Subsurface saline water will penetrate further inland as the ocean rises, pushing less-dense freshwater upward toward the ground surface, thereby raising the water table. The response of the water table is dependent on the distance from the coast, sea level rise, the permeability of the subsurface materials, and rainfall. Rising groundwater can have significant impacts on domestic and agricultural water quality, underground infrastructure (e.g., foundations, basements, and utility lines) as well as human health, and can contribute significantly to coastal flooding in relatively flat areas.

Overpumping of groundwater from freshwater aquifers near the coast lowers the water table and when combined with sea level rise will contribute to increased intrusion of saltwater. If the water table is above sea level, the intrusion of salt water is repelled and no contamination occurs. However, the increased demand for groundwater in many of the state's fertile coastal plain areas, both for agricultural and domestic uses, has led to a lowering of the groundwater table and the intrusion of a wedge of saltwater into aquifers, referred to as seawater intrusion. Salt or brackish water begins to appear in wells making them unusable for drinking and agriculture.[45] Seawater intrusion in the lower Salinas Valley around southern Monterey Bay has been documented since 1944 and now extends eight miles inland nearly to the city of Salinas (Figure 4.2). Seawater intrusion has also been a major problem in the Sacramento Delta area, in Santa Clara County, and on the Oxnard Plain in Ventura County.

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[45] Jakovovic et al., 2016.; Loáiciga et al., 2012.

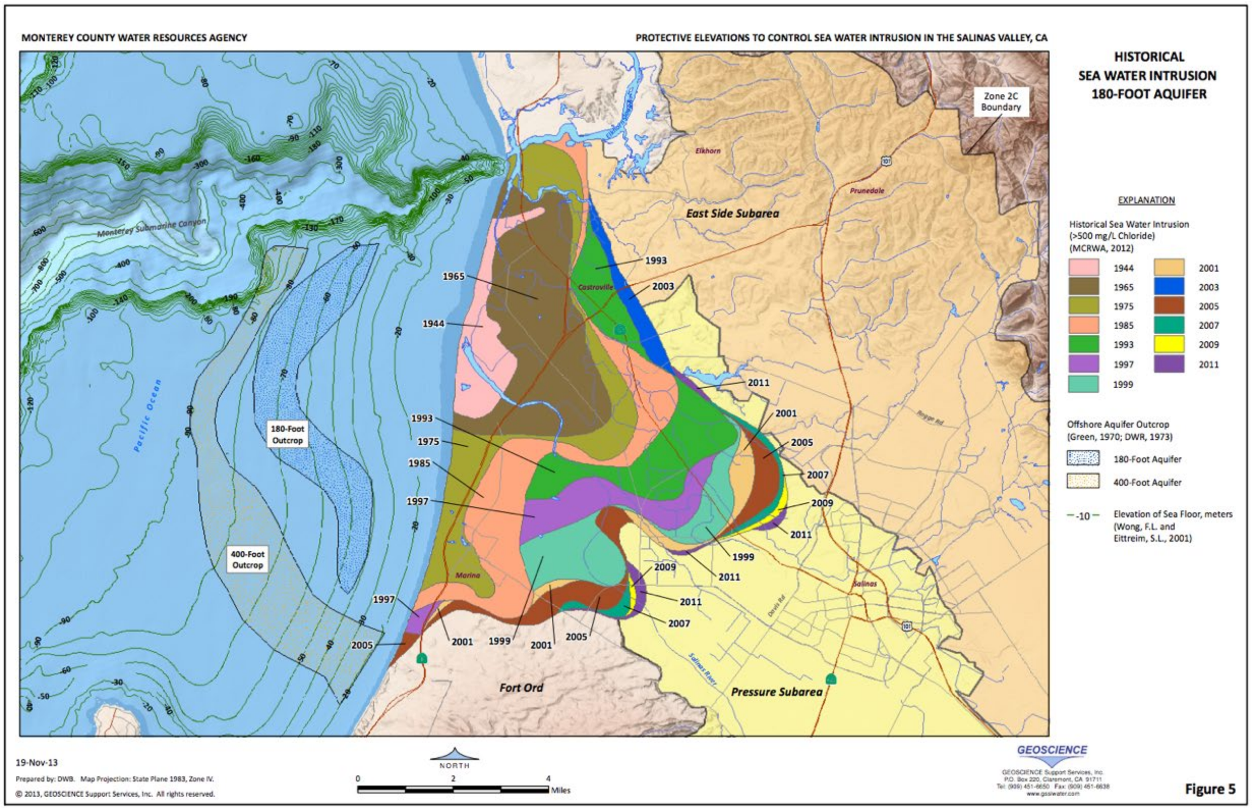

Figure 4.2. Historical progression of seawater intrusion into the 180-foot aquifer in the lower Salinas Valley.

An increase in groundwater salinity and also a higher water table can also impact building foundations, infiltrate sanitary sewers and stormwater pipes, and corrode underground utilities that were not designed to be submerged in saltwater.[46] This puts foundations, underground sewer pipes, and public utility infrastructure (e.g., gas pipelines, fiber optic cables, electrical lines, sewage pump stations) at progressive risk of failure.

Contaminants in the subsurface in the thousands of buried waste disposal sites surrounding San Francisco Bay will be mobilized by rising sea level and groundwater. Mobilization of soil toxins can occur as a result of a gradual increase in groundwater elevation from sea level rise or can happen during a severe storm event that causes flooding and rapid groundwater rise. A recent study found that groundwater rise may affect thousands of contaminated sites in the San Francisco Bay Area, and that socially vulnerable communities are disproportionately exposed to this risk.[47]

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[46] Habel et al., 2023.

[47] Cushing et al., 2023; Hill et al., 2023.

Recent studies show that coastal communities will likely become much more exposed to rising coastal groundwater hazards, defined here as the water table within 6.5 feet (2 m) of the ground surface, than overland flooding alone, potentially affecting 1.9 million California residents for the Intermediate Scenario (i.e., 3.3 feet or 1 m).[48] Preliminary research indicates potential serious risks for human and ecosystem health near urban sites that handle hazardous materials and sites that contain soil contaminants.[49] Over time, with a continuing rise in sea level, the groundwater exposure will gradually shift further inland, exposing new areas that were designed without consideration for shallower, more saline, and emerging water tables.

Screening for exposure to groundwater rise

Our Coast, Our Future – developed by Point Blue Conservation Science and USGS Pacific Coastal and Marine Science Center – is a user-friendly web-based tool for understanding and viewing potential flooding, coastal erosion, and rising groundwater hazards based on model outputs from CoSMoS. This tool allows users to identify areas along California's coastline that will likely be exposed to and are at risk from these coastal hazards due to projected sea level rise.

As it specifically relates to groundwater rise, this tool can be used to assess where coastal assets and resources may be exposed to rising seas and coastal flooding, which are represented as flood extent and flood-prone low-lying areas. By incorporating the sea level scenarios for a given location from this guidance (see Appendix 2), users of this tool can conduct a rapid assessment for where aquifers, communities, and infrastructure may be susceptible to saltwater intrusion and potential groundwater rise.

Additionally, OCOF can also be used to identify areas for groundwater rise (i.e. shoaling) and flooding (i.e. groundwater emergence). By incorporating an area's respective Sea Level Scenarios, OCOF depicts areas of varying groundwater hazards, including: (1) marine inundation (i.e. MHHW sea level), (2) emergent (i.e. water table reaches ground surface), (3) very shallow (i.e. water table within 3.3 ft of ground surface), (4) shallow (i.e. water table within 3.3 - 6.6 ft of ground surface), and (5) moderate (i.e. water table within 6.6 - 16.4 ft of ground surface). These levels represent varying risk from surface flooding – ranging from high to low according to the hazard levels above – but they all may still pose hazards to buried infrastructure. An example of Richmond, CA is provided below (Figure 4.3). With this information in hand, practitioners can better assess the need to collate, or invest in collecting, additional data and information to quantify risk and or potential impacts.

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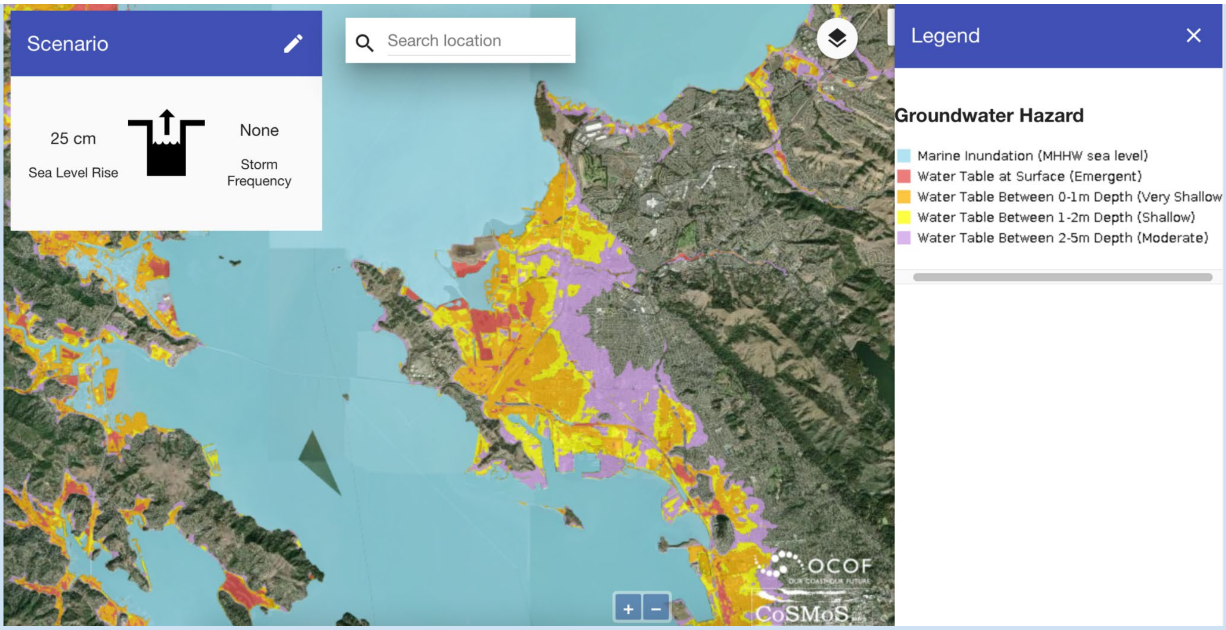
[48] Befus et al., 2020

[49] Cushing et al., 2023.; Hill et al., 2023.



25 cm
Sea Level Rise

None
Storm
Frequency

Groundwater Hazard

- 🟦 Marine Inundation (MHHW sea level)
- 🟥 Water Table at Surface (Emergent)
- 🟧 Water Table Between 0-1m Depth (Very Shallow
- 🟨 Water Table Between 1-2m Depth (Shallow)
- 🟪 Water Table Between 2-5m Depth (Moderate)

Figure 4.3. Snapshot output from OCOF illustrating groundwater hazards for Richmond, CA using the Intermediate Scenario for 2050 (0.8 ft).

4.3. Coastal and Shoreline Erosion

4.3.1. Loss or Migration of Beaches

Beaches serve as the first line of defense for many coastal communities against storm-driven flooding because they dissipate wave energy. Beaches with no back beach obstructions will tend to migrate landward as sea level rises and/or sediment supply is reduced. However, if landward migration is inhibited by physical barriers, such as resistant cliffs, seawalls, rock revetments, railway lines, highways, or other urban development, beaches will narrow and likely drown or be permanently inundated between a rising ocean and the resistant feature, a phenomenon known as coastal squeeze or passive erosion.

The response of California's sandy shoreline to sea level rise and storms has been projected across the entire state using the CoSMoS-COAST shoreline model.[50] This model localizes information on beach behavior based on satellite observations from the last 29 years, and then makes projections of shoreline change based on wave-driven longshore and cross-shore transport of sand due to waves and sea level rise. This model also makes projections considering both the existence and removal of protective shoreline structures such as seawalls or revetments. Across the range of the sea level scenarios, and without preventative or management action, 20 to 60% of sandy beaches could be seasonally or permanently lost by

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[50] Vitousek et al., 2017; 2021; 2023

2100. Changes in sediment supply could reduce or increase this loss; for example, dams have reduced the natural sand supply to California beaches from rivers and streams by 23%, including 50% in Southern California, since the late 19th century.[51]

4.3.2. Cliff and Bluff Retreat

The great majority of California's 1,100-mile coast (790 miles or 72%) consists of actively eroding sea cliffs. About 650 miles of this is composed of lower-relief cliffs and bluffs typically eroded into uplifted marine terraces. Many of the state's communities are built on these features – including Fort Bragg, Mendocino, Pacifica, Half Moon Bay, Santa Cruz, Pismo Beach, Santa Barbara and many of the cities in Orange and northern San Diego Counties. Most of these cliffs and bluffs are actively eroding, although 38% of the coast of Southern California has now been armored. As sea levels continue to rise, waves will reach and impact the base of coastal cliffs, bluffs, and dunes more often which will lead to increased erosion rates and threats to blufftop development and infrastructure as shown in the image below.

Bluff retreat in Pacifica ultimately led to the demolition of these apartments.

Historical cliff retreat rates in California range from several centimeters to a meter or more per year.[52] Cliff recession rates vary based on a number of regional and local factors, including wave impacts at the base of the cliff, tidal range, rock type, joint density, tectonic forces, protection structures, drainage and groundwater flow, climate variability, and storm frequency. However,

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[51] Slagel and Griggs, 2008.

[52] Hapke and Reid, 2007; Swirad and Young et al., 2022; Griggs, et al., 2005.

regardless of these variables, an increase in sea level will result in greater exposure of the cliff base to wave impacts, and the rate of cliff retreat is likely to increase.

Limber et al. (2017) projected statewide cliff retreat for the five Sea Level Scenarios. The results show an increase over historical rates with continued sea level rise, and as much as a doubling with two meters of rise. For example, under the Intermediate Scenario of 1 meter by 2100, cliffs are projected to retreat 23 m (75 ft), on average, by 2100, although retreat rates will vary widely depending upon local cliff properties and wave energy. Nonetheless, both protected and unprotected cliff top communities will be at an even greater risk over the 21st Century. Each coastal community will need to undertake vulnerability assessments to determine which facilities and development are at greatest risk and then agree on how and when to respond or adapt to expected future conditions.

4.3.3. Loss or Migration of Coastal Ecosystems and Species

Coastal ecosystems will be significantly impacted by sea level rise across the state. Habitats such as beaches, dunes, and tidal marshes will be exposed to more frequent flooding, erosion and coastal squeeze, although in undeveloped areas where there are no barriers, they will continue to migrate inland, as they have historically. In many locations, the habitat space for many species will be progressively constricted between rising seas and urban development, restricting landward migration.[53] Hard armoring along the coast, including rock revetments and seawalls, contributes to habitat loss because rising sea levels submerge coastal habitats while these artificial structures prevent landward migration.

Historically, coastal wetland elevation has kept pace with lower rates of sea level rise due to sediment accumulation and available accommodation space.[54] The ability of tidal wetlands and marshes to continue to build elevation at a sustainable rate relative to higher sea levels of the future depends primarily on the rate of sea level rise, sediment deposition,[55] building of below ground peat soils by wetland vegetation[56] and decomposition and sediment compaction rates. Under higher sea level scenarios, Thorne et al. (2018) predict that substantial vegetated tidal marshes in California will transition to mud flats by the end of the 21st century due to constraints on horizontal migration in urbanized estuaries (San Francisco Bay, for example). The historical alteration of tidal marshes across the state and reductions in sediment supply that reduce vertical growth potential will further challenge marsh sustainability and the associated ecosystems under sea level rise. Loss of coastal wetlands and tidal marshes would also mean

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[53] Dugan et al., 2008; Dugan and Hubbard, 2010; Myers et al., 2019; Barnard et al., 2021.

[54] Kirwan and Megonigal, 2013.

[55] Leonard, 1997; Buffington et al., 2021.

[56] Nyman et al., 2006; Cherry et al., 2008.

losing the ecosystem services they provide, including maintaining water quality, sequestering carbon, reducing turbidity, and providing buffers against storm waves and flood waters.[57]

Species that depend upon coastal habitats are also at risk from sea level rise. A 2018 study found that eight imperiled species only occur in areas that are projected to be inundated with five feet of sea level rise, including coastal dunes milk-vetch, California seablite, and California Ridgway's rail.[58] Documented haul-outs and breeding colonies for Pacific harbor seals and Northern elephant seals, which are critical to maintaining populations, are also highly vulnerable to rising seas. Nesting habitats for shorebirds like California least tern, black oystercatcher, and Western snowy plover may be inundated without opportunity for landward migration in locations where beaches are bordered by urban environments, cliffs, or bluffs. Black oystercatchers and Pacific harbor seals rest on beach and rocky intertidal habitats, seeking areas that are free from predators and human disturbance. The small pocket beaches and rocky intertidal areas at the base of cliffs that these species typically select are particularly vulnerable to sea level rise.

4.3.4. Threats to Coastal Access and Recreation

As beaches are lost to rising seas as described above, space available to Californians and visitors for recreation along the coast decreases. Losing beaches to sea level rise in itself constricts available space for recreation, but beach accessibility is also contingent on the infrastructure and amenities that support visitation and recreation.[59] Coastal access features like trails and stairways, parking facilities, lifeguard towers, and amenities like restrooms, showers and picnic areas all contribute to the accessibility of coastal areas. As sea levels rise, these features will become vulnerable to inundation and damage from coastal storms. Beachgoers have different preferences for features, facilities, and amenities at coastal access sites,[60] so loss of infrastructure will not affect all beachgoers equally. For example, loss of restroom amenities will likely be more impactful on visitors who must travel further to reach the beach and loss of lifeguard towers will likely deter individuals with less confidence as swimmers; underlying each of these cases are significant issues relating to equity and environmental justice. An online geodatabase provides a statewide picture of how coastal access locations overlap with rising seas.[61]

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[57] Barbier et al., 2013.

[58] Heady et al., 2018.

[59] Patsch and Reineman, 2023 (accepted).

[60] Christensen and King, 2017.

[61] https://www.arcgis.com/apps/dashboards/19ac80fe57e747ac9caaf966b29cb9c4. Note: While this dataset can provide valuable insights into potential vulnerabilities, it should not be

Rising seas will also have impacts on surf breaks, which hold substantial recreational value in California. As sea levels rise, water depth at current surf break locations will increase. Deeper water means either that only larger waves can break at that precise location, or that smaller waves must break in a location translocated towards shallower water.[62] As shoreline geography and development allows, some surf breaks will migrate landward but most are likely to meet a suite of challenges, imperiling a valued recreational resource.[63]

4.4. Preparing for Extreme Coastal Storms

Although the near-term and cumulative effects of sea level rise described above occur gradually over time, when extreme coastal storms occur coincident with higher background sea levels, very high or king tides and/or short-term sea level rise (such as during an El Niño event), the impacts and damages can be sudden and severe. For example, extreme coastal storms with large waves can cause widespread flooding in low-lying areas, extensive beach loss, and cliff or bluff collapse (image below). As a first pass at understanding coastal risk, communities need to apply the history of damage from past events (January 2023, for example) including large El Niños (1982-83, 1997-98, and 2015-16) to plan in advance for how to respond or adapt to these in the future in order to limit losses and disruption, all of which will be exacerbated with a higher baseline of sea level. Another approach is to refer to the results of modeled extreme storm scenarios, such as the annual, 20-year, and 100-year storm events, coupled with sea level rise, to more broadly understand the risks of climate-driven coastal hazards.

The Coastal Storm Modeling System (CoSMoS)[64] can be used to understand the cumulative impacts of sea level rise and storms on California coastal communities. Adding storms increases population exposure by 50-340% over daily high tide conditions. Approximately 700,000 California residents and $250 billion in property could be exposed to flooding by 2100 under the high scenario and a 100-year storm.[65] The San Francisco Bay Area accounts for two-thirds of future flood risk of the California population and property values state-wide, but low-lying areas across the state are also at risk, including numerous coastal and estuarine communities, as well as airports, port facilities, transportation corridors, and public utilities.

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used as the sole basis for critical decisions related to coastal management, emergency response, or infrastructure planning.

[62] Reineman et al., 2017.

[63] Sadrpour and Reineman, 2023.

[64] http://www.usgs.gov/cosmos

[65] Barnard et al., 2019.

Damage to West Cliff Drive in Santa Cruz during high tides and extreme waves in January 2023.

5.0 Conclusions and Looking Forward

California must take bold and swift action to protect nature and coastal communities from the impacts of sea level rise. This action needs to be grounded in current science, standardized across jurisdictions, and flexible enough to accommodate local priorities while ensuring that the state is adequately prepared to adapt to the expected changes ahead.

As demonstrated in this update, understanding of sea level rise continues to rapidly evolve with increases in data availability and scientific tools. The IPCC, along with U.S. federal agencies, is expected to provide updates on sea level rise trends and projections every five years, which will continue to serve as the foundation for updates to California's sea level rise guidance. Over the next five years, we anticipate that scientific understanding will be further refined, leading to even more precise guidance on anticipated sea level rise and the use of scenarios for adaptation planning and projects. Monitoring sea level rise trends and impacts for adaptive management and planning will continue to be a key part of this process.

This report, based on science from a team of leading experts, provides overarching science and policy guidance to support coordinated and consistent planning and adaptation. Affording local decision-making autonomy is important to ensure that planning is location-specific and tailored to circumstances – and is guided by overarching science. This guidance allows for local planners, elected officials, tribes and additional decisionmakers to make the most appropriate decisions for their communities. OPC is committed to continuing to provide scientific support and build capacity for sea level rise planning and adaptation. OPC actions moving forward include:

- Ongoing coordination with the existing membership of the State Sea-Level Rise Collaborative, including continued implementation, progress accounting, and future update of the State Agency Sea-Level Rise Action Plan for California.
- Prioritized integration of local, regional, and tribal governments on the State Sea-Level Rise Collaborative to further embed local priorities and needs into statewide policies and actions.
- Accelerated access to funding for standardized sea level rise adaptation plans and projects through OPC's Senate Bill (SB) 1 Grant Program; maximized investments to highly vulnerable and under-resourced communities.
- Partnership with the Governor's Office of Planning and Research, California Natural Resources Agency, the California Energy Commission, and the Strategic Growth Council to bridge this guidance with the sea level rise research and recommendations included in California's Fifth Climate Change Assessment scheduled for completion in 2026.
- Integration of updated sea level rise scenarios and policy guidance into OPC's broader Strategic Plan priorities to build climate resilience for marine ecosystems and

communities, advance equity, conserve biodiversity, and promote the sustainable blue economy.

California can continue to serve as a model for the nation for how to integrate science into policy and planning decisions to minimize impacts from sea level rise on ecosystems, cultural resources and traditional practices, livelihoods, and public and private property. There is much work ahead, but collective action at the local, regional, tribal, state and federal levels will build the resilience that California needs to thrive, even in a changing climate.

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Appendices

Appendix 1. Map of California NOAA Tide Gauge Locations (13 total)

Appendix 2. Sea Level Scenarios at NOAA Tide Gauge Locations

For each tide gauge, amounts of sea level rise (in feet) are provided by decade and for each sea level scenario, from 2020 to 2150 (Tables 1 to 12). The results shown in Chapter 2, Table 2.1 are statewide averages. Sea Level Scenarios are also produced at each individual NOAA tide gauge location (see Appendix 1), and these incorporate a local estimate of vertical land motion. The difference between the individual tide gauge numbers and the statewide average (Table 2.1) for any given year or scenario reflects the contribution of vertical land motion in that location. The 2000 baseline is set agnostic of vertical datum, but the scenarios can be set to specific choices of vertical datum for application to projects. This will involve applying a vertical offset to the scenarios to align the 2000 baseline with the baselines of existing tidal datums of interest (e.g. MSL, MHHW). The 2022 Sea Level Rise Technical Report provides regional offsets for 1992-2000, 2000-2005, and 2005-2020 that can be used for these purposes. These scenarios, now set in the appropriate tidal datum, can then be converted to land-based heights (i.e. transform to a geodetic datum such as NAVD88).

Table 1. Sea Level Scenarios for Crescent City.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.1	0.1	0.1	0.1
2030	0.1	0.1	0.2	0.2	0.2
2040	0.1	0.2	0.2	0.3	0.4
2050	0.1	0.3	0.4	0.6	0.8
2060	0.1	0.4	0.6	1.0	1.5
2070	0.2	0.4	0.8	1.6	2.3
2080	0.2	0.6	1.2	2.3	3.4
2090	0.2	0.7	1.7	3.0	4.5
2100	0.2	0.8	2.3	3.9	5.6
2110	0.2	0.9	2.9	4.7	6.9
2120	0.2	1.0	3.4	5.3	7.9
2130	0.2	1.2	3.8	5.8	8.7
2140	0.2	1.3	4.2	6.3	9.6
2150	0.2	1.4	4.7	6.8	10.3

Table 2. Sea Level Scenarios for N. Spit, Humboldt Bay.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.3	0.4	0.4	0.4	0.4
2030	0.5	0.6	0.6	0.6	0.7
2040	0.7	0.8	0.9	1	1.1
2050	0.9	1	1.2	1.4	1.6
2060	1.1	1.3	1.5	2	2.4
2070	1.3	1.5	1.9	2.7	3.5
2080	1.4	1.8	2.5	3.6	4.7
2090	1.6	2.1	3.1	4.5	6
2100	1.8	2.4	3.9	5.5	7.3
2110	1.9	2.7	4.6	6.5	8.7
2120	2.1	3	5.3	7.3	9.9
2130	2.3	3.3	5.9	8	10.8
2140	2.4	3.5	6.5	8.6	11.9
2150	2.6	3.8	7.1	9.3	12.8

Table 3. Sea Level Scenarios for Arena Cove.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.4	0.4
2040	0.3	0.4	0.5	0.6	0.7
2050	0.4	0.5	0.7	0.9	1.1
2060	0.5	0.7	0.9	1.4	1.8
2070	0.5	0.8	1.2	2.1	2.8
2080	0.6	1.0	1.7	2.8	3.9
2090	0.7	1.2	2.2	3.6	5.1
2100	0.8	1.4	2.9	4.5	6.4
2110	0.8	1.6	3.6	5.4	7.6
2120	0.9	1.7	4.1	6.1	8.7
2130	0.9	1.9	4.6	6.7	9.6
2140	1.0	2.1	5.1	7.3	10.5
2150	1.0	2.3	5.6	7.8	11.4

Table 4. Sea Level Scenarios for Point Reyes.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.3	0.3
2030	0.3	0.4	0.4	0.4	0.5
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.7	0.8	1.0	1.3
2060	0.6	0.8	1.1	1.6	2.0
2070	0.7	1.0	1.4	2.2	3.0
2080	0.8	1.2	1.9	3.0	4.1
2090	0.9	1.4	2.5	3.9	5.4
2100	1.0	1.6	3.1	4.8	6.6
2110	1.1	1.8	3.8	5.7	7.9
2120	1.2	2.0	4.4	6.4	9.0
2130	1.2	2.2	4.9	7.0	9.9
2140	1.3	2.4	5.5	7.6	10.9
2150	1.4	2.7	6.0	8.2	11.8

Table 5. Sea Level Scenarios for San Francisco.
Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.3	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.3
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	2.9
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.8	5.3
2100	1.0	1.6	3.1	4.8	6.5
2110	1.0	1.8	3.8	5.6	7.8
2120	1.1	2.0	4.4	6.4	9.0
2130	1.2	2.2	4.9	7.0	9.9
2140	1.3	2.4	5.4	7.6	10.8
2150	1.3	2.6	6.0	8.1	11.7

Table 6. Sea Level Scenarios for Alameda.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.3	0.4
2040	0.3	0.4	0.4	0.5	0.6
2050	0.3	0.5	0.6	0.9	1.1
2060	0.4	0.6	0.9	1.4	1.8
2070	0.5	0.8	1.2	2.0	2.7
2080	0.5	0.9	1.6	2.8	3.8
2090	0.6	1.1	2.1	3.5	5.0
2100	0.6	1.2	2.8	4.4	6.2
2110	0.7	1.4	3.4	5.3	7.5
2120	0.7	1.6	4.0	5.9	8.5
2130	0.8	1.7	4.5	6.5	9.4
2140	0.8	1.9	4.9	7.1	10.3
2150	0.8	2.1	5.4	7.6	11.2

Table 7. Sea Level Scenarios for Monterey.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.4	0.4
2040	0.3	0.4	0.5	0.6	0.7
2050	0.4	0.6	0.7	0.9	1.2
2060	0.5	0.7	1.0	1.4	1.9
2070	0.6	0.9	1.3	2.1	2.8
2080	0.6	1.0	1.7	2.9	3.9
2090	0.7	1.2	2.3	3.7	5.2
2100	0.8	1.4	2.9	4.6	6.4
2110	0.8	1.6	3.6	5.5	7.7
2120	0.9	1.8	4.2	6.2	8.8
2130	0.9	1.9	4.7	6.8	9.7
2140	1.0	2.1	5.2	7.3	10.6
2150	1.1	2.3	5.7	7.9	11.5

Table 8. Sea Level Scenarios for Port San Luis.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.3	0.4
2040	0.3	0.4	0.4	0.5	0.6
2050	0.3	0.5	0.6	0.9	1.1
2060	0.4	0.6	0.9	1.4	1.8
2070	0.5	0.7	1.2	2.0	2.7
2080	0.5	0.9	1.6	2.8	3.8
2090	0.5	1.1	2.1	3.5	5.0
2100	0.6	1.2	2.8	4.5	6.3
2110	0.6	1.4	3.4	5.3	7.5
2120	0.7	1.5	4.0	6.0	8.6
2130	0.7	1.7	4.4	6.6	9.5
2140	0.7	1.9	4.9	7.1	10.4
2150	0.8	2.0	5.5	7.6	11.3

Table 9. Sea Level Scenarios for Santa Barbara.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.3	0.4
2040	0.3	0.4	0.4	0.5	0.6
2050	0.3	0.5	0.6	0.9	1.1
2060	0.4	0.6	0.9	1.4	1.8
2070	0.5	0.7	1.2	2.0	2.7
2080	0.5	0.9	1.6	2.8	3.8
2090	0.5	1.1	2.1	3.5	5.0
2100	0.6	1.2	2.8	4.5	6.3
2110	0.6	1.4	3.4	5.3	7.5
2120	0.7	1.5	4.0	6.0	8.6
2130	0.7	1.7	4.4	6.6	9.5
2140	0.7	1.9	4.9	7.1	10.4
2150	0.8	2.0	5.5	7.6	11.3

Table 10. Sea Level Scenarios for Santa Monica.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.2	0.2
2030	0.3	0.3	0.4	0.4	0.4
2040	0.3	0.4	0.5	0.6	0.7
2050	0.4	0.6	0.7	0.9	1.2
2060	0.5	0.7	1.0	1.5	1.9
2070	0.6	0.9	1.3	2.1	2.8
2080	0.6	1.0	1.7	2.9	3.9
2090	0.7	1.2	2.3	3.7	5.2
2100	0.8	1.4	2.9	4.6	6.4
2110	0.8	1.6	3.6	5.5	7.7
2120	0.9	1.8	4.2	6.2	8.8
2130	0.9	1.9	4.7	6.8	9.7
2140	1.0	2.1	5.2	7.3	10.6
2150	1.1	2.3	5.7	7.9	11.5

Table 11. Sea Level Scenarios for Los Angeles.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.1	0.2	0.2	0.2	0.2
2030	0.2	0.3	0.3	0.4	0.4
2040	0.3	0.4	0.5	0.6	0.7
2050	0.4	0.5	0.7	0.9	1.1
2060	0.4	0.6	0.9	1.4	1.8
2070	0.5	0.8	1.2	2.1	2.7
2080	0.5	0.9	1.6	2.8	3.8
2090	0.6	1.1	2.2	3.6	5.0
2100	0.6	1.3	2.8	4.5	6.3
2110	0.7	1.4	3.5	5.3	7.6
2120	0.7	1.6	4.0	6.0	8.6
2130	0.8	1.8	4.5	6.6	9.5
2140	0.8	1.9	5.0	7.1	10.4
2150	0.8	2.1	5.5	7.7	11.3

Table 12. Sea Level Scenarios for La Jolla.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.3	0.3	0.3
2030	0.3	0.4	0.4	0.4	0.5
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.7	0.8	1.0	1.3
2060	0.6	0.8	1.1	1.6	2.0
2070	0.7	1.0	1.4	2.3	3.0
2080	0.8	1.2	1.8	3.1	4.1
2090	0.9	1.4	2.4	3.9	5.3
2100	0.9	1.6	3.1	4.8	6.6
2110	1.0	1.8	3.8	5.7	7.9
2120	1.1	2.0	4.4	6.4	9.0
2130	1.2	2.2	4.9	7.1	9.9
2140	1.2	2.4	5.5	7.6	10.9
2150	1.3	2.6	6.0	8.2	11.8

Table 13. Sea Level Scenarios for San Diego.

Median values of Sea Level Scenarios, in feet, for each decade from 2020 to 2150, with a baseline of 2000. All median scenario values incorporate the local estimate of vertical land motion.

Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.3	0.3	0.3
2030	0.3	0.4	0.4	0.5	0.5
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.7	0.8	1.1	1.3
2060	0.6	0.9	1.1	1.6	2.0
2070	0.7	1.0	1.4	2.3	3.0
2080	0.8	1.2	1.9	3.1	4.1
2090	0.9	1.4	2.5	3.9	5.4
2100	1.0	1.6	3.2	4.9	6.7
2110	1.1	1.8	3.9	5.7	8.0
2120	1.2	2.1	4.5	6.5	9.1
2130	1.3	2.3	5.0	7.1	10.0
2140	1.3	2.5	5.6	7.7	11.0
2150	1.4	2.7	6.1	8.3	11.9

Appendix 3. Tools and Resources to Support Visualization of Sea Level Rise and Coastal Hazards

Several existing geospatial and data visualization tools can be used to support sea level rise and coastal hazard planning efforts. State and local planners, project managers, and members of the public can leverage these tools to visualize the impacts of future plausible Sea Level Scenarios in concert with coastal hazards such as flooding, erosion, and groundwater rise. These tools can help inform risk and vulnerability assessments so that coastal managers have an understanding of how current populations and infrastructure are likely to be affected by sea level rise, and can help inform future strategies that promote coastal resilience. The tools can also be used for communications efforts to help audiences visualize sea level rise and coastal hazard risks.

The following tools comprise a non-exhaustive list of existing resources publicly available at the time of this report's release. It is possible that additional data visualization tools will become available prior to the next Sea Level Rise Guidance update, so this list should be considered as a starting point for identifying the appropriate data sets and visualization tools for sea level rise and coastal hazard planning. In general, the most detailed tool available for a particular area should be used for planning, though in some cases a suite of tools should be evaluated to get a better picture of the possible risks.

- **Coastal Storm Modeling System (CoSMoS)**[66] is a model that has been developed by the United States Geological Survey (USGS) to make detailed predictions of storm-induced coastal flooding, erosion, cliff failures, and groundwater hazards over large geographic scales. CoSMoS information can either be downloaded as GIS shapefiles through the USGS ScienceBase-Catalog, or can be accessed, viewed, and downloaded through the Our Coast, Our Future flood mapper.
- **Our Coast, Our Future (OCOF)**[67] provides a user-friendly web-based tool for viewing all CoSMoS model results. OCOF was developed by Point Blue Conservation Science and USGS Pacific Coastal and Marine Science Center to provide a platform for data visualization, synthesis, and download of all outputs produced from CoSMoS.
- **Hazards Exposure Reporting and Analytics (HERA)**[68] application developed by the CoSMoS team displays estimates of residents, businesses, and infrastructure that could be exposed to CoSMoS coastal hazard projections from storms and under each of the sea level rise scenarios. HERA can help communities understand how natural hazards could impact their land, people, infrastructure, and livelihoods. In doing so HERA

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[66] https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos

[67] https://ourcoastourfuture.org/

[68] https://www.usgs.gov/apps/hera/

provides tools and data to help communities as they plan and prepare for natural hazards.

- **NOAA Sea-Level Rise Viewer**[69] is a visualization tool for coastal communities showing the potential flooding impacts from sea level rise and high tides. Photo simulations of how future flooding might impact local landmarks are provided, as well as data related to water depth, connectivity, flood frequency, socio-economic vulnerability, wetland loss and migration, and mapping confidence.
- **NASA Flooding Analysis Tool**[70] allows users to view sea level observations and assess past high-tide flooding frequency, view future changes in high-tide flooding frequency under the Sea Level Scenarios, and view statistics and inflection points that support decision making. This tool was developed by scientists at the University of Hawaii Sea Level Center with funding from the NASA Sea Level Change Team and is based on the methods of Thompson et al. (2021).
- **NOAA's Adapting Stormwater Management for Coastal Floods**[71] tool can be used by communities to determine how current and future flooding can affect their stormwater systems. The website allows practitioners to generate reports that can be used to display local information about observed and projected flooding impacts to inform planning efforts. Beyond providing an interface for analyzing flood data, this tool also includes planning recommendations for how to prepare stormwater management systems for coastal flooding.
- **NOAA's Monthly High Tide Flooding Outlook**[72] shows when and where above-normal high tides and high-tide flooding may be experienced. High-tide flooding likelihoods are updated on a monthly basis, and are derived from a probabilistic model that incorporates tide predictions, sea level rise trends, and seasonal changes in coastal sea level to predict the potential that higher than normal high tide may exceed established National Ocean Service flood thresholds.
- **Coastal County Snapshots**[73] produced by NOAA can be leveraged to produce printable reports describing sea level rise and special flood hazards on a county scale. Users can see data superimposed on a map or through a graphic interface with all data accessible for each snapshot. By delivering complex, county-level data into easy-to-understand charts and graphics, Coastal County Snapshots can support communication about planning decisions or processes.

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[69] https://coast.noaa.gov/slr/

[70] https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?

[71] https://coast.noaa.gov/stormwater-floods/

[72] https://tidesandcurrents.noaa.gov/high-tide-flooding/monthly-outlook.html

[73] https://coast.noaa.gov/snapshots/

- **NASA's Interagency Sea Level Rise Scenario Tool**[74] was developed to make the sea level scenarios updated in the 2022 Federal Sea Level Rise Technical Report publicly accessible. The information in the report and this tool is intended to inform coastal communities and others about current and future sea level rise to help contextualize its effects for decision making purposes. The scenarios presented in this tool formed the basis for the California Sea Level Scenarios described in Chapter 2 and presented in Appendix 1 of this report. The Interagency Sea Level Rise Scenario Tool was developed by the Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force, which is the Task Force that authored the federal Technical Report.
- **Cal-Adapt**[75] makes scientific projections and analyses available as a basis for understanding local climate risks and resilience options. Cal-Adapt is designed to provide the public, researchers, government agencies and industry stakeholders with tools and data for climate adaptation planning that can build resilience and foster community engagement.
- **Surging Seas Risk Finder**[76] is a multi-part public web tool that provides local sea level rise and flood risk projections, interactive maps, and exposure tabulations from zip codes and up. The Risk Finder aims to provide citizens, communities and policymakers with easily accessible, science-based, local information that can help users understand and respond to the risks of sea level rise and coastal flooding. This tool was collaboratively developed by a sea level rise group led by Climate Central.
- **Adapting to Rising Tides (ART) Bay Area Flood Explorer**[77] provides a regional-scale illustration of coastal flooding due to specific sea level rise and storm surge scenarios. This tool developed by the San Francisco Bay Conservation and Development Commission is intended to improve sea level rise awareness and preparedness by mapping potential future shoreline inundation of areas.

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[74] https://sealevel.nasa.gov/task-force-scenario-tool/

[75] https://cal-adapt.org/

[76] https://riskfinder.climatecentral.org/

[77] https://explorer.adaptingtorisingtides.org/explorer