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Data Descriptor

Reconstructed River Water Temperature Dataset for Western Canada 1980–2018

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Abstract: Continuous water temperature data are important for understanding historical variability and trends of river thermal regime, as well as impacts of warming climate on aquatic ecosystem health. We describe a reconstructed daily water temperature dataset that supplements sparse historical observations for 55 river stations across western Canada. We employed the air2stream model for reconstructing water temperature dataset over the period 1980–2018, with air temperature and discharge data used as model inputs. The model was calibrated and validated by comparing with observed water temperature records, and the results indicate a reasonable statistical performance. We also present historical trends over the ice-free summer months from June to September using the reconstructed dataset, which indicate- significantly increasing water temperature trends for most stations. Besides trend analysis, the dataset could be used for various applications, such as calculation of heat fluxes, calibration/validation of process-based water temperature models, establishment of baseline condition for future climate projections, and assessment of impacts on ecosystems health and water quality.

Dataset: https://catalogue.ec.gc.ca/geonetwork/srv/eng/catalog.search#/metadata/cc103402-ba59-43eb-820e-f319b6b5f9b4 (accessed on 25 February 2023)

Dataset License: Open Government License–Canada: https://open.canada.ca/en/open-government-licence-canada (accessed on 25 February 2023)

Keywords: air2stream model; data reconstruction; trend analysis; water temperature; western Canada

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1. Summary

We describe a reconstructed daily river water temperature (°C) dataset for 55 stations across western Canada. The dataset was reconstructed using the semi-empirical air2stream model with inputs primarily consisting of extracted air temperature from ~10 km resolution 1980–2018 Regional Deterministic Reforecast System version 2.1, and streamflow data from the Water Survey of Canada hydrometric station network. Air2stream was calibrated/validated with observed water temperature records from various sources and the model provided a reasonable statistical performance. The dataset is designed to supplement sparse observation-based data, which is usually based on a few spot measurements in a year. The dataset could be used for various applications, such as analysis of trend, calculation of heat fluxes, calibration/validation of process-based water temperature models, establishment of baseline condition for future climate projections, analysis of climatic and basin drivers, and assessment of impacts on ecosystems health and water quality. An example application of the dataset, in terms of monthly trend analysis over open-water summer months, is provided.

2. Data Description

The dataset consists of reconstructed river water temperature values (°C) at a daily time step using the air2stream model [1] for 55 stations across western Canada (Figure 1). The dataset for all stations is provided in a single file in comma-separated-format (csv) spanning the period from 1 January 1980 to 31 December 2018 through the Government of Canada data portal. The water temperature station locations (Table A1) correspond to the Water Survey of Canada hydrometric stations (https://wateroffice.ec.gc.ca/ (accessed on 23 February 2023)) and a separate text file provides the station coordinates. Since air2stream simulation requires observed discharge data as an input, the days with no observed discharge data are specified as not available (NA) in the simulated water temperature dataset. Statistical performance of the simulated water temperature compared to observations are summarized in Table A2.

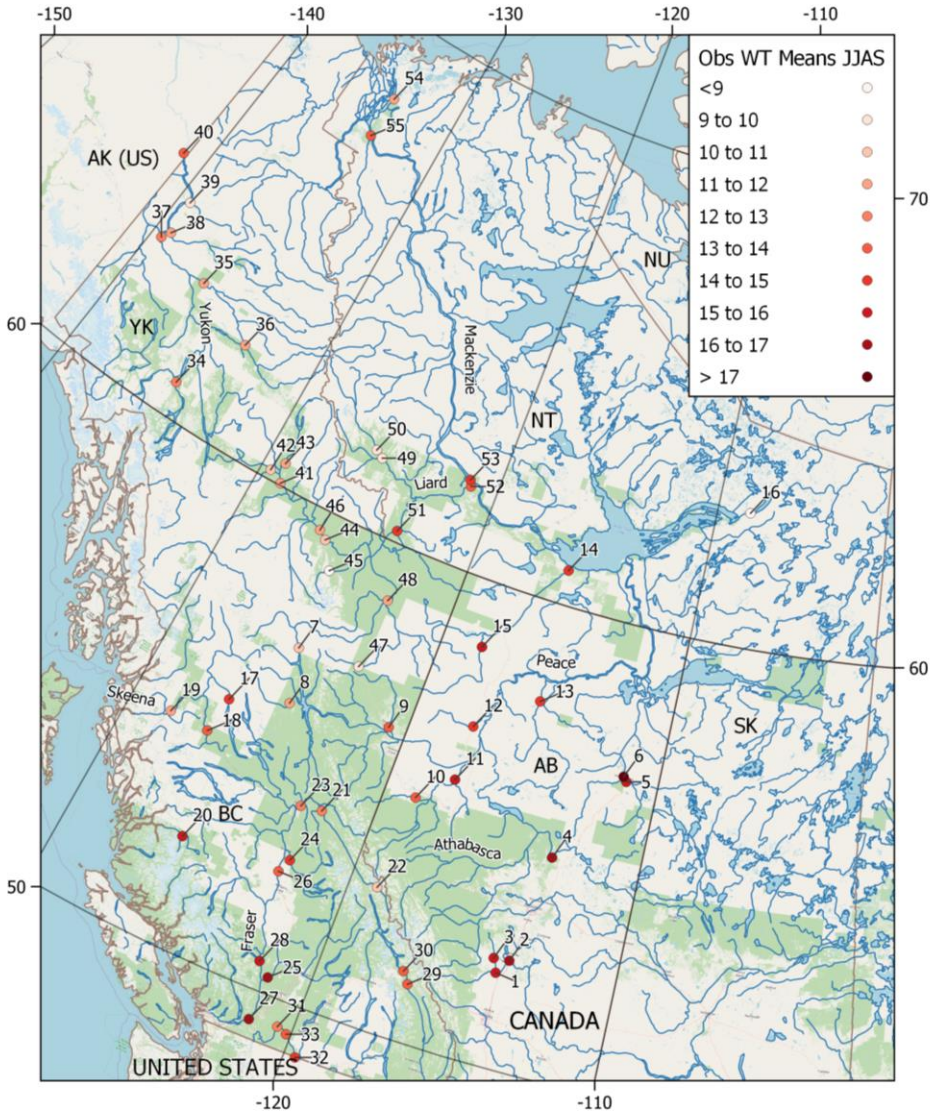

Figure 1. Location map of the river water temperature stations across western Canada. The mean observed June–September water temperature over the period of 1980–2018 is also shown. The station numbers correspond to the station identifiers listed in Table A1.

We also provide 1980–2018 trends over the ice-free summer months of June-September using the reconstructed water temperature data. The trend results are depicted spatially in maps (Figure A1) and summarized in Table A3. The results indicate significantly increasing water temperature trends for most months. Additionally, while most stations in the southern region indicate significant trends for all months, most northern stations show significant trends only for the month of June.

3. Methods

We selected 55 stations across western Canada based on the criteria of at least 50 water temperature observations and drainage basin area >1000 km^2. Additional criteria included continuous streamflow observations and unregulated or relatively minor level of river flow regulation, e.g., Mackenzie and Fraser river stations.

We used the semi-empirical air2stream model [1] to reconstruct the daily water temperature dataset. The model uses simplified process-based equations to simulate river water temperature, with air temperature as the only meteorological forcing and the surface and sub-surface flow contributions considered in terms of lumped discharge. Daily air temperature inputs were extracted from ~10 km resolution Regional Deterministic Reforecast System, version 2.1 (RSRS_v2.1) reanalysis [2], except the high resolution (500 m) NRCanMet_500 data [3] for the Similkameen River near Headley and Nighthawk stations. Discharge inputs consisted of daily streamflow data from the Water Survey of Canada (WSC) hydrometric stations (https://wateroffice.ec.gc.ca/ (accessed on 23 February 2023)) that are nearest to the water temperature stations, except for the USGS streamflow data for the Yukon River at Eagle station AK (https://waterdata.usgs.gov/nwis/ (accessed on 23 February 2023)). We infilled missing observed discharge data with the hydrologic model simulated data for the available stations in the Liard [4] and Similkameen [5] watersheds. For all other stations, we infilled missing discharge values with averages before and after the missing period, and water temperature values for the missing discharge periods were specified as NA values in the uploaded dataset. We obtained observed water temperature records from a number of sources for calibrating/validating air2stream, as summarized in Shrestha and Pesklevits [6].

The air2stream model consists of 3 to 8 parameters (except 6 parameters) depending on the form of equation used. In this study, we calibrated air2stream models for all parameter combinations by using the particle swarm stochastic optimization procedure [1]. The model calibration was performed by comparing the simulated water temperature with observations for either the years 2010–2018 or 2000–2009, with the years with larger (smaller) number of observed water temperature records used for calibration (validation). We selected the best performing model parameter set by using the Nash–Sutcliffe coefficient of efficiency (NSE) as the performance criterion, supplemented by the mean absolute error (MAE), Kling–Gupta coefficient (KGE) and ratio of root mean square error to standard deviation of observation (RSR) as additional criteria. Higher NSE and KGE values (approaching 1) indicate better model performance, and lower MAE and RSR (approaching 0) indicate better model performance. We used the selected best performing models to simulate water temperature over the period of 1980–2018, and the model's statistical performance over the period is summarized in Table A2. The results indicate good model performance in terms of NSE (minimum = 0.79, median = 0.93, maximum = 0.97), KGE (0.81, 0.94, 0.99), MAE (0.51, 0.99, 1.61 °C) and RSR (0.16, 0.27, 0.46) goodness-of-fit metrics.

We used the reconstructed water temperature dataset to calculate trends over the years 1980–2018 by employing the non-parametric Thiel–Sen method. Trend significance was determined by using the Mann–Kendall test with the effects of serial correlation removed by using the iterative pre-whitening method [7], as implemented in the R "zyp" package [8]. Two significance levels of $p \leq 0.05$ and $p \leq 0.10$ were used to consider statistically significant trends.

It is to be noted that the dataset presented is partially based on our previous study [6]. However, this dataset uses an expanded domain with a larger number of stations (55 vs. 18 in the previous study). Additionally, while two studies employed the same input data (RDRS_v2.1) for model calibration and validation, this study uses air temperature extracted from RDRS_v2.1 over the period of 1980–2018 compared to the 1945–2012 air temperature from the Pacific Northwest North-American meteorological (PNWNAmet) dataset [9] in the previous study. Hence, the presented water temperature data and trend analysis results are not expected to match with the previous study. In addition, note that the model reconstructed water temperature is affected by a number of sources of uncertainties arising out of data and model limitations, especially the sparsity of observation data and the lack of representation of physical processes and physiographic controls in the model. Readers are referred to our previous study [6] for a detailed discussion on uncertainties.

4. User Notes

The reconstructed water temperature dataset is designed to supplement sparse observation-based dataset, which is usually based on few spot measurements (typically 6–10 measurements per year), and whose spatial coverage and sampling frequency are low. The reconstructed data could be used for various applications related to analyzing historical variability and change in river thermal characteristics, as well as implications on aquatic ecosystem health. An example application is the presented historical trends, which could be expanded to heat fluxes analyses [10]. The dataset could also provide a useful basis for calibration/validation of process-based water temperature models, e.g., River Basin Model [11] and Dynamic Water Temperature Model [12], and as a baseline condition to compare future climate projections [13,14]. The dataset could also be used for analyzing climatic and basin drivers of water temperature variability and change [6,10,15]. Furthermore, the dataset could provide a useful basis for analyzing the effects of changing water temperature on water quality [16] and aquatic species habitat [17–19].

Author Contributions: Conceptualization, R.R.S.; data curation, analyses, J.C.P.; writing—original draft preparation, R.R.S.; writing—review and editing, R.R.S. and J.C.P.; visualization, J.C.P.; supervision, R.R.S.; project administration, R.R.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Reconstructed water temperature data are available through the Government of Canada data portal: https://catalogue.ec.gc.ca/geonetwork/srv/eng/catalog.search#/metadata/cc103402-ba59-43eb-820e-f319b6b5f9b4 (accessed on 23 February 2023). Gridded air temperature and observed discharge and water temperature datasets are available through the original sources provided in citations.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Figures and Tables

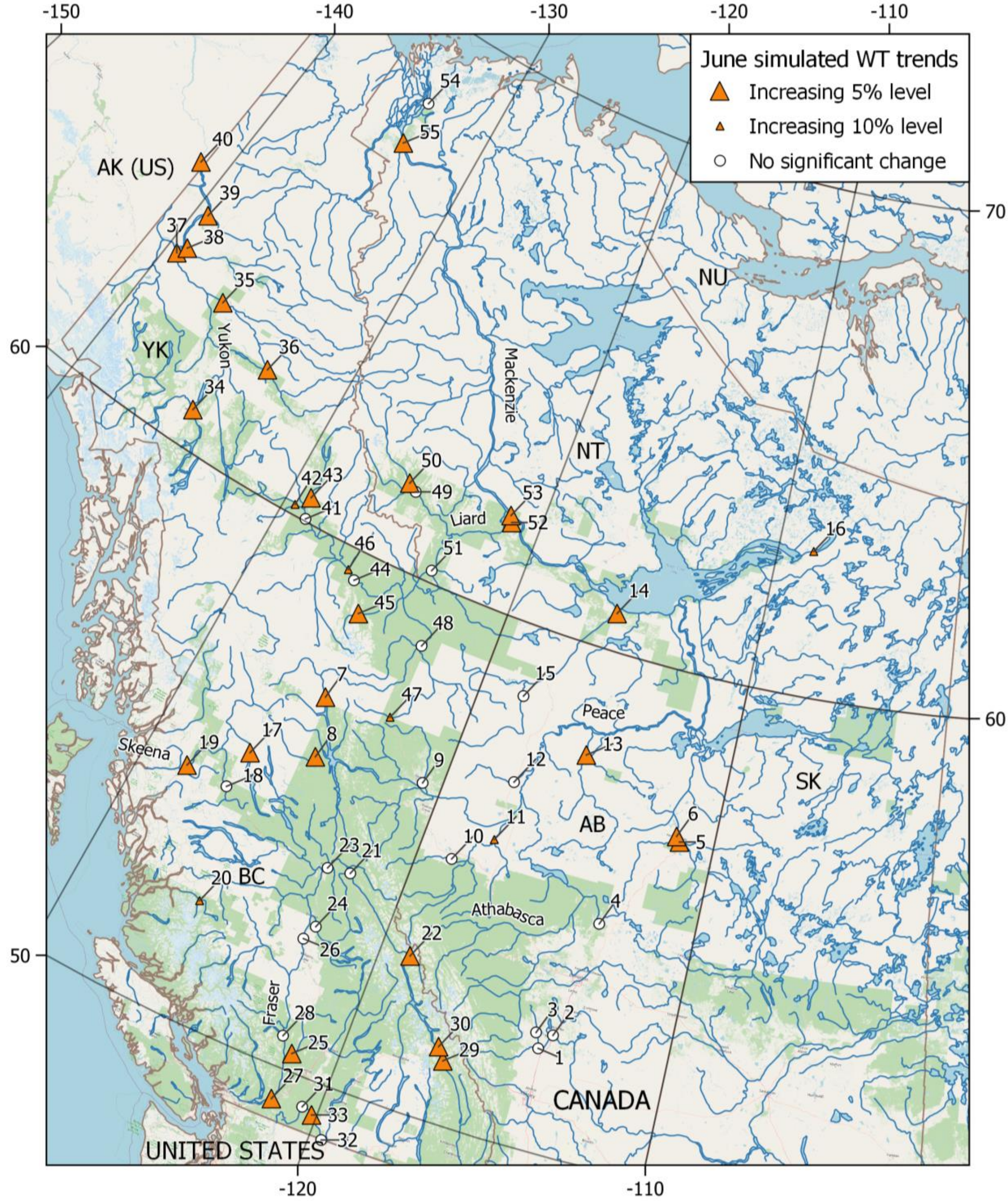

Figure A1. *Cont.*

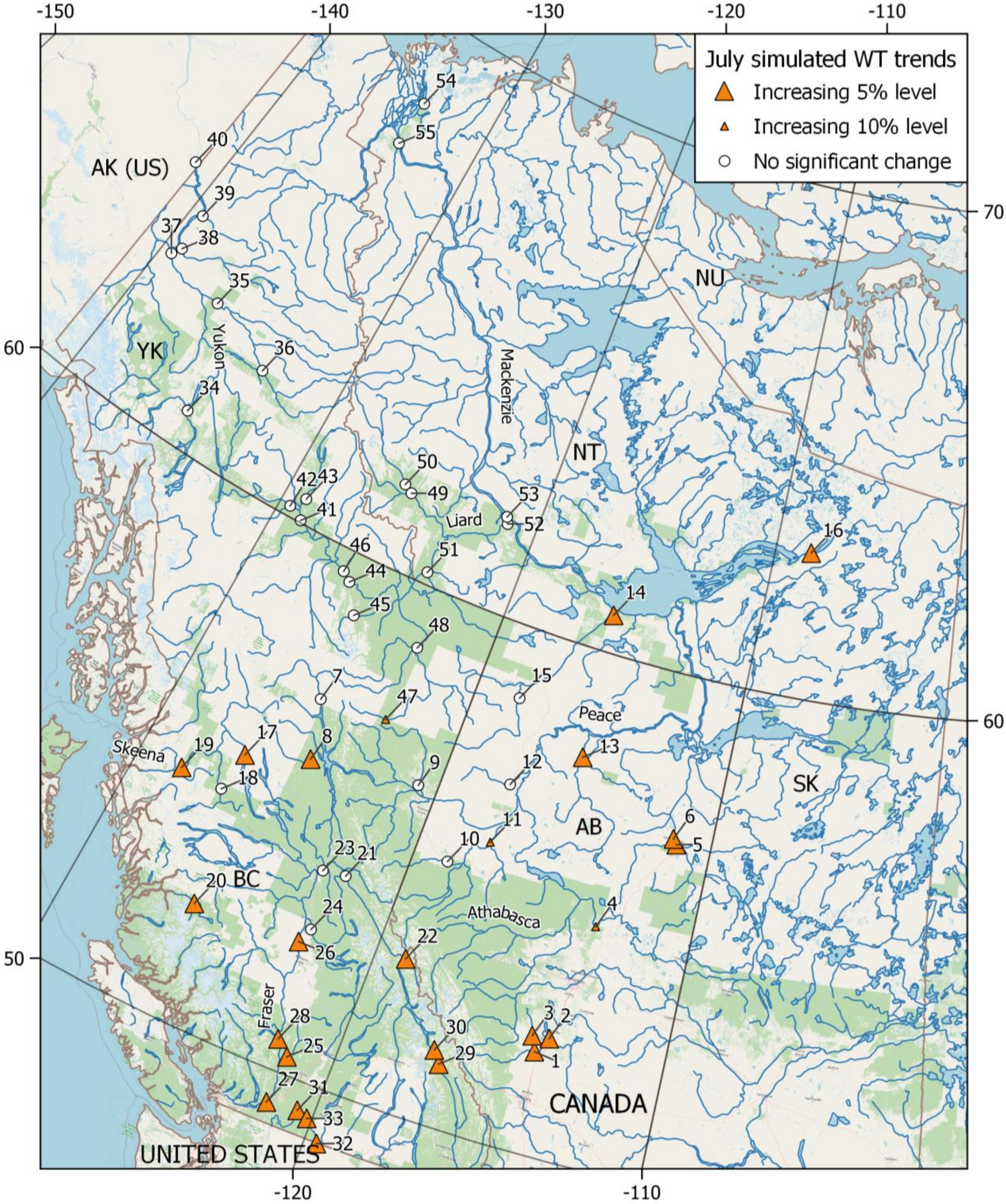

Figure A1. *Cont*.

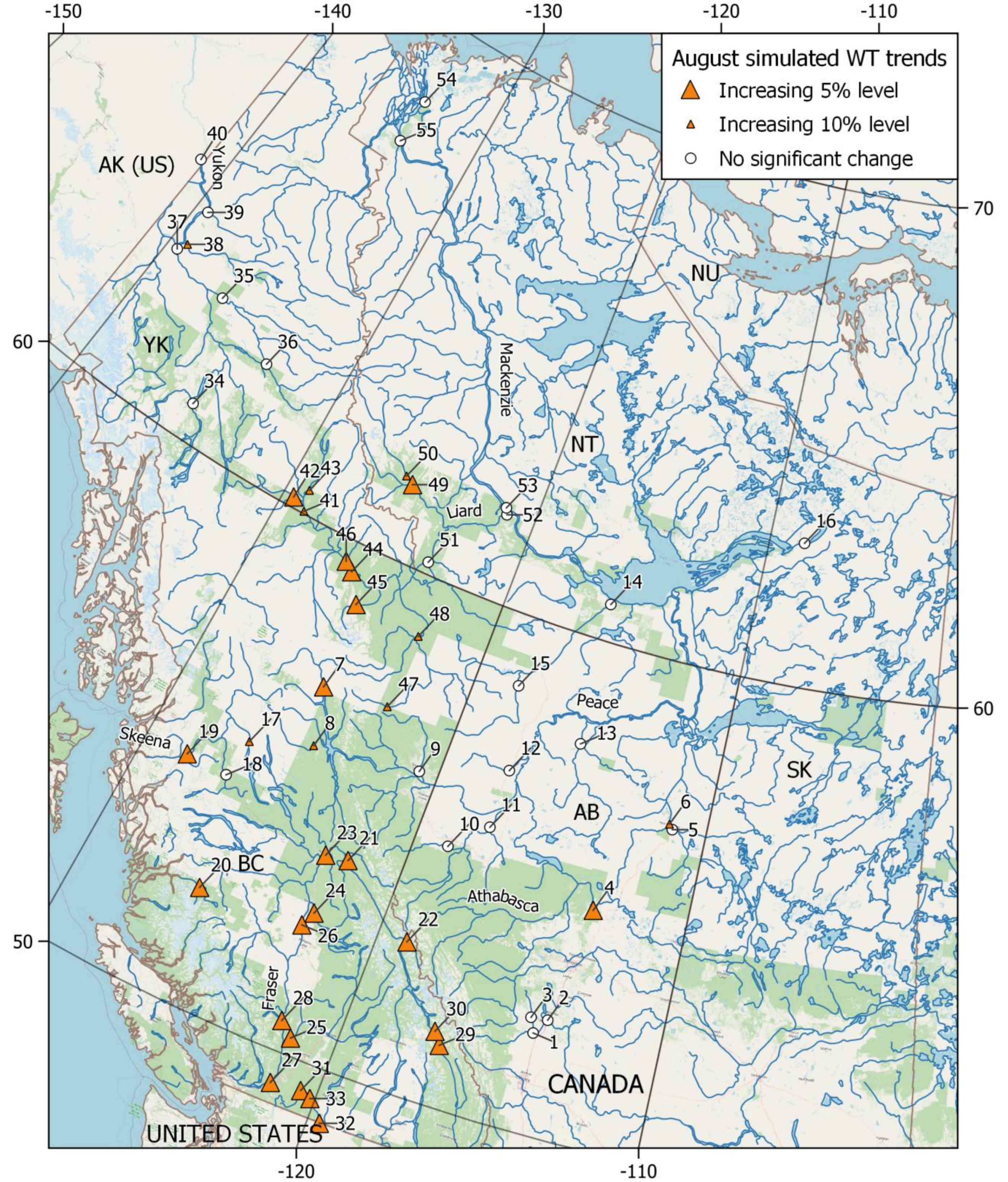

Figure A1. *Cont*.

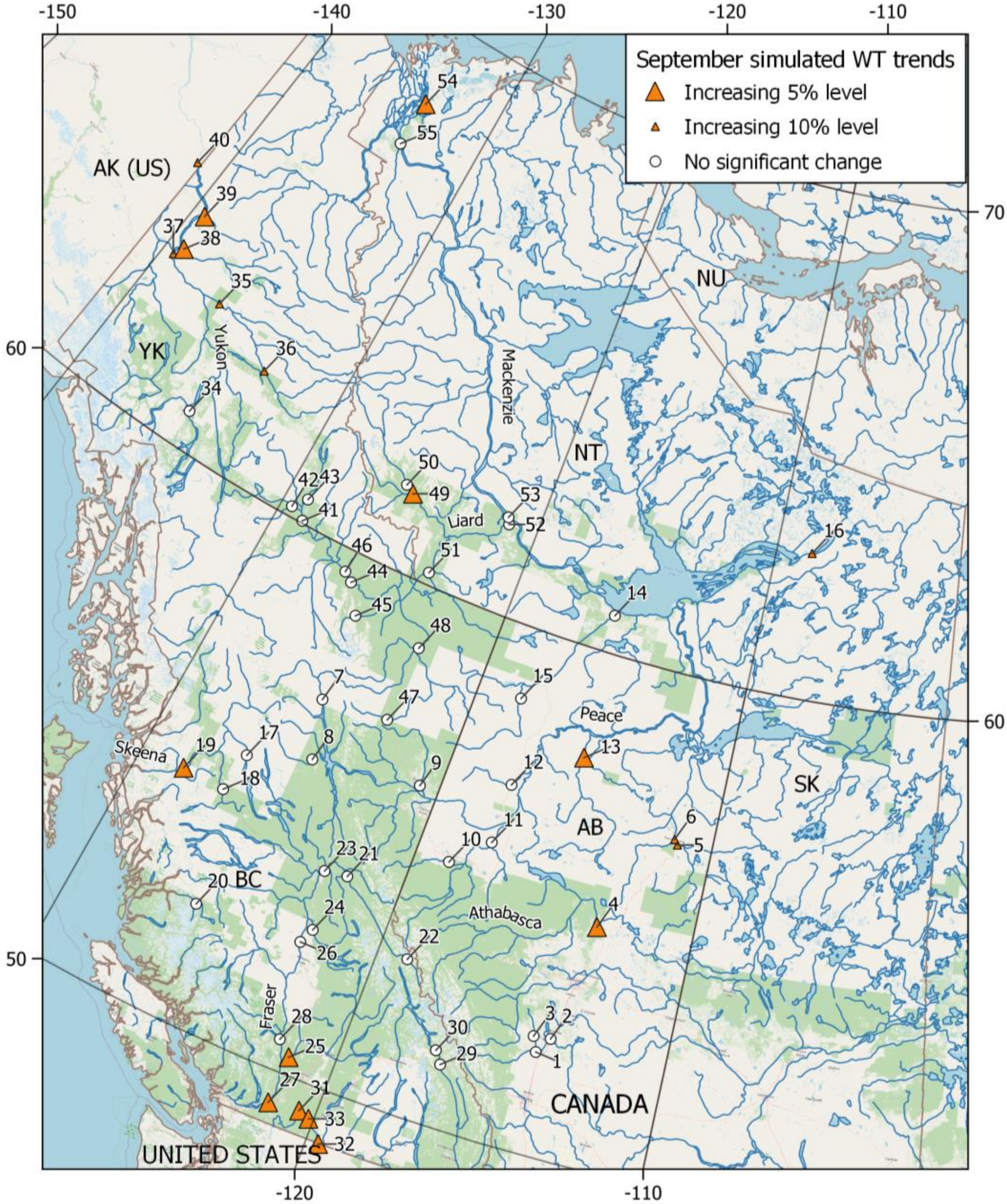

Figure A1. Historical trends in monthly water temperature over 1980–2018. The results show significantly increasing trends at 5 and 10% levels; no significantly decreasing trends were detected. The station numbers correspond to the station identifiers listed in Table A1.

Table A1. Summary of streamflow stations in the water temperature database. WSC_ID corresponds to Water Survey of Canada hydrometric station identifiers.

Station #	WSC_ID	WSC Discharge Station Name	Latitude	Longitude	Drainage Area (km^2)
1	05CB001	Little Red Deer River near the Mouth	52.0282	−114.1403	2578
2	05CC001	Blindman River near Blackfalds	52.3540	−113.7947	1796
3	05CC007	Medicine River near Eckville	52.3196	−114.3442	1916
4	07BE001	Athabasca River at Athabasca	54.7220	−113.2880	74,602
5	07CD001	Clearwater River at Draper	56.6853	−111.2554	30,799
6	07DA001	Athabasca River below Fort Mcmurray	56.7804	−111.4022	132,588
7	07EA005	Finlay River above Akie River	57.0751	−125.1499	15,600
8	07EC002	Omineca River above Osilinka River	55.9169	−124.5676	5560
9	07FC001	Beatton River near Fort St. John	56.2784	−120.6999	15,600
10	07GE001	Wapiti River near Grande Prairie	55.0713	−118.8029	11,300
11	07GJ001	Smoky River at Watino	55.7146	−117.6231	50,300
12	07HC001	Notikewin River at Manning	56.9200	−117.6184	4679
13	07JD002	Wabasca River at Highway No. 88	57.8746	−115.3891	35,800
14	07OB001	Hay River Near Hay River	60.7430	−115.8596	51,700
15	07OC001	Chinchaga River near High Level	58.5971	−118.3341	10,370
16	07RD001	Lockhart River at Outlet of Artillery Lake	62.8941	−108.4660	26,600
17	08EC013	Babine River at Outlet of Nilkitkwa Lake	55.4265	−126.6976	6760
18	08EE004	Bulkley River at Quick	54.6186	−126.9000	7340
19	08EF001	Skeena River at Usk	54.6319	−128.4306	42,300
20	08FB006	Atnarko River near the Mouth	52.3601	−126.0059	2550
21	08KA004	Fraser River at Hansard	54.0787	−121.8504	18,000
22	08KA007	Fraser River at Red Pass	52.9863	−119.0067	1710
23	08KB001	Fraser River at Shelley	54.0037	−122.6247	32,400
24	08KH006	Quesnel River near Quesnel	52.8431	−122.2253	11,500
25	08LF051	Thompson River near Spences Bridge	50.3546	−121.3936	55,400
26	08MC018	Fraser River near Marguerite	52.5303	−122.4443	114,000
27	08MF005	Fraser River at Hope	49.3860	−121.4542	217,000
28	08MF040	Fraser River above Texas Creek	50.6137	−121.8534	154,000
29	08NA002	Columbia River at Nicholson	51.2436	−116.9129	6660
30	08NB005	Columbia River at Donald	51.4833	−117.1804	9700
31	08NL007	Similkameen River at Princeton	49.4597	−120.5035	1810
32	08NL022	Similkameen River near Nighthawk	48.9847	−119.6172	9190
33	08NL038	Similkameen River near Hedley	49.3770	−120.1523	5580
34	09AB001	Yukon River at Whitehorse	60.7445	−135.0640	19,600
35	09BC001	Pelly River at Pelly Crossing	62.8297	−136.5806	48,900
36	09BC004	Pelly River below Vangorda Creek	62.2208	−133.3778	21,900
37	09CD001	Yukon River above White River	63.0825	−139.4969	149,000
38	09DD003	Stewart River at The Mouth	63.2822	−139.2544	51,000
39	09EA003	Klondike River above Bonanza Creek	64.0428	−139.4078	7810
40	09ED001	Yukon River at Eagle	64.7894	−141.1978	288,000
41	10AA001	Liard River at Upper Crossing	60.0508	−128.9069	32,600
42	10AA004	Rancheria River near the Mouth	60.2042	−129.5500	5100
43	10AB001	Frances River near Watson Lake	60.4739	−129.1189	12,800
44	10BE001	Liard River at Lower Crossing	59.4125	−126.0972	104,000
45	10BE004	Toad River above Nonda Creek	58.8550	−125.3826	2540
46	10BE013	Smith River near the Mouth	59.5533	−126.4806	3740
47	10CB001	Sikanni Chief River near Fort Nelson	57.2382	−122.6915	2180
48	10CD001	Muskwa River near Fort Nelson	58.7881	−122.6616	20,300
49	10EA003	Flat River near the Mouth	61.5300	−125.4108	8560
50	10EB001	South Nahanni River above Virginia Falls	61.6361	−125.7970	14,500
51	10ED001	Liard River at Fort Liard	60.2416	−123.4754	222,000
52	10ED002	Liard River near the Mouth	61.7427	−121.2280	275,000
53	10GC001	Mackenzie River at Fort Simpson	61.8684	−121.3589	1,301,440
54	10LC002	Mackenzie River (East Channel) at Inuvik	68.3742	−133.7648	1,703,387
55	10LC014	Mackenzie River at Arctic Red River	67.4560	−133.7533	1,680,000

Table A2. Statistical performance of the best performing air2stream model compared to observed water temperature records over the data reconstruction period 1980–2018. the number of air2stream model parameters and number of water temperature observations are also included.

Station #	WSE_ID	MAE (°C)	NSE	KGE	RSR	Best Performing No. Parameters	No. Non-Zero Observed Water Temperature Records
1	05CB001	1.15	0.92	0.96	0.28	5	249
2	05CC001	1.06	0.94	0.96	0.25	5	252
3	05CC007	1.04	0.94	0.95	0.25	5	251
4	07BE001	0.85	0.96	0.94	0.19	7	368
5	07CD001	0.72	0.96	0.97	0.19	5	88
6	07DA001	0.96	0.96	0.97	0.21	5	264
7	07EA005	0.66	0.96	0.97	0.20	5	4777
8	07EC002	0.97	0.92	0.91	0.28	7	4457
9	07FC001	1.57	0.86	0.89	0.37	7	227
10	07GE001	0.82	0.93	0.95	0.26	5	99
11	07GJ001	0.96	0.93	0.95	0.27	5	111
12	07HC001	0.93	0.93	0.93	0.26	5	186
13	07JD002	0.90	0.93	0.91	0.26	5	111
14	07OB001	1.30	0.91	0.90	0.30	5	132
15	07OC001	1.06	0.93	0.95	0.26	5	156
16	07RD001	1.44	0.79	0.85	0.46	4	92
17	08EC013	1.17	0.94	0.94	0.25	3	1264
18	08EE004	0.67	0.97	0.98	0.17	8	1102
19	08EF001	1.12	0.88	0.88	0.34	7	785
20	08FB006	0.69	0.97	0.97	0.17	5	1370
21	08KA004	1.46	0.85	0.89	0.39	7	421
22	08KA007	1.08	0.88	0.94	0.35	5	656
23	08KB001	0.60	0.97	0.99	0.16	7	4050
24	08KH006	0.93	0.95	0.97	0.22	8	3480
25	08LF051	1.06	0.94	0.96	0.24	5	4841
26	08MC018	1.33	0.87	0.87	0.35	4	621
27	08MF005	0.97	0.95	0.97	0.23	7	3616
28	08MF040	0.84	0.97	0.98	0.16	5	4553
29	08NA002	1.61	0.84	0.90	0.40	5	228
30	08NB005	0.99	0.93	0.96	0.26	5	1969
31	08NL007	1.24	0.89	0.94	0.33	7	822
32	08NL022	1.29	0.91	0.91	0.30	7	833
33	08NL038	1.34	0.89	0.91	0.33	7	262
34	09AB001	1.02	0.92	0.91	0.27	7	639
35	09BC001	1.08	0.91	0.95	0.30	5	179
36	09BC004	1.05	0.91	0.93	0.31	7	200
37	09CD001	1.15	0.92	0.94	0.28	5	117
38	09DD003	1.12	0.92	0.88	0.28	3	89
39	09EA003	0.52	0.96	0.97	0.19	7	1232
40	09ED001	0.82	0.93	0.94	0.26	5	1321
41	10AA001	0.83	0.94	0.91	0.24	7	411
42	10AA004	0.94	0.92	0.92	0.28	7	115
43	10AB001	0.56	0.95	0.95	0.22	5	491
44	10BE001	1.25	0.87	0.87	0.36	5	218
45	10BE004	1.16	0.83	0.83	0.41	4	231
46	10BE013	1.30	0.88	0.88	0.34	3	180
47	10CB001	1.16	0.85	0.89	0.39	5	193
48	10CD001	1.21	0.88	0.94	0.35	5	199
49	10EA003	0.76	0.93	0.96	0.27	7	240
50	10EB001	0.92	0.92	0.93	0.29	8	3382
51	10ED001	0.96	0.93	0.89	0.26	8	195
52	10ED002	0.75	0.94	0.93	0.24	5	158
53	10GC001	0.51	0.97	0.95	0.16	5	79
54	10LC002	0.60	0.94	0.81	0.25	4	51
55	10LC014	0.93	0.93	0.87	0.27	3	199

Table A3. Decadal trends (°/decade) obtained from the simulated water temperature records. The results summarize monthly trends for June to September together with June to September averages. The bold and underlined values indicate significant trends at $p \leq 0.05$ and $p \leq 0.10$, respectively.

Station #	WSC_ID	June	July	August	September	June–September
1	05CB001	0.08	**0.21**	0.20	0.23	**0.18**
2	05CC001	0.13	**0.31**	0.29	0.32	**0.27**
3	05CC007	0.15	**0.35**	0.21	0.27	**0.21**
4	07BE001	−0.01	<u>0.21</u>	**0.33**	**0.39**	**0.20**
5	07CD001	**0.18**	**0.25**	0.16	<u>0.26</u>	**0.22**
6	07DA001	**0.24**	**0.24**	<u>0.22</u>	<u>0.26</u>	**0.25**
7	07EA005	**0.32**	0.08	**0.14**	0.05	**0.12**
8	07EC002	**0.25**	**0.32**	<u>0.42</u>	0.04	<u>0.29</u>
9	07FC001	0.11	0.10	0.25	0.37	0.16
10	07GE001	−0.02	0.19	0.16	0.37	<u>0.19</u>
11	07GJ001	<u>0.15</u>	<u>0.15</u>	0.14	0.17	<u>0.13</u>
12	07HC001	0.10	0.04	0.07	0.37	0.17
13	07JD002	**0.20**	**0.20**	0.18	**0.45**	**0.29**
14	07OB001	**0.10**	**0.12**	0.06	0.15	0.08
15	07OC001	0.19	0.09	0.16	0.37	**0.25**
16	07RD001	<u>0.89</u>	**0.88**	0.34	<u>0.39</u>	**0.65**
17	08EC013	**0.76**	**0.48**	<u>0.30</u>	0.09	**0.45**
18	08EE004	0.12	0.19	0.20	0.05	0.16
19	08EF001	**0.35**	**0.95**	**1.73**	**0.95**	**1.01**
20	08FB006	<u>0.22</u>	**1.22**	**0.42**	0.08	**0.56**
21	08KA004	0.05	0.06	**0.19**	0.06	0.10
22	08KA007	**0.29**	**0.22**	**0.12**	0.07	**0.17**
23	08KB001	0.08	0.13	**0.37**	0.04	0.15
24	08KH006	0.01	0.12	**0.22**	0.10	**0.12**
25	08LF051	**0.14**	**0.24**	**0.17**	**0.12**	**0.16**
26	08MC018	0.10	**0.46**	**0.44**	0.17	**0.28**
27	08MF005	**0.22**	**0.27**	**0.37**	**0.28**	**0.28**
28	08MF040	0.13	**0.41**	**0.30**	0.14	**0.25**
29	08NA002	**0.24**	**0.24**	**0.13**	0.11	**0.18**
30	08NB005	**0.27**	**0.21**	**0.10**	0.10	**0.16**
31	08NL007	0.26	**0.90**	**0.76**	**0.52**	**0.62**
32	08NL022	0.15	**0.62**	**0.49**	**0.42**	**0.39**
33	08NL038	0.13	**0.85**	**0.91**	**0.74**	**0.66**
34	09AB001	**0.23**	0.00	0.07	0.15	0.13
35	09BC001	**0.20**	0.00	0.18	<u>0.16</u>	0.11
36	09BC004	**0.28**	0.00	0.27	<u>0.29</u>	0.20
37	09CD001	**0.11**	-0.01	0.12	<u>0.15</u>	<u>0.10</u>
38	09DD003	**0.51**	-0.01	<u>0.36</u>	**0.38**	**0.32**
39	09EA003	**0.11**	0.04	0.07	**0.15**	0.09
40	09ED001	**0.19**	0.01	0.14	<u>0.17</u>	**0.12**
41	10AA001	0.06	0.02	<u>0.19</u>	0.13	<u>0.09</u>
42	10AA004	<u>0.21</u>	0.02	**0.24**	0.23	**0.16**
43	10AB001	**0.19**	0.02	<u>0.13</u>	0.11	**0.11**
44	10BE001	0.12	0.07	**0.23**	0.18	**0.11**
45	10BE004	**0.36**	0.13	**0.31**	0.18	**0.22**
46	10BE013	<u>0.18</u>	0.06	**0.39**	0.23	0.17
47	10CB001	<u>0.15</u>	<u>0.14</u>	<u>0.20</u>	0.14	**0.14**
48	10CD001	0.06	0.10	<u>0.26</u>	0.21	0.10
49	10EA003	0.04	0.08	**0.22**	**0.30**	<u>0.20</u>
50	10EB001	**0.10**	0.10	<u>0.14</u>	0.15	<u>0.12</u>
51	10ED001	0.01	0.08	0.19	0.14	0.14
52	10ED002	**0.12**	0.07	0.12	0.14	<u>0.11</u>
53	10GC001	**0.19**	0.07	0.12	0.21	0.08
54	10LC002	0.22	0.05	0.50	**0.65**	0.39
55	10LC014	**0.69**	0.23	0.36	0.43	**0.40**

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