APPENDIX A: ABSOLUTE SEA LEVEL METHODS AND PROJECTION TABLES

As described in the main body of this report, absolute sea level projections were developed using a slightly modified approach from Kopp et al. (2014; hereafter referred to as K14). K14 developed separate probability distributions for 23 components of sea level forced by climate change. In addition, K14 quantified a 24th component, termed the "background rate", that projects changes in other drivers of sea level variations that are not related to climate change (reservoir storage, groundwater extraction, glacial isostatic adjustment). Their projections were developed for a global set of tide gauges, including seven in Washington State (**Table A1**).

A suite of Matlab-based tools[1] were provided by K14 to facilitate utilization of their projections. We developed absolute sea level projections for Washington State using these tools to generate absolute sea level realizations for the 23 climatically-controlled components developed by K14, where each realization was an independent combination of the 23 components. We assessed projections for seven Washington State tide gauge locations (**Table A1**), drawn from K14's 23 sea level components. We produced 10,000 separate realizations for the decades 2010 to 2150. Given the large uncertainties in the rate and magnitude of Antarctic ice loss, especially on centennial time scales, we only include projections through 2150. A separate set of realizations was produced for each of the two RCPs; RCP 4.5 and RCP 8.5. RCP 2.6 scenario was excluded because recent research suggests it would require aggressive near-term global emissions reductions than are likely infeasible (e.g., Davis and Socolow, 2014; Pfeiffer, 2016). RCP 6.0 is also omitted due to a lack of global climate model projections that extend beyond the year 2100.

TABLE A1: Tide gauge locations for which absolute sea level rise projections are available from Kopp et al., 2014.

Tide Gauge	Latitude	Longitude	PSMSL* ID	NOAA ID
Toke Point	46.708N	123.967W	1354	9440910
Neah Bay	48.367N	124.612W	385	9443090

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[1] LocalizeSL, available at https://github.com/bobkopp/LocalizeSL. For this project we used Version 1.0, updated May 5 2015.

Port Angeles	48.125N	123.44W	2127	9444090
Port Townsend	48.112N	122.757W	1325	9444900
Friday Harbor	48.547N	123.010W	384	9449880
Cherry Point	48.863N	122.757W	1633	9449424
Seattle	47.602N	122.338W	127	9447130

* Permanent Service for Marine Sea Level (http://www.psmsl.org/), an organization that collects and maintains global tide gauge data.

We conducted a sensitivity analysis to determine if there was a basis for creating multiple absolute sea level projections for coastal Washington. We expected some degree of variation for the absolute sea level projections provided by K14 for a variety of reasons. First, the sea level fingerprinting model employed by K14 (Mitrovica et al., 2011) has a latitudinal gradient that we expected may influence spatial variability in projections. Similarly, K14 derived their "Oceanographic Processes" component (which combines changes in ocean currents and the effect of local warming) from global climate models, drawing their results from the nearest model grid cell. This could also be a source of spatial variability for absolute sea level. We arbitrarily selected a maximum range of 0.5 feet (6 inches) as a threshold for considering that the projections for two tide gauges are distinct. To examine this we simply extracted a set of specific percentiles (probabilities of exceedance) from each set of 10,000 realizations, and compared these for each of the seven locations in Washington State. Specifically, we calculated a maximum range across all seven locations, for each combination of decade and percentile (**Table A2**).

TABLE A2: Maximum range, in feet, across Kopp et al., 2014 sea level projections generated for seven tide gauge locations in Washington State. These numbers exclude Kopp et al.'s (2014) "background processes" component. We used this approach to determine if there were meaningful spatial differences in absolute sea level projections across Washington State.

Assessed likelihood (probability of exceedance)								
Years	**99**	**95**	**83**	**50**	**17**	**5**	**1**	**0.1**
2010	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*

2050	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
2100	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*
2150	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.4*	*0.4*	*0.5*

Our analysis shows that the differences in absolute sea level across Washington State are minimal. Spatial variations in absolute sea level projections tend to increase with time (i.e., the range between projections is greater in 2150 as compared to 2050) and increase with decreasing probability of exceedance. The maximum difference of 0.5 feet is for 2150, at the 0.1% assessed likelihood of exceedance. For projections in the likely range (between 17 and 83%), the maximum range between absolute sea level projections is 0.3 feet. This is well within our acceptable range of variability. Based on these results, we averaged the sea level projections for each of the seven tide gauges into a single uniform set of absolute sea level rise projections for all of Washington State.

K14's "background rate" component is derived from a statistical analysis of global tide gauge data and is intended to estimate the influence of a variety of non-climatic processes (i.e. glacio-isostatic adjustment, sediment compaction, tectonic deformation and others) on relative sea level change at a tide gauge. Our analysis, which relies on the direct measurement of vertical land movements (**Appendix C**), dictates that we take a different approach. Rather than conceptualizing sea level change at a particular location as being driven by a combination of climatic and non-climatic processes, we instead viewed relative sea level change at a particular location as being a combination of absolute sea level change (due to both climatic and non-climatic processes) and measured rates of vertical land movement. The non-climatic processes influencing absolute sea level change are associated with glacio-isostatic adjustment, specifically via changes in the shape of ocean basins and gravitational influences on the distribution of ocean water. For this assessment, we used model estimates of the influence of GIA on absolute sea level in Washington State summarized in Appendix B of NRC (2012; **Table B.2**). Specifically, **Table B.2** of the National Research Council Report on Sea Level Rise in California, Oregon and Washington summarizes estimates of the absolute sea level contributions of GIA for five locations in Washington State from seven different GIA models. The range within models is very small (less than 0.3 mm/yr), suggesting little meaningful spatial variation in the influence of GIA on absolute sea level rates. The range between models, though, is larger, between -1.0 to 0.4 mm/yr.

To arrive at our final absolute sea level projections for Washington we combined our averaged set of absolute sea level "realizations" based on K14's 23 climatically-controlled processes, with a set of values derived from GIA; the uncertainty associated with the influence of GIA on absolute sea level in

Washington State is incorporated directly into the probabilistic framework by allowing for random variation across the full range of modelled GIA rates, assuming a uniform distribution among the high and low GIA estimates from NRC (2012). The result is a probability distribution of future absolute sea level for each decade (from 2000 to 2150) and for three greenhouse gas scenarios.

Below are absolute sea level projection tables (showing the full range of probabilities of exceedance for each decade) for a low and a high greenhouse gas scenario (RCPs 4.5 and 8.5, respectively) for Washington State. We do not include a master projection table for RCP 2.6 scenario because recent research suggests it would require aggressive near-term global emissions reductions than are likely infeasible (e.g., Davis and Socolow, 2014; Pfeiffer, 2016). RCP 6.0 is also omitted due to a lack of global climate model projections that extend beyond the year 2100.

TABLE A1: Master Table of sea level rise projections for RCP 8.5 for Washington State, in feet relative to the 1991-2009 average.

Percent chance that sea level (in feet) under RCP 8.5 will reach or exceed...

	Higher likelihood of exceedance					***Lower Likelihood of exceedance***				
By the 19 year period centered around	**99**	**95**	**90**	**83**	**50**	**17**	**10**	**5**	**1**	**0.1**
2010	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*
2020	*0.0*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.4*	*0.4*
2030	*0.1*	*0.2*	*0.2*	*0.3*	*0.3*	*0.4*	*0.4*	*0.5*	*0.5*	*0.7*
2040	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.5*	*0.7*	*0.7*	*0.9*	*1.2*
2050	*0.2*	*0.3*	*0.4*	*0.6*	*0.7*	*0.8*	*1.0*	*1.1*	*1.3*	*2.0*
2060	*0.3*	*0.5*	*0.6*	*0.8*	*0.9*	*1.0*	*1.3*	*1.4*	*1.8*	*2.9*
2070	*0.4*	*0.6*	*0.7*	*1.0*	*1.2*	*1.3*	*1.6*	*1.8*	*2.4*	*4.0*
2080	*0.5*	*0.8*	*0.9*	*1.2*	*1.4*	*1.6*	*2.1*	*2.3*	*3.1*	*5.2*
2090	*0.6*	*0.9*	*1.1*	*1.5*	*1.7*	*1.9*	*2.5*	*2.8*	*3.9*	*6.6*

2100	*0.6*	*1.0*	*1.2*	*1.7*	*2.0*	*2.3*	*3.1*	*3.5*	*4.8*	*8.3*
2110	*0.9*	*1.2*	*1.4*	*1.9*	*2.2*	*2.5*	*3.3*	*3.8*	*5.5*	*9.8*
2120	*0.9*	*1.3*	*1.6*	*2.1*	*2.5*	*2.9*	*3.8*	*4.5*	*6.5*	*11.6*
2130	*1.0*	*1.5*	*1.7*	*2.4*	*2.8*	*3.2*	*4.4*	*5.1*	*7.5*	*13.6*
2140	*1.1*	*1.6*	*1.9*	*2.6*	*3.1*	*3.6*	*4.9*	*5.8*	*8.7*	*15.9*
2150	*1.1*	*1.7*	*2.0*	*2.9*	*3.4*	*4.0*	*5.6*	*6.6*	*10.0*	*18.3*

TABLE A2: Master Table of sea level rise projections for RCP 4.5 for Washington State, in feet relative to the 1991-2009 average.

Percent chance that sea level (in feet) under RCP 4.5 will reach or exceed…										
	High Likelihood				***Likely Range***				***Lower Likelihood***	
By the 19 year period centered around	**99**	**95**	**90**	**83**	**50**	**17**	**10**	**5**	**1**	**0.1**
2010	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*
2020	*0.0*	*0.1*	*0.1*	*0.1*	*0.2*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*
2030	*0.1*	*0.1*	*0.2*	*0.2*	*0.3*	*0.4*	*0.5*	*0.5*	*0.6*	*0.7*
2040	*0.1*	*0.2*	*0.3*	*0.3*	*0.5*	*0.6*	*0.7*	*0.7*	*0.9*	*1.2*
2050	*0.2*	*0.3*	*0.4*	*0.4*	*0.6*	*0.8*	*0.9*	*1.0*	*1.2*	*1.9*
2060	*0.2*	*0.4*	*0.5*	*0.6*	*0.8*	*1.1*	*1.2*	*1.3*	*1.7*	*2.7*
2070	*0.3*	*0.5*	*0.6*	*0.7*	*1.0*	*1.3*	*1.5*	*1.6*	*2.2*	*3.6*
2080	*0.3*	*0.6*	*0.7*	*0.8*	*1.2*	*1.6*	*1.8*	*2.0*	*2.7*	*4.6*
2090	*0.3*	*0.6*	*0.8*	*0.9*	*1.4*	*1.9*	*2.1*	*2.4*	*3.4*	*6.0*
2100	*0.3*	*0.7*	*0.9*	*1.0*	*1.6*	*2.2*	*2.5*	*2.8*	*4.1*	*7.3*

2110	*0.3*	*0.7*	*0.9*	*1.1*	*1.8*	*2.5*	*2.8*	*3.3*	*4.9*	*8.8*
2120	*0.3*	*0.8*	*1.0*	*1.2*	*1.9*	*2.8*	*3.2*	*3.7*	*5.7*	*10.4*
2130	*0.3*	*0.8*	*1.1*	*1.3*	*2.1*	*3.1*	*3.6*	*4.2*	*6.5*	*12.3*
2140	*0.2*	*0.8*	*1.1*	*1.4*	*2.3*	*3.5*	*4.0*	*4.8*	*7.5*	*14.1*
2150	*0.2*	*0.8*	*1.1*	*1.5*	*2.5*	*3.8*	*4.4*	*5.3*	*8.5*	*16.4*

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