O-55 San Francisco Baykeeper

COMMENT

SAN FRANCISCO
BAYKEEPER®

April 27, 2021

Transmitted Via Electronic Mail

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RE: Comments of San Francisco Baykeeper on the Waterfront Ballpark District at Howard Terminal Draft Environmental Impact Report

Dear City of Oakland:

O-55-1 Thank you for the opportunity to review and comment on the Draft Environmental Impact Report (DEIR) for the proposed Waterfront Ballpark District at Howard Terminal ("Project"). San Francisco Baykeeper has actively monitored this developing project and met with members of the community and the Project proponent to discuss our concerns. We appreciate the opportunity to formally state our concerns and help to shape the final plans for this important part of the City of Oakland.

San Francisco Baykeeper ("Baykeeper") is a non-profit public benefit corporation organized under the laws of the State of California with its office located at 1736 Franklin Street, Suite 800, Oakland, California, 94612. Baykeeper submits these comments on behalf of its approximately 5,000 members and supporters who live and/or recreate in and around the San Francisco Bay area. Baykeeper's mission is to defend San Francisco Bay from the biggest threats and hold polluters and government agencies accountable to create healthier communities and help wildlife thrive. Baykeeper patrols on the water, investigates and stops polluters, and strengthens laws that protect the Bay. Baykeeper is dedicated to preserving, protecting, and defending the environment, wildlife, and natural resources of San Francisco Bay and its tributaries for the benefit of its ecosystems and communities. Baykeeper furthers its goals through education, advocacy, restoration, and directly initiates enforcement of environmental laws on behalf of itself and its members.

I. INTRODUCTION

O-55-2 While Baykeeper appreciates the many exciting opportunities offered by the vision of a waterfront ballpark development, we remain committed to our mission to protect the Bay from its greatest threats. One of those is the threat posed by toxic sites throughout the Bay Area. These sites have the potential to leach harmful pollutants and chemicals into the Bay. Unfortunately, the Project is proposed on just such a site. Any contemplated development at the Howard Terminal site must

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RESPONSE

O-55-1 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here.

O-55-2 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here.

As discussed in the Draft EIR in Section 4.8.2, *Regulatory Setting*, under *Land Use Covenants*, and as explained further in Consolidated Response 4.16, *Remediation Plans, Land Use Covenants, and Human Health and Ecological Risk Assessment*, the Project site is subject to existing land use covenants (LUCs), operations and maintenance (O&M) agreements, soil and groundwater management plans, and risk management plans, all enforced by the California Department of Toxic Substances Control (DTSC), the regulatory agency with jurisdiction. These LUCs and their associated plans would be replaced and consolidated before the start of construction to account for the changes to the Project site. The substantive requirements of these replacement documents would be similar to those in the existing documents, but they would be specifically tailored to ensure protections appropriate for the types of anticipated construction activities and uses, including allowing residential use (which is currently prohibited) under specified conditions.

Similar to the existing plans, the remediation plans prepared under the requirements of the existing LUCs and the mitigation measures discussed in Draft EIR Section 4.8, *Hazards and Hazardous Materials*, Impact HAZ-2, would provide further description of the remediation steps, which would include maintaining a cap over the Project site. As explained in Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures*, the mitigation measures in the Draft EIR are actions that would be enforced by DTSC and the chief building official. Grading, building, or construction permits, and certificates of occupancy or similar operating permits for new buildings and uses, would not be issued until DTSC and the chief building official have approved the various actions required by the mitigation measures.

As discussed in Draft EIR Section 4.8.1, *Environmental Setting*, under *Human Health and Ecological Risk Assessment*, a human health and ecological risk assessment (HHERA) has been prepared, using all testing results collected through August 2020 for the Project site. The HHERA developed specific target cleanup levels that would be protective of human health and the environment. For further explanation of the HHERA, see Consolidated Response 4.16, *Remediation Plans, Land Use Covenants, and Human Health and Ecological Risk Assessment*.

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prioritize the safety of surrounding communities and the Bay by cleaning up the toxic pollution present at this site. While the DEIR pays lip service to this goal, it fails to lay out the kind of detailed plan for remediation necessary for one of the most polluted places in the entire Bay Area.

O-55-2 This incredibly complex site—consisting of five waterfront subareas built on Bay fill and subjected to long-term industrial use, with a resulting wide range of contaminants of concern (COCs) present in soil and groundwater, and at risk from both sea level rise and liquefaction[1]—requires a thorough site analysis to protect and properly inform the public. The DEIR is not that. A full assessment of the impacts of the Project would require a detailed understanding of the soil and shallow groundwater contamination on this site. Such a detailed understanding could be found in a Remedial Action Workplan (RAW) compiled by the California Department of Toxic Substances Control (DTSC). However, a RAW is proposed for the site only *after* the DEIR is finalized.

O-55-3 Overall, the Project contradicts several of Baykeeper's top priorities for protecting the Bay. First, active and legacy industry along the Bay shore poses a pollution risk as rising seas flood contaminated lands. Like many other urban areas, as the Bay Area developed, industries formed along much of its shores. Manufacturing facilities, refineries, food processing, and shipyards lined the Bay in areas like Vallejo, Richmond, Oakland, and southeast San Francisco. Hundreds of active industrial sites and over 1,000 known or likely contaminated historic sites will be subject to flooding even with a conservative 7-foot rise in sea levels. Few policies are in place to plan for risks to communities and wildlife as seas rise and storm surges inundate these sites.

Baykeeper has analyzed publicly available data to identify locations where heavy and light industry are likely to flood under current projections. The Project fits squarely within that profile. Conservative estimates indicate we can expect at least 1 meter of sea level rise by 2100,[2] and flood prone areas will likely be submerged by strong storms. As shown by Baykeeper's maps,[3] a majority

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[1] *See, e.g.*, Department of Toxic Substances Control, Human Health and Ecological Risk Assessment for the Athletics Ballpark Development Howard Terminal Site (Revised August 24, 2020) ("Risk Assessment"), pp. 1-6. According to the Risk Assessment, the "Site includes three separate cleanup sites," each with "a separate DTSC cleanup number" and each with already existing Land Use Covenants that would have to be substantially altered, with the required public process, to allow Project Construction. *Id.* at p. 2. "The COCs identified for the Site (including the three cleanup sites) include cyanide, heavy metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons ("PAHs"), and semi-volatile organic compounds (SVOCs) and volatile organic compounds ("VOCs") in soil and groundwater. Soil, soil gas, and groundwater impacts have been identified and remain at the Site." *Id.* at p. 3.

[2] According to the California Legislative Analyst's Office, "California's coast could experience SLR ranging from about half of 1 foot by 2030 up to about 7 feet by 2100. Periodic events like storms and high tides will produce even higher water levels and increase the risk of flooding. Rising seas will also erode coastal cliffs, dunes, and beaches which will affect shorefront structures and recreation." Petek, Gabriel. "Preparing for Rising Seas: How the State Can Help Support Local Coastal Adaptation Efforts." (2019). The Ocean Protection Council is less conservative, and has found that, "[a]fter 2050, sea-level rise projections increasingly depend on the trajectory of greenhouse gas emissions. For example, under the extreme H++ scenario rapid ice sheet loss on Antarctica could drive rates of sea-level rise in California above 50 mm/year (2 inches/year) by the end of the century, leading to potential sea-level rise exceeding 10 feet." Ocean Protection Council (OPC). 2018. State of California Sea-Level Rise Guidance: 2018 Update.

[3] *See*, Shoreview: Sea Level Rise & Pollution Risk to the Bay, *available at* https://baykeeper.org/shoreview/pollution.html (not yet updated to the more accurate 7-10 feet of sea level rise estimates); *see, also*, Bay Conservation and Development Commission Adapting to Rising Tides Bay Area, *available at* https://explorer.adaptingtorisingtides.org/explorer (up to 12 feet of sea level rise available for mapping). Moreover, sea level rise estimates always have the potential to get worse, as has been the case in recent years.

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O-55-3 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here. See also Response to Comment O-55-2 regarding site remediation.

As discussed in Draft EIR Section 4.9, *Hydrology and Water Quality*, Section 4.9.1, *Environmental Setting*, under *Sea Level Rise*, the anticipated effects of sea level rise have been and continue to be investigated for the margins of San Francisco Bay, including the area at Howard Terminal. Various regulations require projects along the bay's margins to account for the anticipated amount of sea level rise and include the required sea level rise assessment conducted by the Port of Oakland (see Draft EIR Section 4.9.2, *Regulatory Setting*).

As discussed in Draft EIR Section 4.9.3, *Significance Criteria*, under *Approach to Analysis*, a sea level rise design basis memorandum was prepared for the Project, including sea level rise adaptation strategies proposed for both the medium-high risk aversion and extreme risk aversion scenarios. The discussion in Draft EIR Impact HYD-5 includes an analysis of potential flood impacts related to sea level rise. The Project design includes raising the floor levels of structures to avoid flooding from sea level rise. In addition, Impact HYD-5 requires implementation of Mitigation Measure HYD-3: Sea Level Rise Final Adaptive Management and Contingency Plan, which would ensure that adaptation strategies would be implemented and enforced as necessary to address sea level rise. The plan would be subject to the review and approval of the City of Oakland and the California State Lands Commission. If the City or the State Lands Commission were to find that the plan does not meet the conditions related to sea level rise, the Project could not proceed.

O-55-4 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here. Responses to the more detailed specific comments are provided in Responses to Comments O-55-28 and O-55-29, below.

O-55-5 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here. See also Responses to Comments I307-2-11, O-27-59, and O-27-60. In addition, see Draft EIR Section 4.3, *Biological Resources*, for more information, analysis, mitigation, and permitting related to in-water work effects on marine and estuarine biological resources and water quality.

O-55-6 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here.

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of the industrial facilities in the Bay Area are clustered along the shoreline within or near areas expected to flood—raising the risk of industrial waste leaching into the Bay watershed.

O-55-3 Simply put, the Project is proposed for a dangerous toxic site, imperiled by sea level rise, with an inadequate remediation plan. According to the Ocean Protection Council, "[h]igh confidence in projections of sea-level rise over the next three decades can inform preparedness efforts, adaptation actions and hazard mitigation undertaken today, and prevent much greater losses than will occur if action is not taken. Consideration of high and even extreme sea levels in decisions with implications past 2050 is needed to safeguard the people and resources of coastal California." Ocean Protection Council (OPC) (2018), State of California Sea-Level Rise Guidance: 2018 Update (attached as Exhibit 2[4]). The rough outlines presented in the DEIR include simply capping hazardous materials. This fails to head the advice of the Ocean Protection Council, and is insufficient for a site with the magnitude and diversity of toxic conditions present, here.

O-55-4 Second, aside from the risks associated with toxic substances on the site, the Project is, at its core, shoreline development in an area directly threatened by sea level rise. The rough outlines presented in the DEIR indicate that the Project plans to increase the elevation of the site with fill, thus hardening it to rising sea elevations. This is problematic in several ways, as will be detailed in these comments, including potential impacts to surrounding areas from this hardening and removing the possibility of managed retreat.

O-55-5 Finally, the Project's proposed management of stormwater is inadequate. The rough outlines presented in the DEIR indicate that the Project plans to utilize existing infrastructure to direct stormwater away from the site and into the Middle Harbor. With every significant rainfall event, millions of gallons of polluted stormwater originating from industrial sites such as Howard Terminal pour into storm drains and local waterways. The consensus among agencies and water quality specialists is that stormwater pollution accounts for more than half of the total pollution entering surface waters each year, making stormwater the largest source of pollution to San Francisco Bay. When it rains, pollution like trash, oil, pesticides, fertilizers, household chemicals, and legacy toxic pollutants are washed into the Bay without being treated or filtered. Impervious surfaces on roofs, driveways, streets, buildings, and parking lots send rainwater rushing into gutters and storm drains. This storm water—carrying all the pollution it collects along the way–then gets emptied into creeks and sloughs that flow into the Bay, or directly into the Bay itself. Such discharges of pollutants from industrial facilities contribute to the impairment of downstream waters such as the Bay and harm aquatic dependent wildlife. These contaminated discharges can and must be controlled for the ecosystem to regain its health.

O-55-6 The Project's plan to maintain the status quo is not acceptable. Not only does it fail to address pollutants directly discharged to the Bay, but it also fails to address the interaction of more intense storms with rising sea levels and groundwater, all of which is projected to result from climate change. According to the latest science,

[4] Also available at http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.

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The Draft EIR analysis uses the best available science for sea level rise projections, as determined and adopted by the State of California to inform state guidance.[1] The methodology for assessing potential future flood impacts follows San Francisco Bay Conservation and Development Commission (BCDC) guidance.[2] This guidance calls for using the current Federal Emergency Management Agency (FEMA) 100-year flood event as the basis for projecting future flood hazards. BCDC (2021) recognizes that the FEMA 100-year flood event is based on historic data, and thus, does not reflect the possibility of future increased storm intensity that the comment raises by referencing Heogh-Guldberg et al. (2018). BCDC notes that consideration of other risk factors, such as the range of sea level rise projections, helps account for the risk of increased storm intensity. In addition, at the direction of state legislation, Assembly Bill (AB) 1191, the Project considers the changes in flood hazards through 2100 for the medium-high and extreme risk aversion sea level rise scenarios.

The Project proposes to elevate much of the site more than 6 feet above the current base flood elevation, the flood event associated with extreme storm surge with a 100-year return period. Some portions of the site would initially accommodate lower amounts of sea level rise and would then undergo adaptation measures in response to sea level rise,[3] as described in Mitigation Measure HYD-3. By constructing the Project at higher elevations and providing for future adaptation, the Project would accommodate both sea level rise, and, if they do occur, changes in the frequency of extreme events. Mitigation Measure HYD-3 includes a monitoring program that would review future best available science regarding the rate of sea level rise and the frequency of extreme events.

1 California Ocean Protection Council and California Natural Resources Agency (OPC), 2018. *State of California Sea-Level Rise Guidance 2018 Update.*

2 BCDC, 2021. *San Francisco Bay Plan Climate Change Policy Guidance*, July 2021.

3 Moffat & Nichol, 2021. Coastal Flooding, Proposed Grading Strategy, Sea Level Rise Adaptation, and Public Access on Wharf, Oakland Athletics Howard Terminal Project, July 9, 2021.

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> Sea level rise also amplifies the impacts of storms and wave action, with robust evidence that storm surges and damage are already penetrating farther inland than a few decades ago, changing conditions for coastal ecosystems and human communities. This is especially true for [] low-lying coastal communities, where issues such as storm surges can transform coastal areas. Changes in the frequency of extreme events, such as an increase in the frequency of intense storms, have the potential to overwhelm the capacity for natural and human systems to recover following disturbances.

Hoegh-Guldberg, et al. (2018), "Impacts of 1.5ºC Global Warming on Natural and Human Systems," IPCC Special Report (references omitted, attached as Exhibit 3[5]).[6] This interaction poses an additional flooding threat to communities surrounding the Howard Terminal site, especially considering the burden of toxic pollution carried by surrounding sites.

O-55-7

By failing to consider and mitigate these impacts, the DEIR also fails to consider a multitude of opportunities for green infrastructure, stormwater capture, and stormwater treatment. If existing contaminants can be removed or reliably walled off from surface and groundwater, then the Project could be modified to capture stormwater, recharge local or deep aquifers, attenuate flow into the Middle Harbor, and even to reuse stormwater on site. Incorporating these elements into the Project could make it beneficial to adjacent communities and to the Port, and a model for future development along the Bay's shoreline. However, whether these positive outcomes materialize depends on the type, distribution, and, critically, treatment of contaminated soils and shallow groundwater on the site.

O-55-8

Regarding Baykeeper's concerns about Project's direct impacts to the Bay, we do not know how effective the cleanup of the Project site is going to be. While there are some potential solutions posed in the DEIR, we have to know more before we can evaluate those solutions. Regarding Baykeeper's concerns over Project impacts to neighboring communities, the DEIR is inadequate to inform us as to the problems communities will be dealing with for generations to come. The DEIR fails to answer important questions, such as how many truck trips are acceptable to surrounding communities, how much pollution can be safely left in place without harming the people who live nearby, and what sea level rise impacts residents may be most concerned about. The factual basis for answering these questions is left conspicuously absent from the DEIR, in turn leaving these questions functionally unanswerable.

II. THE CALIFORNIA ENVIROMENTAL QUALITY ACT

O-55-9

The lack of critical information in the DEIR directly implicates the Project's compliance with the California Environmental Quality Act (CEQA). California requires that environmental impacts

[5] Also available at https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf.
[6] *See, also*, Biging, et al. (2012). Impacts of Predicted Sea-Level Rise and Extreme Storm Events on the Transportation Infrastructure in the San Francisco Bay Region. California Energy Commission. Publication number: CEC-500-2012-040 (attached as Exhibit 4, also available at https://uc-ciee.org/ciee-old/downloads/Impacts%20of%20Sea%20Level%20Rise%20on%20the%20Transportation%20Infrastructure%20in%20the%20Bay%20Area.pdf).

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RESPONSE

O-55-7 This is a general comment that includes introductory remarks and serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here. See Responses to Comments O-27-59 and O-27-60.

O-55-8 This is a general comment that serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here.

O-55-9 This comment provides a summary of CEQA provisions and case law. This comment raises neither significant environmental issues nor specific questions about the analyses or information in the Draft EIR that would require response pursuant to State CEQA Guidelines Section 15088. The comment will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project.

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O-55-9 from development proposals like the Project be taken into account by agency decisionmakers. CEQA and its implementing regulations "embody California's strong public policy of protecting the environment." (*Tomlinson v. County of Alameda* (2012) 54 Cal.4th 281, 285.) To this protective end, the California Supreme Court has explained that "CEQA was enacted to advance four related purposes: to (1) inform the government and public about a proposed activity's potential environmental impacts; (2) identify ways to reduce, or avoid, environmental damage; (3) prevent environmental damage by requiring project changes via alternatives or mitigation measures when feasible; and (4) disclose to the public the rationale for governmental approval of a project that may significantly impact the environment." (*California Building Industry Assn. v. Bay Area Air Quality Management Dist.* (2015) 62 Cal.4th 369, 382.) As will be discussed fully in the subsequent sections of this comment letter, the Project's failure to disclose in the DEIR the information necessary to inform the public of the Project's potential environmental impacts and failure to provide adequate mitigation to reduce those impacts below the threshold of significance is a violation of CEQA.

O-55-10 "At the 'heart of CEQA' [citation] is the requirement that public agencies prepare an EIR for any 'project' that 'may have a significant effect on the environment.' [Citation.]" (*Friends of College of San Mateo Gardens v. San Mateo County Community College Dist.* (2016) 1 Cal.5th 937, 944, citations omitted.) "Given the statute's text, and its purpose of informing the public about potential environmental consequences, it is quite clear that an EIR is required even if the project's ultimate effect on the environment is far from certain. [Citation.]" (*California Building Industry Assn. v. Bay Area Air Quality Management Dist.* (2015) 62 Cal.4th 369, 382–83, italics and citation omitted.)

"The foremost principle under CEQA is that the Legislature intended the act 'to be interpreted in such manner as to afford the fullest possible protection to the environment within the reasonable scope of the statutory language.'" (*Laurel Heights Improvement Ass'n v. Regents of Univ. of Cal.* (1988) 47 Cal. 3d 376, 390 ("*Laurel Heights I*"), quoting *Friends of Mammoth v. Board of Supervisors* (1972) 8 Cal.3d 247, 259.) An EIR's most basic, fundamental purpose is to "provide public agencies and the public in general with detailed information about the effect which a proposed project is likely to have on the environment; to list ways in which the significant effects of such a project might be minimized; and to indicate alternatives to such a project." (Pub. Resources Code, § 21061; *see* CEQA Guidelines, § 15003(b)–(e).) "Because the EIR must be certified or rejected by public officials, it is a document of accountability. If CEQA is scrupulously followed, the public will know the basis on which its responsible officials either approve or reject environmentally significant action, and the public, being duly informed, can respond accordingly to action with which it disagrees." (*Laurel Heights I, supra*, at p. 392.) The EIR "protects not only the environment but also informed self-government." (*Id.*)

"The ultimate inquiry, as case law and the CEQA guidelines make clear, is whether the EIR includes enough detail 'to enable those who did not participate in its preparation to understand and to consider meaningfully the issues raised by the proposed project.'" (*Sierra Club v. Cty. of Fresno* (2018) 6 Cal. 5th 502, 516, quoting *Laurel Heights I, supra*, 47 Cal.3d at p. 405.) "Whether an EIR will be found in compliance with CEQA involves an evaluation of whether the discussion of environmental impacts reasonably sets forth sufficient information to foster informed public participation and to enable the decision makers to consider the environmental factors necessary to make a reasoned decision." (*Berkeley Keep Jets Over the Bay Com. v. Bd. of Port Cmrs.* (2001) 91

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O-55-10 This comment is a summary of CEQA provisions and case law. This comment raises neither significant environmental issues nor specific questions about the analyses or information in the Draft EIR that would require response pursuant to State CEQA Guidelines Section 15088. The comment will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project. See Responses to Comments O-55-1 through O-55-9 and O-55-11 through O-55-39.

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O-55-10 Cal. App. 4th 1344, 1356.) "An EIR should be prepared with a sufficient degree of analysis to provide decisionmakers with information which enables them to make a decision which intelligently takes account of environmental consequences." (CEQA Guidelines, § 15151.)

O-55-11 Because of its duty to minimize environmental harm, one of the most important functions of an EIR is the study of appropriate mitigation measures. It must describe feasible mitigation measures that could minimize significant adverse impacts. (CEQA Guidelines, § 15126.4(a)(1).) An EIR may not defer the formulation of mitigation measures to a future time. (CEQA Guidelines, § 15126.4(a)(1)(B).) The legal standard for review of such deferral of mitigation is that "'[i]mpermissible deferral of mitigation measures occurs when an EIR puts off analysis or orders a report without either setting standards or demonstrating how the impact can be mitigated in the manner described in the EIR.'" (*Pres. Wild Santee v. City of Santee*, 210 Cal. App. 4th 260, 280-81 (2012) (EIR deficient because of an "absence of standards or guidelines"), quoting *Clover Valley Foundation v. City of Rocklin* (2011) 197 Cal.App.4th 200, 236.)

O-55-12 Finally, CEQA prohibits agencies from "piecemealing" the review of a project's environmental impacts by examining only some stages or aspects of the project while omitting later stages or related aspects. (CEQA Guidelines, § 15378(a); Cal.Pub.Res.Code § 21065.) A "project" under CEQA is defined as "the whole of an action, which has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment." (*Id.*) CEQA forbids segmenting a project into separate actions in order to avoid environmental review of the "whole of the action." (*Bozung v. Local Agency Formation Comm'n*, 13 Cal.3d 263, 283-84 (1975); *Rural Landowners Ass'n v. City Council* (1983) 143 Cal.App.3d 1013, 1024; *Nelson v. County of Kern*, 190 Cal. App. 4th 252, 272 (2010).)

O-55-13 The DEIR is deficient for many of the reasons the statutes, regulations, and case law describe, above. Examples include: (1) the DEIR provides insufficient information to adequately inform the government and the public about the Project's environmental impacts; (2) the DEIR fails to adequately identify ways to mitigate environmental damage; (3) the DEIR does not require project changes or alternatives sufficient to prevent environmental damage; (4) the DEIR does not adequately explain the feasibility of mitigation and alternatives; (5) the DEIR fails to include sufficient information to provide accountability from the approving agency and the project proponent to the public for the decisions made when building the Project, and thereby fails to protect informed self-government; (6) the DEIR does not include sufficient information to enable those who did not participate in the decision-making to understand the issues raised by the Project; (7) the DEIR does not enable decisionmakers or the public to intelligently take into account the environmental consequences of the Project; (8) the DEIR impermissibly defers mitigation measures; and (9) the DEIR piecemeals the review of the Project's environmental impacts. The subsequent sections of this comment letter will fill out these deficiencies with specific examples from the DEIR.

III. HAZARDS AND HAZARDOUS MATERIALS

a. Risks posed by sea level rise are inadequately discussed and are not appropriately mitigated.

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RESPONSE

O-55-11 This comment is a summary of CEQA provisions and case law. This comment raises neither significant environmental issues nor specific questions about the analyses or information in the Draft EIR that would require response pursuant to State CEQA Guidelines Section 15088. The comment will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project. See Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures*.

O-55-12 This comment is a summary of CEQA provisions and case law. This comment raises neither significant environmental issues nor specific questions about the analyses or information in the Draft EIR that would require response pursuant to State CEQA Guidelines Section 15088. The comment will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project. See Consolidated Response 4.1, *Project Description*.

O-55-13 This is a general comment that serves to introduce the more specific comments that are responded to in detail below. As a result, no specific response is provided here. With regard to the commenter's examples of the Draft EIR's alleged deficiency, see the following responses:

(1) See Responses to Comments O-55-14 through O-55-38.

(2) See Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures.*

(3) See Response to Comment O-55-31.

(4) See Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures.*

(5) See Responses to Comments O-55-14 through O-55-38.

(6) See Responses to Comments O-55-14 through O-55-38.

(7) See Responses to Comments O-55-14 through O-55-38.

(8) See Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures*, regarding the alleged deferral of mitigation.

(9) See Consolidated Response 4.1, *Project Description*, regarding purported piecemealing.

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O-55-14 As discussed above, sea level rise poses an inherent risk to toxic hotspots such as the proposed Project site. All around the country we are already seeing the catastrophic consequences of these risks. In 2017, Hurricane Harvey flooded numerous heavy industrial facilities and wastewater treatment plants in the Houston, Texas, region. Local, state, and federal authorities had not planned for flooding on that scale, and the deluge spread huge volumes of toxic industrial contamination in residential neighborhoods, commercial properties, and neighboring wetlands and waterways.

In the Bay Area, increased El Niño storm intensity, coupled with sea level rise and the threat of earthquake-borne tsunamis, will almost certainly result in widespread flooding and the release of toxic contaminants from otherwise safe sites. Remediation of contaminated sites such as the proposed Project site must account for the long-term risks of flooding from sea level rise or storm surges. This threat must be managed comprehensively both from the perspective of the Bay as a whole and on a site-by-site basis. If even one link in the chain is broken, the whole Bay will suffer.

O-55-15 In many cases, sites that have been deemed safe under current conditions—where surface water or groundwater cannot reach contaminants and transport them to the Bay or nearby neighborhoods—will not be safe in the future. Yet today's laws, regulations, and planning documents, including the DEIR, do not adequately take this risk into account. In most instances, contaminants at these sites have already leaked out of underground storage tanks or were spilled as part of routine industrial processes. Such risks are out of sight and difficult to identify in the absence of rigorous analyses and expert assessments. Regulators, including the Regional Water Quality Control Board, Department of Toxic Substances Control, and county agencies tasked with tracking and assessing such issues have few resources to conduct thorough analyzes of complex toxic sites and force adequate cleanup.

O-55-16 One example of a nearby site where remediation required under current regulatory oversight did not adequately take into account sea level rise is the Brooklyn Basin project. Brooklyn Basin is located on a former industrial site south of Jack London Square in Oakland. This site was known to host a number of contaminants including hydrocarbons, PCBs, heavy metals, and other harmful volatile organic compounds. Remediation prior to construction did not adequately take into account the possibility that the site would be inundated, in which case the underlying contaminated soil and groundwater will pose a significant threat to residents and wildlife. This project was conceived nearly 20 years ago and required a $1.5 billion investment to complete. Other sites, such as Howard Terminal, will require more foresight and more investment to do what is needed upfront, instead of passing the bill down to future generations.

O-55-17 Another cautionary tale involves the redevelopment of the Hunters Point Naval Shipyard, one of the region's most notorious attempts to clean up heavily contaminated lands. The San Francisco shipyard closed in 1994 after decades of operation. Among other military operations, the site hosted the Naval Radiological Defense Laboratory, which conducted atomic research and decontamination, resulting in radiological contamination of the site. It was designated a Superfund site in 1989. The site is also widely contaminated by PCBs, heavy metals, and hydrocarbon-related pollutants. In the 2000s, the Navy hoped to pass on the responsibility for remediating the site to Lennar, a private development company, for a 700-acre redevelopment project. In 2011, a court ruling required the Navy to first conduct an environmental cleanup prior to transfer of the site to private ownership. Residential redevelopment is now occurring on lands deemed safe. However,

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O-55-14 As discussed in Draft EIR Section 4.9, *Hydrology and Water Quality,* under *Sea Level Rise*, various recent studies have been conducted to estimate the amount of sea level rise under various climate scenarios and land use considerations. Consequently, the Port of Oakland prepared a sea level rise assessment to prepare Port property and assets for impacts of sea level rise. In addition, the *Tidal Datums and Sea Level Rise Design Basis Memorandum*[4] and *Coastal Flooding, Proposed Grading Strategy, Sea Level Rise Adaptation, and Public Access on Wharf Oakland Athletics Howard Terminal Project*[5] prepared for the Project include sea level rise adaptation strategies proposed for the medium-high risk aversion and extreme risk aversion scenarios. San Francisco Bay is expected to experience about 1.1 feet of sea level rise under the low risk aversion projection, or up to 1.9 feet of rise under the medium-high risk aversion projection. By 2070, this increases to 1.5 to 1.9 feet of sea level rise under the low risk aversion projection, and to 3.1 to 3.5 feet under the medium-high risk aversion projection. The projections for 2100 sea level rise are 2.4 to 3.4 feet under the low risk aversion projection, and 5.7 to 6.9 feet under the medium-high risk aversion projection.

As discussed in Chapter 3.0, *Project Description*, Section 3.11.1, *Sea Level Rise*, fill would be added to most of the Project site such that the floor elevations of residential buildings would be at or above 10 feet City of Oakland datum (COD). The majority of the ballpark structure would be at 5–10 feet COD or higher. Consequently, the proposed raising of elevations of the Project site would be above estimated future base flood elevation of San Francisco Bay for up to 6 feet of sea level rise. In addition, the projected sea level rise would not be able to raise groundwater levels beneath the Project site to above ground surface levels. To further ensure that sea level rise would not adversely affect the Project site, a cutoff wall and groundwater drainage system would be installed beneath the ballpark as described in Draft EIR Section 3.12.2, *Stormwater,* under *Cutoff Wall,* and in Section 4.9.4, *Impacts of the Project*. This system would collect groundwater from behind the cutoff wall and pump that water to the bay. For other areas not raised to 10 feet COD or higher, a sea level rise final adaptive management and contingency plan would be developed to describe monitoring, triggers, and implementation of measures to address future sea level rise impacts.

As discussed in Draft EIR Section 4.8, *Hazards and Hazardous Materials,* under *Current Nature and Extent of Onsite Contamination*, contaminated soil and groundwater is currently encapsulated beneath the existing hardscape and behind the quay wall and wooden bulkhead wall to prevent exposure to people and the environment. The projected sea level rise would be expected to also raise groundwater levels beneath the Project site to higher elevations. This may also mobilize some of the encapsulated contamination. However, as discussed above, the elevation of the Project site would be raised so that groundwater would not be

4 Moffat & Nichol, 2019. Tidal Datums and Sea Level Rise Design Basis. Prepared for the Oakland Athletics. December 18, 2019.

5 Moffat & Nichol, 2021. Coastal Flooding, Proposed Grading Strategy, Sea Level Rise Adaptation, and Public Access on Wharf, Oakland Athletics Howard Terminal Project, July 9, 2021.

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able to reach the ground surface. The previously noted cutoff wall and groundwater drainage system under the ballpark would further ensure that groundwater would not be able to reach the ground surface. The groundwater collected in the drainage system would be treated prior to release to San Francisco Bay. Consequently, the raising of elevations across the Project site and the installation of the cutoff wall and drainage system would prevent exposure of people and the environment to contaminated materials.

O-55-15 See Response to Comment O-55-14, which explains that the anticipated effects of sea level rise were taken into account in the design of the proposed Project.

O-55-16 This comment refers to a separate hazardous materials site that is not located at or adjacent to Howard Terminal. The investigation and remediation activities at the separate site were conducted by others in response to conditions unique to that site, and are therefore not relevant to this Project. The comment is included herein for the record. Note that as discussed previously in Response to Comment O-55-14, the anticipated effects of sea level rise and the potential to mobilize contaminants at the Howard Terminal site have been investigated and the design of the proposed project accounts for this.

O-55-17 This comment refers to a separate hazardous materials site that is not located at or adjacent to Howard Terminal. The investigation and remediation activities at the separate site were conducted by others in response to conditions unique to that site, and are therefore not relevant to this Project. The comment is included herein for the record. Note that as discussed previously in Response to Comment O-55-14, the anticipated effects of sea level rise and the potential to mobilize contaminants at the Howard Terminal site have been investigated and the design of the proposed project accounts for this.

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redevelopment of a large portion of the site is still mired in controversy, including falsification of data related to radiation-contaminated soils. Given that the site lies just above current sea level, serious concerns remain as waters rise to potentially leach contamination to the soil surface and into the Bay.

O-55-17 Hunters Point has acquired the nightmarish aspect of Groundhog Day because areas we thought were safe keep making headlines as a danger to residential and commercial use. At Hunters Point, housing was built in toxic, undesirable areas. Compounding that issue, it has now become clear that sea level rise will mobilize contaminants from non-remediated areas to threaten nearby communities and the entire Bay with the dangerous impacts of leaching contamination. It is critical that the DEIR take these sorts of impacts into account and lay out a comprehensive plan for proper mitigation and remediation that includes guarantees that future generations will not be left to pay the bills.

b. Remediation of the hazardous waste present on the site requires a detailed plan presented to the public as part of the DEIR

The Project site presents a gordian knot of pollution compounded by low-lying unstable soils and sea level rise. Hazards and hazardous materials are discussed in the DEIR at section 4.8, which states that the site has a "long history of industrial use that has resulted in the contamination of fill, soil, and groundwater." DEIR at 4.8-1. The rogues' gallery of chemicals of concern (COCs) present on the site include: petroleum hydrocarbons as gasoline, diesel, and motor oil, including benzene and naphthalene; cyanide; heavy metals such as arsenic, cobalt, and lead; organochlorine pesticides such as dieldrin; polychlorinated biphenyls (PCBs) including Aroclor 1254 and 1260; semi-volatile organic compounds (SVOCs), including polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs).[7] DEIR at 4.8-9 – 4.8-15. Screening levels for these contaminants
O-55-18 exceed residential and commercial benchmarks. *See, e.g.*, DEIR Figures 4.8-2, 4,8-3, and 4.8-4 (onsite areas with screening level (residential, commercial, etc.) exceedances for soil gas, soil, and groundwater); DEIR at 4.8-11 ("most of the Project site has soil gas with COCs at concentrations that exceed commercial screening levels, which would also exceed the lower residential screening levels;" "much of the Project site has soil with COCs at concentrations that exceed commercial screening levels, which would also exceed the lower residential screening levels. Additional areas of the Project site have soil with COC concentrations that exceed commercial screening levels.").

Groundwater, in particular, "is in contact with waters of the Estuary, which could expose aquatic receptors to chemicals in groundwater." DEIR at 4.8-10 – 4.8-11. This is alarming because "certain onsite areas have free product floating in groundwater." 4.8-11. Historical depth to groundwater at the site is a mere 5 to 12 feet below the surface, and is already subject to tidal fluctuation of several feed daily. DEIR at 4.8-15. Local site hydrology (including rate of groundwater flow to the estuary) and contamination of groundwater are likely to change under sea level rise scenarios,[8] increased storm intensity, as a result of seismic activity, and/or during site

[7] The DEIR fails to consider the presence petroleum metabolites, also known as hydrocarbon oxidation products (HOPs), in groundwater.
[8] *See, e.g.*, Plane, E.; Hill, K.; May, C. A Rapid Assessment Method to Identify Potential Groundwater Flooding Hotspots as Sea Levels Rise in Coastal Cities. Water 2019, 11, 2228.https://doi.org/10.3390/w11112228 (attached as Exhibit 5, also available at https://www.mdpi.com/2073-4441/11/11/2228/htm) ("Our study suggested that there is

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O-55-18 This comment repeats information provided in Section 4.8, *Hazards and Hazardous Materials*, regarding the chemicals present in the fill and soil currently encapsulated under the hardscape cap at concentrations above regulatory screening levels, and then expresses concern regarding several topics, as addressed below.

Unstable Soils

The commenter makes a general statement about "unstable soils" but provides no evidence in support. As described in Draft EIR Section 3.2.4, *Existing Wharf Conditions, Utilities, and Site Conditions*, fill and soil at the site are currently under hardscape that covers the entire site. The fill and soil are separated from the estuary by a concrete quay wall protected by riprap. As described in Draft EIR Section 3.13, *Construction*, the proposed Project would add fill across the site to raise the floor elevations of structures above the anticipated amount of sea level rise. This fill would be imported clean fill that would be properly compacted. The quay wall would be raised to meet the new ground surface elevation. Therefore, there would be no unstable soils at the site.

Contaminated Groundwater and Aquatic Receptors

As explained in Draft EIR Section 4.8, *Hazards and Hazardous Materials*, Section 4.8.1, *Environmental Setting, Current Nature and Extent of Onsite Contamination*, groundwater samples collected from wells located on the estuary side of the quay wall verify that contamination is not detected on the estuary side of the quay wall. Therefore, groundwater beneath the site does not pose a risk to aquatic receptors. As explained above in the response to the comment on unstable soils, fill would be added across the site to raise the site above the anticipated amount of sea level rise, and the quay wall would be raised to meet the new raised site elevation. Therefore, the raised quay wall would continue to prevent contaminated groundwater from reaching the estuary and there would be no increased risk to aquatic receptors.

Mobilization of Contaminants by Sea Level Rise

As discussed previously in Response to Comment O-55-14, the anticipated effects of sea level rise and the potential to mobilize contaminants at the Howard Terminal site have been investigated and the design of the proposed Project accounts for this.

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O-55-18 construction. As will be discussed further, below, the DEIR must anticipate these changes before dismissing concerns about the effect of groundwater contamination on surrounding environments and communities.

In order to address these concerns, the Project should produce a detailed plan for remediating the hazardous waste present on the site, as it has for other potential Project impacts.[9] Instead, the DEIR has a plan for producing a plan.[10] This piecemealing and segmentation of the DEIR is insufficient under CEQA.

O-55-19 For example, Impact Haz-1 foresees the "[p]reparation and Approval of Consolidated RAW, LUCs and Associated Plans." DEIR at 4.9-21. A mitigation measure summarizing the contents of an as-yet-not-completed Remedial Action Workplan (RAW) is not adequate to meet the public participation, information, and planning requirements of CEQA.[11] Instead, this mitigation is to develop a mitigation. The DEIR provides no opportunity for the public or decision makers to evaluate the mitigation itself; thus, it is not possible to determine whether the mitigation is or will be adequate.

One of the many problems with this approach is that the DEIR presumes that the unspecified mitigation measures will be 100% effective. Mitigation is never 100% effective. While serious impacts may be mitigated, they are not completely eliminated, and an important part of the publics' interest in the transparency protected by CEQA is the ability to evaluate residual effects.

O-55-20 In many cases, because of the DEIR's strategy of delaying most planning for toxics remediation, control measures and suggestions for possible mitigation strategies are left optional and are not adequately evaluated in the DEIR. For example, construction risk management control

significant potential for groundwater flooding in important Silicon Valley economic hubs (e.g., Mountain View, East Palo Alto, Redwood City), East Bay cities with fast-growing populations (e.g., Oakland, Hayward, Fremont), and major transportation infrastructure, including freeways (e.g., Interstate 580) and airports (Oakland International Airport, San Francisco International Airport). Our results indicate that flooding from emergent groundwater could impact more land by area than direct SLR flooding, with a SLR scenario of one meter in seven of the nine Bay Area counties, and in the region as a whole...").

[9] While Baykeeper lacks expertise in traffic matters, the measures taken by the Project to account for reduced trips and to provide a Draft Transportation Management Plan as part of the DEIR appear to be relatively complete discussions of the issues. *See, e.g.*, DEIR at 3-41 and 3-42 ("Appendix TRA, Transportation Supporting Information, contains the Draft [Transportation Management Plan], which outlines operational strategies to optimize access to and from the ballpark within the constraints inherent to a large public event. Its primary goal is to ensure safe and efficient access for all people traveling to and from the site, with a focus on promoting pedestrian, bicycle, and transit access, thereby reducing motor vehicle impacts to the site and surrounding neighborhoods"). For the same reasons that the Project needs a detailed transportation and parking plan (health and safety of the public and mitigation of climate change effects), the DEIR also needs a detailed plan for management of toxic wastes, contaminated soils, and contaminated groundwater.

[10] There are multiple plans to develop plans in the DEIR. In addition to the contemplated but uncompleted Remedial Action Workplan (RAW), the Project is planning on changing land use covenants that prohibit residential use, updating operations and maintenance plans, compiling a soil and groundwater management plan, and consolidating existing cleanup decision documents for various portions of the Project site, none of which actions have been taken or documents yet exist. DEIR at 4.8-33 – 4.8-44. Therefore, none of these final plans are adequately described in the DEIR.

[11] DTSC may even require a Remedial Action Plan instead of a RAW, as the remediation challenges faced by the Project are substantial. RAWs are usually reserved for more limited excavations and cleanup activities. *See* Health & Safety Code § 253356 (waver of RAP requirement for removal actions that cost less than $2 million).

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O-55-19 As discussed in Draft EIR Section 4.8.2, *Regulatory Setting*, under *Land Use Covenants*, and explained further in Consolidated Response 4.16, *Remediation Plans, Land Use Covenants, and Human Health and Ecological Risk Assessment*, the Project site is subject to existing LUCs, O&M agreements, and associated plans, all enforced by DTSC, the regulatory agency with jurisdiction. These LUCs and their associated plans would be replaced and consolidated and require approval by DTSC before the start of construction to account for the changes to the Project site. The substantive requirements of these replacement documents would be similar to those in the existing documents, but they would be specifically tailored to ensure protections appropriate for the types of anticipated construction activities and uses, including allowing residential use (which is currently prohibited) under specified conditions.

Similar to the existing plans, the remediation plans prepared under the requirements of the existing LUCs and the mitigation measures discussed in Draft EIR Section 4.8, *Hazards and Hazardous Materials*, Impact HAZ-2, would provide further description of the remediation steps, which would include maintaining a cap over the Project site.

As explained in Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures*, the mitigation measures in the Draft EIR would ensure that regulatory requirements have been met before the issuance of grading, building, or construction permits, and certificates of occupancy or similar operating permits for new buildings and uses. DTSC is the agency with jurisdiction and would be responsible for reviewing and approving the remediation plan and related documents. These documents cannot be approved until the EIR is certified and would be specifically crafted to address risks identified in the risk assessment that has already been approved by DTSC.

DTSC has an established public participation process that facilitates and encourages public participation. The DTSC Public Participation Manual is available at: https://dtsc.ca.gov/wp-content/uploads/sites/31/2018/07/DTSC-PublicParticipationManual.pdf. This manual states that remediation documents must be posted on the publicly accessible DTSC website EnviroStor. The address for the Project's EnviroStor webpage is https://www.envirostor.dtsc.ca.gov/public/profile_report.asp?global_id=01440006. Upon receipt and approval by DTSC, the Land Use Covenant and Remedial Action Workplan would be posted to the Project's EnviroStor webpage. In addition, DTSC provides paper copies of documents for public review at designated repositories in the local community, including at the DTSC office at 700 Heinz Avenue, Berkeley. The public would be able to access the documents and provide comments to DTSC by submitting comments to the Public Participation Specialist, whose email address is provided on the webpage. The public could also submit comments by mail to DTSC. The public comment period would be a minimum of 30 days, as required by Health and Safety Code Section 25356. Note that public access to these documents is required by the Public Records Act, Government Code

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O-55-20 measures are labeled "optional." DEIR at 4.8-34. These and other such measures should be made mandatory and evaluated in the DEIR.

O-55-21 Construction and maintenance impacts are also left to be evaluated in not yet completed plans that would detail how all excavated materials would be disposed of. DEIR at 4.8-49. And engineered equivalents to caps do not discuss the potential for rising groundwater due to sea level rise. DEIR at 4.8-49. Instead, the DEIR merely states that there will be no impacts because the cap and other measures will be adequate and will be maintained, without any measures securing such maintenance. DEIR at 4.8-50.

O-55-22 Another example is the DEIR's treatment of stormwater mitigation. The DEIR describes this mitigation solely in terms of redirecting it away from the Project (*see, e.g.,* DEIR at 4.9-28 ("Design and final grading of the Project site would result in capture of all site runoff into the newly installed stormwater drainage system once the site has been resurfaced and structures begin construction"); *but see* Section 4.16, Utilities and Service Systems). Flooding, pollution, and irrigation needs would be minimized by seeking to increase infiltration and retention of water on-site. If hazardous materials and contaminated soils remain on site, this could complicate efforts to increase stormwater retention and infiltration (or make them inadvisable). This is another reason to ensure that hazardous materials and contaminated soils that may be mobilized by water are completely removed from the site.

O-55-23 A final example of the DEIR's reliance on unspecified future plans is the DEIR's treatment of mitigation for future liquefaction conditions. Instead of addressing these impacts, the DEIR defers to the California Building Code's requirements for mitigation. This fails to assess potential impacts of the Project on site conditions as well as cumulative impacts to nearby areas. Onsite and nearby liquefaction could make existing or future caps unstable, and could influence the migration of contaminated groundwater. Impacts should be evaluated in the DEIR, not deferred to a future Final Geotechnical Report. Once again, the DEIR makes a plan to make a plan. DEIR at 4.6-15 – 4.6-22.

O-55-24 The DEIR fails to treat the threat of groundwater contamination with the gravity it deserves. According to the DEIR, groundwater contamination is not of concern as "observed levels of COCs at Howard Terminal do not pose a significant risk to the environment, including aquatic organisms at the groundwater-Inner Harbor interface." 4.8-17. This conclusion is based solely on current conditions and completely fails to take into account the most recent scientific research, as well as common sense, which forecasts that as sea levels rise groundwater will rise as well. This renders suspect any remediation or mitigation measure that involves capping or leaving contaminated soils in place.

O-55-25 These failures amount to deferred mitigation in violation of CEQA. "[S]uccess or failure of mitigating the [P]roject's impacts" depends on what actions the yet-to-be-approved various remediation and mitigation plans will require, as was the case in *Pres. Wild Santee v. City of Santee*, 210 Cal. App. 4th 260, 281 (2012). As stated in that case, "[a]n EIR is inadequate if '[t]he success or failure of mitigation efforts … may largely depend upon management plans that have not yet been formulated, and have not been subject to analysis and review within the EIR.'" (*Id.*, quoting *Communities for a Better Environment v. City of Richmond* (2010) 184 Cal.App.4th 70, 92 and *San Joaquin Raptor Rescue Center v. County of Merced* (2007) 149 Cal.App.4th 645, 670.) So, too, here

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Section 6250, California Health and Safety Code Section 25103, and various other laws and policies.

Note that at the time of the publication of the Draft EIR, it was assumed that a removal action workplan (RAW) would be prepared. Subsequent to the publication of the Draft EIR, the Project sponsor conservatively elected to prepare a remedial action plan (RAP). The Draft RAP is anticipated to be submitted to DTSC in early 2022.

O-55-20 The commenter misunderstands the list of construction risk management measures present on Draft EIR p. 4.8-34, as well as additional risk management measures listed on subsequent pages. Page 4.8-34 presents a listing of dust control measures. The list of "Basic Control Measures for all Construction Sites" and "Enhanced Control Measures: for Construction Sites Greater than Four Acres" would be required for all construction activities that disturb ground at the Project site. The "Optional Control Measures" are additional dust control measures that may be implemented depending on site conditions and on the effectiveness of the previously listed dust control measures.

O-55-21 For concerns regarding reliance on future plans, see Response to Comment O-55-19; for concerns regarding sea level rise, see Response to Comment O-55-14. The Draft EIR quantifies the anticipated amount of soil to be removed from the Project site in Table 4.8-3 (p. 4.8-43) at about 200,000 cubic yards. Draft EIR Section 4.16, *Utilities and Service Systems*, p. 4.16-12, notes that the Altamont Landfill has a permitted capacity of 87.1 million tons with 46 percent of that capacity remaining (i.e., 40 million tons or about 27 million cubic yards).

O-55-22 See Responses to Comments I307-2-11, O-27-59, and O-27-60.

O-55-23 The liquefaction analysis is presented in Draft EIR Section 4.6, *Geology, Soils, and Paleontological Resources*, Impact GEO-1. The preliminary geotechnical analysis provided preliminary recommendations for addressing liquefaction. Upon completion of the CEQA documentation, the Project would be required by the California Building Code, and by the City of Oakland Building Code and Grading Regulations, to conduct a final geotechnical investigation that would further inform the final Project design and provide recommendations to address all identified geotechnical issues, including liquefaction. The Liquefaction Information memorandum prepared by ENGEO on July 7, 2021, provides additional explanation and analysis of the effects of liquefaction.[6] For a discussion of the topics of deferral of mitigation measures and reliance on future documents in the analysis, see Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures*.

6 ENGEO, 2021. Liquefaction Information, Howard Terminal Redevelopment, Oakland, California, July 7, 2021.

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O-55-24 See Response to Comment O-55-14.

O-55-25 This comment is a summary of CEQA provisions and case law. This comment raises neither significant environmental issues nor specific questions about the analyses or information in the Draft EIR that would require response pursuant to State CEQA Guidelines Section 15088. The comment will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project. See Response to Comment O-55-14. See also Consolidated Response 4.2, *Formulation, Effectiveness, and Enforceability of Mitigation Measures.*

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O-55-25 the success of the mitigation measures proposed in the DEIR depend wholly on the formulation of future plans that have yet to be approved by the relevant regulatory agencies.[12]

IV. PROJECT DESCRIPTION

a. Climate Change and Sea Level Rise

O-55-26 Flooding and groundwater management are important elements of the project's planning. Baykeeper is concerned that climate change has not been adequately taken into account by the DEIR for these elements. For instance, the Project's reliance on Federal Emergency Management Agency (FEMA) maps may be misplaced. The DEIR states that, "[a]ccording to [FEMA's] Flood Insurance Rate Map (FIRM), the majority of the Project site is located outside of the 100-year flood zone and would not impede or otherwise redirect any flood flows to other areas." DEIR at 3-8. 100-year storms of the past may occur more frequently in the future because of climate change, and the DEIR is not accounting appropriately for flood risks and the known trend in those risks.[13] In addition, new information on the potential for groundwater to rise as a result of sea level rise has not been adequately incorporated into the DEIR's flood risk and groundwater management elements. The Project site is essentially at sea level right next to the Bay, and anticipates flooding, so a map that shows it is outside of the flood zone is inherently unreliable.

O-55-27 Furthermore, the DEIR's Project Description in Chapter 3 is not clear about what sea level rise elevations were used in the DEIR's assessment of sea level rise preparedness and mitigation. This description should be consistent with Section 4.9.

The DEIR's description of sea level rise mitigation is as follows:

> The Project site would be elevated such that proposed grades include an allowance for sea level rise. ... the Project's proposed grading plan calls for the addition of soil throughout much of the Project site to raise the ground surface elevations. In addition, the finished floor elevations of all residential buildings on the site, except development block #18 at the corner of Embarcadero West and Clay (see Figure 4.9-1), are proposed to

[12] The DEIR even fails to establish target levels for safe remediation of the dangerous pollutants present at the Project site. By stating that future remediation plans will rely on the Final Project EIR, it appears that the Project is attempting to get target remediation levels approved ahead of time without actually describing them in the DEIR. This is impermissible under CEQA.

[13] FIRM maps calculate the risk of flooding using existing sea level conditions; FIRM maps do not account for sea level rise. Risk to the site includes: (1) rising ambient mean high high water (MHHW) up to and perhaps exceeding 10 feet; (2) a substantially larger 100-year flood zone based on new ambient MHHW; and (3) rising groundwater and associated effects on structures and infrastructure (e.g. contaminant mobilization, volatile infiltration, and liquefaction). *See, e.g.,* Hoegh-Guldberg, et al. (2018), "Impacts of 1.5°C Global Warming on Natural and Human Systems," IPCC Special Report ("Mean sea level is increasing, with substantial impacts already being felt by coastal ecosystems and communities. These changes are interacting with other factors, such as strengthening storms, which together are driving larger storm surges, infrastructure damage, erosion and habitat loss" (references omitted)).

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O-55-26 See Response to Comment O-55-6 regarding how the proposed Project would accommodate the potential for more frequent storms.

See Response to Comment O-55-3 regarding how the proposed Project accommodates the potential for groundwater rise in response to sea level rise.

The comment does not provide any new information to support the claim that either FEMA's mapping of current flood hazard zones or the mapping of proposed Project conditions in the future[7], which relies upon best available science and guidance from California, are incorrect or somehow unreliable.

O-55-27 In the Final EIR, a paragraph has been added to Section 3.11.1 to characterize the proposed Project's design basis for sea level rise resilience that is consistent with Section 4.9 (additions are underlined and deletions are ~~crossed-out~~):

> In accordance with state guidance and AB 1191, the Project's design basis for sea level rise resilience extends to 2100 (Moffatt & Nichol 2021a). For the proposed residential buildings and ballpark structure, the Project at its Buildout phase will accommodate more than 6.0 feet of sea level rise with minimal adaptations. For the streets and open space areas, the Buildout phase will accommodate at least the upper range of 2050 sea level rise projections of 1.9 feet. For portions of the site that are not initially resilient to potential 2100 sea level rise, a Sea Level Rise Final Adaptive Management and Contingency Plan will be developed based on Moffat & Nichol (2021a) which identifies specific adaptation measures that would be used to address sea level rise. Moffat & Nichol (2021a) augments Moffat & Nichol (2019) augmented and has been included as part of the Final EIR. The Final Plan will address the sea level rise conditions that may occur in the future based on information available at that time and will describe the specific monitoring, triggers, and implementation of adaptation measures that will provide resilience to the portions of the Project site which become exposed to flood hazard due to future information on actual and projected sea level rise.
>
> Elevating the Project site to reduce flood exposure due to future sea level rise is the Project's primary adaptation measure. The Project's proposed grading plan involves adding soil throughout much of the Project site to raise the ground surface elevations at least several feet ~~to~~ above the base flood elevation of 3.9 feet COD ~~to reduce flood exposure due to future sea level rise~~. Overall, the Project creates a large area of raised ground along the shoreline. The Project sponsor proposes finished floor elevations of all residential buildings on the site to be at or above 10 feet COD to accommodate future increases in the base flood elevation due to future sea level rise. The one exception

[7] Moffat & Nichol, 2021. Potential Extents of Inundation, Oakland Athletics Howard Terminal Project, September 27, 2021.

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> would be on development block at the corner of Embarcadero West and Clay Street, which would have a finished floor elevation of 6.0 feet COD, higher than the base flood elevation, based on the preliminary grading plan. Proposed roadway elevations on the Project site would be approximately 9–14 feet CODabove the City of Oakland Datum for most internal roads and 4.9 feet CODity of Oakland Datum on the north edge of the Project site to match with the existing grade of adjacent properties. The majority of the proposed ballpark structure would be at elevations of 5–10 feet City of Oakland DatumOD and higher, with the potential for lower elevations at field level suites and adjacent areas.

The comment appears to misinterpret the Draft EIR, claiming that "the DEIR acknowledges a high risk (50% or more) that structures will be inundated under Current Sea Level Rise projections during 100-year storm events." The Draft EIR explains how the proposed Project would provide resilience to the 100-year storm event and 6.9 feet of sea level rise, the projected 2100 sea level rise with a 0.5 percent chance of occurrence (two orders of magnitude less than the risk mentioned in the comment) (see Draft EIR pp. 4.9-33 through 36).

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> be at or above 10 feet [City of Oakland Datum (COD)[14]] to accommodate future increases in the base flood elevation (BFE) due to future sea level rise (see Table 4-9.1 in the Environmental Setting). At an elevation of 10 feet COD, the finished floors would remain above the BFE for up to 6.1 feet of sea level rise. This amount of sea level rise by 2100 falls with the guidance range (5.7-6.9 feet) for medium-high risk aversion from the state (Cal OPC, 2018),6 and is above the guidance range (2.6-5.5 feet) from BCDC. Although the elevations for the proposed finished floors only fall within, not above, the medium-high risk aversion range for 2100, the incremental difference of 0.8 feet does not cause substantial additional risk, since minimal adaptations, such as subtle modifications to grades, would be required to keep up with rising sea levels under the medium-high risk aversion scenario. Additionally, the medium-high risk aversion projection has only a 0.5 percent probability of being exceeded (Cal OPC, 2018) and the proposed finished floor elevation meets the medium high risk aversion sea level rise range through 2090 (Table 4.9-1).

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DEIR at 4.9-33 (explanatory footnote added). The DEIR continues,

> The majority of the proposed ballpark structure would be at elevations of 5-10 feet COD and higher (with the potential for lower elevations discussed below). At this elevation, the finished floors would remain above the BFE for 1.1 to 6.1 feet of sea level rise. An exception would be some field-level suite areas of the ballpark (these areas would include social space, dining areas and back of house operations), which would be at 0-4 feet COD. This elevation range is below to just above the current BFE, and would increasingly fall below the BFE with sea level rise. The ballpark may also include garage and storage enclosures at lower elevations then the current BFE, which is typically acceptable for building code compliance, provided their use is limited and provided that these areas meet the definition of an enclosure and other engineering design requirements for an enclosure (e.g., FEMA, 2017). The raised ground between these suite areas and San Francisco Bay would reduce the coastal flood exposure of the suite areas."

DEIR at 4.9-34. Thus, the DEIR acknowledges a high risk (50% or more) that structures will be inundated under current Sea Level Rise projections during 100-year storm events. The DEIR's dismissive treatment of this finding notwithstanding, this is an unacceptable level of risk, particularly given that projections for SLR continue to increase and climatologists expect that 100-year storm intensity will increase on current climate change trajectories.

[14] This refers to a baseline elevation similar to the North American Vertical Datum (the between NAVD and COD is: 0 feet COD = 5.77 feet NAVD); in other words, a surface of zero elevation to which heights of various points are referenced.

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O-55-28 The DEIR's efforts to mitigate or analyze real threats of flooding from SLR and intense storms is minimal. The DEIR acknowledges that additional measures will be needed in the future, post-2100 (if not sooner), yet it does not describe those measures so that they can be evaluated; nor does it seek to implement those measures in advance to increase public safety. *See, e.g.*, DEIR at 4.9-35 (accounting for some risk scenarios through 2090 or 2100 and stating that "adaptations would be required in the future to keep up with rising sea levels"). In addition, public spaces along the water are not resilient to 2100 predicted bay tidal surges. Mitigation measures should not be left as vague promises to adapt to rising seas, and should extend through the end of the projected life of the project, including either conversion of the site to some other use, such as adaptation wetlands, or a plan to permanently protect the site from sea level rise.

O-55-29 The increased elevation of the site detailed in the sections quoted above could also have unstudied consequences on surrounding neighborhoods and nearby sensitive sites. Water that enters the Bay at high tide must go somewhere; as high tides increase, there will be more water and it will inundate more land. Every seawall or other armoring structure built, including the planned increased elevation of the Project, in turn increases hydrological pressure on surrounding areas. In this case, according to the DEIR, nearby hazardous material sites that may be more seriously impacted as a result of the Project's armoring include Schnitzer Steel, the Pacific Gas & Electric Compressed Natural Gas Station, the Port of Oakland and Downtown Oakland Compressed Natural Gas Station, the Pacific Gas and Electric Oakland-1 Manufactured Gas Plant, the Port of Oakland Cinema Project, Jack London Square Parcel D, the Port of Oakland's Site A Ferry Terminal, the Merrit Two Site, the Terradev Jefferson LLC Property, E-D Coat, Inc., and East Bay Ford Truck Sales. DEIR at 4.8-17 – 4.8-23. Each of these sites has unique pollution concerns and the impacts of increased inundation of neighboring sites due to the Project's armoring are not discussed in the DEIR.

b. Maritime Reservation Scenario

O-55-30 Under the Maritime Reservation Scenario, the port has the option to reclaim 10 acres on the southwest corner of the parcel for expansion of the ship turning basin within 10 years. *Compare* DEIR Figures 3-13, 3-15, 3-17, and 3-18 (summarized in Section 3.20); Figures 3-13.MRS and 3-15.MRS (impacts on the project from the port exercising this option). If the Port exercises this option, "[t]he Waterfront Park would be reduced from 10.3 acres to 6.9 acres" (DEIR at 3-38); "public trust-related uses on Blocks 8 and 16" will be impacted; and the Bay Trail benefit will be impacted (i.e., the Bay Trail will be reduced in this area). DEIR at 3-37.

Construction impacts may continue to affect the community over may years. This drawn out timetable is inadequately studied in the DEIR and could create adverse community conditions that are deeply concerning to Baykeeper and our members. The fact that the Port has ten years to exercise this Maritime Reservation option creates a significant unknown in Project effects. Will Project proponents develop this area with public amenities as initially planned and then rip them out if the Port exercises its option? Or will these benefits not occur at all until it is clear that the Port is not exercising its option? Either way, it is difficult to evaluate Project impacts with the uncertainty of construction impacts extending 10 years and beyond. According to the DEIR, overall, the "Project would be constructed over several years and include on-site construction activities, construction along the railroad corridor, and off-site infrastructure construction such as the transportation improvements." DEIR at 3-43. Phase I construction will take 2 years (though the DEIR

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O-55-28 Once the buildout phase of the Project is completed, more than three-quarters of the Project area would be raised above the base flood elevation occurring in conjunction with at least 6 feet of sea level rise. Additional measures to account for additional sea level rise[8] are described in Mitigation Measure HYD-3. In addition, Mitigation Measure HYD-3 provides measures linked to specific amounts of sea level rise that would be implemented for the minor portions of the Project site resilient to less than 6 feet of sea level rise. For instance, the wharf, which provides public access, would be above the base flood elevation for up to 3 feet of sea level rise. After that, adaptation measures would be implemented, such as installing parapet walls along the wharf edge or changing the programming and user experience to accommodate the infrequent and temporary inundation. Mitigation Measure HYD-3: Sea Level Rise Final Adaptive Management and Contingency Plan (Draft EIR, p. 4.9-37) stipulates that prior to the issuance of the first grading permit for the Project, the Project sponsor shall develop a final adaptive management and contingency plan for sea level rise that would further specify the adaptation measures to be implemented.

O-55-29 The Project site is part of a shoreline unit whose flood protection was analyzed in Hummel and Stacey (2021) for effects on other parts of the San Francisco Bay shoreline. This study found that the effect of protecting the more than 35 miles of shoreline comprising the unit that includes the Project area did not have the larger effects seen by some other bay shoreline units: even with 2 meters of sea level rise, the off-site increases in water level due to protecting all of the Oakland, Alameda, and San Leandro shoreline unit was less than 2 inches.[9] In addition, the Project area is only 0.6 mile of the shoreline unit in which it resides. Therefore, the proposed Project would not cause significant changes to flood hazards in surrounding areas, and any hazard due to inundation of pollution on surrounding areas remains the responsibility of the surrounding areas, not the responsibility of the Project.

O-55-30 The analysis of the Maritime Reservation Scenario in each section of Draft EIR Chapter 4 considers the conservative timing assumptions of when the Port could exercise its option and associated construction could commence, including relative to development of other parts of the Project. The analysis in the Draft EIR is complete and no change to the document or the analysis is warranted.

8 Moffat & Nichol, 2021. Coastal Flooding, Proposed Grading Strategy, Sea Level Rise Adaptation, and Public Access on Wharf, Oakland Athletics Howard Terminal Project, July 9, 2021.

9 Hummel and Stacey, 2021. Hummel, M. A., & Stacey, M. T. (2021). Assessing the influence of shoreline adaptation on tidal hydrodynamics: The role of shoreline typologies. Journal of Geophysical Research: Oceans, 126, e2020JC016705.

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O-55-30 acknowledges it may be longer), the next phase is likely to take more than 4 years, and final buildout may occur within 8 calendar years. However, the Maritime Reservation Scenario gives the Port a 10-year option to decide to expand the turning basin, so the 8-year buildout is only possible if the Port exercises its option on the turning basin earlier than 10 years. DEIR at 3-55.

O-55-31 The DEIR does not analyze hydrological or flooding impacts any differently under the scenario where the port exercises its option on 10 acres of the site for expansion of their boat turning area. *See, e.g.*, DIER at 4.9-36. These uncertainties make it very difficult to evaluate whether the Project's sea level rise and flooding mitigation might benefit from an expansion of the turning basin. The DEIR should evaluate these potential benefits, or the lack thereof, as the creation of additional space in the turning basin would create more space for water to go (e.g., especially during a storm). Further, if the Port did not use that space, the DEIR should evaluate the benefits of an alternative that would use that space to mitigate storm surge effects through marsh restoration or a horizontal levee.

c. Trees and Landscaping

O-55-32 Site landscaping can have a major impact on minimizing and mitigating the Project's environmental impacts. Specifically, assuming that contaminated soil and groundwater on site will be removed or fully mitigated (i.e., permanently prevented from contacting ground or surface water), landscaping should be designed to maximize stormwater capture and beneficial use of stormwater and grey water. In addition, landscaping of the site should be designed to maximize carbon sequestration and mitigation of local air quality impacts (including high air temperatures) while minimizing the need for irrigation and application of pesticides and fertilizers. Baykeeper recommends emphasizing plantings that require no pesticides or herbicides or artificial lawn and garden care products as such products are likely to contaminate groundwater and surface water. Because fresh water supplies are limited in the Bay Area and unsustainable diversion of water jeopardizes the Bay ecosystem and water quality, we also recommend that the Project prioritize plants that require little or no imported water for irrigation after establishment and any irrigation water that is needed (including for the baseball field itself) should preferentially utilize recaptured stormwater and/or grey water. In addition, landscaping soil treatments (e.g., compost) and plantings can have a significant effect on carbon sequestration on the Project site; planting and soil management decisions should maximize carbon sequestration.

O-55-33 The DEIR's description of site landscaping does not identify landscaping elements other than trees and does not address maintenance, soil treatment, or irrigation plans. The DEIR provides minimal description of plant choices for the site, saying simply, "The Project anticipates approximately 600 trees within the boundaries of the Project site." DEIR at 3-46. Similarly, there is no description or specifics regarding pesticides anticipated to be used (the Landscaping section could and should address this and, specifically, the Project should commit to not using pesticides, except in well-defined, extreme situations). According to the DEIR, "[o]peration of the Project would include urban uses of pesticides, cleaners, and other common household products that could enter stormwater runoff." DEIR at 4.9-21. This is insufficient, and the DEIR should specify amounts and plans to properly mitigate impacts. Furthermore, there is also no description of the stormwater gardens identified in Figure 3-19. The constituents and capacity of features such as stormwater gardens should be fully described. Baykeeper recommends incorporating soil modifications and amendments, as well as physical features such as swales and retention basins in the landscaping or

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RESPONSE

O-55-31 The flood hazards that pose potential hazards to the Project area are from the entirety of San Francisco Bay. Compared to the volume of the bay, additional flood storage volume that could be created in the turning basin, either for an enlarged boat turning area or for marsh restoration, are negligible. This is consistent with Response to Comment O-55-29. As described in that response, modeling by Hummel and Stacey (2021) that assessed the impacts of changing the flood storage volume for the entire shoreline unit (that includes the Project area) found off-site effects of less than 2 inches, even with 2 meters of sea level rise.[10] Adding flood storage from the storage basin would be a much smaller change than the change for the entire shoreline unit. Therefore, the alternative land uses proposed in this comment would not affect flood levels and do not need to be analyzed by the EIR.

O-55-32 As described on Draft EIR p. 3-51, stormwater treatment areas for the runoff from the Project site would be located in parks and landscaping (within the ballpark and on the remainder of the Project site), in addition to streets, and in development areas near the catch basins or inlets. Landscape-based treatment, bioretention, or flow-through planters are proposed; the ballpark's grass field would be a permeable surface on grade and therefore would also provide the benefit of reduced runoff. The Draft EIR continues that "The parks and open spaces within the development (see Figure 3-13) would provide landscape based treatment areas within, or adjacent to, the footprint of each park and open space." The comment mentions benefits that landscaping of the site could achieve related to reduced air pollutant and greenhouse gas emissions.

O-55-33 See Responses to Comments I307-2-11, O-27-59, and O-27-60. Stormwater gardens identified in Figure 3-19 are described on Draft EIR p. 3-45 as areas where more informal clustering of street trees would be planted along the east-west streets in the Project site. The term *stormwater gardens* has been defined to be more consistent with Section 4.9, *Hydrology and Water Quality*, and Section 4.16, *Utilities and Service Systems*, as pervious surface areas planted with vegetation for stormwater filtration and bioretention. The following text on Draft EIR p. 3-47 has been revised in response to this comment:

- **Secondary Street Tree Clusters,** which would be more-informal clustering of Street trees along the secondary network of east-west streets and within stormwater gardens<u>, defined as pervious surface areas planted with vegetation for stormwater filtration and bioretention</u>;

[10] Hummel and Stacey, 2021. Hummel, M. A., & Stacey, M. T. (2021). Assessing the influence of shoreline adaptation on tidal hydrodynamics: The role of shoreline typologies. Journal of Geophysical Research: Oceans, 126, e2020JC016705.

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O-55-33 cisterns for the structures, to maximize water retention on site and in the soil. This approach to landscaping will reduce the potential for flooding on the site or in the surrounding area, improve the water quality of any storm runoff, and minimize consumption of imported irrigation water on site.

V. HYDROLOGY AND WATER QUALITY

a. Groundwater

O-55-34 Contaminated groundwater must be treated and further contamination prevented. Just because there may be limited evidence that contaminated groundwater is leaking into the Bay, now (*see, e.g.*, DEIR at 4.8-15), does not mean that will remain true in the future. Rising local sea levels, increasing storm intensity, known seismic activity, and development under the Project all threaten to change patterns of groundwater movement (vertically and horizontally). Therefore, the DEIR's statement that "[g]roundwater is estimated at a depth of 5 to 12 feet below the ground surface and likely fluctuates several feet daily with the tidal action, due to the presence of the adjacent San Francisco Bay," is not a sufficient evaluation. DEIR at 4.9-4 (*citing* ENGEO 2019). "Groundwater beneath the Project site is contaminated from previous historical uses on the Project site." DEIR at 4.9-4. Changed patterns in groundwater flow, either by themselves or in combination with the movement of toxins on the site, could lead to harmful impacts to the Bay and to the human communities on the water's edge. Removing the contaminated groundwater and soils eliminates these risks.

O-55-35 Baykeeper is concerned that the Project is proceeding prior to completion of the Groundwater Management Plan for the East Bay Plain. According to the DEIR, the Project site lies above the "East Bay Plain (DWR Groundwater Basin No. 2-9.01) an important and beneficial groundwater basin underlying the East Bay, extending from Richmond to Hayward. ...This deep basin provides municipal, industrial, and agricultural water supply. EBMUD and City of Hayward are currently working on the preparation of a Groundwater Management Plan for the East Bay Plain (EBMUD, 2018)." DEIR at 4.9-3. There is real potential for damage to this Public Trust groundwater resource from this Project (via construction, disturbance and exposure of hazardous materials and contaminated soils, impacts of rising sea levels as they interact with the modified site, and project landscaping and landscaping operations and maintenance). Baykeeper recommends that soil management, hazardous waste mitigation, construction, and landscaping be tailored specifically to protect and enhance the groundwater resources of the East Bay Plain aquifer in the vicinity of the Project.

b. Surface water and flood risks

O-55-36 The Project DEIR focusses on directing stormwater off site, into the Middle Harbor, as quickly as possible. The DEIR states that, "[w]hen heavy rains are coupled with higher-than-normal tides, tide levels can slow the drainage of runoff into San Francisco Bay, increasing the potential for urban stormwater flooding." DEIR at 4.9-4. As described in the DEIR, stormwater management currently consists of collection and export of stormwater into the Bay. *See, e.g.*, DEIR at 4-9-27.

This approach will only exacerbate flooding of adjacent areas (and maybe portions of the Project site) under conditions where heavy rains correspond with higher-than-normal or higher-than-

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O-55-34 This comment repeats concerns regarding sea level rise, addressed previously in Response to Comment O-55-14. This comment also references increasing storm activity and known seismic activity. The comment does not provide information regarding how the commenter believes storms and seismic activity would change patterns of groundwater movement. As discussed in Draft EIR Section 3.11.1, *Sea Level Rise*, the elevations of the Project site would be raised to accommodate the anticipated amount of sea level rise. As discussed in Section 3.12.2, *Stormwater*, a new stormwater drainage system would be installed to manage stormwater. Impact HYD-5 in Draft EIR Section 4.9, *Hydrology and Water Quality*, analyzes potential flood impacts from sea level rise and concludes that the Project site would be elevated such that proposed grades would include an allowance for sea level rise. In addition, Mitigation Measure HYD-3: Sea Level Rise Final Adaptive Management and Contingency Plan would require the preparation and implementation of a sea level rise adaptation plan, as required by AB 1191. This plan would require monitoring of sea levels adjacent to the Project site, development of a plan of adaptation strategies based on measures identified in the mitigation or equivalent measures, and implementation of adaptation actions, as needed. The commenter does not provide information explaining how future seismic events would affect groundwater flow patterns.

O-55-35 See Responses to Comments O-27-59, O-27-60, O-27-61, and O-27-62.

O-55-36 See Responses to Comments I307-2-11, O-27-59, O-27-60, O-27-61, and O-27-62.

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historical tides (e.g., under SLR projections). Rather, the Project should explicitly plan to retain, manage, and treat stormwater before it enters the Middle Harbor.

O-55-36 The need for complex stormwater routing and ongoing water quality testing and management operations would be minimized if (1) hazardous materials, contaminated soils, and polluted groundwater currently on the site were completely remediated (i.e., removed and replaced with clean fill) and (2) the Project was designed to capture stormwater and use it for beneficial purposes (e.g., maintaining soil moisture for landscaping; irrigation water, groundwater recharge). Contaminated soil on site poses an immediate risk, and must be removed or fully mitigated (i.e., permanently prevented from contacting ground or surface water), as discussed earlier. It would be preferable to clean the site and then encourage stormwater infiltration to groundwater in order to (1) treat stormwater by filtration through soil and (2) reduce potential for localized flooding during storm surge events.

O-55-37 The DEIR should discuss the types of pollutants that might be carried in stormwater that discharges to the Bay. The DEIR states that "the use of vehicles on the Project site could result in the release of minor amounts of oil, grease, and other mechanical compounds that could enter stormwater runoff." DEIR at 4.9-21. However, there is no discussion of the types or quantities of oil, grease, and other mechanical compounds that are expected to be carried by stormwater to the Bay. It should be possible to estimate these quantities based on results from other, similar parking situations elsewhere. Also, there is no description of ongoing contamination of the site with micro-plastics (e.g., as arise from degradation of tires) and how those substances are transported to the Bay by stormwater.

Treatment of stormwater through bioswales and other green infrastructure design can reduce toxins in stormwater (including oil, pesticides, herbicides, and microplastics) before they enter the Bay. Landscape plantings and soil amendments (e.g., compost or biochar) can also increase the amount of stormwater retained on site significantly. In addition, green infrastructure can be used to increase stormwater retention times and minimize flooding from storms that occur during high tides. For example, cisterns or retention basins that capture run-off from residential and parking structures and roadways can limit stormwater runoff to Middle Harbor during flooding events. The captured or retained stormwater can be repurposed for on-site uses, minimizing overall water demand on the site. Minimizing surface runoff can be a key environmental benefit of the Project for the local community and for neighboring land uses.

i. Flood risk

O-55-38 The DEIR places structures, including potential housing, within a 100-year flood hazard area. DEIR at 4.9-29. This could impede or redirect flood flows, exposing people or structures to a significant risk of loss, injury or death involving flooding. *Id.* The DEIR does not adequately evaluate or mitigate for these impacts. The DEIR's suggestion that perhaps the structures of concern are not actually in the FEMA flood zone reflects a reliance on the precision of the FEMA flood estimates that is not warranted. DEIR at 4.9-27. Indeed, the DIER also questions the accuracy of these estimates with its statement that, "[g]iven parts of development block #18 are within the SFHA, future surveys are warranted to verify that the building floor levels are above the base flood elevation." *Id.* Estimates of future Sea Level Rise in this area are increasing; similarly, the severity

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O-55-37 See Responses to Comments A-12-43, O-27-59, O-27-60, and O-55-33. See Draft EIR Chapter 3, *Project Description*, pp. 3-46 and 3-47, for information on landscaping providing stormwater filtration and bioretention.

O-55-38 See Response to Comment O-27-59.

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of future storms is expected to increase; if current FEMA flood estimates are slightly inaccurate (as the DEIR suggests is possible), it is just as likely that the risk of site flooding is *higher* than what is reflected in the FEMA estimates than that less flooding will occur. Furthermore, sites that are now on the edge of FEMA's zones of concern are likely to fall within flood zones in just a few years. The Project must assume that areas that are "on the edge" of risk now will actually flood at or soon after flooding is projected to occur.

O-55-38

Mitigation Measure HYD-2, Structures in a Flood Zone, says the final grading plan will show structures above the 100-yr flood zone *or* "would not place structures within flood hazard area that structures in the 100-year flood zone impede or redirect flood flows, exposing people or structures to a significant risk of loss, injury or death involving flooding, and impacts would be less than significant." DEIR at 4.9-29. More detail should be provided in the DEIR about what structures are expected to be in the flood zone and how those structures will be built so as to avoid impeding or redirecting flows. Impacts from flood risks to nearby hazardous sites should also be evaluated. *See, e.g.,* DEIR at 4.8-17 – 4.8-23 (nearby hazardous material sites).

VI. CONCLUSION

Any final EIR produced for the Project must answer the questions posed by these comments, and provide for appropriate mitigation for significant impacts. If the DEIR is unable to reasonably detail toxic materials cleanup measures, one potential mitigation is to provide for a secure financial mechanism for accomplishing the worst case, or most expensive, cleanup scenario. Such a mechanism could include a bond put forward by the Project proponent.

O-55-39

Absent such security, the uncertainty presented in the DEIR has been shifted from the Project proponent and the authorizing agency, where CEQA contemplates responsibility lying for evaluating the potential impacts of projects, to the public, to be borne by future generations. Even beyond the requirements of CEQA, this does not meet the Oakland A's "pledge to redevelop and privately finance the site, we will fully remediate these environmental issues at no cost to taxpayers." Oakland A's Ballpark Environmental Justice and Stewardship Initiative, 2019 (attached as Exhibit A). This DEIR does not lay out a plan that will remediate Project's environmental issues at no cost to taxpayers. Instead, it borrows against the future to pay for more excesses, today. When that bill comes due, however, there is no guarantee that the A's will be ready and eager to pay it.

Baykeeper respectfully requests that the issues described in these comments—issues that amount to a deficient DEIR—be addressed in a recirculated DEIR, as required by CEQA.

Sincerely,

M. Benjamin Eichenberg
Staff Attorney
San Francisco Baykeeper

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RESPONSE

O-55-39 This comment is predicated on other comments in this submittal; see Responses to Comments O-55-2 through O-55-38. As the designated lead agency under CEQA, the City has prepared and circulated the Draft EIR to meet or exceed CEQA requirements, including (for example) requirements related to writing, emphasis, degree of specificity, technical detail, and discussion of environmental impacts (State CEQA Guidelines Sections 15140, 15143, 15146, 15147, and 15126 through 15127). Regarding the statement that the Draft EIR should be revised and recirculated, information has been added to the Draft EIR (see Chapter 7, *City-Initiated Updates and Errata in the Draft EIR*), and no significant new information (e.g., information leading to a new significant impact or a substantial increase in the severity of an impact) has been added since publication of the Draft EIR. Consequently, the Draft EIR need not be recirculated. See Consolidated Response 4.3, *Recirculation of the Draft EIR*, for more information.

Regarding the funding of cleanup, CEQA does not require that the financial details of a proposed project be addressed in the EIR. CEQA requires only that the party or parties responsible for implementing all mitigation measures identified to address significant environmental impacts be detailed in a mitigation monitoring and reporting program, which will also detail the timing and responsible party or parties for monitoring and compliance (State CEQA Guidelines Section 15097).

The comment letter includes several attachments that are not specific to the Project, and do not raise a significant environmental issue or specific questions about the analyses or information in the Draft EIR that would require response pursuant to CEQA Guidelines Section 15088. The attachments will be included as a part of the record and made available to the decision makers prior to a final decision on the proposed Project.

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Preparing for Rising Seas:
How the State Can Help Support Local Coastal Adaptation Efforts

LAO

GABRIEL PETEK
LEGISLATIVE ANALYST
DECEMBER 2019

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AN LAO REPORT

Cover Photo: The cover image of high tides along the Embarcadero in San Francisco was taken by Dave Rauenbuehler, @daver6 via Flickr.

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Executive Summary

Important for Coastal Communities to Begin Preparing for Sea-Level Rise (SLR)

California Faces the Threat of Extensive and Expensive SLR Impacts. California's coast could experience SLR ranging from about half of 1 foot by 2030 up to about 7 feet by 2100. Periodic events like storms and high tides will produce even higher water levels and increase the risk of flooding. Rising seas will also erode coastal cliffs, dunes, and beaches which will affect shorefront structures and recreation.

Most Responsibility for SLR Preparation Lies With Local Governments, However, the State Has a Vested Interest in Ensuring the Coast Is Prepared. Most of the development along the coast is owned by either private entities or local governments—not the state. Additionally, most land use policies and decisions are made by local governments, and they are most knowledgeable about their communities. Local governments will need to grapple with which existing infrastructure, properties, and natural resources to try to protect from the rising tides; which to modify or move; and which may be unavoidably affected. However, given the statewide risks, the state can play an important role in encouraging and supporting local efforts and helping to alleviate some of the challenges local governments face.

Many Coastal Communities Are Only in the Early Stages of Preparing for SLR. The progress of SLR preparation across the state's coastal communities has been slow. Moreover, few coastal communities have yet begun implementing projects to respond to the threat of rising seas. Coastal communities must increase both the extent and pace of SLR preparation efforts if California is to avoid the most severe, costly, and disruptive impacts in the coming decades.

Delaying SLR Preparations Will Result in Lost Opportunities and Higher Costs. Planning ahead means adaptation actions can be strategic and phased, helps "buy time" before more extreme responses are needed, provides opportunities to test approaches and learn what works best, and may make overall adaptation efforts more affordable and improve their odds for success. The next decade represents a crucial time period for taking action to prepare for SLR.

Local Adaptation Efforts Face Several Key Challenges

Funding Constraints Hinder Both Planning and Projects. Local governments cite funding limitations as their primary barrier to making progress on coastal adaptation efforts.

Limited Local Government Capacity Restricts Their Ability to Take Action. The novelty of the climate adaptation field makes it hard for local governments to locate and hire individuals with appropriate experience and expertise.

Adaptation Activities Are Constrained by a Lack of Key Information. Local governments cite a need for additional data and technical assistance to help inform their adaptation decisions.

Few Forums for Shared Planning and Decision-Making Impede Cross-Jurisdictional Collaboration. Even though the interrelated effects of SLR make cross-jurisdictional planning essential, local governments lack formal and strategic ways to learn from each other or make decisions together about coastal adaptation issues.

Responding to SLR Is Not Yet a Priority for Many Local Residents or Elected Officials. Because many California residents are not yet aware of how and when SLR might affect their communities, coastal adaptation actions are not a high priority for them to request from their local governments.

Protracted Process for Attaining Project Permits Delays Adaptation Progress. Achieving regulatory approval for coastal adaptation projects is complicated and takes a long time.

LAO Recommendations for Supporting Local Adaptation Efforts

While our recommendations represent incremental steps that will not be sufficient to address all the anticipated impacts of SLR, they represent prerequisites along the path to more robust statewide preparation.

Foster Regional-Scale Adaptation

- Establish and assist regional climate adaptation collaborative groups to plan together and learn from each other regarding how to respond to the effects of climate change.
- Encourage development of regional coastal adaptation plans to address key risks that SLR poses to the region, as well as strategies the region will take to address them.
- Support implementation of regional adaptation efforts by contributing funding towards construction of projects identified in regional plans.

Support Local Planning and Adaptation Projects

- Increase assistance for cities and counties to conduct vulnerability assessments, adaptation plans, and detailed plans for specific projects.
- Support coastal adaptation projects with widespread benefits such as those that pilot new techniques, protect public resources, reduce damage to critical infrastructure, or address the needs of vulnerable communities.
- Facilitate post-construction monitoring of state-funded demonstration projects to learn more about which adaptation strategies are effective.

Provide Information, Assistance, and Support

- Establish the California Climate Adaptation Center and Regional Support Network to provide technical support and information to local governments on adapting to climate change impacts.
- Develop a standardized methodology and template that local governments can use to conduct economic analyses of SLR risks and adaptation strategies.
- Direct the California Natural Resources Agency to review and report back regarding how regulatory permitting processes can be made more efficient.

Enhance Public Awareness of SLR Risks and Impacts

- Require coastal flooding disclosures for real estate transactions to spread public awareness about SLR and allow Californians to make informed decisions about the risks of purchasing certain coastal properties.
- Require that state funded adaptation plans and projects include robust public engagement efforts to help develop societal awareness about SLR, build acceptance for adaptation steps, and ensure the needs of vulnerable communities are addressed.
- Direct state departments to conduct a public awareness campaign about the threats posed by SLR to develop public engagement in and urgency for taking action.

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INTRODUCTION

State's Climate Change Response Will Require Both Mitigation and Adaptation. In recent years, California has taken steps to limit the effects of climate change by enacting policies and programs to reduce emissions of greenhouse gases. While these efforts—if combined with similar global initiatives—ultimately may constrain the total amount of warming the planet experiences, scientists are conclusive that some degree of climate change already is inevitable. The changing climate will have several consequential effects on California over the coming decades. Indeed, such impacts have already begun. In recent years, the state experienced a severe drought, multiple serious wildfires, and periods of record-breaking heat, all of which scientists suggest likely are harbingers of future conditions. In addition to these more episodic events, science has shown that the changing climate will result in a gradual and permanent rise in global sea levels. Given the significant natural resources, public infrastructure, housing, and commerce located along California's 840 miles of coastline, the certainty of rising seas poses a serious and costly threat. As such, in the coming years the state will need to broaden its focus from efforts to *mitigate* the effects of climate change to also undertake initiatives centered on how communities can *adapt* to the approaching impacts.

Report Responds to Increasing Legislative Interest in Climate Adaptation. This report responds to increasing legislative interest in determining how the state can best prepare for the impacts of climate change, including sea-level rise (SLR). In recent years, the Legislature has held several hearings on SLR and coastal adaptation, formed two related select committees, and deliberated multiple legislative proposals on these topics. In addition, the Governor and some legislative members have indicated interest in placing a new general obligation bond on the 2020 ballot for voter approval that would provide funding for climate adaptation activities.

Report Focuses on How State Can Support Local Coastal Adaptation Efforts. Although the risk presented by SLR is an issue of statewide importance, most of the work to prepare for and respond to these changes has to take place at the local level. This is because most of the development along the coast is owned by either private entities or local governments—not the state. Additionally, most land use policies and decisions are made by local governments, and they are most knowledgeable about the needs and specific circumstances facing their communities. However, the state can play an important role in encouraging and supporting local efforts and helping to alleviate some of the challenges that local governments face in preparing for SLR. Given the importance of protecting the state's residents, economy, and natural resources from considerable damages, this report focuses on how the Legislature can help support and expedite progress in preparing for rising seas at the local level. (While the state will also need to take action to prepare for potential impacts to assets for which it has primary responsibility—like coastal highways and state parks—consideration of those steps is outside the scope of this report.) This focus and our recommendations represent a continuation of the state's long-standing role in facilitating and incentivizing implementation of state objectives at the local level. While adopting our recommended actions will not be sufficient to address all the projected impacts of SLR, they represent important incremental steps towards greater preparation across the state.

Findings Informed by Extensive Interviews and Research. The findings and recommendations presented in this report are informed by interviews we conducted with over 100 individuals. These interviewees represented local governments from across the state, academic researchers, community groups, nongovernmental organizations, federal agencies, and state departments. We also reviewed relevant reports and academic literature, including several statewide surveys conducted on the topics of coastal adaptation, climate change preparation, and local government planning. The resources we reference within the report are listed in the "Appendix."

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CALIFORNIA FACES THREAT OF RISING SEAS AND TIDES

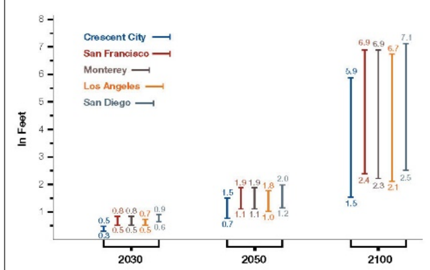
Coast Will Experience Encroaching Seas in Coming Decades. Climate scientists have developed a consensus that one of the effects of a warming planet is that global sea levels will rise. The degree and timing of SLR, however, is still uncertain, and depends in part, upon whether global greenhouse gas emissions and temperatures continue to increase. Figure 1 displays recent scientific guidance compiled by the state for how sea levels may rise in various coastal areas of California in the coming decades. As shown, the magnitude of SLR is projected to be about half of 1 foot in 2030 and as much as 7 feet by 2100. The estimates shown in the figure represent the range between how sea levels might rise across the state under two different climate change scenarios. The bottom end of the range reflects the lower bound of a "likely" scenario (with a projected 66 percent chance of occurring). The top end reflects the upper bound of a higher risk and more impactful scenario (with a projected 1-in-200 chance of occurring). As shown, the range between these scenarios is greater in 2100, reflecting the increased level of uncertainty about the degree of climate change impacts the planet will experience further in the future.

Figure 2 displays a detailed map of how current SLR projections translate into potential flooding in the San Francisco (SF) Bay Area. The map shows flooding projected to occur with 2 feet of SLR combined with a ten-year storm surge (that is, the temporary flood effects from a storm that has a one-in-ten likelihood of occurring in a given year). This combination of events would result in a total water level of over 4 feet. As shown, under this scenario—and given existing shoreline protections and conditions—many portions of the SF Bay shoreline would become inundated. For example, as highlighted in the map, this would result in severe flooding for Foster City, the Oakland International Airport, and the toll plaza for the SF Bay Bridge in Oakland. This combination of SLR and storm is well within the range of possibilities that could occur within the next 50 years. Combining a significantly high-tide event with SLR would result in even more severe flooding across the region than that shown in this map.

Storms and Future Climate Impacts Could Raise Water Levels Further. Although they would have substantial impacts, the SLR scenarios displayed in Figure 1 likely *understate* the increase in water levels that coastal communities will actually experience in the

Figure 1

Range of Sea-Level Rise Projections for the California Coast[a]



[a] Estimates represent the range between "likely" scenarios with a 66 percent chance of occurring and scenarios with a 1-in-200 chance of occurring. Range does not include estimates associated with "extreme" scenarios incorporating the effects of potential ice loss from the West Antarctic Ice Sheet, which are significantly higher.

From the *State of California Sea-Level Rise Guidance Document* published by the California Natural Resources Agency and the California Ocean Protection Council.

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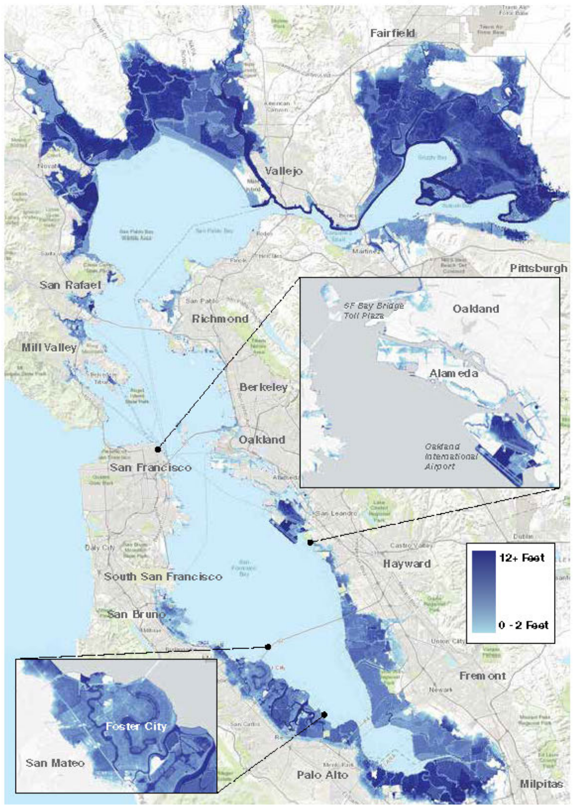
Figure 2

Potential Impacts of Sea-Level Rise (SLR) and Flooding in the San Francisco Bay Area

Predicted Shoreline Flooding With 2 Feet of SLR and a Ten-Year Storm Surge[a]



[a] A ten-year storm surge represents the temporary flood effects from a storm that has a one-in-ten likelihood of occurring in a given year.

Map courtesy of the San Francisco Bay Conservation and Development Commission's Adapting to Rising Tides Bay Shoreline Flood Explorer.

SF = San Francisco

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coming decades. This is because climate change is projected to contribute to more frequent and extreme storms, and the estimates shown in Figure 1 do not incorporate potential increases in sea levels caused by storm surges, exceptionally high "king tides," or El Niño events. These periodic events could produce notably higher water levels than SLR alone. Moreover, the data displayed in the figure do not include significantly higher estimates associated with "extreme" scenarios that incorporate the effects of potential ice loss from the West Antarctic Ice Sheet. The likelihood of these severe scenarios occurring is still uncertain, but possible. If there is considerable loss in the polar ice sheets, scientists estimate that San Francisco could experience over 10 feet of SLR by 2100.

SLR Impacts Have Potential to Be Extensive and Expensive. The potential changes in sea levels and coastal storms will impact both human and natural resources along the coast. These events will increase the risk of flooding and inundation of buildings, infrastructure, wetlands, and groundwater basins. A 2015 economic assessment by the Risky Business Project estimated that if current global greenhouse gas emission trends continue, between $8 billion and $10 billion of existing property in California is likely to be underwater by 2050, with an additional $6 billion to $10 billion at risk during high tide. A recent study by researchers from the U.S. Geological Survey (USGS) estimates that by 2100, roughly 6 feet of SLR and recurring annual storms could impact over 480,000 California residents (based on 2010 census data) and $119 billion in property value (in 2010 dollars). When adding the potential impacts of a 100-year storm, these estimates increase to 600,000 people and over $150 billion of property value.

Rising seas will also erode coastal cliffs, dunes, and beaches—affecting shorefront infrastructure, houses, businesses, and recreation. The state's *Safeguarding California Plan* cites that for every foot of SLR, 50 to 100 feet of beach width could be lost. Moreover, a recent scientific study by USGS researchers predicted that under scenarios of 3 to 6 feet of SLR—and absent actions to mitigate such impacts—up to two-thirds of Southern California beaches may become completely eroded by the year 2100. Such a loss would impact not only Californians' access to and enjoyment of key public resources, but also beach-dependent local economies. While no entity has completed a comprehensive economic assessment of beach-related recreation across the state, a 2016 report by the Center for the Blue Economy estimated that California's ocean economy—including tourism, recreation, and marine transportation—is valued at over $44 billion per year.

SLR Impacts Could Have Fiscal Implications at Both Local and State Levels. The potential impacts of SLR also could have negative impacts on the economy and tax base—both locally and statewide—if significant damage occurs to certain key coastal infrastructure and other assets. These include ports, airports, railway lines, beaches and parks used for recreation, and high-technology companies located along the SF Bay. Furthermore, if property values fall considerably from the increased risk and frequency of coastal flooding, over time this will affect the annual revenues upon which those local governments depend. To the degree local property tax revenues drop, this also could affect the state budget because the California Constitution requires that losses in certain local property tax revenues used to support local schools be backfilled by the state's General Fund.

SLR Threatens Vulnerable Populations. Not all of the assets threatened by SLR are expensive homes and affluent communities. In contrast, many communities with more vulnerable populations also face the risk of more frequent flooding. Such populations include renters (who are less able to prepare their residences for flood events), individuals not proficient in English (who may not be able to access critical information about potential SLR impacts), residents with no vehicle (who may find it more difficult to evacuate), and residents with lower incomes (who have fewer resources upon which to rely to prepare for, respond to, and recover from flood events). For example, a 2012 study conducted by the SF Bay Conservation and Development Commission's (BCDC) Adapting to Rising Tides Project found that SF Bay Area locations at risk of inundation from SLR included more than 9,000 renter-occupied households,

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over 2,500 linguistically isolated households, over 2,000 households with no vehicle, and over 15,500 individuals living in households earning less than 200 percent of the federal poverty level.

COASTAL ADAPTATION ACTIVITIES CAN HELP LESSEN SLR IMPACTS

While the estimates cited above highlight the potential damages, costs, and disruption that SLR could cause, strategies for moderating such impacts exist.

Three Primary Options Exist for Adapting to SLR. The state, coastal communities, and private property owners essentially have three categories of strategies for responding to the threat that SLR poses to assets such as buildings, other infrastructure, beaches, and wetlands. As shown in Figure 3 (on page 8), they can (1) build hard or soft barriers to try to stop or buffer the encroaching water and **protect** the assets from flooding, (2) modify the assets so that they can **accommodate** regular or periodic flooding, or (3) **relocate** assets from the potential flood zone by moving them to higher ground or further inland. Each of these options comes with trade-offs, as discussed in the figure, and not all strategies will work in every situation. Communities and residents are understandably reluctant to relocate existing properties, as this will be disruptive, expensive, and in some cases not logistically possible. Armoring much of the coast to protect most assets, however, also is not practical. Not only would such an approach be prohibitively expensive and have decreasing effectiveness over the years as more intense wave action migrates inland, it also would disrupt natural erosion processes such that it would cause much of the sand on the state's beaches to disappear.

Selecting which combination of SLR adaptation approaches to use in a particular location is an involved process necessitating scientific research, locally specific information, public and stakeholder input and support, both high-level and detailed planning, and—in many cases—additional funding. Local governments planning for SLR are also balancing other—and sometimes competing—land use objectives. As we discuss in the box on page 9, SLR presents particular challenges for coastal jurisdictions—and the state—seeking to expand the supply of housing units.

Undertaking Coastal Adaptation Activities Likely Less Costly Than Avoiding Action. The types of adaptation efforts described in Figure 3 can not only help mitigate disruptive SLR impacts, in many cases they also make sense from a fiscal perspective. That is, while such activities might require up-front investments, the costs of failing to adequately prepare for the impacts of SLR likely would cost even more. Recent research found a strong benefit-to-cost ratio for undertaking mitigation projects ahead of disasters compared to spending on disaster response and recovery. Specifically, a Federal Emergency Management Agency (FEMA)-sponsored study by the National Institute of Building Sciences found that for every $1 the federal government invested in various types of pre-disaster mitigation activities in recent years, it avoided public and private losses totaling $6. Designing new structures to be more resilient to natural hazards was also found to be financially advantageous. For example, in the case of riverine flooding, the study estimates that for every extra $1 spent to build new buildings higher out of the floodplain than international building codes require, $5 in flood damage-related costs was avoided. While the study was based on retrospective data on other types of disasters and did not consider future SLR-related coastal flooding, similar principles likely apply. That is, investing in adaptation activities that will help to mitigate significant flooding, damage, disruption, and erosion that will otherwise occur from SLR is almost certainly a less costly approach overall compared to not taking such actions.

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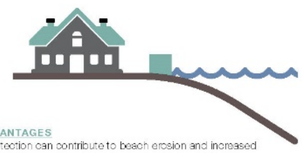
Figure 3

Three Key Strategies for Adapting to Sea-Level Rise (SLR)

PROTECT

Place hard or soft barrier between development and the sea to reduce exposure to flooding or erosion. Hard protection ("armoring") consists of constructing physical structures to keep water back, such as seawalls, groins, revetments, and levees. Soft protection consists of efforts to enhance natural infrastructure's ability to buffer against the water, such as building up sand dunes, adding sand to beaches, and expanding wetlands.



ADVANTAGES
Can allow existing development and infrastructure to remain in place. Can be less costly than other alternatives.

DISADVANTAGES
Hard protection can contribute to beach erosion and increased flooding in adjacent areas. Soft protection likely will become a less viable strategy once sea levels rise to the higher stages of projected levels.

ACCOMODATE

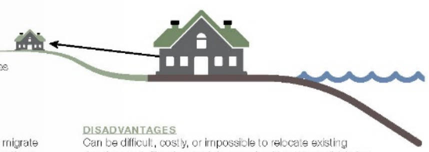
Modify or design development in ways that will withstand SLR without damage, such as by elevating buildings or infrastructure, floodproofing structures, and building on floating structures.

ADVANTAGES
Can allow existing development and infrastructure to remain in place once modified. Can allow for new development in areas that may face flooding in the future.

DISADVANTAGES
Can be difficult and costly, especially to modify existing development.

RELOCATE

Remove or move existing development to less risky areas and limit the construction of new development in vulnerable areas. This could include physically moving an asset or facility that is at risk, or adopting zoning policies that prohibit new development or require that it be "set back" from potential hazard zones.



ADVANTAGES
Can provide space for beach and wetlands to migrate inland as water rises. Ensures development locations are/will be safe from flooding.

DISADVANTAGES
Can be difficult, costly, or impossible to relocate existing development. Renders certain parcels of land unavailable for development.

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SLR Complicates State's Housing Objectives

The potential impacts of sea-level rise (SLR) create complications for a different state and local priority—increasing housing availability and affordability. California faces a serious housing shortage, and the state's coastal areas are experiencing the most acute population growth, high housing costs, and demand for more affordable housing. Our office has estimated that on top of the 100,000 to 140,000 housing units typically built in the state each year, California probably would have to build as many as 100,000 additional units annually—almost exclusively in its coastal communities—to seriously mitigate housing affordability problems. In recent years, the state has implemented a number of measures intended to encourage local governments to build more housing, including providing additional funding and instituting new penalties for jurisdictions that fail to comply with state housing laws.

Flooding caused by SLR poses two serious impediments to coastal jurisdictions seeking to meet these state housing objectives. First, over the coming decades some existing housing units along the coast will experience regular flooding and become uninhabitable. Second, some parcels of land that do not currently contain housing—and therefore may seem like apt locations for new development—also face the likelihood of flooding in future years. While local governments may be reluctant to adopt policies restricting development on these parcels given their current viability, the future hazards make them risky locations to construct new housing. Certain adaptation strategies described in Figure 3 could help to safeguard some existing properties and land parcels from the effects of SLR—including protecting them through armoring, or building or retrofitting structures such that they can accommodate flooding. As described in the figure, however, these strategies come with trade-offs, including costs and effects on adjacent areas. The degree of SLR that is predicted over the next century clearly will affect land use decisions and create additional challenges for local governments—and the state—as they seek to expand housing options for Californians in coastal regions.

LOCAL RESPONSES TO SLR WILL BE KEY TO STATEWIDE PREPAREDNESS

Most Responsibility for SLR Preparation Lies With Local Governments . . . Most of the development along the coast is owned by either private entities or local governments—not the state. Additionally, most land use policies and decisions are made at the local level, and local governments are most familiar with the specific circumstances facing their communities. As such, responsibility to prepare for and respond to the impacts of SLR lies primarily with the affected local communities. Deciding how to confront these challenges and implement the strategies described in Figure 3 will be both difficult and costly. Local governments will need to grapple with which existing infrastructure, properties, and natural resources to try to protect from the rising tides; which to modify or move; and which may be unavoidably affected.

. . . However, the State Has a Vested Interest in Ensuring the Coast Is Prepared. As discussed in more detail later in this report, the 1976 California Coastal Act grants the state special jurisdiction over land use decisions along the coast. Specifically, unlike other areas of California, along certain portions of the coast the state possesses the authority to regulate activities that change the intensity of use of land, with the intended goal of balancing development with protecting the environment and public access. This authority, combined with a motivation to minimize costly and traumatic damage for residents and their property, creates a strong rationale and incentive for the state to help ensure that local jurisdictions plan for and take action to adapt to SLR. Californians could experience serious public health and safety impacts if local governments do not take proper steps to prepare for how SLR will affect certain coastal infrastructure. Such impacts include threats to drinking water (from impacts to coastal groundwater aquifers and water treatment plants, and damage to levees in the Sacramento San Joaquin Delta), sewage treatment, local transportation infrastructure, and other essential facilities such as hospitals and schools. Moreover, the state is charged with overseeing natural resources on behalf of the public trust and, thus, is responsible for ensuring the preservation of public access to the coast and the health of coastal wetlands, wildlife, and habitats. As discussed earlier, SLR damages also would have fiscal implications, which the state will want to try to minimize.

CALIFORNIA IS IN BEGINNING STAGES OF PREPARING FOR SEA-LEVEL RISE

In this section we discuss how the state, federal, and local governments currently are engaged in preparing to adapt to the impacts of SLR.

State-Level Efforts

Multiple State Departments Have SLR-Related Responsibilites. As summarized in Figure 4, a number of state departments are engaged in efforts to prepare for and respond to the impacts of SLR. Additionally, senior-level staff from each of the departments shown in the figure—together with representatives from the Delta Stewardship Council—meet periodically to discuss statewide policy and priorities through a Sea-Level Rise Leadership Team they have formed. Besides the activities described in the figure, many state departments also are taking initial steps to assess how SLR will impact the state facilities and essential services for which they are responsible. Such steps were spurred by Governor Schwarzenegger's Executive Order S-13-08 (which in 2008 directed state agencies to begin planning for SLR and climate impacts), and several iterations of the *Safeguarding California Plan* (which was compiled by the California Natural Resources Agency [CNRA] and serves as the roadmap for steps that state agencies and departments should take to respond to the changing climate). One department managing significant state assets that are at risk from SLR is the California Department of Transportation (Caltrans), which manages state highways along the coast. Another is the Department of Water Resources, which manages the State Water Project, a water conveyance system that is highly dependent on the integrity of the levees in the Sacramento San Joaquin Delta to successfully move drinking water from the northern to the southern part of the state.

Additional Departments May Have More Involvement With SLR Adaptation in the Future. Two state departments not shown in Figure 4 that have had limited involvement with SLR activities thus far but may have increased roles in the future are the Strategic Growth Council (SGC) and California Office of Emergency Services (CalOES). Currently, SGC administers several state programs that are primarily designed to reduce greenhouse gas emissions, and its engagement on SLR-related issues has been relatively limited. As the state expands its focus beyond climate change *mitigation* into a greater emphasis on *adaptation*, however, the Legislature may choose to task SGC with additional responsibilities given the Council's experience in managing climate-related programs. Additionally, CalOES directs disaster preparedness and response activities in California, including overseeing local disaster mitigation planning efforts and administering associated federal programs and funding. Correspondingly, as California communities increase preparation for and begin to experience the impacts of SLR, CalOES likely will play a role in supporting such efforts.

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State Has Been Engaged in SLR Planning, Data Collection, and Information Dissemination. The state has published a number of reports in recent years concerning SLR projections and steps the state and local governments might take to respond. Among these is the *State of California Sea-Level Rise Guidance Document*, which was initially adopted in 2010 and most recently updated in 2018. This document—developed by the Ocean Protection Council (OPC) in coordination with other partner agencies—provides (1) a synthesis of the best available science on SLR projections and rates for California, (2) a stepwise approach for state agencies and local governments to evaluate those projections and related hazard information in their decision-making, and (3) preferred coastal adaptation approaches. Other SLR-related plans and reports the state has released in recent years include several iterations of the aforementioned *Safeguarding California Plan* (each of which consists of multiple companion reports), four *California Climate Change Assessment* reports (also encompassing multiple companion reports), the *California State Hazard Mitigation Plan*, and *Paying It Forward: The Path Toward Climate-Safe Infrastructure in California*.

Additionally, pursuant to Chapter 606 of 2015 (SB 246, Wieckowski), the Governor's Office of Planning and Research (OPR) operates the Integrated Climate Adaptation and Resilience Program. This program is intended to develop a cohesive and coordinated response to the impacts of climate change across the state and has two components. First, a Technical Advisory Council helps OPR and the state improve and coordinate climate adaptation activities. Second, OPR has created a searchable online public database of adaptation and resilience resources—known as the State Adaptation Clearinghouse—including some related to SLR and coastal adaptation. The Clearinghouse includes resources such as local plans, educational materials, policy guidance, data, research, and case studies.

Figure 4

State Departments With Major Sea-Level Rise (SLR) Related Responsibilities

Department	Primary SLR-Related Responsibilities
California Coastal Commission	Regulates the use of land and water in the coastal zone, excluding the San Francisco (SF) Bay Area. (The coastal zone generally extends 1,000 yards inland from the mean high tide line.) Reviews and approves Local Coastal Programs (LCPs)—plans that guide development in the coastal zone. Maintains permitting authority over proposed projects in areas in the coastal zone with no approved LCP and for state-managed lands such as state parks.
SF Bay Conservation and Development Commission	Reviews and issues regulatory permits for projects that would fill or extract materials from the SF Bay, and works to preserve public access along the bay's shore. Participates in the SF Bay Area's multiagency regional effort to address the impacts of SLR on shoreline communities and assets. Administers the Adapting to Rising Tides Program to support SLR-related planning and projects in the SF Bay Area.
Ocean Protection Council	Allocates grants for SLR and coastal adaptation projects and research. Conducts and distributes data and information to help local jurisdictions and state departments plan for SLR, including developing the *State of California Sea-Level Rise Guidance Document*.
State Coastal Conservancy	Allocates grants for and undertakes projects to preserve, protect, and restore the resources of the California coast and the SF Bay Area. Provides grants for planning and projects through its Climate Ready Program to increase the resilience of coastal communities and ecosystems to climate change impacts such as SLR.
State Lands Commission	Stewards sovereign state lands, including those located between the ordinary high water mark of tidal waters and the boundary between state and federal waters three miles offshore. Monitors sovereign state lands the Legislature has delegated to local municipalities to manage in trust for the people of California.
Governor's Office of Planning and Research	Administers the Integrated Climate Adaptation and Resilience Program, which includes a web-based clearinghouse that compiles information about climate change adaptation research and projects, including those related to SLR.
Department of Parks and Recreation	Owns and manages more than one-quarter of California's coastline. Responsible for protecting and conserving these beaches, wetlands, and other coastal resources on behalf of the public.

State departments have undertaken certain other initiatives to support SLR-related activities around the state, some of which are mentioned in Figure 4. For example, BCDC has developed the Adapting to Rising Tides Program which provides adaptation planning support, guidance, tools, and information to SF Bay Area agencies and organizations. BCDC has also developed detailed maps of how potential future flooding might impact the SF Bay region. The State Coastal Conservancy (SCC) has developed additional SLR resources and helps to coordinate the California Coastal Resilience Network, which presents monthly webinars on coastal adaptation. OPC has undertaken several initiatives, including a recently enacted contract to conduct a relatively small-scale public awareness campaign about the risks associated with SLR.

State Has Provided Limited Funding for Coastal Planning and Projects. In addition to undertaking state-level planning and research, the state has also provided some limited funding for SLR planning and projects. Figure 5 summarizes the funding appropriated by the Legislature for coastal adaptation activities over the past five years (2014-15 through 2019-20), totaling $67 million. These funds have been provided from a variety of sources. The Legislature has utilized bonds as the largest source of funding for these coastal adaptation activities ($26 million), followed by the Environmental License Plate Fund ($17.5 million) and the Greenhouse Gas Reduction Fund ($14.8 million). Much of this funding has been or will be used for grants to local governments and nongovernmental organizations for planning and projects, including through SCC's Climate Ready Program. The totals shown in the figure include $25 million for OPC and nearly $4 million for SCC appropriated in the *2018-19 Budget Act* that can be used for coastal adaptation projects, some of which likely has not yet been allocated for specific projects. In addition, a portion of the funds have been used for state department staff to undertake activities that assist local governments, such as staff support from BCDC and the Coastal Commission for local planning efforts.

In addition to the funding specifically for coastal adaptation shown in Figure 5, some other state funds have supported related work in recent years. This includes a program run by the Division of Boating and Waterways within the Department of Parks and Recreation (State Parks) that allocates grants for local beach erosion control and sand replenishment projects. Some other funding has been provided through sub-grants from other state departments. For example, both BCDC and some local governments have received funding from Caltrans for coastal adaptation planning and projects that involve transportation infrastructure. Some of BCDC's work supporting adaptation planning in the SF Bay Area has also been supported by some small grants from the Delta Stewardship Council, and SCC has received grants from the California Department of Fish and Wildlife for wetlands restoration projects.

Figure 5

Summary of Recent State Funding for Coastal Adaptation

2014-15 Through 2019-20 (In Millions)

Department	Primary Uses	Amount
Ocean Protection Council	Grants for adaptation projects, statewide research projects.	$34.6
State Coastal Conservancy	Grants for sea-level rise planning, grants for adaptation projects.	15.4
California Coastal Commission	Grants for local adaptation planning and to update Local Coastal Programs, staff support for those local planning efforts.	14.0
San Francisco Bay Conservation and Development Commission	Regulatory review of adaptation projects, grants for sea-level rise planning, staff support for regional planning efforts.	3.3
Total		$67.3

Federal-Level Efforts

Federal Government Has Supported Some Coastal Adaptation Activities in California. In general, the federal government's role in preparing for SLR in California has largely been to support the state and local agencies by providing technical assistance, scientific research and information, and some limited

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funding. The primary federal agencies engaged in SLR-related activities in California are the National Oceanic and Atmospheric Administration (NOAA) and USGS. As discussed in the nearby box, FEMA has not had much involvement in coastal adaptation activities thus far, but likely will play a larger role in the future.

NOAA Provides Technical Assistance and Some Funding. NOAA works collaboratively with the state to implement the federal Coastal Zone Management Act and help protect coastal resources. Significant SLR-related initiatives that NOAA is undertaking in California include providing training on coastal adaptation planning, developing tools (including the "Sea Level Rise Viewer" that provides detailed digital maps of potential SLR flooding), and collaborating on data collection initiatives. In addition, NOAA annually provides funding to the three state departments designated to help implement the Coastal Zone Management Act—the Coastal Commission, BCDC, and SCC. Between 2016 and 2019, NOAA allocated a total of about $11 million to these three departments for their ongoing coastal management activities, of which about $1.8 million was explicitly for SLR-related projects and policy development. NOAA has also provided some specific one-time grants to state departments and local governments for SLR-response initiatives in California, including $690,000 to San Diego County for a coastal resiliency project described below.

USGS Provides Scientific Research and SLR Modeling. Unlike NOAA, USGS does not give out grants to the state or local agencies; rather,

Role of FEMA in Coastal Adaptation

FEMA Helps Communities Prepare for and Respond to Disasters. The Federal Emergency Management Agency (FEMA) works with the California Office of Emergency Services (CalOES) to help prepare for and recover from disasters. Therefore, like CalOES, FEMA likely will play a role in supporting the state's coastal communities as they get ready for and respond to sea-level rise (SLR) impacts. Such efforts could include providing federal disaster mitigation funding for projects designed to reduce the future impacts of SLR. After a state experiences a federally declared disaster, FEMA provides it with funding to undertake activities intended to lessen the impacts of future disasters through the Hazard Mitigation Grant Program. For example, in 2018 (after experiencing several wildfire disasters) California received over $500 million in disaster mitigation funding from FEMA. The state also received close to $500 million in 2017, when federal disasters were declared after wildfires and severe storms.

FEMA Funds Could Be Used for Coastal Adaptation Projects. While the Legislature could help identify priorities for the use of such funds, thus far it has deferred to CalOES to select which areas of focus and specific projects to support—subject to approval from FEMA—when the state receives disaster mitigation funds. In general, CalOES has opted to use such funds to prevent future disasters of the type that recently occurred. For example, it plans to use essentially all of the 2018 funding on wildfire mitigation projects. However, this is not a FEMA-imposed requirement. While FEMA does have some requirements around how disaster mitigation funds must be used—including that funded projects meet its cost-benefit analysis parameters—it allows these funds to be used to help lessen the potential impacts of many types of disasters, not just those that a state recently experienced. As such, the state could use FEMA pre-disaster funds for coastal adaptation projects to mitigate future SLR-related flooding—even if FEMA provides the funds after the state experiences wildfire-related disasters. CalOES indicates it plans to use about $50 million from the 2017 allocation of federal disaster mitigation funds for coastal projects. In general, however, this has not been a primary area of focus for such funds thus far.

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USGS undertakes scientific research, which those agencies can then utilize. The largest SLR-related activity in which USGS is engaged in California is development of the Coastal Storm Modeling System (CoSMoS). This is a dynamic modeling approach that integrates predictions for (1) future SLR, (2) future coastal storms, and (3) long-term evolving coastal trends such as erosion to beaches and bluffs. Because it forecasts the potential interactions of these multiple events and impacts, this tool—which USGS has already completed for most of the state—allows for more detailed local predictions of future coastal flooding than models which only predict SLR. (The state has also contributed some funding to help develop CoSMoS.) In addition to developing CoSMoS, USGS is engaged in various other scientific research endeavors that relate to SLR, including monitoring coastal erosion and groundwater hazards, sea-floor mapping, and the Hazard Exposure Reporting and Analytics project that assesses the potential socioeconomic impacts of SLR within California's coastal communities.

Local-Level Efforts

Local Governments Can Undertake Multiple Steps to Prepare for SLR. While the magnitude and timing of SLR still are unknown, many of California's coastal communities have begun preparing for what level of risk they face and how they might respond over the coming decades. Figure 6 highlights the key steps in this process. As shown, the first step for local governments typically is to conduct an assessment to ascertain how their residents, infrastructure, and services might be affected under different SLR scenarios. Next, they develop a high-level adaptation plan for how they might address those identified vulnerabilities. Subsequently, they begin to undertake the three stages of actually applying adaptation strategies to mitigate those risks—developing detailed plans, constructing projects, and undertaking ongoing monitoring and modifications to ensure effectiveness. While in many cases communities may undertake adaptation *projects*—such as building up sand dunes or restoring wetlands to serve as a wave buffer, or relocating infrastructure out of flood zones—they also may implement new *policies* as part of their adaptation strategies. These could include imposing limits on (1) where and when hard armoring may be used (in order to prevent the erosion of beaches), (2) new development, or (3) rebuilding in certain coastal areas.

The process described in Figure 6 represents a deliberate, strategic approach to undertaking coastal adaptation. However, state law does not require that local governments progress sequentially through the steps described in the figure—nor, indeed, that they undertake each step at all. (As noted earlier, Coastal Commission staff does encourage local governments that are updating their Local Coastal Programs [LCPs] to undertake SLR vulnerability assessments.) Local governments could opt to skip the first several proactive planning steps of this process and instead implement response activities on a reactive basis once they begin to experience SLR impacts. As we discuss later, however, to the degree local communities avoid undertaking proactive risk assessment and planning activities in the near term, they may lose some opportunities for minimizing damage and disruptive SLR impacts in future years.

Many Coastal Communities Have Begun Preparing for SLR, but Only in Early Stages. Data suggest that many communities around the state have begun to prepare for the effects of climate change. For example, OPR's statewide *Annual Planning Survey* found in 2018 that 60 percent of responding cities and counties have plans or strategies to adapt to the impacts of climate change. (This survey did not ask about SLR specifically.) However, a closer look at the status of adaptation planning around the state suggests that even for those jurisdictions that are beginning to address the impacts of climate change, the majority of coastal jurisdictions still are only in the initial stages of the SLR preparation process displayed in Figure 6. Specifically, a recent statewide survey called the *2016 California Coastal Adaptation Needs Assessment Survey*—conducted as part of *California's Fourth Climate Change Assessment*—asked coastal professionals about the current status of their adaptation work. Respondents included representatives from the local, state, and federal levels of government, as well as private

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consultants and nongovernmental organizations. About one-third of respondents indicated they were primarily engaged in detecting and gathering information—such as by conducting vulnerability assessments. About half of respondents said they were developing adaptation and project plans—the second and third steps of the adaptation process shown in Figure 6. Only 16 percent indicated that they had transitioned to implementing and monitoring projects and policies. While these responses show slight progress compared to a similar survey conducted in 2011—in which a larger share reported they were still assessing their climate risks—the results show that few communities are yet ready to begin *implementing* SLR adaptation projects.

Moreover, the fact that most of the survey respondents indicated that they are engaged in *some* phase of adaptation work is not representative of the whole state, as highlighted by the OPR survey data. That is, this survey's responses seemingly over-represented coastal professionals who are engaging in adaptation work and under-represented those communities that have not yet begun this type of work. That even within this skewed sample group so few respondents indicated they are implementing projects underlines how much preparation work remains to be undertaken statewide.

Several Types of SLR Planning Efforts Underway at Local Level. While some local governments are undertaking SLR vulnerability assessments and adaptation plans on their own initiative, such efforts are also prompted by three key statutory requirements. First, as described in the box on the next page, the 1976 California Coastal Act encouraged coastal communities to develop LCPs, which include policies to govern new and existing development along the coast and protect coastal resources in accordance with state law. Since most LCPs were developed around 30 years ago—before the need to account for the potential effects of climate change—some coastal communities are beginning to work on updates to address SLR. The Coastal Commission reports that 39 jurisdictions are in the process of updating their LCPs for SLR, including 30 that have completed vulnerability assessments. (Coastal Commission staff encourages using SLR vulnerability assessments to inform LCP updates.) Thus far, only three local governments have completed all stages of updating their LCPs for SLR and had them certified by the Coastal Commission. As shown earlier in Figure 5, state funding grants have partially supported these efforts. Specifically, the Coastal Commission reports that between 2013 and September 2019, it provided 50 grants totaling nearly $7 million to 37 local jurisdictions for SLR-related LCP updates.

Second, Chapter 608 of 2015 (SB 379, Jackson) requires communities to update the safety element of their General Plans to address the risks posed by climate change no later than 2022. Data suggest that local jurisdictions still are in the process of working to meet this requirement. Specifically, about 30 percent of the cities and counties that responded to OPR's 2018 survey reported that they have addressed climate adaptation in their adopted General Plan policies.

Figure 6

Key Steps for Local Governments to Prepare for Sea-Level Rise (SLR)

Conduct Vulnerability Assessment
Develop understanding of how SLR might affect the local jurisdiction. Model various SLR inundation scenarios and assess the potential exposure and impacts to key assets (such as infrastructure, property, and natural resources) and local services (such as drinking water and emergency response).

Develop Adaptation Plan
Based on assessed vulnerabilities, determine specific strategies that can be undertaken to reduce the amount of risk and damage the community will experience from SLR. Identify overall approach and priorities, policies, potential projects, and time lines.

Develop Detailed Project Plans and Policies
Develop specific implementation plans for adaptation projects including engineering design, environmental permitting, costs, funding sources, deadlines, and anticipated performance measures. Research and draft new policies and solicit public feedback.

Implement Adaptation Projects and Policies
Construct projects. Adopt and enforce policies.

Monitor and Evaluate Effectiveness of Projects and Policies
Conduct multiyear monitoring to assess how well projects and policies are meeting anticipated objectives as conditions change and whether modifications may be necessary to maintain or improve outcomes.

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State Has Special Jurisdiction Over Land Use Decisions in the Coastal Zone

Enacted in 1976, the California Coastal Act gives the state a unique role in planning and regulating the use of land and water along the coast. Specifically, within the coastal zone—unlike other areas of California—the state possesses the authority to regulate the construction of buildings, divisions of land, and activities that change the intensity of use of land or public access to coastal waters. (The land covered by the coastal zone is specifically delineated in statute and varies in width from several hundred feet in highly urbanized areas up to five miles in certain rural areas, and excludes the San Francisco Bay Area.) The basic goals of the Coastal Act are to balance development along the coast with protecting the environment and public access. The Act includes specific policies that address issues such as shoreline public access and recreation, habitat protection, landform alteration, industrial uses, water quality, transportation, development design, ports, and public works. The Coastal Act tasks the California Coastal Commission with implementing these laws and protecting coastal resources. As such, entities seeking to undertake development activities within the coastal zone must first attain a coastal development permit from the Coastal Commission. (In general, local governments make decisions about land use outside the coastal zone.)

The Coastal Commission may delegate some permitting authority to the 76 cities and counties along the coast if they develop plans—known as Local Coastal Programs (LCPs)—to guide development in the coastal zone. The LCPs specify the appropriate location, type, and scale of new or changed uses of land and water, as well as measures to implement land use policies (such as zoning ordinances). The Coastal Commission reviews and approves ("certifies") these plans to ensure they protect coastal resources in ways that are consistent with the goals and policies of the Coastal Act. Local governments have incentives to complete certified LCPs, as they can then handle development decisions themselves (although stakeholders can appeal such decisions to the Coastal Commission). In contrast, any project undertaken in the coastal zone in communities without certified LCPs must attain a permit from the Coastal Commission. To date, nearly 90 percent of the applicable geographic area is covered by a certified LCP.

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Third, Chapter 592 of 2013 (AB 691, Muratsuchi) required certain coastal cities and special districts to conduct an assessment of how they propose to address SLR on the granted public trust coastal lands for which they are responsible. (These are sovereign state lands for which the Legislature has delegated management to local municipalities for specified uses, such as piers, ports, harbors, airports, and recreation.) For each applicable jurisdiction, these assessments must include: (1) an inventory of public trust assets that are vulnerable to SLR; (2) how SLR may impact those assets in the short, medium, and long term; (3) an evaluation of the financial costs associated with those SLR impacts—including for nonmarket asset values such as recreation and ecosystem services; and (4) a description of how potential SLR adaptation strategies could address the identified vulnerabilities and a proposed time frame for implementing such measures. The State Lands Commission is in the process of reviewing these reports, which had to be submitted by July 2019.

Some Examples of Regional Collaboration on SLR Planning Exist, but Efforts Are Limited. Because the effects of SLR do not stop at the city border or county line, local jurisdictions would benefit from working together with their neighbors on a regional basis to collaborate on plans for addressing the interrelated impacts. While some regional collaborative efforts have been initiated across the state, these initiatives still are emerging and uneven. Perhaps the largest effort consists of seven regional groups that have formed in various areas of the state to work on climate change adaptation issues—including but not limited to SLR—as highlighted in Figure 7. The Local Government Commission and OPR help facilitate a network for these groups to communicate, known as the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). However, these regional groups have experienced varying levels of participation and activity. Most of the groups meet only intermittently to informally share information, none has worked on developing a regional SLR or climate adaptation plan, and typically, they do not have permanent dedicated funding or staff. In some cases, local jurisdictions are only eligible to participate in their region's collaborative if they are willing and able to pay an annual administrative fee. As such, not all cities and counties located within the regions encompassed by these ARCCA groups are active participants that benefit from the potential collaboration. (Orange County is the only coastal county not encompassed by any of the ARRCA regional collaboratives.)

The SF Bay Area has made the most progress on multicounty regional SLR collaborative efforts. In a survey of SF Bay Area stakeholders conducted by University of California (UC), Davis, researchers in the fall of 2018, close to 60 percent of respondents reported that they had shared information about SLR with other organizations in the last year, and about 45 percent said that they had engaged in some joint SLR planning with other organizations. Moreover, in 2016, voters in the nine-county region passed Measure AA, establishing the SF Bay Restoration Authority and imposing a parcel tax that is projected to raise about $25 million annually for 20 years to fund projects to protect and restore the bay. To support this effort, the Authority has established—and funded—the "SF Bay Restoration Regulatory Integration Team," which is intended to expedite and simplify the permitting process

Figure 7

Groups Participating in the Alliance of Regional Collaboratives for Climate Adaptation

- ✓ Bay Area Climate Adaptation Network
- ✓ Capital Region Climate Readiness Collaborative
- ✓ Central Coast Climate Collaborative
- ✓ Los Angeles Regional Collaborative for Climate Action and Sustainability
- ✓ North Coast Resource Partnership
- ✓ San Diego Regional Climate Collaborative
- ✓ Sierra Climate Adaptation and Mitigation Partnership

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for wetland restoration and flood management projects. Additionally, BCDC is initiating efforts to coordinate the development of a "Regional Adaptation Plan" for the SF Bay Area.

Other limited examples of regional collaboration related to SLR exist around the state at the county level. For example, some counties have conducted vulnerability assessments and adaptation planning specifically to address the threat of SLR across the jurisdictions within their counties. These include Marin and San Mateo. San Mateo County also just received statutory approval to reconstitute an existing special flood district to specifically address the anticipated impacts of SLR across the county. Additionally, San Diego County undertook a three-year initiative (funded by grants from NOAA and SCC) called the "Resilient Coastlines Project of Greater San Diego" to coordinate several local SLR initiatives, gather scientific information on a regional basis, develop tools and resources, and connect community members and scientific experts to work together.

In an effort to help encourage regional climate adaptation efforts, the Legislature recently passed Chapter 377 of 2018 (SB 1072, Leyva). This legislation creates a program to assist under-resourced communities in developing the capacity to access grant funding for climate change mitigation and adaptation projects. SGC will administer the program, and still is in the process of determining its structure, selection criteria, and funding sources.

STRONG CASE EXISTS FOR LOCAL GOVERNMENTS TO ACCELERATE ADAPTATION ACTIVITIES

The relatively limited progress that local governments have made in preparing for SLR may not seem overly concerning, given that most of the intense impacts of SLR still are decades in the future. However, waiting too long to initiate adaptation efforts likely will make executing an effective response more difficult and costly. Taking action ahead of when sea levels are projected to significantly encroach on the coast would enable local governments to benefit in several important ways, as summarized in Figure 8 and discussed below.

Planning Ahead Means Adaptation Actions Can Be Strategic and Phased. Time allows cities and counties to (1) be strategic, phased, and

Figure 8

Benefits of Taking Action Early to Prepare for Sea-Level Rise (SLR)

- ✓ ***Planning Ahead Means Adaptation Actions Can Be Strategic and Phased.*** Early planning can allow coastal communities to adopt a phased approach that undertakes escalating actions when certain predetermined conditions or "triggers" are reached.
- ✓ ***Undertaking Near-Term Actions Can "Buy Time" Before More Intensive Responses Are Needed.*** Putting certain adaptation projects and strategies in place now can help postpone and extend the period before which subsequent, more difficult-to-implement actions are needed.
- ✓ ***Early Implementation Provides the Opportunity to Test Approaches and Learn What Works Best.*** Acting to implement adaptation strategies in the near term will provide the opportunity to monitor, evaluate, and revise them in the coming years before SLR threats become more pressing.
- ✓ ***Taking Action Earlier May Make Overall Adaptation Efforts More Affordable.*** Undertaking a multiyear, multistep strategic plan for coastal adaptation can allow local governments to spread costs over a longer period of time.
- ✓ ***Coming Decade Represents a Key Window for SLR Preparation.*** Some adaptation strategies—such as fortifying certain tidal marshes—may not be effective against SLR unless they are implemented before sea levels rise to higher levels.

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thoughtful about which approaches will work best for their communities; (2) gather community input; and (3) implement projects and policies that may take many years to put into effect. Planning ahead can allow coastal communities to adopt a phased approach for when it will undertake escalating actions that is dependent upon when certain predetermined conditions or "triggers" are reached. For example, such a strategy might state that the community will relocate its wastewater treatment plant once sea levels are observed to have risen by 1 foot locally, and that in the meantime, stakeholders will identify a new location for the plant, develop detailed project plans, and acquire funding so they are ready to implement the project once the identified threshold has been reached. A phased approach based on defined triggers can also help address community concerns that a local government might be acting "prematurely" to address SLR and thereby affecting their property values unnecessarily. The *State of California Sea-Level Rise Guidance Document* encourages coastal communities to utilize "adaptation pathways" with multiyear, progressive steps—but such an approach requires time to develop and implement.

Undertaking Certain Near-Term Actions Can "Buy Time" Before More Intensive Responses Are Needed. Putting certain adaptation projects and strategies in place now can help postpone and extend the period before which subsequent, more difficult-to-implement actions are needed. For example, building up wetlands or sand dunes in certain areas could help buffer the effects of SLR and coastal storms and protect the development behind them for the coming few decades. Even if such a strategy would have decreasing effectiveness once sea levels rise to higher levels, implementing such a project in the near term could delay the date at which the buildings begin to regularly flood and need to be relocated or elevated.

Early Implementation Provides Opportunity to Test Approaches and Learn What Works Best. Near-term action allows for time to test theories and determine the most effective approaches. Because SLR poses a unique set of challenges, many uncertainties exist around which potential adaptation strategies might be most effective. For example, scientists are unsure of how successful wetland restoration projects will be at buffering the force of waves during more severe coastal storms. Acting to implement adaptation strategies in the near term will provide the opportunity to monitor, evaluate, and revise them in the coming years. This can help the state and local governments ascertain which types of approaches will be best for particular locations and/or for widespread application as SLR threats become more pressing.

Taking Action Earlier May Make Overall Adaptation Efforts More Affordable. Undertaking a multiyear, multistep strategic plan for coastal adaptation can allow local governments to spread costs over a longer period of time and thereby make them more affordable. A multiyear financing approach—such as utilizing bonds—for large projects also provides the opportunity for costs to be borne by both current and future taxpayers, which is reasonable since such projects are intended to provide benefits over many years. Moreover, if local governments take the opportunity to test out SLR response approaches, they and other coastal communities can learn "best practices" from those pilot projects and likely will be able to replicate similar approaches in more efficient, cost-effective ways in the future.

Coming Decade Represents Key Window for SLR Preparation. Experts suggest the next ten or so years represent a crucial time period for taking action to prepare for SLR. After that point, sea levels may already have risen by around 1 foot in many locations, as shown earlier in Figure 1. Once sea levels have risen to higher levels, the planning window narrows and options for how local governments can respond become more limited. For example, a comprehensive scientific study of the SF Bay, *The Baylands and Climate Change*, suggests tidal marshes that are established by 2030 are more likely to flourish and provide wave-buffering benefits. After that point, marshes may not have sufficient time to develop and fortify—by building up sediment and growing plants—and will instead become submerged. Coastal communities that delay SLR response activities until coastal flooding is more imminent lose opportunities to implement proactive, incremental, and ground-tested adaptation responses. Instead, they will be forced into a more reactive mode with the need to address the threat immediately.

LOCAL ADAPTATION EFFORTS FACE KEY CHALLENGES

Despite the significant threats posed by the projected changes in the coming years and the compelling reasons to take action soon, most local governments still are only in the early stages of preparing for SLR, as discussed earlier. Data suggest that local governments' progress in adapting to the impacts of SLR is constrained by a number of key challenges. For example, Figure 9 displays the top eight barriers that coastal professionals identified in the *2016 California Coastal Adaptation Needs Assessment Survey* as being "big hurdles" in their adaptation efforts. The academic literature on coastal adaptation and the many interviews we conducted in researching this report identified some additional common obstacles. Figure 10 summarizes our compilation of key challenges, which we describe in more detail in this section.

Funding Constraints Hinder Both Planning and Projects

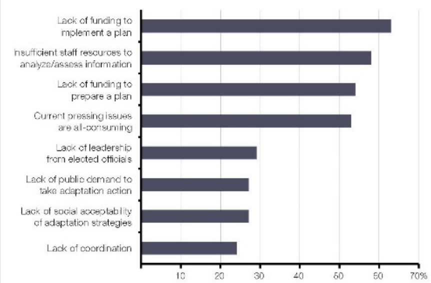
Local Governments Cite Funding Limitations as Primary Barrier to Making Progress on Coastal Adaptation Efforts. Funding for both coastal adaptation project implementation and planning are paramount concerns for local governments seeking to prepare for SLR. These funding challenges were identified in nearly all of the interviews we conducted in researching this report, and also are reflected as the first and third most cited hurdles, respectively, in the survey data displayed in Figure 9. A different statewide survey conducted in 2017 asked local government representatives specifically which adaptation-related activities they needed funding to conduct over the coming five years. (This survey did not ask about SLR or coastal adaptation specifically.) The responses are displayed in Figure 11 on page 22. As shown, comparatively lower—but still significant—proportions of respondents indicate the need for funding to conduct initial assessment and planning activities, with a much higher share needing funding to implement and evaluate projects. That survey also asked local governments whether they had yet acquired the necessary funds to undertake the identified adaptation activities—fewer than 2 percent responded affirmatively. About 32 percent of respondents indicated they had secured *some* funding, whereas about two-thirds responded they had secured *none* of the needed funding.

Responses from our interviewees and both of the above surveys appear to align with the trends cited earlier—that

Figure 9

Survey Results Highlight Significant Barriers to Coastal Adaptation

Percent of Coastal Professionals Indicating Barrier Is a Big Hurdle



From: S. Moser, J. Finzi Hart, A. Newton Mann, N. Sadrpour, P. Grifman (Susanne Moser Research & Consulting and U.S. Geological Survey), 2018. "Growing Effort, Growing Challenge: Findings From the 2016 California Coastal Adaptation Needs Assessment Survey." *California's Fourth Climate Change Assessment.*

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many but not all communities have made headway in beginning to plan for climate change impacts (which is why comparatively fewer cite the need for planning funds), but few have moved into enacting those plans. Moreover, these data suggest that funding is a primary contributor to that lack of progress. The expressed need for funding likely is a result of constraints on available local funding as well as on funding from state, private, or federal sources.

Limited Local Funding Faces Many Competing Priorities. Even though responsibility for addressing SLR lies primarily with local governments, our interviews indicated that they struggle to identify local funding sources they can dedicate to preparation activities. This is echoed by the *2016 California Coastal Adaptation Needs Assessment Survey*, with respondents indicating that only about one-third of the funding currently supporting their adaptation activities comes from local sources. One chief explanation for these responses is that allocating funding from existing sources to respond to a large, long-term, uncertain threat such as SLR is difficult when local governments have to balance such expenditures against many other immediate short-term priorities. Such priorities might include housing shortages, homelessness, schools, aging infrastructure, and other climate-related impacts such as increased wildfires. (Competing funding commitments likely also are factors for the 53 percent of survey respondents shown in Figure 9 who cite the challenge of facing many other pressing, all-consuming issues as a big hurdle in addressing SLR.) Additionally, California local governments' ability to generate new revenues for activities is constrained by certain constitutional limitations, including Proposition 13 (1978, which limits increases in local property taxes) and Proposition 218 (1996, which requires meeting a two-thirds local voter threshold in order to raise certain local taxes and fees). Moreover, local revenues available for adaptation activities may be further constrained in the future *by* SLR. This

Figure 10

Local Adaptation Efforts Face Key Challenges

- ✓ ***Funding Constraints Hinder Both Planning and Projects.*** Local governments cite funding limitations as their primary barrier to making progress on coastal adaptation efforts. This is largely because local funding faces many competing priorities and constraints, and only limited amounts of adaptation funding have been available from other sources.
- ✓ ***Limited Local Government Capacity Restricts Their Ability to Take Action.*** The novelty of the climate adaptation field makes it hard for local governments to locate and hire individuals with appropriate experience and expertise to plan for the impacts of sea-level rise (SLR). These capacity limitations are particularly challenging for small and disadvantaged communities.
- ✓ ***Adaptation Activities Are Constrained by a Lack of Key Information.*** Local governments cite a need for additional data and technical assistance to help inform their adaptation decisions, especially around the costs, trade-offs, and potential economic implications of SLR impacts. The novelty of coastal adaptation efforts means that this type of information is even more in demand—and limited.
- ✓ ***Few Forums for Shared Planning and Decision-Making Impede Cross-Jurisdictional Collaboration.*** Even though the interrelated effects of SLR make cross-jurisdictional planning essential, local governments lack forums and resources for discussing and planning for SLR on a regional basis.
- ✓ ***Responding to SLR Is Not Yet a Priority for Many Local Residents or Elected Officials.*** Because many California residents are not yet aware of how SLR might affect their communities or consider the threat as being far off in the future, coastal adaption actions are not a high priority for them. This makes it difficult for local elected officials or government staff to champion unpopular SLR response actions.
- ✓ ***Protracted Process for Attaining Project Permits Delays Adaptation Progress.*** Achieving approval for coastal adaptation projects is complicated and takes a long time, in part because they represent a new challenge for the existing environmental regulatory system. This is particularly problematic because coastal communities face a pressing need to make progress on preparing for SLR before its impacts become more widespread.

is because existing property values in some areas of the coast likely will decrease if those buildings become or are at risk of becoming flooded, thereby over time affecting the property tax revenues generated for the local jurisdiction.

Only Limited Amounts of Adaptation Funding Have Been Available From Other Sources. Local government respondents to the *2016 California Coastal Adaptation Needs Assessment Survey* indicated that while local sources have provided one-third of their coastal adaptation funding thus far, state funds provided the largest share—45 percent. As shown earlier in Figure 5, however, these funds have been relatively modest. Nevertheless, these findings highlight the important role that state resources have played in encouraging the coastal adaptation activities that have occurred to date. Responses to the aforementioned survey indicate that funding they have received for their adaptation activities from other sources are even more limited—10 percent from foundations or other private sources and 9 percent from the federal government.

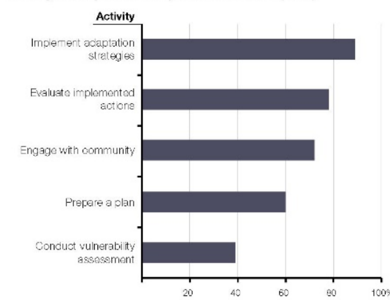
Limited Local Government Capacity Restricts Ability to Take Action

Local Governments Lack Sufficient Staff and Technical Expertise to Address SLR. Inadequate internal capacity to undertake adaptation planning and projects is also a significant barrier to local governments' SLR preparation efforts. We heard this frustration expressed repeatedly in our interviews, with local government staff indicating they need to address adaptation planning activities in addition to their primary job responsibilities. Additionally, local government interviewees indicated that staffing constraints often mean that they do not have the capacity to complete the work necessary to compile successful grant applications for the funding that the state offers for adaptation planning and projects—thereby compounding their challenges in making progress on coastal adaptation efforts. In OPR's *2018 Annual Planning Survey*, 60 percent of responding cities and counties indicated they had very little or no staffing and technical capacity to address climate change or adaptation. These findings are mirrored in the survey responses highlighted in Figure 9. Specifically, insufficient staff resources to analyze and assess information was the second most commonly cited hurdle to coastal adaptation efforts, cited by 58 percent of respondents. Interestingly, some progress to address these capacity issues appears to have been made in recent years, as a comparatively higher percentage of coastal professionals responding to the 2011 version of the same coastal needs assessment survey indicated insufficient staff resources as

Figure 11

Local Governments Express Need for Funding to Advance Adaptation Activities

Survey Respondents Indicating Need For Funding for Adaptation Activity in Next Five Years (2017)



From: S. Moser, J.A. Ekstrom, J. Kim, S. Heitsch (Susanne Moser Research & Consulting, Department of Water Resources, Local Government Commission and ICF), 2018. "Adaptation Finance Challenges: Characteristic Patterns Facing California Local Governments and Ways to Overcome Them." *California's Fourth Climate Change Assessment.* California Natural Resources Agency.

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being a big hurdle—67 percent compared to 58 percent in the 2016 survey.

Adaptation Expertise Is Not Widespread. A couple of key factors may explain these capacity challenges. The first is a direct result of the funding constraints noted earlier—limited funds often translate to a limited ability to hire a sufficient cadre of qualified staff. Additionally, because climate adaptation is a new field, local governments find it hard to locate individuals with appropriate scientific, engineering, and legal experience and expertise to know how to plan for the impacts of SLR, even if they could manage to secure the funds to hire more staff. The *2016 California Coastal Adaptation Needs Assessment Survey* report states that "most coastal practitioners are still essentially learning about adaptation 'on the job' rather than through formal training opportunities." Specifically, the survey found that only about 40 percent of local government respondents indicated that they had received *any* formal training in adaptation.

Small and Disadvantaged Communities Particularly Challenged by Capacity Limitations. Our research indicates the challenges associated with limited government capacity to address climate adaptation needs are especially pronounced for smaller communities and those whose residents have a lower average income and/or lower property values. These communities often have smaller government administrations and fewer financial, business, philanthropic, and community resources upon which to draw. As such, these communities likely find it even harder than their larger and better-resourced neighbors to hire and maintain experienced staff dedicated to adaptation work—which in turn also makes it even more challenging to compete for limited grant funding. This raises an important social equity concern about how adequate preparation for SLR may be influenced by the relative size and wealth of a particular community.

Adaptation Activities Constrained by Lack of Key Information

Local Governments Cite a Need for Additional Data to Help Inform Adaptation Decisions. In the interviews we conducted in preparing this report, one of the most frequently cited obstacles to coastal adaptation was a lack of information to help guide decision-making. Specifically, local entities expressed uncertainty about how to proceed with SLR preparation because they are unsure about details such as:

- ***Trade-Offs of Adaptation Options.*** Data and examples that might help inform which adaptation options might be most appropriate for their community and what factors to consider when making those decisions.
- ***Cost of Adaptation Options.*** Rough estimates for how much different options might cost to implement and what factors influence those costs.
- ***Economic Implications of Adaptation Options and SLR Impacts.*** The potential economic impacts of implementing various adaptation options, including the "no action" alternative.
- ***Locally Specific SLR Projections.*** Specialized estimates and maps for how exactly SLR and coastal storms might affect specific locations, neighborhoods, infrastructure, and resources in their communities.
- ***Legal Clarifications.*** A legal analysis clarifying the responsibilities—and liabilities—local governments face with regard to SLR, particularly related to how potential changes in the mean high-tide line, land use policies, and city services might affect private properties.

The first four information priorities were also cited by city and county respondents to the *2016 California Coastal Adaptation Needs Assessment Survey* when asked which types of information they perceive as most useful for assessing the risks from climate change to local coastal resources. Specifically, about 75 percent rated information on the trade-offs of adaptation as very useful, and a similar percentage said the same about information on the costs of adaptation (representing the top two responses to the question). The usefulness of economic and community vulnerability assessments each were rated as very useful by about 60 percent of respondents. (The survey did not ask about legal information.)

The lack of information on the potential economic impacts that SLR might have on the community was raised repeatedly throughout the interviews we conducted for this report. Even for the local governments that have conducted initial SLR planning activities, few vulnerability assessments include these types of considerations. Similarly, only a handful of completed adaptation plans across the state include an analysis of the economic trade-offs of employing potential adaptation strategies. For example, this could include evaluating and comparing the short- and long-term costs and benefits of approaches like building seawalls, adding sand to beaches, restoring wetlands, and relocating infrastructure. Feedback from our interviewees suggests they have not undertaken these types of analyses because they are complicated and expensive to conduct, with few examples available to serve as models. Yet without an understanding of the economic implications associated with SLR or the costs and benefits of the steps they could take to address those impacts, local governments are constrained in determining the best path forward.

Novelty of Coastal Adaptation Efforts Means Information Is Even More in Demand—and Limited. Interviewees who were able to gather the necessary information to complete vulnerability assessments and high-level adaptation plans indicated that they were unclear how to determine what specifically they should do next. That the coastal adaptation field is so new is a large contributor to this information gap. These uncharted waters present a double challenge—local governments have never undertaken such work before and therefore are urgently in need of guidance, examples, and data to help them make these novel decisions. However, such information is not widely available because few others have undertaken such work either.

Technical Assistance Not Widely Available. Interviewees cited a lack of—and desire for—entities to which they might be able to turn for advice, technical assistance, comparison data, and real-world examples to help inform their adaptation decisions. As noted earlier, OPR created the Adaptation Clearinghouse, which provides an online database of resources for adaptation planning and projects. Our interviews and available research, however, suggest use of this website is not yet widespread. This is due both to a lack of awareness about the resource, and also because users find it overwhelming and difficult to navigate. Rather, local entities express a desire for (1) models and planning templates they can recreate or modify to meet their local circumstances, and (2) experts they can call upon to discuss and help address their specific needs. The Clearinghouse has only limited examples that meet the first need and does not have staff available to address the second. Some entities have provided technical assistance for coastal adaptation efforts within their regions—such as the Adapting to Rising Tides Program administered by BCDC in the SF Bay Area and the University of Southern California Sea Grant program in Los Angeles—but these resources are not available statewide.

Few Forums for Shared Planning and Decision-Making Impede Cross-Jurisdictional Collaboration

Local Governments Lack Robust Forums for Discussing and Planning for SLR on a Regional Basis. Local governments across California lack formal and strategic ways to learn from each other, share information, or make decisions together about coastal adaptation issues. As noted earlier, while some regional collaborative efforts are underway across the state, such initiatives are largely informal, they lack funding and staff, and their level of activity and participation vary by region. Moreover, with the exception of a couple of countywide plans, no region has yet developed a coordinated plan for how it will address SLR impacts on a regional basis. This lack of coordination was frequently mentioned as a significant concern by the individuals we interviewed, and was highlighted as a big hurdle by about one-quarter of survey respondents in Figure 9. When UC Davis researchers surveyed stakeholders in the SF Bay Area about the largest barriers they face in working collaboratively with other stakeholders on SLR issues, the most common response was the lack of an overarching regional plan to address SLR.

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Cross-Jurisdictional Planning Is Challenging. Distinctions across local governments—including bureaucratic and administrative differences, as well as varying interests and priorities—always make cross-jurisdictional planning and coordination difficult. Interviewees indicated that addressing the needs of their own jurisdictions already presents a challenge, and the prospect of incorporating those of their neighbors into their planning efforts feels like an overwhelming task. Moreover, they expressed concerns that regional planning efforts might prioritize the requests of other jurisdictions over their own—especially if their city is small or wields comparatively less political influence—and also that finding common ground around adaptation actions could be difficult. Finally, interviewees stated that regional collaboration would require additional staff time—particularly to organize and attend forums for such discussions to take place—and their resources already face constraints.

Interrelated Effects of SLR Make Cross-Jurisdictional Planning Essential. Given these complications, the lack of collaborative efforts around SLR is not surprising. However, the widespread impacts of SLR make coordinated regional planning fundamental to effective preparation—and the lack of such efforts is therefore particularly concerning. Local jurisdictions planning on their own will not be able to address the SLR impacts that might have substantial impacts on their own community but are dependent upon their neighbors taking action. For example, residents of one city may be precluded from getting to and from their homes or work or from accessing emergency services if a key transportation thoroughfare floods in a neighboring city. Moreover, SLR response actions taken by one jurisdiction could have significant effects on their neighboring cities. For example, if one city decides to construct hard armoring structures—such as seawalls—to protect structures along much of its coastline, the ensuing erosion processes could remove most of the sand from the beaches in a neighboring city. These interconnected SLR impacts increase the importance of coordination, shared input, and joint planning. Even multi-jurisdictional planning efforts might be insufficient to adequately address future SLR impacts if they fail to include key landowners and stakeholders—such as utilities, railroads, Caltrans, State Parks, refineries, and ports—who will be necessary participants in making future land use decisions for the region.

Responding to SLR Is Not Yet a Priority for Many Local Residents or Elected Officials

Many California Residents Do Not See Need for Immediate Action to Address SLR. Two of the barriers cited in the survey data shown in Figure 9 relate to public perceptions about the risk of SLR—the lack of public demand to take adaptation action and the lack of social acceptability of adaptation strategies. These dynamics were echoed in many of the interviews we conducted in preparing this report, and have been on display in some high-profile community mobilization efforts against proposed SLR adaptation actions in certain coastal communities in recent months.

Much of the public lack of engagement about or resistance to coastal adaptation efforts seems to stem from two key factors. First, many California residents are generally unaware of projections about how SLR might impact them. Few communities have undertaken public awareness campaigns about SLR or broadly disseminated maps of areas that are projected to flood in the coming years. Moreover, potential SLR coastal flooding is not currently required to be disclosed during real estate transactions—in contrast with the risks associated with forest fires, earthquakes, or floods. (Existing flood risk notifications are based on historical flood events and therefore do not take potential SLR impacts into account.) California law requires that these potential hazards be disclosed to prospective property buyers. Because residents may not know about SLR predictions or see many obvious SLR-related impacts happening now, coastal adaptation actions likely are not a high priority for them to request from their local governments—especially compared to more current pressing concerns. Second, even many coastal residents who have some awareness that sea levels are projected to rise likely view the threat of SLR as being far off in the future. They therefore feel that for their local governments to take SLR

response actions that might affect their property values or lifestyle in the near future is premature and inappropriate—even if those actions are only planning for what future adaptation responses *might* be. For example, several coastal communities that drafted adaptation plans mentioning the possibility of relocating infrastructure in the future before it becomes flooded (sometimes referred to as "managed retreat") have faced vociferous public backlash—largely because of residents' concerns that such changes might impact their own properties now or in the future.

Local Elected Officials Currently Face Disincentives to Champion Unpopular SLR Response Actions. Resistance against taking aggressive action on SLR now is also demonstrated in the attitudes and actions of many local government leaders. As shown in Figure 9, 29 percent of the survey respondents identify the lack of leadership from elected officials as a big hurdle to making progress on coastal adaptation activities. This dearth of enthusiasm about adaptation may be somewhat predictable, as local officials typically try to reflect the priorities of their constituents. Additionally, the most intense impacts of SLR likely will not manifest for at least a decade—and perhaps multiple decades—into the future. Many current public officials may be disinclined to face the backlash and potential political consequences from enacting unpopular policies now when the evidence for and benefits of taking those actions may not be experienced until long after they are out of office. A lack of public support also makes it difficult for local governing entities to advance proposals for raising additional revenues—such as through new fees or taxes—to undertake adaptation projects now. Moreover, local officials may be reluctant to undertake any adaptation actions or policies that would limit future development or reduce existing property values in fear of restricting or reducing the local revenues on which they currently rely to provide government services.

Despite these disincentives, reluctance to champion coastal adaptation efforts is not a universal position across California's cities and counties. Rather, as noted earlier, many California cities and counties are making some progress on SLR preparation activities, and examples exist of local elected officials around the state taking a leadership role in such efforts.

Protracted Process for Attaining Project Permits Delays Adaptation Progress

Several coastal professionals with whom we spoke in preparing this report reported that the lengthy process for attaining approvals from state and federal agencies to implement adaptation projects is a significant barrier to getting more projects underway.

Achieving Approval for Coastal Adaptation Projects Is Complicated and Takes a Long Time. As with any development project along the coast or SF Bay, adaptation projects must go through a review and approval process and attain permits from numerous state and federal agencies to ensure they are not causing undue harm to the environment. Although such projects often differ from traditional construction and infrastructure projects in that they may be nature-based (such as sand dune or wetland restoration projects), they are not exempt from the standard environmental review process. Agencies that typically must grant regulatory approvals for coastal adaptation projects include the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, NOAA National Marine Fisheries Service, the Regional Water Quality Control Board, the California Department of Fish and Wildlife, the Coastal Commission (for projects in the coastal zone), and BCDC (for projects along the SF Bay). These agencies review potential projects to ascertain how they might affect fish and wildlife and their habitats, water quality, and public access to the shoreline.

In general, project proponents must submit separate permit applications (and associated fees) to each of the applicable agencies, each of which then undertakes its own independent review on its own time line. In addition, each regulatory reviewer typically imposes its own permit requirements, such as requiring activities to help mitigate any anticipated environmental impacts. Because these reviews are conducted independently from each other, in some cases one agency may impose

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permit conditions that can duplicate or even contradict those required by a different agency. For example, while federal and state fish and wildlife agencies work to minimize project impacts on at-risk species, BCDC seeks to maximize public access to the bay shore. These goals can be in direct conflict, as imposing permit requirements to add public access infrastructure and increase human visitors can negatively impact wildlife. In such cases, the project proponents must negotiate between the agencies to develop a set of project requirements that they are capable of implementing. Due to the delays associated with these myriad reviews and ensuing requirements, SCC estimates that attaining permits for a typical adaptation project can take at least one year from when such applications are submitted. As discussed below, this protracted time line is particularly problematic for coastal adaptation efforts given the relatively narrow window for implementing certain types of projects.

SLR and Coastal Adaptation Projects Represent New Challenge for Existing Environmental Regulatory System. In general, the existing set of regulatory requirements for coastal projects was established several decades ago to protect against environmental damage that might be caused by development along the coast or SF Bay. Most of these requirements were developed long before SLR became a concern, and as such did not contemplate the types of adaptation projects currently being proposed or the coming challenges such projects are intended to address. For example, BCDC has long had policies against allowing sediment to be dumped or added within tidal waters to avoid filling in the SF Bay, which was a significant concern in the 1960s that led to BCDC's creation and underlying statutory authority. However, many bay shore adaptation projects require the addition of sediment to build up existing tidal marshes and wetlands to enable them (and the wildlife that live there) to withstand higher water levels and waves. This disconnect has led to problems and delays with attaining BCDC's approval for proposed wetland restoration projects in recent years. (As noted later, BCDC recently modified its Bay Fill policy to address this concern.)

Similarly, to protect coastal resources the Coastal Commission has a rigorous process for evaluating and permitting coastal development—such as hotels, houses, parking lots, or water treatment plants—that has historically posed a *risk* to such resources. The Coastal Commission's regulatory review structure has not typically been faced with how to evaluate natural infrastructure projects that are intended to make the coastline more resilient and that can *benefit* the environment—such as "living shoreline" projects that add sand and plants to the shore to buffer wave action and enhance coastal habitats. (Certain other types of adaptation projects, such as relocating a road or infrastructure inland, however, may more closely resemble traditional development projects.) Because existing regulatory review policies were not developed to evaluate these new types of projects, they can face increased scrutiny, requirements, and delays compared to more traditional and familiar projects (such as adding piles of rocks to the shore to armor the coast ahead of a storm). The increased rigor, complication, and time for these reviews can in turn create disincentives for coastal communities to attempt innovative or nature-based approaches.

Permitting Approach Is Particularly Problematic for Climate Adaptation Projects. Complaints that the environmental permitting system is complicated and protracted are not unique to coastal adaptation projects. Such criticism has often been raised by proponents of many types of projects, including for traditional types of construction and development as well as nature-based projects such as those that restore streams or remove dead trees and dense underbrush from forests. However, such issues raise particular concerns for coastal adaptation projects for two key reasons. First, coastal communities face a pressing need to make progress on preparing for SLR before its impacts become more widespread, and this need will become increasingly urgent in the coming years as sea levels continue to rise. As discussed earlier, the next decade represents a crucial time period for implementing certain types of projects—such as enhancing coastal marshes—before rising water levels preclude their effectiveness. As such, coastal

communities cannot afford to wait at least a year to attain approvals for each project—nor, collectively, can the state, if it wants to improve SLR preparedness levels across California. Second, the state should be encouraging a wide complement of potential approaches to address SLR, including innovative natural infrastructure projects that provide environmental benefits. As discussed, the current regulatory review regime may be having the opposite effect.

While some limited examples of efforts to address these issues exist, they do not apply to coastal adaptation projects statewide. For example, as noted earlier, the SF Bay Area has created the regional SF Bay Restoration Regulatory Integration Team to expedite and simplify the permitting process for certain projects. This team is coordinating permit review and requirements across all the applicable state and federal agencies, however only for SF Bay Area wetland projects funded with local Measure AA funds. Additionally, CNRA has formed a work group to look into ways to coordinate and expedite regulatory review processes, but thus far that effort is limited to permits for forest health projects and does not apply to coastal adaptation.

STATE CAN HELP EXPEDITE LOCAL SLR ADAPTATION EFFORTS

As discussed earlier, the state has a strong interest in helping to ensure that local governments take sufficient actions to mitigate the potential economic, environmental, and public health risks associated with SLR. Moreover, given that delaying adaptation work can result in missed opportunities and higher costs, a strong case exists for the state to help remove barriers at the local level in order to expedite such work.

State Can Play Key Role in Supporting Local Adaptation Efforts. Coastal communities must increase both the extent and pace of SLR preparation efforts if California is to avoid severe, costly, disruptive, and harmful impacts in the coming decades. The state has neither the capacity nor the authority to assume primary responsibility for planning, developing policies, or implementing response activities across California's many coastal communities. Furthermore, local governments are most attuned to the particular needs and circumstances facing their communities. However, this does not mean the state should avoid *any* involvement in coastal adaptation activities—the statewide risks and potential impacts of inadequate preparation are too great. The state can play an important role in encouraging and supporting local efforts and helping to alleviate some of the challenges local governments face. For example, the state can use its over-arching position to help facilitate coordination across jurisdictions and take advantage of economies of scale by collecting and disseminating helpful information statewide. The state can also take action to ensure public trust resources like beaches, wetlands, and coastal access are preserved. Additionally, the state can help ensure that local adaptation efforts adequately address the needs of vulnerable communities that might not have the political or financial resources to guarantee they receive sufficient preparation and protection.

State Cannot Bear Majority of Costs of SLR Preparation . . . The state does not have the fiscal resources to fund most of the coastal adaptation activities that ultimately will be needed to prepare for SLR. Nor would expecting statewide taxpayers to fully subsidize such activities be appropriate, given that most coastal properties and infrastructure are owned by and primarily benefit local governments or private entities. Local governments have the primary responsibility for planning, authorizing, maintaining, and operating their local infrastructure, and they—and their residents—correspondingly should pay the costs associated with those activities, including how their infrastructure may need to be modified for SLR. As is the case with most local infrastructure costs—including construction and maintenance of water and sewer systems, roads and transportation

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systems, and school facilities—the bulk of funding for climate adaptation activities will need to come from local sources.

. . . However, State Investments Can Help Spur Other Actions. Because of the state interest in ensuring that coastal communities are adequately prepared, however, the state has made and will want to continue making some contributions to assist local governments in their SLR adaptation efforts. State dollars can serve as "seed money" that help to spur adaptation project planning efforts for which local governments cannot generate sufficient impetus or funding to get started on their own. Local governments report they often find obtaining local funding sources—such as new dedicated taxes, bonds, or loans—easier when they are requesting the monies to construct specific projects, in contrast to planning activities. As such, state funds play a particularly important role in helping support these initial stages of adaptation work. State funds can also be a key factor enabling the construction of adaptation projects, pairing with local funds to help partially offset what still will be significant upfront costs for local governments. This is consistent with the role the state has played as a contributing funder for many other types of local infrastructure projects. For example, the state frequently funds portions of local water supply and transportation projects, and contributes to the construction of local public school buildings. State funds could be especially important for large regional adaptation projects (which are more difficult and complicated to implement) and projects in economically disadvantaged communities (which often face additional challenges in generating local funding).

RECOMMENDATIONS FOR LEGISLATIVE STEPS

LAO Recommendations Intended to Help Address Key Local Barriers, Help Expedite Adaptation Progress. While effectively preparing for and responding to SLR will be a difficult task for local governments, the threat is on its way. Consequently, the challenges local jurisdictions face will become significantly greater if they do not make additional progress in the coming years. We believe the Legislature can play an important role in helping to increase the types, pace, and scale of coastal adaptation efforts around the state. In this section, we make several recommendations for how the Legislature can help alleviate some of the key barriers to coastal adaptation that local governments are experiencing. Figure 12 summarizes our recommendations, which we discuss in more detail below.

Figure 12

Summary of LAO Recommendations to Support and Enhance Coastal Adaptation Efforts

✓ **Foster Regional-Scale Adaptation**
- Establish and assist regional climate adaptation collaborative groups.
- Encourage development of regional coastal adaptation plans.
- Support implementation of regional adaptation efforts.

✓ **Support Local Planning and Adaptation Projects**
- Increase assistance for cities and counties to plan for sea-level rise (SLR).
- Support coastal adaptation projects with widespread benefits.
- Facilitate monitoring of state-funded demonstration projects.

✓ **Provide Information, Assistance, and Support**
- Establish the California Climate Adaptation Center and Regional Support Network.
- Develop a standard methodology for economic analyses of SLR risks and responses.
- Require a review of how regulatory permitting processes can be made more efficient.

✓ **Enhance Public Awareness of SLR Risks and Impacts**
- Require coastal flooding disclosures for real estate transactions.
- Require that state-funded adaptation plans and projects include robust public engagement.
- Direct state departments to conduct public awareness campaign about threats posed by SLR.

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Foster Regional-Scale Adaptation

More widespread collaboration and planning for the inter-jurisdictional effects of SLR not only will help contribute to greater statewide coastal preparedness, it can also help address coastal communities' challenges with limited funding, information, and capacity. We have three recommendations for how the Legislature can foster adaptation efforts at the regional scale.

Establish and Assist Regional Climate Adaptation Collaborative Groups. We recommend the Legislature support climate adaptation work at a regional scale. Specifically, we recommend establishing collaborative groups in several regions across the state to plan together and learn from each other regarding how to respond to the effects of climate change. These groups can help build on some of the nascent collaborative efforts on climate adaptation that are already underway in some regions but help make them more consistent, sustainable, and available across all areas of the state.

By sharing information and resources, such groups have the potential to address many of the adaptation barriers identified by coastal professionals. They can help with coordinating how to respond to cross-jurisdictional climate impacts, creating efficiencies and economies of scale, and building capacity through shared learning and pooling of resources. Participants should primarily include representatives from local governments, but the groups should also create a forum for them to liaison with other key planning partners such as community-based organizations, state agencies, and utilities.

While collaboration will be particularly helpful for SLR preparation because of the cross-jurisdictional effects of coastal flooding, we believe limiting the scope of these groups solely to coastal regions and issues would be a missed opportunity. Local governments must confront and plan to address multiple climate-related challenges, including an increased risk of wildfires, droughts, and incidents of extreme heat. Working with and learning from regional neighbors will be not only helpful but essential in all of these interrelated efforts.

In implementing this recommendation, the Legislature will want to carefully consider how to define and delineate regions, how many regions to fund, and which entities should serve as the fiscal and administrative agents for the groups. These collaborative groups should be large enough to encompass impacts that will affect the whole region and take advantage of economies of scale, but not so large that they inevitably overlook important issues, concerns, and constituents specific to the region. Moreover, they should consider natural processes that will impact participants similarly (such as tidal impacts and sand migration patterns) around which regional planning makes particular sense. Based on existing regional models and feedback we solicited in researching this report, we think the state should look to fund around 10 or 12 collaborative groups. Because of its experience administering climate mitigation programs and its current work establishing a regional program pursuant to SB 1072 (as mentioned on page 18), we recommend the Legislature direct SGC to administer this program, including developing criteria for selecting regions and regional leads, soliciting applications, and choosing the collaborative leads for each region. The seven existing ARCCA groups highlighted in Figure 7 on page 17 may be appropriate entities to lead this effort in some regions because of their previous work and relationships, but this may not be the case in all areas of the state. Moreover, not all counties are covered by the existing ARCCA groups.

In order to sustain the regional groups on an ongoing basis, we recommend providing them with an annual appropriation. The amount of state funding to provide to each region should be sufficient to support a couple staff members, administrative costs, and regular opportunities to plan and share information together (such as meetings and conferences)—perhaps around $500,000 per region annually. The overall cost to the state will depend upon how many regions the Legislature chooses to fund. This level of consistent base funding should make certain the groups can be sustained, however it will not be sufficient to fund all of their activities. To ensure local buy-in and accountability that the groups' work remains helpful

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and relevant to them, collaborative participants should also be expected to contribute to the groups' costs and operations. These contributions could include in-kind staff time and involvement as well as a physical location to house the staff and group's operations.

Encourage Development of Regional Coastal Adaptation Plans. In addition to establishing and sustaining forums for regional collaboration around climate issues, we also recommend the Legislature support those groups in developing coastal adaptation plans. These plans should address key vulnerabilities and risks that SLR poses to the region, as well as adaptation strategies the region will take to address them. We envision such a regional plan as distinct from planning efforts occurring at the individual city and county levels in that it would focus on more broad, interconnected, cross-jurisdictional issues that would be outside the scope of single-jurisdiction plans and projects. Additionally, we view these plans as an opportunity to incentivize the region to work together to help address the needs of under-resourced communities that might not be able to adequately prepare if left to plan their own, as well as public trust resources which benefit all local constituents. The plans should not be simply a collection of unrelated vulnerabilities and projects compiled by the region but rather should be focused on issues that have cross-jurisdictional importance. To ensure this emphasis, we recommend the Legislature require that these plans be focused on three categories of regional issues:

- ***Interrelated natural effects*** such as erosion and sand migration patterns, as well as wetlands that buffer wave action.
- ***Interrelated human impacts*** such as addressing potential flooding in important transportation corridors and for important infrastructure that affect multiple jurisdictions.
- ***Key regional priorities*** such as addressing the needs of vulnerable communities, preserving public access to the shoreline, and protecting natural resources such as beaches and coastal habitats.

Because these regional coastal adaptation plans would be coordinated and developed by the regional collaborative groups described above, we similarly recommend the Legislature task SGC with their administration. We recommend the Legislature direct SGC to develop criteria for what the plans should include (pursuant to priorities specified in legislation), what types of entities should be included in the development process, as well as a process for reviewing and approving the plans once they have been developed to ensure they meet the required elements. We recommend the Legislature appropriate funding for grants that SGC would allocate to the regional collaborative groups to support the development of these plans. The state has provided funding for regional plans in other sectors that can serve as models for these coastal adaptation plans. These include regional transportation plans, integrated regional water management plans, and sustainable communities strategies. Based on these examples, we estimate that a few million dollars per region is a reasonable amount to provide for plan development. Assuming the state establishes between six and eight collaborative groups that encompass the coast, adopting this recommendation would have an overall one-time cost of $15 million to $30 million. This amount likely would not be sufficient to cover all costs for these planning efforts, but we believe expecting that local governments contribute a share of the costs is reasonable.

While the state's regions face a number of climate-related challenges for which they have to prepare, we recommend focusing state support for this initial planning effort on coastal adaptation. Because of its cross-jurisdictional impacts and imminence, we think SLR is a fitting issue for the state to select for a pilot regional adaptation planning initiative. As such, only the regional collaborative groups containing coastal counties would be eligible for this proposed planning grant. Limiting the exercise in this way can help participating cities and counties undertake and accomplish the work more quickly compared to if they had to also address potential regional impacts from wildfires, droughts, and heat. (The state should not prohibit regional collaborative groups from widening the scope of their adaptation plans should they wish to do so, but should only provide funding for a targeted coastal focus.) If this regional

planning exercise proves to be productive and effective, the Legislature could consider funding similar efforts to address other climate threats in the future.

In areas where planning efforts already are underway, regional coastal adaptation plans can build upon and connect work that has already been undertaken by individual cities and counties, help fill in gaps, and focus the emphasis on issues of regional importance. In other areas of the state where fewer planning efforts have yet been undertaken, more initial research and planning will be needed. Additionally, an overall regional plan could encompass sub-regional plans and projects based on what makes the most sense for the region. For example, the adaptation plan for the SF Bay Area may be divided into a set of interrelated strategies for the North Bay that differ from those developed for the East Bay.

Consistent with many other local planning efforts—including LCPs—we do not propose making the development of regional coastal adaptation plans a required state mandate. Even if the Legislature were to make these planning efforts optional, we believe most jurisdictions and regions would participate. This is because coastal communities already have a rationale to seek to avoid the potential damages and disruption from SLR; the state providing a forum, structure, and funding to undertake regional planning can help remove barriers and facilitate those communities taking essential steps to meet those objectives. Additionally, implementing our recommendation to provide future project funding that is contingent upon the development of these plans—as discussed next—would provide incentives for cities and counties to participate in these regional efforts.

Support Implementation of Regional Adaptation Efforts. Once they have developed coastal adaptation plans, we recommend the Legislature provide some funding to help regions begin implementing the projects identified in those plans. Because of its experience in allocating grants for coastal projects, we recommend the Legislature task SCC with administering this program. As noted earlier, the need for funding to undertake projects is a primary barrier for coastal communities seeking to prepare for SLR. The state making a commitment to help assist in the funding of projects—even if it might be appropriated across multiple years—will help incentivize participants to spend time on collaborative planning. State contributions for implementing larger-scale, multiyear coastal adaptation projects will be particularly important because such projects likely will be more logistically complicated and expensive to undertake if multiple jurisdictions are involved. As discussed earlier, we recommend the state require that local governments also acquire funding contributions from other sources for these projects.

Estimating an appropriate range of funding for the state to provide for coastal adaptation projects is difficult until regional plans and priorities are developed and submitted. However, stakeholders whom we interviewed for this report emphasized that having some certainty that project implementation funding will be available and forthcoming from the state will be a critical factor for ensuring robust participation by local governments in the planning process. Given the magnitude of the threats posed by SLR, regional projects could easily cost billions of dollars. Because local governments likely will not be ready to spend these funds for a few years—until after they complete regional plans and initial project design work—the Legislature could select an initial target amount to plan to set aside now and revisit that amount as plans and project proposals are developed, particularly in the context of its other spending priorities. For example, if the Legislature is considering asking voters to approve a new general obligation bond for climate adaptation in the coming years, it could reserve a portion of these funds for regional coastal adaptation projects.

Support Local Planning and Adaptation Projects

Not all SLR preparation efforts are appropriate to undertake at the regional scale. Individual cities and counties also will need to address anticipated impacts within their own jurisdictions that do not have a regional impact. Moreover, communities around the state share the need to learn more about which types of coastal adaptation strategies

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are most effective. We have three recommendations to help achieve these objectives.

Increase Assistance for Cities and Counties to Plan for SLR. While some SLR impacts would be covered by our proposed regional planning effort, this would not preclude the need for cities and counties to plan for how they will address their more localized vulnerabilities. We recommend the Legislature provide additional support for individual jurisdictions to continue to plan for the effects of SLR. Specifically, we recommend the Legislature appropriate funding to SCC for a grant program that would offset a portion of local governments' costs for conducting vulnerability assessments, adaptation plans, and detailed plans for specific projects. This would continue previous efforts funded through SCC's Climate Ready Program. The funding would help communities that have not yet completed the initial steps of the SLR planning process. Moreover, even cities and counties that have completed vulnerability assessments and adaptation plans report a need for financial assistance in developing detailed project plans and feasibility studies, and in proceeding through the environmental permitting process—activities for which obtaining private financing is often more difficult.

Based on indications from previous rounds of Climate Ready Program grant funding, we find that roughly $5 million per year for the next five years would be reasonable to help local governments make additional progress in SLR planning. After five years the Legislature can reassess the need to continue providing these planning funds, or whether by that point the local demand for funding has largely shifted from planning to project implementation. These planning funds would be in addition to the $1.5 million per year in ongoing Greenhouse Gas Reduction Fund monies the Coastal Commission currently uses to support local governments in planning for SLR and updating their LCPs. (The Coastal Commission uses half of these funds for local grants and half for staff support.)

Support Coastal Adaptation Projects With Widespread Benefits. In addition to planning funds, we also recommend the Legislature support local jurisdictions in undertaking coastal adaptation projects. As discussed, project implementation funding is the most significant barrier to adaptation progress cited by coastal professionals, and state funding plays a crucial role in helping to spur investments from other sources. However, limited state funding should not be used to benefit a small number of private property owners, but rather be targeted for projects with widespread benefits. To this end, we recommend the Legislature appropriate funding explicitly to support these types of projects. Specifically, we recommend the Legislature provide funding to SCC to administer a competitive grant program for coastal adaptation projects that fall under at least one of the following four categories:

- ***Pilot Demonstration Projects to Test Adaptation Strategies.*** Such projects should be designed to experiment with innovative approaches, learn about which strategies are—or are not—most effective in different conditions, and include methods for disseminating lessons learned to other jurisdictions.
- ***Projects With Broad Public Benefits.*** Such projects should protect public resources such as beaches, wetlands, shoreline access, and fish and wildlife habitat.
- ***Projects for Critical Infrastructure.*** Such projects should demonstrate that they address significant risks to public health and safety by reducing potential damage to public infrastructure such as water treatment plants or highways.
- ***Projects Addressing the Needs of Vulnerable Communities.*** Such projects should benefit communities in which a large proportion of residents have comparatively low incomes and therefore likely would not otherwise be able to undertake adequate SLR preparation.

Facilitate Monitoring of State-Funded Demonstration Projects. We recommend the Legislature facilitate some multiyear monitoring, evaluation, and future modification—or "adaptive management"—of coastal adaptation projects. Specifically, we recommend that state grants provided for construction of coastal adaptation projects intended to pilot new approaches—as

described above—also include sufficient funding to conduct several years of post-construction follow-up activities. The Legislature can direct SCC to design adaptation project grant awards to support these additional costs.

In order to verify which types of coastal adaptation projects are most effective, project implementers will need to continue to observe and potentially modify them after construction is completed. While ongoing monitoring and adaptive management is recommended for any type of project—especially those that are nature-based—such practices are particularly essential for coastal adaptation projects for two reasons. First, because of the unprecedented challenge that SLR presents, many response strategies will necessarily be new and untested. Second, conditions will shift as sea levels rise, potentially affecting the project's original design and performance. These uncertainties add to the need to monitor the project to evaluate whether modifications are necessary in the coming years.

In most cases, when the state provides grant funding for capital projects, responsibility for undertaking—and paying for—post-construction activities such as maintenance and monitoring falls to the grantees. Because of the oft-mentioned fiscal constraints local governments face, however, such activities do not always take place at a robust level. For these coastal adaptation projects, we believe a strong rationale exists for the state to help support such costs and ensure that meaningful scientific monitoring and adaptive management occur. This is because of the statewide usefulness of learning lessons from new and innovative coastal adaptation projects, as well as the importance to the public of ensuring their ultimate success in mitigating SLR impacts. We believe that the state helping to fund such follow-up work will ensure that it takes place and thereby help to inform the quality and amount of knowledge about effective adaptation strategies across the state. That, in turn, can help address the need that local governments cite for additional information about the trade-offs of coastal adaptation strategies. Post-construction follow-up activities can help answer the key questions of "how well does the strategy work, does it last, and how can we make it work better?" To this end, we recommend the state require that as a condition of receiving state funding, local grantees must submit regular project reports to SCC summarizing project performance and lessons learned. SCC could then disseminate this information through the aforementioned regional climate collaborative groups and the California Climate Adaptation Center and support network we propose below.

While the amount needed for these follow-up activities will vary by project, a rough guideline might be about 10 percent of the amount provided for construction. For example, if SCC allocated a grant of $10 million to construct a living shoreline project, it might then also provide an additional $1 million to be used over several years for monitoring and adaptive management. This proportional approach likely will not cover all of the associated costs. As with project construction costs, state funding can help enable and enhance monitoring efforts, but project proponents should be expected to help pay the full costs of post-construction activities.

In addition to project-specific follow-up activities, we recommend the Legislature allow SCC to use a portion of adaptation project funds to conduct—or award grants for another entity to conduct—large-scale scientific monitoring on coastal conditions. For example, this could include tracking changes in beach width along a whole region of coastline—rather than each jurisdiction or project grantee having to conduct such monitoring for its own portion of beach. Such larger scale monitoring not only could take advantage of economies of scale, it also could allow for analyses across different locations to test the effectiveness of strategies employed in one area as compared to those in another.

Implementing this recommendation need not require a separate appropriation from the Legislature. However, the Legislature should consider these post-construction costs when determining the overall amount it wants to appropriate for coastal adaptation.

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Provide Information, Assistance, and Support

As discussed earlier, local governments are struggling with how to determine next steps in preparing for SLR and seeking tools to help make such decisions. The state is uniquely positioned to take advantage of economies of scale, centralized communication forums and expertise, and state-level authority to help support local adaptation efforts. We have three specific recommendations to help advance these objectives.

Establish California Climate Adaptation Center and Regional Support Network. We recommend the Legislature establish a system for providing technical support and information to local governments on adapting to climate change impacts. The goal of this system would be to connect practitioners undertaking adaptation work with state policy and guidance, useable scientific information, and technical assistance that is both easily accessible and applicable. This system would seek to address local governments' frequently expressed need for "a *person* to call" to answer their questions and provide real-world advice, guidance, expertise, and examples of how to proceed with adaptation work. Because of the many climate-related challenges facing local governments, we recommend this effort not be limited to coastal adaptation and the threat of SLR but rather be designed to support a broad array of climate adaptation efforts.

Specifically, we recommend the Legislature establish the California Climate Adaptation Center with funding for a staff of roughly 20 employees. We estimate this would cost a few million dollars annually. We recommend that about half of these employees be located in a central location—such as Sacramento—and represent expertise in several disciplines essential to adaptation work. For example, these could include experts in planning, engineering, land use law, finance, and community outreach. The remaining staff could be located in regional locations—ideally co-located with staff from our proposed regional climate collaborative groups—so they can be an easily accessible and familiar "go-to" resource for nearby local governments. These regional staff should seek to develop robust relationships at the local level and be engaged in local planning and collaborative meetings and efforts. Regional-based staff should work together with Center-based staff as a network to share information and best practices across the state, disseminate updates and guidance from various state agencies *to* local governments, as well as provide feedback *from* local governments back to state policymakers about challenges and needs at the local level. The Center should also be charged with establishing formal partnerships with the state's universities and coastal researchers to help provide a bridge between local governments and the latest scientific information. Because of its work overseeing the Integrated Climate Adaptation and Resilience Program, we recommend the Center be housed under OPR as an expansion of that effort. As discussed earlier, that program is intended to develop a cohesive and coordinated response to the impacts of climate change across the state.

Develop Standard Methodology for Economic Analyses of SLR Risks and Responses. We recommend the Legislature require OPC to contract for development of a standardized methodology and template for conducting economic analyses of SLR risks and adaptation strategies. This template can serve as a model for local governments to use in conducting their own analyses to assess their local risks and the best options for taking action. It should guide local governments on *how* to undertake such an analysis, as well as include a database of pre-populated statewide data (such as employment data by sector) which local governments can download in lieu having to search for it on their own. In addition to traditional market-based factors, this methodology should provide a framework for how local governments might assign value to nonmarket factors such as ecosystem services and maintaining—or losing—local beaches. Moreover, it should help local governments in evaluating the economic implications of a no action alternative to help them truly assess the trade-offs of potential adaptation steps they might be considering.

Providing such a tool for local governments across the state to use would achieve three

important goals. First, the availability of such a tool likely would lead to more local governments conducting in-depth analyses of how SLR might impact their communities. This increased awareness can in turn help spur additional preparation efforts across the state and make sure such efforts are more data driven and cost effective. Second, the state completing this activity can take advantage of economies of scale and save taxpayers the costs of many individual local governments having to develop or pay the full costs of such work on their own. While local governments still will incur some costs to undertake a customized local economic assessment, their expenses will be lower since they will not have to start "from scratch." Third, a consistent methodology would allow the state to compare and compile data across jurisdictions that conduct such analyses to get a sense of statewide economic risk and inform how future state investments should be targeted.

Understanding the costs and benefits of various adaptation approaches—including the implications of avoiding taking action—is essential input for local governments weighing the trade-offs of how they should proceed. Moreover, such information will be key for them to explain and defend their decisions to local constituents—especially when such decisions might be politically unpopular.

In order to support the development of a standardized methodology and template, we estimate that OPC would need roughly $1 million in one-time funding. A handful of examples of such economic analyses exist that can serve as models for developing a statewide template, including those conducted for San Diego County, the City of Imperial Beach, and the five-state Mid-Atlantic region along the east coast of the U.S.

Require Review of How Regulatory Permitting Processes Can Be Made More Efficient. We recommend the Legislature direct CNRA to explore and implement options for a more coordinated and efficient regulatory review process for coastal adaptation projects, and to report back to the Legislature on suggestions for improvement. This would be similar to the work the agency is undertaking to help simplify and expedite the permitting process for forest health projects. CNRA might identify ways to improve current processes without changes to statute or additional resources, such as by directing departments to consult with each other during their permit review process and to coordinate the conditions and requirements they impose on project proponents. CNRA's review might also reveal that changes to current law or regulations are needed to address existing permit complications. For example, BCDC recently revised its policies to allow for the placement of increased amounts of sediment along the shore of the SF Bay for projects that will restore and enhance the natural habitat. Additionally, CNRA should look at the degree to which additional funding might be necessary to help expedite review and implementation of coastal adaptation projects. The agency should also evaluate the example of the SF Bay Restoration Regulatory Integration Team to see if similar practices could and should be replicated in other regions of the state.

The state's environmental permitting system is designed to protect valuable public trust resources. We are not recommending these important protections be repealed, removed, or ignored. However, the current protracted review process is both causing undue delays for implementing coastal adaptation projects and inhibiting innovative approaches that need to be tried and tested. Because the state has a vested interest in local governments making progress in preparing for SLR and avoiding potential damage—and in them taking such action soon—we recommend reducing regulatory obstacles that currently prevent them from doing so.

Implementing this recommendation will not have any upfront costs for the state. CNRA's review, however, could conclude that significantly expediting permit review time lines would require hiring additional state department staff. The Legislature could then decide if a compelling case exists that departments cannot implement CNRA's suggested changes within existing resources and whether to provide additional funding to improve permitting processes.

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Enhance Public Awareness of SLR Risks and Impacts

Coastal communities cite the lack of support for—and, in some cases, direct resistance to—coastal adaptation activities from the public and locally elected leaders as a key barrier to SLR preparation. This is primarily due to a lack of public awareness about coming threats and the need to address SLR. As such, we offer three recommendations for how the state can help build such awareness.

Require Coastal Flooding Disclosures for Real Estate Transactions. We recommend the Legislature adopt legislation requiring that the sale of coastal properties in areas at risk of flooding from SRL be accompanied by a "Vulnerable Coastal Property Statement." This would help to ensure that buyers are aware of the risks posed by SRL and other coastal hazards. Instituting such a requirement would be comparable to the real estate disclosures currently required for properties at risk of forest fires, earthquakes, or other types of flooding. Requiring this information would help spread awareness about SLR among the public and allow Californians to make informed decisions about the risk they are assuming before purchasing coastal properties.

Implementing this recommendation would necessitate the state determining how to define which areas—and encompassed properties—should be designated as "vulnerable" and require disclosures. Moreover, the state would have to decide which time lines and assumptions to make in selecting from the many potential SLR scenarios that scientists have developed. Several tools exist that could be utilized to draw these maps, including the CoSMoS system developed by USGS that incorporates coastal erosion trends. We recommend the Legislature direct OPC to assemble a technical advisory committee to help determine the best approach for implementing this recommendation, including a process for how often the maps should be updated to reflect updated projections.

While uncertainty exists around the degree and time line for SLR, this is no different from the natural hazards for which the state already requires real estate disclosures. The state has already determined that despite the inherent uncertainty, alerting purchasers when a property faces a *potential* risk of future damage from earthquakes, fires, or floods is important public policy. The same rationale applies to potential—and, in some areas, probable—coastal flooding. Indeed, the case for coastal disclosures is arguably even stronger since the certainty of some amount of SLR occurring is greater than that associated with threats such as earthquakes.

We acknowledge that implementing this recommendation has the potential to impact local property tax revenues if such disclosures result in a reduction in the market value of affected coastal properties. Specifically, if a property sells for a lower price than it otherwise would have because of the buyers' heightened awareness of SLR-related flood risks, the local governments would receive less local property tax revenue than if it sold for a higher price. As noted earlier, to the degree local property tax revenues drop, this also could affect the state budget. This is because the California Constitution requires that decreases in certain local property tax revenues used to support local schools be backfilled by the state's General Fund. Despite these potential implications, we believe a strong case still exists for the state to facilitate greater public awareness about the risks that buyers are assuming when purchasing certain coastal properties. Moreover, the value of properties that experience flooding when sea levels reach higher levels will eventually decrease regardless of whether or not the state requires disclosure warnings.

Require That State-Funded Adaptation Plans and Projects Include Robust Public Engagement. If the Legislature opts to establish new grant programs to support coastal adaptation planning and projects at the regional and local levels, we recommend it ensure public outreach and engagement are key components of those programs. Specifically, in the statutes it adopts to create these programs, we recommend directing implementing departments—such as SGC and SCC—to include meaningful public involvement requirements in the criteria they develop for adaptation planning and project

grant programs. We also recommend requiring that the administering departments validate the adequacy of the public engagement efforts that were undertaken by grant recipients before approving final plans and grant awards. That is, final approval of plans and grants by the state should be contingent upon the grantee showing evidence that it met state requirements for public engagement.

Outreach to and participation of the public will be essential to both regional and single-jurisdiction planning processes to help develop societal awareness about SLR and climate risks and to build acceptance for the adaptation steps that will be undertaken. Moreover, to ensure the needs of vulnerable communities are included and accurately reflected in the plans and proposed projects, undertaking broad-based outreach efforts in coordination with community-based organizations is important.

Direct State Departments to Conduct Public Awareness Campaign About Threats Posed by SLR. We recommend the Legislature direct state departments to intensify their efforts to increase public awareness of the time lines, risks, and options for addressing SLR. This should include developing resources which local governments can use in their own local public education efforts, such as templates for social media campaigns, posters and signs, and easily customizable inundation maps. While certain state departments have developed some resources—such as reports, fact sheets, and webinars—most are not widely disseminated and many are not particularly user-friendly. For example, many documents contain technical scientific language and do not clearly explain how SLR will affect California residents' daily lives in the coming years.

We believe that state-level efforts to educate the public about SLR can help local governments in several ways. Among the most important potential benefits would be to help the public better understand the potential risks associated with SLR and develop a sense of engagement in and urgency for taking action. Not only could this reduce the active public *resistance* that some local governments are encountering in their SLR preparation activities, it could foster an atmosphere of organized *support* and advocacy for such efforts. Moreover, greater awareness could build encouragement for—and pressure on—local officials to take action. Another key advantage of undertaking such a campaign on a statewide basis is that it would preclude the need for each individual coastal community to develop such materials and strategies on its own, thereby saving taxpayer money.

We recommend the Legislature direct state departments to focus on increasing public awareness and disseminating information within their existing resources by making it a priority within their regular operations. This could include BCDC, SCC, and the Coastal Commission dedicating a small portion of the annual funding that they receive from NOAA to implement the federal Coastal Management Act towards expanding public awareness activities. Additionally, OPC reports that it recently entered a contract for roughly $200,000 to initiate a public awareness campaign about SLR, which is a positive step in this effort. We recommend the Legislature request regular updates from OPC on the progress and perceived effectiveness of this campaign and what additional steps might be merited—including, potentially, expanding the scope and reach of this work. The Legislature can then evaluate whether additional appropriations might be merited in the future to make these efforts more widespread and effective. The "Save Our Water" water conservation campaign that the state undertook during the recent statewide drought can serve as an example of this type of effort, however that was a more expansive and expensive initiative than what we are recommending here.

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FUNDING OPTIONS FOR IMPLEMENTING RECOMMENDATIONS

Multiple Funding Options Available. Given the relatively limited level of state involvement and funding in supporting local coastal adaptation efforts thus far, many of our recommended actions—unsurprisingly—would result in additional costs. We do not identify specific funding sources for each activity, as the Legislature has multiple options upon which it could rely.

Some of the costs associated with our recommendations could be significant, such as if the state opts to play a large role in supporting and expanding implementation of coastal adaptation projects. The state would need to rely on funding sources that can support significant—multimillion dollar—levels of spending for such projects, such as the General Fund or the Greenhouse Gas Reduction Fund. Other recommended actions, however, encompass more modest steps that are intended to help support local governments in their preparation efforts. For these activities—such as supporting regional climate collaborative groups or developing a template for undertaking economic analyses—the Legislature also has the option of using funding sources that are able to support smaller, less-costly expenditures. Such sources include the Environmental License Plate Fund, which provides roughly $50 million annually from the sale of license plates for environmental programs and projects. The state has used this fund to support some coastal activities in the past. Additionally, over $30 million remains unappropriated that voters authorized for coastal restoration and adaptation activities via Proposition 68, the 2018 natural resources bond. The Legislature could direct these resources for implementing some of our recommendations—particularly for supporting adaptation projects. As noted earlier, the Legislature is also contemplating proposals to ask voters to approve a new general obligation bond targeted for climate adaptation activities, which would obligate future General Fund dollars to repay the bond.

Both State and Local Governments Could Look to Alternative Funding Sources to Support Adaptation Activities. In addition to the funding sources upon which the state has historically relied for coastal activities—the General Fund, general obligation bonds, the Greenhouse Gas Reduction Fund, and the Environmental License Plate Fund—the Legislature could also prioritize other existing sources to increase support for coastal adaptation activities. For example, the Legislature could direct CalOES to use a portion of the federal funds the state often receives from FEMA through the Hazard Mitigation Grant Program for these purposes. As discussed earlier, the state receives significant amounts of these funds in years after it experiences federally declared disasters. The Legislature historically has deferred to CalOES on how to utilize these funds, and with a few limited exceptions, thus far the department has not targeted coastal adaptation projects as a priority area of focus. The Legislature could also direct Caltrans and the California Transportation Commission to place a greater priority on SLR adaptation projects in its use of transportation funds along the coast.

Similarly, local governments likely also will need to identify funding sources to support intensified climate adaptation efforts. This could include designing adaptation projects that allow them to take advantage of other available funding sources such as those targeted for transportation, recreation, or water system infrastructure maintenance and replacement projects. For example, if a local government already has plans to upgrade an aged water treatment plant using rate-payer funding, it could incorporate features that would make the project more resilient to future SLR, such as by elevating or moving key components of the facility.

Local governments could also pass new taxes, fees, or bonds at the local level. A few examples of such strategies have already been approved by local voters. These include Measure AA in the nine-county SF Bay Area (which imposed a new parcel tax to be used for shoreline restoration projects), Proposition A in the City of San Francisco (which authorized a $425 million local general obligation bond to repair and improve the Embarcadero seawall), and Measure W in Los Angeles (which imposed a parcel

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tax to be used for stormwater capture projects that improve water quality and may also increase water supply in the face of climate change and increased droughts).

Larger Fiscal Context of Implementing LAO Recommendations. For all of the state funding sources we have identified as options for implementing our recommendations—both large and comparatively smaller—the Legislature already faces many competing priorities. Directing funding to implement our recommended actions and support local governments in their coastal adaptation efforts would mean less funding available from any of these sources for other state expenditures. As with all its budgetary decisions, the Legislature will have to balance its multiple priorities. While spending on coastal adaptation now to prevent higher disaster response and recovery costs in the future makes sense, this is not the only pressing issue facing the state and its budgetary resources. For example, the Legislature has also set important goals for addressing housing and homelessness, paying down unfunded pension obligations, and expanding access to child care and health care—all of which could create pressures for additional state funding. Moreover, multiple indicators suggest an economic slowdown could be on the horizon, which would constrain state revenues and further complicate the Legislature's budget decisions. The same types of fiscal trade-offs also exist at the local level.

We note, however, the coming decade is a key period for escalating the pace and scale of adaptation progress. As discussed, taking action soon will allow coastal communities—and the state—to be more strategic about phasing in responses to SLR, and to learn what approaches work best before the risk of severe flooding becomes imminent. We believe that this sense of urgency and the costly implications of failing to adequately prepare for SLR merit consideration of our recommendations alongside other state priorities, especially while the state is still in a strong fiscal position.

CONCLUSION

Recommended Actions Represent Next Step in What Will Be a Multiyear, Multistage Process. The overall goals of our recommendations are to prompt more widespread progress in local coastal preparation efforts. We believe implementing our recommended steps would help build partnerships and capacity at the local level that will both extend adaptation activities to more coastal communities and assist those that are already engaged in planning efforts to transition into implementing policies and projects. While these are incremental steps that will not be sufficient to address all the anticipated impacts of SLR, they represent prerequisites along the path to more robust statewide preparation. Specifically, in order to adequately address the potential impacts of SLR and avoid costly damage and disruption, local governments must first establish collaborative cross-jurisdictional relationships, strengthen their knowledge base about which strategies work (and which do not), and increase public awareness about the coming threats. The Legislature assisting them in these tasks in the near term will help lay the groundwork for local governments to tackle the more difficult—and costly—decisions and actions in future years as floodwaters become more imminent.

Given the scope of this report, we developed our recommendations specifically to expedite coastal adaptation progress at the local level. Yet we believe adopting our suggested actions could help facilitate state-level adaptation efforts as well. Specifically, several of our recommendations also would benefit the state departments responsible for preparing state-owned assets—such as highways and parks—for the impacts of climate change and SLR. For example, state department actions could be informed and improved by the expertise housed within our proposed California Climate Adaptation Center. Similarly, state departments that need to evaluate the potential economic impacts of SLR on state assets could avoid incurring some additional costs if they could rely on a state-developed standardized methodology to conduct such analyses.

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AN LAO REPORT

Additional Issues Will Need Legislative Attention in Future Years. This report is meant to be a preliminary step at looking at how the Legislature can help address the specific climate challenge of SLR. Additional activities and investments will be needed as coastal impacts become more pressing and prevalent in the future. We knowingly did not address certain issues within this report, either because they were too complex for us to study in detail within our time frame or because they fell outside of the scope we identified for this report. In order for local governments and the state to effectively tackle the coming challenges presented by SLR and other climate risks, however, the Legislature will need to confront some of these difficult topics in the coming years. These include:

- ***Clarifying Uncertain Legal Questions.*** At some point, statutory clarification likely will be needed to address some unprecedented legal issues. These include questions about when and where seawalls can be built and fortified, given the associated trade-offs between protecting the assets behind them and the resulting erosion of nearby beaches.
- ***Defining Statewide Priorities and Responsibilities.*** As threats become more pressing, the Legislature may want to set statewide priorities and expectations for responding to SLR. For example, it will have to weigh whether the state should step in to compel local jurisdictions to protect health and safety and public resources if they fail to adequately prepare for coastal flooding or if they plan to implement actions that will have negative impacts on beaches. The Legislature may also consider establishing statewide decision-making guidelines for which types of resources and facilities should be protected and which might have to be abandoned as sea levels rise.
- ***Rethinking How and Where We Build.*** As water levels rise and areas of the coast begin to experience regular flooding, it will constrain where new development can take place, and some existing properties will have to be renovated or relocated. These challenges will be particularly difficult given the state's existing housing shortage, and therefore an effective response will require thorough and strategic state-level planning and guidance. The Legislature may want to consider how to help local governments confront land use decisions complicated by SLR, including how to facilitate and encourage needed relocations, whether to place restrictions on rebuilding after a flood event, and how to support innovative and resilient approaches to building and development.
- ***Responding to Changes in Insurance Markets.*** As has started to occur in areas of high wildfire risk, the cost and availability of property insurance in coastal communities likely will change as the risk of SLR-related flooding increases. The Legislature may want to determine what role the state should play to support California residents and business owners when property insurance becomes unaffordable or unavailable for some existing properties.
- ***Addressing Additional Climate-Related Risks and Challenges.*** Clearly, SLR is not the only way that the effects of climate change will impact California. The Legislature will also need to determine how to prepare—and help local governments to prepare—for other challenges such as increases in intense heat events, droughts, wildfires, and inland flooding from severe storms.

Further legislative involvement in addressing these issues will be important—particularly when statutory changes are needed to clarify and resolve issues, offer guidance, or provide funding. The Legislature has many avenues through which to engage in these topics, including holding policy and select committee hearings, proposing and participating in robust deliberation over legislation, and requesting research and input from experts within state departments and universities. While the challenges facing the state's coastline are daunting, the science is clear—sea levels are rising. The impacts these coming changes ultimately will have on California's residents, economy, and natural resources will depend directly upon the actions that local governments and the state take to prepare in the coming years.

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LAO PUBLICATIONS

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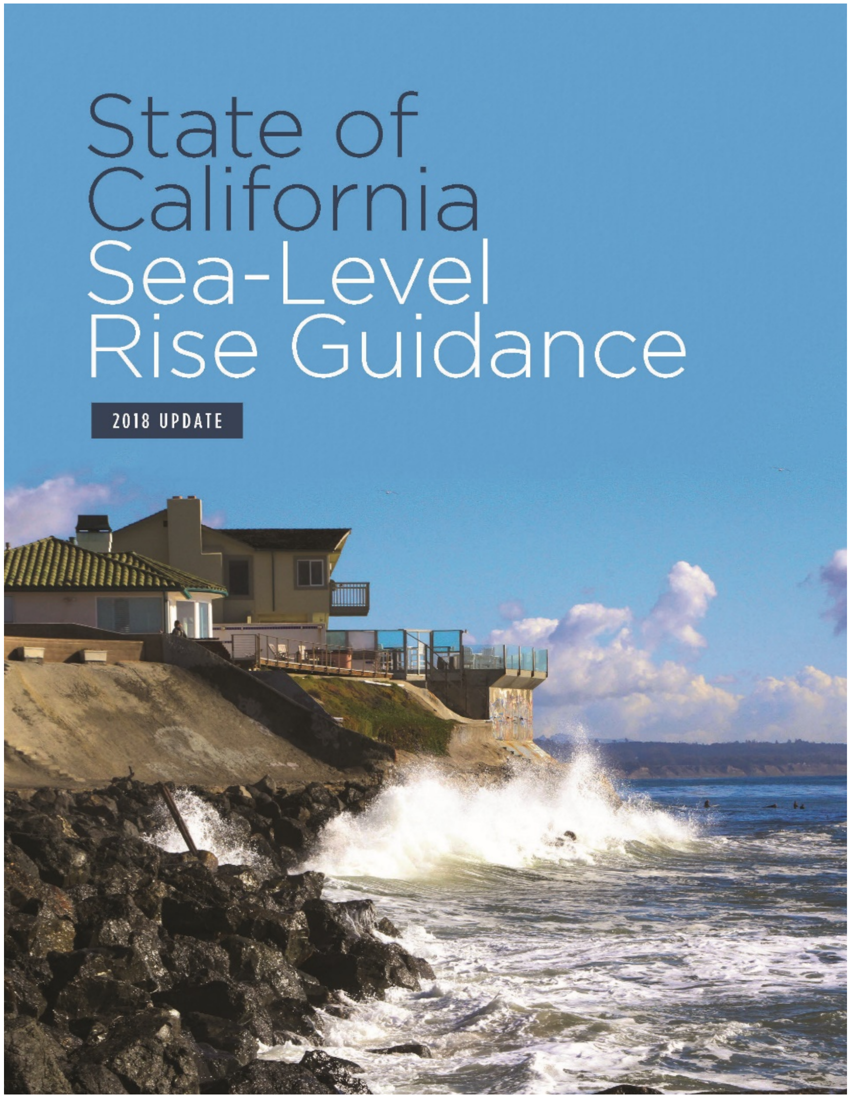

State of California Sea-Level Rise Guidance

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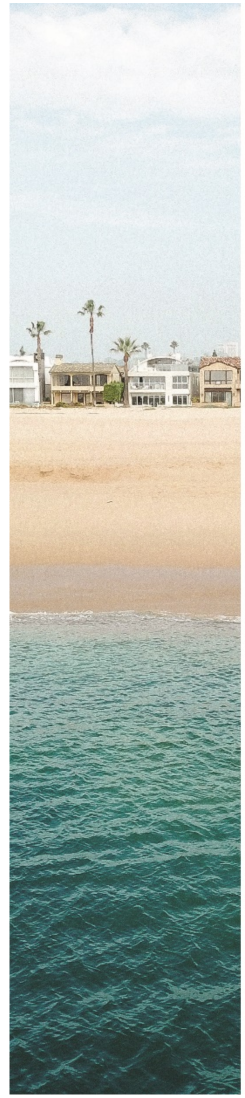

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Executive Summary

THE CLIMATE ACROSS CALIFORNIA is changing, and the effects, such as rising average temperatures, shrinking mountain snowpack, more intense storms, and higher sea levels are expected to continue and worsen in the coming decades. Sea-level rise is caused by the thermal expansion of warming ocean water and melting of land ice as the Earth warms. It is one of the most obvious manifestations of the trend of climate change and is an immediate and real threat to lives, livelihoods, transportation, economies, and the environment in California.

In April 2017, catalyzed by direction from Governor Brown and the need to ensure that best available science was informing sea-level rise planning decisions in California, a Working Group of the California Ocean Protection Council's Science Advisory Team (OPC-SAT) released a report, entitled "Rising Seas in California: An Update on Sea-Level Rise." The Rising Seas Report was prepared and peer-reviewed by some of the nation's foremost experts in coastal processes, climate and sea-level rise science, observational and modeling science, the science of extremes, and decision-making under uncertainty. The report synthesized the current state of sea-level rise science, including advances in modeling and improved understanding of the processes that could drive extreme global sea-level rise as a result of ice loss from the Greenland and Antarctic ice sheets. The report found that:

- Scientific understanding of sea-level rise is advancing at a rapid pace.
- The direction of sea-level change is clear; sea levels are rising.
- The rate of ice loss from the Greenland and Antarctic ice sheets is increasing, and California is particularly vulnerable to sea-level rise caused by ice loss from West Antarctica.
- New scientific evidence has highlighted the potential for extreme sea-level rise.
- Probabilities of specific sea-level increases can inform decisions.
- Current policy decisions are shaping our coastal future.
- Waiting for scientific certainty is neither a safe nor prudent option.

The increased understanding of sea-level rise projections and polar ice sheet loss warranted an update to the State's sea-level rise guidance document to ensure decisions were based on the best available science. Additionally, an increased policy focus requiring state and local governments to incorporate climate change into decision making merited an update to address the needs of both state and local audiences.

This updated document, the "State of California Sea-Level Rise Guidance" (Guidance), provides a bold, science-based methodology for state and local governments to analyze and assess the risks associated with sea-level rise, and to incorporate sea-level rise into their planning, permitting, and investment decisions. This Guidance provides:

1. A synthesis of the best available science on sea-level rise projections and rates for California;
2. A step-by-step approach for state agencies and local governments to evaluate those projections and related hazard information in decision making; and
3. Preferred coastal adaptation approaches.

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What Has Changed Since the 2013 Update to the Guidance?

New policy context and expanded audience

State agencies were the target audience for the earlier versions of this Guidance, which was initially developed in 2010 and updated in 2013. However, over the past five years, there has been a multitude of policy and legislative directives and mandates focused on improving climate adaptation and resiliency in California at both the state and local level, including:

- Governor Brown's Executive Order B-30-15 directing state agencies to factor climate change into their planning and investment decisions;
- Senate Bill 379 (Jackson) requiring local governments to incorporate climate adaptation and resiliency strategies into their General Plans; and
- Senate Bill 246 (Wieckowski), which established the Governor's Office of Planning and Research's Integrated Climate Adaptation and Resiliency Program to coordinate local and state climate adaptation strategies.

With this increased policy direction and improved understanding of possible impacts, the 2018 Guidance aims to respond to the needs for guidance that can help cities, counties and the State prepare for, and adapt to, sea-level rise.

Significant advances in the scientific understanding of sea-level rise.

- Scenario-based versus probabilistic sea-level rise projections. The 2013 version of the State's sea-level rise guidance provided scenario-based sea-level rise projections based on a 2012 National Research Council report; these scenario-based projections were partially but not fully tied to specific emissions scenarios presented in the Intergovernmental Panel on Climate Change's Fourth Assessment Report and do not include a likelihood of occurrence. Since the 2013 Guidance, the scientific community has made significant progress in producing probabilistic projections of future sea level rise, and the team of scientists advising the Ocean Protection Council (OPC) on this Guidance strongly recommended that decision-makers use probabilistic projections to understand and address potential sea-level rise impacts and consequences. This updated Guidance thus incorporates probabilistic sea-level rise projections, which associate a likelihood of occurrence (or probability) with sea-level rise heights and rates, and are directly tied to a range of emissions scenarios.
- H++ scenario. The probabilistic projections may underestimate the likelihood of extreme sea-level rise (resulting from loss of the West Antarctic ice sheet), particularly under high emissions scenarios. Therefore, the 2018 update to the Guidance also includes an extreme scenario called the H++ scenario. The probability of this scenario is currently unknown, but its consideration is important, particularly for high-stakes, long-term decisions.

The science on sea-level rise will continue to evolve, possibly significantly, in coming years. Continual updates to our scientific understanding must be expected as observations and models improve, and as the environment continues to change. Planners should remain cognizant of this evolving picture, while at the same time beginning to plan today under this uncertainty. This Guidance is based on the recognition that it is no longer appropriate to assume a static environment in planning and decision making and that communities can nonetheless effectively plan and take action in such changing conditions.

Extended stakeholder engagement in Guidance development.

The 2018 update to the Guidance was developed by OPC, in close coordination with a Policy Advisory Committee with representation from the California Natural Resources Agency, the Governor's Office of Planning and Research, and the California Energy Commission. To improve coordination and consistency in sea-level rise planning, OPC also collaborated closely with state coastal management agencies and other member agencies of the State's Coastal and Ocean Working Group of California's Climate Action Team (CO-CAT). In addition, OPC, with assistance from the Ocean Science Trust

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and engagement experts, solicited input from coastal stakeholders including local governments, regional agencies, federal agencies, coastal consultants, environmental groups, Tribes, and others to better understand the needs and concerns related to planning for sea-level rise and related risks across the state.

Sea-level rise risk analysis and decision framework.

This Guidance provides a step-wise approach to help decision makers assess risk by evaluating a range of sea-level rise projections and the impacts or consequences associated with these projections. Depending on the finite factors of a proposed project's location and lifespan, decision makers can evaluate the potential impacts and adaptive capacity of the project across a spectrum of sea-level rise projections. This analysis will enable state agencies and local governments to incorporate the latest sea-level rise projections and related hazard information to consider in different types of decisions across California.

The following steps, outlined in the figure and in more detail below, provide a decision framework to evaluate the consequences and risk tolerance of various planning decisions. This framework should be used to guide selection of appropriate sea-level rise projections, and, if necessary, develop adaptation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded or prematurely reached:

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

>> STEP 2: *Evaluate project lifespan.*

>> STEP 3: *For the nearest tide gauge and project lifespan, identify range of sea-level rise projections.*

>> STEP 4: *Evaluate potential impacts and adaptive capacity across a range of sea-level rise projections and emissions scenarios.*

>> STEP 5: *Select sea-level rise projections based on risk tolerance and, if necessary, develop adapation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded.*

STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

Preferred Coastal Adaptation Planning Approaches.

This Guidance expands the preferred coastal adaptation planning approaches identified in OPC's previous guidance, incorporating existing law, expressed policy preferences by the Governor and Legislature, and the goal of fostering consistency across coastal and ocean government agencies. The following is a summary of the new recommendations:

- Adaptation strategies should prioritize protection of vulnerable communities and take into consideration social equity and environmental justice.
- Coastal habitats and public access should be protected and preserved.
- Adaptation strategies should consider the unique characteristics, constraints and values of water-dependent infrastructure, ports and Public Trust uses.
- Acute increases in sea-level rise caused by storm surges, El Niño events, king tides, or large waves should be considered. These events could produce significantly higher water levels than sea-level rise alone and will likely be the drivers of the strongest impacts to coastal communities, ecosystems, and infrastructure.
- Cross-jurisdictional coordination and consistency among permitting entities should be sought in selecting sea-level rise projections. These entities should also prioritize implementation of consistent or complementary adaptation strategies.
- Local conditions, including the diversity of shoreline types, natural conditions, and community characteristics, should be evaluated to inform risk tolerance and adaptation decisions.
- Adaptive capacity should be built into project design and planning.
- Risk assessment and adaptation planning efforts should be conducted at community and regional levels, when possible.

Mapping Tools.

This Guidance also describes and provides links to a variety of geospatial and visualization tools to assist decision makers in understanding the impacts of sea-level rise. The document is accompanied by a library and database of additional resources – hosted on the State Adaptation Clearinghouse and OPC's website – to help visualize change, access funding opportunities, gather policy and scientific background related to specific jurisdictions, and provide additional support to address a challenge of this nature and magnitude. This library and database will be released in mid-2018 when the State Adaptation Clearinghouse is publicly launched.

How Often Will the State of California Sea-Level Rise Guidance be Updated?

Based on recommendations from OPC's Scientific Working Group, OPC anticipates updating the Guidance periodically, and at a minimum of every five years, to reflect the latest scientific understanding of climate change sea-level rise in California. Rapid advances in sea-level rise and climate science, and subsequent release of relevant, peer-reviewed studies from the Intergovernmental Panel on Climate Change (IPCC), state and national climate assessments, and equivalently recognized sources may generate the need for more frequent updates. By incorporating periodic updates at least every five years, this Guidance attempts to establish a strong foundation for sea-level rise planning and decision making at both local, regional, and statewide scales that can be perpetuated in future updates to sea-level rise projections.

In developing this Guidance, the State took intentional action to engage users and decision makers to ensure that the scientific information and policy direction was understandable and useful for sea-level rise planning and adaptation efforts. Going forward, OPC will continue to prioritize opportunities for co-production of future decision-support products by scientists, practitioners, and policy and decision makers to further improve the translation of sea-level rise science into action.

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Introduction

The climate across California is changing, and the effects, such as rising average temperatures, shrinking mountain snowpack, more intense storms, and higher sea levels are expected to continue and worsen in the coming decades. Sea-level rise, caused by the thermal expansion of warming ocean and melting of land ice as the Earth warms, is one of the most obvious manifestations of the trend of climate change and is an immediate and real threat to lives, livelihoods, transportation, economies, and the environment in California.

The impacts of sea-level rise on California are significant. The vast majority of California's population lives in coastal counties and will directly experience the effects of sea-level rise on homes, roads, public services, and infrastructure. More frequent and chronic flooding and erosion are inevitable. Inland populations are not immune. For example, Sacramento-San Joaquin River Delta communities can expect to see inundation, saltwater intrusion, and transportation disruptions (for people and goods); and even further from the San Francisco Bay and California coast, communities will experience the far-reaching ripple effects of coastal changes on lives and livelihoods. California's ocean economy – including tourism, recreation and marine transportation – is the nation's largest, valued at over $44 billion per year.[1] This important and lucrative sector will be directly disrupted by the effects of sea-level rise.Many of the facilities and much of the infrastructure that support California's

1. Kildow, Judith, Colgan, Charles, and Johnston, Pat. "Coastal and Ocean Economic Summaries of the Coastal States – Update 2016" National Ocean Economics Program, Center for the Blue Economy, Middlebury Institute of International Studies at Monterey. 2016. http://centerfortheblueeconomy.org/2016-noep-report

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ocean economy, as well as the state's many miles of public beaches, lie within a few feet of the present high-tide line and therefore are at risk from future sea-level rise and coastal storm events as a result of a changing climate.

Because the threats cascade beyond the immediate coastline, a proper and coordinated response and clear guidance about how to plan and prepare for change is crucial. California has exhibited strong and global leadership across both climate adaptation and mitigation. This Guidance seeks to build upon that leadership by providing a bold science-based methodology for state and local governments to analyze and assess the risks associated with sea-level rise. Catalyzed by direction from Governor Brown in 2016, this Guidance document reflects advances in sea-level rise science and addresses the needs of state agencies and local governments as they incorporate sea-level rise into their planning, permitting, and investment decisions.

State agencies were the target audience for the earlier versions of this Guidance, which was initially developed in 2010 and updated in 2013. However, over the past five years, there has been a multitude of policy and legislative directives and mandates focused on improving climate adaptation and resiliency in California at both the state and local level, including: Governor Brown's Executive Order B- 30-15 directing state agencies to factor climate change into their planning and investment decisions; Senate Bill 379 (Jackson) requiring local governments to incorporate climate adaptation and resiliency strategies into their General Plans; and Senate Bill 246 (Wieckowski), which established the Governor's Office of Planning and Research's Integrated Climate Adaptation and Resiliency Program (ICARP) to coordinate local and state climate adaptation strategies.[2] Increased policy direction and improved understanding of possible impacts are driving the need for guidance that can help cities, counties, and the State prepare for, and adapt to, sea-level rise.

In parallel with California's leadership across the climate change policy landscape, advances in scientific understanding warranted an update to the Guidance to ensure decisions were based on the best available science.[3] These advances include improved sea-level rise modeling (namely, improved methods for estimating probabilities of local sea-level change) and better understanding of potential ice loss from the Greenland and Antarctic ice sheets – and the implications of this loss for both global average sea-level rise and sea-level rise off the West Coast of the United States.

The 2018 update to the Guidance was developed by OPC, in coordination with the California Natural Resources Agency, the Governor's Office of Planning and Research, and the California Energy Commission. To ensure that the updated Guidance was understandable and useful for local and state decision making, the update process included extensive public outreach, with interviews, listening sessions and public workshops to solicit input from local, regional, state and federal stakeholders. To improve coordination and consistency in sea-level rise planning, OPC also collaborated closely with state coastal management agencies and other member agencies of the State's Coastal and Ocean Working Group of California's Climate Action Team (CO-CAT). See Appendix 1 for a full summary on the Guidance development.

Purpose and Intended Use

The purpose of this Guidance is to assist decision makers at state and local levels in planning for, and making decisions about, sea-level rise and related coastal hazards in light of the current state of the science.

This Guidance aims to:

1. Synthesize – at a high level – the key findings of the science report solicited in preparation for this Guidance update, thereby establishing what constitutes "the best available science," and outlining sea level projections and rates for

2. Executive Order B-30-15 (2015): https://www.gov.ca.gov/news.php?id=18938; SB 379 (Jackson), Land use: general plan: safety element: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB379; SB 264 (Wieckowski), Integrated Climate Adaptation and Resiliency Program: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB246

3. The 2013 document incorporated the sea-level rise projections from the 2012 National Research Council report on sea-level rise along the West Coast titled: "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future": https://www.nap.edu/read/13389/chapter/1

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California, for purposes of planning and decision making by state and local governments;

2. Provide a step-by-step approach for state agencies and local governments to incorporate and adapt to the latest sea-level rise projections and related hazard information in different types of decisions across California; and
3. Articulate OPC's preferred coastal adaptation planning approaches in the context of existing law, expressed policy preferences by the Governor and the Legislature, and OPC's goal to foster consistency across coastal and ocean government agencies.

This Guidance is consistent with OPC's commitments to use the best available science in the management of ocean resources, to employ a precautionary approach in the face of scientific uncertainty and the potential for significant harm, and to improve coordination across government agencies in addressing the complex challenges of climate change.[4]

This statewide policy document is necessarily a high-level framework that allows state agencies, local authorities and other users to incorporate the essential principles and recommendations while accommodating the diversity of processes and decisions across agencies and authorities. It is not a "how-to" guide but rather a guiding framework. Thus, accompanying this policy Guidance is a library and database of resources to help visualize change, access funding opportunities, gather policy and scientific background related to specific jurisdictions, and in general provide additional support to address a challenge of this nature and magnitude. This database and library of resources will be available on the State Adaptation Clearinghouse[5] in mid-2018, as well as OPC's website. It draws on an extensive resource database developed pursuant to AB 2516,[6] as well as additional resources compiled in response to outreach conducted as part of the Guidance update process.

Planning, permitting, and investment decisions initiated after OPC's adoption of the 2018 Guidance should incorporate the updated analysis and adaptation measures described below. Recognizing the considerable time and resources necessary to incorporate sea-level rise into planning processes, planning or development projects currently underway at the time of Guidance adoption should complete those efforts while evaluating potential adaptation pathways to prepare for projected increases in sea-level rise contained herein. To the extent possible, and where applicable, projects in the scoping or early stages at the time of the Guidance adoption should adjust sea-level rise projections to incorporate the latest projections in order to maximize a project's lifetime and plan for a more resilient coastline.

Frequency of Future Updates

Based on recommendations from OPC's Scientific Working Group, OPC anticipates updating the Guidance periodically, and at a minimum of every five years, to reflect the latest scientific understanding of climate change driven sea-level rise in California. Rapid advances in science and subsequent release of relevant, peer-reviewed studies from the Intergovernmental Panel on Climate Change (IPCC), state and national climate assessments, and equivalently recognized sources may generate the need for more frequent updates. By incorporating periodic updates at least every five years, this Guidance attempts to establish a strong foundation for sea-level rise planning and decision making at both local, regional, and statewide scales that can be perpetuated in future updates to sea-level rise projections. Wherever possible, California is integrating and aligning updates to the Guidance with other State-mandated policy and assessment efforts, such as the Governor's Office of Planning and Research's (OPR) Integrated Climate Adaptation and Resiliency Program, the recommendations and next steps of the Safeguarding California Plan, California's Fourth Climate Change Assessment, the Climate-Safe Infrastructure Working Group, and various guidance documents issued by the California Coastal Commission and other regulatory agencies.

4. http://www.opc.ca.gov/about/
5. https://www.opr.ca.gov/s_icarpclearinghouse.php
6. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB2516

STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

Guidance Implementation

This high-level Guidance was developed to help state and local governments analyze the risks associated with sea-level rise, and develop precautionary adaptation pathways and strategies that ensure community, regional, and statewide resilience in the face of rising seas. The updated projections and recommendations, which fit within a larger body of work assessing sea-level rise vulnerabilities and preparing for future conditions, may be incorporated by state agencies into planning and investment decisions. The Guidance may also be integrated into local government planning and adaptation efforts through statutory, regulatory, and policy mechanisms including, but not limited to: the Coastal Commission's Local Coastal Programs, the San Francisco Bay Conservation and Development Commission's permitting process, and General Plans updates that must include climate change adaptation and resiliency strategies pursuant to Senate Bill 379. OPC is committed to continued outreach and collaboration with stakeholders and agencies to ensure effective implementation of this Guidance.

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Best Available Science to Support Planning for Sea-Level Rise in California

Rising Seas In California: An Update On Sea-Level Rise Science

In April 2017, at the request of OPC, a Working Group of OPC's Science Advisory Team (OPC-SAT) released a report synthesizing the state of sea-level rise science entitled "Rising Seas in California: An Update on Sea-Level Science" (Rising Seas Report).[7] The Rising Seas Report was prepared and peer-reviewed by some of the nation's foremost experts in coastal processes, climate and sea-level rise science, observational and modeling science, the science of extremes, and decision-making under uncertainty. The Rising Seas Report, which provides the scientific foundation for this update to the Guidance, included advances in sea-level rise modeling and improved understanding of the processes that could drive extreme global sea-level rise from ice loss from the Greenland and Antarctic ice sheets. This work, along with other authoritative peer-reviewed science (as long as not less precautionary than the foundation set forth by the Rising Seas Report) serve as the best available science on which to base future planning and investing decisions in California.

Key findings from *Rising Seas in California: An Update on Sea-Level Rise Science*

There are seven key findings from the Rising Seas Report that provide a succinct summary statement of the latest understanding of and advancements in sea-level rise science. The report provides the foundation for state and local governments to make decisions associated with sea-level rise utilizing timely, well-vetted scientific analysis. Its fundamental

7. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf

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messages, which are relied on throughout this Guidance, are as follows:

1. **Scientific understanding of sea-level rise is advancing at a rapid pace.**
   Projections of future sea-level rise, especially under high emissions scenarios, have increased substantially over the last few years, primarily due to new and improved understanding of mass loss from continental ice sheets. These sea-level rise projections will continue to change as scientific understanding increases and as the impacts of local, state, national and global policy choices become manifest. New processes that allow for rapid incorporation of new scientific data and results into policy will enable state and local agencies to proactively prepare.

2. **The direction of sea-level change is clear.**
   Coastal California is already experiencing the early impacts of a rising sea level, including more extensive coastal flooding during storms, periodic tidal flooding, and increased coastal erosion.

3. **The rate of ice loss from the Greenland and Antarctic Ice Sheets is increasing.**
   These ice sheets will soon become the primary contributor to global sea-level rise, overtaking the contributions from ocean thermal expansion and melting mountain glaciers and ice caps. Ice loss from Antarctica, and especially from West Antarctica, causes higher sea-level rise in California than the global average: for example, if the loss of West Antarctic ice were to cause global sea-level to rise by 1 foot, the associated sea-level rise in California would be about 1.25 feet.

4. **New scientific evidence has highlighted the potential for extreme sea-level rise.**
   If greenhouse gas emissions continue unabated, key glaciological processes could cross thresholds that lead to rapidly accelerating and effectively irreversible ice loss. Aggressive reductions in greenhouse gas emissions may substantially reduce but do not eliminate the risk to California of extreme sea-level rise from Antarctic ice loss. Moreover, current observations of Antarctic melt rates cannot rule out the potential for extreme sea-level rise in the future, because the processes that could drive extreme Antarctic Ice Sheet retreat later in the century are different from the processes driving loss now.

5. **Probabilities of specific sea-level increases can inform decisions.**
   A probabilistic approach to sea-level rise projections, combined with a clear articulation of the implications of uncertainty and the decision support needs of affected stakeholders, is the most appropriate approach for use in a policy setting. This report employs the framework of Kopp et al. 2014 to project sea-level rise for three representative tide gauge locations along the Pacific coastline: Crescent City in Northern California, San Francisco in the Bay Area, and La Jolla in Southern California. These projections may underestimate the likelihood of extreme sea-level rise, particularly under high-emissions scenarios, so this report also includes an extreme scenario called the H++ scenario. The probability of this scenario is currently unknown, but its consideration is important, particularly for high-stakes, long-term decisions.

6. **Current policy decisions are shaping our coastal future.**
   Before 2050, differences in sea-level rise projections under different emissions scenarios are minor but they diverge significantly past mid-century. After 2050, sea-level rise projections increasingly depend on the trajectory of greenhouse gas emissions. For example, under the extreme H++ scenario rapid ice sheet loss on Antarctica could drive rates of sea-level rise in California above 50 mm/year (2 inches/year) by the end of the century, leading to potential sea-level rise exceeding 10 feet. This rate of sea-level rise would be about 30-40 times faster than the sea-level rise experienced over the last century.

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7. **Waiting for scientific certainty is neither a safe nor prudent option.**
   High confidence in projections of sea-level rise over the next three decades can inform preparedness efforts, adaptation actions and hazard mitigation undertaken today, and prevent much greater losses than will occur if action is not taken. Consideration of high and even extreme sea levels in decisions with implications past 2050 is needed to safeguard the people and resources of coastal California.

Global Greenhouse Gas Emissions Scenarios

The pace and severity of sea-level rise will depend on several factors, including – most importantly – the pace and scale of global greenhouse gas (GHG) emissions and the success of subsequent reduction measures over this century. During the past five years, the atmospheric greenhouse gas concentrations have continued to increase. Since late 2015, measurements of the atmospheric CO_2 concentration have consistently exceeded 400 parts per million (PPM). Recent concentrations are approximately 45% higher than the pre-industrial level, and about 2.5% higher than in 2012. Increases in CO_2 and other greenhouse gases have resulted in the Earth's climate system absorbing more energy than it is emitting back to space. More than 90% of this excess heat is being captured by the global ocean, leading to a subsequent increase in sea surface temperatures and ocean heat content. Rising temperatures are melting glaciers and ice sheets. Combined with the expansion of seawater as it warms, these changes are causing sea levels to rise.

For this Guidance, the emissions scenarios included are the same as those used by the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC Fifth Assessment) and are called Representative Concentration Pathways or RCPs. There are four RCPs, named for the associated radiative forcing level, in watts per square meter, in 2100: RCP 8.5, 6.0, 4.5 and 2.6. Each RCP represents a family of possible underlying socioeconomic conditions, policy options and technological considerations, spanning from a low-end scenario (RCP 2.6) that requires significant emissions reductions to a high-end, "business-as-usual," fossil-fuel-intensive emission scenario (RCP 8.5). For this Guidance, we focus on RCP 2.6 and RCP 8.5 to bound a range of potential sea level futures based on GHG emissions trajectories.

RCP 8.5, often referred to as a "business-as-usual" scenario, is consistent with a future where there are few global efforts to limit or reduce emissions. Under RCP 8.5, global CO_2 emissions nearly double between years 2015 and 2050. At the other end of the spectrum, RCP 2.6 is an aggressive emissions reduction scenario that assumes global greenhouse gas emissions will be significantly curtailed. Under this scenario, global CO_2 emissions decline by about 70% between 2015 and 2050, to zero by 2080, and below zero thereafter. Though more aggressive, RCP 2.6 most closely corresponds to the aspirational goals of the United Nations Framework Convention on Climate Change (UNFCCC) 2015 Paris Agreement, which calls for limiting global mean warming to less than 2°C and achieving net-zero greenhouse gas emissions in the second half of this century.

We include RCP 8.5 as an upper bound for California's sea-level response projections because thus far, our greenhouse gas emissions worldwide have continued to follow the business-as-usual trajectory. Without a significant and timely commitment to reducing emissions across the globe, we will remain on this dangerous trajectory. We include RCP 2.6 as a lower bound because, although it will be challenging to achieve, it is important that we align with California's ambitious greenhouse gas reduction efforts. California has established emission reduction targets through efforts such as Assembly Bill 32 (Global Warming Solutions Act of 2006, which requires California to reduce its GHG emissions to 1990 levels by 2020),[8] Senate Bill 32 (which codifies a 2030 emissions reduction target of 40% below 1990 levels),[9] and the Under2 Coalition.[10] Throughout this Guidance, we refer to RCP 8.5 and RCP 2.6 as "high-emissions" and "low-emissions" scenarios, respectively.

8. http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.pdf
9. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32
10. Under2 Coalition: Subnational Global Climate Leadership Memorandum of Understanding: http://under2mou.org/

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Advances in Sea-Level Rise Modeling

The OPC Scientific Working Group extensively analyzed different scientific approaches to modeling sea-level rise. They ultimately concluded that the best available approach today is the comprehensive probability approach based on Kopp et al. 2014, described below. Recognizing that the comprehensive probability approach may underestimate the likelihood of extreme sea-level rise, particularly under high emission scenarios, the Scientific Working Group also concluded that the H++ extreme sea-level rise scenario in the Fourth National Climate Assessment should be considered as well. A brief description of the scientific approaches is described in part here, and in significant detail in Rising Seas.

One approach, commonly referred to as scenario-based projections, focuses on providing scenarios that span a range of possible futures, without assessing the relative likelihood or probability of those scenarios. Another approach, called probabilistic projections, focuses on estimating the probability of different levels of future sea-level change, either by estimating a central projection with an associated range or by attempting to estimate a comprehensive probability distribution that also estimates the likelihood of extreme 'tail' outcomes. Probabilistic projections provide estimates of probability distributions of possible future sea-level rise outcomes, whereas scenario-based projections do not forecast future changes, but describe plausible conditions that support decision making under uncertainty.

DISCUSSION OF PROBABILISTIC PROJECTIONS

Probabilistic projections of sea-level rise included in this Guidance, based on Kopp et al. 2014 and the Rising Seas Report, represent the best available science. However, it is important to understand how these projections are developed and recognize that they serve as a guide for decision makers to understand current knowledge rather than as precise predictions of future conditions. As with all climate change projections, methodologies will continue to evolve over time as scientific knowledge and modeling capabilities improve.

Bayesian Probabilities:
Scientific statements about the probability or likelihood of different future pathways, such as those made by probabilistic sea-level rise projections or by the Intergovernmental Panel on Climate Change, are examples of Bayesian probabilities. Bayesian probabilities are based upon a synthesis of multiple lines of evidence and represent an assessment of the strength of the observational, modeling, and theoretical evidence supporting different future outcomes. Probabilistic projections differ from frequentist probabilities, as described below.

Frequentist Probabilities:
Frequentist probabilities are based on the historical frequency of occurrence, such as those commonly seen in estimating disease rates or determining flood risk. For example, the 1% annual exceedance probability flood (or the 100-year flood) is a flood of a level that historically occurred in about 1 in 100 years.

A Bayesian probabilistic framework can support improved decision making and easily integrate new lines of scientific evidence but may under- or overestimate sea-level rise contributions beyond 2050 and could lead to confusion if decision makers are unclear about the difference between Bayesian and frequentist probabilities.[11] Nonetheless, probabilistic projections represent consensus on the best available science for sea-level rise projections through 2150. With continued advances in sea-level rise science, it is expected that probabilistic projections will change in the future. However, the evolving nature of sea-level rise projections does not merit taking a 'wait and see' approach. Acting now is critical to safeguard the people and resources of California.

11. D. Behar, R Kopp, R. DeConto, C Weaver, K. White, K. May, R. Bindschadler. Planning for Sea Level Rise: An AGU Talk in the Form of a Co-Production Experiment Exploring Recent Science. December 2017. https://www.wucaonline.org/assets/pdf/pubs-agu-consensus-statement.pdf

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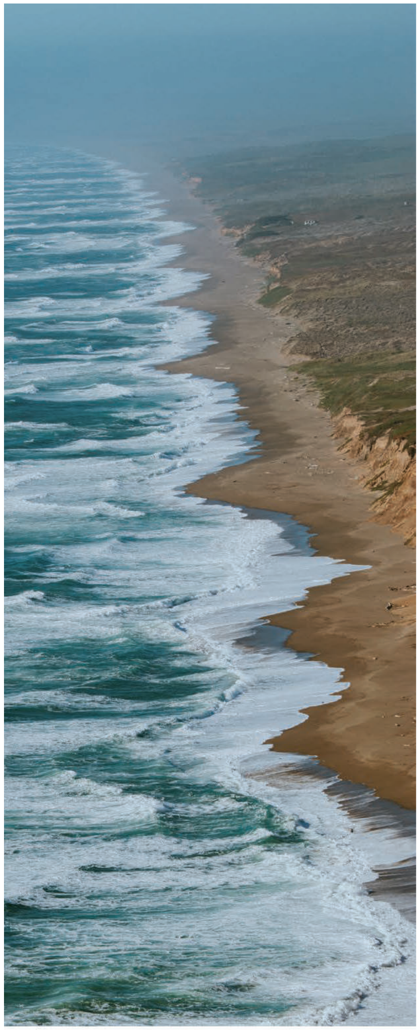

Importantly, the scenario-based and probabilistic approaches differ in how they represent the dependence of future sea-level change on specific greenhouse gas emission scenarios (RCPs). Scenario-based projections are often informed by greenhouse gas emissions scenarios but may not be tied to specific RCPs and do not include a measure of likelihood of occurrence. In contrast, probabilistic projections estimate probability distributions regarding sea-level rise under the various RCPs. It is important to note that probabilistic projections do not provide actual probabilities of occurrence of sea-level rise but provide probabilities that the ensemble of climate models used to estimate contributions of sea-level rise (from processes such as thermal expansion, glacier and ice sheet mass balance, and oceanographic conditions, among others) will predict a certain amount of sea-level rise. As climate science continues to evolve and models are updated in the future, the probability distribution of model results - and the associated probabilities - are also likely to change.

The 2013 OPC Guidance was based on scenario-based sea-level rise projections from the 2012 National Research Council report, which produced a set of three scenarios (low, central, and high), with greater weight given to the central scenario. Subsequently, in 2013, the IPCC Fifth Assessment Report adopted a probabilistic approach and produced estimates of the likely range of global sea-level rise under different emission scenarios, where 'likely' covers the central 66% of the probability distribution (i.e., the sea levels that fall within the range created by the value that is 17% likely to occur and the value that is 83% likely to occur). The IPCC Fifth Assessment Report did not estimate sea-level rise outside these central 66% probability ranges or produce local projections for California.[11]

The IPCC Fifth Assessment served as a starting point for further probabilistic modeling and represented a shift away from scenario-based approaches. However, the absence of local projections and the failure to account for estimated probabilities outside the 66% range led Kopp et al. 2014 to synthesize

12. See Rising Seas Report, page 19

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several lines of evidence to estimate comprehensive probability distributions for global mean sea level and local relative sea level changes under different emissions scenarios. In this approach, outputs from process-based models are combined with estimates of contributions from the polar ice sheets derived from an expert elicitation process.[13]

After considering a range of approaches, the OPC-SAT Scientific Working Group concluded in the Rising Seas Report that the comprehensive probabilistic approach employed by Kopp et al. 2014 was most appropriate for use in a policy setting in California. Consequently, for projections of sea-level rise other than that associated with the West Antarctic ice melt scenario, this Guidance adopts the comprehensive probabilistic approach. Similar modeling methods and frameworks have been utilized in other states and regions, including New York City[14], New Jersey[15], Oregon[16], regional groups in Washington State[17], and Boston[18]. It is important to note that the comprehensive probabilistic approach may underestimate the likelihood of extreme sea-level rise in the second half of this century and beyond, particularly under high-emissions scenarios.[19]

To address the potential for extreme sea-level rise as a result of ice loss from the West Antarctic Ice Sheet, this Guidance adopts the scientific approach in the Rising Seas Report by incorporating an extreme scenario—without an assigned probability—that is based on more recent understanding of Antarctic marine ice instability. Ice loss from the West Antarctic Ice Sheet has the potential to be a key contributor to sea-level rise in California in the coming decades. The OPC-SAT Scientific Working Group concluded that the H++ extreme sea-level rise scenario developed by Sweet et al. 2017 for the Fourth National Climate Assessment should be considered alongside the Kopp et al. 2014 comprehensive probability distributions for the RCPs. Sweet et al. 2017 maintained a scenario-based approach, but drew upon the Kopp et al. 2014 framework to localize projections and to discuss the likelihood of scenarios under different emissions pathways. Sweet et al. 2017 also developed an "extreme" scenario, leading to 8.2 feet of global mean sea-level rise in 2100 that is based on considerations derived from recent ice-sheet observations and new model simulations from Deconto and Pollard 2016[20] and also other attempts in the literature to estimate 'maximum physically plausible' sea-level rise.

Including consideration of this rapidly developing science is critical given the important role of the Antarctic Ice Sheet in both local and global sea-level rise projections. However, at this point, it is difficult to estimate the probability that the H++ scenario will occur, and when the world may shift to the H++ trajectory. Although sea-level rise is not following the H++ scenario at this moment, this scenario cannot be excluded for the second half of this century given the potential for non-linear acceleration of sea-level rise driven by positive feedbacks of ice-sheet dynamics and the significant consequences to California's coastline.

The approach to sea-level rise projections for the Guidance update is slightly more conservative than California's Fourth Climate Assessment, which is currently underway and due out in fall 2018. California's Fourth Climate Assessment directly adopted the Antarctic projections of Deconto and Pollard 2016, replacing in full the Antarctic projections of Kopp et al., 2014. For the purposes of use in policy guidance, the authors of the Rising Seas Report chose to include the H++ projections as a stand-alone scenario rather than incorporating ice sheet dynamics associated with this extreme into the model ensemble used to generate probabilistic projections. Because of the high level of uncertainty associated with physical processes that would trigger the H++ scenario and the emerging nature of the science, the authors felt the stand-alone scenario application was more appropriate for planning and permitting decisions at this time.

13. See Rising Seas Report, page 20
14. https://www.nyclimatescience.org/catalog/doc?DocId=vitroIndividual:http://www.nyclimatescience.org/individual/n8040
15. http://njadapt.rutgers.edu/docman-lister/conference-materials/167-njcaa-stap-final-october-2016/file
16. http://www.occri.net/media/1042/ocar3_final_125_web.pdf
17. http://docs.wixstatic.com/ugd/a3bdcc_1c4b6b33caf54836a2cac641b7ebe53b.pdf
18. https://www.boston.gov/sites/default/files/03_climate_ready_boston_digital_climateprojectionconsensus.pdf
19. See Rising Seas Report, page 22

20. http://www.nature.com/nature/journal/v531/n7596/full/nature17145.html?foxtrotcallback=true

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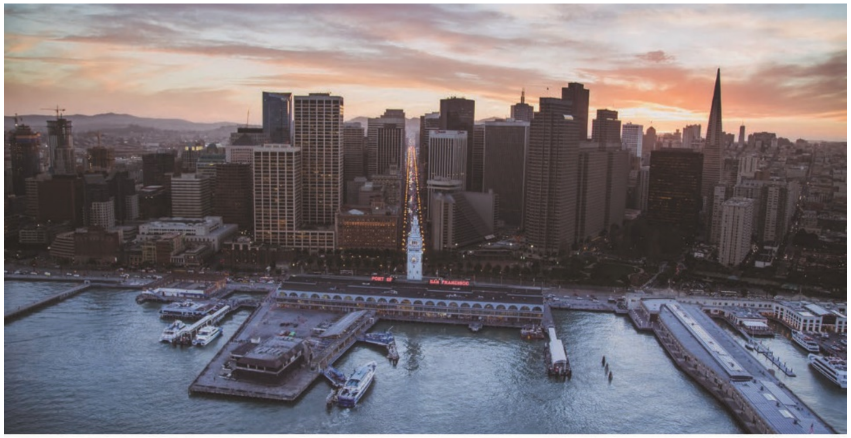

Sea-Level Rise Projections for California

THE RISING SEAS REPORT PRESENTED a range of sea-level rise projections for a subset of the active tide gauges in California based on emission trajectories, acknowledging that projected sea-level rise has a significant range of variation as a result of uncertainty in future greenhouse gas emissions and their geophysical effects, such as the rate of land ice melt. Below are tables that build on those included in the Rising Seas Report for projections over different time frames and emission scenarios at the San Francisco tide gauge. The same details included for the San Francisco tide gauge below can also be found for all 12 active tide gauges along the California coast[21] in Appendix 3.

The baseline for the sea-level rise projections presented in the Rising Seas Report and this Guidance is the year 2000[22]. Projections begin at 2030, consistent with the 2013 Guidance; however, the maximum planning horizon has been extended to 2150 to support precautionary planning and decision making for projects with longer lifespans.

21. Active tide gauges locations include: Crescent City, North Spit (Eureka), Arena Cove, Point Reyes, San Francisco, Monterey, Port San Luis, Santa Barbara, Santa Monica, Los Angeles, San Diego and La Jolla; see Appendix 2 for map.
22. The year 2000 baseline is based on the average relative sea-level rise from 1991-2009.

How much sea-level rise will California experience over this century?

The following table provides probabilistic projections for the height of sea-level rise over various timescales for RCP 2.6 (low emissions) and RCP 8.5 (high emissions), along with the extreme H++ scenario (which is a single scenario and not a probabilistic projection). These numbers do not include impacts of El Niño, storms or other acute additions to sea-level rise. As discussed in more detail below, before 2050, differences in sea-level rise projections under different emissions scenarios are minor, and currently the world is on the RCP 8.5 emission trajectory. However, beyond 2050, different emissions pathways will result in significantly different levels of sea-level rise. Therefore, this Guidance includes projections only for a high greenhouse gas emissions scenario through 2050, and includes projections for both high and low emissions scenarios from 2050 through 2150.

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TABLE 1: Projected Sea-Level Rise (in feet) for San Francisco

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1.0
	2040	0.6	0.5	-	0.8	1.0	1.3	1.8
	2050	0.9	0.6	-	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6	-	1.3	1.6	2.4	
High emissions	2060	1.1	0.8	-	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8	-	1.5	1.9	3.1	
High emissions	2070	1.4	1.0	-	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9	-	1.8	2.3	3.9	
High emissions	2080	1.7	1.2	-	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0	-	2.1	2.8	4.7	
High emissions	2090	2.1	1.4	-	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0	-	2.4	3.2	5.7	
High emissions	2100	2.5	1.6	-	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2	-	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9	-	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2	-	2.8	3.9	7.4	
High emissions	2120	3	2.2	-	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3	-	3.1	4.4	8.5	
High emissions	2130	3.3	2.4	-	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3	-	3.4	4.9	9.7	
High emissions	2140	3.7	2.6	-	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3	-	3.8	5.5	11.0	
High emissions	2150	4.1	2.8	-	5.8	5.7	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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When is sea-level rise going to exceed a particular height in California?

In addition to understanding the potential range of sea-level rise projections as presented in the table above, it may be helpful for decision makers to understand when a particular level is projected to occur. The following table provides information on the likelihood that sea-level rise will meet or exceed a specific height over various timescales. However, the H++ scenario is not included in this table. Again, this information is presented for a high-emissions scenario through 2050 and both low- and high-emissions scenarios post-2050. It is important to note that episodic events, such as king tides, storms, El Niños, and waves may cause acute increases in sea level heights sooner than is shown in Table 2 below.

TABLE 2: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in San Francisco

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 - 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

SAN FRANCISCO - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	3.3%									
2050	31%	0.4%								
2060	65%	3%	0.2%	0.1%						
2070	84%	13%	1.2%	0.2%	0.1%					
2080	93%	34%	5%	0.9%	0.3%	0.1%	0.1%			
2090	96%	55%	14%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	28%	8%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	52%	28%	15%	8%	4%	3%	2%

SAN FRANCISCO - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	43%	1.4%	0.2%							
2070	62%	4%	0.6%	0.2%	0%					
2080	74%	11%	2%	0.4%	0.2%	0.1%				
2090	80%	20%	3%	1.0%	0.4%	0.2%	0.1%	0.1%		
2100	84%	31%	7%	2%	0.8%	0.4%	0.2%	0.1%	0.1%	
2150	93%	62%	31%	14%	7%	4%	2%	2%	1%	1%

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What will the rate of sea-level rise be in California?

The rate at which sea levels will rise can help inform the planning and implementation timelines of state and local adaptation efforts. Rates of sea-level rise are also important to consider when evaluating the ability of natural and restored coastal habitats to adapt to rising seas. In some cases, sea-level rise may exceed the rate at which habitats, such as coastal wetlands, can accrete sediment, migrate inland or to adjacent neighboring low-lying areas, resulting in flooding and loss and destruction of these important ecological systems. Understanding the speed at which sea level is rising can provide context for planning decisions and establish thresholds for action to better protect habitats and their ecological and resiliency benefits. The information in the table listed below is presented for a high-emissions scenario through 2050 and both low- and high-emissions scenarios post-2050.

TABLE 3: Projected Average Rate of Sea-Level Rise (mm/year) for San Francisco

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column). Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				*H++ scenario (Sweet et al. 2017) *Single scenario*
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	*66% probability sea-level rise is between...*	*5% probability sea-level rise meets or exceeds...*	*0.5% probability sea-level rise meets or exceeds...*	
			Low Risk Aversion		**Medium - High Risk Aversion**	**Extreme Risk Aversion**
High emissions	2030-2050	6.7	4.5 - 9.3	12	17	26
Low emissions	2060-2080	5.3	3.1 - 8.2	12	22	
High emissions	2060-2080	9.5	6.4 - 13	17	28	42
Low emissions	2080-2100	5.2	2.3 - 9.1	14	28	
High emissions	2080-2100	11	6.0 - 16	22	37	55

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Guidance on How to Select Sea-Level Rise Projections

SELECT SEA-LEVEL RISE PROJECTIONS BY TAKING A STEP-WISE APPROACH AND CONSIDERING A SUITE OF FACTORS AND CONDITIONS.

This Guidance summarizes the best available sea-level rise science, which includes probabilistic projections, an extreme scenario, and a recognition that these projections may change in the future. Although sea-level projections may change in the future, when used as part of the risk management process outlined in this Guidance, they provide vital information for adaptation actions and hazard mitigation undertaken today. Decisions about which sea-level rise projections to select - and the necessary adaptation pathways and contingency plans to ensure resilience - will be based on factors including location, lifespan of the given project or asset, sea-level rise exposure and associated impacts, adaptive capacity, and risk tolerance/aversion.

An adaptation pathway is a planning approach addressing the uncertainty and challenges of climate change decision-making. It enables consideration of multiple possible futures, and allows analysis of the robustness and flexibility of various options across those multiple futures.[23]

Adaptive capacity is the ability of a system or community to evolve in response to, or cope with the impacts of sea-level rise.[24] 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

23. South West Climate Change Portal: Catchment Planning - Using Adaptation Pathway: http://www.swclimatechange.com.au/cb_pages/adaptation_pathways.php
24. Willows RI, RK Connell (eds.). 2003. Climate Adaptation: Risk, Uncertainty and Decisionmaking. UKCIP Technical Report. Oxford: UKCIP. 154 pp. http://www.ukcip.org.uk/wordpress/wp-content/PDFs/UKCIP-Risk-framework.pdf

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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.

Risk tolerance is the level of comfort associated with the consequences of sea-level rise and associated hazards in project planning and design.[25] 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 projections and determine their tolerance for, or aversion to, those risks

Assessing risk requires evaluation of two dimensions: 1) uncertainty, which can be analyzed and assessed using a range of sea-level rise projections, and 2) impacts or consequences, which may require a combination of quantitative and qualitative assessments. The step-wise approach we provide guides decision makers through both dimensions of the risk analysis. Depending on the finite factors of location and project lifespan, decision makers will evaluate the potential impacts and adaptive capacity of the project across a spectrum of sea-level rise projections. This analysis will enable the decision maker to select the appropriate projection for the particular project while building in adaptation pathways and contingency plans should that projection be exceeded. These steps complement other State guidance documents that provide a step-wise approach to the analysis needed to incorporate sea-level rise into planning and decision making, such as the California Coastal Commission's Sea Level Rise Policy Guidance[26] and Draft Residential Adaptation Policy Guidance.[27]

25. Parris A, P Bromirski, V Burkett, D Cayan, M Culver, J Hall, R Horton, K Knuuti, R Moss, J Obeysekera, A Sallenger, J Weiss. 2012. Global Sea-level rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp. http://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf
26. https://documents.coastal.ca.gov/assets/slr/guidance/August2015/0_Full_Adopted_Sea_Level_Rise_Policy_Guidance.pdf
27. https://documents.coastal.ca.gov/reports/2017/8/w6h/w6h-8-2017-exhibits.pdf#page=2

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The following steps, outlined in the figure and in more detail below, provide a decision framework to evaluate the consequences and risk tolerance of various planning decisions, and should be used to guide selection of appropriate sea-level rise projections, and, if necessary, develop adaptation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded:

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

>> STEP 2: *Evaluate project lifespan.*

>> STEP 3: *For the nearest tide gauge and project lifespan, identify range of sea-level rise projections.*

>> STEP 4: *Evaluate potential impacts and adaptive capacity across a range of sea-level rise projections and emissions scenarios.*

>> STEP 5: *Select sea-level rise projections based on risk tolerance and, if necessary, develop adapation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded.*

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STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

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

Sea levels and rates of sea-level rise will vary along the California coast due to variable land elevations resulting from factors such as tectonic activity and subsidence. This difference between the height of the sea surface and the height of the land is called relative sea level, and the National Oceanic and Atmospheric Administration (NOAA) provides a summary of the trends in the measured relative sea level at 12 active tide gauges (water level recorders) in California that have been operating for at least 39 years and up to 162 years.[28,29] For localized sea-level rise projections, relative trends in sea level from changes in land elevation should be factored into the analysis. Therefore, of the 12 tide gauges across California, start by identifying the tide gauge nearest to the project location, in Appendix 2. This step will orient the user to the appropriate projection table. If the project is located in an area between two tide gauges, refer to Appendix 2 to determine which tide gauge is closest to your location. If the project is nearly equidistant between two tide gauges, it is appropriate to interpolate between or average the two tide gauges. The 12 active tide gauges along the California coast cannot account for specific local variation across the entire shoreline of the state; however, data driven projections using information from these tide gauges provides the most scientifically rigorous approach to estimating localized sea-level rise projections. If additional scientific data is available, it may be evaluated and considered in local planning decisions.

>> STEP 2: *Evaluate project lifespan.*

Prior to 2050, differences in sea-level rise projections under different emissions scenarios are minor. This is because near-term sea-level rise has been locked in by past greenhouse gas emissions and the slow response times of the ocean and land ice to warming. The long-lived nature of most greenhouse gases means that their impacts on the environment are felt and experienced long after being emitted. Comparatively, after 2050, sea-level rise projections increasingly depend on the pathway of future greenhouse gas emissions. Therefore, this Guidance only includes sea-level rise projections based on a high scenario of greenhouse gas emissions (RCP 8.5; "high emissions") through 2050, and includes projections for both the RCP 2.6 "low-emissions" scenario as well as the RCP 8.5, "high-emissions" scenario after 2050 through 2150. The Guidance also includes an extreme sea-level rise scenario, the H++ scenario, which is not tied to a specific emissions trajectory but should be considered for projects with a lifespan beyond 2050 that have a low tolerance for risk, such as large power plants, major airports and roads, wastewater treatment plants, and hazardous waste and toxic storage sites. The H++ scenario may also be relevant to communities considering regional or general plans, climate action plans, local hazard mitigation plans, regional transportation plans, and other planning efforts, due to the interrelated nature of critical infrastructure, homes, businesses, etc. Determining project lifespan will guide whether to evaluate sea-level rise projections for the high-emissions scenario only (in the case of projects with a lifespan that ends before 2050) or across the range of high- and low-emissions scenarios for projects with a lifespan beyond 2050.

28. https://tidesandcurrents.noaa.gov/water_level_info.html
29. See Rising Seas Report, Box 2, page 23

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JUSTIFICATION FOR RECOMMENDED LOW, MEDIUM-HIGH AND EXTREME RISK AVERSION PROJECTIONS

This guidance document will inform a breadth of planning and adaptation decisions at both the state and local level. As such, it provides high-level guidance on the appropriate range of sea-level rise projections to be considered in project planning and design, while providing enough flexibility to allow for local priorities and trade-offs to determine final decisions. To ensure that consideration of sea-level rise is precautionary enough to safeguard the people and resources of California and that sufficient adaptation pathways and contingency plans are developed, we recommend that decisions evaluate a range of projections based on low, medium-high and extreme levels of risk aversion:

Projection for decisions with low risk aversion: Use the upper value of the "likely range" for the appropriate timeframe. This recommendation is fairly risk tolerant, as it represents an approximately 17% chance of being overtopped, and as such, provides an appropriate projection for adaptive, lower consequence decisions (e.g. unpaved coastal trail) but will not adequately address high impact, low probability events. Additionally, it is important to note that the probabilistic projections may underestimate the likelihood of extreme sea-level rise, particularly under high-emissions scenarios.

Projection for decisions with medium – high risk aversion: Use the 1-in-200 chance for the appropriate timeframe. The likelihood that sea-level rise will meet or exceed this value is low, providing a precautionary projection that can be used for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea-level rise (e.g. coastal housing development). Again, this value may underestimate the potential for extreme sea-level rise.

Projection for decisions with extreme risk aversion: Use the H++ scenario for the appropriate timeframe. For high consequence projects with a design life beyond 2050 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 should this level of sea-level rise occur, the H++ extreme scenario should be included in planning and adaptation strategies (e.g. coastal power plant). Although estimating the likelihood of the H++ scenario is not possible at this time (due to advancing science and the uncertainty of future emissions trajectory), the extreme sea-level rise projection is physically plausible and will provide an understanding of the implications of a worst-case scenario.

>> STEP 3: *For the nearest tide gauge and project lifespan, identify range of sea level rise projections.*

Considering a range of different sea-level rise projections allows decision makers to evaluate the vulnerability of people, natural resources and infrastructure under various future flooding conditions, as well as their level of comfort with over- or underestimating sea-level rise. Because future projections of sea-level rise along California's coastline are uncertain (due to uncertainty associated with modeling and the trajectory of global emissions), it is critical to consider a range of projections to understand the consequences of various decisions, determine the tolerance for risk associated with those decisions, and to inform adaptation strategies necessary to prepare for change in the face of uncertainty. We recommend using a set of projections appropriate for low, medium-high and extreme levels of risk aversion to evaluate a spectrum of potential impacts, consequences and responses. (See adjacent call-out box for justification on the recommended projections.)

For the low risk aversion sea-level rise projection, use the upper end in the "likely range" as shown in Table 1 above or in Appendix 3. For the medium-high risk aversion sea-level rise projection, use the 1-in-200 chance projection. For highly vulnerable or critical assets that have a lifespan beyond 2050 and would result in significant consequences if damaged, the H++ scenario (extreme risk aversion projection) should also be included in planning analyses. For example, for a project in San Francisco with a lifespan to 2050 under a high-emissions scenario (RCP 8.5), the recommended range of projections from Table 1 are:

Low risk aversion projection:	1.1 feet
Medium-high risk aversion projection:	1.9 feet
Extreme risk aversion projection:	2.7 feet

For projects with a lifespan beyond 2050, the range of low, medium-high and extreme risk aversion projections should be evaluated across the range of high and low emissions scenarios (RCP 8.5 and RCP 2.6, respectively). For example, for a project with a lifespan to 2100, the recommended range of projections from Table 1 are:

Low risk aversion projection:	2.4 - 3.4 feet
Medium-high risk aversion projection:	5.7- 6.9 feet
Extreme risk aversion projection:	10.2 feet

>> STEP 4: *Evaluate potential impacts and adaptive capacity across a range of sea level rise projections and emissions scenarios.*

After the appropriate low, medium-high, and extreme risk aversion projections have been identified based on location and timespan, the next step is to conduct a vulnerability assessment to evaluate the potential impacts of sea-level rise on the project and the project's adaptive capacity. This can be done using the sea-level rise mapping tools discussed later in this Guidance. In analyzing impacts and adaptive capacity, consider the following questions for each identified sea-level rise projection, which mirror components outlined in OPR's risk management approach of the Governor's Office of Planning and Research's "Planning and Investing for a Resilient California: A Guidebook for State Agencies[30]":

Consequence of potential impacts: If sea-level rise is not addressed adequately, will the consequences of the project on equity, environment, economy and governance (both to the development itself and to the surrounding environment and community) be minimal, moderate, or catastrophic?

What is at stake: Will vulnerable communities, coastal habitats, or critical infrastructure be significantly impacted?

Adaptive capacity: Can people, natural systems, and infrastructure readily respond or adapt to rising sea levels?

Economic impacts: Will failure to adequately plan for sea-level rise create significant economic burden now or in the future?

Evaluating these factors will help decision makers understand the vulnerabilities of people, assets and the natural environment under a range of sea-level rise possibilities and determine their tolerance for the risks associated with the consequences of over- or underestimating sea-level rise. This approach aligns with ongoing efforts throughout the state to complete vulnerability assessments, including the California Coastal Commission's Statewide Sea Level Rise Vulnerability Synthesis.[31] OPC recognizes that that the social, economic and environmental impacts of sea-level rise at different levels of exposure may be difficult to quantify and qualify, and ultimate decisions will require a balance of tradeoffs and priorities that may not be consistent across communities or jurisdictions.

30. https://opr.ca.gov/planning/icarp/resilient-ca.html
31. https://documents.coastal.ca.gov/assets/climate/slr/vulnerability/FINAL_Statewide_Report.pdf

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>> STEP 5: *Select sea-level rise projections based on risk tolerance and, if necessary, develop adaptation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded.*

OPC recommends utilizing a decision framework to assist in evaluating tradeoffs and determining the appropriate sea-level rise projections for the condition and characteristics of the shoreline being evaluated. The decision framework in Appendix 4 builds on the work of OPR in response to Governor Brown's Executive Order B-30-15, as well as the U.S. Climate Resilience Toolkit's guidance.[32] In general, decision makers may have a higher tolerance for risk (or lower risk aversion) when considering projects with a shorter lifespan, minimal consequences, flexibility to adapt, or low economic burden as a result of sea-level rise. In this decision context, it may be appropriate to select low sea-level rise projections across the range of RCP 2.6 and 8.5. However, for longer lasting projects with less adaptive capacity and medium to high consequences should sea-level rise be underestimated, we suggest that decision makers take the more precautionary, more risk-averse approach of using the medium-high sea-level rise projections across the range of emissions scenarios. We further recommend incorporating the H++ scenario in planning and adaptation strategies for projects that could result in threats to public health and safety, natural resources and critical infrastructure, should extreme sea-level rise occur.

In addition to selecting sea-level rise projections, coastal communities should consider phasing in short and long-term adaptation strategies over time when planning for sea-level rise. This concept of adaptation pathways considers the challenges of planning for uncertain timing and extent of rising sea levels while providing a structure for sequencing adaptation measures using the time horizon of projected hazards from a changing climate. The adaptation pathway approach links the choice of near-term adaptation actions with identification of pre-determined threshold events. Observation of such threshold events would trigger subsequent actions in the planning or implementation stages of adaptation strategies. Often an adaptation pathway includes low-regret, near-term actions that preserve future options to adjust if necessary. Observable events that might trigger new phases of adaptation might include the extent of flooding, frequency of damage, or the extent of economic development along the coast. These triggers should reflect a community's risk tolerance, local conditions, and adaptation vision.

Communities should look for signs that some adaptation options have run their course and plan adaptation pathways to transition actions as needed. Analyzing a worst-case "high" projection for the planning horizon of the project provides a conservative upper bound for planning pathways based on current information. Following this approach, which is used in other recent sea-level rise guidance documents[33,34] and cited in more recent policy writing,[35,36] a community or project might consider an adaptive plan, which includes contingency responses if climate hazards occurs more quickly than expected. The adaptive plan need not choose between future options now, but would include steps to keep future options open. For instance, the plan could include identifying a future inland site and zoning the land so that it would be available in the future if needed. This trigger-based adaptation planning is discussed further in Recommendation 7 below.

32. https://toolkit.climate.gov/topics/coastal/sea-level-rise

33. Coastal Hazards and Climate Change. Guidance for Local Government. New Zealand Government, Ministry for the Environment. http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government

34. California Coastal Commission Draft Residential Adaptation Policy Guidance. July 2017. https://documents.coastal.ca.gov/reports/2017/8/w6h/w6h-8-2017-exhibits.pdf#page=2

35. Haasnoot, M., J. Kwakkel, W. Walker, J. Maat. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change. 2013. 485-498. https://documents.coastal.ca.gov/assets/slr/guidance/August2015/0_Full_Adopted_Sea_Level_Rise_Policy_Guidance.pdf

36. Center for Ocean Solutions. Coastal Adaptation Policy Brief. December 2017. http://centerforoceansolutions.org/sites/default/files/Triggers%20WEB.pdf

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Recommendations for Sea-Level Rise Planning and Adaptation

The step-wise approach above provides guidance on how to select sea-level rise projections by evaluating risk and vulnerability. The following recommendations 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 vulnerable communities.

Communities of color, low-income communities, and Native Nations 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 places of ancient and contemporary cultural and 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

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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 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 and Native 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 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 Californians.

- ***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 groundwater could help prevent major long-term economic damage to agriculture and farmworkers.

- ***Address emergency services and response to natural disasters.*** Low-income, immigrant communities and other vulnerable populations 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, including managed retreat.*** Strategies to protect shoreline development from sea-level rise impacts should prioritize the use of natural infrastructure where feasible or appropriate and minimize shoreline armoring and flood barriers. 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, may increase wave and storm run-up, and can prevent coastal habitats from migrating inland, 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. There is a breadth of resources available to guide the implementation of natural solutions including a recently released report, "Case Studies of Natural Shoreline Infrastructure in Coastal California"[37] as part of California's Fourth Climate Change Assessment.

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.[38] 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 overall ecological function of coastal systems.

In addition to prioritizing natural infrastructure, managed retreat should be considered as a possible adaptation strategy to address rising sea levels. Managed retreat refers to varying approaches to managing coastal hazard risk by structure relocation and/or abandonment of land.[39] These strategies can result in a landward redevelopment pattern and a managed realignment of development along the coast so that natural erosion and other coastal processes, including beach formation and creation, can continue. Managed retreat allows shorelines to migrate inland naturally, rather than using seawalls, flood barriers, or rock revetments to anchor them in a specific location. This strategy may involve removal or relocation of residential, commercial, or industrial development and restoration of natural areas to enhance ecosystem services, make sound infrastructure investments, and provide additional protection and safety against flooding through buffering effects, as described above.

37. http://scc.ca.gov/files/2017/11/tnc_Natural-Shoreline-Case-Study_hi.pdf

38. Newkirk, S, S. Veloz, M. Hayden, W. Heady, K. Leo, J. Judge, R. Battalio, T. Cheng, T. Ursell, and M. Small. (The Nature Conservancy and Point Blue Conservation Science). 2018. Toward Natural Infrastructure to Manage Shoreline Change in California. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CNRA-CCC4A-2018-3B. Expected release August 2018.

39. Hino, M., Field, C.B. and Mach, K.J., 2017. Managed retreat as a response to natural hazard risk. Nature Climate Change. https://www.nature.com/articles/nclimate3252.

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Managed retreat 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 retreat 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 managed retreat, 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 grey 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.

Future sea-level rise projections presented in this Guidance do not include acute increases in water level associated with El Niño events, king tides, storm surges or large waves. Alone or in combination, these events will produce significantly higher water levels than 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 for the San Francisco Bay to understand current and future flood risk.[40] 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.[41]

40. www.adaptingtorisingtides.org
41. https://www.fema.gov/coastal-frequently-asked-questions#How is FEMA accounting for sea level rise and climate change on the FIRMs? Does sea level rise/climate change affect the FIRMs?

5. Coordinate and collaborate with local, state and federal agencies when selecting sea-level rise projections; where feasible, use consistent sea-level rise projections 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 projections 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. Include adaptive capacity in design and planning.

Uncertainty around the magnitude and timing of future sea-level rise, coupled with the potential impacts of rising seas on California's coastline, warrant a proactive approach that builds adaptive capacity into project design and planning. Projects or resources that can more easily adapt to sea-level rise will experience fewer consequences and will be

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more resilient against risks associated with sea-level rise and other coastal climate-related impacts.

If designing a project to accommodate high or extreme sea-level rise is not critical in the near term, but the likelihood of impacts is expected to increase with rising sea level, adaptive capacity should be built into project design or planning using triggers and phased adaptation measures or adaptation pathways, as described in Step 5 above. Triggers are predetermined thresholds that, when crossed, prompt implementation of identified adaptation measures. For example, one trigger mechanism could require that, when sea-level rise reaches a certain level, identified adaptive measures must be taken. Alternatively, the occurrence of a specific impact such as the flooding of a highway could act as a trigger. An increase in the frequency of a specific sea-level rise-associated impact, such as the flooding of a coastal trail ten times in a year rather than a historically traditional three times a year, also could be a trigger.

Adaptation measures may include, but are not limited to, removal of threatened structures (including identification of parties responsible for removal) or relocation of public access. Trigger-based adaptation planning may also include the following approaches: 1) a no-regrets response, involving prohibition or restriction of development in the most vulnerable areas; 2) a tempered response, involving restriction or changing conditions for redevelopment after an event; and 3) a proactive response, involving investigation of opportunities to relocate vulnerable communities, critical infrastructure or coastal habitats.

Providing adaptive capacity for higher sea-level rise will allow projects to be designed for a more moderate level of sea-level rise but planned with enough flexibility that adaptation measures to minimize impacts can be implemented if the amount of sea-level rise is higher than anticipated in the original design. In other words, projects should be scoped (planned and designed) with the potential to be updated or changed if lower-probability, higher-impact sea level rise projections come to occur. Design and planning efforts that include a trigger-based adaptation pathways approach should include a monitoring component to ensure timely implementation of adaptation or contingency measures once impact or risk thresholds are crossed.

8. 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 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[42] are examples of regional planning efforts that can serve as models for other regional planning efforts throughout the state.

42. https://www.sdclimatecollaborative.org

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Tools Available to Visualize Sea-Level Rise Spatially

THERE ARE SUITES OF EXISTING GEOSPATIAL AND VISUALIZATION TOOLS that can be readily paired with the latest and best available sea-level rise projections. These include CoSMoS/Our Coast Our Future,[43,44] the NOAA Sea-Level Rise Viewer,[45] Cal-Adapt,[46] The Nature Conservancy (TNC) Coastal Resilience Toolkit[47] and Surging Seas Risk Finder.[48] Each viewer serves a unique niche, target audience and role, has strengths and limitations, and requires varying levels of skill to use. More information on these tools can be found on Sea the Future[49] (formerly known as Lifting the Fog) and on the State Adaptation Clearinghouse. In addition to assisting in the visualization and analysis of sea-level rise, these tools are also helpful aids in communicating about sea-level rise across local, state, and regional communities and planning and decision-making venues. In general, we recommend that the most detailed tool available for a particular area be used for planning, though in some cases a suite of tools should be evaluated to get a better picture of the possible risks.

- **CoSMoS** is a model that has been developed by the United States Geological Survey (USGS) in order to allow for more detailed predictions of coastal flooding due to both future sea-level rise and storms integrated with long-term coastal evolution (i.e., beach changes and cliff/bluff retreat) over large geographic areas. CoSMoS models the relevant physics of a coastal storm (e.g., tides, waves, and

43. https://walrus.wr.usgs.gov/coastal_processes/cosmos/
44. http://data.pointblue.org/apps/ocof/cms/
45. https://coast.noaa.gov/digitalcoast/tools/slr
46. http://cal-adapt.org/
47. http://coastalresilience.org/
48. https://riskfinder.climatecentral.org/
49. http://sealevel.climatecentral.org/matrix/CA.html?v=1

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storm surge), which are then scaled down to local flood projections for use in community-level coastal planning and decision-making. Rather than relying on historic storm records, CoSMoS uses wind and pressure from global climate models to project coastal storms under changing climatic conditions during the 21st century. CoSMoS projections are currently available for the north-central coast, San Francisco Bay, and Southern California. Modeling is underway for the Central Coast, to be completed in summer 2018. The North Coast of California is expected to be complete by the end of 2019. CoSMoS information can also be accessed, viewed, and downloaded through the Our Coast, Our Future (OCOF) flood mapper, which provides a user-friendly web-based tool for viewing results. OCOF provides resources and guidance for helping communities navigate the information provided by CoSMoS.

- **The NOAA Sea-Level Rise Viewer** is a visualization tool for coastal communities showing the potential impacts from sea-level rise and coastal flooding. The NOAA Viewer allows users to select the nearest NOAA tide gauge and identify relative sea-level rise scenarios based on the NOAA 2017 Technical Report[50], which includes the federal government's most updated scenarios that will inform the Fourth National Climate Assessment. These scenarios are similar to the probabilistic ranges for California. The tool allows users to visualize inundation by scenario or year and explore thresholds for levee overtopping. It also includes the ability to look at flood frequency, marsh migration, socio-economic impacts, and uncertainty. The maps consider static sea-level rise on top of mean higher high water[51] (MHHW) and are created using a "modified" bathtub approach that includes a hydrologic connectivity assessment. This means that areas are only shown as inundated if there is a feasible pathway for water to flow. The viewer is a screening-level, planning tool that uses nationally consistent data sets and analyses. Data and maps can be downloaded directly from the tool to enable users to develop their own visualizations to gauge trends and prioritize actions.

- **Cal-Adapt** makes scientific projections and analyses available as a basis for understanding local climate risks and resilience options. To date, development has been supported by the California Energy Commission and has targeted resilience needs of the energy sector. Released in 2017, Cal-Adapt 2.0 dramatically expands the capacities of the initial (2011) version of Cal-Adapt in five main ways, providing new climate projections, more powerful and flexible visualizations, improved access to data, a public applications programming interface (API) platform that enables external development of custom tools, and connection with supporting resources such as OPR's Integrated Climate Adaptation and Resiliency Program (ICARP). Forthcoming enhancements to Cal-Adapt will expand its sea-level rise tool to include selected results from USGS's CoSMoS model (portrayed in detail by the Our Coast, Our Future tool) as well as an expanded range of sea-level rise projections for which UC Berkeley has modeled inundation associated with an extreme storm event for the Delta, San Francisco Bay, and the entire California coast.

- **The Nature Conservancy Coastal Resilience tool** is a visualization and decision support platform where ecological, social, and economic information can be viewed alongside sea-level rise and storm surge scenarios to develop risk reduction and restoration solutions. The decision support tool was first created in 2008 and now covers multiple regions including: 10 U.S. States (Alabama, California, Connecticut, Florida, Louisiana, Mississippi, New Jersey, New York, Texas, Washington), four countries in Latin America (Mexico, Belize, Guatemala, Honduras) and three island nations in the

50. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf
51. California experiences semidiurnal tides, with two high tides and two low tides each day. One of the two high tides is higher than the other and one of the two low tides is lower than the other. Mean higher high water is the average of the higher high tides over the National Tidal Data Epoch. https://tidesandcurrents.noaa.gov/datum_options.html

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Caribbean (Grenada, St. Vincent and the Grenadines, U.S Virgin Islands). There also is a U.S. national and global application. Coastal Resilience 2.0 was released in October 2013 to better enable decision makers to assess risk and identify nature-based solutions to reduce socio-economic vulnerability to coastal hazards. The purpose of the tool is to inform county hazard mitigation planning. Its intended uses are to: 1) raise awareness of coastal hazards issues; 2) examine local flood risk; and 3) identify potential adaptation solutions.

- **Surging Seas Risk Finder** 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. Projections integrate extreme flood statistics with dozens of sea-level rise models and scenarios to choose from. Maps are based on the same modified bathtub model used by NOAA's Sea-Level Rise Viewer and consider static sea-level rise up to 10 feet above mean higher high water (MHHW). Maps illustrate which areas are or are not hydrologically connected to the ocean at each one-foot increment, and have layers for population, social vulnerability, property value, point features and more. Exposure assessments tabulate over 100 demographic, economic, infrastructure and environmental variables for every zip code and municipality, as well as planning, legislative and other districts. Additional features include heat maps showing wide-area exposure comparisons, and extensive data downloads including localized fact sheets, reports, and PowerPoint slides. Tutorial videos and step-by-step guides are also available.[52]

52. http://sealevel.climatecentral.org/ssrf/help-page

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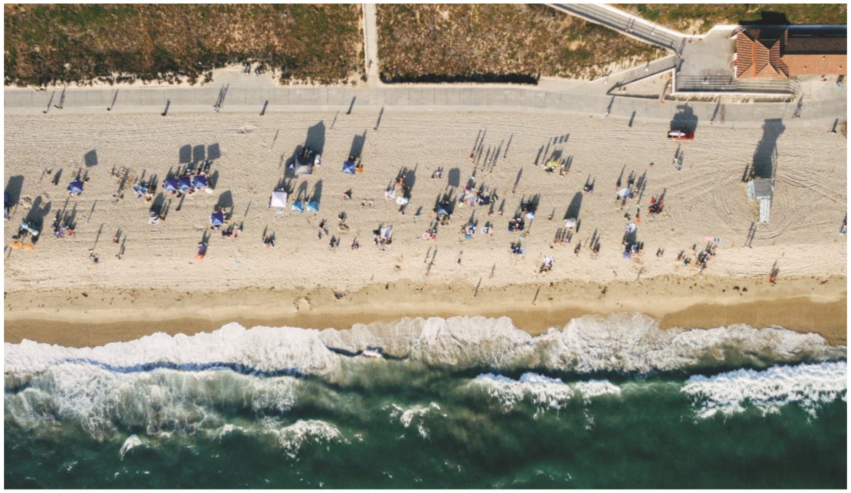

Conclusion

EXACT RATES AND MAGNITUDE OF SEA-LEVEL RISE IN CALIFORNIA over the next century are uncertain, though the direction of change is not. California has an immediate opportunity to make smart, informed, and risk-based decisions that prepare our coastal and inland communities for change while ingraining sustainability, longevity, and resiliency into our planning, permitting, investment, development, transportation, and recreational decisions. This Guidance document serves as a precautionary, though realistic and scientifically rigorous, recommendation on how best to approach sea-level rise in California no matter the decision at hand. The Guidance should be considered and cited throughout local, regional, and statewide sea-level rise discussions and decisions. And while sea-level rise science is rapidly evolving, the Guidance was prepared so that it can be a living document and swiftly updated as needed and recommended.

Depending on the time or planning horizon being considered, different sources of uncertainty (i.e., emission scenario or model uncertainty) play smaller or bigger roles in projections of sea-level rise. For example, as we consider the more distant future and our ability to predict what society will do lessens, different models will be more or less dependable, and the processes generating or driving the extreme sea-level rise scenarios will unfold. This uncertainty is why the State included the extreme sea-level rise scenario but did not assign a likelihood or probability to this scenario. Similarly, it is worth explicitly noting that probabilistic projections need to be taken as an evolving representation of the scientific field, open to updates and modifications. In this context of continued and unquantifiable uncertainties, incorporating long-range planning for sea-level rise in decisions is increasingly urgent. We know we will experience significant increases in sea-level rise, though it remains a challenge to say when this will occur and with what level of confidence it will occur in the given timeframe. This is precisely why it is critical to plan now for a range of possibilities, and integrate these possible futures in planning and preparing across specific communities.

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This risk-based approach outlined in the Guidance, with consideration of the full range of outcomes including potentially consequential outcomes with low probability of occurrence, is consistent with standard practice across risk-centered fields.

California's state agencies and local jurisdictions along the coast and inland Delta are taking action to assess the risks and reduce the anticipated short and long-term impacts of climate change. Steps to incorporate sea-level rise in planning and investment decisions must be taken at the local and State levels to be appropriately relevant, precautionary, agile and progressive. This Guidance serves to increase our understanding of risks as they relate to sea-level rise and apply a set of principles so we are as adaptive and responsive as possible. While the Guidance currently pertains mostly to the coast, it is critical that we consider inland impacts of sea-level rise for long-term planning and follow the same set of recommendations and principles beyond the immediate coastal zone. For future updates to the Guidance, we will incorporate inland sea-level rise modelling and projections to the extent they are available and based on rigorous and peer-reviewed science.

This Guidance, accompanied by a set of resources provided on the State's Adaptation Clearinghouse and OPC's website, serves to be a living tool and resource for state and local planners, decision makers, and stakeholders. It is deliberately structured to be both precautionary and flexible with a core set of recommendations and principles that can readily infuse new scientific approaches and methods to sea-level rise projections as they arise. This adaptability and commitment to actionable science is what will ensure that California is prepared and responsive to the host of changes to come.

Finally, in developing this Guidance, the State took intentional action to engage users and decision makers to ensure that the scientific information and policy direction was understandable and useful for sea-level rise planning and adaptation efforts. There is a continued need for ongoing coordination and collaboration across state, regional and local entities to guarantee effective implementation this Guidance. Going forward, OPC will continue to prioritize opportunities for co-production of future decision-support products by scientists, practitioners, and policy and decision makers to further improve the translation of sea-level rise science into action.

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ADAPTATION (climate change): Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[53]

ADAPTATION PATHWAY: An adaptation pathway is a planning approach addressing the uncertainty and challenges of climate change decision-making. It enables consideration of multiple possible futures, and allows analysis/exploration of the robustness and flexibility of various options across those multiple futures.[54]

ADAPTIVE MANAGEMENT: A process of iteratively planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change. Adaptive management involves adjusting approaches in response to observations of their effect and changes in the system brought on by resulting feedback effects and other variables.[55]

ADAPTIVE CAPACITY: The ability of a system to respond to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, and to cope with the consequences.[56]

CLIMATE CHANGE: Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.[57]

COMMUNITY RESILIENCE: Community resilience is the ability of communities to withstand, recover, and learn from past disasters to strengthen future response and recovery efforts. This can include but is not limited to physical and psychological health of the population, social and economic equity and well-being of the community, effective risk communication, integration of organizations (governmental and nongovernmental) in planning, response, and recovery, and social connectedness for resource exchange, cohesion, response, and recovery.[58]

DISADVANTAGED COMMUNITIES: Areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation, or with concentrations of people that are of low income, high unemployment, low levels of homeownership, high-rent burden, sensitive populations, or low levels of educational attainment.[59]

53. Glossary of Climate Change Terms. Office of Air and Radiation/Office of Atmospheric Programs/Climate Change Division. September 9, 2013: https://19january2017snapshot.epa.gov/climatechange_.html
54. South West Climate Change Portal: Catchment Planning - Using Adaptation Pathway: http://www.swclimatechange.com.au/cb_pages/adaptation_pathways.php
55. IPCC Climate Change 2014: Impacts, Adaptation, and Vulnerability http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-AnnexII_FINAL.pdf
56. Willows RI, RK Connell (eds.). 2003. Climate Adaptation: Risk, Uncertainty and Decisionmaking. UKCIP Technical Report. Oxford: UKCIP. 154 pp. http://www.ukcip.org.uk/wordpress/wp-content/PDFs/UKCIP-Risk-framework.pdf
57. IPCC Climate Change 2014: Impacts, Adaptation, and Vulnerability https://www.ipcc.ch/report/ar5/wg2/
58. Los Angeles County Community Disaster Resilience: http://www.laresilience.org/resources/glossary.php
59. California Health and Safety Code Section 39711: http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_0501-0550/sb_535_bill_20120910_enrolled.html

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EMISSIONS SCENARIOS: Scenarios representing alternative rates of global greenhouse gas emissions growth, which are dependent on rates of economic growth, the success of emission reduction strategies, and rates of clean technology development and diffusion, among other factors.[60]

ENVIRONMENTAL JUSTICE: The structures, policies, practices, and norms resulting in differential access to the goods, services, and opportunities of society by "race." It is normative, sometimes legalized, and often manifests as inherited disadvantage. Examples include differential access to quality education, sound housing, gainful employment, appropriate medical facilities, and a clean environment (Gov. Code §65040.12[e]).

EQUITY: Equity is just and fair inclusion into a society in which all can participate, prosper, and reach their full potential.[61]

EQUITY (climate): The central equity challenges for climate change policy involve several core issues: addressing the impacts of climate change, which are felt unequally; identifying who is responsible for causing climate change and for actions to limit its effects; and understanding the ways in which climate policy intersects with other dimensions of human development, both globally and domestically.[62]

EXTREME (climate) EVENTS: The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.[63]

GLOBAL CLIMATE MODELS: A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties.[64]

INTEGRATED CLIMATE ACTIONS: Program, plans, or policies that simultaneously reduce greenhouse gas emissions and decrease the risks posed by climate change on the system where the action is implemented.

MITIGATION (climate change): A human intervention to reduce the human impact on the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.[65]

MITIGATION (of disaster risk and disaster): The lessening of the potential adverse impacts of physical hazards (including those that are human-induced) through actions that reduce hazard, exposure, and vulnerability.[66]

NATURAL & GREEN INFRASTRUCTURE: Natural 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.[67]

REPRESENTATIVE CONCENTRATION PATHWAYS: Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its Fifth Assessment Report in 2014. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5).[68]

60. Bedsworth L, E Hanak. 2008. Preparing California for a Changing Climate. PPIC Research Report. Public Policy Institute of California. San Francisco, USA. http://www.ppic.org/content/pubs/report/R_1108LBR.pdf
61. PolicyLink: http://www.policylink.org/
62. World Resources Institute. Building Climate Equity: Creating a New Approach from the Ground Up. July 2014. https://www.wri.org/sites/default/files/building-climate-equity-072014.pdf
63. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. IPCC, 2012. http://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf
64. IPCC, 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. https://www.ipcc.ch/pdf/special-reports/srex/SREX-Annex_Glossary.pdf
65. Glossary of Climate Change Terms. Office of Air and Radiation/Office of Atmospheric Programs/Climate Change Division. September 9, 2013. https://www.epa.gov/climatechange
66. IPCC Climate Change 2014: Impacts, Adaptation, and Vulnerability. https://www.ipcc.ch/report/ar5/wg2/
67. Newkirk, S., S. Veloz, M. Hayden, W. Heady, K. Leo, J. Judge, R. Battalio, T. Cheng, T. Ursell, and M. Small. (The Nature Conservancy and Point Blue Conservation Science). 2018. Toward Natural Infrastructure to Manage Shoreline Change in California. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CNRA-CCC4A-2018-3B. Expected release August 2018.
68. IPCC, 2014: Climate Change 2014: Synthesis Report. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf

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RESILIENCE (climate): Resilience is the capacity of any entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience.[69]

RISK: Commonly considered to be the combination of the likelihood of an event and its consequences – i.e., risk equals the probability of climate hazard occurring multiplied by the consequences a given system may experience.[70]

RISK AVERSION: The strong inclination to avoid taking risks in the face of uncertainty.

RISK TOLERANCE: A community's or decision maker's willingness to accept a higher or lower probability of impacts.[71]

SCENARIO-BASED ANALYSIS: A tool for developing a science-based decision-making framework to address environmental uncertainty. In general, a range of plausible impacts based on multiple time scales, emissions scenarios, or other factors is developed to inform further decision-making regarding the range of impacts and vulnerabilities.[72]

SEA-LEVEL RISE: The worldwide average rise in mean sea level, which may be due to a number of different causes, such as the thermal expansion of sea water and the addition of water to the oceans from the melting of glaciers, ice caps, and ice sheets; contrast with relative sea-level rise.[73]

VULNERABILITY: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[74]

VULNERABILITY ASSESSMENT: A practice that identifies who and what is exposed and sensitive to change and how able a given system is to cope with extremes and change. It considers the factors that expose and make people or the environment susceptible to harm and access to natural and financial resources available to cope and adapt, including the ability to self-protect, external coping mechanisms, support networks, etc.[75]

VULNERABLE POPULATIONS: Vulnerable populations include, but are not limited to women; racial or ethnic groups; low-income individuals and families; individuals who are incarcerated or have been incarcerated; individuals with disabilities; individuals with mental health conditions; children; youth and young adults; seniors; immigrants and refugees; individuals who are limited English proficient (LEP); and Lesbian, Gay, Bisexual, Transgender, Queer, and Questioning (LGBTQQ) communities, or combinations of these populations.[76]

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APPENDIX 1:

Guidance Document Development

THE PURPOSE OF THE 2018 UPDATE TO THE STATE'S SEA-LEVEL RISE GUIDANCE (Guidance) was to reflect recent advances in ice loss science and projections of sea-level rise and focus on the needs of state agencies and local governments as they incorporate sea-level rise into their planning, permitting and investment decisions. The development of the Guidance update included three components: 1) a science synthesis to reflect the latest advances in sea-level rise science; 2) a robust public outreach and engagement effort to ensure the updated Guidance is understandable and useful for decision making; 3) and integration of components 1 and 2 to create a science-based, user-informed policy document.

Updating the Science.
Ocean Science Trust (OST), with support from the Ocean Protection Council (OPC), led the scientific component of the update and convened an OPC Science Advisory Team (OPC-SAT) Working Group. The Working Group members, who have subject-matter experts in coastal processes, risk assessment, climatic change, ice loss and ice sheet behavior, and statistical modeling, included: Gary Griggs, University of California Santa Cruz, OPC-SAT (Working Group Chair); Dan Cayan, Scripps Institution of Oceanography, OPC-SAT; Robert Kopp, Rutgers University; Claudia Tebaldi, National Center for Atmospheric Research; Helen Fricker, Scripps Institution of Oceanography; Joe Arvai, University of Michigan; and Rob DeConto, University of Massachusetts.

To ensure that the science synthesis could provide a foundation for policy decisions made in the updated Guidance, a Policy Advisory Committee (PAC) comprised of OPC, the California Natural Resources Agency, the Governor's Office of Planning and Research, and the California Energy Commission developed a list of questions to elicit information about the current estimates of SLR for California and how to understand the scientific context around those estimates. The full list of PAC questions can be found in Appendix 5.

Using the PAC questions as a guide, the working group compiled and reviewed the latest climate research, including the implications of recent scientific advances on ice loss dynamics for updating sea-level rise projections and provided a summary of key findings along with updated projections for three representative tide gauges in California. This science summary, entitled "Rising Seas in California: An Update on Sea-Level Rise Science," was presented to the California Ocean Protection Council at its April 2017 meeting, where the Council then adopted a resolution[77] acknowledging the report as the best available science on which the updated Guidance should be based and directing OPC staff to engage in an inclusive public engagement process to share the scientific findings and solicit feedback on how the updated guidance document will be used.

Public Outreach and Engagement.
Input from users of the guidance document was solicited at multiple points throughout the update process. In February, March and April 2017, an engagement team led by Susanne Moser Research & Consulting and Climate Access, a not-for-profit organization, conducted interviews[78] and five listening sessions to better understand the needs of those who will use the guidance document. In addition, throughout the summer 2017, the OPC and OST, with support from the engagement team, convened four public workshops with state, regional, and local stakeholders in Eureka, San

77. Resolution of the California Ocean Protection Council on Updating the State of California Sea-level Rise Guidance Document, Adopted on April 26, 2017: http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20170426/ADOPTED-SLR-Resolution-20170426.pdf
78. Interviews were conducted with representatives from local, state and federal governments including: U.S. Geological Survey, San Francisco Bay Conservation and Development Commission, California Coastal Commission, California Coastal Conservancy, Delta Stewardship Council, California Department of Public Health, Department of Water Resources, State Lands Commission, California State Parks, Strategic Growth Council, State Water Resources Control Board, LA Regional Water Quality Control Board, Governor's Office of Planning and Research, Governor's Office of Emergency Services, Caltrans, the cities of Eureka, Arcata, Seaside, Santa Monica, Long Beach; Marin and San Mateo counties, and the San Diego Regional Collaborative. Several consulting firms were also interviewed.

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Francisco, Los Angeles and San Diego. The purpose of these workshops was to share the science findings and to solicit feedback on how stakeholders will utilize the guidance document. Close to 400 coastal stakeholders from city, county, and regional government entities, consulting groups, non-profits, state and federal agencies and tribal representatives provided input that helped shape the framework for the Guidance update and associated web resources.

OPC also coordinated closely with the Sea-Level Rise Coastal Leadership Team (California Coastal Commission, San Francisco Bay Conservation and Development Commission, State Lands Commission, California State Parks, State Coastal Conservancy) and the Coastal and Ocean working group of the State's Climate Action Team (CO-CAT), an entity comprised of senior level staff from California state agencies with ocean and coastal resource management responsibilities.

Update to Policy Guidance.
Using the Rising Seas Report and the input from public engagement efforts, OPC staff drafted a science-based, user-informed updated Guidance document in coordination with the PAC and Sea-Level Rise Coastal Leadership Team. The draft will be circulated for formal public comment in the fall of 2017, with final adoption by the Ocean Protection Council scheduled for March 2018.

In response to user needs, the policy Guidance will be supported by a library and database of resources to help visualize change, access funding opportunities, gather policy and scientific background related to specific jurisdictions, and in general provide additional support to address a challenge of this nature and magnitude. This database and library of resources will be available on the State Adaptation Clearinghouse in mid-2018, as well as OPC's website.

STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

APPENDIX 2:

Map of Tide Gauge Locations

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APPENDIX 3:

Sea-Level Rise Projections For All 12 Tide Gauges

TABLE 1: Projected Sea-Level Rise (in feet) for Crescent City

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.1	0.0 -	0.3	0.4	0.5	0.8
	2040	0.3	0.1 -	0.4	0.6	0.9	1.4
	2050	0.4	0.2 -	0.7	0.9	1.5	2.3
Low emissions	2060	0.4	0.1 -	0.7	1.0	1.8	
High emissions	2060	0.6	0.2 -	0.9	1.3	2.1	3.3
Low emissions	2070	0.5	0.1 -	0.9	1.3	2.4	
High emissions	2070	0.8	0.4 -	1.2	1.7	2.8	4.5
Low emissions	2080	0.6	0.1 -	1.1	1.6	3.1	
High emissions	2080	1.0	0.5 -	1.6	2.2	3.7	5.9
Low emissions	2090	0.7	0.1 -	1.3	1.9	3.9	
High emissions	2090	1.2	0.6 -	2.0	2.8	4.7	7.4
Low emissions	2100	0.7	0.1 -	1.5	2.3	4.8	
High emissions	2100	1.5	0.7 -	2.5	3.4	5.9	9.3
Low emissions	2110*	0.8	0.2 -	1.5	2.4	5.3	
High emissions	2110*	1.5	0.9 -	2.5	3.4	6.2	11.0
Low emissions	2120	0.8	0.1 -	1.7	2.8	6.3	
High emissions	2120	1.8	1.0 -	3.0	4.1	7.4	13.1
Low emissions	2130	0.9	0.1 -	1.9	3.2	7.3	
High emissions	2130	2.1	1.1 -	3.4	4.8	8.7	15.3
Low emissions	2140	1.0	0.1 -	2.2	3.6	8.4	
High emissions	2140	2.3	1.2 -	3.9	5.5	10.1	17.8
Low emissions	2150	1.0	0.0 -	2.4	4.2	9.6	
High emissions	2150	2.6	1.3 -	4.4	6.2	11.6	20.6

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 2: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Crescent City

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

CRESCENT CITY - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030										
2040	0.3%									
2050	3%	0.1%								
2060	13%	1%	0.1%							
2070	31%	2%	0.4%	0.1%	0.1%					
2080	49%	8%	1%	0.4%	0.2%	0.1%				
2090	63%	17%	4%	1%	0.4%	0.2%	0.1%	0.1%		
2100	72%	30%	9%	3%	1%	1%	0.3%	0.2%	0.1%	0.1%
2150	90%	67%	40%	21%	11%	6%	3%	2%	1%	1%

CRESCENT CITY - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	6%	0.3%	0.1%							
2070	13%	1%	0.2%	0.1%						
2080	20%	2%	1%	0.2%	0.1%	0.1%				
2090	28%	5%	1%	0.4%	0.2%	0.1%	0.1%			
2100	36%	8%	2%	1%	0.4%	0.2%	0.1%	0.1%	0.1%	
2150	52%	23%	11%	6%	3%	2%	1%	1%	1%	1%

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TABLE 3: Projected Average Rate of Sea-Level Rise (mm/year) for Crescent City

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	3.8	1.6	- 6.4	8.6	14	23
Low emissions	2060 - 2080	2.5	0.2	- 5.5	8.9	20	
High emissions	2060 - 2080	6.6	3.4	- 11	15	26	40
Low emissions	2080 – 2100	2.6	-0.2	- 6.4	11	25	
High emissions	2080 – 2100	7.7	3.4	- 13	19	34	51

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TABLE 4: Projected Sea-Level Rise (in feet) for North Spit

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.6	0.5	- 0.7	0.8	1	1.2
	2040	0.9	0.7	- 1.1	1.2	1.6	2.0
	2050	1.2	0.9	- 1.5	1.7	2.3	3.1
Low emissions	2060	1.3	1.0	- 1.7	2	2.8	
High emissions	2060	1.5	1.2	- 1.9	2.2	3.1	4.3
Low emissions	2070	1.6	1.2	- 2	2.4	3.5	
High emissions	2070	1.9	1.4	- 2.4	2.9	4	5.6
Low emissions	2080	1.8	1.4	- 2.4	2.9	4.4	
High emissions	2080	2.3	1.7	- 2.9	3.5	5.1	7.2
Low emissions	2090	2.1	1.5	- 2.7	3.4	5.3	
High emissions	2090	2.7	2.0	- 3.5	4.3	6.2	8.9
Low emissions	2100	2.3	1.7	- 3.1	3.9	6.3	
High emissions	2100	3.1	2.3	- 4.1	5.1	7.6	10.9
Low emissions	2110*	2.5	1.9	- 3.3	4.2	7.1	
High emissions	2110*	3.3	2.6	- 4.3	5.2	8	12.7
Low emissions	2120	2.7	2.0	- 3.7	4.8	8.2	
High emissions	2120	3.7	2.9	- 4.9	6.1	9.4	15.0
Low emissions	2130	3	2.1	- 4	5.3	9.4	
High emissions	2130	4.2	3.1	- 5.5	6.9	10.9	17.4
Low emissions	2140	3.2	2.3	- 4.4	5.9	10.7	
High emissions	2140	4.6	3.4	- 6.2	7.8	12.5	20.1
Low emissions	2150	3.4	2.3	- 4.8	6.6	12.1	
High emissions	2150	5	3.7	- 6.8	8.7	14.1	23.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 5: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in North Spit

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

NORTH SPIT - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.5%									
2040	27.2%	0.1%								
2050	76%	1.4%	0.1%							
2060	94%	12%	0.6%	0.1%						
2070	98%	40%	3.4%	0.5%	0.1%	0.1%				
2080	99%	68%	14%	2.1%	0.5%	0.2%	0.1%			
2090	100%	83%	33%	7%	1.8%	0.6%	0.3%	0.1%	0.1%	
2100	100%	90%	54%	19%	6%	2%	0.8%	0.4%	0.2%	0.1%
2150	100%	100%	94%	76%	50%	28%	15%	8%	4%	3%

NORTH SPIT - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	86%	5.2%	0.3%							
2070	94%	18%	1.4%	0.3%						
2080	97%	37%	4%	0.8%	0.3%	0.1%				
2090	98%	55%	10%	2.0%	0.7%	0.3%	0.2%	0.1%	0.1%	
2100	98%	68%	20%	4%	1.5%	0.6%	0.3%	0.2%	0.1%	
2150	100%	91%	63%	32%	15%	7%	4%	2%	2%	1%

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TABLE 6: Projected Average Rate of Sea-Level Rise (mm/year) for North Spit

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	8.7	6.4 -	11	14	19	28
Low emissions	2060 - 2080	7.4	5.1 -	10	14	24	
High emissions	2060 - 2080	11	8.2 -	16	20	31	44
Low emissions	2080 – 2100	7.4	4.5 -	11	16	29	
High emissions	2080 – 2100	13	8.1 -	18	24	39	56

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TABLE 7: Projected Sea-Level Rise (in feet) for Arena Cove

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.3	0.2	-	0.5	0.5	0.7	1.0
	2040	0.5	0.3	-	0.7	0.9	1.2	1.6
	2050	0.7	0.5	-	1.0	1.2	1.8	2.6
Low emissions	2060	0.8	0.5	-	1.1	1.4	2.2	
High emissions	2060	1.0	0.6	-	1.3	1.7	2.5	3.7
Low emissions	2070	0.9	0.5	-	1.3	1.8	2.9	
High emissions	2070	1.2	0.8	-	1.7	2.2	3.3	5.0
Low emissions	2080	1.0	0.6	-	1.6	2.1	3.6	
High emissions	2080	1.5	1.0	-	2.2	2.8	4.3	6.4
Low emissions	2090	1.2	0.7	-	1.8	2.5	4.5	
High emissions	2090	1.8	1.1	-	2.6	3.4	5.4	8.0
Low emissions	2100	1.3	0.7	-	2.1	3.0	5.4	
High emissions	2100	2.1	1.3	-	3.1	4.1	6.7	9.9
Low emissions	2110*	1.4	0.8	-	2.2	3.1	6.0	
High emissions	2110*	2.3	1.5	-	3.2	4.2	7.0	11.6
Low emissions	2120	1.5	0.9	-	2.5	3.6	7.1	
High emissions	2120	2.6	1.8	-	3.8	5.0	8.2	13.9
Low emissions	2130	1.7	0.9	-	2.8	4.1	8.1	
High emissions	2130	2.9	1.9	-	4.3	5.7	9.7	16.2
Low emissions	2140	1.8	0.9	-	3.1	4.6	9.4	
High emissions	2140	3.2	2.1	-	4.8	6.5	11.1	18.7
Low emissions	2150	1.9	0.9	-	3.4	5.1	10.7	
High emissions	2150	3.6	2.3	-	5.4	7.3	12.6	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 8: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Arena Cove

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 - 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

ARENA COVE - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030										
2040	1.5%									
2050	17%	0.3%								
2060	44%	2%	0.2%							
2070	68%	8%	0.8%	0.2%	0.1%					
2080	82%	22%	3%	0.7%	0.2%	0.1%	0.1%			
2090	89%	40%	9%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2100	91%	56%	20%	6%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	99%	89%	66%	40%	22%	12%	6%	4%	2%	1%

ARENA COVE - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	25%	0.9%	0.1%							
2070	42%	3%	0.4%	0.1%						
2080	55%	7%	1%	0.3%	0.2%	0.1%				
2090	63%	13%	3%	0.8%	0.3%	0.2%	0.1%	0.1%		
2100	69%	20%	5%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2150	81%	48%	22%	11%	5%	3%	2%	1%	1%	1%

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STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

TABLE 9: Projected Average Rate of Sea-Level Rise (mm/year) for Arena Cove

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	5.8	3.5 -	8.4	11	17	25
Low emissions	2060 - 2080	4.4	2.1 -	7.4	11	22	
High emissions	2060 - 2080	8.6	5.4 -	13	17	28	42
Low emissions	2080 – 2100	4.4	1.4 -	8.4	13	27	
High emissions	2080 – 2100	9.6	5.0 -	15	21	36	54

APPENDIX 3: SEA-LEVEL RISE PROJECTIONS FOR ALL 12 TIDE GAUGES | 53

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STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

TABLE 10: Projected Sea-Level Rise (in feet) for Point Reyes

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 -	0.6	0.6	0.8	1
	2040	0.6	0.5 -	0.8	1.0	1.3	1.8
	2050	0.9	0.6 -	1.1	1.4	2.0	2.8
Low emissions	2060	1.0	0.7 -	1.3	1.6	2.4	
High emissions	2060	1.1	0.8 -	1.5	1.9	2.7	3.9
Low emissions	2070	1.1	0.8 -	1.6	2.0	3.1	
High emissions	2070	1.4	1.0 -	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9 -	1.8	2.4	3.9	
High emissions	2080	1.8	1.2 -	2.4	3.0	4.6	6.7
Low emissions	2090	1.5	1.0 -	2.1	2.8	4.8	
High emissions	2090	2.1	1.4 -	2.9	3.7	5.6	8.3
Low emissions	2100	1.7	1.0 -	2.5	3.3	5.7	
High emissions	2100	2.5	1.6 -	3.5	4.5	7.0	10.3
Low emissions	2110*	1.8	1.2 -	2.6	3.5	6.4	
High emissions	2110*	2.6	1.9 -	3.6	4.6	7.3	12.0
Low emissions	2120	1.9	1.2 -	2.9	4.0	7.5	
High emissions	2120	3.0	2.2 -	4.2	5.3	8.6	14.3
Low emissions	2130	2.1	1.3 -	3.2	4.5	8.6	
High emissions	2130	3.4	2.4 -	4.7	6.1	10.1	16.6
Low emissions	2140	2.3	1.3 -	3.5	5.0	9.8	
High emissions	2140	3.7	2.6 -	5.3	6.9	11.5	19.2
Low emissions	2150	2.4	1.3 -	3.8	5.6	11.2	
High emissions	2150	4.1	2.8 -	5.9	7.8	13.1	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

APPENDIX 3: SEA-LEVEL RISE PROJECTIONS FOR ALL 12 TIDE GAUGES | 54

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TABLE 11: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Point Reyes

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

POINT REYES - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	4.0%									
2050	34%	0.4%								
2060	66%	3%	0.3%	0.1%						
2070	84%	15%	1.3%	0.3%	0.1%					
2080	93%	36%	5%	1.0%	0.3%	0.1%	0.1%			
2090	96%	56%	15%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	30%	9%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	53%	30%	16%	8%	5%	3%	2%

POINT REYES - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	45%	1.5%	0.2%							
2070	64%	5%	0.6%	0.2%						
2080	75%	12%	2%	0.4%	0.2%	0.1%				
2090	81%	21%	4%	1.1%	0.4%	0.2%	0.1%	0.1%		
2100	84%	33%	8%	2%	0.9%	0.4%	0.2%	0.1%	0.1%	
2150	93%	63%	32%	15%	7%	4%	2%	2%	1%	1%

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STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

TABLE 12: Projected Average Rate of Sea-Level Rise (mm/year) for Point Reyes

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	6.8	4.5 - 9.4	12	18	26
Low emissions	2060 - 2080	5.4	3.1 - 8.4	12	23	
High emissions	2060 - 2080	9.6	6.4 - 14	18	29	43
Low emissions	2080 – 2100	5.3	2.4 - 9.3	14	28	
High emissions	2080 – 2100	11	6.0 - 16	22	38	55

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TABLE 13: Projected Sea-Level Rise (in feet) for San Francisco

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…			5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1.0
	2040	0.6	0.5	-	0.8	1.0	1.3	1.8
	2050	0.9	0.6	-	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6	-	1.3	1.6	2.4	
High emissions	2060	1.1	0.8	-	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8	-	1.5	1.9	3.1	
High emissions	2070	1.4	1.0	-	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9	-	1.8	2.3	3.9	
High emissions	2080	1.7	1.2	-	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0	-	2.1	2.8	4.7	
High emissions	2090	2.1	1.4	-	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0	-	2.4	3.2	5.7	
High emissions	2100	2.5	1.6	-	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2	-	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9	-	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2	-	2.8	3.9	7.4	
High emissions	2120	3	2.2	-	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3	-	3.1	4.4	8.5	
High emissions	2130	3.3	2.4	-	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3	-	3.4	4.9	9.7	
High emissions	2140	3.7	2.6	-	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3	-	3.8	5.5	11.0	
High emissions	2150	4.1	2.8	-	5.8	7.7	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

TABLE 14: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in San Francisco

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

SAN FRANCISCO - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	3.3%									
2050	31%	0.4%								
2060	65%	3%	0.2%	0.1%						
2070	84%	13%	1.2%	0.2%	0.1%					
2080	93%	34%	5%	0.9%	0.3%	0.1%	0.1%			
2090	96%	55%	14%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	28%	8%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	52%	28%	15%	8%	4%	3%	2%

SAN FRANCISCO - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	43%	1.4%	0.2%							
2070	62%	4%	0.6%	0.2%						
2080	74%	11%	2%	0.4%	0.2%	0.1%				
2090	80%	20%	3%	1.0%	0.4%	0.2%	0.1%	0.1%		
2100	84%	31%	7%	2%	0.8%	0.4%	0.2%	0.1%	0.1%	
2150	93%	62%	31%	14%	7%	4%	2%	2%	1%	1%

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TABLE 15: Projected Average Rate of Sea-Level Rise (mm/year) for San Francisco

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	6.7	4.5	-	9.3	12	17	26
Low emissions	2060 - 2080	5.3	3.1	-	8.2	12	22	
High emissions	2060 - 2080	9.5	6.4	-	13	17	28	42
Low emissions	2080 – 2100	5.2	2.3	-	9.1	14	28	
High emissions	2080 – 2100	11	6.0	-	16	22	37	55

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TABLE 16: Projected Sea-Level Rise (in feet) for Monterey

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3	-	0.5	0.6	0.8	1.0
	2040	0.6	0.4	-	0.8	0.9	1.2	1.7
	2050	0.8	0.5	-	1.1	1.3	1.9	2.7
Low emissions	2060	0.9	0.5	-	1.2	1.5	2.3	
High emissions	2060	1.0	0.7	-	1.4	1.8	2.6	3.8
Low emissions	2070	1.0	0.6	-	1.4	1.9	3.0	
High emissions	2070	1.3	0.9	-	1.8	2.3	3.4	5.1
Low emissions	2080	1.2	0.7	-	1.7	2.3	3.8	
High emissions	2080	1.6	1.1	-	2.3	2.9	4.4	6.6
Low emissions	2090	1.3	0.8	-	2.0	2.7	4.6	
High emissions	2090	2.0	1.3	-	2.8	3.5	5.5	8.2
Low emissions	2100	1.5	0.9	-	2.3	3.1	5.5	
High emissions	2100	2.3	1.5	-	3.3	4.3	6.9	10.1
Low emissions	2110*	1.6	1.0	-	2.4	3.3	6.1	
High emissions	2110*	2.5	1.7	-	3.4	4.4	7.2	11.8
Low emissions	2120	1.7	1.0	-	2.7	3.8	7.3	
High emissions	2120	2.8	2.0	-	4.0	5.2	8.5	14.0
Low emissions	2130	1.9	1.1	-	3.0	4.2	8.3	
High emissions	2130	3.1	2.2	-	4.5	5.9	9.9	16.4
Low emissions	2140	2.0	1.1	-	3.2	4.7	9.5	
High emissions	2140	3.5	2.4	-	5.1	6.7	11.3	18.9
Low emissions	2150	2.1	1.1	-	3.6	5.3	10.8	
High emissions	2150	3.8	2.6	-	5.7	7.6	12.9	21.8

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 17: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Monterey

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

MONTEREY - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	2.5%									
2050	24%	0.3%								
2060	55%	2%	0.2%	0.1%						
2070	77%	11%	1.1%	0.2%	0.1%					
2080	88%	29%	4%	0.8%	0.3%	0.1%	0.1%			
2090	93%	48%	12%	3%	0.8%	0.3%	0.2%	0.1%	0.1%	
2100	94%	63%	25%	7%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	100%	93%	73%	46%	25%	14%	7%	4%	2%	2%

MONTEREY - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	34%	1.2%	0.1%							
2070	52%	4%	0.5%	0.1%						
2080	64%	9%	1%	0.4%	0.2%	0.1%				
2090	72%	16%	3%	0.9%	0.3%	0.2%	0.1%	0.1%		
2100	77%	25%	6%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2150	87%	55%	26%	12%	6%	4%	2%	1%	1%	1%

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TABLE 18: Projected Average Rate of Sea-Level Rise (mm/year) for Monterey

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	6.3	4.0 - 9.0	11	17	25
Low emissions	2060 - 2080	4.9	2.6 - 7.8	11	22	
High emissions	2060 - 2080	9.1	5.9 - 13	17	28	43
Low emissions	2080 – 2100	4.7	1.8 - 8.7	13	27	
High emissions	2080 – 2100	10	5.5 - 16	22	37	54

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TABLE 19: Projected Sea-Level Rise (in feet) for Port San Luis

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…		5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.3	0.2 -	0.5	0.5	0.7	1.0
	2040	0.5	0.3 -	0.7	0.8	1.2	1.6
	2050	0.7	0.5 -	1.0	1.2	1.8	2.6
Low emissions	2060	0.8	0.4 -	1.1	1.4	2.2	
High emissions	2060	1.0	0.6 -	1.3	1.7	2.5	3.7
Low emissions	2070	0.9	0.5 -	1.3	1.7	2.9	
High emissions	2070	1.2	0.8 -	1.7	2.2	3.3	5.0
Low emissions	2080	1.0	0.6 -	1.6	2.1	3.6	
High emissions	2080	1.5	1.0 -	2.1	2.8	4.3	6.4
Low emissions	2090	1.1	0.6 -	1.8	2.5	4.5	
High emissions	2090	1.8	1.1 -	2.6	3.4	5.3	8.0
Low emissions	2100	1.3	0.7 -	2.1	2.9	5.4	
High emissions	2100	2.1	1.3 -	3.1	4.1	6.7	9.9
Low emissions	2110*	1.4	0.8 -	2.2	3.1	5.9	
High emissions	2110*	2.3	1.5 -	3.2	4.2	7.0	11.6
Low emissions	2120	1.5	0.8 -	2.4	3.5	7.0	
High emissions	2120	2.6	1.8 -	3.7	4.9	8.2	13.8
Low emissions	2130	1.6	0.9 -	2.7	4.0	8.0	
High emissions	2130	2.9	2.0 -	4.3	5.7	9.6	16.2
Low emissions	2140	1.7	0.9 -	3.0	4.5	9.2	
High emissions	2140	3.2	2.1 -	4.8	6.4	11.1	18.7
Low emissions	2150	1.9	0.8 -	3.3	5.1	10.5	
High emissions	2150	3.6	2.3 -	5.4	7.3	12.6	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

TABLE 20: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Port San Luis

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

PORT SAN LUIS - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030										
2040	1.5%									
2050	16%	0.3%								
2060	44%	2%	0.2%	0.1%						
2070	68%	8%	0.8%	0.2%	0.1%					
2080	82%	22%	3%	0.7%	0.2%	0.1%	0.1%			
2090	89%	40%	9%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2100	91%	56%	20%	6%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	99%	89%	66%	40%	21%	11%	6%	4%	2%	1%

PORT SAN LUIS - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	24%	0.9%	0.1%							
2070	40%	3%	0.4%	0.1%						
2080	52%	6%	1%	0.3%	0.2%	0.1%				
2090	61%	12%	2%	0.7%	0.3%	0.2%	0.1%	0.1%		
2100	67%	19%	4%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2150	80%	46%	21%	10%	5%	3%	2%	1%	1%	1%

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TABLE 21: Projected Average Rate of Sea-Level Rise (mm/year) for Port San Luis

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	5.8	3.5	- 8.4	11	17	24
Low emissions	2060 - 2080	4.3	2.1	- 7.2	11	21	
High emissions	2060 - 2080	8.5	5.4	- 13	17	27	42
Low emissions	2080 – 2100	4.1	1.2	- 8.0	13	27	
High emissions	2080 – 2100	9.6	5.0	- 15	21	37	54

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TABLE 22: Projected Sea-Level Rise (in feet) for Santa Barbara

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.3	0.2	- 0.4	0.5	0.7	1.0
	2040	0.5	0.3	- 0.7	0.8	1.1	1.6
	2050	0.7	0.4	- 1.0	1.2	1.8	2.5
Low emissions	2060	0.7	0.4	- 1.0	1.4	2.2	
High emissions	2060	0.9	0.6	- 1.3	1.6	2.5	3.6
Low emissions	2070	0.9	0.5	- 1.3	1.7	2.8	
High emissions	2070	1.1	0.7	- 1.7	2.1	3.3	4.9
Low emissions	2080	1.0	0.5	- 1.5	2.0	3.6	
High emissions	2080	1.4	0.9	- 2.1	2.7	4.3	6.3
Low emissions	2090	1.1	0.6	- 1.8	2.4	4.4	
High emissions	2090	1.7	1.1	- 2.6	3.3	5.3	7.9
Low emissions	2100	1.2	0.6	- 2.0	2.9	5.3	
High emissions	2100	2.1	1.2	- 3.1	4.1	6.6	9.8
Low emissions	2110*	1.3	0.7	- 2.1	3.0	5.9	
High emissions	2110*	2.2	1.4	- 3.2	4.2	6.9	11.5
Low emissions	2120	1.4	0.7	- 2.4	3.5	7.0	
High emissions	2120	2.5	1.7	- 3.7	4.9	8.2	13.7
Low emissions	2130	1.5	0.8	- 2.6	3.9	8.0	
High emissions	2130	2.9	1.8	- 4.2	5.6	9.5	16.0
Low emissions	2140	1.6	0.8	- 2.9	4.4	9.1	
High emissions	2140	3.1	2.0	- 4.8	6.4	11.0	18.6
Low emissions	2150	1.8	0.7	- 3.2	5.0	10.5	
High emissions	2150	3.5	2.2	- 5.3	7.2	12.6	21.4

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 23: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Santa Barbara

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

SANTA BARBARA - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030										
2040	1.3%									
2050	14%	0.2%								
2060	40%	2%	0.2%							
2070	64%	7%	0.8%	0.2%	0.1%					
2080	78%	20%	3%	0.7%	0.2%	0.1%	0.1%			
2090	86%	37%	8%	2%	0.7%	0.3%	0.1%	0.1%	0.1%	
2100	89%	53%	19%	6%	2%	1%	0.3%	0.2%	0.1%	0.1%
2150	98%	87%	63%	38%	20%	11%	6%	3%	2%	1%

SANTA BARBARA - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	21%	0.8%	0.1%							
2070	35%	2%	0.3%	0.1%						
2080	48%	6%	1%	0.3%	0.1%	0.1%				
2090	57%	11%	2%	0.7%	0.3%	0.2%	0.1%	0.1%		
2100	63%	17%	4%	1%	0.6%	0.3%	0.2%	0.1%	0.1%	
2150	76%	42%	19%	9%	5%	3%	2%	1%	1%	1%

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TABLE 24: Projected Average Rate of Sea-Level Rise (mm/year) for Santa Barbara

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	5.6	3.3 - 8.2	11	16	24
Low emissions	2060 - 2080	4.1	1.9 - 7.0	10	21	
High emissions	2060 - 2080	8.3	5.1 - 12	16	27	41
Low emissions	2080 – 2100	3.9	0.91 - 7.8	12	27	
High emissions	2080 – 2100	9.4	4.8 - 15	21	36	53

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TABLE 25: Projected Sea-Level Rise (in feet) for Santa Monica

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds…	66% probability sea-level rise is between…		5% probability sea-level rise meets or exceeds…	0.5% probability sea-level rise meets or exceeds…	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 -	0.5	0.6	0.8	1
	2040	0.6	0.4 -	0.8	0.9	1.2	1.7
	2050	0.8	0.6 -	1.1	1.3	1.9	2.6
Low emissions	2060	0.9	0.6 -	1.2	1.5	2.3	
High emissions	2060	1.1	0.8 -	1.4	1.8	2.6	3.8
Low emissions	2070	1.0	0.7 -	1.4	1.9	3.0	
High emissions	2070	1.3	1.0 -	1.8	2.3	3.4	5.1
Low emissions	2080	1.2	0.8 -	1.7	2.3	3.8	
High emissions	2080	1.7	1.1 -	2.3	2.9	4.4	6.5
Low emissions	2090	1.3	0.8 -	2.0	2.7	4.6	
High emissions	2090	2.0	1.3 -	2.8	3.5	5.5	8.1
Low emissions	2100	1.5	0.9 -	2.3	3.1	5.5	
High emissions	2100	2.3	1.5 -	3.3	4.3	6.8	10.0
Low emissions	2110*	1.6	1.0 -	2.4	3.3	6.1	
High emissions	2110*	2.5	1.8 -	3.5	4.5	7.2	11.7
Low emissions	2120	1.7	1.0 -	2.7	3.8	7.3	
High emissions	2120	2.9	2.0 -	4.0	5.2	8.5	14.0
Low emissions	2130	1.9	1.1 -	3.0	4.2	8.3	
High emissions	2130	3.2	2.2 -	4.5	5.9	9.8	16.3
Low emissions	2140	2.0	1.1 -	3.2	4.7	9.4	
High emissions	2140	3.5	2.4 -	5.1	6.7	11.3	18.9
Low emissions	2150	2.2	1.1 -	3.6	5.3	10.8	
High emissions	2150	3.9	2.6 -	5.7	7.6	12.9	21.7

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

TABLE 26: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Santa Monica

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

SANTA MONICA - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	2.5%									
2050	25%	0.3%								
2060	58%	2%	0.2%	0.1%						
2070	79%	11%	1.0%	0.2%	0.1%					
2080	89%	30%	4%	0.8%	0.3%	0.1%	0.1%			
2090	94%	50%	12%	3%	0.8%	0.3%	0.2%	0.1%	0.1%	
2100	95%	65%	25%	7%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	100%	94%	74%	47%	26%	14%	7%	4%	2%	2%

SANTA MONICA - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	35%	1.2%	0.1%							
2070	53%	4%	0.5%	0.1%						
2080	66%	9%	1%	0.4%	0.2%	0.1%				
2090	74%	16%	3%	0.9%	0.3%	0.2%	0.1%	0.1%		
2100	78%	25%	6%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2150	89%	56%	26%	12%	6%	4%	2%	1%	1%	1%

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TABLE 27: Projected Average Rate of Sea-Level Rise (mm/year) for Santa Monica

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	6.4	4.3	-	8.9	11	17	24
Low emissions	2060 - 2080	4.9	2.8	-	7.8	11	22	
High emissions	2060 - 2080	9.2	6.0	-	13	17	28	42
Low emissions	2080 – 2100	4.6	1.6	-	8.5	13	27	
High emissions	2080 – 2100	10	5.6	-	16	22	37	54

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TABLE 28: Projected Sea-Level Rise (in feet) for Los Angeles

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.3	0.2	-	0.5	0.6	0.7	1.0
	2040	0.5	0.4	-	0.7	0.9	1.2	1.7
	2050	0.7	0.5	-	1.0	1.2	1.8	2.6
Low emissions	2060	0.8	0.5	-	1.1	1.4	2.2	
High emissions	2060	1.0	0.7	-	1.3	1.7	2.5	3.7
Low emissions	2070	0.9	0.6	-	1.3	1.8	2.9	
High emissions	2070	1.2	0.8	-	1.7	2.2	3.3	5.0
Low emissions	2080	1.0	0.6	-	1.6	2.1	3.6	
High emissions	2080	1.5	1.0	-	2.2	2.8	4.3	6.4
Low emissions	2090	1.2	0.7	-	1.8	2.5	4.5	
High emissions	2090	1.8	1.2	-	2.7	3.4	5.3	8.0
Low emissions	2100	1.3	0.7	-	2.1	3.0	5.4	
High emissions	2100	2.2	1.3	-	3.2	4.1	6.7	9.9
Low emissions	2110*	1.4	0.9	-	2.2	3.1	6.0	
High emissions	2110*	2.3	1.6	-	3.3	4.3	7.1	11.5
Low emissions	2120	1.5	0.9	-	2.5	3.6	7.1	
High emissions	2120	2.7	1.8	-	3.8	5.0	8.3	13.8
Low emissions	2130	1.7	0.9	-	2.8	4.0	8.1	
High emissions	2130	3.0	2.0	-	4.3	5.7	9.7	16.1
Low emissions	2140	1.8	0.9	-	3.0	4.5	9.2	
High emissions	2140	3.3	2.2	-	4.9	6.5	11.1	18.7
Low emissions	2150	1.9	0.9	-	3.3	5.1	10.6	
High emissions	2150	3.7	2.4	-	5.4	7.3	12.7	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 29: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Los Angeles

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

LOS ANGELES - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030										
2040	1.6%									
2050	17%	0.3%								
2060	47%	2%	0.2%							
2070	71%	8%	0.8%	0.2%	0.1%					
2080	84%	23%	3%	0.7%	0.2%	0.1%	0.1%			
2090	90%	42%	9%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2100	92%	58%	21%	6%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	99%	90%	68%	42%	23%	12%	6%	4%	2%	1%

LOS ANGELES - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	25%	0.9%	0.1%							
2070	42%	3%	0.4%	0.1%						
2080	55%	7%	1%	0.3%	0.2%	0.1%				
2090	64%	13%	2%	0.7%	0.3%	0.2%	0.1%	0.1%		
2100	69%	20%	5%	2%	0.7%	0.3%	0.2%	0.1%	0.1%	
2150	82%	48%	22%	10%	5%	3%	2%	1%	1%	1%

TABLE 30: Projected Average Rate of Sea-Level Rise (mm/year) for Los Angeles

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	5.9	3.8 - 8.4	11	16	25
Low emissions	2060 - 2080	4.5	2.3 - 7.3	11	21	
High emissions	2060 - 2080	8.7	5.5 - 13	17	27	42
Low emissions	2080 – 2100	4.1	1.1 - 8.0	13	27	
High emissions	2080 – 2100	9.7	5.1 - 15	21	37	54

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TABLE 31: Projected Sea-Level Rise (in feet) for La Jolla

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.5	0.4	-	0.6	0.7	0.9	1.1
	2040	0.7	0.5	-	0.9	1.0	1.3	1.8
	2050	0.9	0.7	-	1.2	1.4	2.0	2.8
Low emissions	2060	1.0	0.7	-	1.3	1.7	2.5	
High emissions	2060	1.2	0.9	-	1.6	1.9	2.7	3.9
Low emissions	2070	1.2	0.9	-	1.6	2.0	3.1	
High emissions	2070	1.5	1.1	-	2.0	2.5	3.6	5.2
Low emissions	2080	1.4	1.0	-	1.9	2.4	4.0	
High emissions	2080	1.9	1.3	-	2.5	3.1	4.6	6.7
Low emissions	2090	1.6	1.0	-	2.2	2.9	4.8	
High emissions	2090	2.2	1.6	-	3.0	3.8	5.7	8.3
Low emissions	2100	1.7	1.1	-	2.5	3.3	5.8	
High emissions	2100	2.6	1.8	-	3.6	4.6	7.1	10.2
Low emissions	2110*	1.9	1.3	-	2.7	3.5	6.4	
High emissions	2110*	2.8	2.0	-	3.7	4.7	7.5	12.0
Low emissions	2120	2.0	1.3	-	3.0	4.1	7.6	
High emissions	2120	3.1	2.3	-	4.3	5.5	8.8	14.3
Low emissions	2130	2.2	1.4	-	3.2	4.5	8.6	
High emissions	2130	3.5	2.5	-	4.9	6.3	10.2	16.6
Low emissions	2140	2.4	1.5	-	3.6	5.1	9.7	
High emissions	2140	3.9	2.8	-	5.4	7.1	11.7	19.2
Low emissions	2150	2.5	1.5	-	3.9	5.7	11.1	
High emissions	2150	4.3	3.0	-	6.1	7.9	13.3	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

TABLE 32: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in La Jolla

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 - 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

LA JOLLA - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	5.5%									
2050	40%	0.5%								
2060	74%	4%	0.3%	0.1%						
2070	89%	17%	1.5%	0.3%	0.1%					
2080	95%	41%	6%	1.1%	0.3%	0.1%	0.1%			
2090	97%	62%	17%	4%	1.0%	0.4%	0.2%	0.1%	0.1%	
2100	98%	75%	33%	10%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	97%	83%	58%	33%	17%	9%	5%	3%	2%

LA JOLLA - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	52%	1.7%	0.2%							
2070	70%	6%	0.7%	0.2%						
2080	80%	14%	2%	0.4%	0.2%	0.1%				
2090	85%	24%	4%	1.1%	0.4%	0.2%	0.1%	0.1%		
2100	88%	36%	8%	2%	0.9%	0.4%	0.2%	0.1%	0.1%	
2150	96%	68%	35%	16%	8%	4%	3%	2%	1%	1%

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TABLE 33: Projected Average Rate of Sea-Level Rise (mm/year) for Los Jolla

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column). Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	7.2	5.1	-	9.6	12	18	26
Low emissions	2060 - 2080	5.7	3.5	-	8.6	12	22	
High emissions	2060 - 2080	9.9	6.7	-	14	18	29	43
Low emissions	2080 – 2100	5.3	3.4	-	9.2	14	28	
High emissions	2080 – 2100	11	6.5	-	17	22	38	54

TABLE 34: Projected Sea-Level Rise (in feet) for San Diego

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)						H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE			1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...			5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
					Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030		0.4	-	0.6	0.7	0.9	1.1
	2040	0.7	0.5	-	0.9	1.0	1.3	1.8
	2050	0.9	0.7	-	1.2	1.4	2.0	2.8
Low emissions	2060	1.0	0.7	-	1.3	1.7	2.5	
High emissions	2060	1.2	0.9	-	1.6	1.9	2.7	3.9
Low emissions	2070	1.2	0.9	-	1.6	2.0	3.1	
High emissions	2070	1.5	1.1	-	2.0	2.5	3.6	5.2
Low emissions	2080	1.4	1.0	-	1.9	2.4	3.9	
High emissions	2080	1.9	1.3	-	2.5	3.1	4.6	6.7
Low emissions	2090	1.6	1.0	-	2.2	2.9	4.8	
High emissions	2090	2.2	1.6	-	3.0	3.7	5.7	8.3
Low emissions	2100	1.7	1.1	-	2.5	3.3	5.8	
High emissions	2100	2.6	1.8	-	3.6	4.5	7.0	10.2
Low emissions	2110*	1.9	1.3	-	2.7	3.5	6.4	
High emissions	2110*	2.8	2.0	-	3.7	4.7	7.5	12.0
Low emissions	2120	2.0	1.3	-	3.0	4.1	7.6	
High emissions	2120	3.1	2.3	-	4.3	5.5	8.8	14.3
Low emissions	2130	2.2	1.4	-	3.3	4.6	8.6	
High emissions	2130	3.5	2.6	-	4.9	6.3	10.2	16.6
Low emissions	2140	2.4	1.5	-	3.6	5.1	9.8	
High emissions	2140	3.9	2.8	-	5.4	7.1	11.7	19.2
Low emissions	2150	2.5	1.5	-	3.9	5.7	11.1	
High emissions	2150	4.3	3.0	-	6.1	7.9	13.3	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

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TABLE 35: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in San Diego

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050;. ***the H++ scenario is not included in this table.***

SAN DIEGO - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	5.4%									
2050	40%	0.5%								
2060	74%	4%	0.3%	0.1%						
2070	89%	17%	1.5%	0.3%	0.1%					
2080	95%	41%	6%	1.1%	0.3%	0.1%	0.1%			
2090	97%	62%	17%	3%	1.0%	0.4%	0.2%	0.1%	0.1%	
2100	98%	76%	33%	10%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	97%	83%	58%	33%	17%	9%	5%	3%	2%

SAN DIEGO - Low emissions (RCP 2.6)

	Probability that sea-level rise will meet or exceed... (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2060	52%	1.7%	0.2%							
2070	70%	5%	0.6%	0.2%						
2080	80%	14%	2%	0.4%	0.2%	0.1%				
2090	86%	24%	4%	1.1%	0.4%	0.2%	0.1%	0.1%		
2100	88%	36%	8%	2%	0.9%	0.4%	0.2%	0.1%	0.1%	
2150	96%	68%	35%	16%	8%	4%	3%	2%	1%	1%

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STATE OF CALIFORNIA SEA-LEVEL RISE GUIDANCE

TABLE 36: Projected Average Rate of Sea-Level Rise (mm/year) for San Diego

Probabilistic projections for the rates of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column.) Values are presented in this table as mm/yr, as opposed to feet as in the previous two tables, to avoid reporting values in fractions of an inch. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. For low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050.

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
High emissions	2030 – 2050	7.2	5.1 - 9.6	12	17	26
Low emissions	2060 - 2080	5.7	3.5 - 8.6	12	22	
High emissions	2060 - 2080	9.9	6.7 - 14	18	29	43
Low emissions	2080 – 2100	5.4	2.4 - 9.2	14	28	
High emissions	2080 – 2100	11	6.5 - 17	22	38	54

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APPENDIX 4:

Risk Decision Framework

(Adapted from the Governor's Office of Planning and Research's "Planning and Investing for a Resilient California: A Guidebook for State Agencies")

This framework serves to help planners and decision makers evaluate sea-level rise impacts across a range of projections to inform appropriate design, adaptation pathways, and contingency plans that build resilience.

	Consequences of Impact or Disruption	LOW *Minimum Disruption, Limited Scale and Scope*	MEDIUM TO HIGH *Inconvenience, but Limited in Scope and Scale*	EXTREME *Unacceptable Risk and/or Extensive Scale and Scope*
RISK CONSIDERATIONS & EVALUATION	Adaptive Capacity	• Future flexibility maintained • People or systems readily able to respond or adapt	• Limited future flexibility	• Irreversible • Threat to public health and safety
	Who or What Is Affected?	• Low impact on communities, infrastructure, or natural systems	• Communities, systems, or infrastructure readily able to adapt or respond to change	• Vulnerable populations • Critical infrastructure • Critical natural systems • Areas of economic, historic, or cultural significance
	Economic Impacts	LOW	MEDIUM	HIGH
EMISSIONS SCENARIO EVALUATION	Pre-2050	RCP 8.5 *(high emissions)*	RCP 8.5 *(high emissions)*	RCP 8.5 *(high emissions)*
	Post-2050	EVALUATE RCP 2.6 AND RCP 8.5 *(low emissions and high emissions)*		
SLR PROJECTIONS SELECTION		LOW RISK AVERSION	MEDIUM-HIGH RISK AVERSION	EXTREME RISK AVERSION

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APPENDIX 5:

Questions from the Policy Advisory Committee to the OPC-SAT Working Group

THE QUESTIONS BELOW were developed by the Policy Advisory Committee to the OPC-SAT Working Group to elicit information about the current estimates of sea-level rise for the California coast and how to understand the scientific context around those estimates, including the state of the science (e.g., areas of uncertainty, emerging science), the importance of each contributor to sea-level rise, and sensitivity of the estimates to policy actions. Sections noted in parentheses reference locations in the Rising Seas Report where these questions were addressed.

Estimates of Sea-level Rise

1. What is the current range of estimates of sea level rise for the California coast? *(Section 3)*
   - **a.** What probabilities can be assigned to those estimates given the current state of science? *(Section 3.1)*
   - **b.** Should more weight be given to certain parts of the range, and if so, why? *(Section 3.2)*
2. Across the physically plausible range of sea-level rise projections, is it possible to say which scenario(s) are more likely than others? *(Section 3.1.2)*
   - **a.** What progress has been made since the existing State Sea-level Rise Guidance Document was published in 2013 on assigning probabilities to different emissions, warming and sea-level rise scenarios? *(Section 3.1.2)*
   - **b.** Which contributors to sea-level rise (e.g., thermal expansion, ice loss) are currently included in developing probabilistic sea-level rise scenarios? *(Section 3.1.2)*
   - **c.** What is the OPC-SAT Working Group's recommendation on how to estimate the likelihood of certain amounts of sea-level rise occurring at future dates for a given global emissions scenario? *(Section 3.1.2)*
   - **d.** What other approaches is the OPC-SAT Working Group aware of, or could the Working Group recommend, for presenting uncertain sea-level rise projections? *(Section 3.1.2)*
   - **e.** Is it possible to identify and characterize the degree of uncertainty in different contributors to sea-level rise? Where do the biggest uncertainties lie and what causes these uncertainties? *(Box 3)*

State of the Science

These questions are designed to elicit information on the state of sea-level rise science, including emerging issues and the treatment of ice loss in Antarctica.

3. What are the significant and notable emerging insights in sea-level rise science since the current State Sea-Level Rise Policy Guidance was issued? Why do they warrant attention? *(Section 2.2)*
   - **a.** Have there been any notable changes in understanding how thermal expansion of ocean water contributes to sea-level rise? *(Section 2.1.1 and Section 2.2)*
   - **b.** Have there been any notable changes in understanding of the role of ice loss from inland glaciers and major ice sheets? *(Section 2.1 and 2.2)*

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c. Have there been any notable changes in understanding of steric or dynamic ocean current changes that affect regional sea-level rise projections? *(Section 3.1.2)*

d. Have there been any notable changes in understanding of local or regional land movement that could affect projections of relative sea level change? *(Section 2.2)*

4. Does the OPC-SAT Working Group consider the emerging science important and significant enough to warrant consideration in the current update to the State Sea-level Rise Guidance Document? If yes, why? If no, why? Please comment on the current confidence in new scientific insights or advances. *(Section 2.2, Section 3.1.1, Appendix 2)*

5. Existing models, including Kopp et al. (2014) and Cayan et al. (2016), project very different sea-level rise estimates under different emissions scenarios. However, some scientists suggest that sea levels in 2100 are determined by events in Antarctica, regardless of future GHG emission levels and trajectories. What is your scientific opinion about this issue? *(Section 2.1, Section 3.2)*

6. What are the scientific advances in best approaches to project sea-level rise since the publication of the existing State Sea-level Rise Guidance Document (2013)? What makes some modeling approaches better than others; in what way? *(Section 3.1)*

   a. What are the strengths and weaknesses of the different approaches for projecting global sea-level rise? *(Section 3.1)*

   b. Which approach or combination of approaches would the OPC-SAT Working Group recommend for estimating future global sea levels? *(Section 3.1.2)*

7. What are the best/most reliable approaches for translating global projections into regional projections? *(Section 3.1.2)*

8. What are the factors that cause sea-level rise projections to differ among locations? *(Section 2.1.2, Box 2)*

9. How are these factors considered in regional projections? *(Section 3.1.2)*

10. Is the OPC-SAT Working Group aware of additional research/modeling efforts, etc., presently underway that should inform the update to the State Sea-level Rise Guidance Document? *(Section 4.1)*

   a. How soon does the OPC-SAT Working Group expect major breakthroughs in understanding of sea-level changes? What would constitute a major breakthrough? How might these breakthroughs affect sea-level rise projections? Given current uncertainties in scientific understanding, and the anticipated rate of accumulation of new knowledge or observations, can the Working Group provide a recommended frequency for reviewing the latest available science to update guidance for state and local decision-makers? *(Section 1.4, Section 4.1, Appendix 2)*

   b. Similarly, can the Working Group provide recommendations, from a scientific perspective, on how this science could be considered in a policy setting (e.g., establishing an appropriate frequency for policy updates, establishing a scientific body to provide regular updates)? *(Section 1.4)*

Understanding the Contributors to Local Sea-Level Rise

11. In addition to projecting future sea levels, other factors may also be important.

   a. What is the state of science on identifying future (a) tidal amplitude and/or phase, and (b) frequency and intensity of extreme events (e.g., high water due to storm surges, ENSO events)? *(Box 1)*

   b. What are the pros and cons of different approaches of arriving at total water level? *(Box 4)*

   c. What is the OPC-SAT Working Group's recommendation on how to integrate (global or regional) sea-level rise projections with expected changes in tidal and extreme events? *(Box 4)*

   d. What is the OPC-SAT Working Group's assessment of the adequacy of superimposing historical extreme event departures from mean onto projected mean sea levels to estimate future values? *(Box 4)*

Policy Sensitivity of Sea-Level Rise Projections

12. How "policy dependent" are the different contributors to sea-level rise? *(Section 2.3)*

   a. Are the different contributors to sea-level rise equally sensitive to changes in global emissions/temperature? *(Section 2.1)*

   b. How much sea-level rise can be avoided or how much can it be slowed down by significant emission reductions (e.g., achieving the global commitments made at COP21 in Paris or 80% GHG emissions reductions by 2050)? *(Section 2.1, Section 3.2, and Section 3.3)*

   c. What new implications for planning and decision making, if any, are introduced by including ice loss scenarios in sea-level rise projections (e.g., magnitude, timing, non-linear rates, nature of the impact)? *(Section 3.1.2. Appendix 2)*

13. Sea-level rise projections typically use emissions scenarios (e.g., IPCC emissions scenarios/Representative Concentration Pathways (RCPs) as inputs into general circulation/sea-level rise models. The RCP 2.6 scenario (lowest IPCC emission scenario) appears out of reach, given current greenhouse gas emission trends, and the unlikely development of more ambitious emission reduction targets in the near future. Is there any physically plausible scenario under which it remains sensible to retain such low-end scenarios in the range of projections? If not, what is the lowest plausible sea-level rise scenario? *(Section 3.1.1)*

Sea-Level Rise Exposure vs. Risk-based Assessment

14. Risk (often defined as probability multiplied by consequence) is a critical input to planning and decision-making.?

   a. What is the OPC-SAT Working Group's recommendation on whether and, if so, how to incorporate consideration of risk as part of the State Sea-level Rise Guidance Document to state and local decision-makers? *(Section 1.3, Section 4.2)*

   b. How would this approach take account of the uncertainties in sea-level rise projections? *(Section 4.2, Box 3)*

15. What other questions should we be asking that we haven't asked? What other considerations should be brought to bear on this topic?

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Impacts of 1.5°C of Global Warming on Natural and Human Systems

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Executive Summary

This chapter builds on findings of AR5 and assesses new scientific evidence of changes in the climate system and the associated impacts on natural and human systems, with a specific focus on the magnitude and pattern of risks linked for global warming of 1.5°C above temperatures in the pre-industrial period. Chapter 3 explores observed impacts and projected risks to a range of natural and human systems, with a focus on how risk levels change from 1.5°C to 2°C of global warming. The chapter also revisits major categories of risk (Reasons for Concern, RFC) based on the assessment of new knowledge that has become available since AR5.

1.5°C and 2°C Warmer Worlds

The global climate has changed relative to the pre-industrial period, and there are multiple lines of evidence that these changes have had impacts on organisms and ecosystems, as well as on human systems and well-being (*high confidence*). The increase in global mean surface temperature (GMST), which reached 0.87°C in 2006–2015 relative to 1850–1900, has increased the frequency and magnitude of impacts (*high confidence*), strengthening evidence of how an increase in GMST of 1.5°C or more could impact natural and human systems (1.5°C versus 2°C). {3.3, 3.4, 3.5, 3.6, Cross-Chapter Boxes 6, 7 and 8 in this chapter}

Human-induced global warming has already caused multiple observed changes in the climate system (*high confidence*). Changes include increases in both land and ocean temperatures, as well as more frequent heatwaves in most land regions (*high confidence*). There is also *high confidence* that global warming has resulted in an increase in the frequency and duration of marine heatwaves. Further, there is substantial evidence that human-induced global warming has led to an increase in the frequency, intensity and/or amount of heavy precipitation events at the global scale (*medium confidence*), as well as an increased risk of drought in the Mediterranean region (*medium confidence*). {3.3.1, 3.3.2, 3.3.3, 3.3.4, Box 3.4}

Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4}

Several regional changes in climate are assessed to occur with global warming up to 1.5°C as compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

There is no single '1.5°C warmer world' (*high confidence*). In addition to the overall increase in GMST, it is important to consider the size and duration of potential overshoots in temperature. Furthermore, there are questions on how the stabilization of an increase in GMST of 1.5°C can be achieved, and how policies might be able to influence the resilience of human and natural systems, and the nature of regional and subregional risks. Overshooting poses large risks for natural and human systems, especially if the temperature at peak warming is high, because some risks may be long-lasting and irreversible, such as the loss of some ecosystems (*high confidence*). The rate of change for several types of risks may also have relevance, with potentially large risks in the case of a rapid rise to overshooting temperatures, even if a decrease to 1.5°C can be achieved at the end of the 21st century or later (*medium confidence*). If overshoot is to be minimized, the remaining equivalent CO_2 budget available for emissions is very small, which implies that large, immediate and unprecedented global efforts to mitigate greenhouse gases are required (*high confidence*). {3.2, 3.6.2, Cross-Chapter Box 8 in this chapter}

Robust[1] global differences in temperature means and extremes are expected if global warming reaches 1.5°C versus 2°C above the pre-industrial levels (*high confidence*). For oceans, regional surface temperature means and extremes are projected to be higher at 2°C compared to 1.5°C of global warming (*high confidence*). Temperature means and extremes are also projected to be higher at 2°C compared to 1.5°C in most land regions, with increases being 2–3 times greater than the increase in GMST projected for some regions (*high confidence*). Robust increases in temperature means and extremes are also projected at 1.5°C compared to present-day values (*high confidence*) {3.3.1, 3.3.2}. There are decreases in the occurrence of cold extremes, but substantial increases in their temperature, in particular in regions with snow or ice cover (*high confidence*) {3.3.1}.

Climate models project robust[1] differences in regional climate between present-day and global warming up to 1.5°C[2], and between 1.5°C and 2°C[2] (*high confidence*), depending on the variable and region in question (*high confidence*). Large, robust and widespread differences are expected for temperature extremes (*high confidence*). Regarding hot extremes, the strongest warming is expected to occur at mid-latitudes in the warm season (with increases of up to 3°C for 1.5°C of global warming, i.e., a factor of two) and at high latitudes in the cold season (with increases of up to 4.5°C at 1.5°C of global warming, i.e., a factor of three) (*high confidence*). The strongest warming of hot extremes is projected to occur in central and eastern North America, central and southern Europe, the Mediterranean region (including southern Europe, northern Africa and the Near East), western and central Asia, and southern Africa (*medium confidence*). The number of exceptionally hot days are expected to increase the most in the tropics, where interannual temperature variability is lowest; extreme heatwaves are thus projected to emerge earliest in these regions, and they are expected to already become widespread there at 1.5°C global warming (*high confidence*). Limiting global warming to 1.5°C instead of 2°C could result in around 420

[1] Robust is used here to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

[2] Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean near-surface air temperature.

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million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to exceptional heatwaves, assuming constant vulnerability (*medium confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in this chapter}

Limiting global warming to 1.5°C would limit risks of increases in heavy precipitation events on a global scale and in several regions compared to conditions at 2°C global warming (*medium confidence*). The regions with the largest increases in heavy precipitation events for 1.5°C to 2°C global warming include: several high-latitude regions (e.g. Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe and northern Asia); mountainous regions (e.g., Tibetan Plateau); eastern Asia (including China and Japan); and eastern North America (*medium confidence*). Tropical cyclones are projected to decrease in frequency but with an increase in the number of very intense cyclones (*limited evidence, low confidence*). Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C of global warming (*medium confidence*). Heavy precipitation, when aggregated at a global scale, is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*) {3.3.3, 3.3.6}

Limiting global warming to 1.5°C is expected to substantially reduce the probability of extreme drought, precipitation deficits, and risks associated with water availability (i.e., water stress) in some regions (*medium confidence*). In particular, risks associated with increases in drought frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C in the Mediterranean region (including southern Europe, northern Africa and the Near East) and southern Africa (*medium confidence*). {3.3.3, 3.3.4, Box 3.1, Box 3.2}

Risks to natural and human systems are expected to be lower at 1.5°C than at 2°C of global warming (*high confidence*). This difference is due to the smaller rates and magnitudes of climate change associated with a 1.5°C temperature increase, including lower frequencies and intensities of temperature-related extremes. Lower rates of change enhance the ability of natural and human systems to adapt, with substantial benefits for a wide range of terrestrial, freshwater, wetland, coastal and ocean ecosystems (including coral reefs) (*high confidence*), as well as food production systems, human health, and tourism (*medium confidence*), together with energy systems and transportation (*low confidence*). {3.3.1, 3.4}

Exposure to multiple and compound climate-related risks is projected to increase between 1.5°C and 2°C of global warming with greater proportions of people both exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new – and exacerbating current – hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). Small island states and economically disadvantaged populations are particularly at risk (*high confidence*). {3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9, Box 3.5}

Global warming of 2°C would lead to an expansion of areas with significant increases in runoff, as well as those affected by flood hazard, compared to conditions at 1.5°C (*medium confidence*). Global warming of 1.5°C would also lead to an expansion of the global land area with significant increases in runoff (*medium confidence*) and an increase in flood hazard in some regions (*medium confidence*) compared to present-day conditions. {3.3.5}

The probability of a sea-ice-free Arctic Ocean[3] during summer is substantially higher at 2°C compared to 1.5°C of global warming (*medium confidence*). Model simulations suggest that at least one sea-ice-free Arctic summer is expected every 10 years for global warming of 2°C, with the frequency decreasing to one sea-ice-free Arctic summer every 100 years under 1.5°C (*medium confidence*). An intermediate temperature overshoot will have no long-term consequences for Arctic sea ice coverage, and hysteresis is not expected (*high confidence*). {3.3.8, 3.4.4.7}

Global mean sea level rise (GMSLR) is projected to be around 0.1 m (0.04 – 0.16 m) less by the end of the 21st century in a 1.5°C warmer world compared to a 2°C warmer world (*medium confidence*). Projected GMSLR for 1.5°C of global warming has an indicative range of 0.26 – 0.77m, relative to 1986–2005, (*medium confidence*). A smaller sea level rise could mean that up to 10.4 million fewer people (based on the 2010 global population and assuming no adaptation) would be exposed to the impacts of sea level rise globally in 2100 at 1.5°C compared to at 2°C. A slower rate of sea level rise enables greater opportunities for adaptation (*medium confidence*). There is *high confidence* that sea level rise will continue beyond 2100. Instabilities exist for both the Greenland and Antarctic ice sheets, which could result in multi-meter rises in sea level on time scales of century to millennia. There is *medium confidence* that these instabilities could be triggered at around 1.5°C to 2°C of global warming. {3.3.9, 3.4.5, 3.6.3}

The ocean has absorbed about 30% of the anthropogenic carbon dioxide, resulting in ocean acidification and changes to carbonate chemistry that are unprecedented for at least the last 65 million years (*high confidence*). Risks have been identified for the survival, calcification, growth, development and abundance of a broad range of marine taxonomic groups, ranging from algae to fish, with substantial evidence of predictable trait-based sensitivities (*high confidence*). There are multiple lines of evidence that ocean warming and acidification corresponding to 1.5°C of global warming would impact a wide range of marine organisms and ecosystems, as well as sectors such as aquaculture and fisheries (*high confidence*). {3.3.10, 3.4.4}

Larger risks are expected for many regions and systems for global warming at 1.5°C, as compared to today, with adaptation required now and up to 1.5°C. However, risks would be larger at 2°C of warming and an even greater effort would be needed for adaptation to a temperature increase of that magnitude (*high confidence*). {3.4, Box 3.4, Box 3.5, Cross-Chapter Box 6 in this chapter}

[3] Ice free is defined for the Special Report as when the sea ice extent is less than 106 km^2. Ice coverage less than this is considered to be equivalent to an ice-free Arctic Ocean for practical purposes in all recent studies.

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Future risks at 1.5°C of global warming will depend on the mitigation pathway and on the possible occurrence of a transient overshoot (*high confidence*). The impacts on natural and human systems would be greater if mitigation pathways temporarily overshoot 1.5°C and return to 1.5°C later in the century, as compared to pathways that stabilize at 1.5°C without an overshoot (*high confidence*). The size and duration of an overshoot would also affect future impacts (e.g., irreversible loss of some ecosystems) (*high confidence*). Changes in land use resulting from mitigation choices could have impacts on food production and ecosystem diversity. {3.6.1, 3.6.2, Cross-Chapter Boxes 7 and 8 in this chapter}

Climate Change Risks for Natural and Human systems

Terrestrial and Wetland Ecosystems

Risks of local species losses and, consequently, risks of extinction are much less in a 1.5°C versus a 2°C warmer world (*high confidence*). The number of species projected to lose over half of their climatically determined geographic range at 2°C global warming (18% of insects, 16% of plants, 8% of vertebrates) is projected to be reduced to 6% of insects, 8% of plants and 4% of vertebrates at 1.5°C warming (*medium confidence*). Risks associated with other biodiversity-related factors, such as forest fires, extreme weather events, and the spread of invasive species, pests and diseases, would also be lower at 1.5°C than at 2°C of warming (*high confidence*), supporting a greater persistence of ecosystem services. {3.4.3, 3.5.2}

Constraining global warming to 1.5°C, rather than to 2°C and higher, is projected to have many benefits for terrestrial and wetland ecosystems and for the preservation of their services to humans (*high confidence*). Risks for natural and managed ecosystems are higher on drylands compared to humid lands. The global terrestrial land area projected to be affected by ecosystem transformations (13%, interquartile range 8–20%) at 2°C is approximately halved at 1.5°C global warming to 4% (interquartile range 2–7%) (*medium confidence*). Above 1.5°C, an expansion of desert terrain and vegetation would occur in the Mediterranean biome (*medium confidence*), causing changes unparalleled in the last 10,000 years (*medium confidence*). {3.3.2.2, 3.4.3.2, 3.4.3.5, 3.4.6.1, 3.5.5.10, Box 4.2}

Many impacts are projected to be larger at higher latitudes, owing to mean and cold-season warming rates above the global average (*medium confidence*). High-latitude tundra and boreal forest are particularly at risk, and woody shrubs are already encroaching into tundra (*high confidence*) and will proceed with further warming. Constraining warming to 1.5°C would prevent the thawing of an estimated permafrost area of 1.5 to 2.5 million km^2 over centuries compared to thawing under 2°C (*medium confidence*). {3.3.2, 3.4.3, 3.4.4}

Ocean Ecosystems

Ocean ecosystems are already experiencing large-scale changes, and critical thresholds are expected to be reached at 1.5°C and higher levels of global warming (*high confidence*). In the transition to 1.5°C of warming, changes to water temperatures are expected to drive some species (e.g., plankton, fish) to relocate to higher latitudes and cause novel ecosystems to assemble (*high confidence*). Other ecosystems (e.g., kelp forests, coral reefs) are relatively less able to move, however, and are projected to experience high rates of mortality and loss (*very high confidence*). For example, multiple lines of evidence indicate that the majority (70–90%) of warm water (tropical) coral reefs that exist today will disappear even if global warming is constrained to 1.5°C (*very high confidence*). {3.4.4, Box 3.4}

Current ecosystem services from the ocean are expected to be reduced at 1.5°C of global warming, with losses being even greater at 2°C of global warming (*high confidence*). The risks of declining ocean productivity, shifts of species to higher latitudes, damage to ecosystems (e.g., coral reefs, and mangroves, seagrass and other wetland ecosystems), loss of fisheries productivity (at low latitudes), and changes to ocean chemistry (e.g., acidification, hypoxia and dead zones) are projected to be substantially lower when global warming is limited to 1.5°C (*high confidence*). {3.4.4, Box 3.4}

Water Resources

The projected frequency and magnitude of floods and droughts in some regions are smaller under 1.5°C than under 2°C of warming (*medium confidence*). Human exposure to increased flooding is projected to be substantially lower at 1.5°C compared to 2°C of global warming, although projected changes create regionally differentiated risks (*medium confidence*). The differences in the risks among regions are strongly influenced by local socio-economic conditions (*medium confidence*). {3.3.4, 3.3.5, 3.4.2}

Risks of water scarcity are projected to be greater at 2°C than at 1.5°C of global warming in some regions (*medium confidence*). Depending on future socio-economic conditions, limiting global warming to 1.5°C, compared to 2°C, may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Regions with particularly large benefits could include the Mediterranean and the Caribbean (*medium confidence*). Socio-economic drivers, however, are expected to have a greater influence on these risks than the changes in climate (*medium confidence*). {3.3.5, 3.4.2, Box 3.5}

Land Use, Food Security and Food Production Systems

Limiting global warming to 1.5°C, compared with 2°C, is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in

sub-Saharan Africa, Southeast Asia, and Central and South America; and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*). A loss of 7–10% of rangeland livestock globally is projected for approximately 2°C of warming, with considerable economic consequences for many communities and regions (*medium confidence*). {3.4.6, 3.6, Box 3.1, Cross-Chapter Box 6 in this chapter}

Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe and the Amazon (*medium confidence*). This suggests a transition from medium to high risk of regionally differentiated impacts on food security between 1.5°C and 2°C (*medium confidence*). Future economic and trade environments and their response to changing food availability (*medium confidence*) are important potential adaptation options for reducing hunger risk in low- and middle-income countries. {Cross-Chapter Box 6 in this chapter}

Fisheries and aquaculture are important to global food security but are already facing increasing risks from ocean warming and acidification (*medium confidence*). These risks are projected to increase at 1.5°C of global warming and impact key organisms such as fin fish and bivalves (e.g., oysters), especially at low latitudes (*medium confidence*). Small-scale fisheries in tropical regions, which are very dependent on habitat provided by coastal ecosystems such as coral reefs, mangroves, seagrass and kelp forests, are expected to face growing risks at 1.5°C of warming because of loss of habitat (*medium confidence*). Risks of impacts and decreasing food security are projected to become greater as global warming reaches beyond 1.5°C and both ocean warming and acidification increase, with substantial losses likely for coastal livelihoods and industries (e.g., fisheries and aquaculture) (*medium to high confidence*). {3.4.4, 3.4.5, 3.4.6, Box 3.1, Box 3.4, Box 3.5, Cross-Chapter Box 6 in this chapter}

Land use and land-use change emerge as critical features of virtually all mitigation pathways that seek to limit global warming to 1.5°C (*high confidence*). Most least-cost mitigation pathways to limit peak or end-of-century warming to 1.5°C make use of carbon dioxide removal (CDR), predominantly employing significant levels of bioenergy with carbon capture and storage (BECCS) and/or afforestation and reforestation (AR) in their portfolio of mitigation measures (*high confidence*). {Cross-Chapter Box 7 in this chapter}

Large-scale deployment of BECCS and/or AR would have a far-reaching land and water footprint (*high confidence*). Whether this footprint would result in adverse impacts, for example on biodiversity or food production, depends on the existence and effectiveness of measures to conserve land carbon stocks, measures to limit agricultural expansion in order to protect natural ecosystems, and the potential to increase agricultural productivity (*medium agreement*). In addition, BECCS and/or AR would have substantial direct effects on regional climate through biophysical feedbacks, which are generally not included in Integrated Assessments Models (*high confidence*). {3.6.2, Cross-Chapter Boxes 7 and 8 in this chapter}

The impacts of large-scale CDR deployment could be greatly reduced if a wider portfolio of CDR options were deployed, if a holistic policy for sustainable land management were adopted, and if increased mitigation efforts were employed to strongly limit the demand for land, energy and material resources, including through lifestyle and dietary changes (*medium confidence*). In particular, reforestation could be associated with significant co-benefits if implemented in a manner than helps restore natural ecosystems (*high confidence*). {Cross-Chapter Box 7 in this chapter}

Human Health, Well-Being, Cities and Poverty

Any increase in global temperature (e.g., +0.5°C) is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*), and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence*). Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks for some vector-borne diseases, such as malaria and dengue fever are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). Overall for vector-borne diseases, whether projections are positive or negative depends on the disease, region and extent of change (*high confidence*). Lower risks of undernutrition are projected at 1.5°C than at 2°C (*medium confidence*). Incorporating estimates of adaptation into projections reduces the magnitude of risks (*high confidence*). {3.4.7, 3.4.7.1, 3.4.8, 3.5.5.8}

Global warming of 2°C is expected to pose greater risks to urban areas than global warming of 1.5°C (*medium confidence*). The extent of risk depends on human vulnerability and the effectiveness of adaptation for regions (coastal and non-coastal), informal settlements and infrastructure sectors (such as energy, water and transport) (*high confidence*). {3.4.5, 3.4.8}

Poverty and disadvantage have increased with recent warming (about 1°C) and are expected to increase for many populations as average global temperatures increase from 1°C to 1.5°C and higher (*medium confidence*). Outmigration in agricultural-dependent communities is positively and statistically significantly associated with global temperature (*medium confidence*). Our understanding of the links of 1.5°C and 2°C of global warming to human migration are limited and represent an important knowledge gap. {3.4.10, 3.4.11, 5.2.2, Table 3.5}

Key Economic Sectors and Services

Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century (*medium confidence*). {3.5.2, 3.5.3}

The largest reductions in economic growth at 2°C compared to 1.5°C of warming are projected for low- and middle-income countries and regions (the African continent, Southeast Asia, India, Brazil and Mexico) (*low to medium confidence*). Countries

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in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2°C (*medium confidence*). {3.5}

Global warming has already affected tourism, with increased risks projected under 1.5°C of warming in specific geographic regions and for seasonal tourism including sun, beach and snow sports destinations (*very high confidence*). Risks will be lower for tourism markets that are less climate sensitive, such as gaming and large hotel-based activities (*high confidence*). Risks for coastal tourism, particularly in subtropical and tropical regions, will increase with temperature-related degradation (e.g., heat extremes, storms) or loss of beach and coral reef assets (*high confidence*). {3.3.6, 3.4.4.12, 3.4.9.1, Box 3.4}

Small Islands, and Coastal and Low-lying areas

Small islands are projected to experience multiple inter-related risks at 1.5°C of global warming that will increase with warming of 2°C and higher levels (*high confidence*). Climate hazards at 1.5°C are projected to be lower compared to those at 2°C (*high confidence*). Long-term risks of coastal flooding and impacts on populations, infrastructures and assets (*high confidence*), freshwater stress (*medium confidence*), and risks across marine ecosystems (*high confidence*) and critical sectors (*medium confidence*) are projected to increase at 1.5°C compared to present-day levels and increase further at 2°C, limiting adaptation opportunities and increasing loss and damage (*medium confidence*). Migration in small islands (internally and internationally) occurs for multiple reasons and purposes, mostly for better livelihood opportunities (*high confidence*) and increasingly owing to sea level rise (*medium confidence*). {3.3.2.2, 3.3.6–9, 3.4.3.2, 3.4.4.2, 3.4.4.5, 3.4.4.12, 3.4.5.3, 3.4.7.1, 3.4.9.1, 3.5.4.9, Box 3.4, Box 3.5}

Impacts associated with sea level rise and changes to the salinity of coastal groundwater, increased flooding and damage to infrastructure, are projected to be critically important in vulnerable environments, such as small islands, low-lying coasts and deltas, at global warming of 1.5°C and 2°C (*high confidence*). Localized subsidence and changes to river discharge can potentially exacerbate these effects. Adaptation is already happening (*high confidence*) and will remain important over multi-centennial time scales. {3.4.5.3, 3.4.5.4, 3.4.5.7, 5.4.5.4, Box 3.5}

Existing and restored natural coastal ecosystems may be effective in reducing the adverse impacts of rising sea levels and intensifying storms by protecting coastal and deltaic regions (*medium confidence*). Natural sedimentation rates are expected to be able to offset the effect of rising sea levels, given the slower rates of sea level rise associated with 1.5°C of warming (*medium confidence*). Other feedbacks, such as landward migration of wetlands and the adaptation of infrastructure, remain important (*medium confidence*). {3.4.4.12, 3.4.5.4, 3.4.5.7}

Increased Reasons for Concern

There are multiple lines of evidence that since AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming levels of up to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). {3.5.2}

1. **The category 'Unique and threatened systems' (RFC1) display a transition from high to very high risk which is now located between 1.5°C and 2°C of global warming** as opposed to at 2.6°C of global warming in AR5, owing to new and multiple lines of evidence for changing risks for coral reefs, the Arctic and biodiversity in general (*high confidence*). {3.5.2.1}
2. **In 'Extreme weather events' (RFC2), the transition from moderate to high risk is now located between 1.0°C and 1.5°C of global warming**, which is very similar to the AR5 assessment but is projected with greater confidence (*medium confidence*). The impact literature contains little information about the potential for human society to adapt to extreme weather events, and hence it has not been possible to locate the transition from 'high' to 'very high' risk within the context of assessing impacts at 1.5°C versus 2°C of global warming. There is thus *low confidence* in the level at which global warming could lead to very high risks associated with extreme weather events in the context of this report. {3.5}
3. **With respect to the 'Distribution of impacts' (RFC3) a transition from moderate to high risk is now located between 1.5°C and 2°C of global warming**, compared with between 1.6°C and 2.6°C global warming in AR5, owing to new evidence about regionally differentiated risks to food security, water resources, drought, heat exposure and coastal submergence (*high confidence*). {3.5}
4. **In 'global aggregate impacts' (RFC4) a transition from moderate to high levels of risk is now located between 1.5°C and 2.5°C of global warming**, as opposed to at 3.6°C of warming in AR5, owing to new evidence about global aggregate economic impacts and risks to Earth's biodiversity (*medium confidence*). {3.5}
5. **Finally, 'large-scale singular events' (RFC5), moderate risk is now located at 1°C of global warming and high risk is located at 2.5°C of global warming**, as opposed to at 1.6°C (moderate risk) and around 4°C (high risk) in AR5, because of new observations and models of the West Antarctic ice sheet (*medium confidence*). {3.3.9, 3.5.2, 3.6.3}

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3.1 About the Chapter

Chapter 3 uses relevant definitions of a potential 1.5°C warmer world from Chapters 1 and 2 and builds directly on their assessment of gradual versus overshoot scenarios. It interacts with information presented in Chapter 2 via the provision of specific details relating to the mitigation pathways (e.g., land-use changes) and their implications for impacts. Chapter 3 also includes information needed for the assessment and implementation of adaptation options (presented in Chapter 4), as well as the context for considering the interactions of climate change with sustainable development and for the assessment of impacts on sustainability, poverty and inequalities at the household to subregional level (presented in Chapter 5).

This chapter is necessarily transdisciplinary in its coverage of the climate system, natural and managed ecosystems, and human systems and responses, owing to the integrated nature of the natural and human experience. While climate change is acknowledged as a centrally important driver, it is not the only driver of risks to human and natural systems, and in many cases, it is the interaction between these two broad categories of risk that is important (Chapter 1).

The flow of the chapter, linkages between sections, a list of chapter- and cross-chapter boxes, and a content guide for reading according to focus or interest are given in Figure 3.1. Key definitions used in the chapter are collected in the Glossary. Confidence language is used throughout this chapter and likelihood statements (e.g., *likely*, *very likely*) are provided when there is *high confidence* in the assessment.

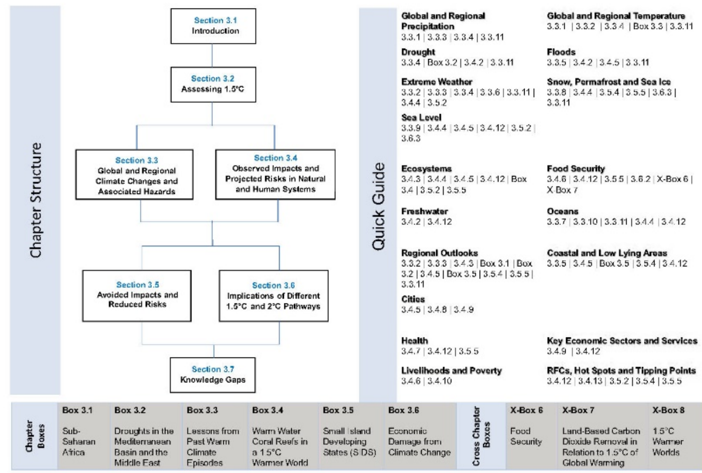

Figure 3.1 | Chapter 3 structure and quick guide.

The underlying literature assessed in Chapter 3 is broad and includes a large number of recent publications specific to assessments for 1.5°C of warming. The chapter also utilizes information covered in prior IPCC special reports, for example the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; IPCC, 2012), and many chapters from the IPCC WGII Fifth Assessment Report (AR5) that assess impacts on natural and managed ecosystems and humans, as well as adaptation options (IPCC, 2014b). For this reason, the chapter provides information based on a broad range of assessment methods. Details about the approaches used are presented in Section 3.2.

Section 3.3 gives a general overview of recent literature on observed climate change impacts as the context for projected future risks. With a few exceptions, the focus here is the analysis of transient responses at 1.5°C and 2°C of global warming, with simulations of *short-term stabilization scenarios* (Section 3.2) also assessed in some cases. In general, *long-term equilibrium stabilization responses* could not be

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assessed owing to a lack of data and analysis. A detailed analysis of detection and attribution is not provided but will be the focus of the next IPCC assessment report (AR6). Furthermore, possible interventions in the climate system through radiation modification measures, which are not tied to reductions of greenhouse gas emissions or concentrations, are not assessed in this chapter.

Understanding the observed impacts and projected risks of climate change is crucial to comprehending how the world is likely to change under global warming of 1.5°C above temperatures in the pre-industrial period (with reference to 2°C). Section 3.4 explores the new literature and updates the assessment of impacts and projected risks for a large number of natural and human systems. By also exploring adaptation opportunities, where the literature allows, the section prepares the reader for discussions in subsequent chapters about opportunities to tackle both mitigation and adaptation. The section is mostly globally focused because of limited research on regional risks and adaptation options at 1.5°C and 2°C. For example, the risks of 1.5°C and 2°C of warming in urban areas, as well as the risks of health outcomes under these two warming scenarios (e.g. climate-related diseases, air quality impacts and mental health problems), were not considered because of a lack of projections of how these risks might change in a 1.5°C or 2°C warmer world. In addition, the complexity of many interactions of climate change with drivers of poverty, along with a paucity of relevant studies, meant it was not possible to detect and attribute many dimensions of poverty and disadvantage to climate change. Even though there is increasing documentation of climate-related impacts on places where indigenous people live and where subsistence-oriented communities are found, relevant projections of the risks associated with warming of 1.5°C and 2°C are necessarily limited.

To explore avoided impacts and reduced risks at 1.5°C compared with at 2°C of global warming, the chapter adopts the AR5 'Reasons for Concern' aggregated projected risk framework (Section 3.5). Updates in terms of the aggregation of risks are informed by the most recent literature and the assessments offered in Sections 3.3 and 3.4, with a focus on the impacts at 2°C of warming that could potentially be avoided if warming were constrained to 1.5°C. Economic benefits that would be obtained (Section 3.5.3), climate change 'hotspots' that could be avoided or reduced (Section 3.5.4 as guided by the assessments of Sections 3.3, 3.4 and 3.5), and tipping points that could be circumvented (Section 3.5.5) at 1.5°C compared to higher degrees of global warming are all examined. The latter assessments are, however, constrained to regional analyses, and hence this particular section does not include an assessment of specific losses and damages.

Section 3.6 provides an overview on specific aspects of the mitigation pathways considered compatible with 1.5°C of global warming, including some scenarios involving temperature overshoot above 1.5°C global warming during the 21st century. Non-CO_2 implications and projected risks of mitigation pathways, such as changes to land use and atmospheric compounds, are presented and explored. Finally, implications for sea ice, sea level and permafrost beyond the end of the century are assessed.

The exhaustive assessment of literature specific to global warming of 1.5°C above the pre-industrial period, presented across all the sections in Chapter 3, highlights knowledge gaps resulting from the heterogeneous information available across systems, regions and sectors. Some of these gaps are described in Section 3.7.

3.2 How are Risks at 1.5°C and Higher Levels of Global Warming Assessed in this Chapter?

The methods that are applied for assessing observed and projected changes in climate and weather are presented in Section 3.2.1, while those used for assessing the observed impacts on and projected risks to natural and managed systems, and to human settlements, are described in Section 3.2.2. Given that changes in climate associated with 1.5°C of global warming were not the focus of past IPCC reports, dedicated approaches based on recent literature that are specific to the present report are also described. Background on specific methodological aspects (climate model simulations available for assessments at 1.5°C global warming, attribution of observed changes in climate and their relevance for assessing projected changes at 1.5°C and 2°C global warming, and the propagation of uncertainties from climate forcing to impacts on ecosystems) are provided in the Supplementary Material 3.SM.

3.2.1 How are Changes in Climate and Weather at 1.5°C versus Higher Levels of Warming Assessed?

Evidence for the assessment of changes to climate at 1.5°C versus 2°C can be drawn both from observations and model projections. Global mean surface temperature (GMST) anomalies were about +0.87°C (±0.10°C likely range) above pre-industrial industrial (1850–1900) values in the 2006—2015 decade, with a recent warming of about 0.2°C (±0.10°C) per decade (Chapter 1). Human-induced global warming reached approximately 1°C (±0.2°C *likely* range) in 2017 (Chapter 1). While some of the observed trends may be due to internal climate variability, methods of detection and attribution can be applied to assess which part of the observed changes may be attributed to anthropogenic forcing (Bindoff et al., 2013b). Hence, evidence from attribution studies can be used to assess changes in the climate system that are already detectable at lower levels of global warming and would thus continue to change with a further 0.5°C or 1°C of global warming (see Supplementary Material 3.SM.1 and Sections 3.3.1, 3.3.2, 3.3.3, 3.3.4 and 3.3.11). A recent study identified significant changes in extremes for a 0.5°C difference in global warming based on the historical record (Schleussner et al., 2017). It should also be noted that attributed changes in extremes since 1950 that were reported in the IPCC AR5 report (IPCC, 2013) generally correspond to changes in global warming of about 0.5°C (see 3.SM.1)

Climate model simulations are necessary for the investigation of the response of the climate system to various forcings, in particular to forcings associated with higher levels of greenhouse gas concentrations. Model simulations include experiments with global and regional climate models, as well as impact models – driven with output from climate models – to evaluate the risk related to climate

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change for natural and human systems (Supplementary Material 3.SM.1). Climate model simulations were generally used in the context of particular 'climate scenarios' from previous IPCC reports (e.g., IPCC, 2007, 2013). This means that emissions scenarios (IPCC, 2000) were used to drive climate models, providing different projections for given emissions pathways. The results were consequently used in a 'storyline' framework, which presents the development of climate in the course of the 21st century and beyond for a given emissions pathway. Results were assessed for different time slices within the model projections such as 2016–2035 ('near term', which is slightly below a global warming of 1.5°C according to most scenarios, Kirtman et al., 2013), 2046–2065 (mid-21st century, Collins et al., 2013), and 2081–2100 (end of 21st century, Collins et al., 2013). Given that this report focuses on climate change for a given mean global temperature response (1.5°C or 2°C), methods of analysis had to be developed and/or adapted from previous studies in order to provide assessments for the specific purposes here.

A major challenge in assessing climate change under 1.5°C, or 2°C (and higher levels), of global warming pertains to the **definition of a '1.5°C or 2°C climate projection'** (see also Cross-Chapter Box 8 in this chapter). Resolving this challenge includes the following considerations:

A. The need to distinguish between (i) **transient climate responses** (i.e., those that 'pass through' 1.5°C or 2°C of global warming), (ii) **short-term stabilization responses** (i.e., scenarios for the late 21st century that result in stabilization at a mean global warming of 1.5°C or 2°C by 2100), and (iii) **long-term equilibrium stabilization responses** (i.e., those occurring after several millennia once climate (temperature) equilibrium at 1.5°C or 2°C is reached). These responses can be very different in terms of climate variables and the inertia associated with a given climate forcing. A striking example is sea level rise (SLR). In this case, projected increases within the 21st century are minimally dependent on the scenario considered, yet they stabilize at very different levels for a long-term warming of 1.5°C versus 2°C (Section 3.3.9).

B. The '1.5°C or 2°C emissions scenarios' presented in Chapter 2 are targeted to hold warming below 1.5°C or 2°C with a certain probability (generally two-thirds) over the course, or at the end, of the 21st century. These scenarios should be seen as the operationalization of 1.5°C or 2°C warmer worlds. However, when these emission scenarios are used to drive climate models, some of the resulting simulations lead to warming above these respective thresholds (typically with a probability of one-third, see Chapter 2 and Cross-Chapter Box 8 in this chapter). This is due both to discrepancies between models and to internal climate variability. For this reason, the climate outcome for any of these scenarios, even those excluding an overshoot (see next point, C.), include some probability of reaching a global climate warming of more than 1.5°C or 2°C. Hence, a comprehensive assessment of climate risks associated with '1.5°C or 2°C climate scenarios' needs to include consideration of higher levels of warming (e.g., up to 2.5°C to 3°C, see Chapter 2 and Cross-Chapter Box 8 in this chapter).

C. Most of the '1.5°C scenarios', and some of the '2°C emissions scenarios' presented in Chapter 2 include a temperature overshoot during the course of the 21st century. This means that median temperature projections under these scenarios exceed the target warming levels over the course of the century (typically 0.5°C–1°C higher than the respective target levels at most), before warming returns to below 1.5°C or 2°C by 2100. During the overshoot phase, impacts would therefore correspond to higher transient temperature increases than 1.5°C or 2°C. For this reason, impacts of transient responses at these higher warming levels are also partly addressed in Cross-Chapter Box 8 in this chapter (on a 1.5°C warmer world), and some analyses for changes in extremes are also presented for higher levels of warming in Section 3.3 (Figures 3.5, 3.6, 3.9, 3.10, 3.12 and 3.13). Most importantly, different overshoot scenarios may have very distinct impacts depending on (i) the peak temperature of the overshoot, (ii) the length of the overshoot period, and (iii) the associated rate of change in global temperature over the time period of the overshoot. While some of these issues are briefly addressed in Sections 3.3 and 3.6, and in the Cross-Chapter Box 8, the definition of overshoot and related questions will need to be more comprehensively addressed in the IPCC AR6 report.

D. The levels of global warming that are the focus of this report (1.5°C and 2°C) are measured relative to the pre-industrial period. This definition requires an agreement on the exact reference time period (for 0°C of warming) and the time frame over which the global warming is assessed, typically 20 to 30 years in length. As discussed in Chapter 1, a climate with 1.5°C global warming is one in which temperatures averaged over a multi-decade time scale are 1.5°C above those in the pre-industrial reference period. Greater detail is provided in Cross-Chapter Box 8 in this chapter. Inherent to this is the observation that the mean temperature of a '1.5°C warmer world' can be regionally and temporally much higher (e.g., with regional annual temperature extremes involving warming of more than 6°C; see Section 3.3 and Cross-Chapter Box 8 in this chapter).

E. The interference of factors unrelated to greenhouse gases with mitigation pathways can strongly affect regional climate. For example, biophysical feedbacks from changes in land use and irrigation (e.g., Hirsch et al., 2017; Thiery et al., 2017), or projected changes in short-lived pollutants (e.g., Z. Wang et al., 2017), can have large influences on local temperatures and climate conditions. While these effects are not explicitly integrated into the scenarios developed in Chapter 2, they may affect projected changes in climate under 1.5°C of global warming. These issues are addressed in more detail in Section 3.6.2.2.

The assessment presented in the current chapter largely focuses on the analysis of **transient responses in climate at 1.5°C versus 2°C** and higher levels of global warming (see point A. above and Section 3.3). It generally uses the empirical scaling relationship (ESR) approach (Seneviratne et al., 2018c), also termed the 'time sampling' approach (James et al., 2017), which consists of sampling the response at 1.5°C and other levels of global warming from all available global climate model scenarios for the 21st century (e.g., Schleussner et al., 2016b;

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Seneviratne et al., 2016; Wartenburger et al., 2017). The ESR approach focuses more on the derivation of a continuous relationship, while the term 'time sampling' is more commonly used when comparing a limited number of warming levels (e.g., 1.5°C versus 2°C). A similar approach in the case of regional climate model (RCM) simulations consists of sampling the RCM model output corresponding to the time frame at which the driving general circulation model (GCM) reaches the considered temperature level, for example, as done within IMPACT2C (Jacob and Solman, 2017), see description in Vautard et al. (2014). As an alternative to the ESR or time sampling approach, pattern scaling may be used. Pattern scaling is a statistical approach that describes relationships of specific climate responses as a function of global temperature change. Some assessments presented in this chapter are based on this method. The disadvantage of pattern scaling, however, is that the relationship may not perfectly emulate the models' responses at each location and for each global temperature level (James et al., 2017). Expert judgement is a third methodology that can be used to assess probable changes at 1.5°C or 2°C of global warming by combining changes that have been attributed to the observed time period (corresponding to warming of 1°C or less if assessed over a shorter period) with known projected changes at 3°C or 4°C above pre-industrial temperatures (Supplementary Material 3.SM.1). In order to assess effects induced by a 0.5°C difference in global warming, the historical record can be used at first approximation as a proxy, meaning that conditions are compared for two periods that have a 0.5°C difference in GMST warming (such as 1991–2010 and 1960–1979, e.g., Schleussner et al., 2017). This in particular also applies to attributed changes in extremes since 1950 that were reported in the IPCC AR5 report (IPCC, 2013; see also 3.SM.1). Using observations, however, it is not possible to account for potential non-linear changes that could occur above 1°C of global warming or as 1.5°C of warming is reached.

In some cases, assessments of **short-term stabilization responses** are also presented, derived using a subset of model simulations that reach a given temperature limit by 2100, or driven by sea surface temperature (SST) values consistent with such scenarios. This includes new results from the 'Half a degree additional warming, prognosis and projected impacts' (HAPPI) project (Section 1.5.2; Mitchell et al., 2017). Notably, there is evidence that for some variables (e.g., temperature and precipitation extremes), responses after short-term stabilization (i.e., approximately equivalent to the RCP2.6 scenario) are very similar to the transient response of higher-emissions scenarios (Seneviratne et al., 2016, 2018c; Wartenburger et al., 2017; Tebaldi and Knutti, 2018). This is, however, less the case for mean precipitation (e.g., Pendergrass et al., 2015), for which other aspects of the emissions scenarios appear relevant.

For the assessment of **long-term equilibrium stabilization responses**, this chapter uses results from existing simulations where available (e.g., for sea level rise), although the available data for this type of projection is limited for many variables and scenarios and will need to be addressed in more depth in the IPCC AR6 report.

Supplementary Material 3.SM.1 of this chapter includes further details of the climate models and associated simulations that were used to support the present assessment, as well as a background on detection and attribution approaches of relevance to assessing changes in climate at 1.5°C of global warming.

3.2.2 How are Potential Impacts on Ecosystems Assessed at 1.5°C versus Higher Levels of Warming?

Considering that the impacts observed so far are for a global warming lower than 1.5°C (generally up to the 2006–2015 decade, i.e., for a global warming of 0.87°C or less; see above), direct information on the impacts of a global warming of 1.5°C is not yet available. The global distribution of observed impacts shown in AR5 (Cramer et al., 2014), however, demonstrates that methodologies now exist which are capable of detecting impacts on systems strongly influenced by factors (e.g., urbanization and human pressure in general) or where climate may play only a secondary role in driving impacts. Attribution of observed impacts to greenhouse gas forcing is more rarely performed, but a recent study (Hansen and Stone, 2016) shows that most of the detected temperature-related impacts that were reported in AR5 (Cramer et al., 2014) can be attributed to anthropogenic climate change, while the signals for precipitation-induced responses are more ambiguous.

One simple approach for assessing possible impacts on natural and managed systems at 1.5°C versus 2°C consists of identifying impacts of a global 0.5°C of warming in the observational record (e.g., Schleussner et al., 2017) assuming that the impacts would scale linearly for higher levels of warming (although this may not be appropriate). Another approach is to use conclusions from analyses of past climates combined with modelling of the relationships between climate drivers and natural systems (Box 3.3). A more complex approach relies on laboratory or field experiments (Dove et al., 2013; Bonal et al., 2016), which provide useful information on the causal effect of a few factors, which can be as diverse as climate, greenhouse gases (GHG), management practices, and biological and ecological variables, on specific natural systems that may have unusual physical and chemical characteristics (e.g., Fabricius et al., 2011; Allen et al., 2017). This last approach can be important in helping to develop and calibrate impact mechanisms and models through empirical experimentation and observation.

Risks for natural and human systems are often assessed with impact models where climate inputs are provided by representative concentration pathway (RCP)-based climate projections. The number of studies projecting impacts at 1.5°C or 2°C of global warming has increased in recent times (see Section 3.4), even if the four RCP scenarios used in AR5 are not strictly associated with these levels of global warming. Several approaches have been used to extract the required climate scenarios, as described in Section 3.2.1. As an example, Schleussner et al. (2016b) applied a time sampling (or ESR) approach, described in Section 3.2.1, to estimate the differential effect of 1.5°C and 2°C of global warming on water availability and impacts on agriculture using an ensemble of simulations under the RCP8.5 scenario. As a further example using a different approach, Iizumi et al. (2017) derived a 1.5°C scenario from simulations with a crop model using an interpolation between the no-change (approximately 2010) conditions and the RCP2.6 scenario (with a global warming of 1.8°C in 2100), and they derived the corresponding 2°C scenario from RCP2.6 and RCP4.5 simulations in 2100. The Inter-Sectoral Impact Model

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Integration and Intercomparison Project Phase 2 (ISIMIP2; Frieler et al., 2017) extended this approach to investigate a number of sectoral impacts on terrestrial and marine ecosystems. In most cases, risks are assessed by impact models coupled offline to climate models after bias correction, which may modify long-term trends (Grillakis et al., 2017).

Assessment of local impacts of climate change necessarily involves a change in scale, such as from the global scale to that of natural or human systems (Frieler et al., 2017; Reyer et al., 2017d; Jacob et al., 2018). An appropriate method of downscaling (Supplementary Material 3.SM.1) is crucial for translating perspectives on 1.5°C and 2°C of global warming to scales and impacts relevant to humans and ecosystems. A major challenge associated with this requirement is the correct reproduction of the variance of local to regional changes, as well as the frequency and amplitude of extreme events (Vautard et al., 2014). In addition, maintaining physical consistency between downscaled variables is important but challenging (Frost et al., 2011).

Another major challenge relates to the propagation of the uncertainties at each step of the methodology, from the global forcings to the global climate and from regional climate to impacts at the ecosystem level, considering local disturbances and local policy effects. The risks for natural and human systems are the result of complex combinations of global and local drivers, which makes quantitative uncertainty analysis difficult. Such analyses are partly done using multimodel approaches, such as multi-climate and multi-impact models (Warszawski et al., 2013, 2014; Frieler et al., 2017). In the case of crop projections, for example, the majority of the uncertainty is caused by variation among crop models rather than by downscaling outputs of the climate models used (Asseng et al., 2013). Error propagation is an important issue for coupled models. Dealing correctly with uncertainties in a robust probabilistic model is particularly important when considering the potential for relatively small changes to affect the already small signal associated with 0.5°C of global warming (Supplementary Material 3.SM.1). The computation of an impact per unit of climatic change, based either on models or on data, is a simple way to present the probabilistic ecosystem response while taking into account the various sources of uncertainties (Fronzek et al., 2011).

In summary, in order to assess risks at 1.5°C and higher levels of global warming, several things need to be considered. Projected climates under 1.5°C of global warming differ depending on temporal aspects and emission pathways. Considerations include whether global temperature is (i) temporarily at this level (i.e., is a transient phase on its way to higher levels of warming), (ii) arrives at 1.5°C, with or without overshoot, after stabilization of greenhouse gas concentrations, or (iii) is at this level as part of long-term climate equilibrium (complete only after several millennia). Assessments of impacts of 1.5°C of warming are generally based on climate simulations for these different possible pathways. Most existing data and analyses focus on transient impacts (i). Fewer data are available for dedicated climate model simulations that are able to assess pathways consistent with (ii), and very few data are available for the assessment of changes at climate equilibrium (iii). In some cases, inferences regarding the impacts of further warming of 0.5°C above present-day temperatures (i.e., 1.5°C of global warming) can also be drawn from observations of similar sized changes (0.5°C) that have occurred in the past, such as during the last 50 years. However, impacts can only be partly inferred from these types of observations, given the strong possibility of non-linear changes, as well as lag effects for some climate variables (e.g., sea level rise, snow and ice melt). For the impact models, three challenges are noted about the coupling procedure: (i) the bias correction of the climate model, which may modify the simulated response of the ecosystem, (ii) the necessity to downscale the climate model outputs to reach a pertinent scale for the ecosystem without losing physical consistency of the downscaled climate fields, and (iii) the necessity to develop an integrated study of the uncertainties.

3.3 Global and Regional Climate Changes and Associated Hazards

This section provides the assessment of changes in climate at 1.5°C of global warming relative to changes at higher global mean temperatures. Section 3.3.1 provides a brief overview of changes to global climate. Sections 3.3.2–3.3.11 provide assessments for specific aspects of the climate system, including regional assessments for temperature (Section 3.3.2) and precipitation (Section 3.3.3) means and extremes. Analyses of regional changes are based on the set of regions displayed in Figure 3.2. A synthesis of the main conclusions of this section is provided in Section 3.3.11. The section builds upon assessments from the IPCC AR5 WGI report (Bindoff et al., 2013a; Christensen et al., 2013; Collins et al., 2013; Hartmann et al., 2013; IPCC, 2013) and Chapter 3 of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; Seneviratne et al., 2012), as well as a substantial body of new literature related to projections of climate at 1.5°C and 2°C of warming above the pre-industrial period (e.g., Vautard et al., 2014; Fischer and Knutti, 2015; Schleussner et al., 2016b, 2017; Seneviratne et al., 2016, 2018c; Déqué et al., 2017; Maule et al., 2017; Mitchell et al., 2017, 2018a; Wartenburger et al., 2017; Zaman et al., 2017; Betts et al., 2018; Jacob et al., 2018; Kharin et al., 2018; Wehner et al., 2018b). The main assessment methods are as already detailed in Section 3.2.

3.3.1 Global Changes in Climate

There is *high confidence* that the increase in global mean surface temperature (GMST) has reached 0.87°C (±0.10°C *likely* range) above pre-industrial values in the 2006–2015 decade (Chapter 1). AR5 assessed that the globally averaged temperature (combined over land and ocean) displayed a warming of about 0.85°C [0.65°C to 1.06°C] during the period 1880–2012, with a large fraction of the detected global warming being attributed to anthropogenic forcing (Bindoff et al., 2013a; Hartmann et al., 2013; Stocker et al., 2013). While new evidence has highlighted that sampling biases and the choice of approaches used to estimate GMST (e.g., using water versus air temperature over oceans and using model simulations versus observations-based estimates) can affect estimates of GMST increase (Richardson et al., 2016; see also Supplementary Material 3.SM.2), the present assessment is consistent with that of AR5 regarding a detectable and dominant effect of anthropogenic forcing on observed trends in global temperature (also confirmed in Ribes et al., 2017). As highlighted in Chapter 1, human-induced warming

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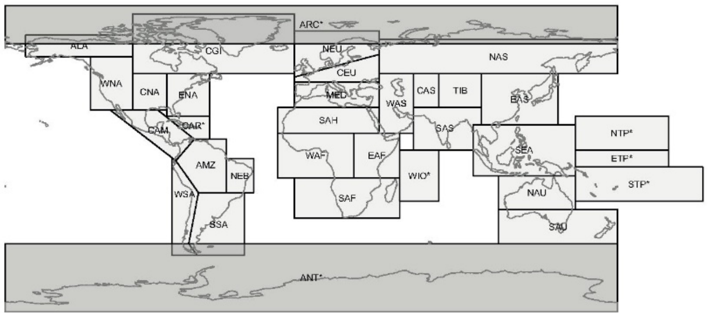

Abbreviation	Name	Abbreviation	Name	Abbreviation	Name	Abbreviation	Name
ALA	Alaska/N.W. Canada	CNA	Central North America	NEU	North Europe	TIB	Tibetan Plateau
AMZ	Amazon	EAF	East Africa	NTP*	Pacific Islands region[2]	WAF	West Africa
ANT*	Antarctica	EAS	East Asia	SAF	Southern Africa	WAS	West Asia
ARC*	Arctic	ENA	East North America	SAH	Sahara	WIO*	West Indian Ocean
CAM	Central America/Mexico	ETP*	Pacific Islands region[3]	SAS	South Asia	WNA	West North America
CAR*	small islands regions Caribbean	MED	South Europe/Mediterranean	SAU	South Australia/New Zealand	WSA	West Coast South America
CAS	Central Asia	NAS	North Asia	SEA	Southeast Asia		
CEU	Central Europe	NAU	North Australia	SSA	Southeastern South America		
CGI	Canada/Greenland/Iceland	NEB	North-East Brazil	STP*	Southern Topical Pacific		

Figure 3.2 | Regions used for regional analyses provided in Section 3.3. The choice of regions is based on the IPCC Fifth Assessment Report (AR5, Chapter 14, Christensen et al., 2013 and Annex 1: Atlas) and the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, Chapter 3, Seneviratne et al., 2012), with seven additional regions in the Arctic, Antarctic and islands not included in the IPCC SREX report (indicated with asterisks). Analyses for regions with asterisks are provided in the Supplementary Material 3.SM.2

reached approximately 1°C (±0.2°C *likely* range) in 2017. More background on recent observed trends in global climate is provided in the Supplementary Material 3.SM.2.

A global warming of 1.5°C implies higher mean temperatures compared to during pre-industrial times in almost all locations, both on land and in oceans (*high confidence*) (Figure 3.3). In addition, a global warming of 2°C versus 1.5°C results in robust differences in the mean temperatures in almost all locations, both on land and in the ocean (*high confidence*). The land–sea contrast in warming is important and implies particularly large changes in temperature over land, with mean warming of more than 1.5°C in most land regions (*high confidence;* see Section 3.3.2 for more details). The largest increase in mean temperature is found in the high latitudes of the Northern Hemisphere (*high confidence*; Figure 3.3, see Section 3.3.2 for more details). Projections for precipitation are more uncertain, but they highlight robust increases in mean precipitation in the Northern Hemisphere high latitudes at 1.5°C global warming versus pre-industrial conditions, as well as at 2°C global warming versus pre-industrial conditions (*high confidence*) (Figure 3.3). There are consistent but less robust signals when comparing changes in mean precipitation at 2°C versus 1.5°C of global warming. Hence, it is assessed that there is *medium confidence* in an increase of mean precipitation in high-latitudes at 2°C versus 1.5°C of global warming (Figure 3.3). For droughts, changes in evapotranspiration and precipitation timing are also relevant (see Section 3.3.4). Figure 3.4 displays changes in temperature extremes (the hottest daytime temperature of the year, TXx, and the coldest night-time temperature of the year, TNn) and heavy precipitation (the annual maximum 5-day precipitation, Rx5day). These analyses reveal distinct patterns of changes, with the largest changes in TXx occurring on mid-latitude land and the largest changes in TNn occurring at high latitudes (both on land and in oceans). Differences in TXx and TNn compared to pre-industrial climate are robust at both global warming levels. Differences in TXx and TNn at 2°C versus 1.5°C of global warming are robust across most of the globe. Changes in heavy precipitation

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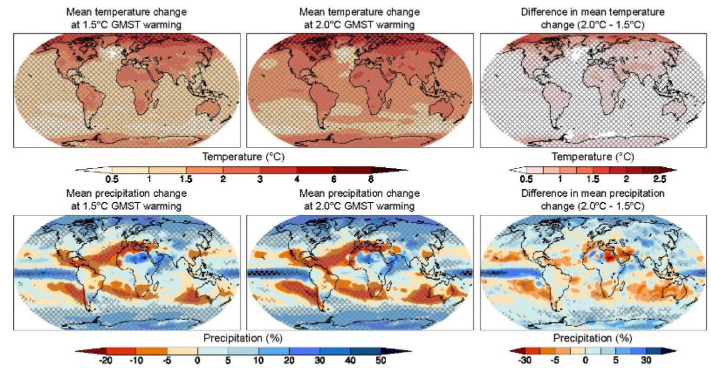

Figure 3.3 | Projected changes in mean temperature (top) and mean precipitation (bottom) at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26). Values were assessed from the transient response over a 10-year period at a given warming level, based on Representative Concentration Pathway (RCP)8.5 Coupled Model Intercomparison Project Phase 5 (CMIP5) model simulations (adapted from Seneviratne et al., 2016 and Wartenburger et al., 2017, see Supplementary Material 3.SM.2 for more details). Note that the responses at 1.5°C of global warming are similar for RCP2.6 simulations (see Supplementary Material 3.SM.2). Differences compared to 1°C of global warming are provided in the Supplementary Material 3.SM.2.

are less robust, but particularly strong increases are apparent at high latitudes as well as in the tropics at both 1.5°C and 2°C of global warming compared to pre-industrial conditions. The differences in heavy precipitation at 2°C versus 1.5°C global warming are generally not robust at grid-cell scale, but they display consistent increases in most locations (Figure 3.4). However, as addressed in Section 3.3.3, statistically significant differences are found in several large regions and when aggregated over the global land area. We thus assess that there is *high confidence* regarding global-scale differences in temperature means and extremes at 2°C versus 1.5°C global warming, and *medium confidence* regarding global-scale differences in precipitation means and extremes. Further analyses, including differences at 1.5°C and 2°C global warming versus 1°C (i.e., present-day) conditions are provided in the Supplementary Material 3.SM.2.

These projected changes at 1.5°C and 2°C of global warming are consistent with the attribution of observed historical global trends in temperature and precipitation means and extremes (Bindoff et al., 2013a), as well as with some observed changes under the recent global warming of 0.5°C (Schleussner et al., 2017). These comparisons are addressed in more detail in Sections 3.3.2 and 3.3.3. Attribution studies have shown that there is *high confidence* that anthropogenic forcing has had a detectable influence on trends in global warming (*virtually certain* since the mid-20th century), in land warming on all continents except Antarctica (*likely* since the mid-20th century), in ocean warming since 1970 (*very likely*), and in increases in hot extremes and decreases in cold extremes since the mid-20th century (*very likely*) (Bindoff et al., 2013a). In addition, there is *medium confidence* that anthropogenic forcing has contributed to increases in mean precipitation at high latitudes in the Northern Hemisphere since the mid-20th century and to global-scale increases in heavy precipitation in land regions with sufficient observations over the same period (Bindoff et al., 2013a). Schleussner et al. (2017) showed, through analyses of recent observed tendencies, that changes in temperature extremes and heavy precipitation indices are detectable in observations for the 1991–2010 period compared with those for 1960–1979, with a global warming of approximately 0.5°C occurring between these two periods (*high confidence*). The observed tendencies over that time frame are thus consistent with attributed changes since the mid-20th century (*high confidence*).

The next sections assess changes in several different types of climate-related hazards. It should be noted that the different types of hazards are considered in isolation but some regions are projected to be affected by collocated and/or concomitant changes in several types of hazards (*high confidence*). Two examples are sea level rise and heavy precipitation in some regions, possibly leading together to more flooding, and droughts and heatwaves, which can together increase the risk of fire occurrence. Such events, also called compound events, may substantially increase risks in some regions (e.g., AghaKouchak et al., 2014; Van Den Hurk et al., 2015; Martius et al., 2016; Zscheischler et al., 2018). A detailed assessment of physically-defined compound events was not possible as part of this report, but aspects related to overlapping multi-sector risks are highlighted in Sections 3.4 and 3.5.

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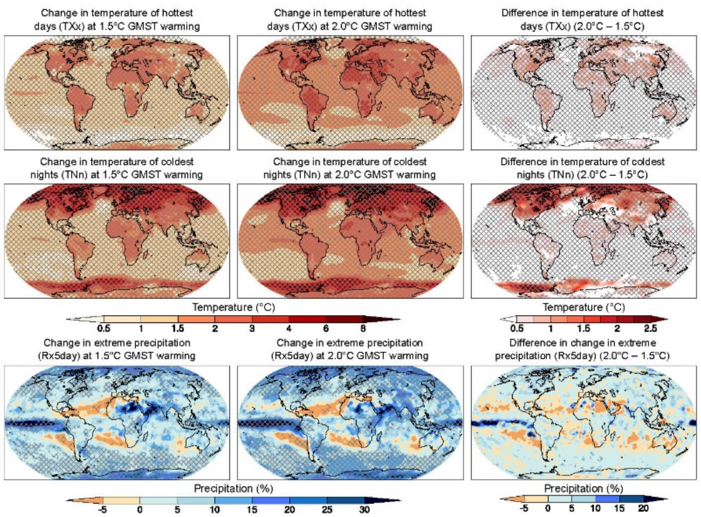

Figure 3.4 | Projected changes in extremes at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26): temperature of annual hottest day (maximum temperature), TXx (top), and temperature of annual coldest night (minimum temperature), TNn (middle), and annual maximum 5-day precipitation, Rx5day (bottom). The underlying methodology and data basis are the same as for Figure 3.3 (see Supplementary Material 3.SM.2 for more details). Note that the responses at 1.5°C of global warming are similar for Representative Concentration Pathway (RCP)2.6 simulations (see Supplementary Material 3.SM.2). Differences compared to 1°C of global warming are provided in the Supplementary Material 3.SM.2.

3.3.2 Regional Temperatures on Land, Including Extremes

3.3.2.1 Observed and attributed changes in regional temperature means and extremes

While the quality of temperature measurements obtained through ground observational networks tends to be high compared to that of measurements for other climate variables (Seneviratne et al., 2012), it should be noted that some regions are undersampled. Cowtan and Way (2014) highlighted issues regarding undersampling, which is most problematic at the poles and over Africa, and which may lead to biases in estimated changes in GMST (see also Supplementary Material 3.SM.2 and Chapter 1). This undersampling also affects the confidence of assessments regarding regional observed and projected changes in both mean and extreme temperature. Despite this partly limited coverage, the attribution chapter of AR5 (Bindoff et al., 2013a) and recent papers (e.g., Sun et al., 2016; Wan et al., 2018) assessed that, over every continental region and in many sub-continental regions, anthropogenic influence has made a substantial contribution to surface temperature increases since the mid-20th century.

Based on the AR5 and SREX, as well as recent literature (see Supplementary Material 3.SM), there is *high confidence* (*very likely*) that there has been an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale on land. There is also *high confidence* (*likely*) that consistent changes are detectable on the continental scale in North America, Europe and Australia. There is *high confidence* that these observed changes in temperature extremes can be attributed to anthropogenic forcing (Bindoff et al., 2013a). As highlighted in Section 3.2, the observational record can be used to assess past changes associated with a global warming of 0.5°C. Schleussner et al. (2017) used this approach to assess observed changes in extreme indices for the 1991–2010 versus the 1960–1979 period, which corresponds to just about a 0.5°C GMST difference in the observed record (based on the Goddard Institute for Space Studies Surface Temperature Analysis

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(GISTEMP) dataset, Hansen et al., 2010). They found that substantial changes due to 0.5°C of warming are apparent for indices related to hot and cold extremes, as well as for the Warm Spell Duration Indicator (WSDI). In particular, they identified that one-quarter of the land has experienced an intensification of hot extremes (maximum temperature on the hottest day of the year, TXx) by more than 1°C and a reduction in the intensity of cold extremes by at least 2.5°C (minimum temperature on the coldest night of the year, TNn). In addition, the same study showed that half of the global land mass has experienced changes in WSDI of more than six days, as well as an emergence of extremes outside the range of natural variability (Schleussner et al., 2017). Analyses from Schleussner et al. (2017) for temperature extremes are provided in the Supplementary Material 3.SM, Figure 3.SM.6. It should be noted that assessments of attributed changes in the IPCC SREX and AR5 reports were generally provided since 1950, for time frames also approximately corresponding to a 0.5°C global warming (3.SM).

3.3.2.2 Projected changes in regional temperature means and extremes at 1.5°C versus 2°C of global warming

There are several lines of evidence available for providing a regional assessment of projected changes in temperature means and extremes at 1.5°C versus 2°C of global warming (see Section 3.2). These include: analyses of changes in extremes as a function of global warming based on existing climate simulations using the empirical scaling relationship (ESR) and variations thereof (e.g., Schleussner et al., 2017; Dosio and Fischer, 2018; Seneviratne et al., 2018c; see Section 3.2 for details about the methodology); dedicated simulations of 1.5°C versus 2°C of global warming, for instance based on the Half a degree additional warming, prognosis and projected impacts (HAPPI) experiment (Mitchell et al., 2017) or other model simulations (e.g., Dosio et al., 2018; Kjellström et al., 2018); and analyses based on statistical pattern scaling approaches (e.g., Kharin et al., 2018). These different lines of evidence lead to qualitatively consistent results regarding changes in temperature means and extremes at 1.5°C of global warming compared to the pre-industrial climate and 2°C of global warming.

There are statistically significant differences in temperature means and extremes at 1.5°C versus 2°C of global warming, both in the global average (Schleussner et al., 2016b; Dosio et al., 2018; Kharin et al., 2018), as well as in most land regions (*high confidence*) (Wartenburger et al., 2017; Seneviratne et al., 2018c; Wehner et al., 2018b). Projected temperatures over oceans display significant increases in means and extremes between 1.5°C and 2°C of global warming (Figures 3.3 and 3.4). A general background on the available evidence on regional changes in temperature means and extremes at 1.5°C versus 2°C of global warming is provided in the Supplementary Material 3.SM.2. As an example, Figure 3.5 shows regionally-based analyses for the IPCC SREX regions (see Figure 3.2) of changes in the temperature of hot extremes as a function of global warming (corresponding analyses for changes in the temperature of cold extremes are provided in the Supplementary Material 3.SM.2). As demonstrated in these analyses, the mean response of the intensity of temperature extremes in climate models to changes in the global mean temperature is approximately linear and independent of the considered emissions scenario (Seneviratne et al., 2016; Wartenburger et al., 2017). Nonetheless, in the case of changes in the number of days exceeding a given threshold, changes are approximately exponential, with higher increases for rare events (Fischer and Knutti, 2015; Kharin et al., 2018); see also Figure 3.6. This behaviour is consistent with a linear increase in absolute temperature for extreme threshold exceedances (Whan et al., 2015).

As mentioned in Section 3.3.1, there is an important land–sea warming contrast, with stronger warming on land (see also Christensen et al., 2013; Collins et al., 2013; Seneviratne et al., 2016), which implies that regional warming on land is generally more than 1.5°C even when mean global warming is at 1.5°C. As highlighted in Seneviratne et al. (2016), this feature is generally stronger for temperature extremes (Figures 3.4 and 3.5; Supplementary Material 3.SM.2). For differences in regional temperature extremes at a mean global warming of 1.5°C versus 2°C, that is, a difference of 0.5°C in global warming, this implies differences of as much as 1°C–1.5°C in some locations, which are two to three times larger than the differences in global mean temperature. For hot extremes, the strongest warming is found in central and eastern North America, central and southern Europe, the Mediterranean, western and central Asia, and southern Africa (Figures 3.4 and 3.5) (*medium confidence*). These regions are all characterized by a strong soil-moisture–temperature coupling and projected increased dryness (Vogel et al., 2017), which leads to a reduction in evaporative cooling in the projections. Some of these regions also show a wide range of responses to temperature extremes, in particular central Europe and central North America, owing to discrepancies in the representation of the underlying processes in current climate models (Vogel et al., 2017). For mean temperature and cold extremes, the strongest warming is found in the northern high-latitude regions (*high confidence*). This is due to substantial ice-snow-albedo-temperature feedbacks (Figure 3.3 and Figure 3.4, middle) related to the known 'polar amplification' mechanism (e.g., IPCC, 2013; Masson-Delmotte et al., 2013).

Figure 3.7 displays maps of changes in the number of hot days (NHD) at 1.5°C and 2°C of GMST increase. Maps of changes in the number of frost days (FD) can be found in Supplementary Material 3.SM.2. These analyses reveal clear patterns of changes between the two warming levels, which are consistent with analysed changes in heatwave occurrence (e.g., Dosio et al., 2018). For the NHD, the largest differences are found in the tropics (*high confidence*), owing to the low interannual temperature variability there (Mahlstein et al., 2011), although absolute changes in hot temperature extremes tended to be largest at mid-latitudes (*high confidence*) (Figures 3.4 and 3.5). Extreme heatwaves are thus projected to emerge earliest in the tropics and to become widespread in these regions already at 1.5°C of global warming (*high confidence*). These results are consistent with other recent assessments. Coumou and Robinson (2013) found that 20% of the global land area, centred in low-latitude regions, is projected to experience highly unusual monthly temperatures during Northern Hemisphere summers at 1.5°C of global warming, with this number nearly doubling at 2°C of global warming.

Figure 3.8 features an objective identification of 'hotspots' / key risks in temperature indices subdivided by region, based on the ESR approach applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (Wartenburger et al., 2017). Note that results based on the HAPPI multimodel experiment (Mitchell et al., 2017) are similar (Seneviratne et al., 2018c). The considered regions follow

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the classification used in Figure 3.2 and also include the global land areas. Based on these analyses, the following can be stated: significant changes in responses are found in all regions for most temperature indices, with the exception of i) the diurnal temperature range (DTR) in most regions, ii) ice days (ID), frost days (FD) and growing season length (GSL) (mostly in regions where differences are zero, because, e.g., there are no ice or frost days), iii) the minimum yearly value of the maximum daily temperature (TXn) in very few regions. In terms of the sign of the changes, warm extremes display an increase in intensity, frequency and duration (e.g., an increase in the temperature of the hottest day of the year (TXx) in all regions, an increase in the proportion of days with a maximum temperature above the 90th percentile of Tmax (TX90p) in all regions, and an increase in the length of the WSDI in all regions), while cold extremes display a decrease in intensity, frequency and duration (e.g., an increase in the temperature of the coldest night of the year (TNn) in all regions, a decrease in the proportion of days with a minimum temperature below the 10th percentile of Tmin (TN10p), and a decrease in the cold spell duration index (CSDI) in all regions). Hence, while warm extremes are intensified, cold extremes become less intense in affected regions.

Overall, large increases in hot extremes occur in many densely inhabited regions (Figure 3.5), for both warming scenarios compared to pre-industrial and present-day climate, as well as for 2°C versus 1.5°C GMST warming. For instance, Dosio et al. (2018) concluded, based on a modelling study, that 13.8% of the world population would be exposed to 'severe heatwaves' at least once every 5 years under 1.5°C of global warming, with a threefold increase (36.9%) under 2°C of GMST warming, corresponding to a difference of about 1.7 billion people between the two global warming levels. They also concluded that limiting global warming to 1.5°C would result in about 420 million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to 'exceptional heatwaves' compared to conditions at 2°C GMST warming. However, changes in vulnerability were not considered in their study. For this reason, we assess that there is *medium confidence* in their conclusions.

In summary, there is *high confidence* that there are robust and statistically significant differences in the projected temperature means and extremes at 1.5°C versus 2°C of global warming, both in the global average and in nearly all land regions[4] (*likely*). Further, the observational record reveals that substantial changes due to a 0.5°C GMST warming are apparent for indices related to hot and cold extremes, as well as for the WSDI (*likely*). A global warming of 2°C versus 1.5°C would lead to more frequent and more intense hot extremes in all land regions[4], as well as longer warm spells, affecting many densely inhabited regions (*very likely*). The strongest increases in the frequency of hot extremes are projected for the rarest events (*very likely*). On the other hand, cold extremes would become less intense and less frequent, and cold spells would be shorter (*very likely*). Temperature extremes on land would generally increase more than the global average temperature (*very likely*). Temperature increases of extreme hot days in mid-latitudes are projected to be up to two times the increase in GMST, that is, 3°C at 1.5°C GMST warming (*high confidence*). The highest levels of warming for extreme hot days are expected to occur in central and eastern North America, central and southern Europe, the Mediterranean, western and central Asia, and southern Africa (*medium confidence*). These regions have a strong soil-moisture-temperature coupling in common as well as increased dryness and, consequently, a reduction in evaporative cooling. However, there is a substantial range in the representation of these processes in models, in particular in central Europe and central North America (*medium confidence*). The coldest nights in high latitudes warm by as much as 1.5°C for a 0.5°C increase in GMST, corresponding to a threefold stronger warming (*high confidence*). NHD shows the largest differences between 1.5°C and 2°C in the tropics, because of the low interannual temperature variability there (*high confidence*); extreme heatwaves are thus projected to emerge earliest in these regions, and they are expected to become widespread already at 1.5°C of global warming (*high confidence*). Limiting global warming to 1.5°C instead of 2°C could result in around 420 million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to exceptional heatwaves, assuming constant vulnerability (*medium confidence*).

3.3.3 Regional Precipitation, Including Heavy Precipitation and Monsoons

This section addresses regional changes in precipitation on land, with a focus on heavy precipitation and consideration of changes to the key features of monsoons.

3.3.3.1 Observed and attributed changes in regional precipitation

Observed global changes in the water cycle, including precipitation, are more uncertain than observed changes in temperature (Hartmann et al., 2013; Stocker et al., 2013). There is *high confidence* that mean precipitation over the mid-latitude land areas of the Northern Hemisphere has increased since 1951 (Hartmann et al., 2013). For other latitudinal zones, area-averaged long-term positive or negative trends have *low confidence* because of poor data quality, incomplete data or disagreement amongst available estimates (Hartmann et al., 2013). There is, in particular, *low confidence* regarding observed trends in precipitation in monsoon regions, according to the SREX report (Seneviratne et al., 2012) and AR5 (Hartmann et al., 2013), as well as more recent publications (Singh et al., 2014; Taylor et al., 2017; Bichet and Diedhiou, 2018; see Supplementary Material 3.SM.2).

For heavy precipitation, AR5 (Hartmann et al., 2013) assessed that observed trends displayed more areas with increases than decreases in the frequency, intensity and/or amount of heavy precipitation (*likely*). In addition, for land regions where observational coverage is sufficient for evaluation, it was assessed that there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century (Bindoff et al., 2013a).

Regarding changes in precipitation associated with global warming of 0.5°C, the observed record suggests that increases in precipitation extremes can be identified for annual maximum 1-day precipitation

[4] Using the SREX definition of regions (Figure 3.2)

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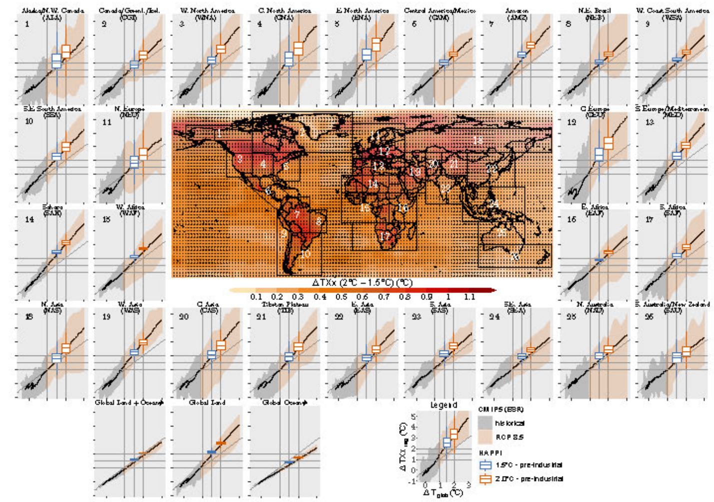

Figure 3.5 | Projected changes in annual maximum daytime temperature (TXx) as a function of global warming for IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2), based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data (adapted from Seneviratne et al., 2016 and Wartenburger et al., 2017) together with projected changes from the Half a degree additional warming, prognosis and projected impacts (HAPPI) multimodel experiment (Mitchell et al., 2017; based on analyses in Seneviratne et al., 2018c) (bar plots on regional analyses and central plot, respectively). For analyses for other regions from Figure 3.2 (with asterisks), see Supplementary Material 3.SM.2. (The stippling indicates significance of the differences in changes between 1.5°C and 2°C of global warming based on all model simulations, using a two-sided paired Wilcoxon test (P = 0.01, after controlling the false discovery rate according to Benjamini and Hochberg, 1995). See Supplementary Material 3.SM.2 for details.

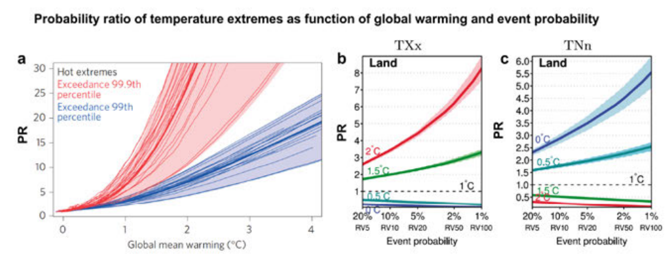

Figure 3.6 | Probability ratio (PR) of exceeding extreme temperature thresholds. (a) PR of exceeding the 99th (blue) and 99.9th (red) percentile of pre-industrial daily temperatures at a given warming level, averaged across land (from Fischer and Knutti, 2015). (b) PR for the hottest daytime temperature of the year (TXx). (c) PR for the coldest night of the year (TNn) for different event probabilities (with RV indicating return values) in the current climate (1°C of global warming). Shading shows the interquartile (25–75%) range (from Kharin et al., 2018).

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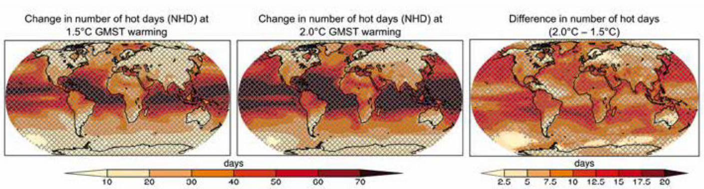

Figure 3.7 | Projected changes in the number of hot days (NHD; 10% warmest days) at 1.5°C (left) and at 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26). The underlying methodology and the data basis are the same as for Figure 3.2 (see Supplementary Material 3.SM.2 for more details). Differences compared to 1°C global warming are provided in the Supplementary Material 3.SM.2.

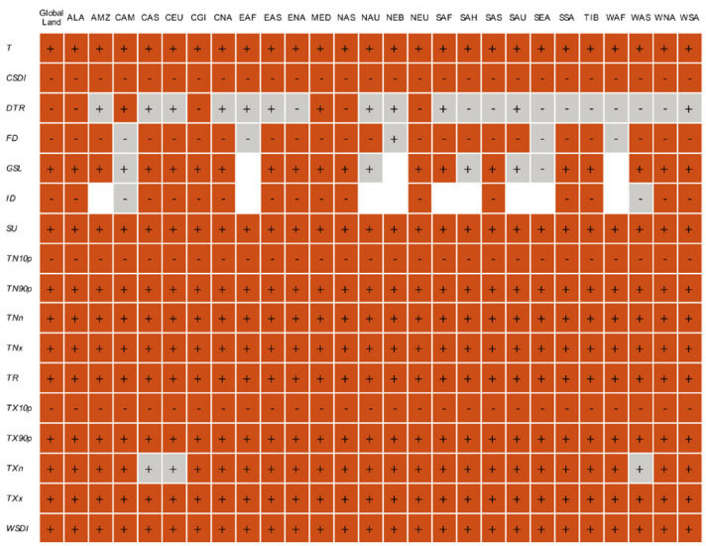

Figure 3.8 | Significance of differences in regional mean temperature and range of temperature indices between the 1.5°C and 2°C global mean temperature targets (rows). Definitions of indices: T: mean temperature; CSDI: cold spell duration index; DTR: diurnal temperature range; FD: frost days; GSL: growing season length; ID: ice days; SU: summer days; TN10p: proportion of days with a minimum temperature (TN) lower than the 10th percentile of TN; TN90p: proportion of days with TN higher than the 90th percentile of TN; TNn: minimum yearly value of TN; TNx: maximum yearly value of TN; TR: tropical nights; TX10p: proportion of days with a maximum temperature (TX) lower than the 10th percentile of TX; TX90p: proportion of days with TX higher than the 90th percentile of TX; TXn: minimum yearly value of TX; TXx: maximum yearly value of TX; WSDI: warm spell duration index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in red shading, with increases indicated with + and decreases indicated with –, while non-significant differences are shown in grey shading. White shading indicates when an index is the same at the two global warming levels (i.e., zero changes). Note that decreases in CSDI, FD, ID, TN10p and TX10p are linked to increased temperatures on cold days or nights. Significance was tested using a two-sided paired Wilcoxon test (P=0.01, after controlling the false discovery rate according to Benjamini and Hochberg, 1995) (adapted from Wartenburger et al., 2017).

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(RX1day) and consecutive 5-day precipitation (RX5day) for GMST changes of this magnitude (Supplementary Material 3.SM.2, Figure 3.SM.7; Schleussner et al., 2017). It should be noted that assessments of attributed changes in the IPCC SREX and AR5 reports were generally provided since 1950, for time frames also approximately corresponding to a 0.5°C global warming (3.SM).

3.3.3.2 Projected changes in regional precipitation at 1.5°C versus 2°C of global warming

Figure 3.3 in Section 3.3.1 summarizes the projected changes in mean precipitation at 1.5°C and 2°C of global warming. Both warming levels display robust differences in mean precipitation compared to the pre-industrial period. Regarding differences at 2°C vs 1.5°C global warming, some regions are projected to display changes in mean precipitation at 2°C compared with that at 1.5°C of global warming in the CMIP5 multimodel average, such as decreases in the Mediterranean area, including southern Europe, the Arabian Peninsula and Egypt, or increases in high latitudes. The results, however, are less robust across models than for mean temperature. For instance, Déqué et al. (2017) investigated the impact of 2°C of global warming on precipitation over tropical Africa and found that average precipitation does not show a significant response, owing to two phenomena: (i) the number of days with rain decreases whereas the precipitation intensity increases, and (ii) the rainy season occurs later during the year, with less precipitation in early summer and more precipitation in late summer. The results from Déqué et al. (2017) regarding insignificant differences between 1.5°C and 2°C scenarios for tropical Africa are consistent with the results presented in Figure 3.3. For Europe, recent studies (Vautard et al., 2014; Jacob et al., 2018; Kjellström et al., 2018) have shown that 2°C of global warming was associated with a robust increase in mean precipitation over central and northern Europe in winter but only over northern Europe in summer, and with decreases in mean precipitation in central/southern Europe in summer. Precipitation changes reaching 20% have been projected for the 2°C scenario (Vautard et al., 2014) and are overall more pronounced than with 1.5°C of global warming (Jacob et al., 2018; Kjellström et al., 2018).

Regarding changes in heavy precipitation, Figure 3.9 displays projected changes in the 5-day maximum precipitation (Rx5day) as a function of global temperature increase, using a similar approach as in Figure 3.5. Further analyses are available in Supplementary Material 3.SM.2. These analyses show that projected changes in heavy precipitation are more uncertain than those for temperature extremes. However, the mean response of model simulations is generally robust and linear (see also Fischer et al., 2014; Seneviratne et al., 2016). As observed for temperature extremes, this response is also mostly independent of the considered emissions scenario (e.g., RCP2.6 versus RCP8.5; see also Section 3.2). This feature appears to be specific to heavy precipitation, possibly due to a stronger coupling with temperature, as the scaling of projections of mean precipitation changes with global warming shows some scenario dependency (Pendergrass et al., 2015).

Robust changes in heavy precipitation compared to pre-industrial conditions are found at both 1.5°C and 2°C global warming (Figure 3.4). This is also consistent with results for, for example, the European continent, although different indices for heavy precipitation changes have been analysed. Based on regional climate simulations, Vautard et al. (2014) found a robust increase in heavy precipitation everywhere in Europe and in all seasons, except southern Europe in summer at 2°C versus 1971–2000. Their findings are consistent with those of Jacob et al. (2014), who used more recent downscaled climate scenarios (EURO-CORDEX) and a higher resolution (12 km), but the change is not so pronounced in Teichmann et al. (2018). There is consistent agreement in the direction of change in heavy precipitation at 1.5°C of global warming over much of Europe, compared to 1971–2000 (Jacob et al., 2018).

Differences in heavy precipitation are generally projected to be small between 1.5°C and 2°C GMST warming (Figure 3.4 and 3.9 and Supplementary Material 3.SM.2, Figure 3.SM.10). Some regions display substantial increases, for instance southern Asia, but generally in less than two-thirds of the CMIP5 models (Figure 3.4, Supplementary Material 3.SM.2, Figure 3.SM.10). Wartenburger et al. (2017) suggested that there are substantial differences in heavy precipitation in eastern Asia at 1.5°C versus 2°C. Overall, while there is variation among regions, the global tendency is for heavy precipitation to increase at 2°C compared with at 1.5°C (see e.g., Fischer and Knutti, 2015 and Kharin et al., 2018, as illustrated in Figure 3.10 from this chapter; see also Betts et al., 2018).

AR5 assessed that the global monsoon, aggregated over all monsoon systems, is *likely* to strengthen, with increases in its area and intensity, while the monsoon circulation weakens (Christensen et al., 2013). A few publications provide more recent evaluations of projections of changes in monsoons for high-emission scenarios (e.g., Jiang and Tian, 2013; Jones and Carvalho, 2013; Sylla et al., 2015, 2016; Supplementary Material 3.SM.2). However, scenarios at 1.5°C or 2°C global warming would involve a substantially smaller radiative forcing than those assessed in AR5 and these more recent studies, and there appears to be no specific assessment of changes in monsoon precipitation at 1.5°C versus 2°C of global warming in the literature. Consequently, the current assessment is that there is *low confidence* regarding changes in monsoons at these lower global warming levels, as well as regarding differences in monsoon responses at 1.5°C versus 2°C.

Similar to Figure 3.8, Figure 3.11 features an objective identification of 'hotspots' / key risks outlined in heavy precipitation indices subdivided by region, based on the approach by Wartenburger et al. (2017). The considered regions follow the classification used in Figure 3.2 and also include global land areas. Hotspots displaying statistically significant changes in heavy precipitation at 1.5°C versus 2°C global warming are located in high-latitude (Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe, northern Asia) and high-elevation (e.g., Tibetan Plateau) regions, as well as in eastern Asia (including China and Japan) and in eastern North America. Results are less consistent for other regions. Note that analyses for meteorological drought (lack of precipitation) are provided in Section 3.3.4.

In summary, observations and projections for mean and heavy precipitation are less robust than for temperature means and extremes (*high confidence*). Observations show that there are more areas with increases than decreases in the frequency, intensity and/or amount of

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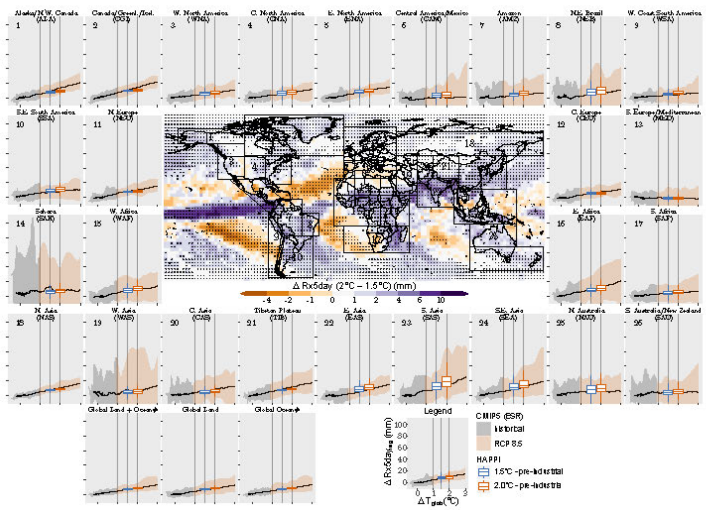

Figure 3.9 | Projected changes in annual 5-day maximum precipitation (Rx5day) as a function of global warming for IPCC Special Report on the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2), based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data together with projected changes from the HAPPI multimodel experiment (bar plots on regional analyses and central plot). The underlying methodology and data basis are the same as for Figure 3.5 (see Supplementary Material 3.SM.2 for more details).

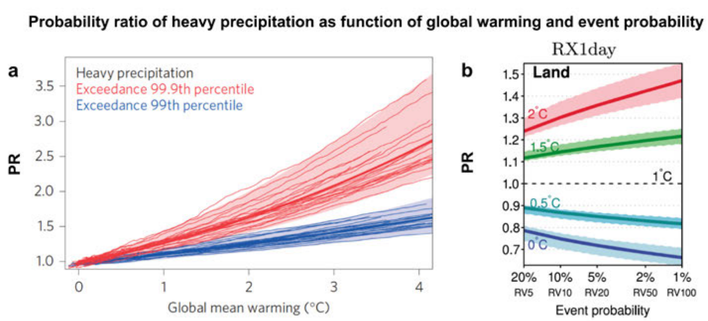

Figure 3.10 | Probability ratio (PR) of exceeding (heavy precipitation) thresholds. (a) PR of exceeding the 99th (blue) and 99.9th (red) percentile of pre-industrial daily precipitation at a given warming level, averaged across land (from Fischer and Knutti, 2015). (b) PR for precipitation extremes (RX1day) for different event probabilities (with RV indicating return values) in the current climate (1°C of global warming). Shading shows the interquartile (25–75%) range (from Kharin et al., 2018).

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3.3.3.2 (continued)

heavy precipitation (*high confidence*). Several large regions display statistically significant differences in heavy precipitation at 1.5°C versus 2°C GMST warming, with stronger increases at 2°C global warming, and there is a global tendency towards increases in heavy precipitation on land at 2°C compared with 1.5°C warming (*high confidence*). Overall, regions that display statistically significant changes in heavy precipitation between 1.5°C and 2°C of global warming are located in high latitudes (Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe, northern Asia) and high elevation (e.g., Tibetan Plateau), as well as in eastern Asia (including China and Japan) and in eastern North America (*medium confidence*). There is *low confidence* in projected changes in heavy precipitation in other regions.

	Global Land	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
PRCPTOT	+	+	-	+	+	+	+	+	-	+	+	-	+	-	-	+	-	+	-	-	+	-	+	+	-	+	-
CWD	-	+	-	-	-	-	+	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-
R95ptot	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+
R99ptot	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Rx1day	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+
Rx5day	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	+	-	+	+	+	-	+	+
SDII	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-	+	+
R1mm	+	+	-	-	-	-	+	-	-	+	+	-	+	-	-	+	-	-	-	-	-	-	+	-	-	+	-
R10mm	+	+	-	-	+	+	+	+	-	+	+	-	+	-	-	+	-	-	+	+	-	-	+	+	-	+	-
R20mm	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+	-	+	+	+	+	+	+	+

Figure 3.11 | Significance of differences in regional mean precipitation and range of precipitation indices between the 1.5°C and 2°C global mean temperature targets (rows). Definition of indices: PRCPTOT: mean precipitation; CWD: consecutive wet days; R10mm: number of days with precipitation >10 mm; R1mm: number of days with precipitation >1 mm; R20mm: number of days with precipitation >20 mm; R95ptot: proportion of rain falling as 95th percentile or higher; R99ptot: proportion of rain falling as 99th percentile or higher; RX1day: intensity of maximum yearly 1-day precipitation; RX5day: intensity of maximum yearly 5-day precipitation; SDII: Simple Daily Intensity Index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in light blue (wetting tendency) or brown (drying tendency) shading, with increases indicated with '+' and decreases indicated with '–', while non-significant differences are shown in grey shading. The underlying methodology and the data basis are the same as in Figure 3.8 (see Supplementary Material 3.SM.2 for more details).

3.3.4 Drought and Dryness

3.3.4.1 Observed and attributed changes

The IPCC AR5 assessed that there was *low confidence* in the sign of drought trends since 1950 at the global scale, but that there was *high confidence* in observed trends in some regions of the world, including drought increases in the Mediterranean and West Africa and drought decreases in central North America and northwest Australia (Hartmann et al., 2013; Stocker et al., 2013). AR5 assessed that there was *low confidence* in the attribution of global changes in droughts and did not provide assessments for the attribution of regional changes in droughts (Bindoff et al., 2013a).

The recent literature does not suggest that the SREX and AR5 assessment of drought trends should be revised, except in the Mediterranean region. Recent publications based on observational and modelling evidence suggest that human emissions have substantially increased the probability of drought years in the Mediterranean region (Gudmundsson and Seneviratne, 2016; Gudmundsson et al., 2017). Based on this evidence, there is *medium confidence* that enhanced greenhouse forcing has contributed to increased drying in the Mediterranean region (including southern Europe, northern Africa and the Near East) and that this tendency will continue to increase under higher levels of global warming.

3.3.4.2 Projected changes in drought and dryness at 1.5°C versus 2°C

There is *medium confidence* in projections of changes in drought and dryness. This is partly consistent with AR5, which assessed these projections as being '*likely* (*medium confidence*)' (Collins et al., 2013; Stocker et al., 2013). However, given this *medium confidence*, the current assessment does not include a likelihood statement, thereby maintaining consistency with the IPCC uncertainty guidance document (Mastrandrea et al., 2010) and the assessment of the IPCC SREX report (Seneviratne et al., 2012). The technical summary of AR5 (Stocker et al., 2013) assessed that soil moisture drying in the Mediterranean, southwestern USA and southern African regions was consistent with projected changes in the Hadley circulation and increased surface temperatures, and it concluded that there was *high confidence* in *likely* surface drying in these regions by the end of this century

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Box 3.1 | Sub-Saharan Africa: Changes in Temperature and Precipitation Extremes

Sub-Saharan Africa has experienced the dramatic consequences of climate extremes becoming more frequent and more intense over the past decades (Paeth et al., 2010; Taylor et al., 2017). In order to join international efforts to reduce climate change, all African countries signed the Paris Agreement. In particular, through their nationally determined contributions (NDCs), they committed to contribute to the global effort to mitigate greenhouse gas (GHG) emissions with the aim to constrain global temperature increases to 'well below 2°C' and to pursue efforts to limit warming to '1.5°C above pre-industrial levels'. The target of limiting global warming to 1.5°C above pre-industrial levels is useful for conveying the urgency of the situation. However, it focuses the climate change debate on a temperature threshold (Section 3.3.2), while the potential impacts of these global warming levels on key sectors at local to regional scales, such as agriculture, energy and health, remain uncertain in most regions and countries of Africa (Sections 3.3.3, 3.3.4, 3.3.5 and 3.3.6).

Weber et al. (2018) found that at regional scales, temperature increases in sub-Saharan Africa are projected to be higher than the global mean temperature increase (at global warming of 1.5°C and at 2°C; see Section 3.3.2 for further background and analyses of climate model projections). Even if the mean global temperature anomaly is kept below 1.5°C, regions between 15°S and 15°N are projected to experience an increase in hot nights, as well as longer and more frequent heatwaves (e.g., Kharin et al., 2018). Increases would be even larger if the global mean temperature were to reach 2°C of global warming, with significant changes in the occurrence and intensity of temperature extremes in all sub-Saharan regions (Sections 3.3.1 and 3.3.2; Figures 3.4, 3.5 and 3.8).

West and Central Africa are projected to display particularly large increases in the number of hot days, both at 1.5°C and 2°C of global warming (Section 3.3.2). This is due to the relatively small interannual present-day variability in this region, which implies that climate-change signals can be detected earlier there (Section 3.3.2; Mahlstein et al., 2011). Projected changes in total precipitation exhibit uncertainties, mainly in the Sahel (Section 3.3.3 and Figure 3.8; Diedhiou et al., 2018). In the Guinea Coast and Central Africa, only a small change in total precipitation is projected, although most models (70%) indicate a decrease in the length of wet periods and a slight increase in heavy rainfall. Western Sahel is projected by most models (80%) to experience the strongest drying, with a significant increase in the maximum length of dry spells (Diedhiou et al., 2018). Above 2°C, this region could become more vulnerable to drought and could face serious food security issues (Cross-Chapter Box 6 and Section 3.4.6 in this chapter; Salem et al., 2017; Parkes et al., 2018). West Africa has thus been identified as a climate-change hotspot with negative impacts from climate change on crop yields and production (Cross-Chapter Box 6 and Section 3.4.6; Sultan and Gaetani, 2016; Palazzo et al., 2017). Despite uncertainty in projections for precipitation in West Africa, which is essential for rain-fed agriculture, robust evidence of yield loss might emerge. This yield loss is expected to be mainly driven by increased mean temperature, while potential wetter or drier conditions – as well as elevated CO_2 concentrations – could modulate this effect (Roudier et al., 2011; see also Cross-Chapter Box 6 and Section 3.4.6). Using Representative Concentration Pathway (RCP)8.5 Coordinated Regional Climate Downscaling Experiment (CORDEX) scenarios from 25 regional climate models (RCMs) forced with different general circulation models (GCMs), Klutse et al. (2018) noted a decrease in mean rainfall over West Africa in models with stronger warming for this region at 1.5°C of global warming (Section 3.3.4). Mba et al. (2018) used a similar approach and found a lack of consensus in the changes in precipitation over Central Africa (Figure 3.8 and Section 3.3.4), although there was a tendency towards a decrease in the maximum number of consecutive wet days (CWD) and a significant increase in the maximum number of consecutive dry days (CDD).

Over southern Africa, models agree on a positive sign of change for temperature, with temperature rising faster at 2°C (1.5°C–2.5°C) as compared to 1.5°C (0.5°C–1.5°C) of global warming. Areas in the south-western region, especially in South Africa and parts of Namibia and Botswana, are expected to experience the largest increases in temperature (Section 3.3.2; Engelbrecht et al., 2015; Maúre et al., 2018). The western part of southern Africa is projected to become drier with increasing drought frequency and number of heatwaves towards the end of the 21st century (Section 3.3.4; Engelbrecht et al., 2015; Dosio, 2017; Maúre et al., 2018). At 1.5°C, a robust signal of precipitation reduction is found over the Limpopo basin and smaller areas of the Zambezi basin in Zambia, as well as over parts of Western Cape in South Africa, while an increase is projected over central and western South Africa, as well as in southern Namibia (Section 3.3.4). At 2°C, the region is projected to face robust precipitation decreases of about 10–20% and increases in the number of CDD, with longer dry spells projected over Namibia, Botswana, northern Zimbabwe and southern Zambia. Conversely, the number of CWD is projected to decrease, with robust signals over Western Cape (Maúre et al., 2018). Projected reductions in stream flow of 5–10% in the Zambezi River basin have been associated with increased evaporation and transpiration rates resulting from a rise in temperature (Section 3.3.5; Kling et al., 2014), with issues for hydroelectric power across the region of southern Africa.

For Eastern Africa, Osima et al. (2018) found that annual rainfall projections show a robust increase in precipitation over Somalia and a less robust decrease over central and northern Ethiopia (Section 3.3.3). The number of CDD and CWD are projected to increase and decrease, respectively (Section 3.3.4). These projected changes could impact the agricultural and water sectors in the region (Cross-Chapter Box 6 in this chapter and Section 3.4.6).

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under the RCP8.5 scenario. However, more recent assessments have highlighted uncertainties in dryness projections due to a range of factors, including variations between the drought and dryness indices considered, and the effects of enhanced CO_2 concentrations on plant water-use efficiency (Orlowsky and Seneviratne, 2013; Roderick et al., 2015). Overall, projections of changes in drought and dryness for high-emissions scenarios (e.g., RCP8.5, corresponding to about 4°C of global warming) are uncertain in many regions, although a few regions display consistent drying in most assessments (e.g., Seneviratne et al., 2012; Orlowsky and Seneviratne, 2013). Uncertainty is expected to be even larger for conditions with a smaller signal-to-noise ratio, such as for global warming levels of 1.5°C and 2°C.

Some published literature is now available on the evaluation of differences in drought and dryness occurrence at 1.5°C and 2°C of global warming for (i) precipitation minus evapotranspiration (P–E, a general measure of water availability; Wartenburger et al., 2017; Greve et al., 2018), (ii) soil moisture anomalies (Lehner et al., 2017; Wartenburger et al., 2017), (iii) consecutive dry days (CDD) (Schleussner et al., 2016b; Wartenburger et al., 2017), (iv) the 12-month standardized precipitation index (Wartenburger et al., 2017), (v) the Palmer drought severity index (Lehner et al., 2017), and (vi) annual mean runoff (Schleussner et al., 2016b, see also next section). These analyses have produced consistent findings overall, despite the known sensitivity of drought assessments to chosen drought indices (see above paragraph). These analyses suggest that increases in drought, dryness or precipitation deficits are projected at 1.5°C or 2°C global warming in some regions compared to the pre-industrial or present-day conditions, as well as between these two global warming levels, although there is substantial variability in signals depending on the considered indices or climate models (Lehner et al., 2017; Schleussner et al., 2017; Greve et al., 2018) (*medium confidence*). Generally, the clearest signals are found for the Mediterranean region (*medium confidence*).

Greve et al. (2018, Figure 3.12) derives the sensitivity of regional changes in precipitation minus evapotranspiration to global temperature changes. The simulations analysed span the full range of available emission scenarios, and the sensitivities are derived using a modified pattern scaling approach. The applied approach assumes linear dependencies on global temperature changes while thoroughly addressing associated uncertainties via resampling methods. Northern high-latitude regions display robust responses tending towards increased wetness, while subtropical regions display a tendency towards drying but with a large range of responses. While the internal variability and the scenario choice play an important role in the overall spread of the simulations, the uncertainty stemming from the climate model choice usually dominates, accounting for about half of the total uncertainty in most regions (Wartenburger et al., 2017; Greve et al., 2018). The sign of projections, that is, whether there might be increases or decreases in water availability under higher global warming levels, is particularly uncertain in tropical and mid-latitude regions. An assessment of the implications of limiting the global mean temperature increase to values below (i) 1.5°C or (ii) 2°C shows that constraining global warming to the 1.5°C target might slightly influence the mean

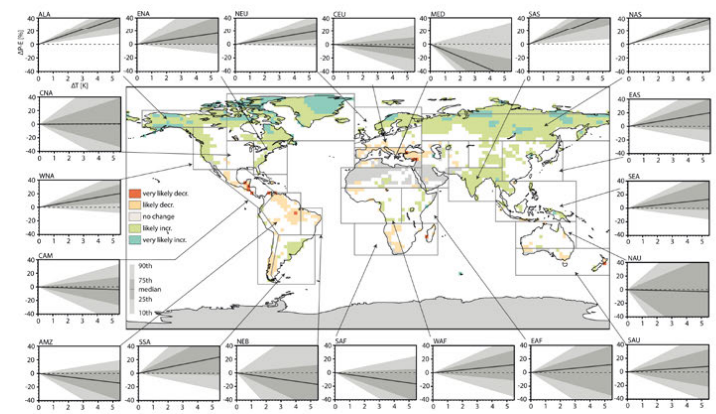

Figure 3.12 | Summary of the likelihood of increases/decreases in precipitation minus evapotranspiration (P–E) in Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations considering all scenarios and a representative subset of 14 climate models (one from each modelling centre). Panel plots show the uncertainty distribution of the sensitivity of P–E to global temperature change, averaged for most IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2) outlined in the map (from Greve et al., 2018).

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response but could substantially reduce the risk of experiencing extreme changes in regional water availability (Greve et al., 2018).

The findings from the analysis for the mean response by Greve et al. (2018) are qualitatively consistent with results from Wartenburger et al. (2017), who used an ESR (Section 3.2) rather than a pattern scaling approach for a range of drought and dryness indices. They are also consistent with a study by Lehner et al. (2017), who assessed changes in droughts based on soil moisture changes and the Palmer-Drought Severity Index. Notably, these two publications do not provide a specific assessment of changes in the tails of the drought and dryness distribution. The conclusions of Lehner et al. (2017) are that (i) 'risks of consecutive drought years show little change in the US Southwest and Central Plains, but robust increases in Europe and the Mediterranean', and that (ii) 'limiting warming to 1.5°C may have benefits for future drought risk, but such benefits are regional, and in some cases highly uncertain'.

Figure 3.13 features projected changes in CDD as a function of global temperature increase, using a similar approach as for Figures 3.5 (based

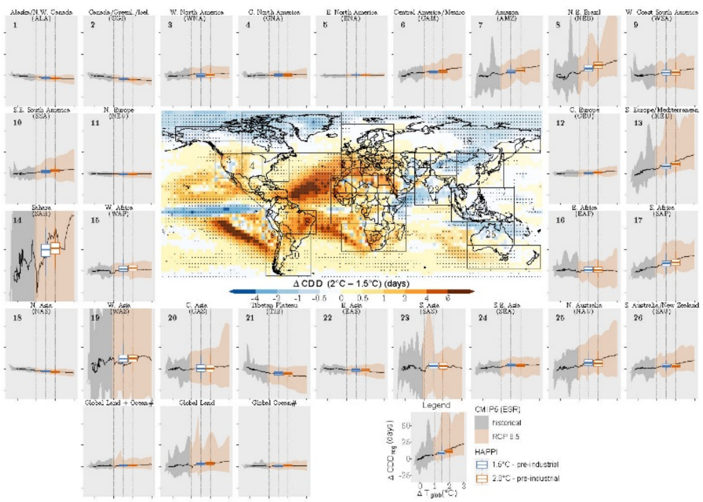

Figure 3.13 | Projected changes in consecutive dry days (CDD) as a function of global warming for IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions, based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data together with projected changes from the HAPPI multimodel experiment (bar plots on regional analyses and central plot, respectively). The underlying methodology and the data basis are the same as for Figure 3.5 (see Supplementary Material 3.SM.2 for more details).

	Global Land	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
CDD	+	-	+	+	+	+	-	+	+	-	-	+	-	+	+	+	+	+	+	+	-	+	-	+	+	-	+
P − E	+	+	+	-	+	+	+	+	+	+	-	-	+	-	-	+	-	-	+	-	+	+	-	+	-	+	-
SMA	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	-	+	-
SPI12	+	+	-	+	+	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-	+	-	+	-	-	+	+

Figure 3.14 | Significance of differences in regional drought and dryness indices between the 1.5°C and 2°C global mean temperature targets (rows). Definition of indices: CDD: consecutive dry days; P–E: precipitation minus evapotranspiration; SMA: soil moisture anomalies; SPI12: 12-month Standarized Precipitation Index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in light blue/brown shading (increases indicated with +, decreases indicated with –; light blue shading indicates decreases in dryness (decreases in CDD, or increases in P–E, SMA or SPI12) and light brown shading indicates increases in dryness (increases in CDD, or decreases in P–E, SMA or SPI12). Non-significant differences are shown in grey shading. The underlying methodology and the data basis are the same as for Figure 3.7 (see Supplementary Material 3.SM.2 for more details).

on Wartenburger et al., 2017). The figure also include results from the HAPPI experiment (Mitchell et al., 2017). Again, the CMIP5-based ESR estimates and the results of the HAPPI experiment agree well. Note that the responses vary widely among the considered regions.

Similar to Figures 3.8 and 3.11, Figure 3.14 features an objective identification of 'hotspots' / key risks in dryness indices subdivided by region, based on the approach by Wartenburger et al. (2017). This analysis reveals the following hotspots of drying (i.e. increases in CDD and/or decreases in P–E, soil moisture anomalies (SMA) and 12-month Standardized Precipitation Index (SPI12), with at least one of the indices displaying statistically significant drying): the Mediterranean region (MED; including southern Europe, northern Africa, and the Near East), northeastern Brazil (NEB) and southern Africa.

Consistent with this analysis, the available literature particularly supports robust increases in dryness and decreases in water availability in southern Europe and the Mediterranean with a shift from 1.5°C to 2°C of global warming (*medium confidence*) (Figure 3.13; Schleussner et al., 2016b; Lehner et al., 2017; Wartenburger et al., 2017; Greve et al., 2018; Samaniego et al., 2018). This region is already displaying substantial drying in the observational record (Seneviratne et al., 2012; Sheffield et al., 2012; Greve et al., 2014; Gudmundsson and Seneviratne, 2016; Gudmundsson et al., 2017), which provides additional evidence supporting this tendency and suggests that it will be a hotspot of dryness change at global warming levels beyond 1.5°C (see also Box 3.2). The other identified hotspots, southern Africa and northeastern Brazil, also consistently display drying trends under higher levels of forcing in other publications (e.g., Orlowsky and Seneviratne, 2013), although no published studies could be found reporting observed drying trends in these regions. There are substantial increases in the risk of increased dryness (*medium confidence*) in both the Mediterranean region and Southern Africa at 2°C versus 1.5°C of global warming because these regions display significant changes in two dryness indicators (CDD and SMA) between these two global warming levels (Figure 3.14); the strongest effects are expected for extreme droughts (*medium confidence*) (Figure 3.12). There is *low confidence* elsewhere, owing to a lack of consistency in analyses with different models or different dryness indicators. However, in many regions there is *medium confidence* that most extreme risks of changes in dryness are avoided if global warming is constrained at 1.5°C instead of 2°C (Figure 3.12).

In summary, in terms of drought and dryness, limiting global warming to 1.5°C is expected to substantially reduce the probability of extreme changes in water availability in some regions compared to changes under 2°C of global warming (*medium confidence*). For shift from 1.5°C to 2°C of GMST warming, the available studies and analyses suggest strong increases in the probability of dryness and reduced water availability in the Mediterranean region (including southern Europe, northern Africa and the Near East) and in southern Africa (*medium confidence*). Based on observations and modelling experiments, a drying trend is already detectable in the Mediterranean region, that is, at global warming of less than 1°C (*medium confidence*).

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Box 3.2 | Droughts in the Mediterranean Basin and the Middle East

Human society has developed in tandem with the natural environment of the Mediterranean basin over several millennia, laying the groundwork for diverse and culturally rich communities. Even if advances in technology may offer some protection from climatic hazards, the consequences of climatic change for inhabitants of this region continue to depend on the long-term interplay between an array of societal and environmental factors (Holmgren et al., 2016). As a result, the Mediterranean is an example of a region with high vulnerability where various adaptation responses have emerged. Previous IPCC assessments and recent publications project regional changes in climate under increased temperatures, including consistent climate model projections of increased precipitation deficit amplified by strong regional warming (Section 3.3.3; Seneviratne et al., 2012; Christensen et al., 2013; Collins et al., 2013; Greve and Seneviratne, 2015).

The long history of resilience to climatic change is especially apparent in the eastern Mediterranean region, which has experienced a strong negative trend in precipitation since 1960 (Mathbout et al., 2017) and an intense and prolonged drought episode between 2007 and 2010 (Kelley et al., 2015). This drought was the longest and most intense in the last 900 years (Cook et al., 2016). Some authors (e.g., Trigo et al., 2010; Kelley et al., 2015) assert that very low precipitation levels have driven a steep decline in agricultural productivity in the Euphrates and Tigris catchment basins, and displaced hundreds of thousands of people, mainly in Syria. Impacts on the water resources (Yazdanpanah et al., 2016) and crop performance in Iran have also been reported (Saeidi et al., 2017). Many historical periods of turmoil have coincided with severe droughts, for example the drought which occurred at the end of the Bronze Age approximately 3200 years ago (Kaniewski et al., 2015). In this instance, a number of flourishing eastern Mediterranean civilizations collapsed, and rural settlements re-emerged with agro-pastoral activities and limited long-distance trade. This illustrates how some vulnerable regions are forced to pursue drastic adaptive responses, including migration and societal structure changes.

The potential evolution of drought conditions under 1.5°C or 2°C of global warming (Section 3.3.4) can be analysed by comparing the 2008 drought (high temperature, low precipitation) with the 1960 drought (low temperature, low precipitation) (Kelley et al., 2015). Though the precipitation deficits were comparable, the 2008 drought was amplified by increased evapotranspiration induced by much higher temperatures (a mean increase of 1°C compared with the 1931–2008 period in Syria) and a large population increase (from