

Water Resources Research

Supporting Information for

**Seasonal hydrologic responses to climate change in the Pacific Northwest**

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Text and Tables A1 to A3.

**Introduction**

The text provides additional details on the seasonal sensitivity-based method (Eq. 1), including two equations, an alternative version of Eq. 1 (Eq. A1) and the form of the equation if the method did not include interaction terms (Eq. A2). The first two tables (A1, A2) provide values used to generate figures and demonstrate how superposition applies with an increment of 0.1°C. The third table (A3) provides an example of superposition with a larger increment of 3°C.

### Additional information on Equation 1

Equation 1 provides a mathematically concise representation of eight simple equations (Eq. A1), where variables are similar to those in Eq. 1 except OND, JFM, AMJ, and JAS are the seasons represented by  $j$  and  $Q_{1,2,...,7}^i$  demonstrate how the change of one season is incorporated into the next. The sequence of these equations does not matter (e.g.,  $Q_1^i$  could be for AMJ instead of OND). We show these equations here to provide an alternative form of the equation and further demonstrate what we test in the Yakima (Table 1).

$$\begin{aligned}
 Q_1^i &= Q_{his}^i + Q_{his}^i \times \Delta P_{OND}^i \times \varepsilon_{OND}^i \\
 Q_2^i &= Q_1^i + Q_1^i \times \Delta T_{OND}^i \times S_{OND}^i \\
 Q_3^i &= Q_2^i + Q_2^i \times \Delta P_{JFM}^i \times \varepsilon_{JFM}^i \\
 Q_4^i &= Q_3^i + Q_3^i \times \Delta T_{JFM}^i \times S_{JFM}^i \\
 Q_5^i &= Q_4^i + Q_4^i \times \Delta P_{AMJ}^i \times \varepsilon_{AMJ}^i \\
 Q_6^i &= Q_5^i + Q_5^i \times \Delta T_{AMJ}^i \times S_{AMJ}^i \\
 Q_7^i &= Q_6^i + Q_6^i \times \Delta P_{JAS}^i \times \varepsilon_{JAS}^i \\
 Q_{fut}^i &= Q_7^i + Q_7^i \times \Delta T_{JAS}^i \times S_{JAS}^i
 \end{aligned} \tag{A1}$$

In this sequence of equations, interaction terms are captured by using the streamflow values of the previous equation to calculate the new percent change. Alternatively, each of these equations could be calculated using the historical streamflow and summing the changes together (which can be represented by Eq. A2, where variables are the same as defined in Eq. 1). This approach does not capture the seasonal interactions (“No interactions” in Table 1).

$$Q_{fut}^i = Q_{his}^i \left( 1 + \sum_{j=1}^4 (\varepsilon_j^i \Delta P_j + S_j^i \Delta T_j) \right) \tag{A2}$$

In the Yakima, we investigated the effect of the interaction terms by comparing three different approaches: 1) P and T interactions (Eq. 1 or Eq. A1), 2) No interactions (Eq. A2), 3) T interactions only. Where in approach 3, we calculate interactions for T, but not for P. Results are discussed in section 4.4.

Tables A1 and A2 provide values used to generate Fig. 7 (Table A1 for precipitation elasticity and Table A2 for temperature sensitivity). These values can be used, in combination with seasonal estimates of future temperature and precipitation changes from global climate models to generate sensitivity-based hydrographs for the five basins shown (Figs. 9 and 10). The tables also demonstrate how superposition applies when increments of change are 0.1 °C.

TABLE A1 Monthly precipitation elasticities ( $\epsilon$ ) and superposition

period 1% P change applied		O	N	D	J	F	M	A	M	J	J	A	S
Willamette													
ALL		2.0	1.5	1.2	1.1	1.1	1.1	1.2	1.3	1.5	1.7	2.0	2.2
OND		1.3	1.4	1.2	0.5	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1
JFM		0.0	0.0	0.0	0.6	0.9	1.0	0.6	0.3	0.3	0.4	0.4	0.1
AMJ		0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	1.0	0.9	0.7	0.3
JAS		0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.8
monthly sum		2.0	1.5	1.2	1.1	1.1	1.1	1.2	1.3	1.5	1.7	2.0	2.2
% difference		-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.2%	-0.1%
Yakima													
ALL		1.7	1.8	1.5	1.3	1.3	1.4	1.5	1.4	1.6	2.2	2.0	1.6
OND		1.2	1.4	1.3	0.4	0.4	0.4	0.5	0.5	0.6	0.8	0.7	0.3
JFM		0.1	0.0	0.0	0.8	0.8	0.9	0.6	0.6	0.7	1.1	0.9	0.3
AMJ		0.1	0.1	0.1	0.0	0.0	0.0	0.4	0.3	0.3	0.2	0.2	0.1
JAS		0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.3	0.8
monthly sum		1.7	1.8	1.5	1.3	1.3	1.4	1.5	1.4	1.6	2.2	2.0	1.5
% difference		-0.5%	0.0%	0.1%	-0.3%	-0.1%	-0.1%	-0.2%	0.2%	-0.7%	-0.2%	0.1%	-4.7%
Upper Columbia													
ALL		1.4	1.2	1.0	0.9	0.9	0.8	0.7	0.8	1.3	1.9	1.9	1.5
OND		0.5	0.6	0.5	0.4	0.4	0.2	0.2	0.2	0.5	0.7	0.5	0.2
JFM		0.1	0.0	0.0	0.1	0.1	0.3	0.3	0.3	0.5	0.7	0.4	0.1
AMJ		0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.2	0.4	0.3	0.2	0.1
JAS		0.7	0.5	0.4	0.4	0.3	0.2	0.1	0.0	0.0	0.2	0.7	1.1
monthly sum		1.4	1.2	1.0	0.9	0.9	0.8	0.7	0.8	1.3	1.9	1.9	1.5
% difference		-0.2%	-0.1%	0.0%	0.0%	0.1%	-0.1%	0.0%	0.1%	0.0%	-0.2%	0.1%	-0.1%
Snake													
ALL		1.2	1.5	1.5	1.4	1.5	1.7	1.9	2.0	1.9	2.0	1.2	1.0
OND		0.5	0.9	1.0	0.7	0.6	0.6	0.6	0.5	0.5	0.6	0.3	0.1
JFM		0.1	0.1	0.1	0.3	0.6	0.9	0.8	0.7	0.7	0.8	0.3	0.2
AMJ		0.2	0.1	0.1	0.1	0.1	0.1	0.4	0.6	0.6	0.4	0.3	0.2
JAS		0.4	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.0	0.2	0.3	0.5
monthly sum		1.2	1.5	1.5	1.4	1.5	1.7	1.9	2.0	1.9	2.0	1.2	1.0
% difference		-0.2%	-0.2%	-0.2%	-0.2%	-0.3%	-0.3%	-0.2%	-0.2%	-0.2%	-0.1%	-0.6%	-0.1%
The Dalles													
ALL		1.3	1.4	1.4	1.3	1.3	1.4	1.6	1.6	1.6	1.9	1.7	1.3
OND		0.5	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.7	0.5	0.2
JFM		0.1	0.1	0.1	0.3	0.6	0.7	0.7	0.6	0.6	0.7	0.5	0.2
AMJ		0.1	0.1	0.1	0.1	0.1	0.0	0.3	0.5	0.5	0.4	0.3	0.2
JAS		0.6	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.2	0.4	0.8
monthly sum		1.3	1.4	1.4	1.3	1.3	1.4	1.6	1.6	1.6	1.9	1.7	1.3
% difference		-0.2%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	0.1%

TABLE A2 Monthly temperature sensitivities (S) and superposition

period 0.1 °C change applied		O	N	D	J	F	M	A	M	J	J	A	S
<b>Willamette</b>													
ALL		-2.2%	0.8%	2.2%	3.9%	3.0%	1.2%	-2.4%	-9.2%	-16.2%	-21.9%	-19.4%	-7.7%
OND		-0.4%	1.0%	2.3%	0.7%	0.0%	-0.4%	-1.2%	-2.9%	-4.7%	-6.1%	-5.4%	-1.3%
JFM		0.0%	0.0%	0.0%	3.2%	3.0%	1.6%	-2.8%	-6.7%	-7.7%	-7.4%	-5.1%	-1.1%
AMJ		-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%	0.5%	-4.0%	-9.3%	-8.5%	-2.2%
JAS		-1.1%	-0.2%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	-3.1%	-3.2%
monthly sum		-1.7%	0.8%	2.2%	3.9%	3.0%	1.2%	-2.2%	-9.1%	-16.4%	-22.3%	-22.0%	-7.8%
total difference*		0.5	0.0	0.0	0.0	0.0	0.0	0.2	0.1	-0.2	-0.5	-2.6	-0.1
<b>Yakima</b>													
ALL		-5.1%	8.3%	27.2%	39.3%	37.4%	19.0%	1.9%	-10.5%	-31.6%	-51.5%	-35.4%	-17.5%
OND		0.8%	12.4%	29.9%	10.0%	4.8%	-0.3%	-3.7%	-6.7%	-10.1%	-13.1%	-9.7%	-4.2%
JFM		-1.5%	-0.8%	-0.5%	30.9%	33.7%	20.8%	-10.3%	-11.4%	-12.7%	-12.2%	-7.0%	-2.3%
AMJ		-2.8%	-1.6%	-1.0%	-0.8%	-0.6%	-0.5%	16.9%	8.3%	-8.9%	-29.4%	-16.1%	-6.3%
JAS		-2.8%	-1.7%	-1.1%	-0.8%	-0.6%	-0.6%	-0.6%	-0.4%	-0.2%	2.6%	-4.4%	-3.1%
monthly sum		-6.3%	8.2%	27.3%	39.3%	37.3%	19.4%	2.4%	-10.2%	-31.9%	-52.0%	-37.1%	-15.9%
total difference*		-1.2	0.0	0.1	0.0	-0.1	0.4	0.4	0.3	-0.3	-0.6	-1.7	1.6
<b>Upper Columbia</b>													
ALL		0.2%	9.3%	11.4%	12.0%	16.2%	24.4%	22.9%	14.5%	-0.4%	-24.4%	-22.0%	-9.0%
OND		4.9%	12.4%	14.0%	12.4%	10.6%	4.2%	0.2%	-1.1%	-2.5%	-3.4%	-1.9%	-0.7%
JFM		-0.2%	-0.1%	-0.1%	2.1%	7.8%	21.4%	4.1%	-0.8%	-1.3%	-1.3%	-0.8%	-0.3%
AMJ		-2.4%	-1.5%	-1.2%	-1.1%	-0.9%	-0.5%	18.9%	16.7%	3.5%	-21.2%	-13.4%	-5.0%
JAS		-2.2%	-1.6%	-1.4%	-1.3%	-1.2%	-0.7%	-0.3%	-0.1%	-0.2%	1.4%	-6.2%	-3.2%
monthly sum		0.1%	9.2%	11.3%	12.0%	16.1%	24.4%	22.9%	14.6%	-0.4%	-24.5%	-22.3%	-9.2%
total difference*		-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	-0.2	-0.2
<b>Snake</b>													
ALL		-4.1%	1.8%	11.8%	18.3%	22.3%	14.5%	3.3%	-5.8%	-20.2%	-30.5%	-11.2%	-5.3%
OND		-0.2%	4.9%	14.3%	10.0%	6.8%	2.1%	-1.9%	-3.6%	-5.2%	-5.8%	-1.6%	-0.6%
JFM		-0.5%	-0.4%	-0.3%	9.9%	16.9%	13.8%	-1.9%	-6.0%	-6.5%	-5.0%	-1.5%	-0.7%
AMJ		-1.5%	-1.1%	-0.8%	-0.6%	-0.5%	-0.4%	8.1%	4.5%	-8.3%	-20.2%	-5.8%	-2.2%
JAS		-1.9%	-1.6%	-1.4%	-1.0%	-0.9%	-0.9%	-0.8%	-0.6%	-0.3%	0.0%	-2.4%	-1.8%
monthly sum		-4.1%	1.8%	11.8%	18.3%	22.3%	14.6%	3.5%	-5.7%	-20.3%	-31.0%	-11.4%	-5.3%
total difference*		0.0	0.0	0.0	0.0	-0.1	0.1	0.2	0.1	-0.1	-0.6	-0.2	0.0
<b>The Dalles</b>													
ALL		-3.4%	3.9%	12.1%	16.9%	19.1%	13.4%	6.3%	0.9%	-9.4%	-26.8%	-19.2%	-7.4%
OND		0.9%	6.8%	14.5%	9.3%	5.8%	1.5%	-1.6%	-2.9%	-3.9%	-4.9%	-2.5%	-0.8%
JFM		-0.4%	-0.3%	-0.3%	9.3%	14.7%	13.0%	-0.5%	-4.8%	-4.3%	-3.5%	-1.7%	-0.6%
AMJ		-1.9%	-1.2%	-0.9%	-0.7%	-0.6%	-0.4%	9.2%	9.2%	-1.0%	-19.6%	-11.3%	-3.5%
JAS		-2.0%	-1.5%	-1.2%	-1.0%	-0.8%	-0.7%	-0.6%	-0.4%	-0.3%	0.9%	-4.2%	-2.5%
monthly sum		-3.5%	3.9%	12.1%	16.9%	19.1%	13.4%	6.5%	1.0%	-9.5%	-27.0%	-19.6%	-7.4%
total difference*		-0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0	-0.2	-0.4	0.0

\*total difference in percentage points

Table A3 is similar to A2 for values in the Yakima but a larger increment of 3 °C is used to calculate the temperature sensitivities. This larger increment has less monthly superposition than the smaller increment of 0.1 °C. This is discussed in greater detail in section 4.3.2.

TABLE A3 Monthly temperature sensitivities (S) and superposition with a 3°C increment in the Yakima

period 3°C change applied	O	N	D	J	F	M	A	M	J	J	A	S
ALL	-3.1%	5.5%	24.5%	47.0%	35.5%	10.9%	-7.9%	-18.0%	-24.0%	-25.3%	-18.2%	-9.2%
OND	0.2%	8.5%	27.2%	8.6%	3.9%	0.2%	-2.5%	-5.6%	-9.1%	-12.2%	-8.2%	-3.4%
JFM	-1.3%	-0.8%	-0.5%	42.1%	38.5%	17.4%	-10.5%	-13.2%	-14.1%	-13.8%	-8.0%	-3.1%
AMJ	-2.0%	-1.2%	-0.9%	-0.7%	-0.5%	-0.4%	19.0%	3.9%	-12.0%	-19.3%	-11.6%	-5.3%
JAS	-2.1%	-1.5%	-1.0%	-0.7%	-0.5%	-0.5%	-0.5%	-0.4%	-0.2%	1.8%	-5.1%	-3.8%
sum of 3-month	-5.3%	5.0%	24.8%	49.3%	41.4%	16.6%	5.6%	-15.3%	-35.4%	-43.5%	-32.9%	-15.6%
total difference*	-2.2	-0.6	0.2	2.3	5.9	5.8	13.5	2.7	-11.4	-18.2	-14.7	-6.4

\*total difference in percentage points