Online Supplemental Material

Article title: *Intertidal spring discharge to a coastal ecosystem and the impacts of climate change on future groundwater temperature: A multi-method investigation*

Journal name: *Hydrology and Earth System Sciences*

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Tables begin on the following page.

Table S1: Information on sensors deployed for this study. See figures in the Figure Reference column for locations. The IDs in the Map ID column in this table align with the IDs noted in Fig. S6 in this supplement. All associated data can be found in the dataset described in the Data Availability section at the end of the main paper.

	Parameter(s) Provided	Sensor Make/Model	Number of Sensors	Map ID (prefix and ID#)	Approximate Location(s) by ID# (Long, Lat)	Data Period Provided (Discontinuous and varies per parameter)	Figure Reference(s)
Streams	Water temperature	Onset HOBO MX2203 TidbiTs	4	St1, 2, 3, and 4	1) 62.1243660°W 46.3865830°N 2) 62.1246730°W 46.3862840°N 3) 62.0914720°W 46.3957510°N 4) 62.0889510°W 46.3971560°N	Start: 2020-07-21 11:15 End: 2020-11-02 16:30	1 and 6
	Water flow	HOBO U20-001-04 & SonTek Flow Tracker 2	4	St5, 6, 7, and 8	5) 62.1273340°W 46.3867770°N 6) 62.1270000°W 46.3900000°N 7) 62.0952870°W 46.3974070°N 8) 62.0906230°W 46.3987880°N	Start: 2020-07-21 13:00 End: 2020-08-31 23:00	1 and S6
Springs	Water temperature	Onset HOBO MX2203 TidbiTs	2	Sp1 and 2	1) 62.1194598°W 46.3848724°N 2) 62.0998038°W 46.3905342°N	Start: 2020-07-25 17:30 End: 2020-11-02 16:30	1, 6, 7, S2, S3, and S4
	Water temperature	Onset HOBO MX2203 TidbiTs	1	Sp3	3) 62.0889360°W 46.3941150°N	Start: 2019-06-26 0:00 End: 2020-11-02 16:30	1, 7, S2, S5, and S7
Lagoon	Water temperature	Onset HOBO MX2203 TidbiTs	2	L3 and 4	3&4) 62.0879200°W 46.3950140°N	Start: 2019-06-26 2:45 End: 2020-11-02 16:30	1, 6, and S7
	Water temperature	Onset HOBO MX2203 TidbiTs	2	L1 and 2	1&2) 62.0953385°W 46.3910513°N	Start: 2020-07-25 15:30 End: 2020-11-02 16:30	1
	Water temperature and pressure	Solinst Levelogger 5 LTC	1	L5	5) 62.1106386°W 46.3817063°N	Start: 2020-07-21 12:30 End: 2020-11-02 16:30	1, 6, and 8
Piezometer	Water temperature and pressure	Onset HOBO U20-001-01	1	P1	1) 62.1020736°W 46.3900142°N	Start: 2019-08-17 14:45 End: 2020-11-02 16:30	1
Climate Station	Air temperature, radiation, and precipitation	Onset HOBO Micro Station Logger	1	Cl1	1) 62.1030470°W 46.3890710°N	Start: 2019-06-26 0:00 End: 2020-11-02 16:30	1, 6, and S7

Table S2: Measured thermal plume areas of 34 springs in Basin Head lagoon over the study period (locations displayed in Figure 1b and Figures S2-S5). The instantaneous discharge of Springs A, B, and C (grey rows) were measured and used to develop the plume size-spring discharge relationship, whereas Springs 1-31 were estimated using their measured area and the developed relationship. The date/time indicates when the thermal image was captured. Area was obtained as indicated in Figure 2 and Figure S1 and included short distances of overland flow.

Spring ID	Date/time	Area (m^2)	Discharge ($m^3 s^{-1}$)	Spring location (Lat; Long)
A	22-07-2020 19:37	360	3.1E-03*	46.389305; -62.102322
B	22-07-2020 19:35	51	5.2E-04*	46.390244; -62.10096
C	22-07-2020 19:36	10	7.5E-05*	46.388714; -62.103432
1	29-08-2020 15:27	694	6.2E-03	46.386246; -62.110306
2	29-08-2020 15:33	360	3.1E-03	46.38493; -62.119438
3	24-07-2020 19:33	289	2.5E-03	46.390179; -62.101189
4	22-07-2020 19:36	259	2.2E-03	46.396149; -62.08857
5	21-07-2020 20:17	171	1.4E-03	46.394167; -62.088889
6	24-07-2020 18:16	164	1.4E-03	46.386944; -62.115067
7	24-07-2020 18:16	133	1.1E-03	46.386944; -62.115067
8	24-07-2020 19:29	115	9.6E-04	46.39827; -62.080589
9	22-07-2020 19:36	65	5.3E-04	46.390114; -62.101421
10	21-07-2020 20:15	59	4.8E-04	46.392818; -62.090939
11	24-07-2020 19:29	57	4.6E-04	46.398132; -62.080959
12	22-07-2020 17:04	55	4.4E-04	46.386448; -62.107201
13	24-07-2020 19:30	48	3.9E-04	46.396732; -62.08556
14	22-07-2020 19:37	48	3.9E-04	46.390339; -62.100193
15	24-07-2020 19:36	41	3.3E-04	46.394882; -62.089233
16	24-07-2020 19:31	31	2.5E-04	46.396442; -62.086929
17	24-07-2020 18:13	25	2.0E-04	46.386459; -62.118565
18	21-07-2020 20:15	22	1.8E-04	46.392975; -62.090805
19	24-07-2020 18:18	21	1.6E-04	46.386646; -62.111988
20	24-07-2020 19:36	15.9	1.2E-04	46.394653; -62.088825
21	22-07-2020 19:37	13.3	1.0E-04	46.390591; -62.099422
22	22-07-2020 17:07	12.6	9.7E-05	46.386269; -62.110722
23	21-07-2020 20:16	11.2	8.6E-05	46.393421; -62.089939
24	24-07-2020 19:31	9.2	7.0E-05	46.396744; -62.085999
25	24-07-2020 18:15	7.4	5.6E-05	46.38686; -62.116539
26	24-07-2020 18:14	6.7	5.1E-05	46.386528; -62.118763
27	21-07-2020 20:16	3.1	2.3E-05	46.393661; -62.089458
28	24-07-2020 18:13	2.4	1.7E-05	46.386433; -62.11874
29	21-07-2020 20:16	2.0	1.4E-05	46.393745; -62.089233
30	24-07-2020 19:37	1.9	1.4E-05	46.393871; -62.089138
31	21-07-2020 20:14	1.7	1.2E-05	46.392387; -62.092205

*Measured spring discharges used in the plume size-spring discharge relationship. The accuracy of measured discharges was estimated to be within ±25%.

Table S3: Summary of groundwater springs, baseflow-fed streams and shallow porewaters collected in August and November 2020. Porewater values in parentheses indicate sample collection depth. Stream locations are shown in Figure 1.

Sample ID	Sample Type	Temperature (°C)	Salinity (psu)	^{222}Rn (Bq m^{-3})
August 2020				
Spring A	fractured sandstone spring	8.6	0.93	8,360 ± 1,280
Spring B(1)	fractured sandstone spring	9.8	0.76	10,080 ± 1,670
Spring B(2)	fractured sandstone spring	9.4	0.87	16,570 ± 1,180
Spring C	fractured sandstone spring	11.6	0.25	6,740 ± 880
November 2020				
Spring A	fractured sandstone spring	7.9	0.87	7,530 ± 1,060
Spring B(1)	fractured sandstone spring	9.5	0.71	13,220 ± 470
Spring B(2)	fractured sandstone spring	9.2	0.80	12,620 ± 680
Spring C	fractured sandstone spring	9.3	0.21	7,880 ± 770
Stream S1	Stream	5.3	0.25	3,410 ± 590
Stream S2	Stream	5.0	0.30	410 ± 100
Stream S3	Stream	6.2	0.15	360 ± 110
Stream S4	Stream	6.1	0.15	360 ± 60
Stream S6	Stream	6.2	0.13	940 ± 140
WT1	Porewater (0.2 m)	0.7	16.6	710 ± 300
WT2	Porewater (0.4 m)	0.7	17.3	1,000 ± 410
OP1	Porewater (0.2 m)	7.9	19.6	500 ± 240
MP2	Porewater (0.4 m)	1.6	18.0	340 ± 140

Table S4: Summary of parameters and fluxes used in the ^{222}Rn mass balance.

Term	Definition	Value	Uncertainty	Units
A	Lagoon area	5.90E+05	5.90E+04	m^2
I	Mean excess ^{222}Rn inventory	18	15	Bq m^{-2}
Q_{stream}	Stream discharge	0.05	0.02	m^3 s^{-1}
C_{stream}	Stream ^{222}Rn	1100	1200	Bq m^{-3}
C_{GW}	Fractured-sandstone spring ^{222}Rn	10400	3700	Bq m^{-3}
C_{Ra}	^{226}Ra activity	10	8	Bq m^{-3}
λ_{Rn}	^{222}Rn decay constant	0.181	-	d^{-1}
^{222}Rn Sinks				
J_{atm}	Atmospheric evasion	6.4E+06	6.6E+06	Bq d^{-1}
J_{mix}	Mixing losses	8.4E+07	5.9E+07	Bq d^{-1}
J_{decay}	Radioactive decay	1.9E+06	1.6E+06	Bq d^{-1}
^{222}Rn Sources				
J_{diff}	Molecular diffusion	6.4E+06	3.2E+06	Bq d^{-1}
J_{Ra-226}	^{226}Ra production	1.1E+06	8.5E+05	Bq d^{-1}
J_{stream}	Stream ^{222}Rn flux (inc. baseflow)	4.7E+06	5.6E+06	Bq d^{-1}
J_{spring}	Groundwater ^{222}Rn	8.0E+07	6.0E+07	Bq d^{-1}
-	Groundwater discharge	0.09	0.07	m^3 s^{-1}

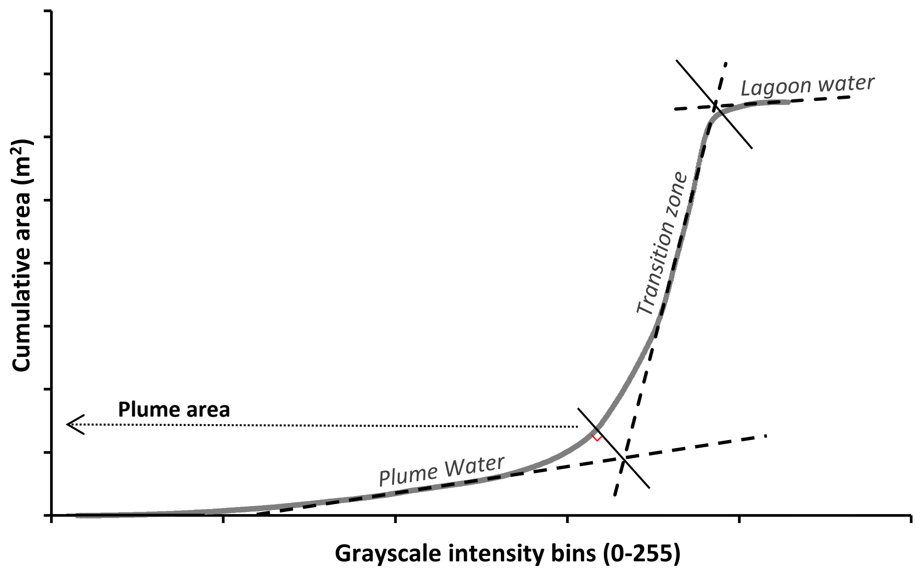

Figure S1. Generic characteristic type-curve used in the areal analysis of a thermal-discharge assessment. Inflection points are identified using near-perpendicular lines connecting the type-curve and the linear intersects. The plume thermal group (i.e., plume area) extends to the plume area inflection point. The lagoon thermal group begins at the second inflection point and extends onward, and there is a steep transition zone between groups. See Roseen (2002) for a description of a similar approach.

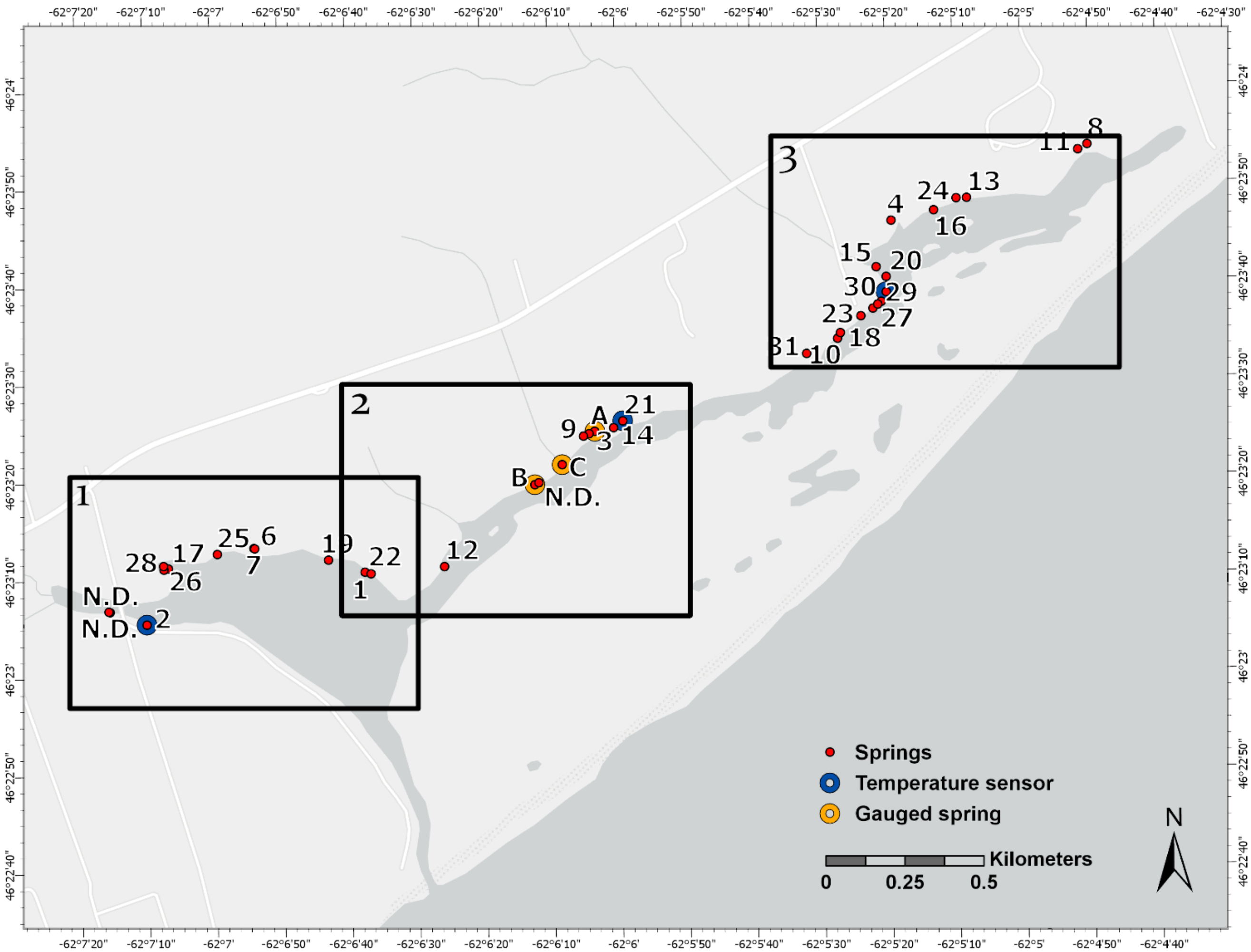

Figure S2. (Series image 1 of 4) Spring locations in the Basin Head lagoon. Black boxes each represent an area depicted in subsequent series images that include spring IDs with reference to Table S1. (1) Figure S, (2) Figure S, and (3) Figure S. Basemap is attributed to Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

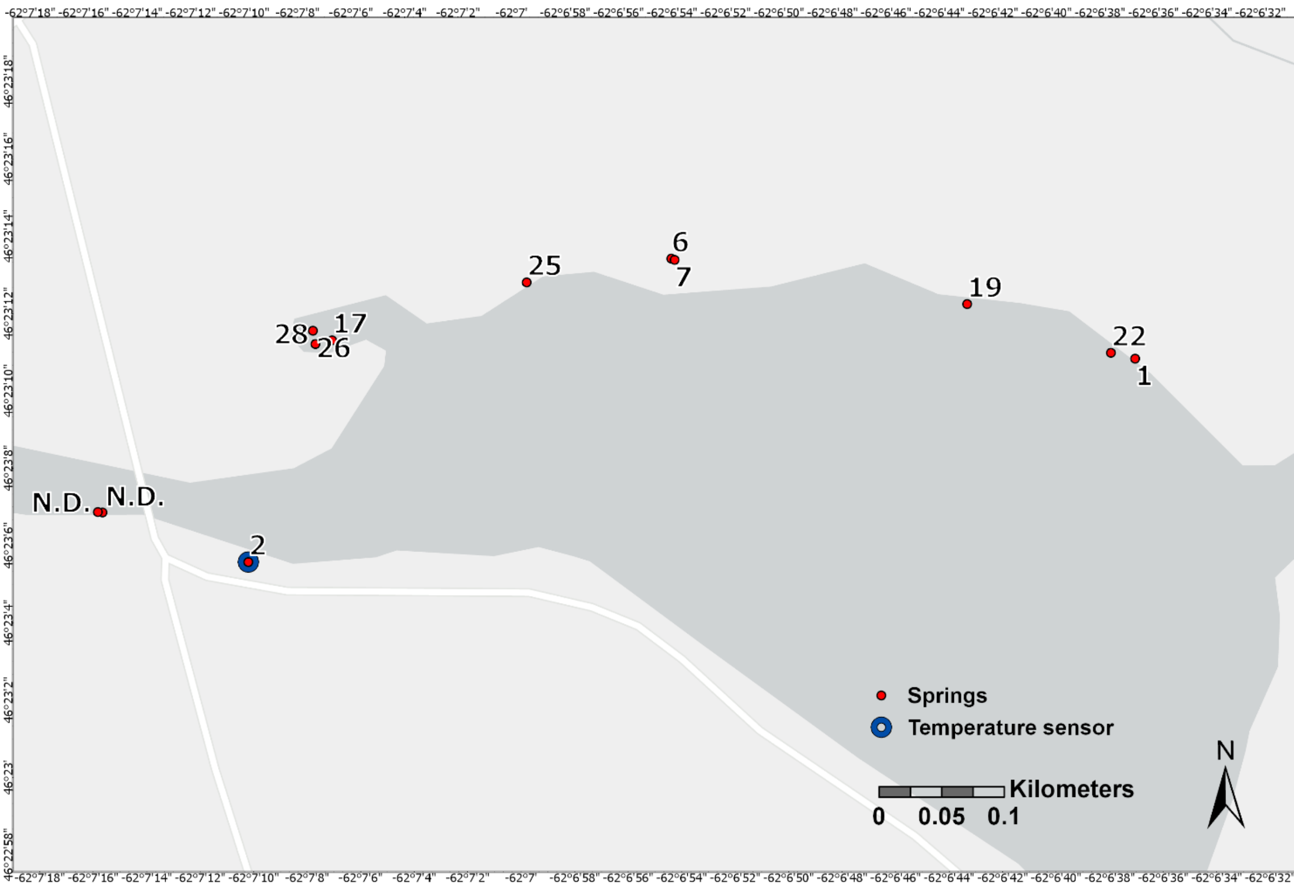

Figure S3. (Series image 2 of 4) Locations and IDs of springs in main basin of the Basin Head lagoon. N.D. = No Data. Basemap is attributed to Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

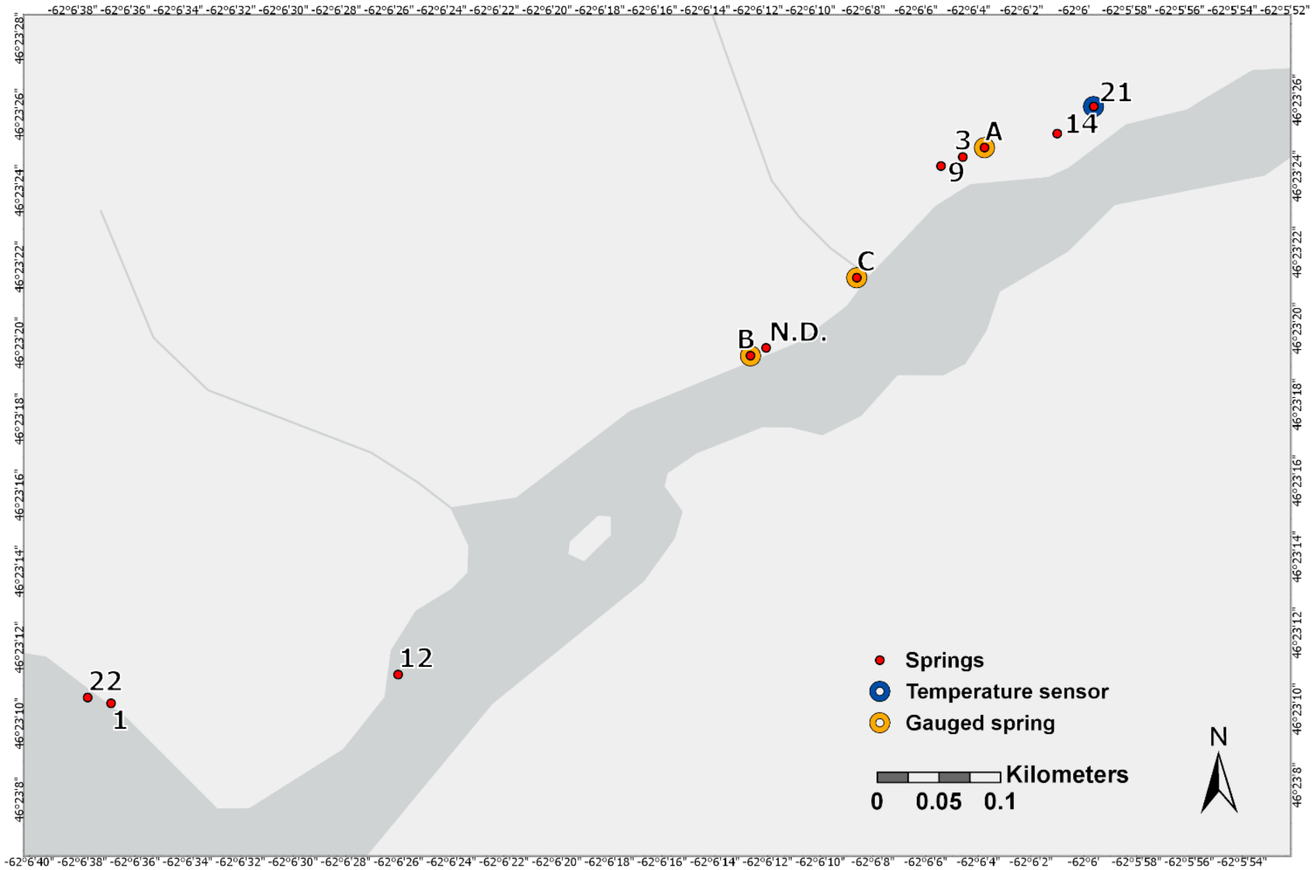

Figure S4. (Series image 3 of 4) Locations and IDs of springs in the main basin and north-east arm of the Basin Head lagoon. N.D. = No Data. Map prepared in ArcGIS Pro (Version 2.3.3, 2018). Basemap is attributed to Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

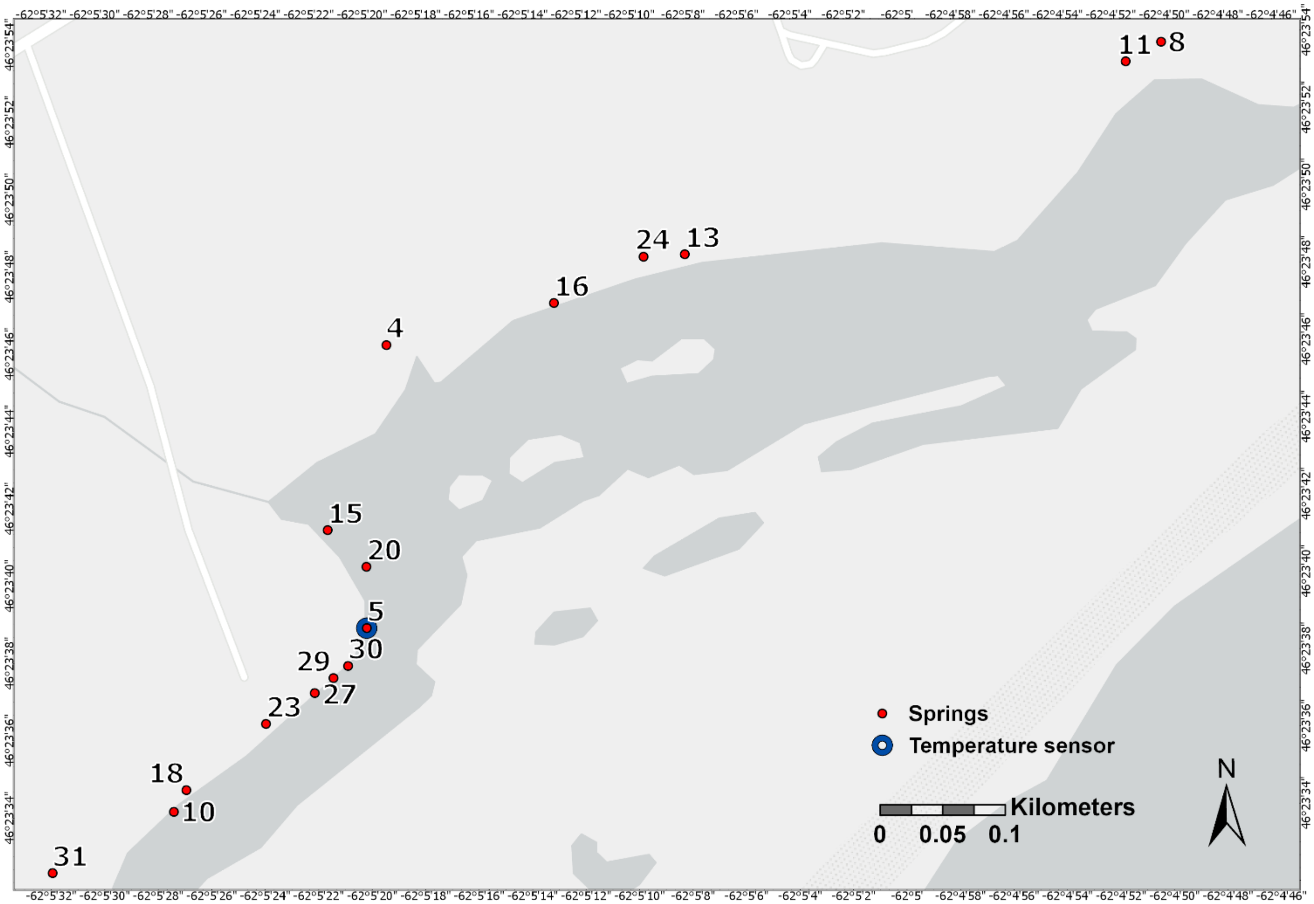

Figure S5. (Series image 4 of 4) Locations and IDs of springs in the upper north-east arm of the Basin Head lagoon. Basemap is attributed to Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

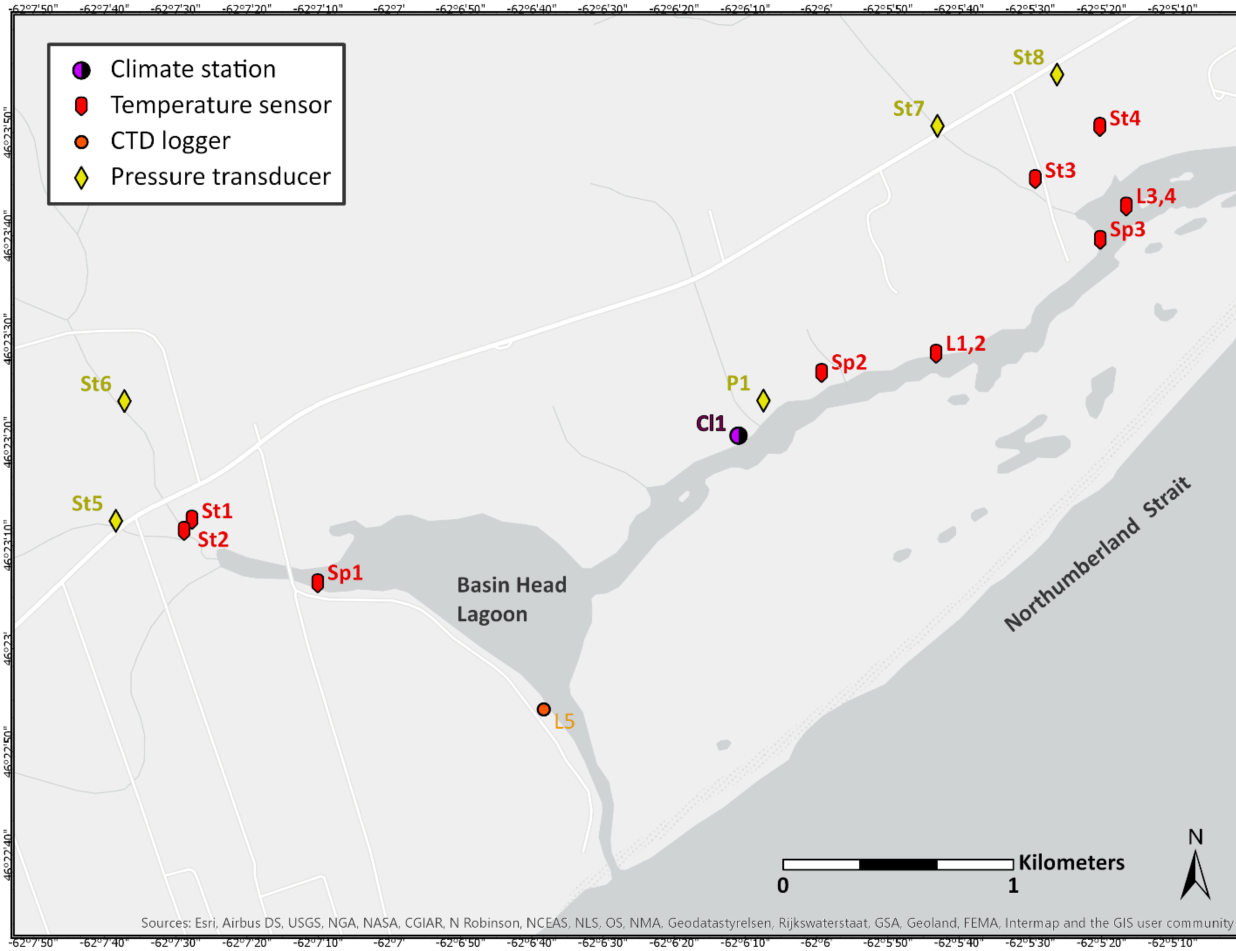

Figure S6: A map of all sensors with data include in the data archive (see Data Availability section of main paper). This additional map is included to provide context for the Sensor IDs noted in Table S1, which correspond to the sensor IDs in the figure. To enable the clear presentation of the sensor IDs, no springs are shown in this figure. Basemap is attributed to Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community.

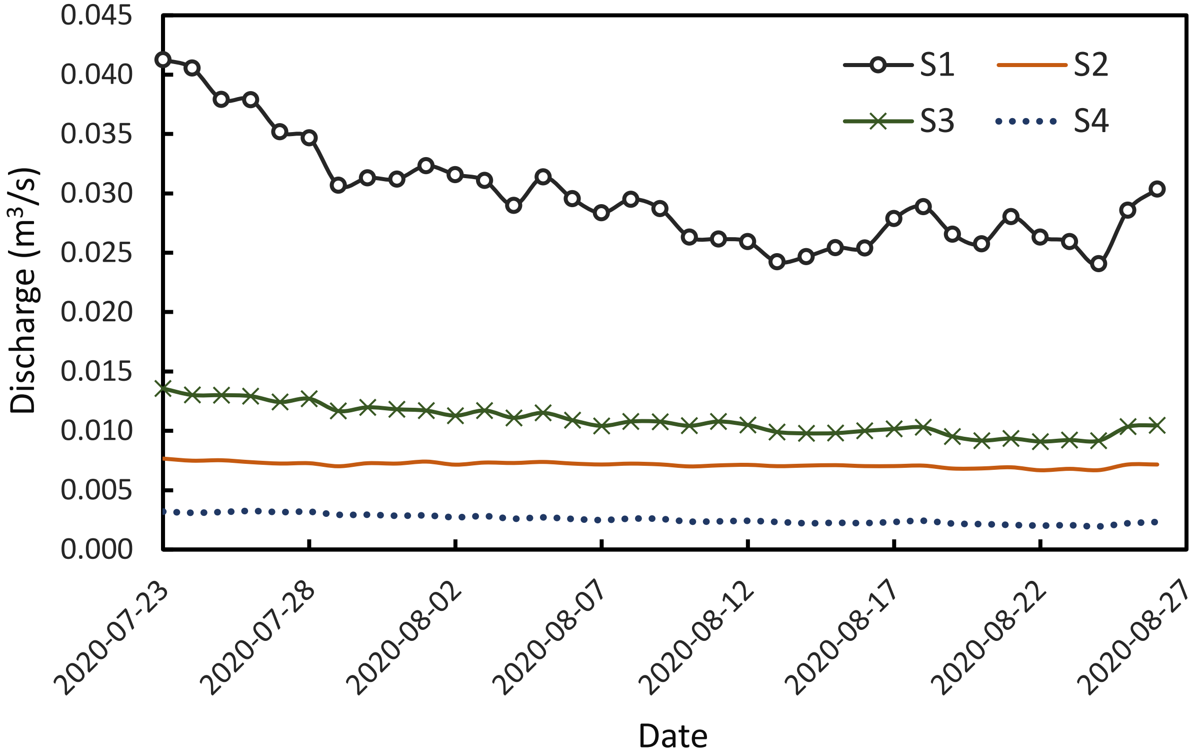

Figure S7: Daily stream hydrographs of the primary four tributaries discharging to Basin Head lagoon over the 35-day focussed study period (date presented as yyyy-mm-dd). Discharge is entirely attributed to baseflow over this period.

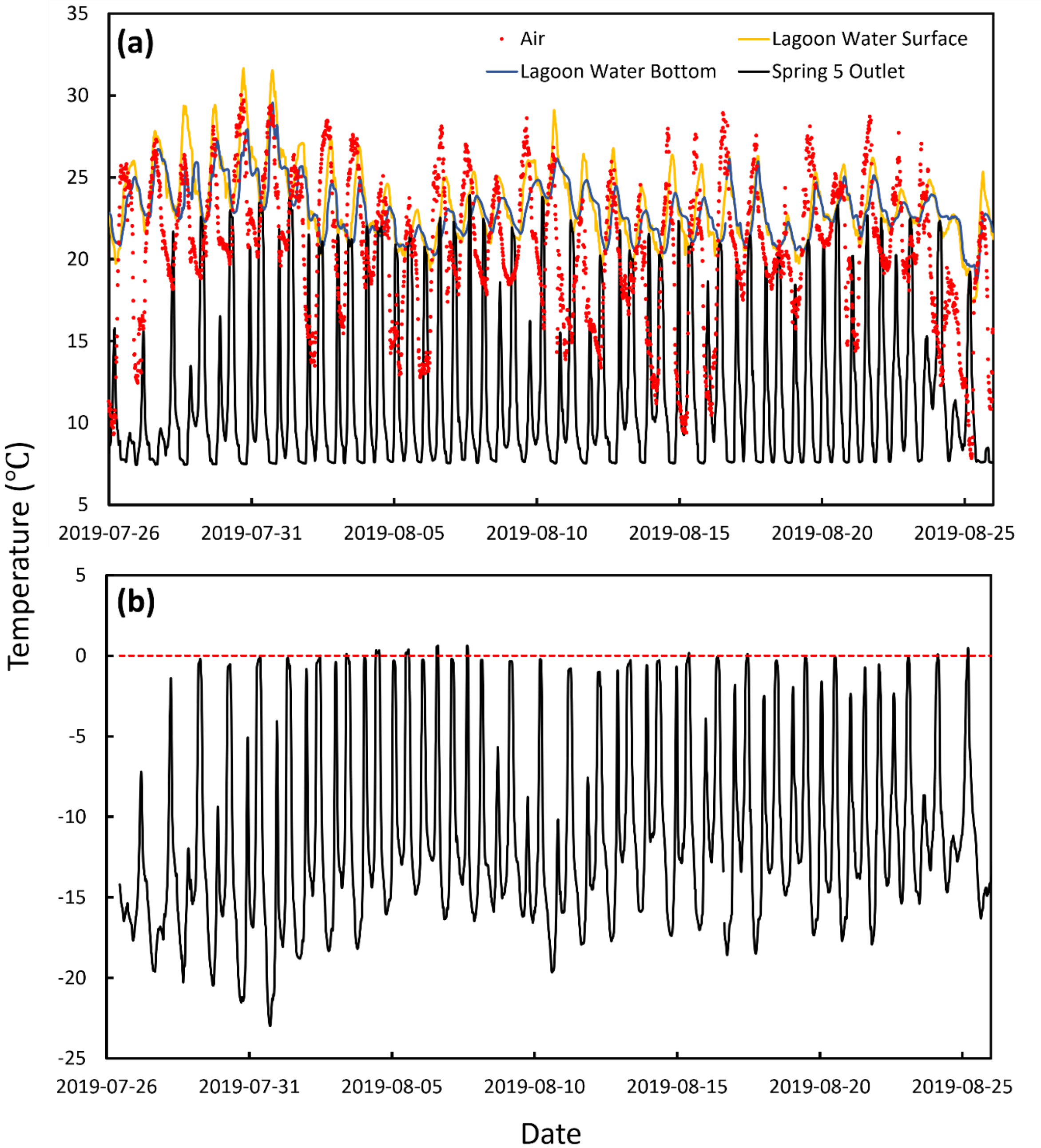

Figure S8: (a) Hourly local air temperature and water temperature data (top and bottom of water column) from the upper north-east arm of Basin Head lagoon (date presented as yyyy-mm-dd). (b) The difference between Spring 5 temperature and the average of the channel surface and bottom temperature (shown in a) approximately 30 m away. This difference demonstrates the local cooling effect of springs on the lagoon water temperature and can be inserted into Eq. (1) in the main text.