TO: Cat Kuhlman, *Executive Director*, California Ocean Protection Council

FROM: Skyli McAfee*, Executive Director*, California Ocean Science Trust;
Science Advisor, California Ocean Protection Council

DATE: October 20, 2014

SUBJECT: Understanding Sea-Level Rise Estimates for California

MEMORANDUM

My staff and I have prepared this short memo in response to your request for further explanation of the estimates for sea-level rise presented in the 2012 National Research Council Report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, Future*. These estimates include both the "ranges", which are presented in the State of California Sea-Level Rise Guidance Document (here after, the State Guidance Document), in addition to the "projection" values that fall within those ranges, and which do not appear in the State Guidance Document, but are represented in the 2012 NRC report.

This effort was prompted by confusion on the part of constituents regarding the 2012 NRC Report sea-level rise estimate values, and the components associated with their calculation. This memo attempts to clarify some of this confusion in a way that may be helpful to potential users of both the State Guidance Document, and the NRC report itself.

The information below is drawn from both the 2012 NRC report, and the California State Sea-Level Rise Guidance Document. We would also like to acknowledge and thank the several NRC Committee and OPC Science Advisory Team members who provided expertise and interpretation of technical content to develop and refine the content of this memo.

UNDERSTANDING SEA-LEVEL RISE ESTIMATES FOR CALIFORNIA

Background

The California Ocean Protection Council (OPC) developed the State of California Sea-Level Rise Guidance Document (hereafter the guidance document) to help state agencies and non-state entities implementing projects with state funds or on state lands to incorporate future sea-level rise impacts into planning and decision-making. The guidance document incorporates best available science for the state of California, including estimates of future sea-level rise recommended for use in planning and decision-making. These estimates were taken from the

2012 National Research Council report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, Future* (hereafter, The NRC report), which was mandated by Executive Order S-13-08. The purpose of this memo is to provide further explanation of the estimates for sea-level rise presented in the NRC report, including both the "ranges" presented in the state guidance document, and the "projection" values that fall within those ranges, and which do not appear in the guidance document, but were put forward by the NRC report.

It is important to emphasize that all sea-level rise estimates are subject to uncertainty stemming from a variety of factors. For example, we cannot accurately predict society's carbon emissions over the coming decades, our understanding of the global climate system is incomplete, and global climate models are limited in their ability to accurately represent all components of the climate system. As explained in the guidance document, sea-level rise estimates provide a guide for thinking about the future, but cannot give definitive future sea-level values. The guidance document indicates that decision making regarding future sea-level rise should take these and other uncertainties into account, combined with careful assessments of adaptive capacity and risk tolerance. Refer to the guidance document for further information about a risk-based framework for decision making under uncertainty.

National Research Council Sea-Level Rise Estimates: Ranges and Projections

The NRC report provides two types of estimates of sea-level rise: "projections" and "ranges." It presents these estimates for four locations along the West Coast of the United States[1] at 2030, 2050, and 2100 (Figure 1). Both the ranges and the projections represent summations of various components that contribute to sea-level rise. These components include: 1) local changes in sea-water density (thermal expansion) and wind driven changes, averaged across an ensemble of global climate models, 2) extrapolations of land-based ice melt, and 3) estimates of increasing and decreasing land height due to tectonics, land subsidence from sediment compaction and effects from the last deglaciation period. It is important to note that these different components and their associated uncertainties are estimated and calculated through different scientific approaches.

Ranges: The ranges represent "best case" and "worst case" sea-level rise scenarios, and encompass the full range of plausible outcomes for sea-level rise in California based on current understanding (though an outcome outside of the range is possible). They are generated by calculating mean sea-level rise projections associated with the thermal expansion of ocean water for the lowest (B1) and highest (A1F1) emissions scenarios from the IPCC's Fourth Assessment Report (See Box 1) and adding the minimum estimates for other sea-level rise components to the resulting lowest value and the maximum estimates for other sea-level rise components to the resulting highest value. Range estimates reflect an effort to capture sea-level rise extremes caused by high impact, low likelihood events that are especially difficult to

[1] Los Angeles, California; San Francisco, California; Newport, Oregon; Seattle, Washington.

predict. The numbers are very approximate, and the probability of their occurrence has not been estimated.

Projections: The projection values represent the NRC Committee's "best estimates." Each projection combines a multi-model mean for changes in water density (due to thermal expansion), calculated from downscaled global climate models (based on the intermediate A1B global emission scenario), with middle-range values for other sea-level rise components. Projection values are more directly constrained by projected climate forcings than the range values, and are considered by the committee as more likely estimates of actual sea level rise than the range values. The NRC presents each projection with a standard deviation as a calculation of uncertainty. The projection values and their standard deviations are calculated with an 85% confidence interval,[2] indicating an 85% likelihood that the true sea-level rise value will be at or below the upper end of that confidence interval (the projection value plus one standard deviation).

Box 1. IPCC Emissions Scenarios

Uncertainty about society's future carbon emissions is one of several sources of uncertainty associated with sea-level rise estimates. The NRC Report considers three different emissions scenarios from the 2007 IPCC Fourth Assessment Report (AR4) Special Report on Emission Scenarios (SRES). The SRES scenarios are alternative images of how the future might unfold based on population growth, future economic growth, and the introduction of clean and efficient technologies:

A1F1 scenario. Assumes continued intensive fossil fuel use, high economic growth and low population growth that peaks mid-century with the highest CO2 emissions in 2100.

A1B scenario. Assumes a more balanced energy approach of both fossil-intensive and non-fossil sources, high economic growth and low population growth.

B1 scenario. Assumes significant reduction in fossil fuel use, increase in clean technologies and low population growth with the lowest CO2 emissions in 2100

Since the release of the 2012 NRC Report, the IPCC has developed and released its Fifth Assessment Report (AR5), which presents a new set of climate change scenarios known as Representative Concentration Pathways (RCPs). While the projected changes in climate change based on the AR5 RCPs are similar to those based on the AR4's SRES emission scenarios in patterns and magnitude, there are some marked differences. The overall spread of projections for the high RCPs is narrower than for comparable SRES scenarios from the AR4. In addition, projections of sea-level rise are larger in the AR5 than in the AR4 due to improved modeling of land-ice contributions. However, due to the latency in ocean dynamics and the inertia of ice systems, any significant effects from variations in emissions scenarios are unlikely until beyond the 2000-2050 timescale.

[2] Pg. 11, Appendix C, State of California Sea-Level Rise Guidance Document (2013)

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Additional Considerations/Conclusions

The NRC Report's estimates for future sea-level rise can provide valuable insight into the trajectory of sea-level rise along the West Coast. There are important aspects of these values and their underlying methodologies that warrant additional consideration for planning and decision-making purposes.

Confidence in the projection values decreases over time. For the years 2030 and 2050, the range of the projections (the projection value minus and plus one standard deviation) provides a useful guidepost for expected sea-level rise. However, this calculation is subject to numerous uncertainties (uncertainties in the global climate system and uncertainties in global climate models) and relies on some key assumptions about future climate conditions that are less likely to hold true over long timescales. Thus, while the NRC report provides a "best estimate" projection value for the year 2100, confidence in the underlying assumptions for this time period is much lower. [3,4,5]

Consult the state guidance. This document examines both types of estimates (ranges and projections) presented in the 2012 NRC Report. It also highlights aspects of these estimates with implications for planning and decision-making. The guidance document provides more information about applying a risk-based framework for decision-making under uncertainty, and should be consulted as the primary document for planning decisions.

IN CLOSE

We hope this information has provided clarity and further understanding of the estimates presented in the 2012 NRC Report. We believe this information to represent best available science and thinking with regards to future estimates of sea-level rise for the California coast.

Sincerely

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Executive Director, California Ocean Science Trust

CC: Abe Doherty; Ryan Meyer; Marisa Villarreal

[3] Pg. 11, Appendix C, State of California Sea-Level Rise Guidance Document (2013)
[4] Pg. 101, Sea –Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future (2012). http://www.nap.edu/catalog.php?record_id=13389
[5] These judgments are also based on multiple conversations with scientists involved in the development of the 2012 NRC Report.

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NORTH OF CAPE MENDOCINO

		2030					2050					2100	
		Lowest estimate (Range)	Low estimate (Projection - SD)	Middle estimate (Projection)	High estimate (Projection + SD)	Highest estimate (Range)	Lowest estimate (Range)	Low estimate (Projection - SD)	Middle estimate (Projection)	High estimate (Projection + SD)	Highest estimate (Range)	Lowest estimate (Range)	Highest estimate (Range)
Seattle, WA	cm	- 4	1	7	12	23	- 3	6	17	27	48	10	143.0
	ft	- 0.13	0.03	0.23	0.39	0.76	- 0.10	0.20	0.56	0.89	1.57	0.32	4.69
Newport, OR	cm	-4	1	7	12	23	- 2	7	17	28	48	12	142
	ft	- 0.13	0.03	0.23	0.39	0.76	- 0.07	0.23	0.56	0.92	1.57	0.39	4.66

SOUTH OF CAPE MENDOCINO

		2030					2050					2100	
		Lowest estimate (Range)	Low estimate (Projection - SD)	Middle estimate (Projection)	High estimate (Projection + SD)	Highest estimate (Range)	Lowest estimate (Range)	Low estimate (Projection - SD)	Middle (Projection)	High estimate (Projection + SD)	Highest estimate (Range)	Lowest estimate (Range)	Highest estimate (Range)
San Francisco, CA	cm	4	9	14	19	30	12	19	28	37	61	42	166
	ft	0.13	0.30	0.46	0.62	0.98	0.39	0.62	0.92	1.21	2.00	1.38	5.45
Los Angeles, CA	cm	5	10	15	20	30	13	19	28	37	61	44	167
	ft	0.16	0.33	0.49	0.66	0.98	0.43	0.62	0.92	1.21	2.00	1.44	5.48

Increasing uncertainty

Figure 1. Projected Sea-Level Rise Values (Ranges & Projections) from 2000 – 2100.

These tables present the ranges and projections of estimated sea-level rise for north and south of Cape Mendocino from the year 2000 to 2100. These values are taken from the 2012 NRC Report, *Sea –Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. For the 2000-2030 and 2000–2050 timescale five values are presented. The "lowest" and "highest" estimates represent the lowest and highest values of the ranges, respectively. The "middle" estimates represent the projection values, with the "low" and "high" estimates representing the projection value minus and plus one standard deviation, respectively. The projections and their standard deviations (SD) are calculated with an 85% confidence interval, indicating an 85% likelihood that the true value for sea-level rise will fall at, or below the upper bound of the projection (n + SD). Note projection values for the 2000-2100 timescale were omitted due to the large uncertainties and low confidence associated with the projection values at this timescale. This judgment was supported and confirmed by NRC Committee members directly involved in the generation of these projection values.