

Supplemental Information

Climate change impacts on snow and streamflow drought regimes in four ecoregions of British Columbia

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3 Methodology

Table S1. Land cover and associated surface roughness (Manning's M) values based on the dominant land cover of watershed.

Watershed	Dominant Land cover	Surface Type from Chow (1959; Table 5-6)	Manning's n	Manning's M
Fort Nelson River	young & old forest	D-2.d. 3-4	0.08	12
Blueberry River	young forest	D-2.d. 3	0.06	17
Whiteman Creek	young & old forest	D-2.d. 3-4	0.08	12
Capilano River	subalpine	D-1.b. 1 or C.d. 2.	0.04	25

Table S2. Fort Nelson unsaturated/saturated zone parameters. McConachie soil – sphagnum peat over morainal till. Fine clastic sedimentary (mudstone, siltstone, shale) bedrock of the Fort St. John Group.

Depth below ground surface (m)	Layer	Density (kg/m ³)	θ_s	θ_r	α (cm ⁻¹)	n	Sy	K _z (m/s)	K _{xy} (m/s)	Ss
0-0.2	O fibric	40	0.85	0.04	0.08	1.9	0.68	4.8E-5	4.8E-5	1E-4
0.2-0.4	O hemic	130	0.50	0.15	0.02	1.7	0.16	1.4E-5	1.4E-5	1E-4
0.4-0.6	O sapric	170	0.40	0.22	0.003	1.6	0.009	5.5E-7	7.0E-7	1E-4
0.6-2	C horizon	1500	0.35	0.068	0.016	1.31	0.062	2.7E-6	7.0E-6	1E-4
2-5	Saprolite	2200	0.20	0.068	0.008	1.31	0.02	1.0E-7	3.0E-7	1E-5
5-200	Bedrock	2400	0.12	0.068	0.008	1.31	0.01	1.0E-10	5.0E-10	1E-5

Table S3. Blueberry unsaturated/saturated zone parameters. Wonowon soil – morainal till. Dunvegan sandstone bedrock.

Depth below ground surface (m)	Layer	Density (kg/m ³)	θ_s	θ_r	α (cm ⁻¹)	n	Sy	K _z (m/s)	K _{xy} (m/s)	Ss
0-0.2	A horizon	1310	0.45	0.067	0.02	1.41	0.23	2.7E-6	3.0E-5	1E-4
0.2-0.85	B horizon	1560	0.43	0.089	0.01	1.23	0.17	2.7E-7	5.0E-6	1E-4
0.85-1.5	C horizon	1420	0.36	0.07	0.005	1.09	0.1	2.7E-7	5.0E-6	1E-4
1.5-5	Saprolite	2200	0.27	0.05	0.03	1.45	0.2	2.0E-6	3.0E-6	1E-5
5-200	Bedrock	2400	0.25	0.05	0.008	1.45	0.2	5.0E-8	5.0E-8	1E-5

Table S4. Whiteman unsaturated/saturated zone parameters. Grant soil – morainal till. Trachyandesite bedrock of the Kitley Lake Member.

Depth below ground surface (m)	Layer	Density (kg/m ³)	θ_s	θ_r	α (cm ⁻¹)	n	Sy	K _z (m/s)	K _{xy} (m/s)	Ss
0-0.1	A horizon	1300	0.41	0.065	0.075	1.89	0.2	2E-5	2E-5	1E-4
0.1-0.5	B horizon	1450	0.41	0.095	0.019	1.31	0.2	1.6E-5	5E-5	1E-4
0.4-0.75	C horizon	1600	0.41	0.065	0.075	1.89	0.2	1.1E-5	5E-5	1E-4
0.8-5	Saprolite	2400	0.15	0.05	0.0036	2.75	0.02	5E-7	6E-7	1E-5
5-200	Bedrock	2500	0.1	0.05	0.0036	2.75	0.01	3E-8	3E-8	1E-5

Table S5. Capilano unsaturated/saturated zone parameters. Sayres soil – colluvial underlain by igneous acidic bedrock. Mid-cretaceous unnamed quartz diorite bedrock.

Depth below ground surface (m)	Layer	Density (kg/m ³)	θ_s	θ_r	α (cm ⁻¹)	n	Sy	K _z (m/s)	K _{xy} (m/s)	Ss
0-0.1	A horizon	1400	0.39	0.10	0.059	1.48	0.2	2E-6	5E-6	1E-4
0.1-0.8	B horizon	1450	0.39	0.10	0.059	1.48	0.2	2E-6	2E-6	1E-4
0.8-5	Saprolite	2700	0.05	0.01	0.0036	2.75	0.02	5E-7	5E-7	1E-5
5-200	Bedrock	2800	0.03	0.01	0.0036	2.75	0.01	1E-7	1E-7	1E-5

4. Results

4.1 Climate change impacts on annual and intra-annual water balance

Table S6. Mean annual values and absolute difference (°C) in mean annual temperature (Temp) and mean annual values (mm/year) and relative difference (%) in mean annual precipitation (Precip), peak snow water equivalent (SWE), annual runoff, actual evapotranspiration (AET), and groundwater recharge for 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

	Time Period	RCP	Fort Nelson		Blueberry		Whiteman		Capilano	
			Mean	Δ	Mean	Δ	Mean	Δ	Mean	Δ
Temp	1980s	--	-0.6	--	0.0	--	2.1	--	5.9	--
	2050s	4.5	2.1	+2.8	2.7	+2.7	4.8	+2.8	8.4	+2.6
	2050s	8.5	2.9	+3.5	3.3	+3.4	5.5	+3.4	9.1	+3.2
	2080s	4.5	2.8	+3.4	3.3	+3.3	5.6	+3.5	9.1	+3.2
	2080s	8.5	5.2	+5.9	5.8	+5.9	8.2	+6.1	11.4	+5.6
Precip	1980s	--	459	--	498	--	650	--	2346	--
	2050s	4.5	521	+13.5%	566	+13.7%	667	+2.6%	2440	+4.0%
	2050s	8.5	554	+20.7%	599	+20.3%	706	+8.6%	2524	+7.6%
	2080s	4.5	546	+19.0%	585	+17.6%	712	+9.5%	2576	+9.8%
	2080s	8.5	588	+28.2%	607	+21.9%	726	+11.7%	2594	+10.6%
SWE	1980s	--	123	--	124	--	312	--	398	--
	2050s	4.5	127	+4.0%	119	-3.8%	272	-12.9%	103	-74.1%
	2050s	8.5	132	+7.5%	123	-1.0%	252	-19.3%	77	-80.7%
	2080s	4.5	135	+10.0%	128	+3.3%	268	-14.0%	77	-80.6%
	2080s	8.5	140	+14.5%	101	-18.8%	162	-48.1%	31	-92.3%
Runoff	1980s	--	12	--	104	--	273	--	1588	--
	2050s	4.5	16	+27.8%	122	+17.6%	288	+5.7%	1668	+5.0%
	2050s	8.5	19	+57.6%	140	+34.5%	314	+15.1%	1729	+8.9%
	2080s	4.5	20	+60.3%	134	+28.7%	325	+19.0%	1773	+11.7%
	2080s	8.5	24	+96.3%	140	+34.8%	338	+23.9%	1785	+12.4%
AET	1980s	--	429	--	354	--	365	--	471	--
	2050s	4.5	479	+11.6%	395	+11.5%	364	-0.3%	471	+0.0%
	2050s	8.5	500	+16.4%	403	+13.8%	374	+2.3%	484	+2.8%
	2080s	4.5	491	+14.3%	397	+12.1%	371	+1.7%	483	+2.4%
	2080s	8.5	518	+20.6%	409	+15.5%	371	+1.7%	486	+3.2%
Recharge	1980s	--	288	--	194	--	234	--	774	--
	2050s	4.5	339	+17.6%	211	+9.2%	244	+4.4%	769	-0.6%
	2050s	8.5	368	+27.5%	221	+14.0%	258	+10.6%	783	+1.1%
	2080s	4.5	360	+24.9%	213	+10.0%	254	+8.7%	771	-0.4%
	2080s	8.5	394	+36.5%	229	+18.5%	264	+13.0%	742	-4.1%

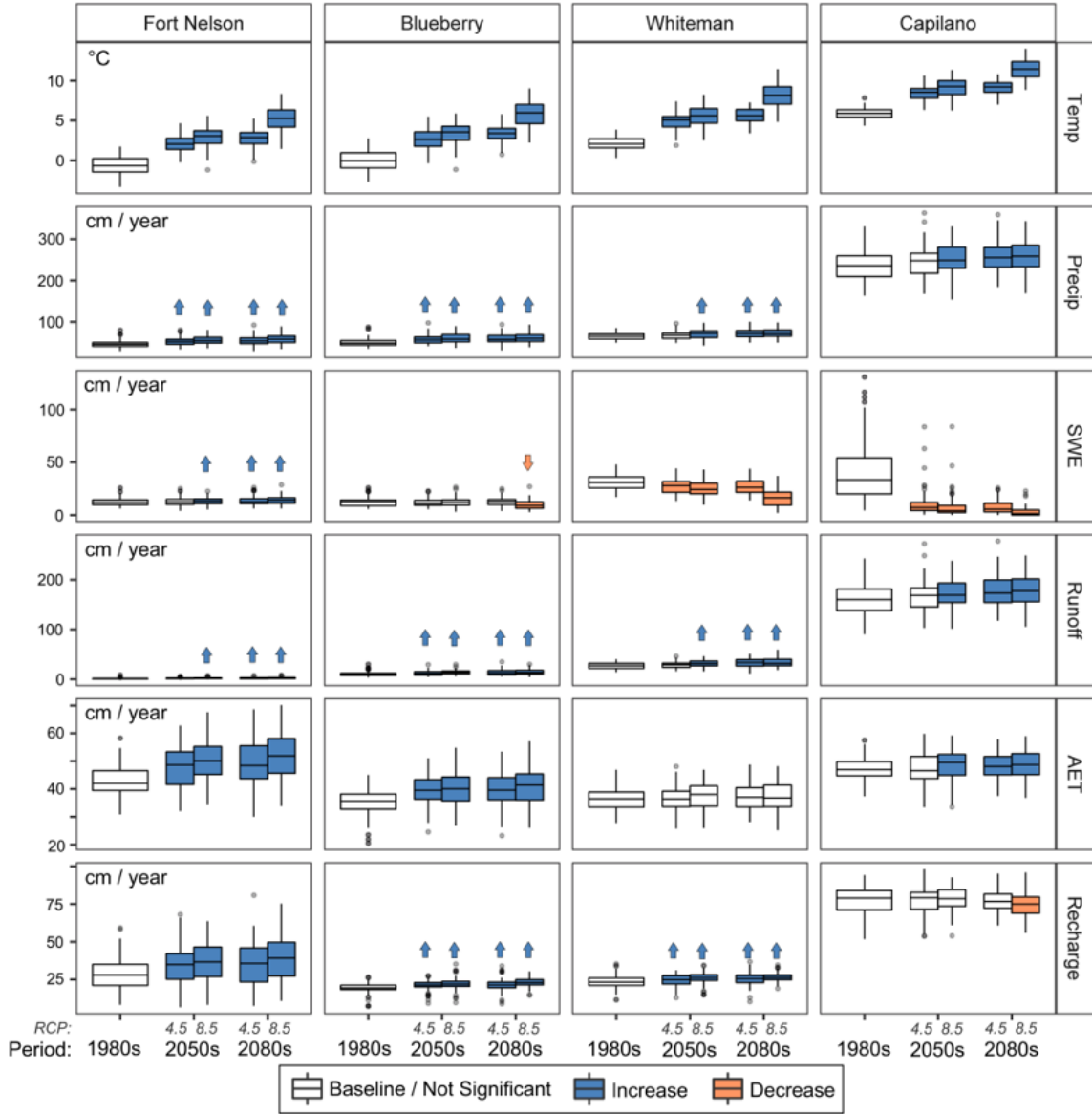


Figure S1. Absolute change in annual climate and water balance components for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5, including mean annual temperature (Temp), annual precipitation (Precip), peak snow water equivalent (SWE), annual runoff, annual actual evapotranspiration (AET), and annual groundwater recharge. Blue and orange shading indicate a significant ($p < 0.05$) increase or decrease relative to the baseline period, as assessed with the two-sided Mann-Whitney U test. Arrows are added for clarity where boxplot shading is unclear.

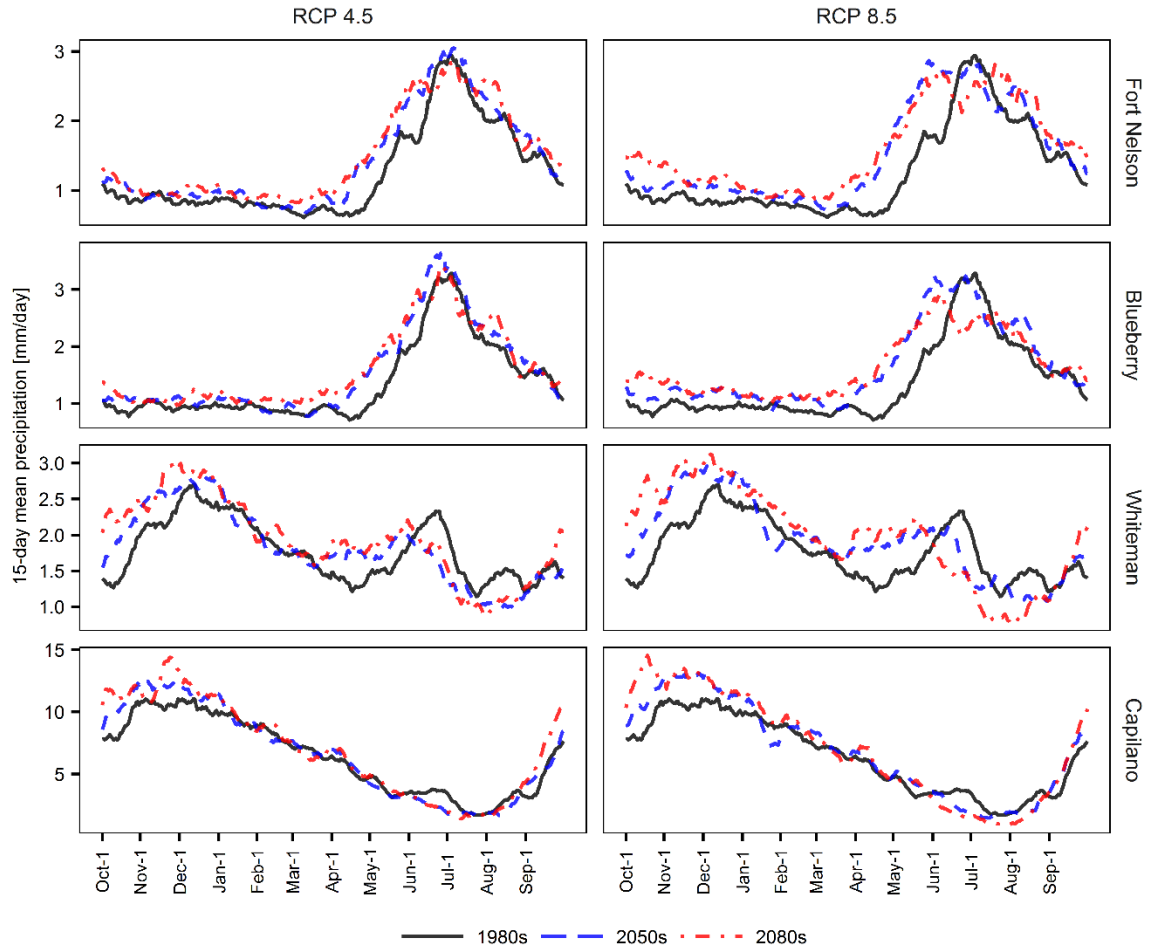


Figure S2. Smoothed 15-day mean precipitation rate for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

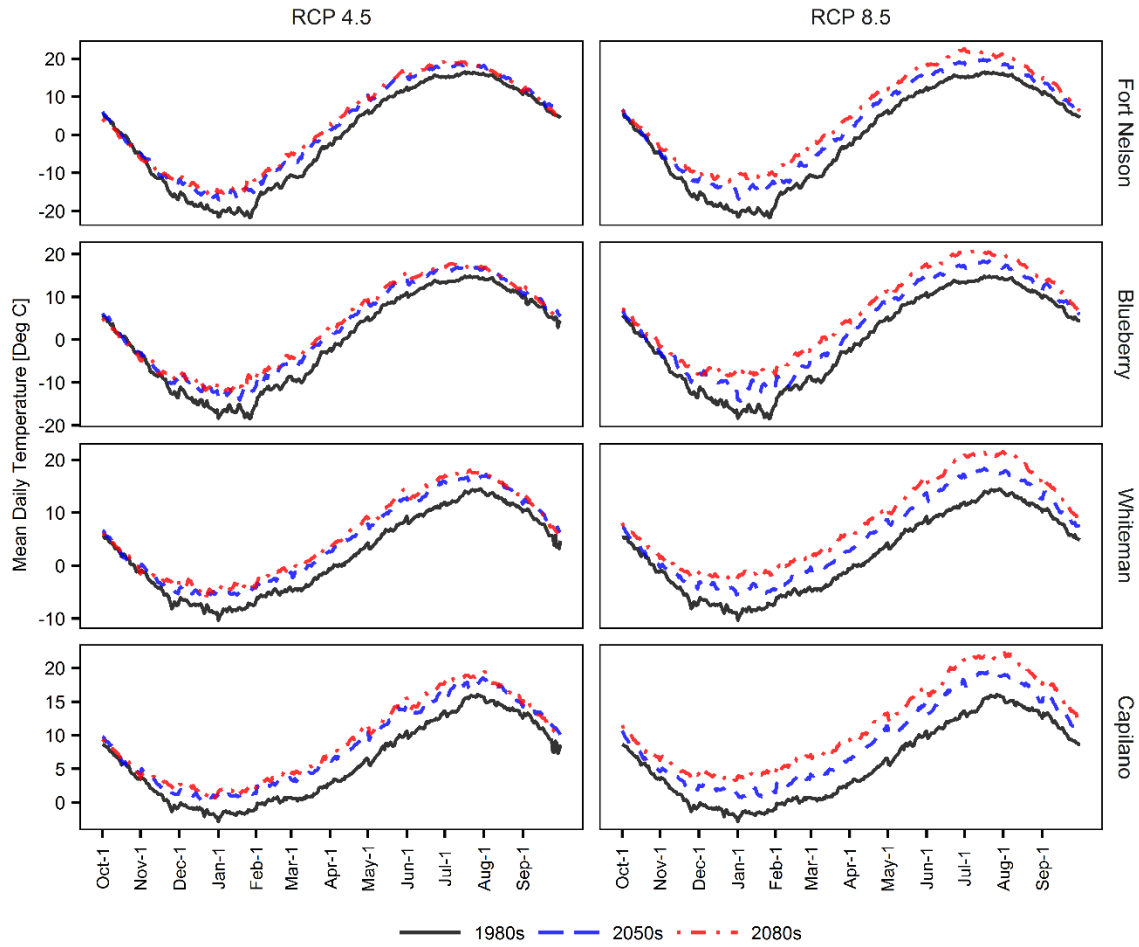


Figure S3. Mean daily temperature for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

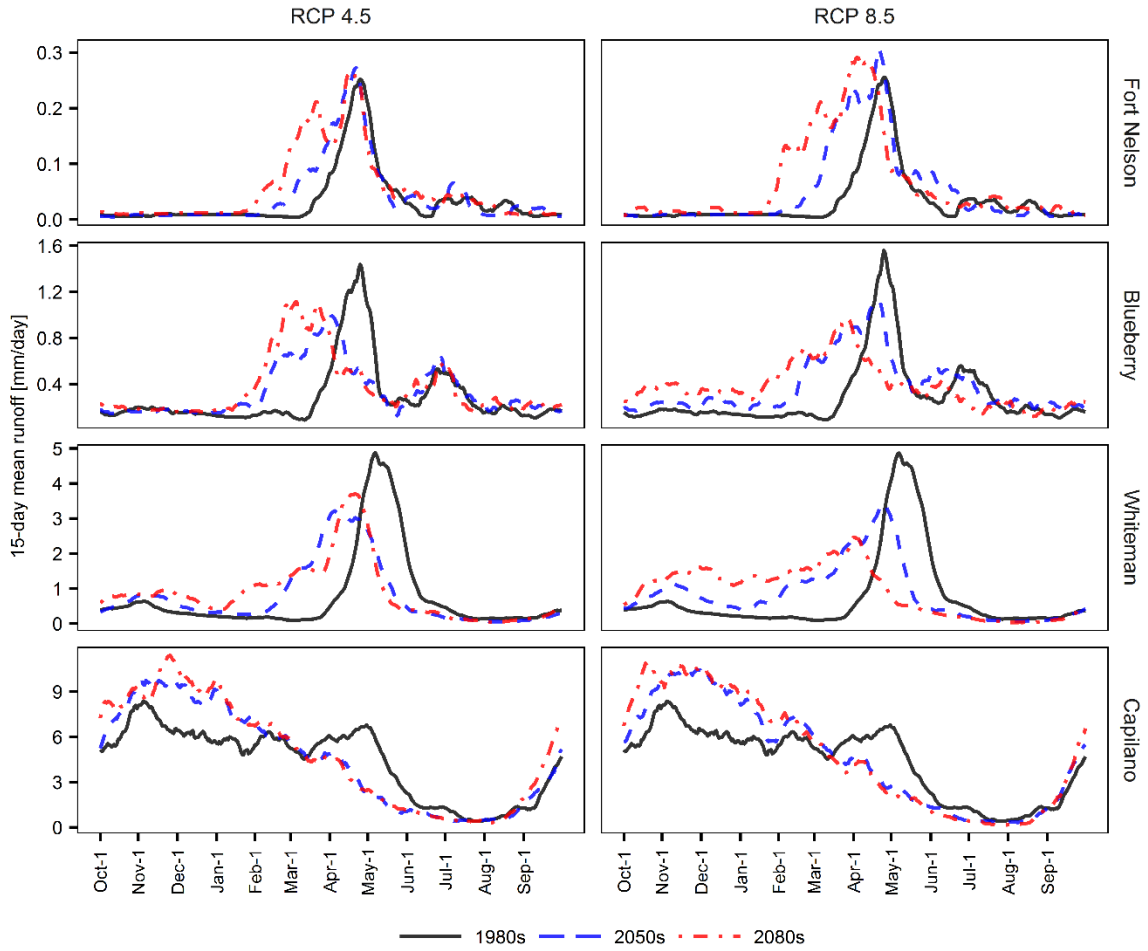


Figure S4. Smoothed 15-day mean daily runoff for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

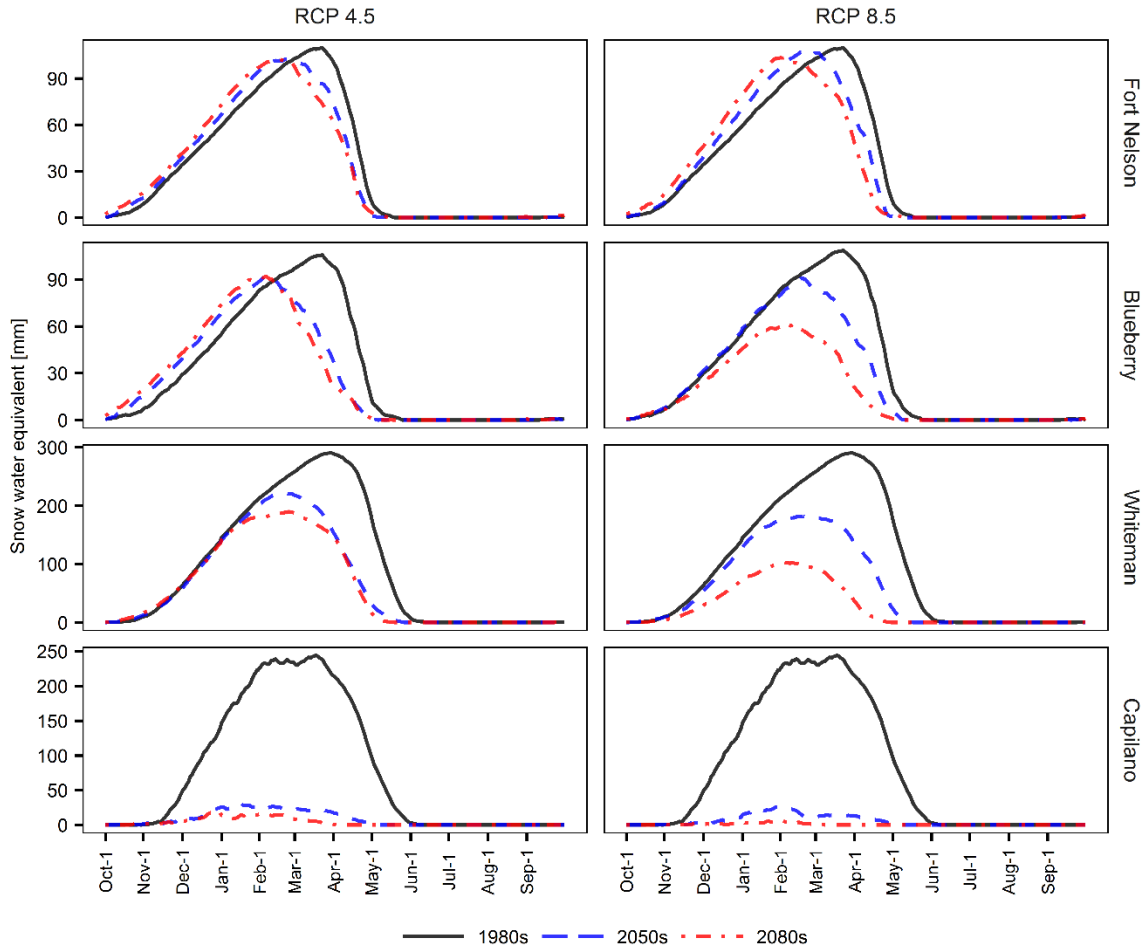


Figure S5. Mean daily snow water equivalent for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

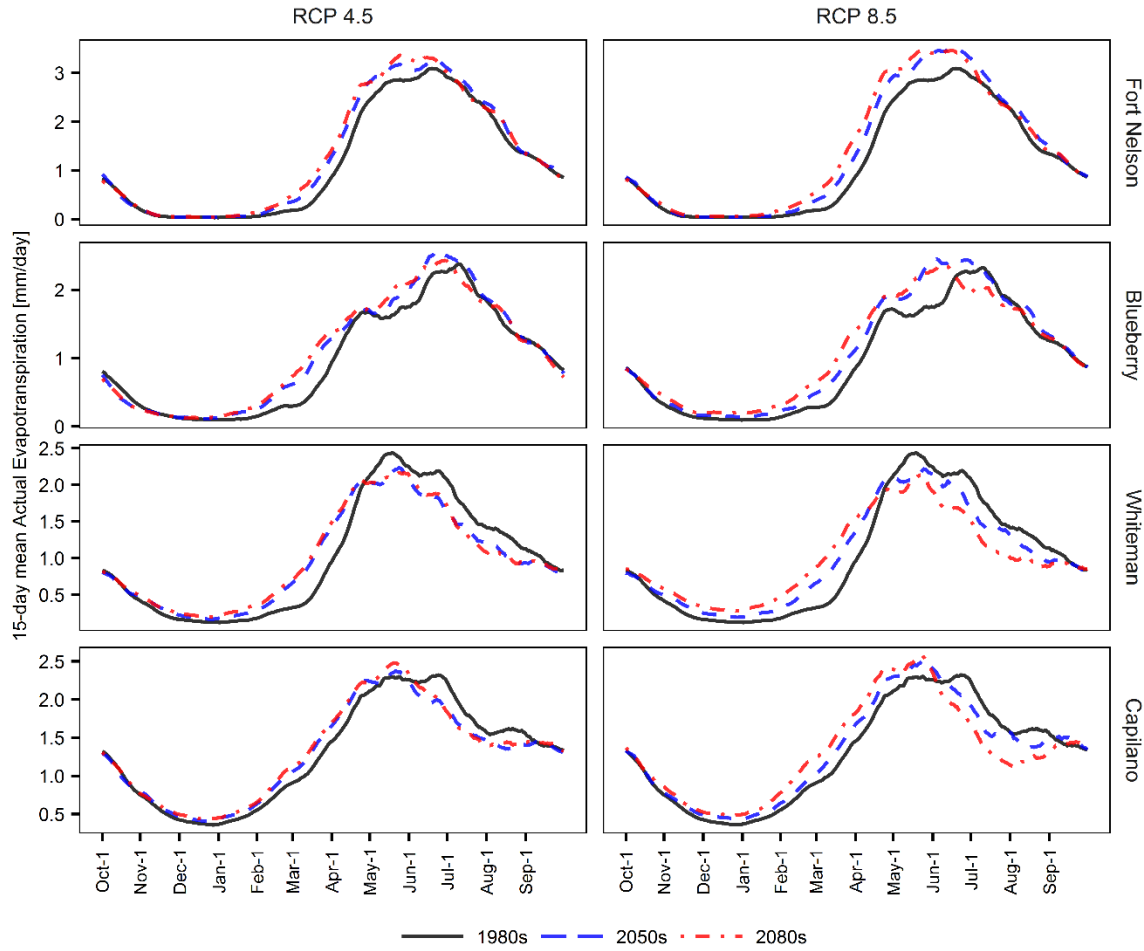


Figure S6. Smoothed 15-day mean actual evapotranspiration rate for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

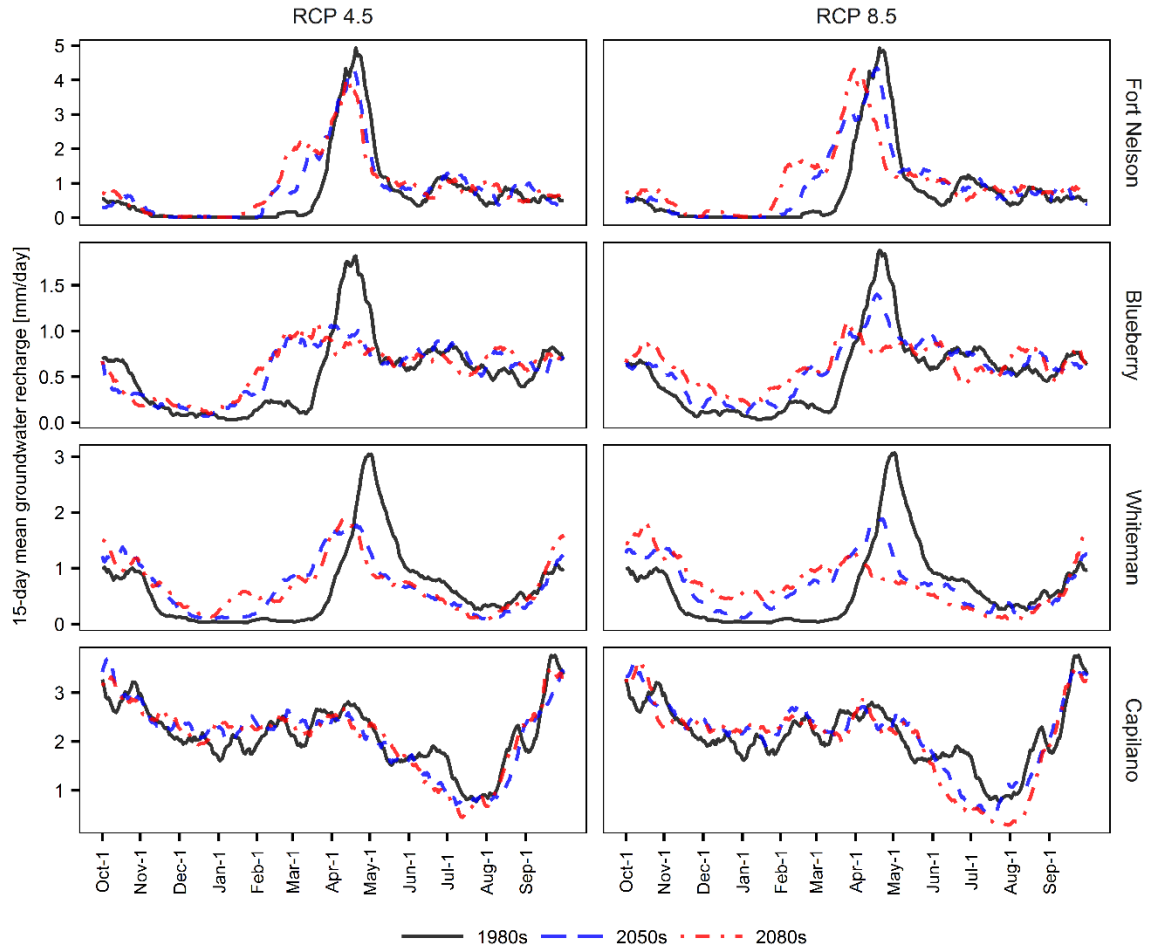


Figure S7. Smoothed 15-day mean groundwater recharge rate for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

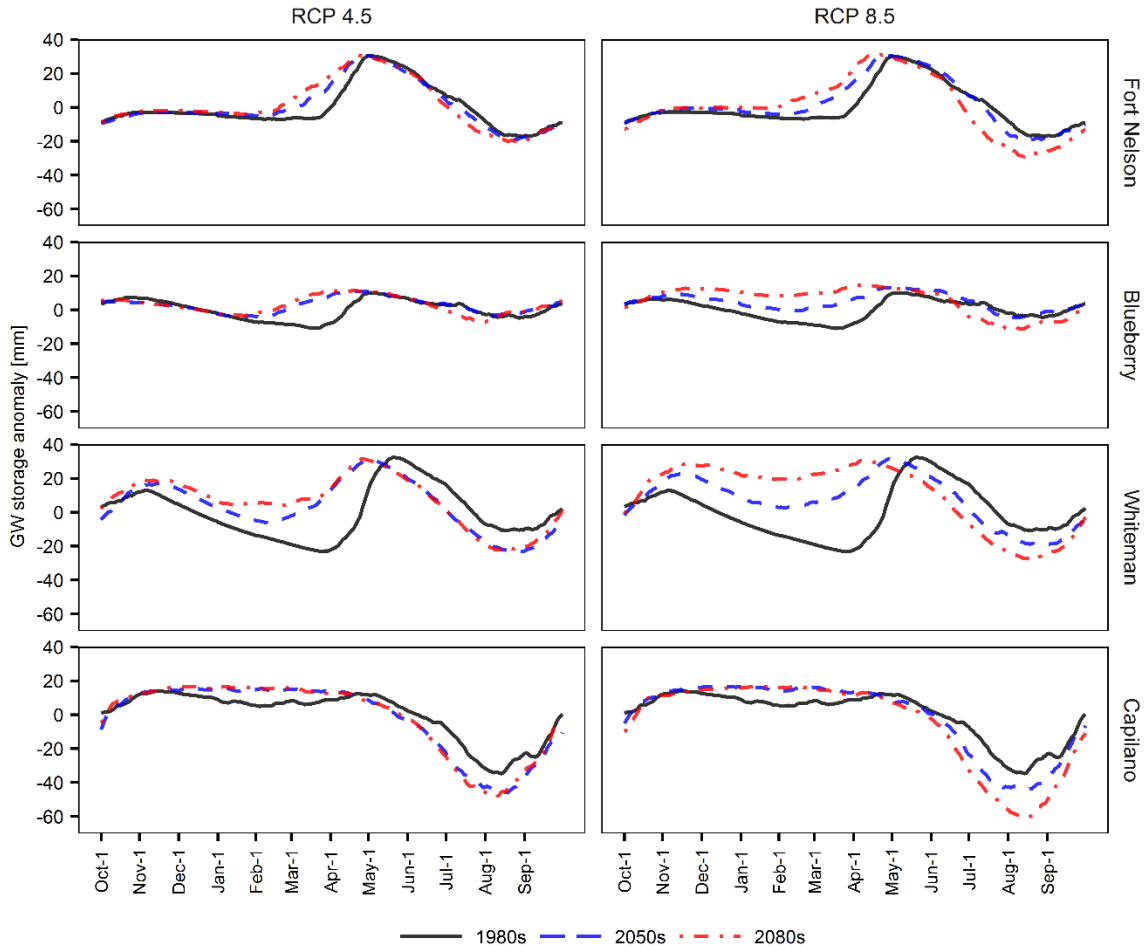


Figure S8. Mean daily groundwater (GW) storage anomaly (calculated as the mean *daily* value minus the baseline mean *annual* value) for the 1980s baseline (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathway (RCP) 4.5 and RCP 8.5.

4.2 Snow drought

Table S7. Frequency (fraction of years) of dry (D), warm (W), and warm and dry (W&D) snow droughts. Baseline 1980s (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathways (RCP) 4.5 and 8.5.

		Fort Nelson		Blueberry		Whiteman		Capilano	
1980s	D	0.16		0.16		0.22		0.07	
	W	0.08		0.09		0.07		0.30	
	W&D	0.30		0.26		0.22		0.21	
	<i>RCP</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>
2050s	D	0.04	--	0.01	--	0.01	--	0.01	--
	W	0.23	0.20	0.34	0.39	0.37	0.59	0.54	0.63
	W&D	0.27	0.19	0.29	0.19	0.33	0.19	0.41	0.34
2080s	D	--	--	--	--	--	--	--	--
	W	0.28	0.32	0.32	0.71	0.51	0.79	0.60	0.60
	W&D	0.22	0.08	0.22	0.04	0.20	0.13	0.40	0.40

Table S8. Mean severity (fraction below baseline normal) of dry (D), warm (W), and warm and dry (W&D) snow droughts. Baseline 1980s (1970-1999) versus 2050s (2040-2069) and 2080s (2070-2099) for representative concentration pathways (RCP) 4.5 and 8.5.

		Fort Nelson		Blueberry		Whiteman		Capilano	
1980s	D	0.20		0.18		0.17		0.45	
	W	0.16		0.19		0.12		0.47	
	W&D	0.21		0.22		0.23		0.56	
	<i>RCP</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>	<i>4.5</i>	<i>8.5</i>
2050s	D	0.31	0.03	0.16	0.23	0.29	0.16	0.70	0.79
	W	0.13	0.16	0.20	0.26	0.20	0.27	0.82	0.82
	W&D	0.23	0.22	0.27	0.23	0.25	0.29	0.82	0.88
2080s	D	--	--	--	--	0.34	--	0.51	--
	W	0.15	0.22	0.20	0.37	0.22	0.49	0.84	0.92
	W&D	0.23	0.23	0.27	0.49	0.31	0.53	0.84	0.95

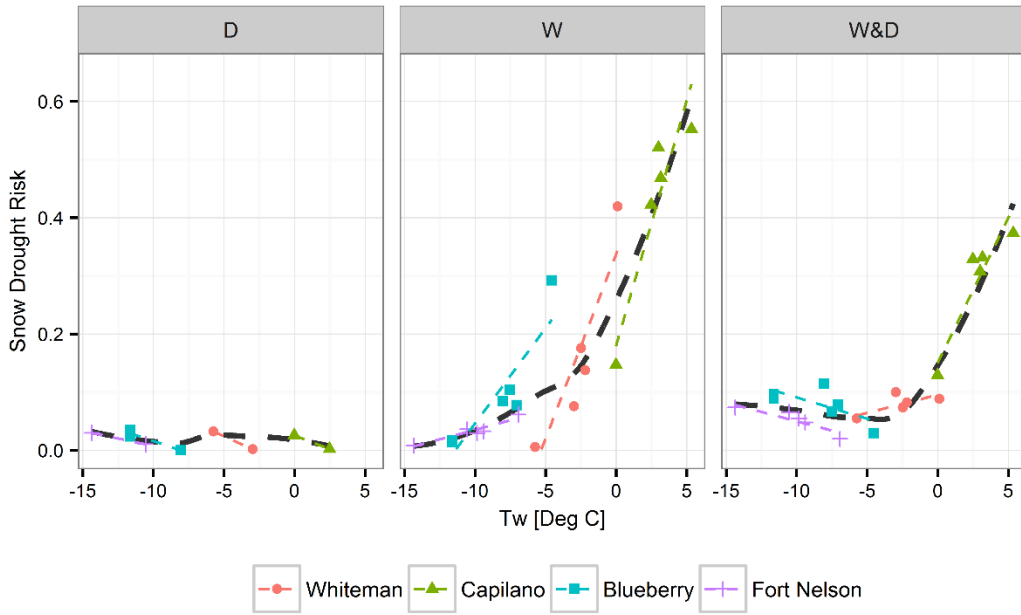


Figure S9. Snow drought risk (frequency x severity) for dry (D), warm (W), and warm and dry (W&D) snow droughts versus the mean winter (1-Nov to 1-Apr) temperature (T_w). Linear trend lines plotted by watershed. The dark gray dashed line is a locally weighted smoothing of all data points to highlight the non-linear relationship between risk and T_w .