APPENDIX A
Hydrologic Projections From the Integrated Scenarios dataset

There are two principal datasets that are often used to evaluate hydrologic projections for Puget Sound and the greater Pacific Northwest:

- ***Integrated Scenarios for the Future Northwest Environment.*** The current set of projections, developed by Mote et al. in 2015,[1] which stem from the newer 2013 IPCC report,[2] and
- ***The Pacific Northwest Hydroclimate Scenarios Project.*** A previous set of projections, developed by Hamlet et al. in 2010,[3] which are based on the climate projections used in the IPCC's 2007 report.[4]

Although newer, the hydrologic projections from the "Integrated Scenarios" dataset appear to contain biases, especially in mountainous areas. Specifically, the simulations assume winter temperatures that appear to be too cold at high elevations. This has a large impact on model simulations of snow accumulation and melt, which in turn has implications for streamflow. In addition, this dataset is currently being further refined through calibration – these refinements may partially alleviate the issues associated with the temperature bias.

In looking at projections from the Integrated Scenarios dataset, we found that projected changes in snow-influenced basins were large compared to expectations. For example, for the Nooksack River Basin, the projected increase in the 100-year peak flow event is +71 to +102%,[A,B,1] on average for the Integrated Scenarios dataset, as compared with +27%,[C,3] on average, for the Hamlet et al. dataset. Differences between the two datasets appear to be greatest for streamflow extremes.

Since there were concerns about the hydrologic projections obtained from the Integrated Scenarios dataset, most of the projections included in Section 3 stemmed from the Hamlet et al. dataset. For comparison, this appendix includes a summary of hydrologic projections from the Integrated Scenarios dataset.

[A] Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "moderate" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 1 for more details.

[B] Projected change is for ten global climate models, averaged over the Puget Sound region. Scenarios include a low (RCP 4.5) to a high (RCP 8.5) greenhouse gas scenario.

[C] Projected change for ten global climate models, averaged over the Puget Sound region. Range spans from a low (B1) to a moderate (A1B) greenhouse gas scenario.

Table A-1. Projected changes in hydrology, for comparison with projections included in Section 3.

Variable	*Projected Long-term Change*
Snow	
Snowpack	Declines • Declines projected for all greenhouse gas scenarios; specific amount depends on the amount of greenhouse gases emitted.[A] • Projected change in April 1st snowpack,[D] on average for Puget Sound:[A,1] 2050s (2040-2069, relative to 1970-1999): low emissions (RCP 4.5): −45% (range: −53 to −32%) high emissions (RCP 8.5): −53% (range: −66 to −37%) 2080s (2070-2099, relative to 1970-1999): low emissions (RCP 4.5): −56% (range: −65 to −50%) high emissions (RCP 8.5): −74% (range: −85 to −59%)
Streamflow	
Annual	Small changes projected. Some models project increases while other project decreases. • Change in annual runoff, on average for Puget Sound:[A,1] 2050s (2040-2069, relative to 1970-1999): low emissions (RCP 4.5): 0% (range: −5 to +12%) high emissions (RCP 8.5): −1% (range: −10 to +12%) 2080s (2070-2099, relative to 1970-1999): low emissions (RCP 4.5): +1% (range: −8 to +8%) high emissions (RCP 8.5): −2% (range: −12 to +2%)
Winter	All scenarios project an increase in winter streamflow. • Change in Winter (Oct-Mar) runoff, on average for the Puget Sound region:[A,1] 2050s (2040-2069, relative to 1970-1999): low emissions (RCP 4.5): +26% (range: +17 to +38%) high emissions (RCP 8.5): +34% (range: +20 to +55%)

[D] These numbers indicate changes in April 1st Snow Water Equivalent (SWE). SWE is a measure of the total amount of water contained in the snowpack. April 1st is the approximate current timing of peak annual snowpack in the mountains of the Northwest. Changes are only calculated for locations that regularly accumulate snow (historical April 1st SWE of at least 10 mm, or about 0.4 inch, on average).

Variable	Projected Long-term Change
	2080s (2070-2099, relative to 1970-1999): low emissions (RCP 4.5): +40% (range: +20 to +56%) high emissions (RCP 8.5): +60% (range: +43 to +77%)
Summer	All scenarios project a decrease in summer streamflow. • Change in Summer (Apr-Sep) runoff, on average for the Puget Sound region:[A,1] 2050s (2040-2069, relative to 1970-1999): low emissions (RCP 4.5): −15% (range: −20 to −7%) high emissions (RCP 8.5): −18% (range: −26 to −8%) 2080s (2070-2099, relative to 1970-1999): low emissions (RCP 4.5): −19% (range: −25 to −9%) high emissions (RCP 8.5): −29% (range: −41 to −20%)
Streamflow timing	Peak streamflows are projected to occur earlier in many snowmelt-influenced rivers in the Puget Sound region. • Change in the timing of peak streamflow for 12 Puget Sound watersheds for the 2080s (2070-2099, relative to 1970-1999).[E,F] Average change for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario:[A,1] Nooksack R.: −21 days (RCP 4.5), −28 days (RCP 8.5) Samish R.: −6 days (RCP 4.5), −7 days (RCP 8.5) Skagit R.: −21 days (RCP 4.5), −33 days (RCP 8.5) Stillaguamish R.: −19 days (RCP 4.5), −24 days (RCP 8.5) Snohomish R.: −23 days (RCP 4.5), −30 days (RCP 8.5) Cedar R.: −21 days (RCP 4.5), −24 days (RCP 8.5) Green R.: −18 days (RCP 4.5), −20 days (RCP 8.5) Nisqually R.: −17 days (RCP 4.5), −19 days (RCP 8.5) Puyallup R.: −19 days (RCP 4.5), −26 days (RCP 8.5) Skokomish R.: −11 days (RCP 4.5), −14 days (RCP 8.5) Dungeness R.: −25 days (RCP 4.5), −40 days (RCP 8.5) Elwha R.: −28 days (RCP 4.5), −37 days (RCP 8.5)
Flooding	Increases projected for most scenarios. • Projected change in streamflow volume associated with the 100-year

[E] Projected changes in streamflow were calculated for 12 Puget Sound watersheds. Listed in clock-wise order, starting at the US-Canadian border, they are: the Nooksack, Samish, Skagit, Stillaguamish, Snohomish, Cedar, Green, Nisqually, Puyallup, Skokomish, Dungeness, and Elwha Rivers.

[F] Calculations are based on the change in streamflow "Center Timing" (CT). CT is defined as the day of the water year (starting on October 1st) when cumulative streamflow reaches half of its total annual volume.

Variable	*Projected Long-term Change*
	(1% annual probability) flood event for 12 Puget Sound watersheds, on average for the 2080s (2070-2099, relative to 1970-1999):[E] Average change for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario:[A,1] Nooksack R.: +71% (RCP 4.5), +102% (RCP 8.5) Samish R.: +56% (RCP 4.5), +60% (RCP 8.5) Skagit R.: +111% (RCP 4.5), +147% (RCP 8.5) Stillaguamish R.: +55% (RCP 4.5), +99% (RCP 8.5) Snohomish R.: +72% (RCP 4.5), +104% (RCP 8.5) Cedar R.: +44% (RCP 4.5), +84% (RCP 8.5) Green R.: +43% (RCP 4.5), +71% (RCP 8.5) Nisqually R.: +37% (RCP 4.5), +57% (RCP 8.5) Puyallup R.: +49% (RCP 4.5), +80% (RCP 8.5) Skokomish R.: +5% (RCP 4.5), +38% (RCP 8.5) Dungeness R.: +99% (RCP 4.5), +119% (RCP 8.5) Elwha R.: +81% (RCP 4.5), +94% (RCP 8.5)
Minimum flows	Decreased flow in all Puget Sound watersheds • Projected changes in summer minimum streamflow (7Q10)[G] for 12 Puget Sound watersheds, on average for the 2080s (2070-2099, relative to 1970-1999).[E] Average change for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario:[A,1] Nooksack R.: −34% (RCP 4.5), −51% (RCP 8.5) Samish R.: −20% (RCP 4.5), −31% (RCP 8.5) Skagit R.: −46% (RCP 4.5), −71% (RCP 8.5) Stillaguamish R.: −40% (RCP 4.5), −53% (RCP 8.5) Snohomish R.: −39% (RCP 4.5), −53% (RCP 8.5) Cedar R.: −44% (RCP 4.5), −49% (RCP 8.5) Green R.: −42% (RCP 4.5), −48% (RCP 8.5) Nisqually R.: −38% (RCP 4.5), −47% (RCP 8.5) Puyallup R.: −32% (RCP 4.5), −47% (RCP 8.5) Skokomish R.: −42% (RCP 4.5), −61% (RCP 8.5) Dungeness R.: −52% (RCP 4.5), −74% (RCP 8.5) Elwha R.: −56% (RCP 4.5), −77% (RCP 8.5)

[G] The 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years. 7Q10 flows are a common standard for defining low flow for the purpose of setting permit discharge limits.

1 Mote, P. W., Rupp, D. E., Abatzoglou, J. T., Hegewisch, K. C., Nijssen, B., Lettenmaier, D. P., Stumbaugh, M., Lee, S.-Y., & Bachelet, D., 2015. Integrated Scenarios for the Future Northwest Environment. Version if relevant. USGS ScienceBase. Data set accessed 2015-03-02 at https://www.sciencebase.gov/catalog/item/5006eb9de4b0abf7ce733f5c

2 Seattle Public Utilities, 2013. *2013 Water System Plan: Our Water.* Our Future. Volume 1, July 2012. http://www.seattle.gov/util/MyServices/Water/AbouttheWaterSystem/Plans/WaterSystemPlan/index.htm

3 Hamlet, A.F. et al., 2013. An overview of the Columbia Basin Climate Change Scenarios Project: Approach, methods, and summary of key results. *Atmosphere-Ocean* 51(4): 392-415. doi: 10.1080/07055900.2013.819555

4 Hamman, J.J., 2012. *Effects of Projected Twenty-First Century Sea Level Rise, Storm Surge, and River Flooding on Water Levels in Puget Sound Floodplains and Estuaries.* Master's Thesis, University of Washington.