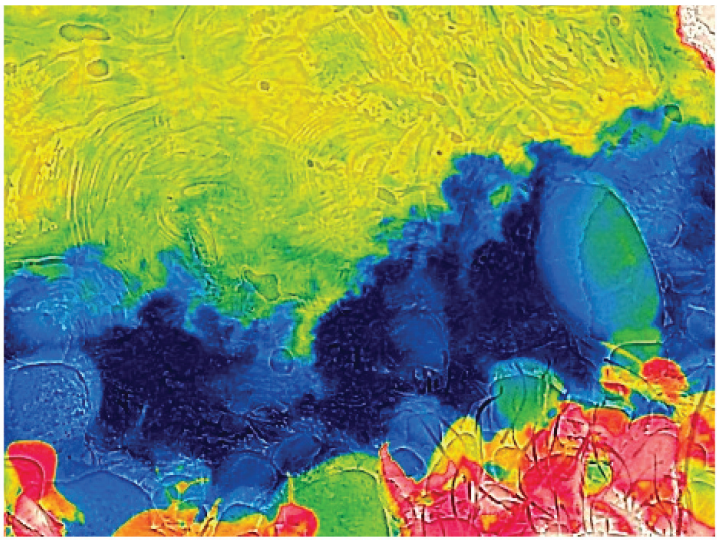
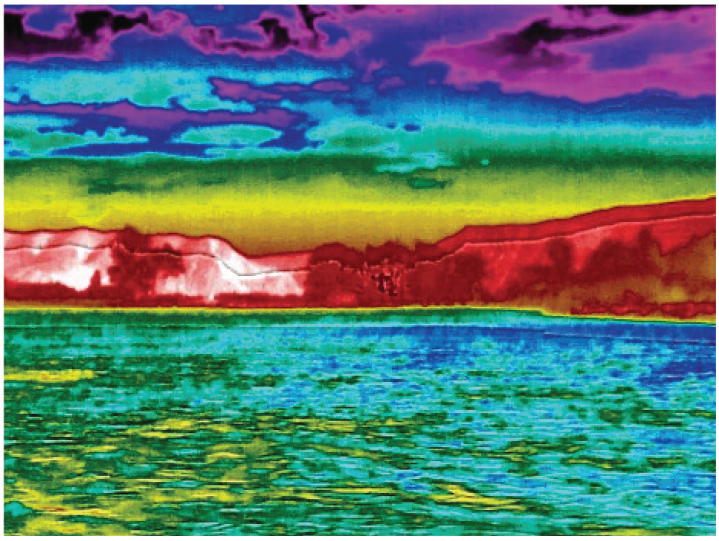
TEMPERATURE AND SITE DATA FOR GROUNDWATER SEEPS, TRIBUTARIES, AND TAILWATER RETURNS TO THE BIG HOLE RIVER NEAR GLEN, MONTANA

Ann E.H. Hanson and Jenna M. Dohman

Montana Bureau of Mines and Geology





MBMG
Montana Bureau of Mines and Geology

Cover Photo: Visible light (left) and thermal infrared images (right) along the Big Hole River. Top: Groundwater appears cooler (blue colors) than surface water (yellow colors) in the summer. Bottom: View of the bedrock notch that the river flows through. The thermal infrared image demonstrates relative temperature differences (purples are cold, reds are warm), which are affected by absorbed and reflected thermal energy.

TEMPERATURE AND SITE DATA FOR GROUNDWATER SEEPS, TRIBUTARIES, AND TAILWATER RETURNS TO THE BIG HOLE RIVER NEAR GLEN, MONTANA

Ann E.H. Hanson and Jenna M. Dohman

Montana Bureau of Mines and Geology
Ground Water Investigation Program

Montana Bureau of Mines and Geology Open-File Report 775

https://doi.org/10.59691/TUHJ7391

June 2025

TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

The Big Hole River is a headwater tributary to the Missouri River within the Northern Rocky Mountain intermontane basins that supports both recreation and agricultural economies. High water temperatures and low flows during late summer can stress trout populations and limit water availability for irrigation and recreation. Near Glen, Montana (fig. 1), high flows of ~3,000–8,000 cubic feet per second (cfs) occur from snowmelt during May–June, with low flows of less than 500 cfs during August–September. The river morphology varies from a single channel to anabranching. Basin width in this reach is generally less than 2 mi across and land use is dominated by agriculture (ranching and irrigated crops).

The Montana Bureau of Mines and Geology (MBMG) Ground Water Investigation Program (GWIP) undertook this study to understand the hydrogeologic components that affect water supply and temperature on the Big Hole River. A primary objective was to identify and monitor groundwater seeps, tributaries, and tailwater returns to the Big Hole River within the study area. Groundwater temperatures are typically cooler than the river during the summer; therefore, temperature contrast (as captured by thermal infrared imagery), as well as visual observations and water-quality data, were used to identify areas of groundwater discharge to the river.

This report describes the methods and presents the data collected from monitored sites. The data are also available in the MBMG Ground Water Information Center (GWIC) at https://mbmggwic.mtech.edu/.

METHODS

A 13-mi reach of the Big Hole River, between the USGS gaging stations Big Hole River near Melrose, MT (06025500) and Big Hole River near Glen, MT (06026210), was floated with a kayak to identify areas of groundwater discharge and surface-water sites (fig. 1). The river was floated twice a month during July–October 2023 and monthly during July–October 2024 (fig. 2). Sites were identified and categorized as either a groundwater discharge (seep), or a surface-water tributary or tailwater return (fig. 1).

Groundwater Seeps

A handheld thermal infrared camera (FLIR T840) was used to detect temperature differences indicative of groundwater discharge along saturated riverbanks; the camera was used to scan both riverbanks from the center of the river channel. The thermal infrared camera can only detect surface temperatures and therefore could only identify seeps along the riverbank and not upwelling from the riverbed within the stream.

Iron-oxide staining and/or deposition along the riverbanks was also used to identify groundwater discharge to the river. Groundwater that contains low dissolved oxygen (DO) and has low oxidation-reduction potential (ORP) can contain a higher concentration of dissolved iron. Where groundwater discharges to the surface and is exposed to the atmosphere, the iron can oxidize and precipitate, leaving an iron stain and/or iron-oxide deposition.

Thermal differences and/or iron-oxide deposition were suggestive of seeps at 20 sites; at each, additional information was collected, including GPS coordinates, site photographs, thermal infrared images, a description of the discharge area (size, presence of iron-oxide deposition or biofilm, etc.), and whether the groundwater input was diffuse (continuous along the riverbank) or from discrete points.

At seep sites, subsurface groundwater temperatures were measured using a RTD Platinum Traceable Thermometer that was inserted into the saturated cobbles/soils to a depth of 10–14 cm (tables 1, 2). Water-quality parameters were measured in the water at the seep using a YSI ProQuatro Multiparameter Meter (tables 1, 2); parameters included temperature, specific conductivity (SC), pH, DO, and ORP. The groundwater-quality parameters were compared to river measurements that were regularly taken along the river (fig. 2). Water-quality parameters were only measured in 2023.

Continuous temperature measurements were obtained from all 20 seep sites by burying temperature loggers (HOBO Pendant MX2201, set to record every 15 min) approximately 10 cm deep within the coldest identified area of the seep (tables 1, 2). Drive-point piezometers (Solonist model 615N) were installed at four sites (seeps 2, 4, 16, and 20; fig. 1; table 2) to monitor temperatures and water levels at depths between 1.5 and 5 ft. Pressure transducers (In-Situ

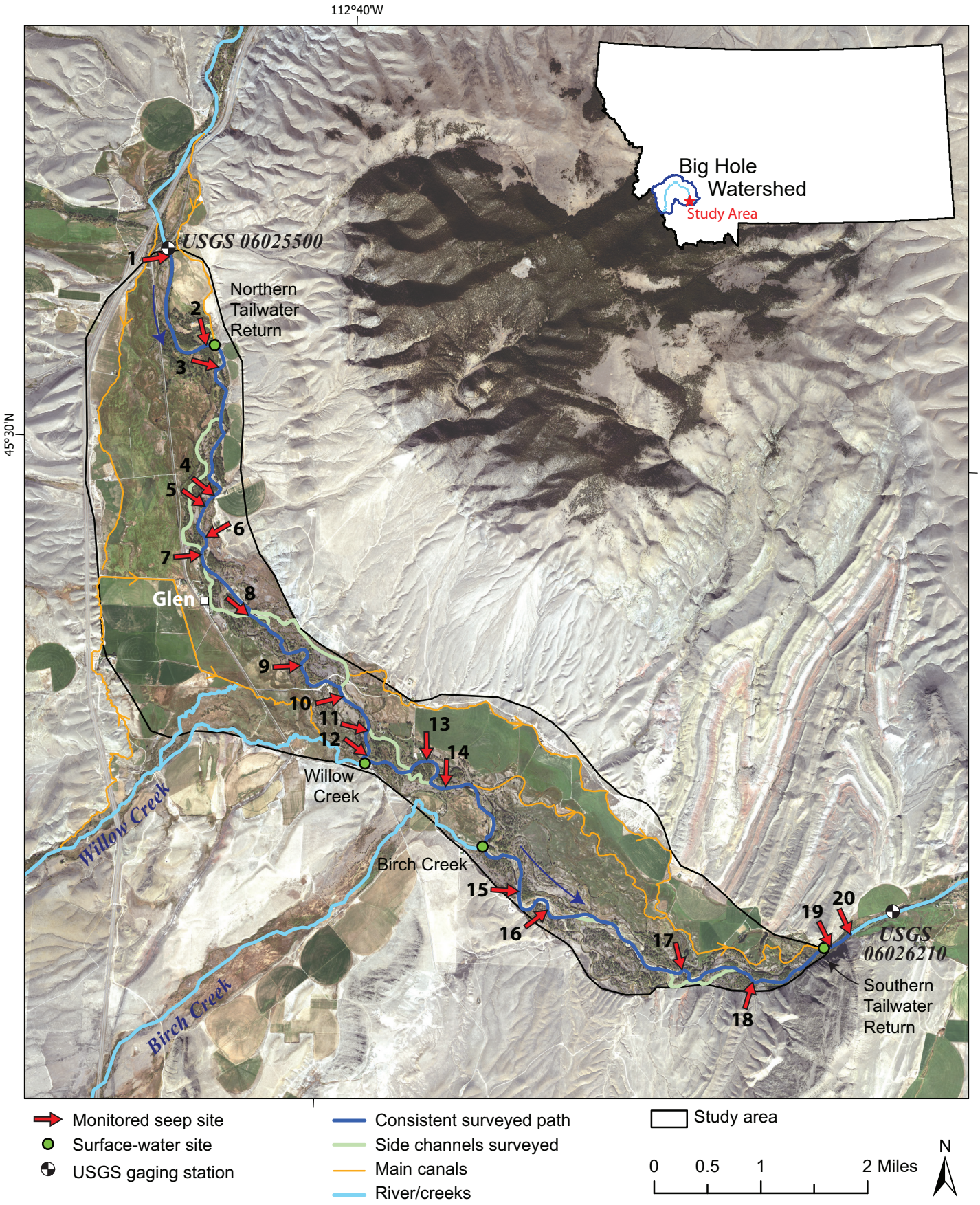


Figure 1. Study area map in the Big Hole Watershed, southwest Montana. River surveys were between USGS gaging stations Big Hole River near Melrose, MT (06025500) and Big Hole River near Glen, MT (06026210). Map shows location of seeps 1–20 from upstream to downstream and the 4 surface-water sites. Seep arrows are located on the side of the river where they were observed and pointing towards the river to imply relative flow direction.

Table 1. Name and description of the temperature methods used throughout this report and the advantages and disadvantages of each method.

Name of Temperature Method	Description of Method	Method Advantages	Method Disadvantages
Thermal Infrared Temperatures	Temperature measured by the handheld FLIR camera.	Able to visually conceptualize spatial differences in temperature gradients with pictures and videos (cool areas vs. warm areas).	Temperatures were considered qualitative, not quantitative, since reflected heat could bias readings.
Subsurface Temperatures	Subsurface temperatures were measured within the saturated cobbles/soils at the seep using a RTD Platinum Traceable Thermometer. The thermometer probe was pushed into the ground 10–14 cm at multiple places for a range of measurements.	Able to measure seep temperatures that are less affected by solar radiation since they were subsurface.	Only provides a few point measurements in both space and time. Thermometer had to be tested at different spots within the seep to find the coolest temperature that was least affected by heat conducted from the surface.
YSI Temperatures	Temperature measured using the YSI water-quality meter submerged near the groundwater seep. River measurements were measured where river appeared well mixed, which was not always possible from shore. In these cases, temperatures were taken periodically in the thalweg between sites.	Temperatures were directly associated with the SC, pH, DO, and ORP collected with the YSI.	Seep temperature and water-quality measurements were often biased by mixing with nearby river water or by being in shallow seep water that was in direct sunlight. Stabilized measurements were time-intensive. River temperatures varied locally based on shading and river morphology.
Logged Temperatures	Temperatures measured using the HOBO Pendant MX2201 loggers buried to 10 cm deep in the seep or at the bottom of the surface-water inflow and logged every 15 min.	Time series temperatures were captured for each of the sites.	Logged temperatures only provided measurements at one point within the seep at 10 cm depth.
Drive Point Temperatures	Temperatures measured with In-Situ Inc. Level Troll 400 data loggers at various drive point depths logged every 15 min.	Time series temperatures were captured for each site at deeper depths in the groundwater seep.	Difficult and expensive to install in cobble riverbanks.
USGS River Temperatures	Temperatures downloaded from the nearest USGS river gaging site from https://waterdata.usgs.gov/nwis.	High quality, publicly available time series data of river temperatures every 15 min for comparison with field methods.	River temperatures can vary between USGS gaging stations and study stations depending on shading and river morphology.

Table 2. Temperature methods collected at each site.

	Site Name	Thermal Infrared Temperatures	Subsurface Temperatures	YSI Temperatures	Logged Temperatures	Drive Point Temperatures
Appendix A	Site 1	x	x	x	x	
	Site 2	x	x	x	x	x
	Site 3	x	x	x	x	
	Site 4	x	x	x	x	x
	Site 5	x	x	x	x	
	Site 6	x	x	x	x	
	Site 7	x	x	x	x	
	Site 8	x	x	x	x	
	Site 9	x	x	x	x	
	Site 10	x	x	x	x	
	Site 11	x	x	x	x	
	Site 12	x	x	x	x	
	Site 13	x	x		x	
	Site 14	x	x	x	x	
	Site 15	x	x	x	x	
	Site 16	x	x	x	x	x
	Site 17	x	x	x	x	
	Site 18	x	x	x	x	
	Site 19	x	x	x	x	
	Site 20	x	x	x	x	x
Appendix B	Northern Tailwater Return			x	x	
	Willow Creek			x	x	
	Birch Creek			x	x	
	Southern Tailwater Return			x	x	

Inc. Level Troll 400) were deployed in the piezometers to obtain continuous temperature and water-level measurements (tables 1, 2). Both HOBO Pendant and In-Situ loggers were pre- and post-calibrated to ensure accuracy. Table 1 provides an overview of the methods used to collect and record temperature, along with their advantages and disadvantages.

For this study, temperature was used to distinguish between hyporheic seeps (shallow, recirculated river water) and groundwater seeps. Seeps with continuous temperature measurements that were similar to the river temperature were considered hyporheic. Seeps with cooler temperatures relative to the river during the summer were considered groundwater seeps. It is likely many sites were a mix of hyporheic and groundwater. The seeps might not affect the overall river volume but could affect temperature and water quality, at least locally. Detailed descriptions of the monitored seeps (from upstream to downstream) are provided in appendix A.

Surface-Water Sites

Surface-water sites, including tributaries and tailwater returns, were also inventoried and instrumented to collect temperature and water-quality data. Four surface-water sites were identified and basic site information was recorded at each (e.g., GPS coordinates, site descriptions, and water-quality parameters). Temperature loggers were deployed at all four sites (HOBO Pendant MX2201; table 2) by tying them to rocks that were submerged upside down in the surface water to shield the logger from direct sunlight. The surface-water discharge was measured in 2024 (in July and August) with a SonTek FlowTracker2. Detailed descriptions of the four surface-water sites are included in appendix B.

Appendix C provides a glossary of definitions and abbreviations used in this project to describe observations and characteristics of the sites discussed in appendices A and B.

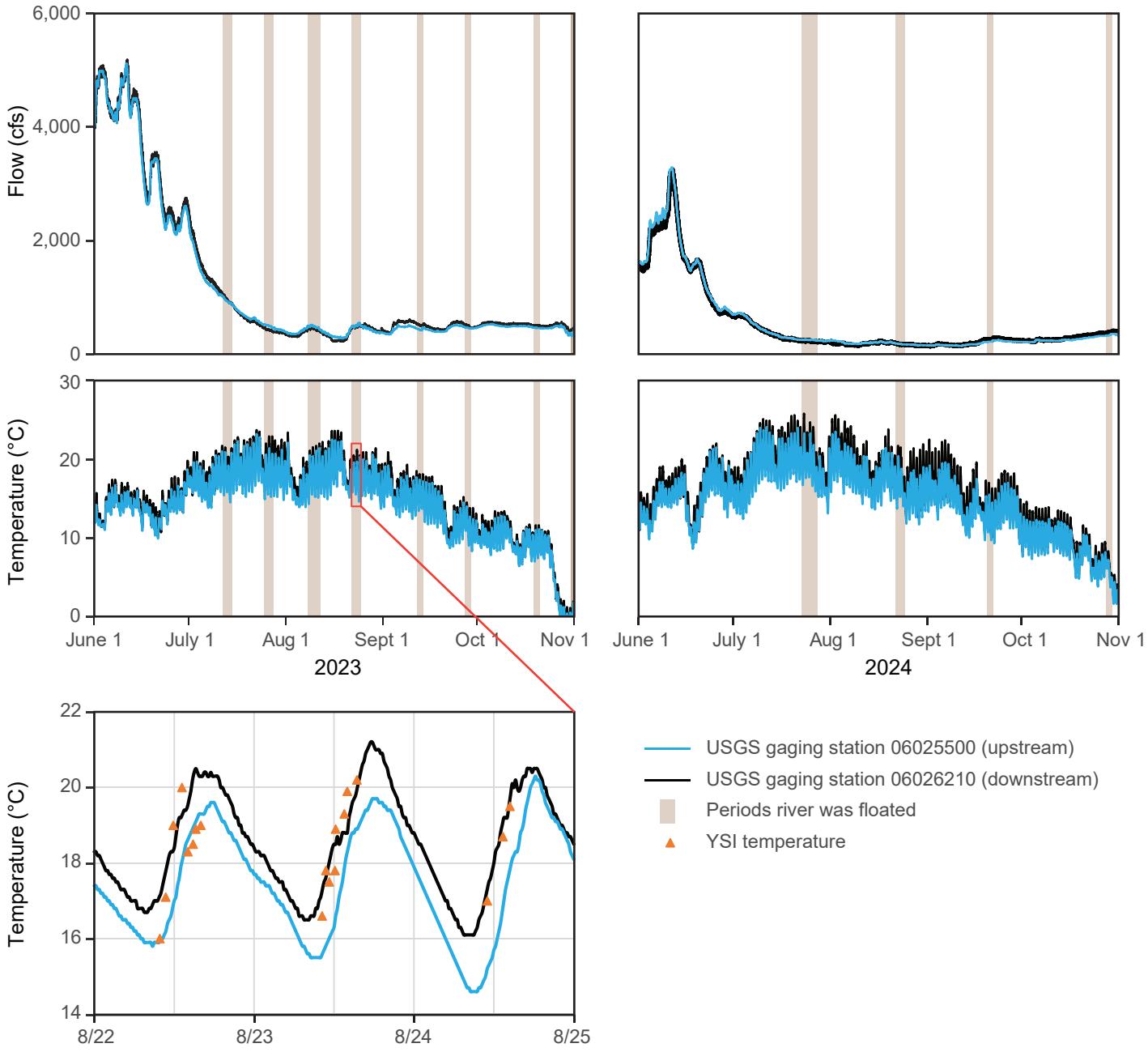


Figure 2. The river was floated twice per month during 2023 and monthly during 2024. River temperatures were warmest during July and August. Temperatures measured with a YSI meter during the floats were similar to the USGS gage temperatures with some variability.

OVERVIEW OF FIELD OBSERVATIONS

Similarities were observed among the monitored sites. The following provides a list of field observation "takeaways" from the data collected:

1. Locations of seeps were consistent in 2023 and 2024. However, the amount of water discharging (apparent visually with pictures and videos from the thermal infrared camera) commonly decreased and the diel temperature fluctuations (using the temperature loggers) commonly increased with decreasing river stage.

2. Seeps were observed to discharge both diffusely along the riverbank (e.g., water appeared to discharge continuously for tens to hundreds of meters) and from discrete points.

3. Groundwater seeps were cooler than the river from July to mid-September and warmer than the river from mid-September through November.

4. Groundwater seeps generally had lower pH, DO, and ORP compared to the river. Groundwater SC varied temporally and spatially; values could be higher or lower than those of the river.

5. Seeps that became ponded before reaching the river or seeps that were not quickly mixed with the river became warm from direct solar radiation. These seeps added water to the river that was warmer than the river during July and August afternoons even though subsurface temperatures of the seep (that were more protected from solar radiation) were cooler than the river.

6. Two of the four surface-water sites (1 tributary, 1 tailwater return) were generally cooler than the river. At the other two surface-water sites (1 tributary, 1 tailwater return), temperatures could be warmer or cooler than the river due to diel fluctuations.

APPENDIX A
DESCRIPTIONS OF SEEPS 1–20

Site 1

GWIC #: 334283
Latitude/Longitude: 45.52526, -112.70153
Description: Site 1 had discrete areas of groundwater discharging for ~800 ft along a cobble riverbank (fig. A1.1). The pH, DO, and ORP of the groundwater seep were generally less than those measured for the river; groundwater SC could be higher or lower than the river (table A1.1). Iron-oxide deposition, iron-oxidizing microbial mats, and biofilm were present between the cobbles (fig. A1.2). Thermal infrared temperatures showed the discharged groundwater was often slightly warmer than the river during the morning when the site was visited (fig. A1.3). The logged temperatures showed the diel groundwater fluctuations were much greater (>10°C) when stage was lower, suggesting less groundwater flow at that location during low stage (fig. A1.4).

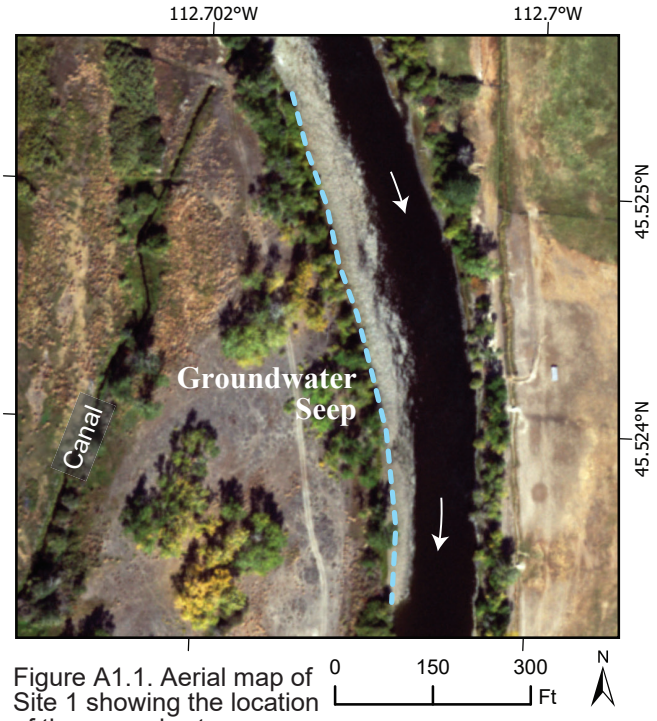


Figure A1.1. Aerial map of Site 1 showing the location of the groundwater seep (dashed blue line).

Table A1.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 9:59 AM	16.4	7.41	260.2	5.8	14.1
River	8/22/2023 9:51 AM	16.0	8.09	190.5	7.5	200.0
Groundwater	9/12/2023 9:50 AM	14.9	7.53	210.5	6.6	-16.2
River	9/12/2023 10:06 AM	13.6	8.14	191.8	8.4	195.0
Groundwater	9/27/2023 9:39 AM	11.4	7.88	179.7	6.8	85.0
River	9/27/2023 9:52 AM	10.9	8.24	183.6	8.8	91.3
Groundwater	10/18/2023 9:20 AM	7.1	7.54	194.2	6.8	191.2
River	10/18/2023 9:25 AM	7.1	8.04	173.8	9.1	188.6
Groundwater	11/1/2023 10:08 AM	1.1	7.30	186.0	10.0	139.2
River	11/1/2023 10:27 AM	0.1	7.98	182.0	12.5	133.1

Figure A1.2. Saturated riverbank with iron-oxide deposition, iron-oxidizing microbial mats, and biofilm between the cobbles.

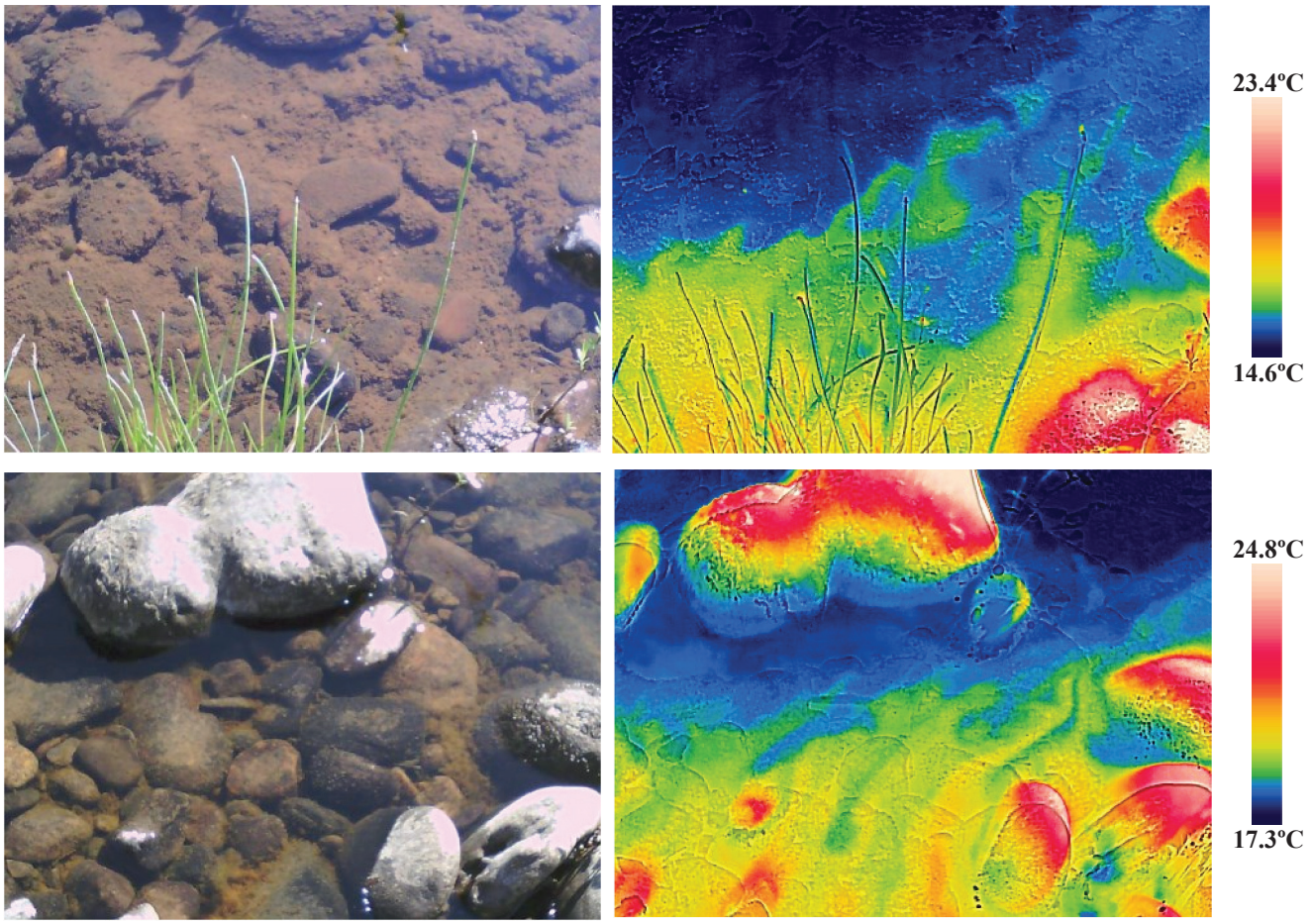


Figure A1.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 1. This site commonly showed the groundwater to be warmer (yellow, ~16-20ºC) than the river (blue, ~14-17ºC); groundwater discharged from the riverbank (top) and between cobbles (bottom).

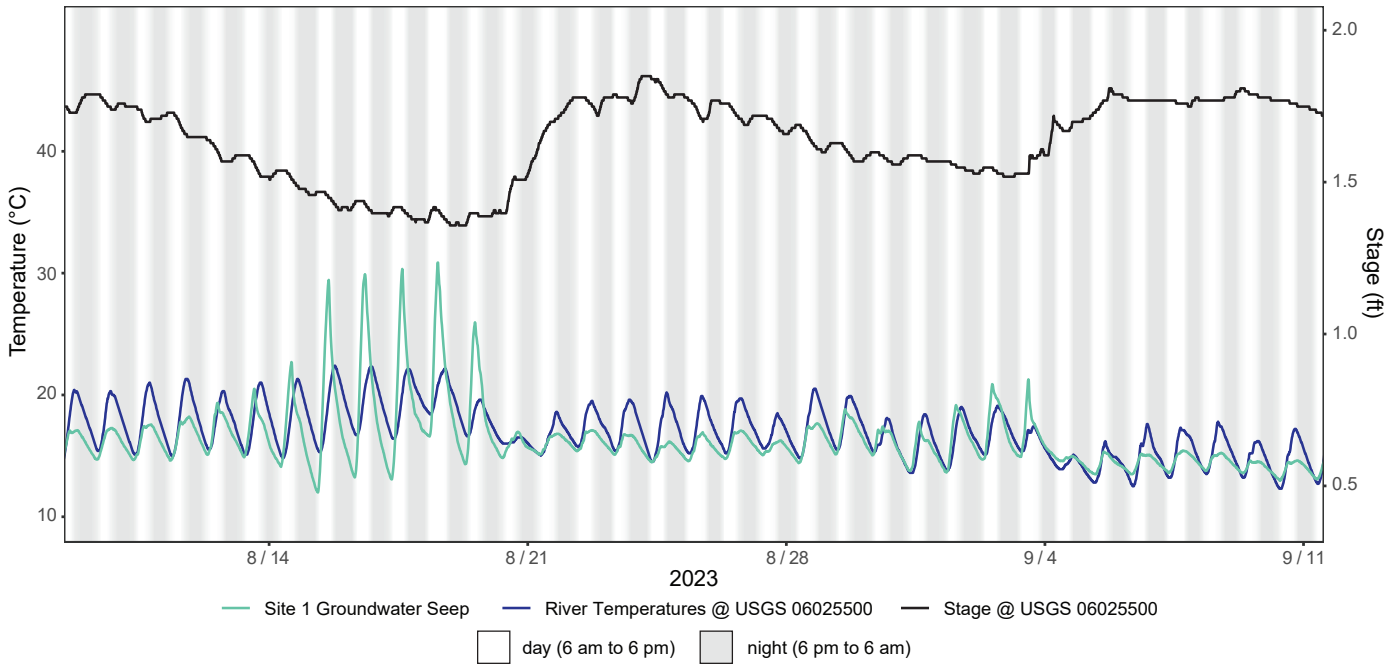


Figure A1.4. August–September 2023 logged temperatures at Site 1 groundwater seep (334283) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The minimum groundwater seep temperatures are similar to the river temperatures. Higher diel fluctuations occur when river stage was lower.

Site 2

GWIC #: 327565 (drive point), 334286 (groundwater seep), 334285 (hyporheic), 334287 (seep joins river)
Latitude/Longitude: 45.51336, -112.69359
Description: Site 2 had groundwater discharging along the riverbank for ~480 ft (fig. A2.1). Cool thermal infrared temperatures and significant iron-oxide deposition were observed along the riverbank (fig. A2.2, A2.3); iron-oxide deposition was greater on the upstream end of the seep during early summer and greater on the downstream end of the seep during late summer. Subsurface temperatures ranged from 9.8°C to 14.9°C. The pH, DO, and ORP of the groundwater were less than those measured for the river; SC was higher in the groundwater than the river (table A2.1). Logged groundwater temperatures were consistently around 12°C (fig. A2.4). The logged hyporheic flow temperatures were similar to the USGS river temperatures with smaller diel fluctuations. Some of the groundwater combined with the hyporheic flow and became ponded, causing the water to warm during the day before joining the river.

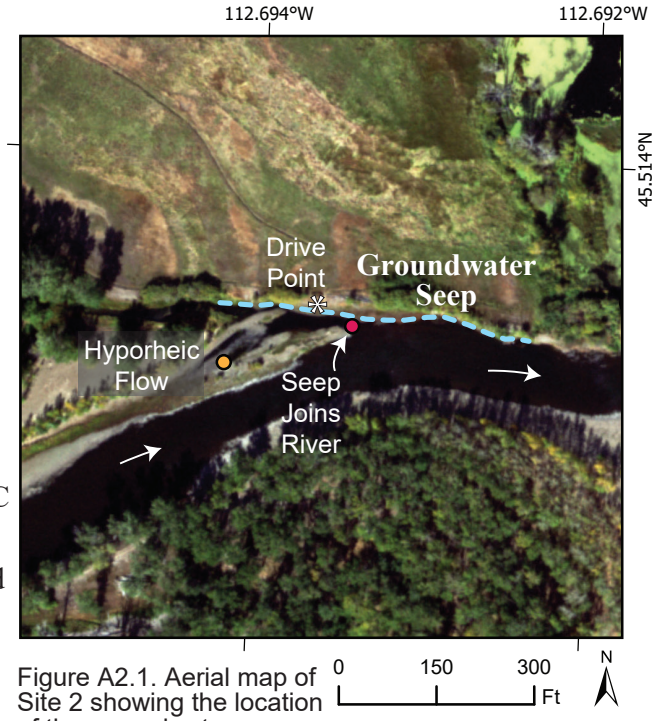


Figure A2.1. Aerial map of Site 2 showing the location of the groundwater seep (dashed blue line).

Table A2.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 10:49 AM	13.0	7.13	435.4	3.5	-49.3
River	8/22/2023 10:44 AM	17.1	8.45	188.9	8.5	147.4
Groundwater	9/12/2023 10:38 AM	13.7	7.15	448.9	3.5	-22.9
River	9/12/2023 11:21 AM	14.8	8.56	189.5	9.6	57.6
Groundwater	9/27/2023 10:21 AM	11.5	7.38	278.1	3.3	-3.7
River	9/27/2023 11:28 AM	11.5	8.58	183.1	9.4	32.0
Groundwater	10/18/2023 10:08 AM	8.1	7.37	475.8	2.3	-18.4
River	10/18/2023 9:49 AM	7.1	8.27	172.8	9.4	180.1
Groundwater	11/1/2023 10:44 AM	6.5	7.36	474.1	1.6	-62.4
River	11/1/2023 10:27 AM	0.1	7.98	182.0	12.5	133.1

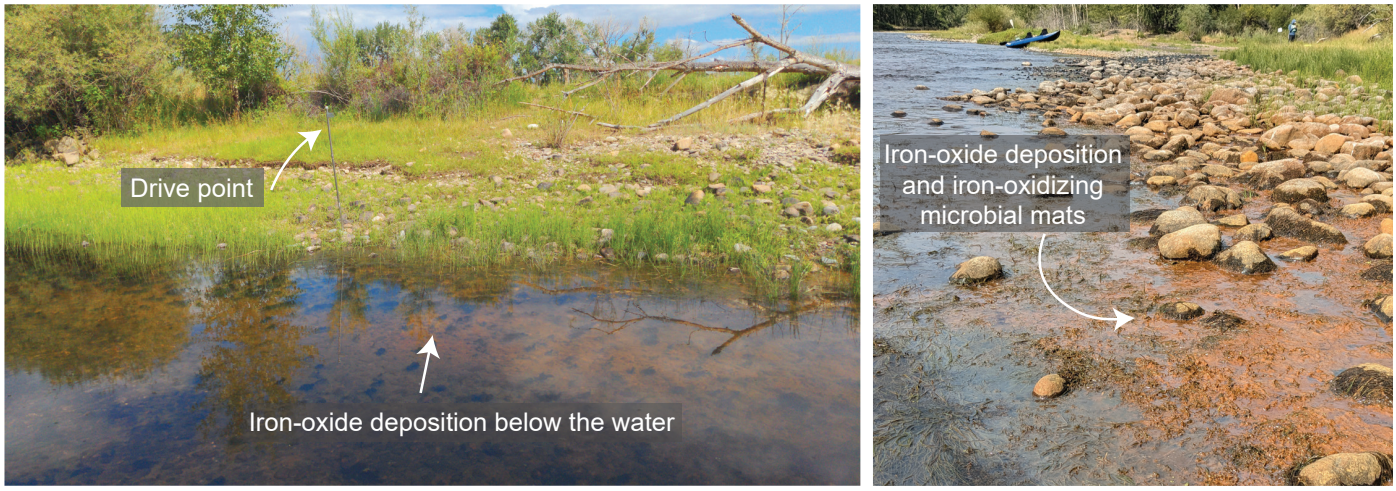


Figure A2.2. Iron-oxide deposition and iron-oxidizing microbial mats below the surface of the water (left). Farther along the riverbank, the iron deposition became more prevalent later in the summer (right).

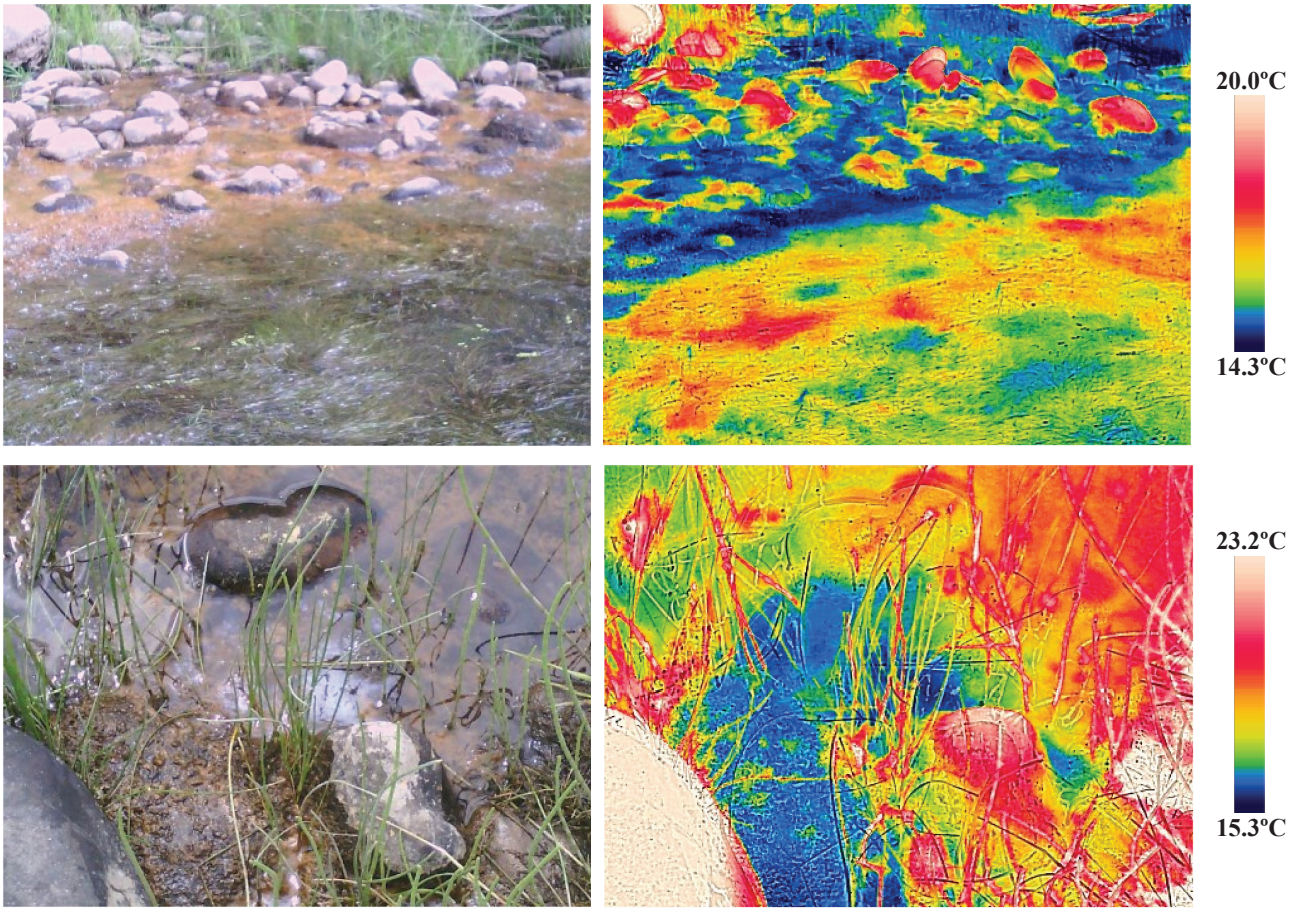


Figure A2.3. Representative visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 2. Cool (blue, ~14-15ºC) groundwater could be seen discharging outward from the riverbank (top) which had iron-oxide deposition (top, left) and a closeup of the groundwater discharging between cobbles where biofilm was present (bottom).

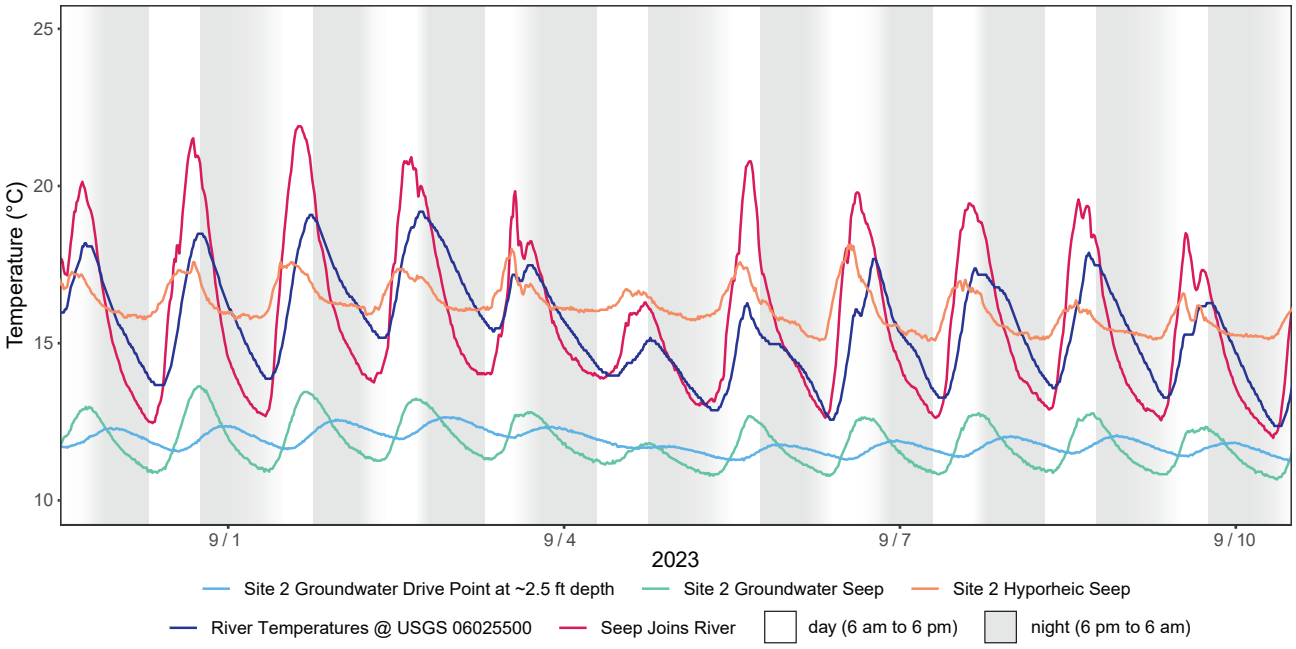


Figure A2.4. August-September 2023 logged temperatures at Site 2 groundwater seep. Groundwater temperatures at the drive point (327565) and near the surface (334286) were cooler than river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The logged temperatures of the hyporheic flow (334285) were similar to river temperatures with smaller diel fluctuations. Some of the groundwater mixed with hyporheic water (fig. A2.1) and remained ponded before joining the river (334287), causing the discharged groundwater to warm during the day.

Site 3

GWIC #: 334288 (groundwater seep), 334289 (hyporheic)
Latitude/Longitude: 45.51057, -112.69096
Description: Site 3 had groundwater discharging for ~115 ft in a backwater on the inside of a river meander. Hyporheic water was observed within the point bar (fig. A3.1). Subsurface temperatures ranged from 11.9°C to 12.2°C. The pH, DO, and ORP of the groundwater were less than those measured for the river; SC could be higher or lower than the river (table A3.1). Site 3 was sandy/muddy with iron- and manganese-oxide deposition and microbial mats in the ponded water (fig. A3.2). Thermal infrared showed the hyporheic and groundwater temperatures were cooler than the surrounding water (fig. A3.3). Average logged groundwater temperatures in August were ~13-15°C (fig. A3.4). Hyporheic and groundwater temperatures showed greater diel fluctuations when stage was lower (fig. A3.4).

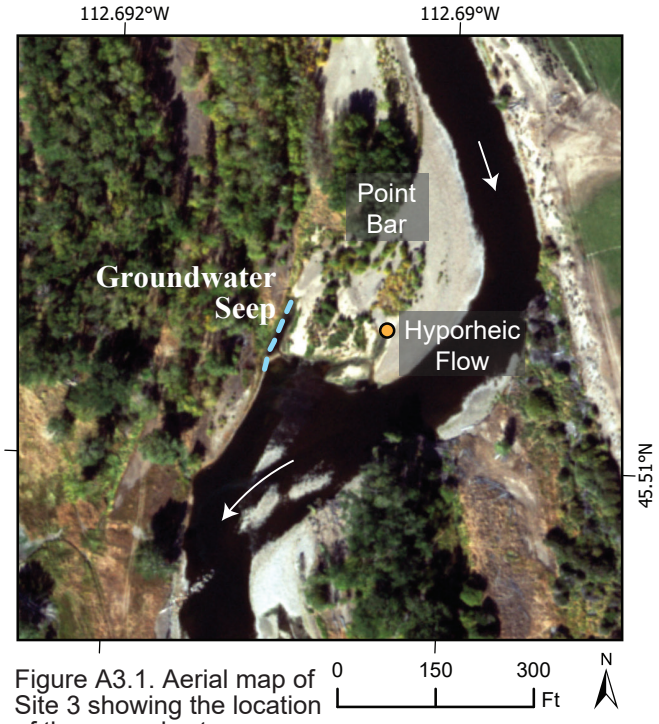


Figure A3.1. Aerial map of Site 3 showing the location of the groundwater seep (dashed blue line).

Table A3.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 12:17 PM	17.3	6.94	179.4	3.3	-60.1
River	8/22/2023 11:52 AM	19.0	8.60	189.7	8.2	68.4
Groundwater	9/12/2023 11:59 AM	14.4	7.05	200.0	0.1	-101.2
River	9/12/2023 11:21 AM	14.8	8.56	189.5	9.6	57.6
Groundwater	9/27/2023 11:49 AM	13.9	7.07	208.4	0.4	-54.8
River	9/27/2023 11:28 AM	11.5	8.58	183.1	9.4	32.0
Groundwater	10/18/2023 10:54 AM	10.3	7.15	214.7	0.8	-39.9
River	10/18/2023 11:04 AM	7.4	8.39	172.8	9.7	1.6
Groundwater	11/1/2023 11:46 AM	9.0	7.22	219.1	1.8	-79.0
River	11/1/2023 12:08 PM	0.9	8.27	181.4	12.9	24.0

Figure A3.2. Backwater with groundwater seeping (left) and the hyporheic seep (right). Both sites had iron- and manganese-oxide deposition.

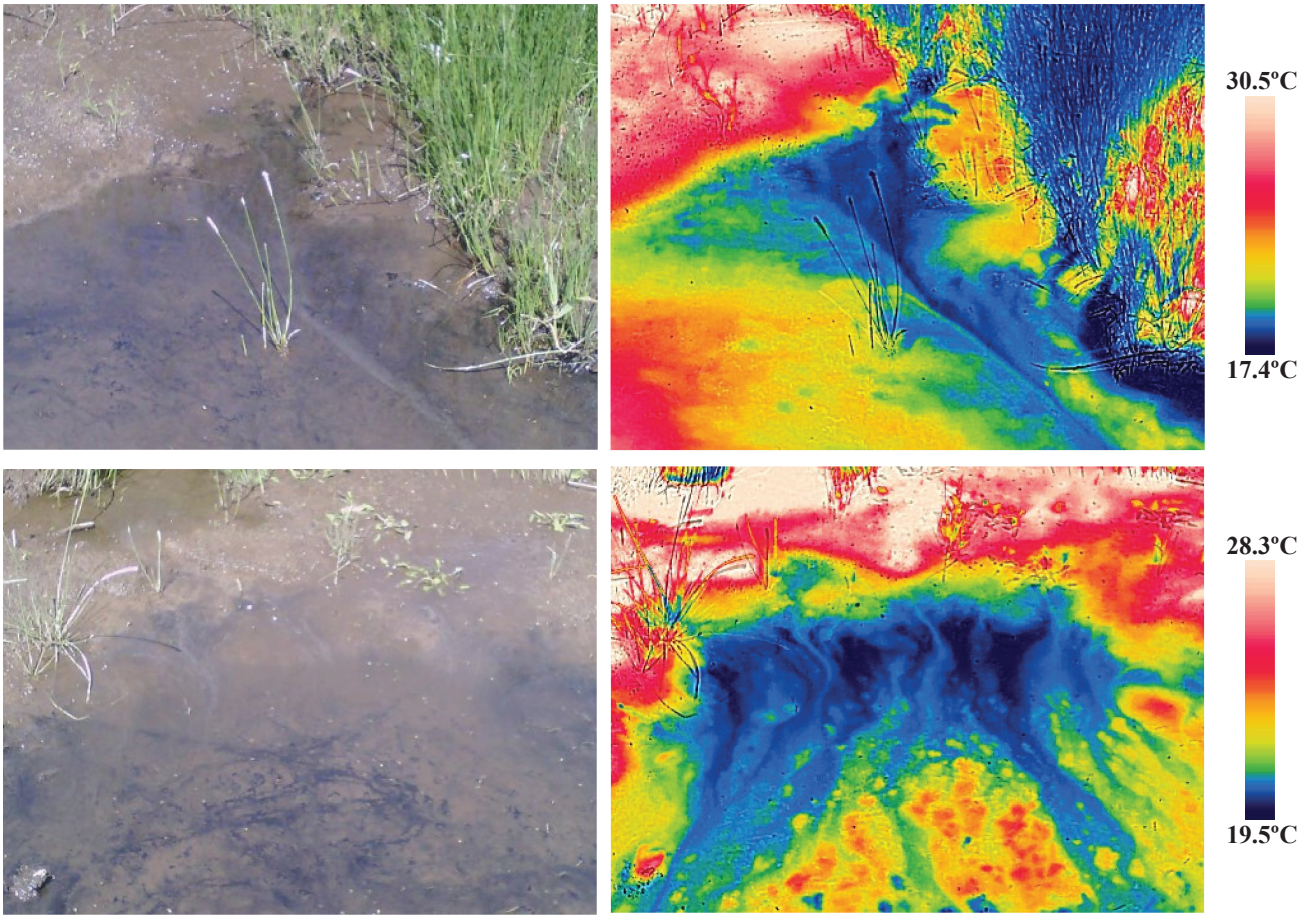


Figure A3.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep (top) and hyporheic seep (bottom) at Site 3. This site was sandy/muddy and often warmed more than other sites. The groundwater and hyporheic flow were cooler (blue, ~17-20ºC) than the surrounding ponded water.

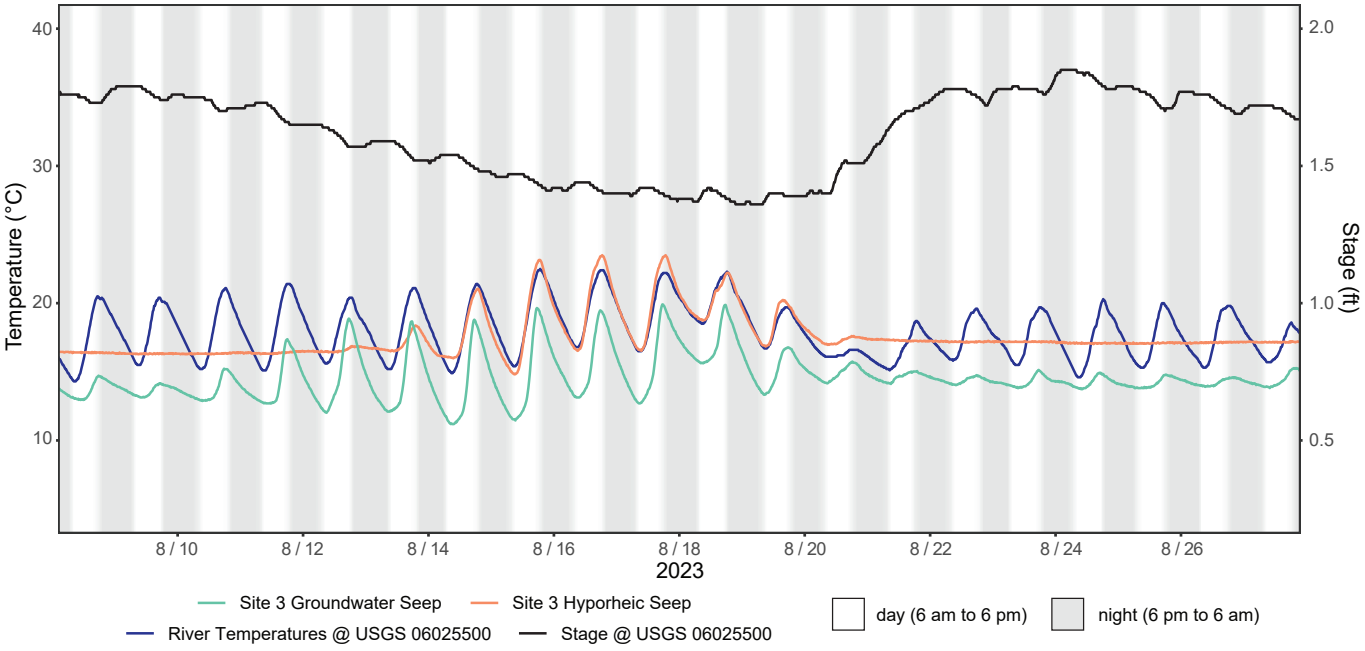


Figure A3.4. August 2023 logged temperatures at Site 3 groundwater seep (334288) and hyporheic seep (334289) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The hyporheic temperatures approximated average river temperatures while the groundwater seep temperatures were cooler than the river. Diel temperature fluctuations were greater when stage was lower suggesting less flow at the monitored spots when stage decreased.

Site 4

GWIC #: 327516
Latitude/Longitude: 45.492987,-112.690615
Description: Site 4 had groundwater discharging along a cobble riverbank for ~180 ft (fig. A4.1). The pH, DO, and ORP of the groundwater seep were less than those measured for the river; groundwater SC was within 13% of river SC (table A4.1). Iron-oxide deposition, iron-encrusted algae mats, and biofilm were present between the cobbles (fig. A4.2). The thermal infrared showed obvious cool temperatures on the riverbank from a distance (fig. A4.3); subsurface temperatures ranged from 10.9°C to 12.5°C. Cool groundwater temperatures appeared to move outward from the riverbank at lower river stages. Groundwater temperatures in the drive point showed minimal diel fluctuations. When stage decreased, the groundwater was warmer and showed greater diel fluctuations (fig. A4.4).

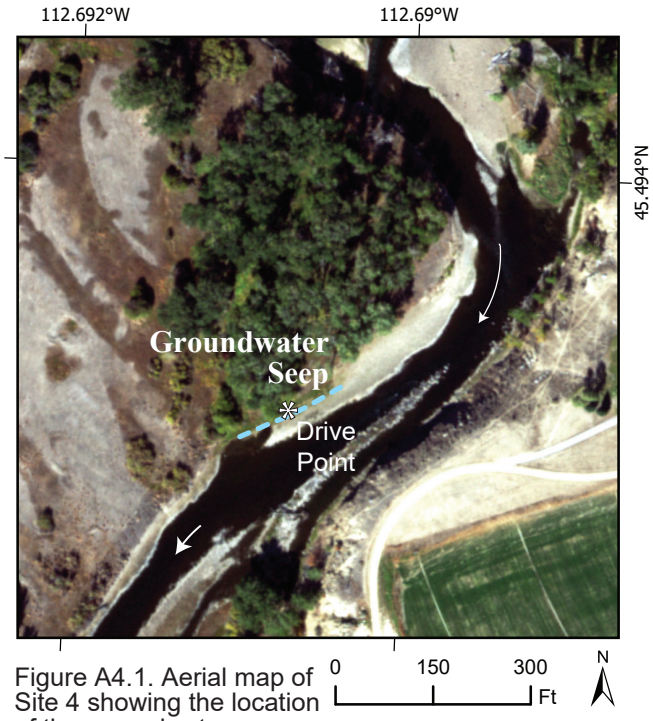


Figure A4.1. Aerial map of Site 4 showing the location of the groundwater seep (dashed blue line).

Table A4.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 1:18 PM	19.4	7.82	164.9	6.2	-29.3
River	8/22/2023 1:10 PM	20.0	8.53	185.7	7.9	61.2
Groundwater	9/12/2023 1:17 PM	20.1	7.84	164.6	6.8	13.6
River	9/12/2023 1:11 PM	15.8	8.81	189.7	9.7	30.3
Groundwater	9/27/2023 12:40 PM	14.1	7.67	171.8	5.4	10.3
River	9/27/2023 12:31 PM	11.9	8.71	182.6	9.5	40.8
Groundwater	10/18/2023 11:37 AM	12.0	7.37	173.3	1.2	8.9
River	10/18/2023 11:29 AM	8.7	8.23	166.1	9.4	39.8
Groundwater	11/1/2023 12:41 PM	10.4	7.31	177.8	0.9	-85.5
River	11/1/2023 12:52 PM	5.4	7.91	176.4	10.5	31.4

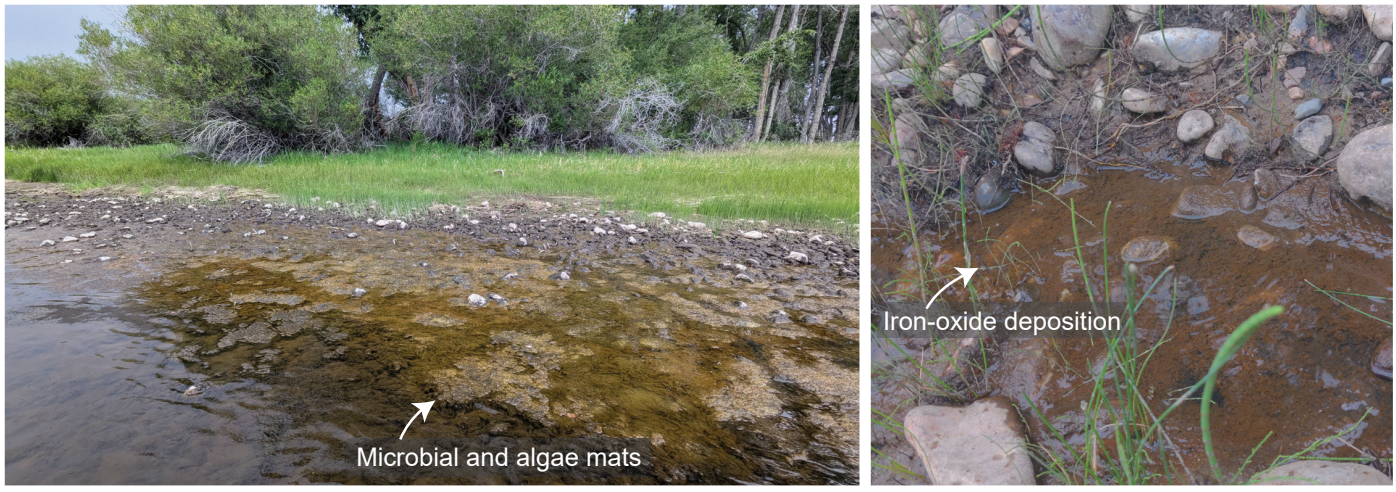


Figure A4.2. Saturated cobble riverbank (left) with iron-oxide deposition (right). Iron-encrusted algae and microbial mats were more prevalent at this site in 2024 when stage was lower.

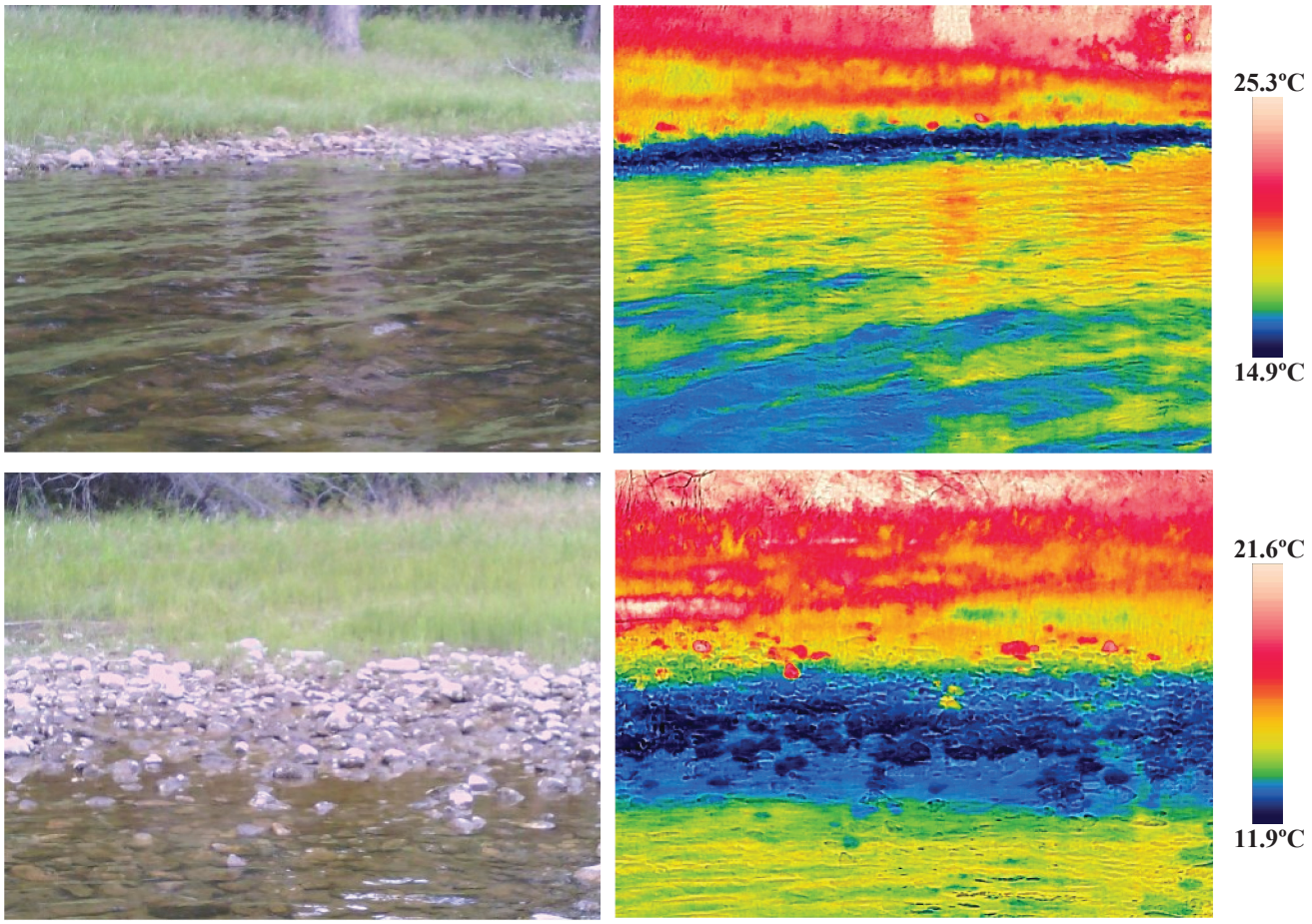


Figure A4.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 4. Cool (dark blue, ~12-15ºC) groundwater was observed discharging outward from the riverbank. Note that the river temperatures in the top thermal infrared image are affected by reflected temperatures and are not true temperatures.

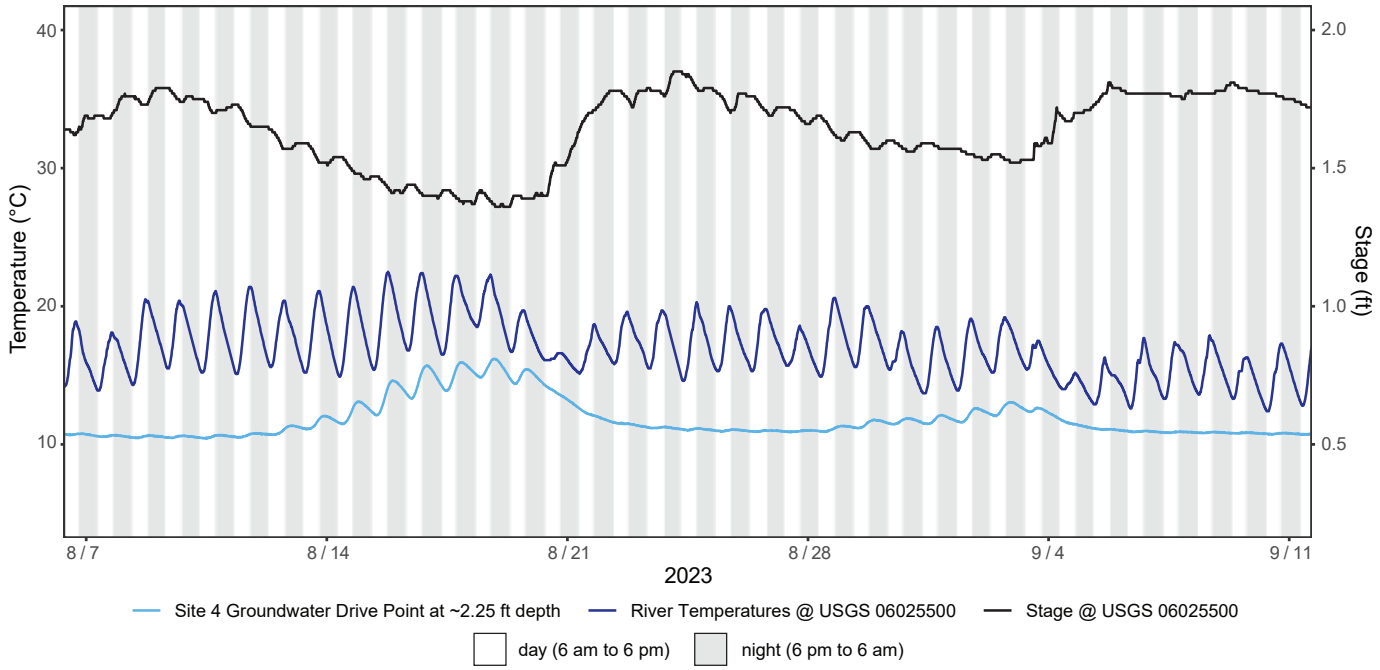


Figure A4.4. August-September 2023 logged temperatures at Site 4 groundwater seep (327516) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The groundwater temperatures at 2.25 ft depth in the drive point are cooler (~11°C) compared to the river (~15-21°C). Groundwater temperatures increased and diel groundwater temperature fluctuations were greater when river stage decreased.

Site 5

GWIC #: 334290
Latitude/Longitude: 45.49114, -112.69246
Description: Site 5 had groundwater discharging along a cobble riverbank for ~290 ft (fig. A5.1). The groundwater seep was visually identified by the iron-stained cobbles (fig. A5.2). Cool groundwater was observed flowing from the riverbank using thermal infrared (fig. A5.3). Subsurface temperatures ranged from 9.7°C to 11.4°C. The pH, DO, and ORP of the groundwater seep were generally less than those measured for the river; groundwater SC was within 5% of river SC (table A5.1); however, it was hard to isolate the groundwater from the river using the YSI probe at this site. Logged groundwater temperatures were consistent around 12°C with greater diel temperature fluctuations when river stage was lower (fig. A5.4).

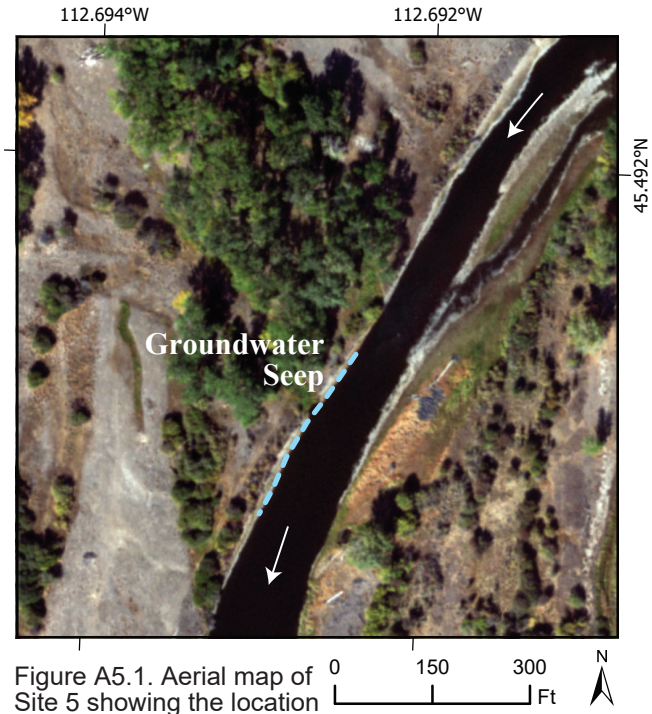


Figure A5.1. Aerial map of Site 5 showing the location of the groundwater seep (dashed blue line).

Table A5.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 1:31 PM	18.2	8.64	189.8	8.5	-17.0
River	8/22/2023 1:10 PM	20.0	8.53	185.7	7.9	61.2
Groundwater	9/12/2023 1:33 PM	16.4	8.58	192.4	9.0	-46.2
River	9/12/2023 1:11 PM	15.8	8.81	189.7	9.7	30.3
Groundwater	9/27/2023 12:59 PM	12.4	8.10	191.6	8.7	-83.5
River	9/27/2023 12:31 PM	11.9	8.71	182.6	9.5	40.8
Groundwater	10/18/2023 12:23 PM	8.8	8.13	178.1	8.9	-34.5
River	10/18/2023 12:46 PM	8.5	8.36	181.5	9.8	16.5
Groundwater	11/1/2023 1:13 PM	2.7	7.91	192.6	11.1	-35.6
River	11/1/2023 1:32 PM	1.1	8.10	187.1	12.3	36.8

Figure A5.2. Iron staining on the cobbles (left) and iron-oxide deposition below the water surface (right) where groundwater was seeping into the river.

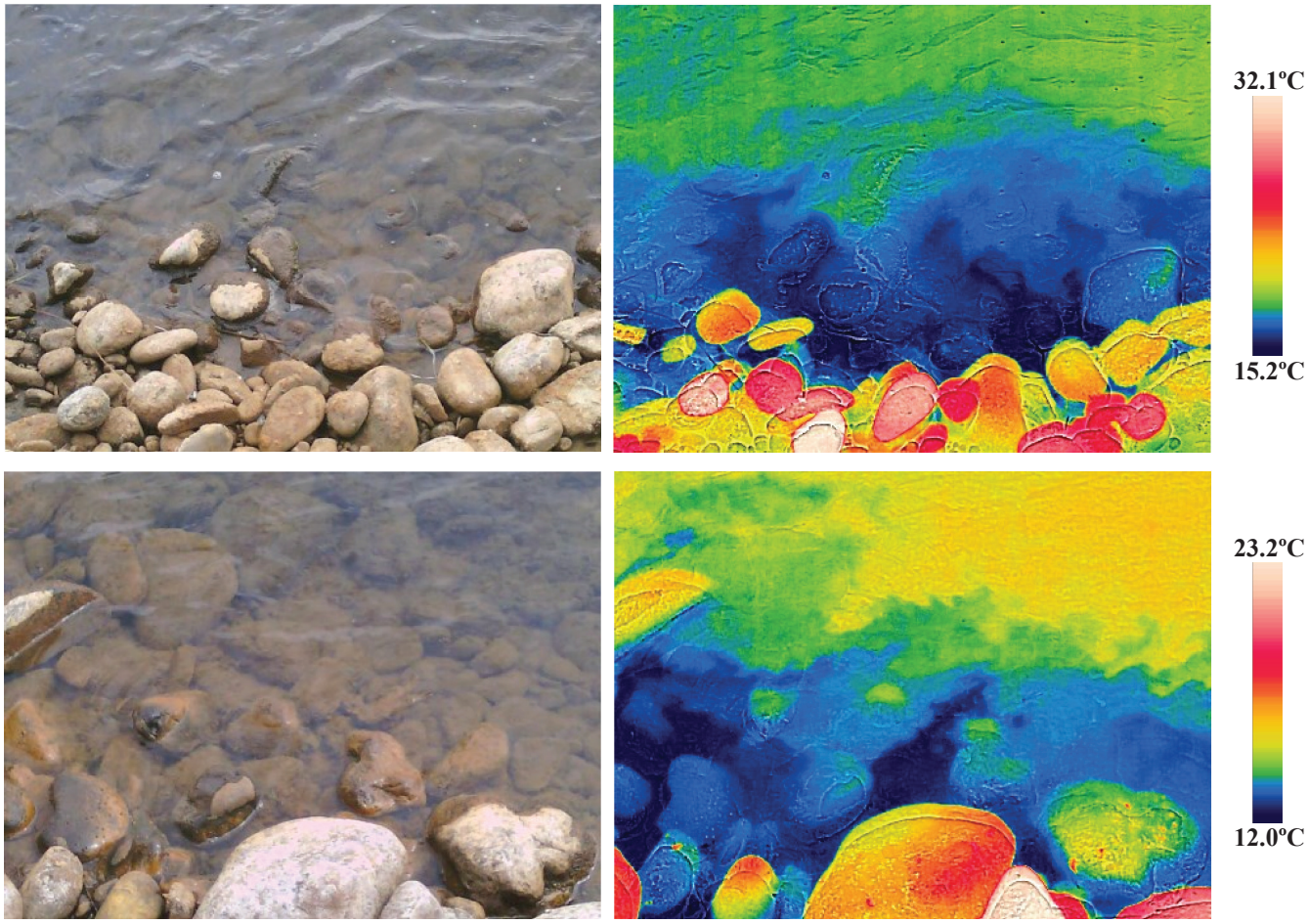


Figure A5.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 5. Cool (blue, ~12-15ºC) groundwater was observed discharging outward from the cobble riverbank

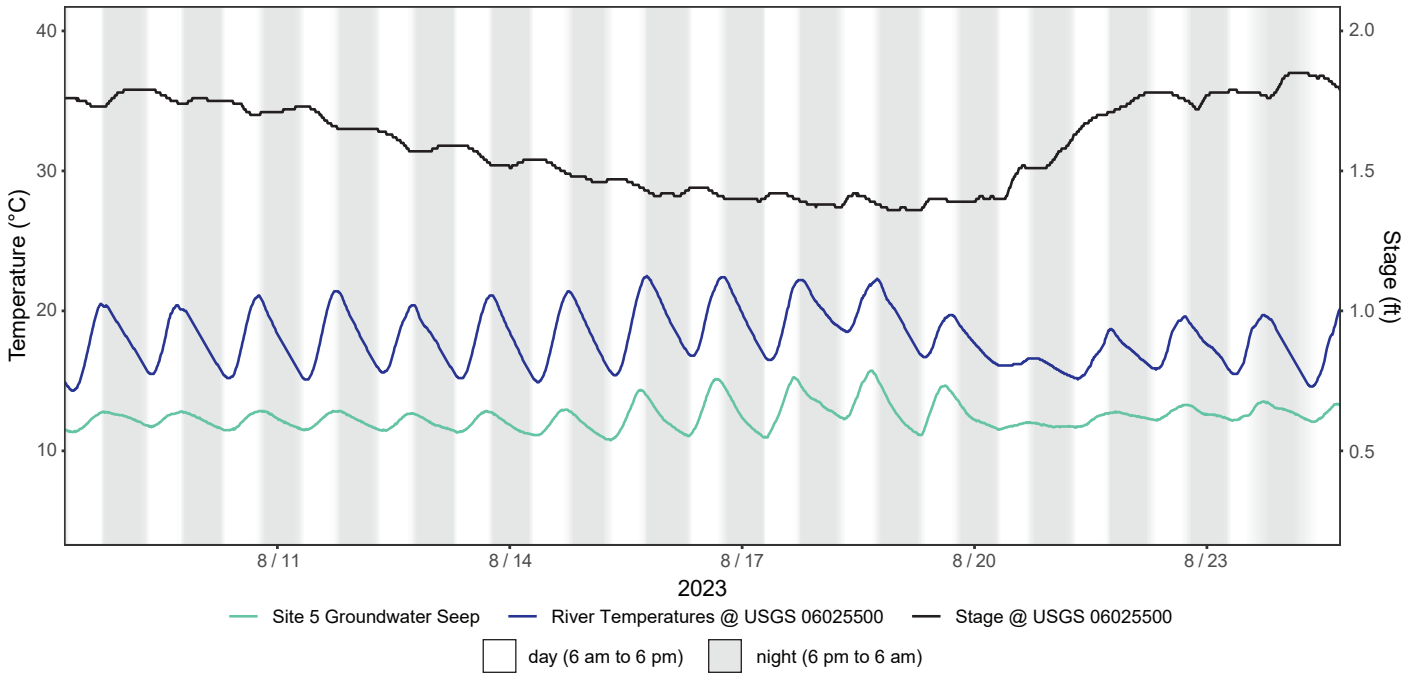


Figure A5.4. August 2023 logged temperatures at Site 5 groundwater seep (334290) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). Diel groundwater temperature fluctuations were greater when stage was lower.

Site 6

GWIC #: 334291
Latitude/Longitude: 45.487196, -112.691903
Description: Site 6 had discrete areas of groundwater discharging along a cobble riverbank for ~60 ft (fig. A6.1). Iron-encrusted algae/iron-stained cobbles (fig. A6.2) and cooler thermal infrared temperatures (~11-15°C; fig. A6.3) were observed at this groundwater seep. Subsurface temperatures ranged from 9.5°C to 11.4°C. The pH, DO, and ORP of the groundwater were less than those measured for the river; groundwater SC was within 5% of river SC (table A6.1). The logged groundwater temperatures were steady around 11°C with <0.5°C diel variations (fig. A6.4).

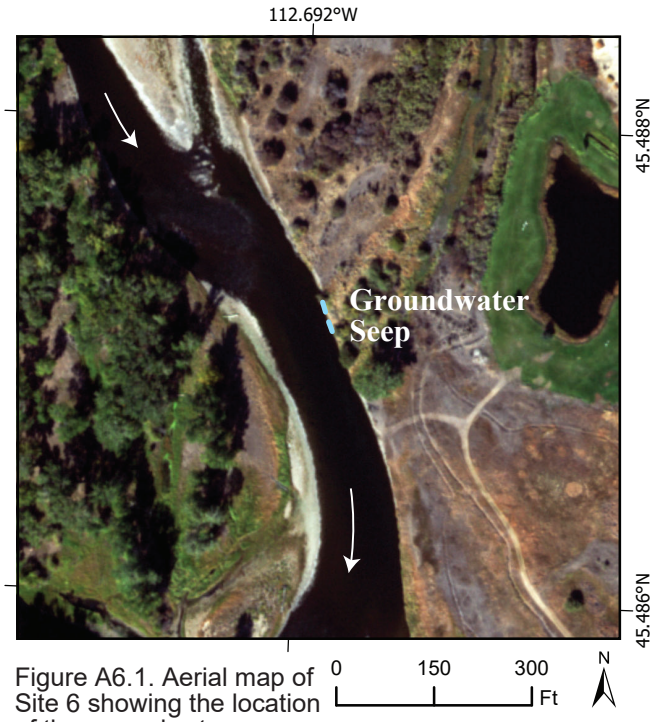


Figure A6.1. Aerial map of Site 6 showing the location of the groundwater seep (dashed blue line).

Table A6.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 2:03 PM	17.0	7.68	194.7	6.6	-80.0
River	8/22/2023 2:03 PM	18.3	8.78	188.7	8.5	188.7
Groundwater	9/12/2023 1:46 PM	17.0	8.72	190.1	9.4	-41.9
River	9/12/2023 1:11 PM	15.8	8.81	189.7	9.7	30.3
Groundwater	9/27/2023 1:17 PM	12.4	7.67	191.6	8.1	-70.8
River	9/27/2023 12:31 PM	11.9	8.71	182.6	9.5	40.8
Groundwater	10/18/2023 12:35 PM	8.9	7.96	175.3	8.7	-43.7
River	10/18/2023 12:46 PM	8.5	8.36	181.5	9.8	16.5
Groundwater	11/1/2023 1:23 PM	3.3	7.85	184.3	9.4	-39.9
River	11/1/2023 1:32 PM	1.1	8.10	187.1	12.3	36.8

Figure A6.2. A patch of iron-encrusted algae at the Site 6 groundwater seep (left). A close-up of the iron-encrusted algae (right).

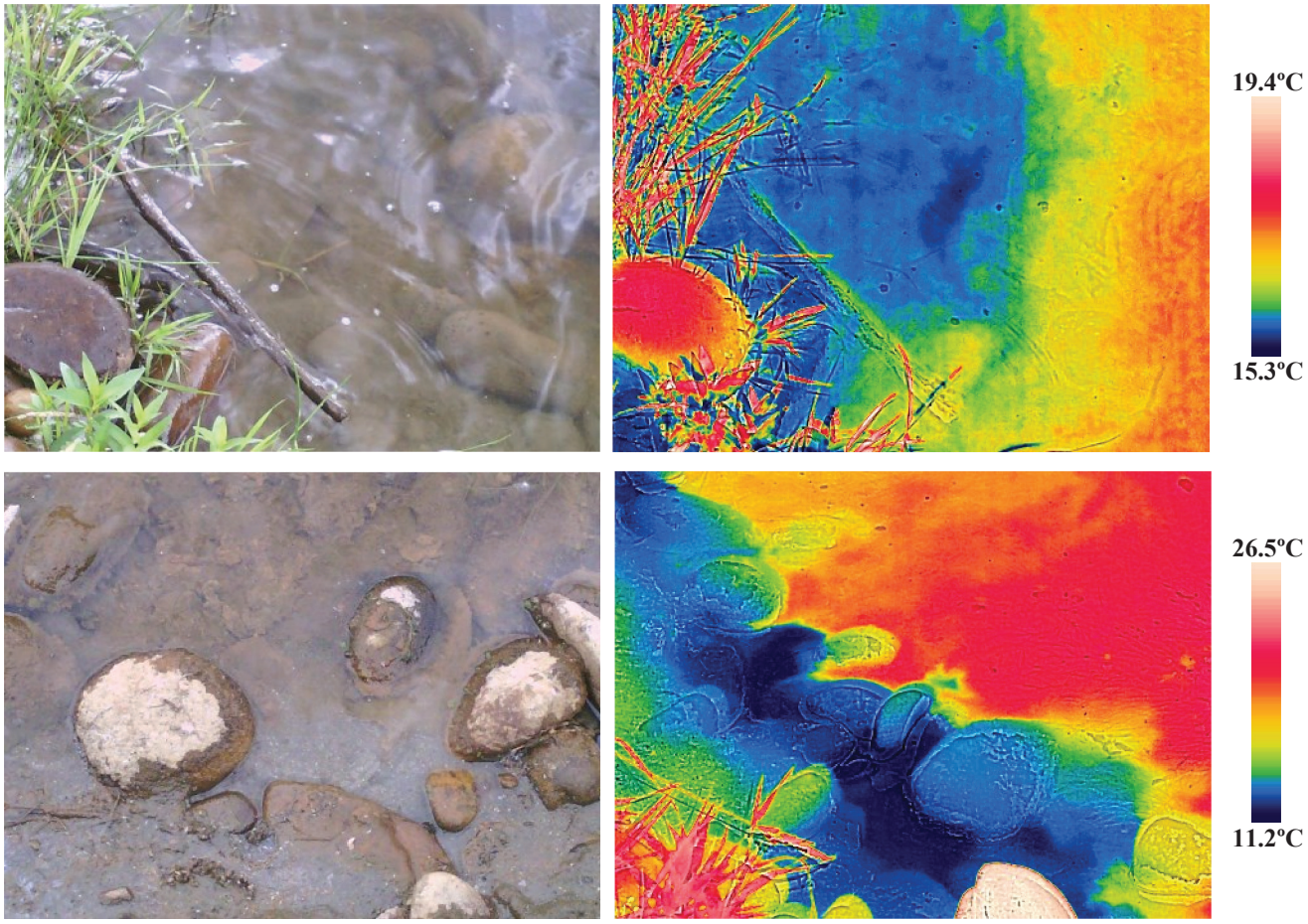


Figure A6.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 6. Cool (blue, ~11-15ºC) groundwater could be seen discharging outward from the cobble riverbank.

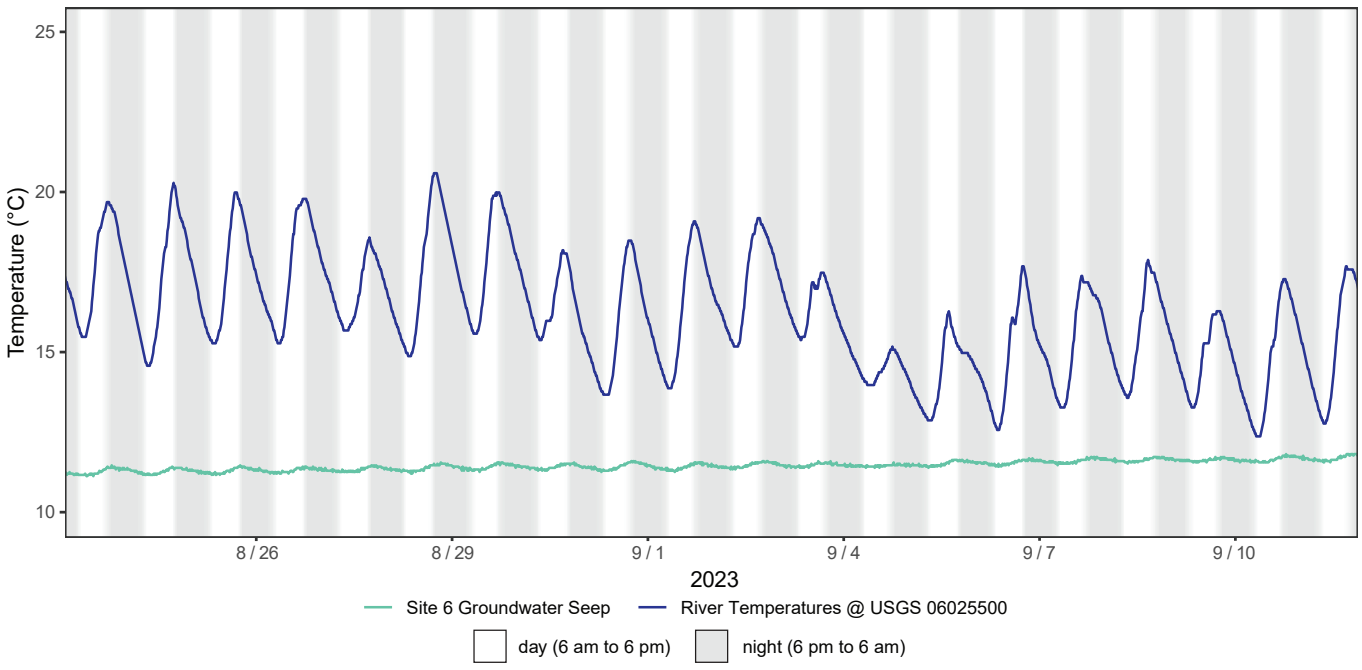


Figure A6.4. August-September 2023 logged temperatures at Site 6 groundwater seep (334291) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). Groundwater temperatures were consistent around 11-12°C with generally small <0.5°C diel fluctuations compared to the ~5-6°C diel fluctuations of the river.

Site 7

GWIC #: 334292
Latitude/Longitude: 45.48502, -112.69268
Description: Site 7 had groundwater discharging along a continuous, ~135 ft section of a cobble riverbank that was downstream of a river side channel (fig. A7.1-A7.3). The extent of groundwater discharging from the riverbank varied during site visits; sometimes thermal infrared showed cooler temperatures stretching 2-3 ft out from the riverbank and other times cooler temperatures were only noted within <1 ft of the riverbank (fig. A7.3). Iron staining was present on the cobbles (fig. A7.2). Iron-oxidizing microbial mats and iron-encrusted algae were intermittently present at this site. Subsurface temperatures ranged from 12.1°C to 13.8°C. The pH, DO, and ORP of the groundwater were less than those measured for the river; SC was higher in the groundwater than the river (table A7.1). Logged groundwater temperatures generally showed diel fluctuations of <0.5°C–5.4°C, with larger fluctuations when stage was lower (fig. 7.4).

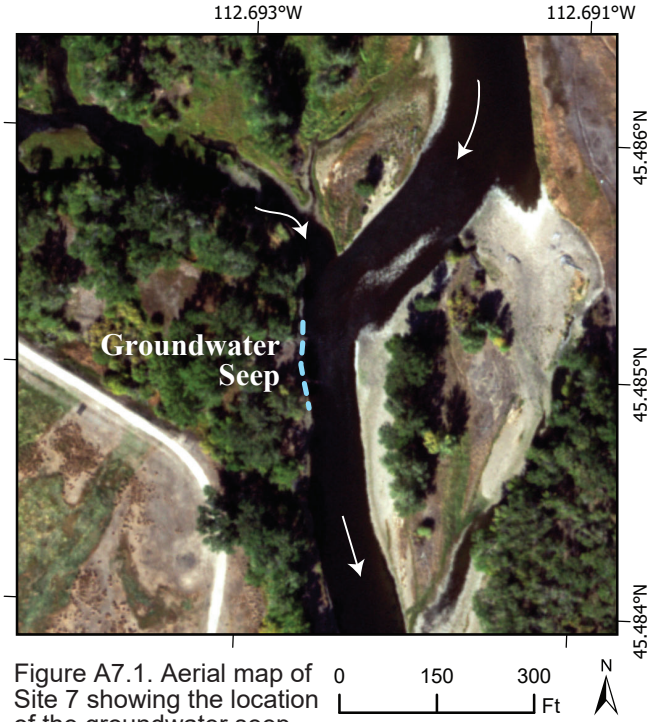


Figure A7.1. Aerial map of Site 7 showing the location of the groundwater seep (dashed blue line).

Table A7.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 2:18 PM	15.9	7.60	229.5	4.7	-39.7
River	8/22/2023 2:03 PM	18.3	8.78	188.7	8.5	188.7
Groundwater	9/12/2023 2:02 PM	16.4	8.21	225.3	8.5	-48.0
River	9/12/2023 1:11 PM	15.8	8.81	189.7	9.7	30.3
Groundwater	9/27/2023 1:34 PM	12.7	8.00	214.4	7.0	-63.8
River	9/27/2023 1:46 PM	12.4	8.75	187.0	9.5	9.8
Groundwater	10/18/2023 12:53 PM	9.6	7.79	215.2	6.4	-24.5
River	10/18/2023 12:46 PM	8.5	8.36	181.5	9.8	16.5
Groundwater	11/1/2023 1:38 PM	4.7	7.71	228.6	6.2	-31.8
River	11/1/2023 1:32 PM	1.1	8.10	187.1	12.3	36.8

Figure A7.2. Iron-stained cobbles (left). Iron-oxide deposition on algae, iron-oxidizing microbial mats, and biofilm were found at this site (right).

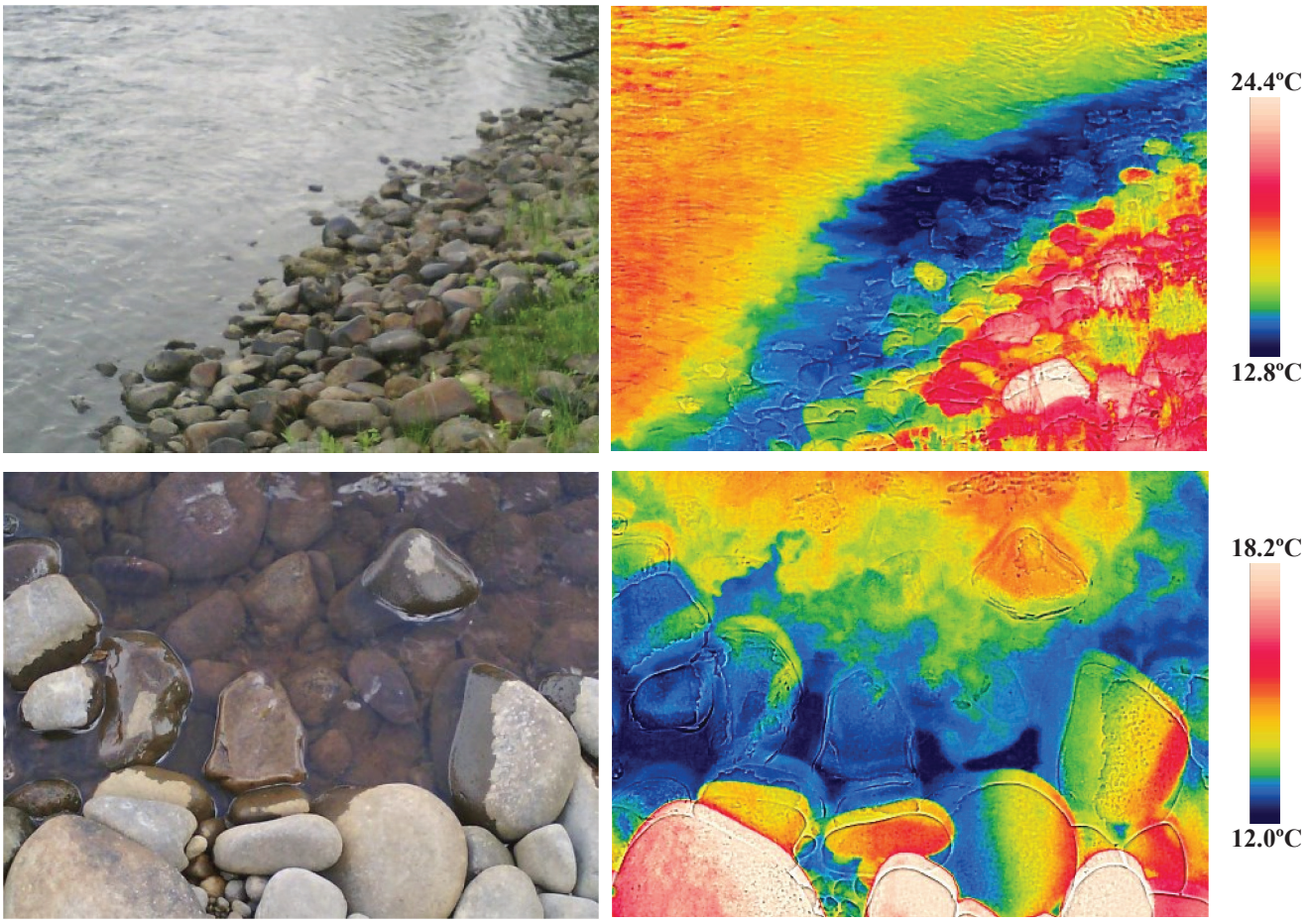


Figure A7.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep. Cool (blue, ~12ºC) groundwater was observed discharging 2-3 ft outward from the riverbank (top). A closeup of the groundwater discharging <1 ft outward from the riverbank (bottom).

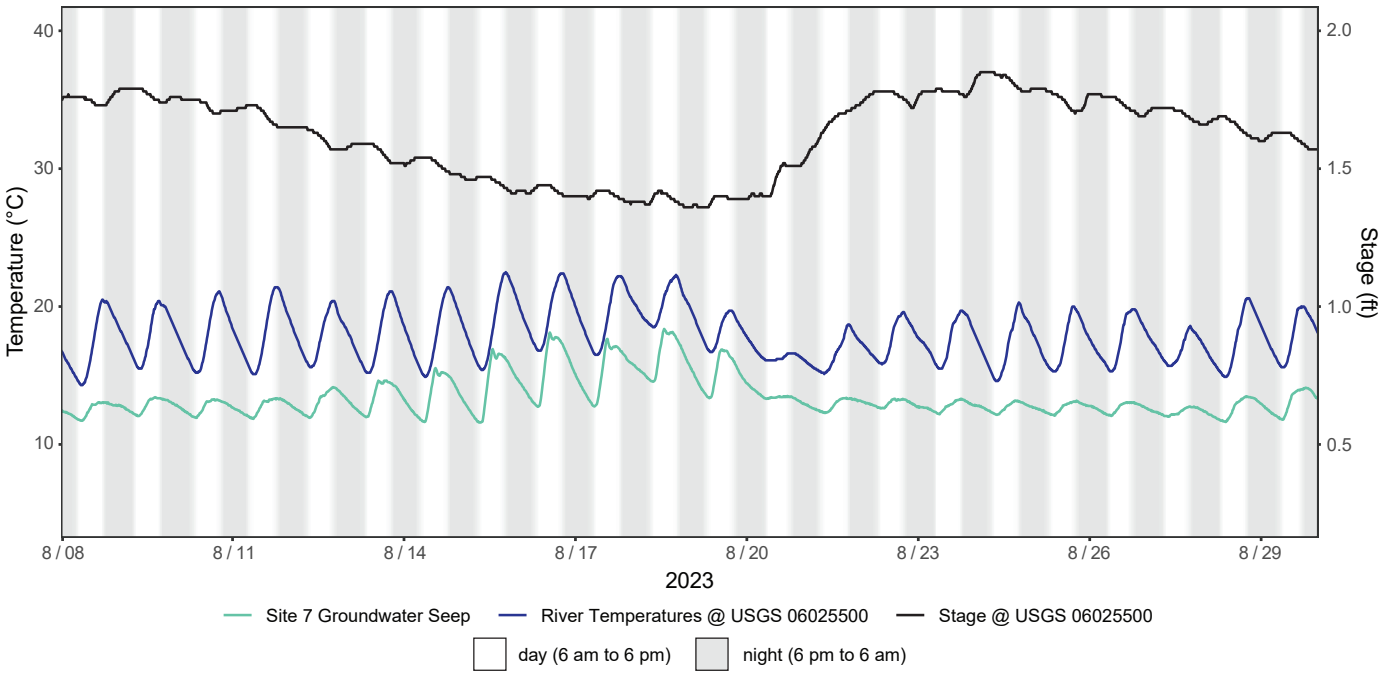


Figure A7.4. August 2023 logged temperatures at Site 7 groundwater seep (334292) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). Diel groundwater temperature fluctuations were greater when stage was lower suggesting less flow at the monitored location when stage decreased.

Site 8

GWIC #: 334293
Latitude/Longitude: 45.47731, -112.6836
Description: Site 8 had hyporheic water discharging for ~160 ft along the downgradient side of a gravel bar (fig. A8.1). The riverbank was consistently saturated and upwelling water was seen below the surface of the water (fig. A8.2). Depending on the temperature of the river in the afternoon, thermal infrared temperatures showed the hyporheic flow as slightly warmer or cooler than the river (fig. A8.3). The pH and DO of the hyporheic seep were lower than the river; SC and ORP of the hyporheic seep varied and could be higher or lower than the river (table A8.1). Algae was commonly present at the site (fig. A8.3). The logged hyporheic temperatures generally had minimal (<1.0°C) diel fluctuations and a temperature that averaged river temperature (fig. A8.4). Larger diel hyporheic temperature fluctuations were observed when river stage decreased (fig. A8.4).

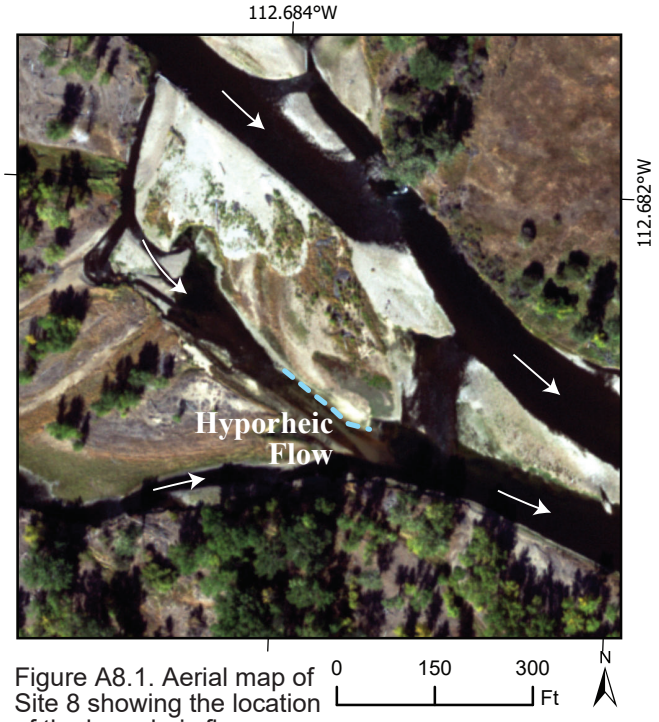


Figure A8.1. Aerial map of Site 8 showing the location of the hyporheic flow through the middle gravel bar (dashed blue line).

Table A8.1. YSI water quality parameters measured during site visits of the hyporheic flow compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Hyporheic	8/22/2023 2:42 PM	18.0	7.24	205.3	0.3	27.7
River	8/22/2023 2:50 PM	18.5	8.67	199.1	8.7	50.5
Hyporheic	9/12/2023 2:27 PM	17.8	7.43	193.7	1.4	12.9
River	9/12/2023 3:27 PM	17.3	8.84	199.6	8.9	45.7
Hyporheic	9/27/2023 2:01 PM	15.4	7.69	188.1	2.3	22.3
River	9/27/2023 2:14 PM	12.8	8.80	188.3	9.8	27.4
Hyporheic	10/18/2023 1:17 PM	11.8	7.66	130.6	2.8	40.1
River	10/18/2023 1:09 PM	8.6	8.61	174.0	10.1	24.8
Hyporheic	11/1/2023 1:56 PM	8.0	7.73	172.7	6.3	52.3
River	11/1/2023 2:09 PM	1.6	8.34	184.8	12.4	26.2

Figure A8.2. Saturated riverbank from hyporheic water (left). Often water was observed upwelling from the sand below the surface (right).

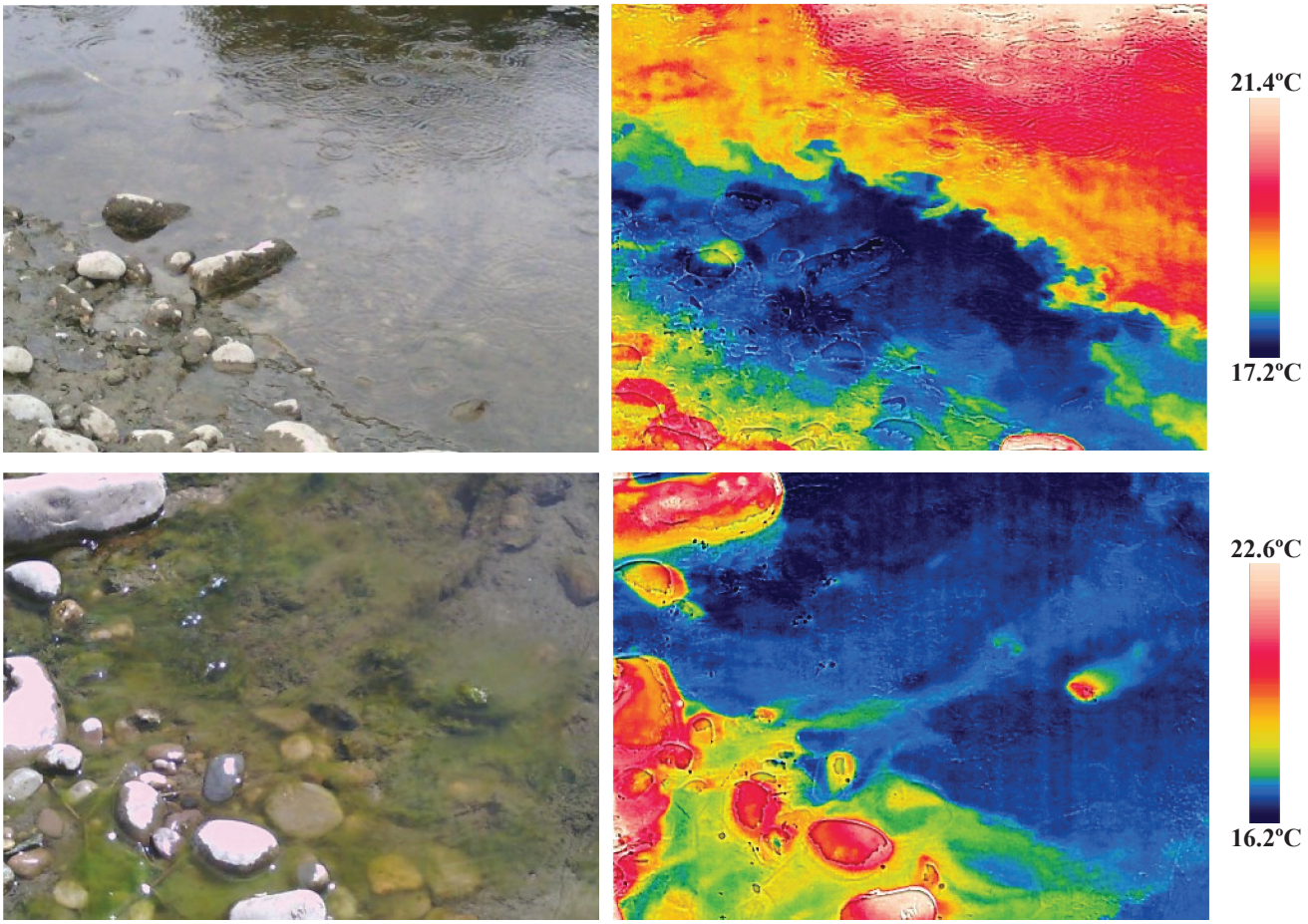


Figure A8.3. Visible light (left) and thermal infrared (right) photos of the hyporheic seep at Site 8. Depending on the river temperatures, the hyporheic water appeared cool (top; July 2024) or warm (bottom; August 2024) compared to the river temperatures. Algae was common near the hyporheic site during low flow (bottom left).

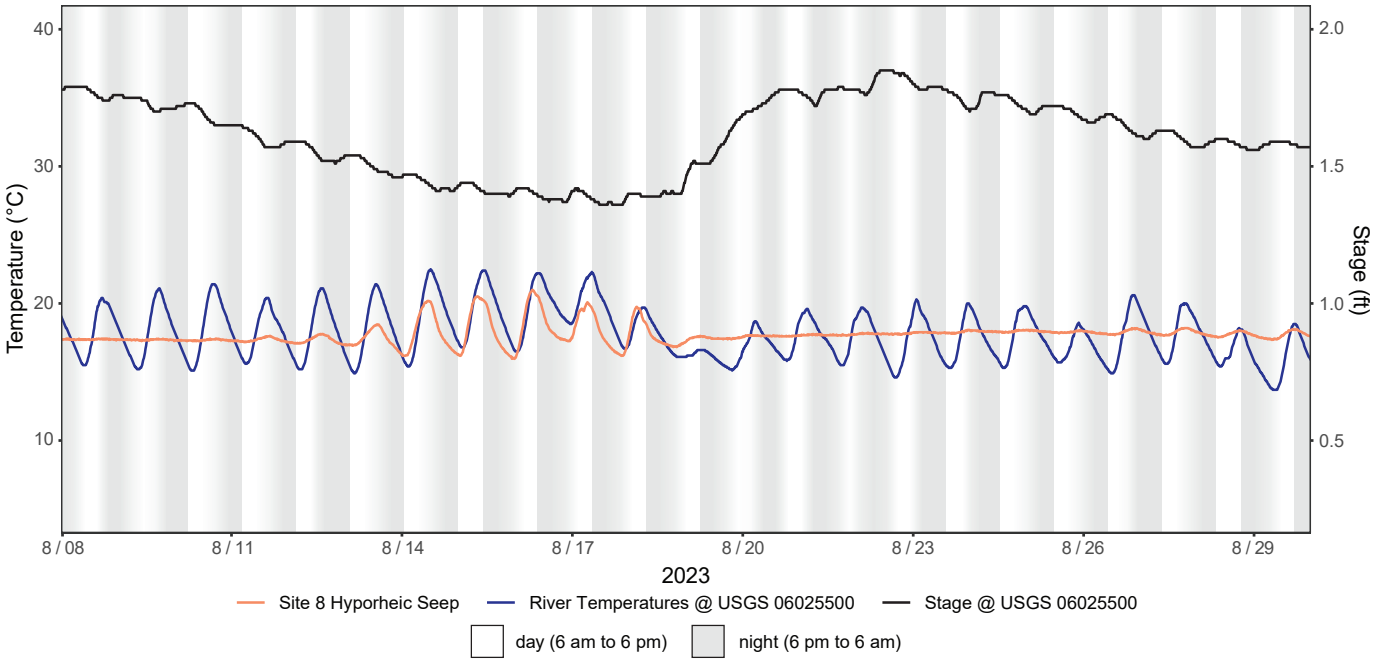


Figure A8.4. August 2023 logged temperatures at Site 8 hyporheic seep (334293) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The hyporheic temperatures were approximately the average of river temperatures. Diel hyporheic temperature fluctuations were greater when stage was lower.

Site 9

GWIC #: 334294
Latitude/Longitude: 45.47015, -112.67252
Description: Site 9 had groundwater discharging along a continuous section of a cobble riverbank for ~280 ft (fig. A9.1). The groundwater seep was visually recognized by the iron-stained cobbles and water flowing out from the cobbles (fig. A9.2). Cool thermal infrared temperatures were also observed along the entire riverbank (fig. A9.3). Subsurface temperatures ranged from 10.9°C to 12.1°C. The pH, SC, ORP, and DO of the groundwater were generally less than the river (table A9.1). Logged groundwater temperatures were around 12-15°C with diel temperature fluctuations <2°C (fig. A9.4); groundwater temperatures were cooler than the river temperatures in late summer and warmer than river temperatures in fall and winter (fig. A9.4).

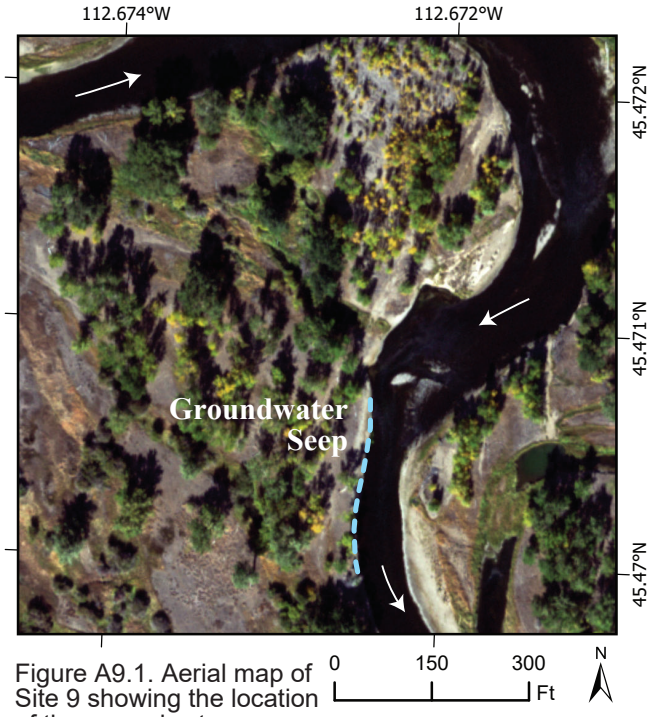


Figure A9.1. Aerial map of Site 9 showing the location of the groundwater seep (dashed blue line).

Table A9.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/22/2023 3:47 PM	16.1	7.25	177.0	3.2	15.9
River	8/22/2023 4:00 PM	19.0	8.81	196.9	8.0	76.2
Groundwater	9/12/2023 3:06 PM	14.9	7.11	186.3	1.2	4.7
River	9/12/2023 3:27 PM	17.3	8.84	199.6	8.9	45.7
Groundwater	9/27/2023 2:24 PM	14.1	7.34	186.7	1.2	-3.2
River	9/27/2023 2:14 PM	12.8	8.80	188.3	9.8	27.4
Groundwater	10/18/2023 1:59 PM	13.1	7.32	178.4	1.9	-3.3
River	10/18/2023 1:46 PM	9.1	8.68	174.6	10.1	41.8
Groundwater	11/1/2023 2:27 PM	8.2	7.67	179.2	5.0	41.4
River	11/1/2023 2:45 PM	1.8	8.37	182.5	12.6	43.2

Figure A9.2. Iron staining on the cobbles (left) and water flowing out from the riverbank cobbles (right). Algae and iron-encrusted microbial mats were commonly observed at this site.

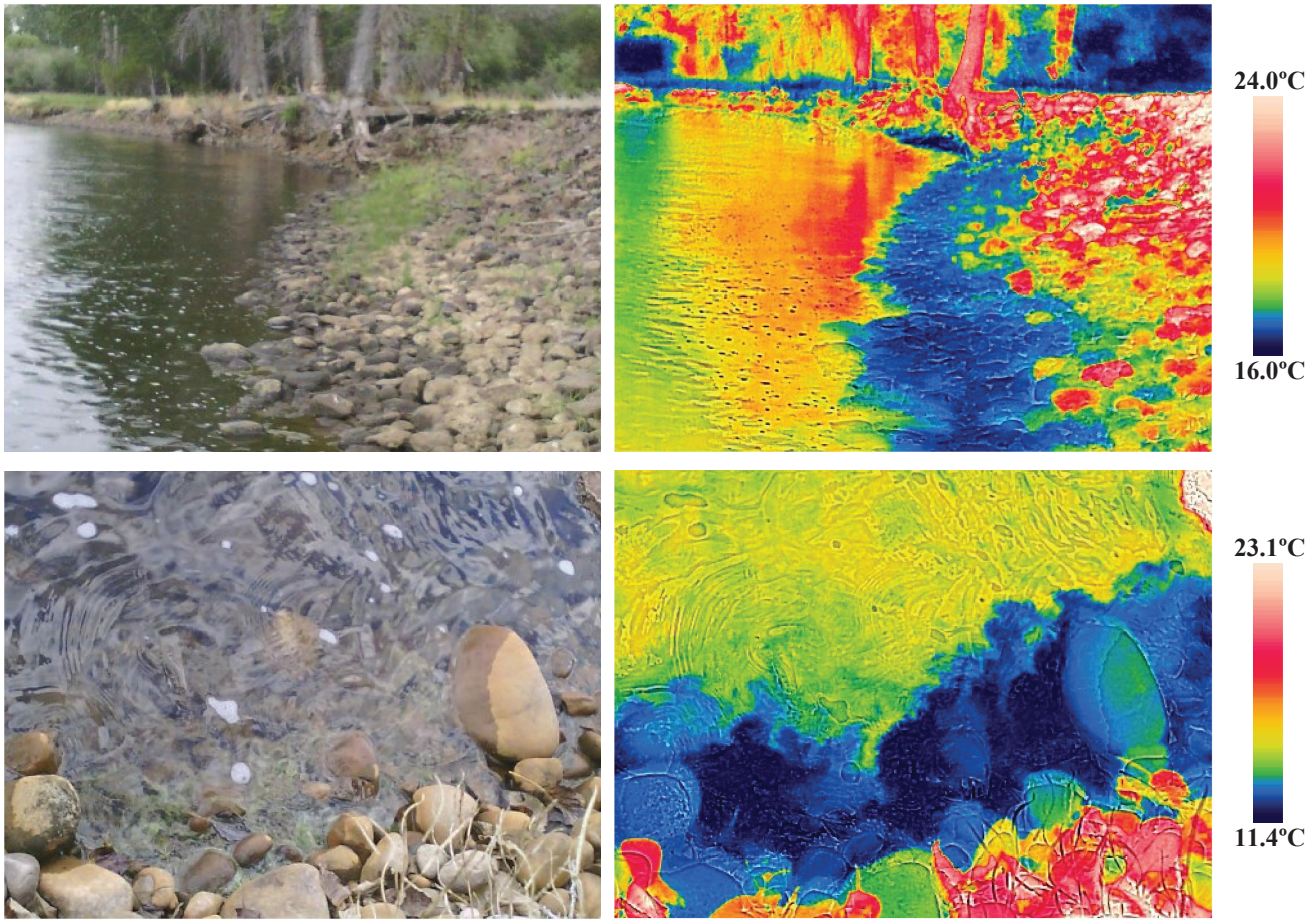


Figure A9.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 9. Cool (blue, ~11-16ºC) groundwater was observed discharging outward 2-4 ft from the cobble riverbank (top). A view from above the site showed the groundwater mixing with the river (bottom).

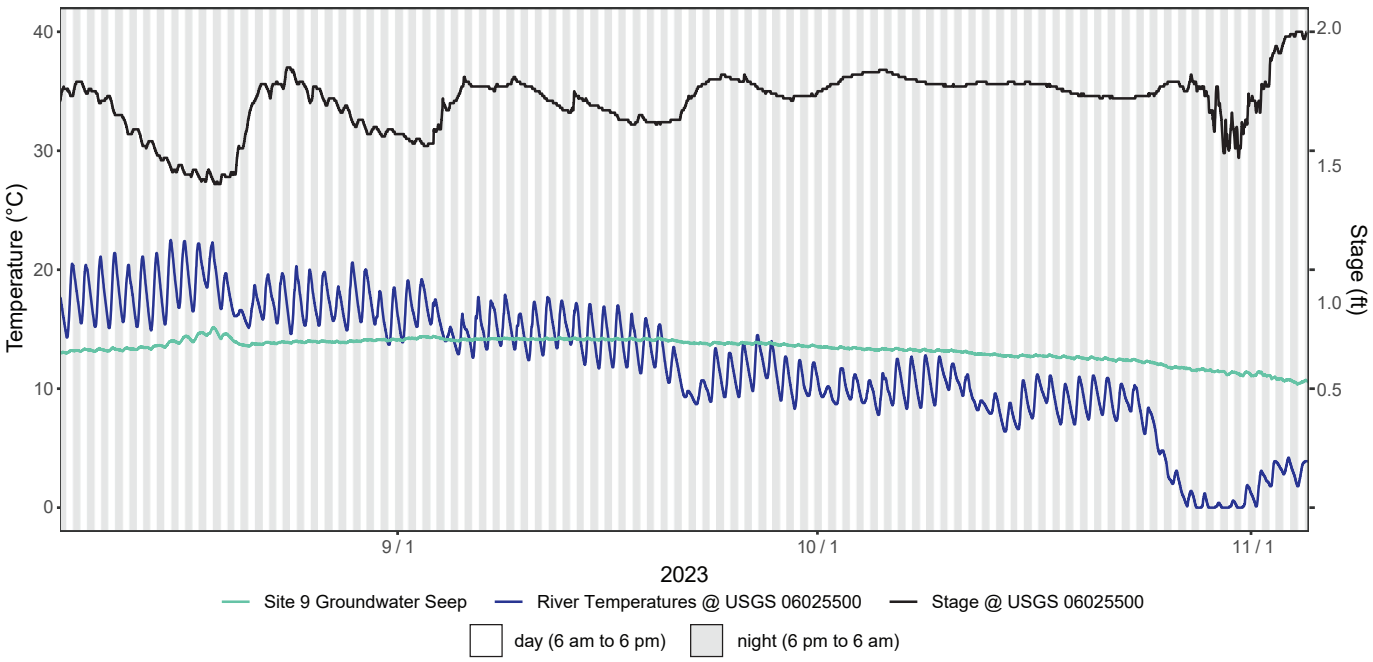


Figure A9.4. August-November 2023 logged temperatures at Site 9 groundwater seep (334294) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). Groundwater temperatures were consistent at around 13-15°C; groundwater temperatures were cooler than the river during August and early September and warmer than the river in late September through November.

Site 10

GWIC #: 334295
Latitude/Longitude: 45.466082, -112.664482
Description: Site 10 had groundwater discharging in a ponded backwater (fig. A10.1). The <2 ft deep backwater varies in depth with stage; it commonly became stagnant and disconnected from the river during summer. Subsurface temperatures were as cold as 11.9°C. The pH, DO, and ORP of the groundwater seep were generally less than those measured for the river; SC was higher in the groundwater than the river (table A10.1). Iron-oxide staining/deposition and iron-oxide microbial mats were common throughout the backwater (fig. A10.2). Subsurface groundwater temperatures were often cool, but the groundwater would become ponded at the surface and appeared warm in thermal infrared photos (fig. A10.3). The logged groundwater temperatures were around 14.5°C with ~2°C diel fluctuations (fig. A10.4).

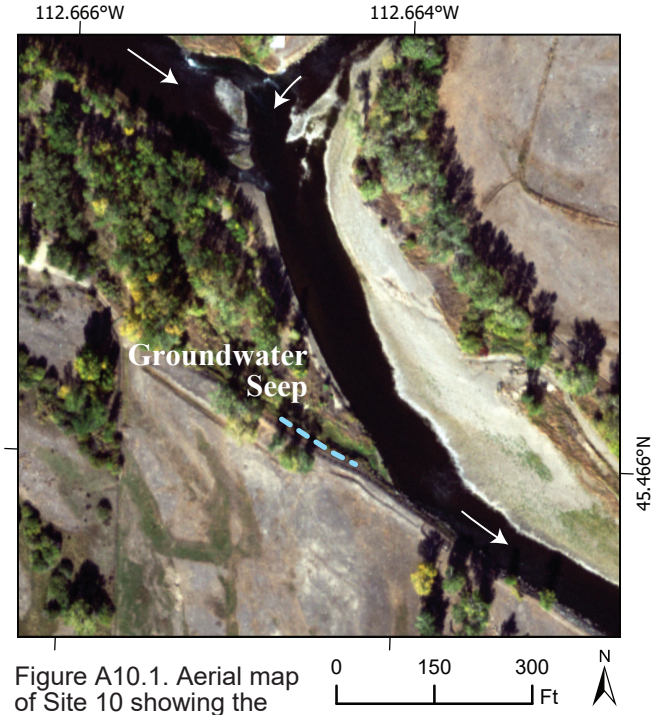


Figure A10.1. Aerial map of Site 10 showing the location of the groundwater seep (dashed blue line).

Table A10.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 10:36 AM	17.0	6.83	293.5	3.2	25.2
River	8/23/2023 10:13 AM	16.6	8.22	195.9	8.2	187.3
Groundwater	9/13/2023 9:09 AM	11.2	6.94	293.3	1.5	-30.1
River	9/13/2023 9:24 AM	14.4	8.17	203.9	7.9	34.2
Groundwater	9/28/2023 9:39 AM	9.2	7.04	296.6	1.1	-16.1
River	9/28/2023 9:24 AM	9.6	8.22	190.9	9.5	159.6
Groundwater	10/19/2023 9:26 AM	5.4	7.02	294.6	1.9	58.4
River	10/19/2023 9:42 AM	7.3	8.18	177.4	9.8	28.7
Groundwater	11/2/2023 10:18 AM	4.7	7.08	270.0	1.4	-8.8
River	11/2/2023 10:33 AM	2.6	8.14	175.4	11.7	49.0

Figure A10.2. Iron-oxidizing microbial mats were commonly observed in the backwater with groundwater seeping into it (left). Early in the spring, the grasses were stained red from the iron oxides (right).

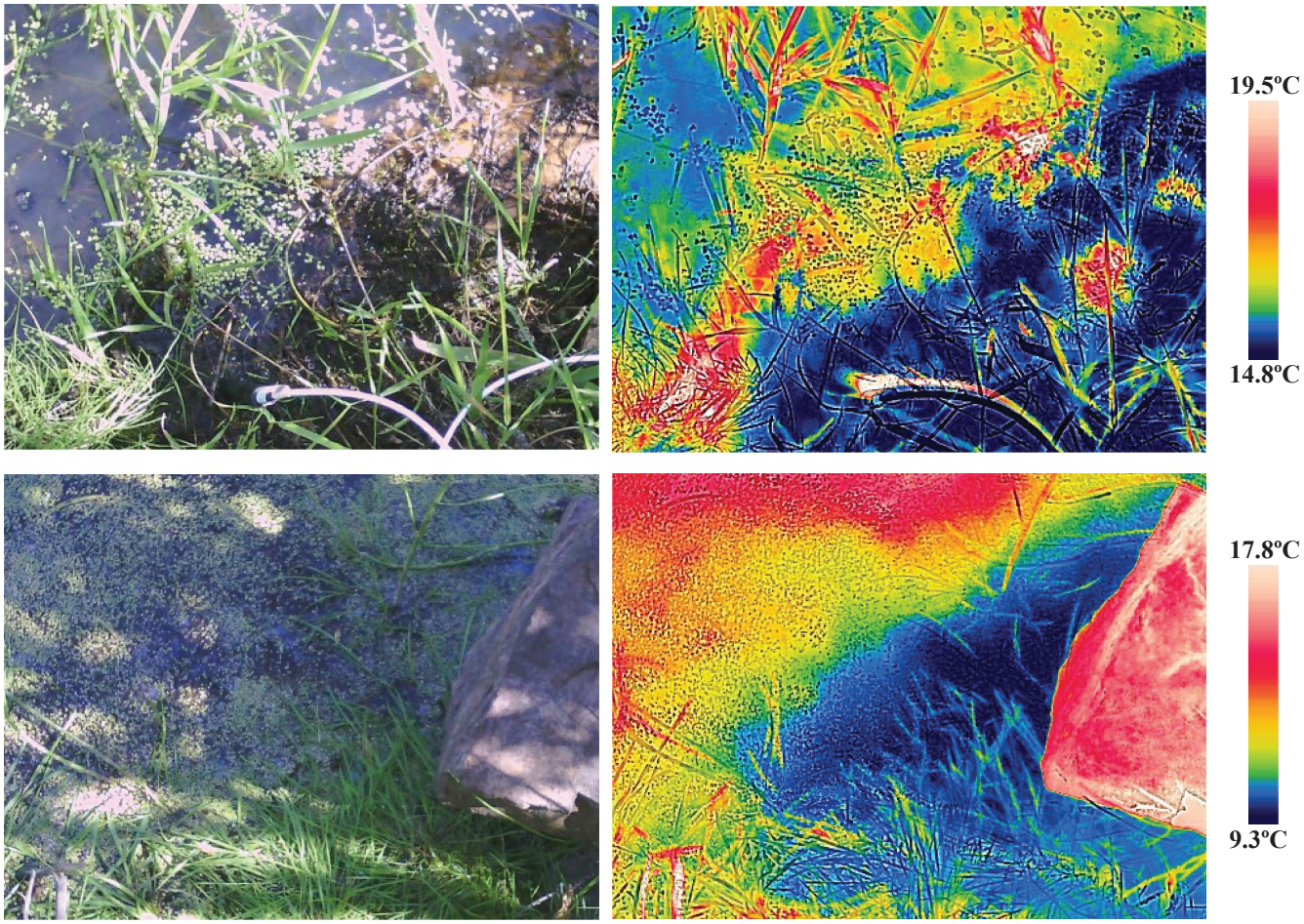


Figure A10.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 10. Thermal contrast was only seen at the edges of the ponded water because the ponded water often became warm during the day.

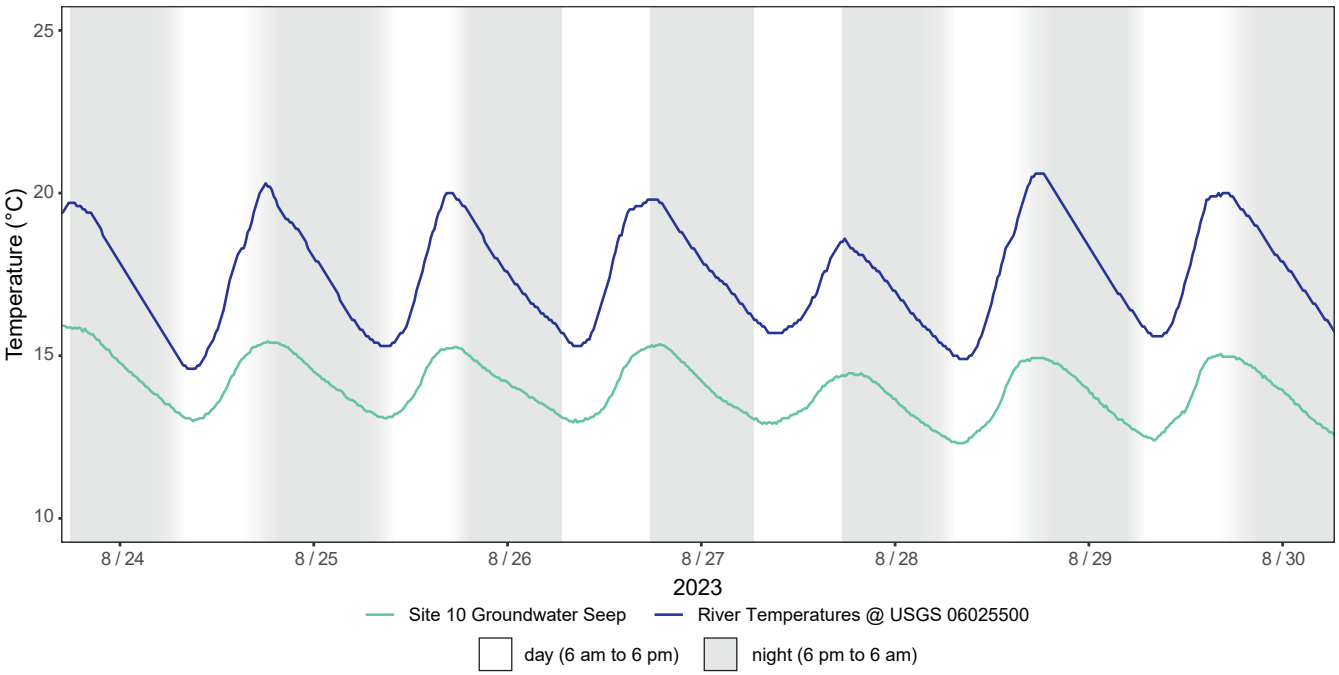


Figure A10.4. August 2023 logged temperatures at Site 10 groundwater seep (334295) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The groundwater temperatures were cooler than river temperatures. Diel groundwater fluctuations were ~2°C.

Site 11

GWIC #: 334296
Latitude/Longitude: 45.46175, -112.65985
Description: Site 11 had discrete areas of groundwater discharging for ~200 ft along a small river chute that was cross-cutting a point bar (fig. A11.1). Groundwater discharge was observed where iron-oxide depositions/iron-oxidizing microbial mats (fig. A11.2) and cooler thermal infrared temperatures (~14°C) occurred (fig. A11.3). Subsurface temperatures ranged from 10.2°C to 14.3°C. The pH, DO, and ORP of the groundwater seep were less than those measured for the river; groundwater SC could be higher or lower than the river (table A11.1). The logged groundwater temperatures were steady with minimal to no diel variation in Summer 2023; the diel groundwater temperatures varied in Summer 2024 up to 1.5°C (fig. A11.4).

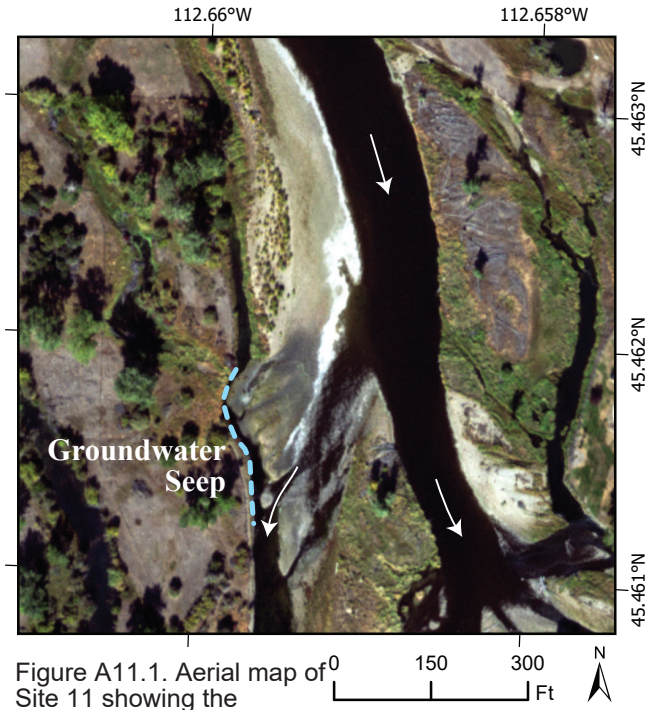


Figure A11.1. Aerial map of Site 11 showing the location of the groundwater seep (dashed blue line).

Table A11.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 11:02 AM	14.7	7.00	159.8	0.1	41.6
River	8/23/2023 10:47 AM	17.8	8.39	195.1	8.9	135.4
Groundwater	9/13/2023 9:33 AM	13.5	6.97	186.8	0.6	-45.1
River	9/13/2023 9:24 AM	14.4	8.17	203.9	7.9	34.2
Groundwater	9/28/2023 10:04 AM	12.9	7.05	197.2	0.2	-78.7
River	9/28/2023 9:54 AM	10.0	8.36	190.0	9.9	34.7
Groundwater	10/19/2023 9:52 AM	11.5	7.02	199.3	0.3	-65.2
River	10/19/2023 9:42 AM	7.3	8.18	177.4	9.8	28.7
Groundwater	11/2/2023 10:45 AM	10.3	7.03	207.1	0.6	-68.4
River	11/2/2023 10:33 AM	2.6	8.14	175.4	11.7	49.0

Figure A11.2. Discrete areas of groundwater seeping can be seen visually by the iron-oxide deposition and iron-oxidizing microbial mats.

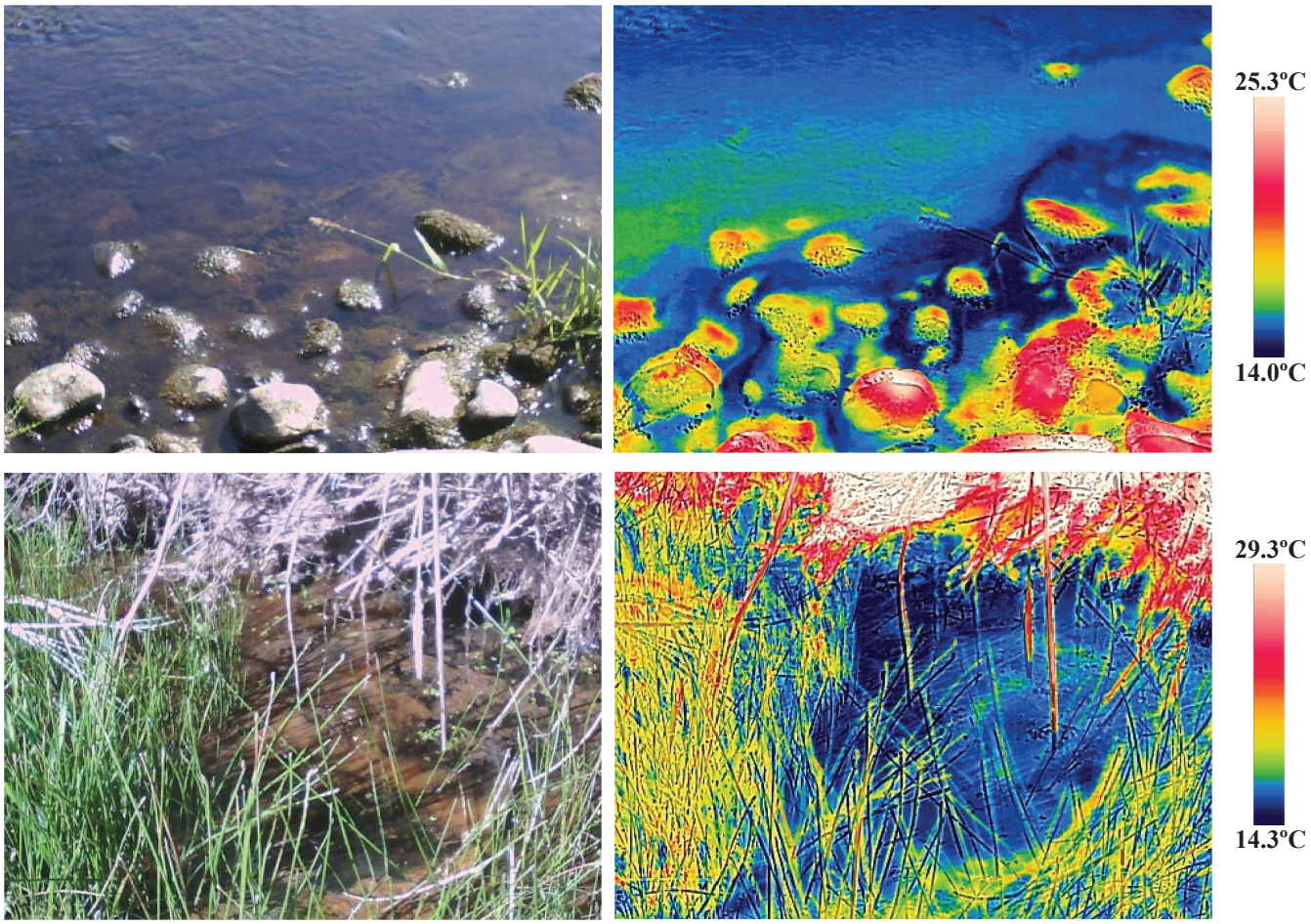


Figure A11.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 11. Cool (blue, ~14ºC) groundwater was observed discharging between partially submerged rocks (top) and vegetation (bottom). Iron-oxide deposition/iron-oxidizing microbial mats were observed in between the vegetation in the bottom left photo.

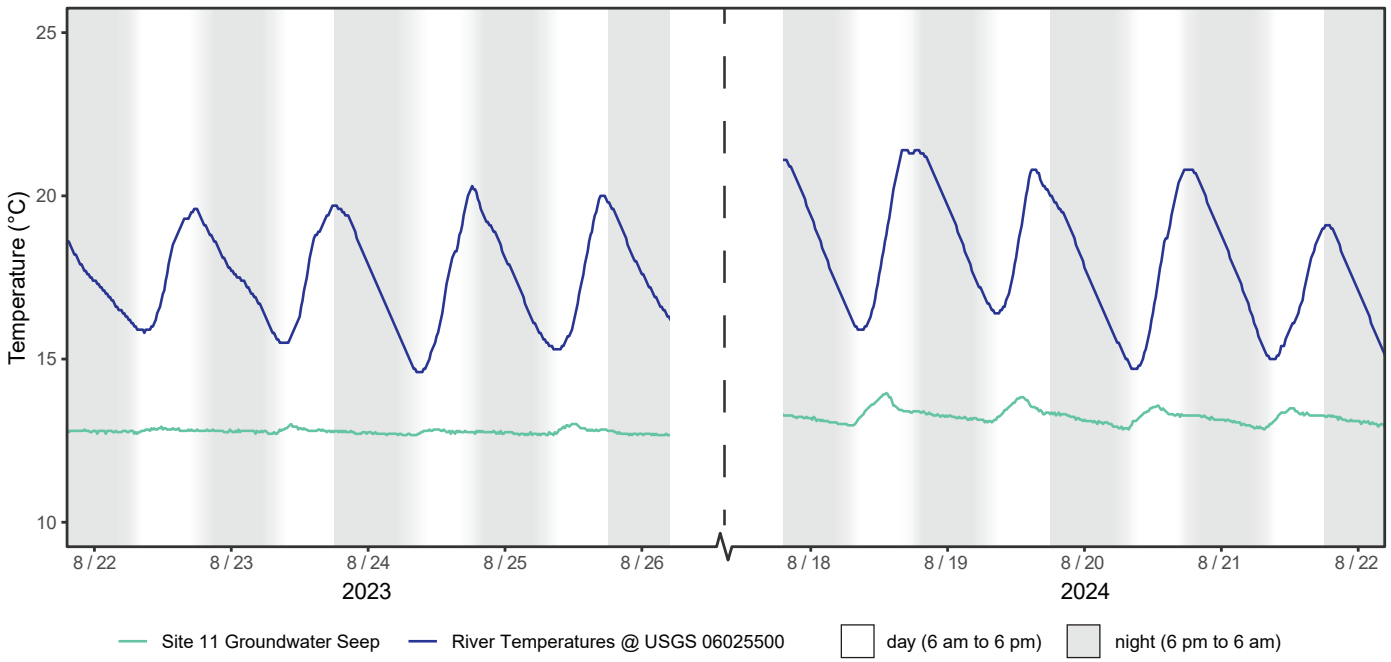


Figure A11.4. Comparison of August 2023 and 2024 logged temperatures at Site 11 groundwater seep (334296) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The groundwater seep temperatures remained steady around 13ºC; diel fluctuations were smaller in 2023.

Site 12

GWIC #: 334297
Latitude/Longitude: 45.45863, -112.65943
Description: Site 12 had groundwater discharging from inside a point bar meander for ~160 ft (fig. A12.1). The groundwater was discharging into a ponded area that was also mixing with warmer hyporheic water. Water quality parameters (pH, SC, DO, and ORP) were generally less than those measured for the river (table A12.1). Deposition of iron-oxides was commonly seen in depressions and ponded water (fig. A12.3). Subsurface temperatures ranged from 9.8°C to 11.7°C. The ponded water often warmed more than the river, while the groundwater discharging from the edges had cooler thermal infrared temperatures than the ponded water (fig. A12.3). The logged groundwater temperatures were around 11°C with greater diel fluctuations when river stage was higher (fig. A12.4), which was opposite of most other sites.

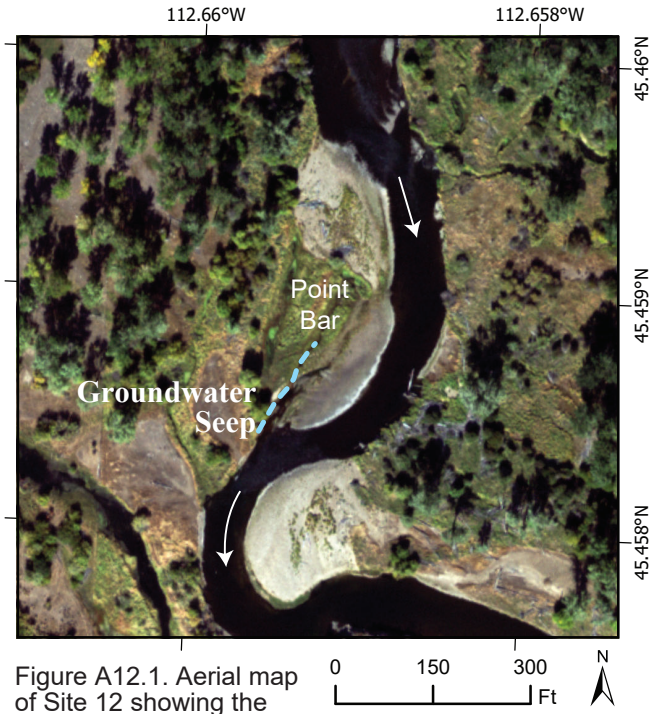


Figure A12.1. Aerial map of Site 12 showing the location of the groundwater seep (dashed blue line).

Table A12.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 11:23 AM	19.4	7.27	185.2	4.0	-22.8
River	8/23/2023 11:17 AM	17.5	8.40	194.6	8.6	96.7
Groundwater	9/13/2023 9:59 AM	14.0	7.48	181.3	2.6	-52.5
River	9/13/2023 9:24 AM	14.4	8.17	203.9	7.9	34.2
Groundwater	9/28/2023 10:24 AM	11.8	7.29	173.8	2.3	-87.5
River	9/28/2023 9:54 AM	10.0	8.36	190.0	9.9	34.7
Groundwater	10/19/2023 10:26 AM	10.5	6.87	184.4	2.4	-80.1
River	10/19/2023 10:11 AM	7.4	8.21	168.2	9.6	17.0
Groundwater	11/2/2023 11:01 AM	8.5	7.42	177.4	3.8	-17.1
River	11/2/2023 10:33 AM	2.6	8.14	175.4	11.7	49.0

Figure A12.2. Ponded groundwater seep at Site 12 (left). Iron-oxide deposition was common at this site filling depressions (right) and the bottom of the ponded water.

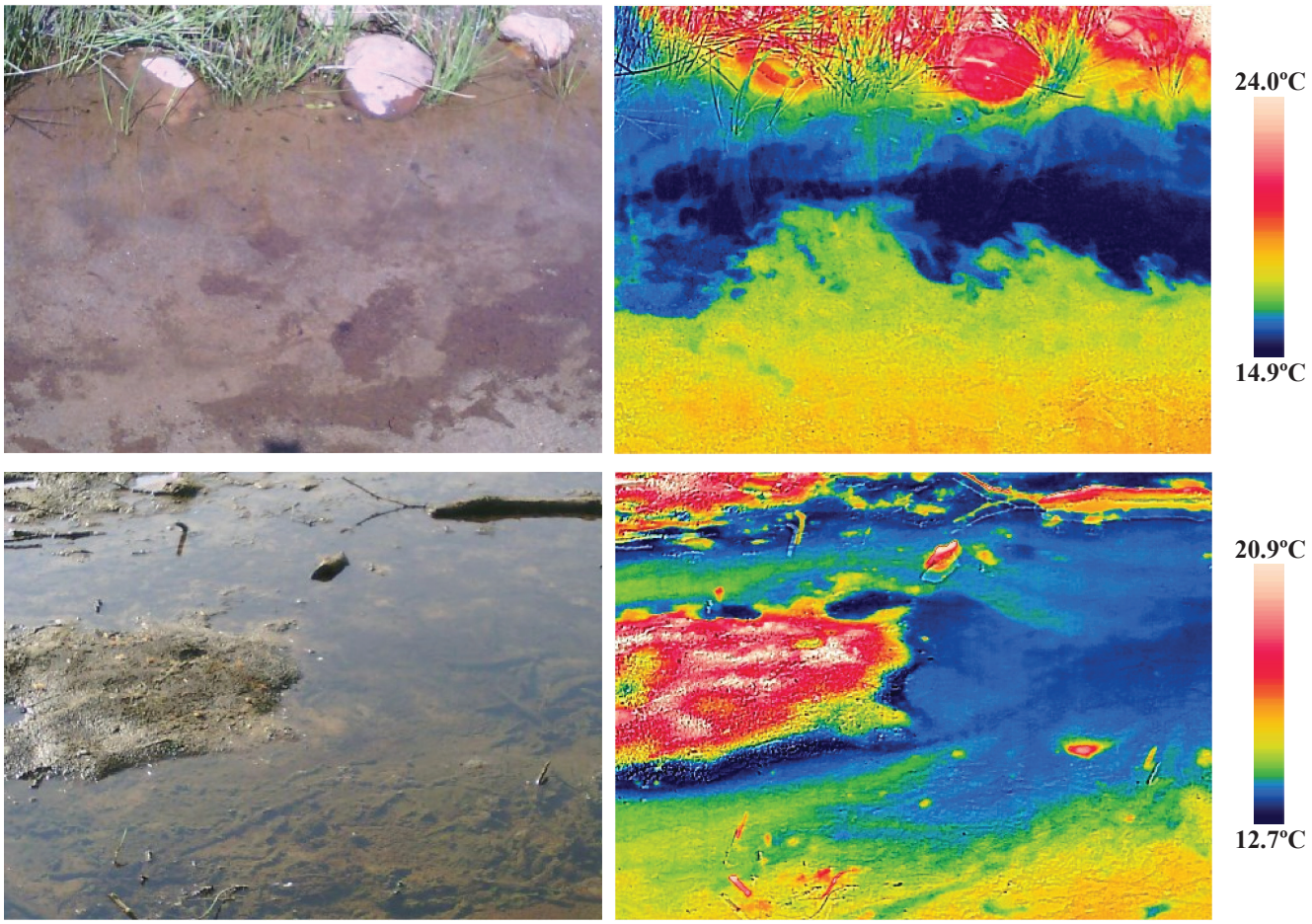


Figure A12.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 12. Cool (blue, ~12-14ºC) groundwater was observed discharging from the edge of the riverbank (top) and from raised sandy mounds (bottom). Iron oxides were deposited on top of the sand in the top left photo.

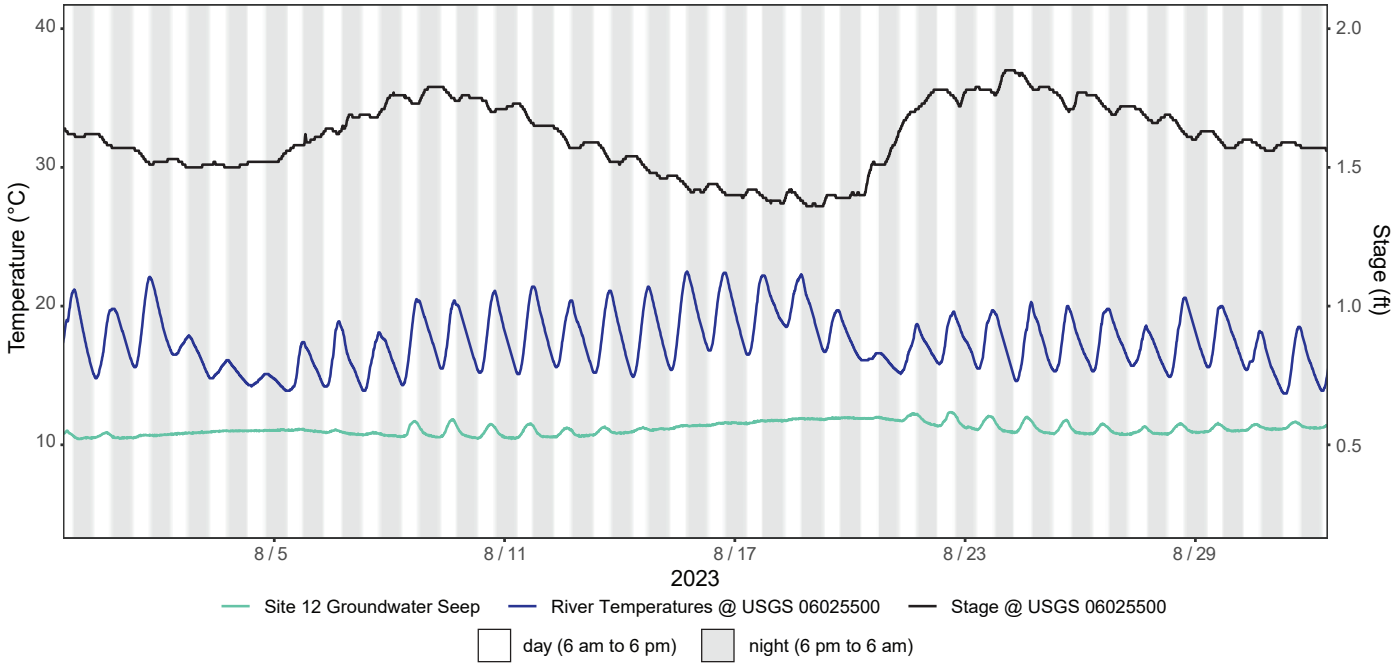


Figure A12.4. August 2023 logged temperatures at Site 12 groundwater seep (334297) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The groundwater seep showed greater diel fluctuations when the stage was higher (and likely the ponded area was also higher).

Site 13

GWIC #: 334298
Latitude/Longitude: 45.45817, -112.64769
Description: Site 13 had groundwater discharging for ~180 ft along a cobble riverbank (fig. A13.1). This site was found in Summer 2024 but not during Summer 2023, possibly due to lower stage levels during 2024. Visible flow was observed between cobbles of the saturated riverbank. Subsurface temperatures ranged from 12.9°C to 13.1°C. Algae was present along the groundwater seep (fig. A13.2). Thermal infrared temperatures of the groundwater appeared cooler than the river (fig. A13.3); however, the thermal infrared showed the algae was often warmer than the river and caused the area to appear warmer on the surface (fig. A13.3). Logged groundwater temperatures were cooler than the river during July and August but similar to river temperatures in September (fig. A13.4). The diel groundwater temperature fluctuations appeared to increase throughout the summer and did not appear to be related to changes in river stage (fig. A13.4).

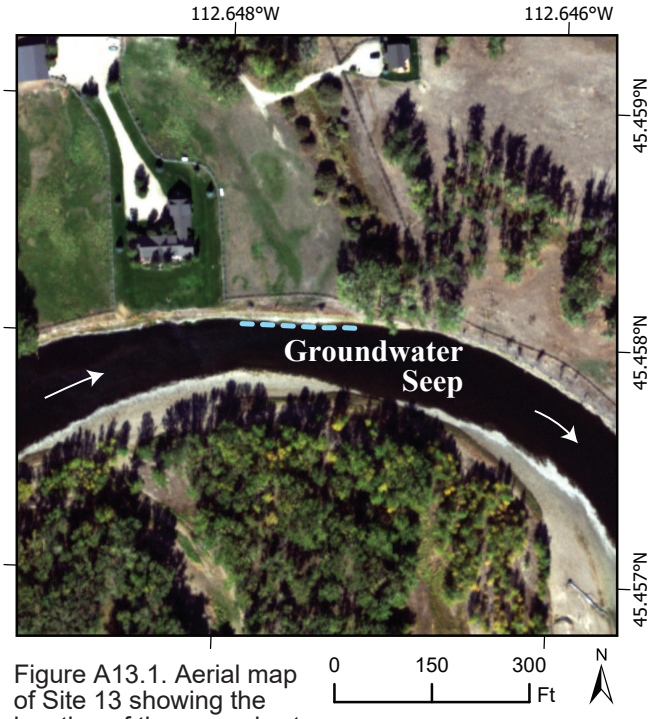


Figure A13.1. Aerial map of Site 13 showing the location of the groundwater seep (dashed blue line).

Water quality parameters are not available for this site because they were not measured in 2024 when this site was found.

Figure A13.2. Visible signs of the groundwater seep at Site 13 included algae growth along the edge and a saturated riverbank above the river elevation.

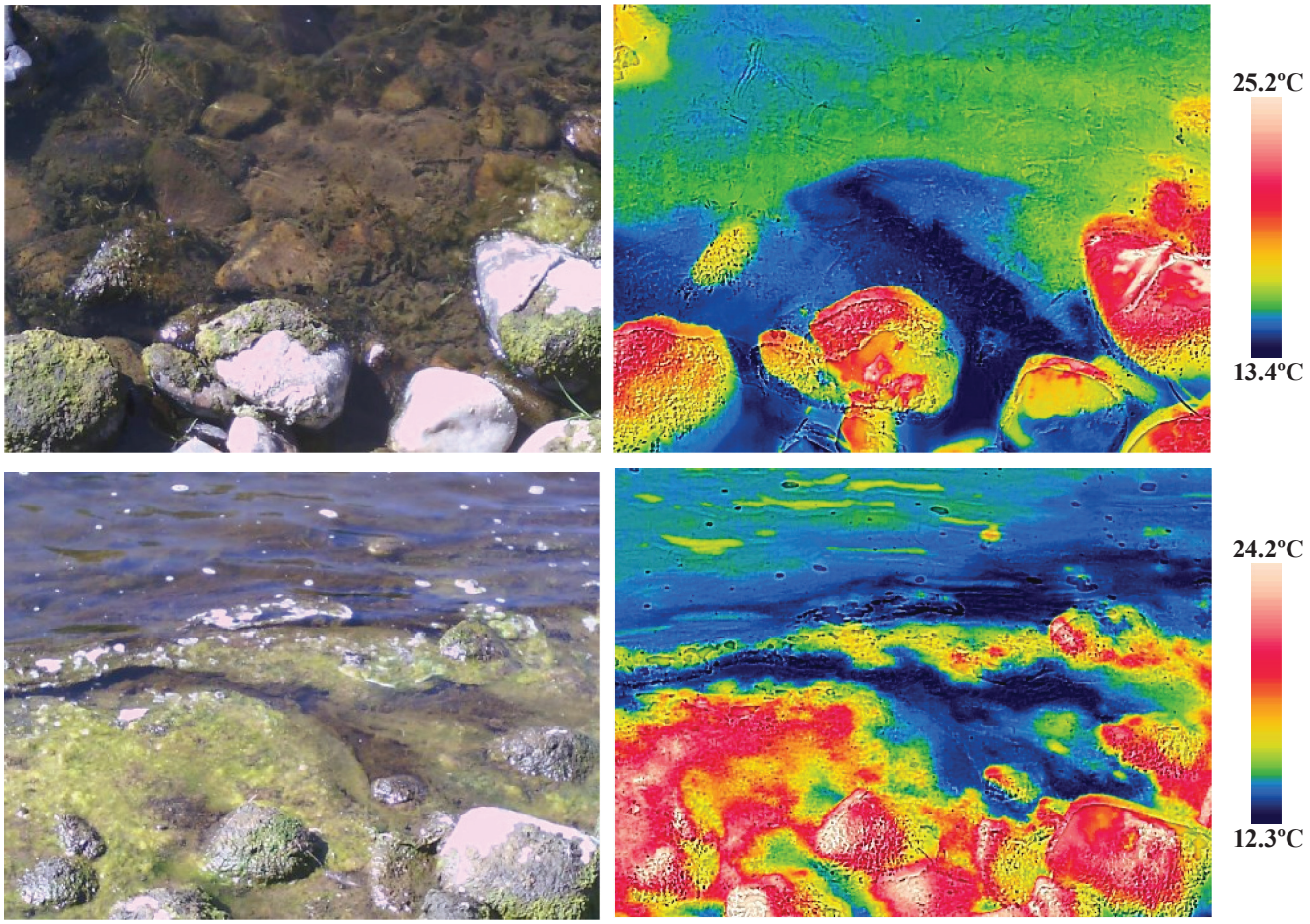


Figure A13.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 13. Cool (blue, ~12-13ºC) groundwater was observed discharging outward from the riverbank (top). Algae around the groundwater seep was warmer than the river and masked some of the cool groundwater discharging (bottom).

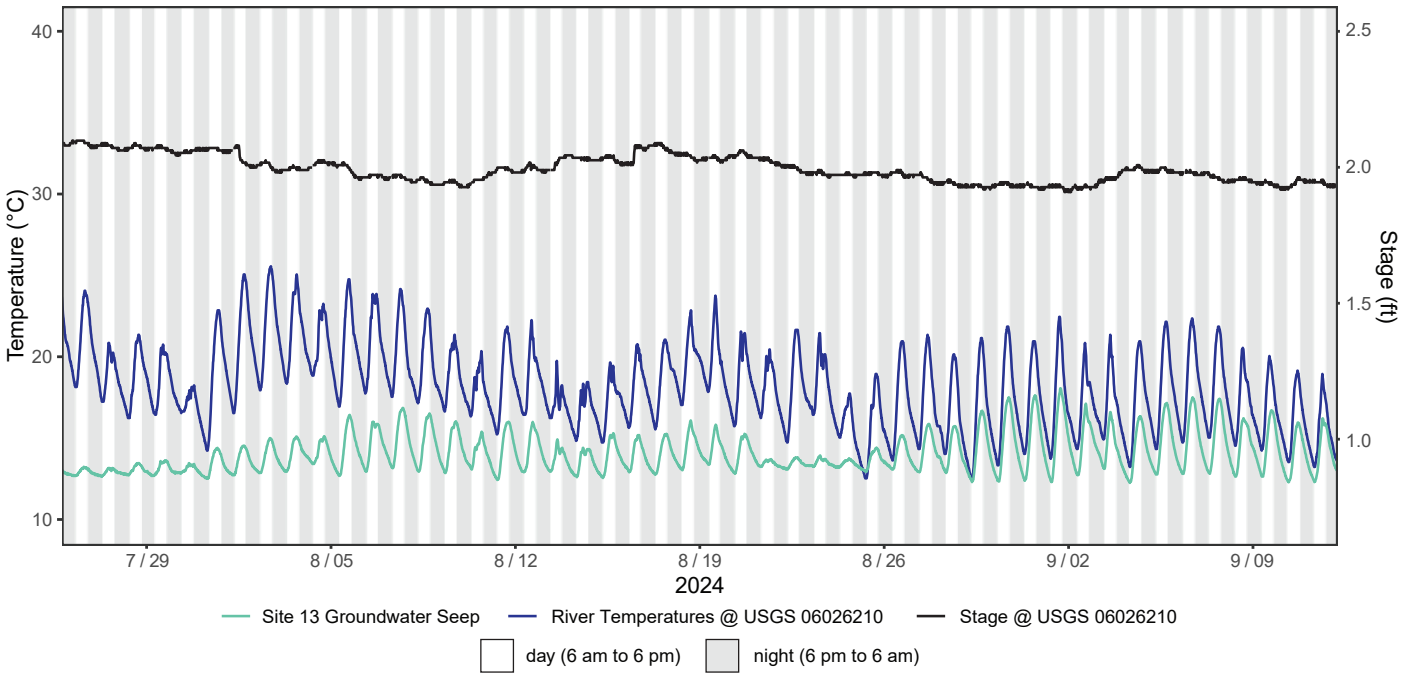


Figure A13.4. July–September 2024 logged temperatures at Site 13 groundwater seep (334298) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). Diel groundwater temperature fluctuations generally increased throughout the summer.

Site 14

GWIC #: 334299
Latitude/Longitude: 45.45458, -112.64386
Description: Site 14 has groundwater and/or hyporheic water discharging for ~650 ft along a cobble riverbank (fig. A14.1). The pH, DO, and ORP of the seep were less than those measured for the river; SC was generally similar to the river (table A14.1). Iron staining was observed on the cobbles; biofilm was common between cobbles (fig. A14.2). Flow outward from the riverbank was difficult to see with the thermal infrared camera because it was very slow and generally appeared slightly warmer than the river (fig. A14.3). The logged temperatures of the seep were warmer compared to the river (fig. A14.4) indicating that flow may have been small enough that it was conductively heated before reaching the surface. During October, the seeping water was slightly warmer than the river (fig. A14.4).

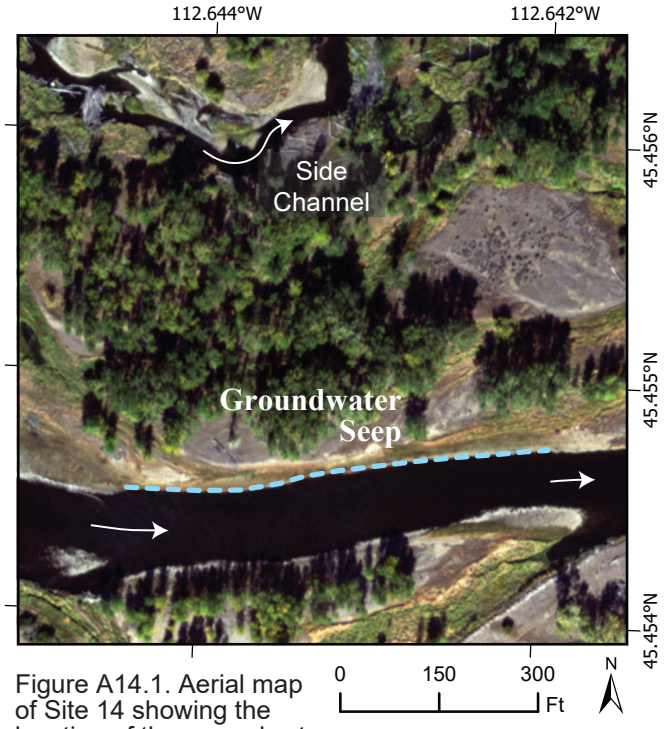


Figure A14.1. Aerial map of Site 14 showing the location of the groundwater seep (dashed blue line).

Table A14.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 1:38 PM	21.6	7.03	164.3	1.3	-39.4
River	8/23/2023 12:09 PM	17.8	8.49	209.3	8.9	112.4
Groundwater	9/13/2023 10:49 AM	14.8	7.90	203.6	7.8	-44.7
River	9/13/2023 11:00 AM	14.5	8.42	208.3	8.9	12.6
Groundwater	9/28/2023 11:30 AM	13.1	7.82	189.9	7.9	-11.1
River	9/28/2023 11:13 AM	10.5	8.54	193.6	10.4	19.4
Groundwater	10/19/2023 11:54 AM	11.9	7.44	180.0	6.7	-2.1
River	10/19/2023 11:19 AM	8.1	8.37	180.7	10.4	13.0
Groundwater	11/2/2023 11:56 AM	4.9	7.89	177.5	10.3	-2.1
River	11/2/2023 12:12 PM	3.2	8.29	177.7	11.8	26.6

Figure A14.2. Iron-stained riverbank (left) and the biofilm between the cobbles (right).

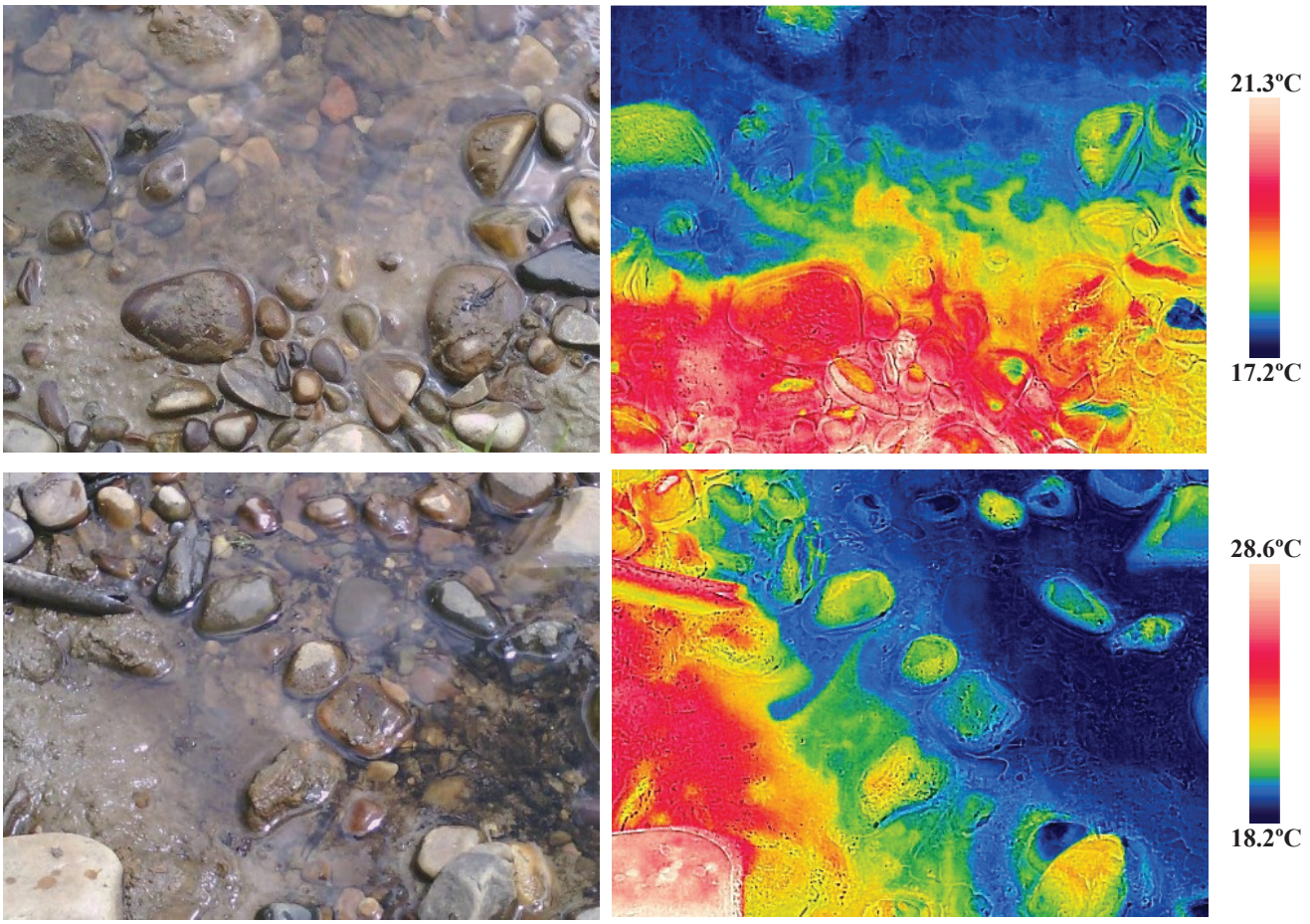


Figure A14.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 14. The seep was often warmer (yellow, ~18-22ºC) than the river.

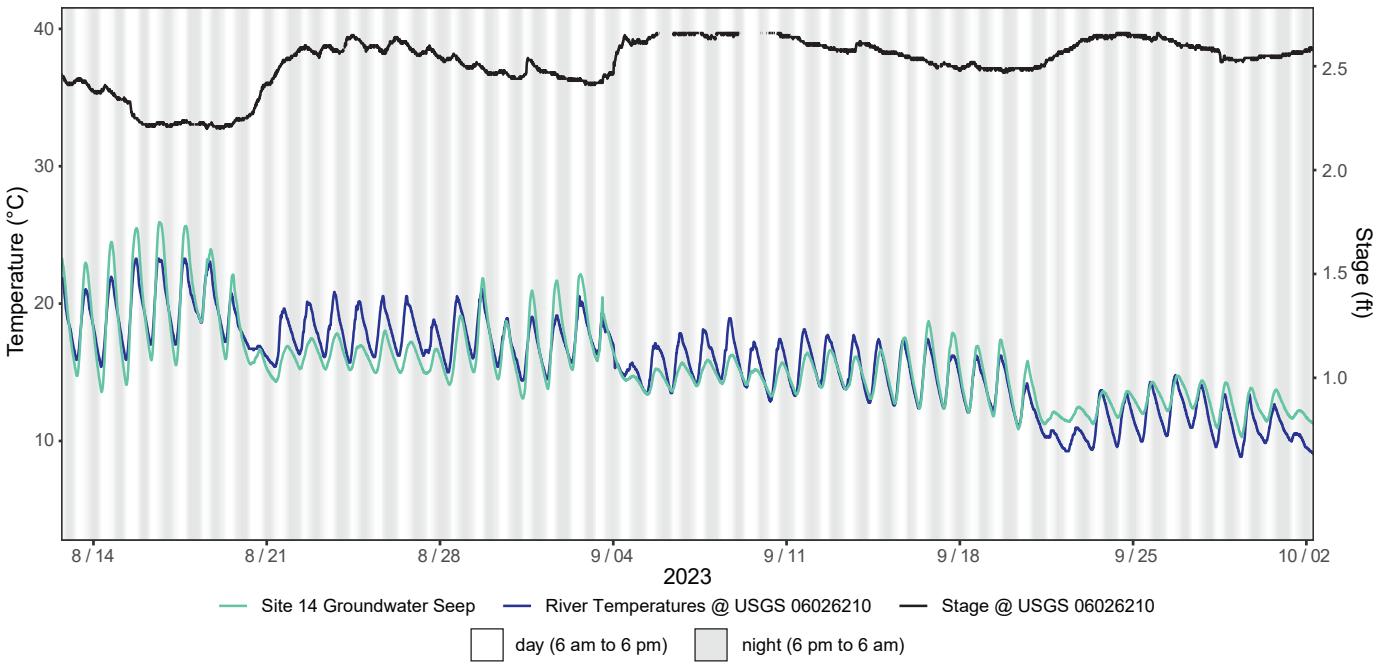


Figure A14.4. August–October 2023 logged temperatures at Site 14 groundwater seep (334299) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). The small amount of groundwater flow coming from the site was cooler within the saturated riverbank before entering the river during late August. Groundwater temperatures were slightly warmer than the river during late September.

Site 15

GWIC #: 334300
Latitude/Longitude: 45.44057, -112.62935
Description: Site 15 had groundwater discharging for ~200 ft along a cobble riverbank. The groundwater flow to the side channel was shallow, slow, and not shaded (fig. A15.1). The pH, DO, and ORP of the groundwater were generally less than those measured for the river; groundwater SC was within 5% of river SC (table A15.1). Iron-oxide deposition was observed between the cobbles (fig. A15.2). Both the side channel and the groundwater at the surface were slightly warmer than the main river channel. However, the points of groundwater discharge did appear cooler compared to the surrounding surface-water and cobbles using thermal infrared (fig. A15.3). Subsurface temperatures were as cool as 12.3°C. The logged diel groundwater temperature fluctuations were inconsistent (fig. A15.4) which may suggest the volume of flow from this groundwater seep varied over time (fig. A15.4).

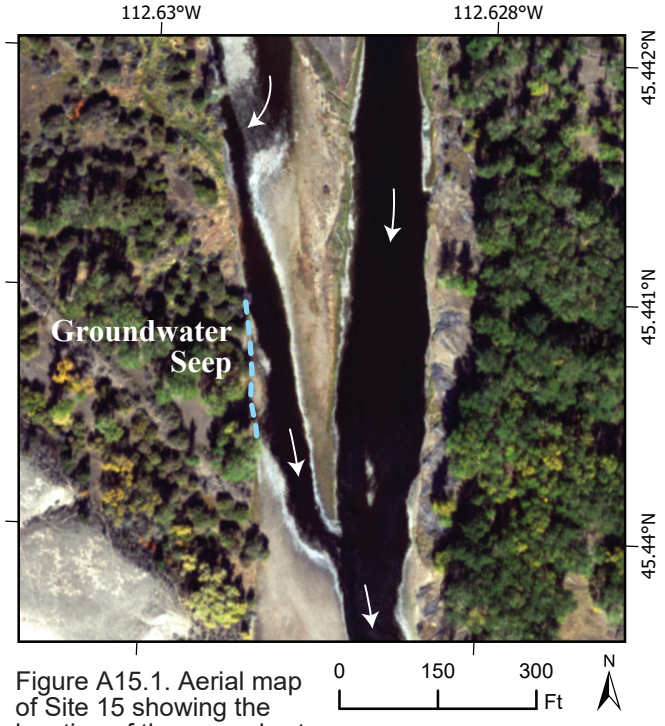


Figure A15.1. Aerial map of Site 15 showing the location of the groundwater seep (dashed blue line).

Table A15.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 3:27 PM	22.7	8.37	207.5	7.2	64.3
River	8/23/2023 3:27 PM	20.2	8.87	198.5	9.7	57.4
Groundwater	9/13/2023 12:06 PM	14.9	8.04	213.8	7.9	-38.5
River	9/13/2023 12:39 PM	14.8	8.55	210.5	9.0	25.6
Groundwater	9/28/2023 12:42 PM	14.2	8.08	201.7	9.2	-25.4
River	9/28/2023 12:32 PM	11.1	8.65	195.0	10.6	19.5
Groundwater	10/19/2023 1:06 PM	11.8	8.00	190.0	9.3	-30.5
River	10/19/2023 12:57 PM	8.9	8.53	182.3	10.7	28.6
Groundwater	11/2/2023 12:52 PM	3.9	8.19	181.8	10.8	41.5
River	11/2/2023 1:01 PM	3.2	8.36	179.3	12.1	42.5

Figure A15.2. The groundwater seep (left) with a close-up showing iron-oxide deposition (right).

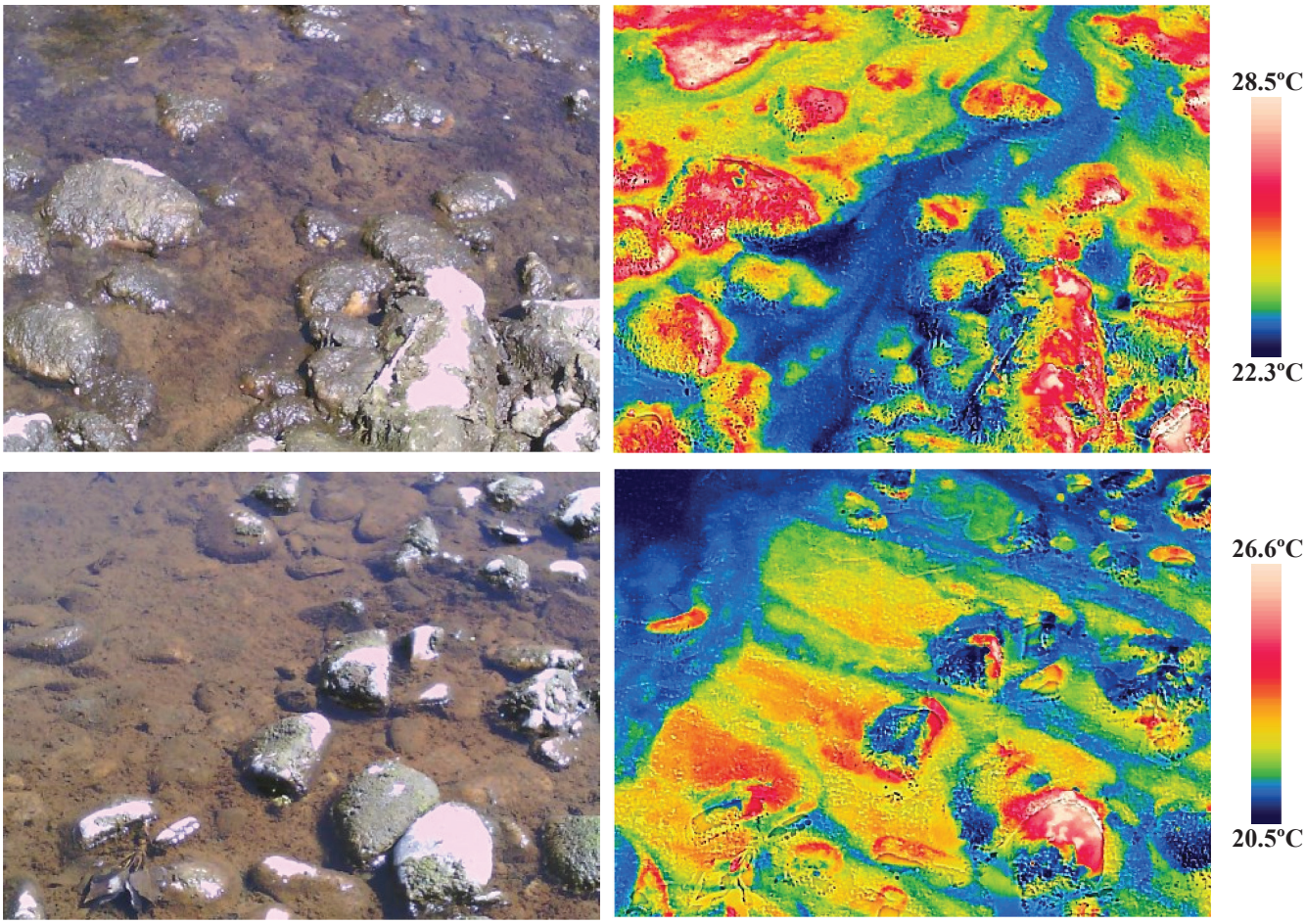


Figure A15.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 15. This site was shallow and heated up during the day. Groundwater appeared cooler than the surroundings, but was warm (20–22°C) compared to other groundwater sites.

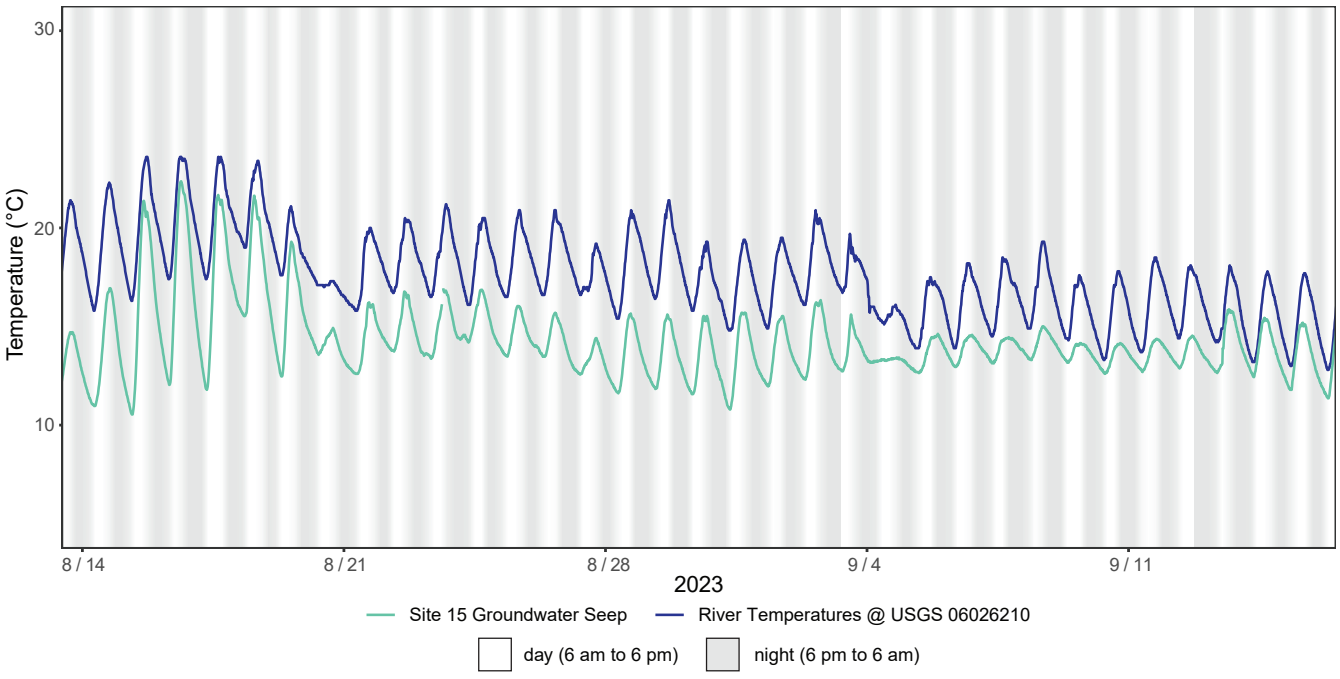


Figure A15.4. August–September 2023 logged temperatures at Site 15 groundwater seep (334300) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). The diel fluctuations of the groundwater seep were inconsistent, but the overall temperature was generally cooler than the river.

Site 16

GWIC #: 327572 (drive point), 334301 (seep joins river)
Latitude/Longitude: 45.43885, -112.62356
Description: Site 16 had groundwater discharging for ~200 ft along the inside of a point bar (fig. A16.1). In 2023, the groundwater became shallowly ponded and flowed across the land surface before entering the river. In 2024, it was disconnected from the river (fig. A16.1, A16.2). The pH and DO of the groundwater seep were less than those measured for the river; groundwater ORP could be higher or lower than the river ORP. Groundwater SC was within 5% of the river (table A16.1). Thermal infrared temperatures showed the groundwater was cooler than the river (fig. A16.3). Subsurface temperatures ranged from 13ºC to 16ºC. However, logged temperatures of the ponded groundwater were often warmer than the river during the summer afternoons and cooler than the groundwater in the drive point during summer nights (fig. A16.4).

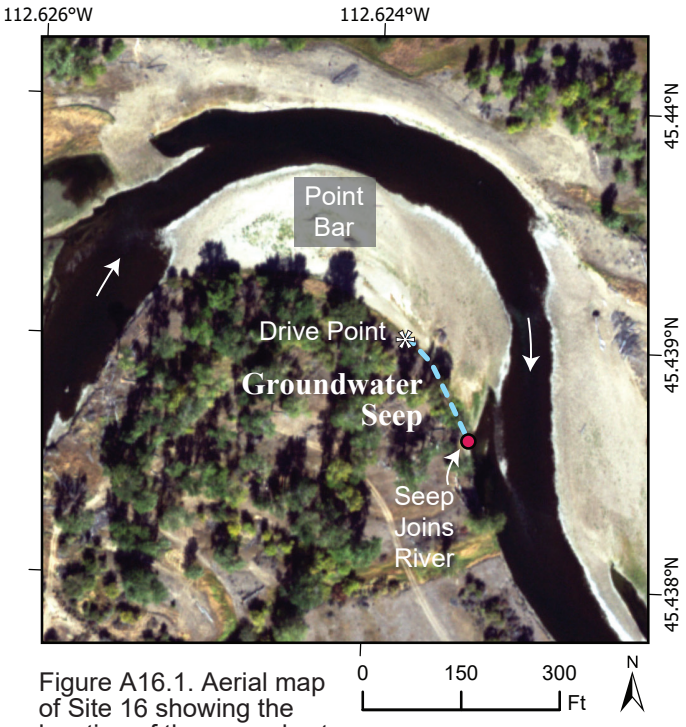


Figure A16.1. Aerial map of Site 16 showing the location of the groundwater seep (dashed blue line).

Table A16.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/24/2023 11:14 AM	17.8	7.07	188.9	1.8	30.9
River	8/24/2023 11:04 AM	17.0	8.34	198.3	8.6	161.0
Groundwater	9/13/2023 12:44 PM	15.8	7.33	199.5	2.7	35.1
River	9/13/2023 12:39 PM	14.8	8.55	210.5	9.0	25.6
Groundwater	9/28/2023 1:10 PM	14.7	7.30	197.1	1.6	32.0
River	9/28/2023 12:58 PM	11.9	8.75	193.5	10.5	21.1
Groundwater	10/19/2023 1:26 PM	11.6	7.34	186.8	0.8	34.2
River	10/19/2023 1:19 PM	9.5	8.61	182.0	10.6	10.1
Groundwater	11/2/2023 1:10 PM	7.7	7.80	180.8	3.0	61.9
River	11/2/2023 1:27 PM	3.5	8.33	177.0	11.9	34.6

Figure A16.2. The groundwater seep had more ponded water in 2023 (right) than in 2024 (left).

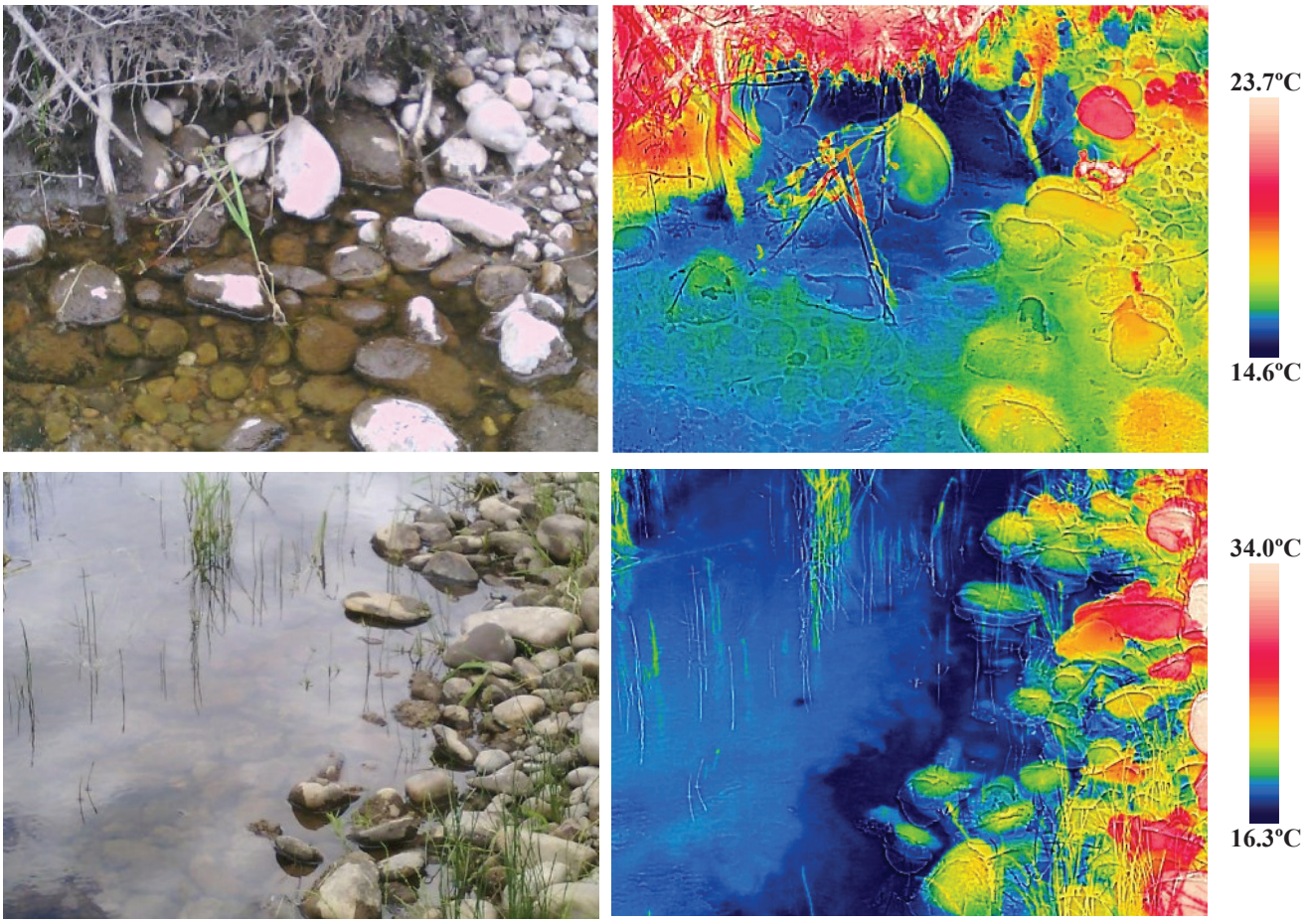


Figure A16.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 16. This site commonly showed cool groundwater (dark blue, ~14-16ºC) seeping from the edge and ponding. Sometimes it was discrete areas (top) and other times it was diffuse along the riverbank (bottom).

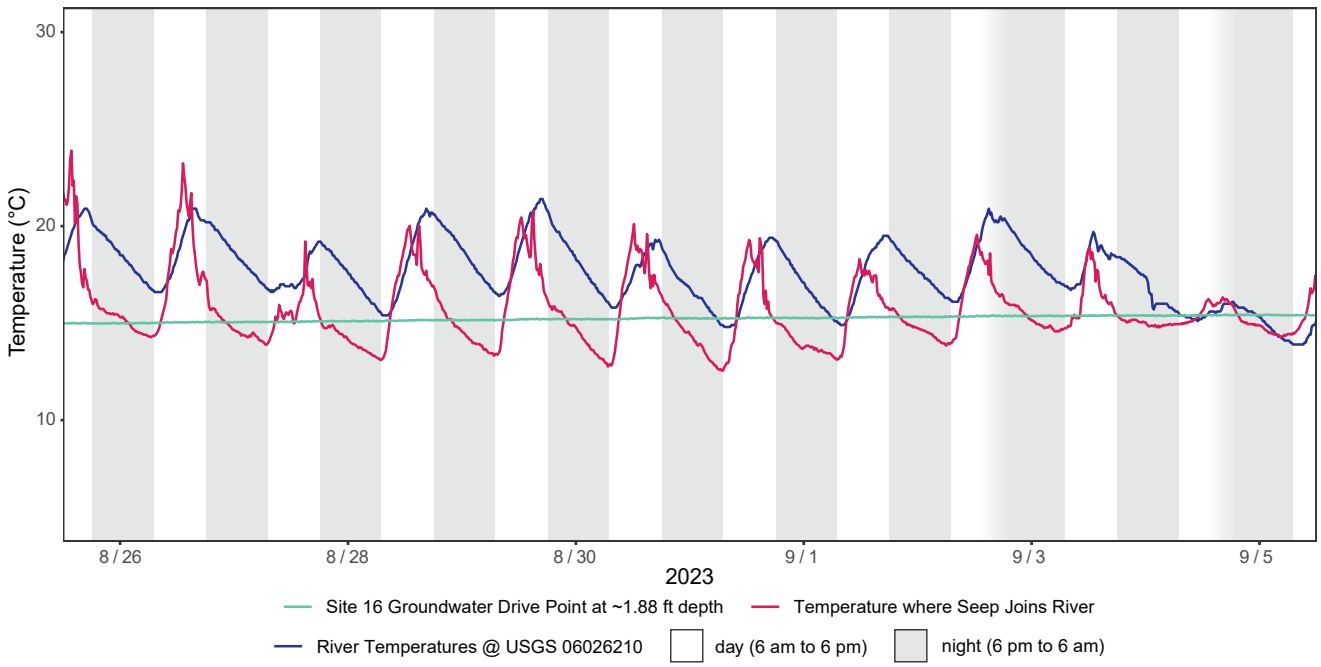


Figure A16.4. Late August to September 2023 logged temperatures at Site 16 groundwater seep (327572) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). Temperature was also monitored where the ponded groundwater reached the river (~200 ft away; 334301) which was commonly warmer than the river during midday after flowing along the surface of the gravel bar (see fig. 16.2).

Site 17

GWIC #: 334302
Latitude/Longitude: 45.43116, -112.59665
Description: Site 17 had discrete areas of groundwater discharging within a backwater channel for ~150 ft (fig. A17.1). The pH of the groundwater seep in the backwater was less than in the river; SC was higher in the groundwater than the river; ORP and DO varied on different visits (table A17.1). Iron-oxide and manganese-oxide deposition were present at the bottom of the backwater (fig. A17.2). Thermal infrared temperatures showed groundwater was often cooler than the river; however, it was difficult to see because surface temperatures were masked by vegetation (fig. A17.3). The groundwater appeared to be seeping in discrete areas in the backwater; this resulted in differences in diel fluctuations depending on how much the logger was influenced by groundwater (fig. A17.4). Smaller fluctuations suggest greater influence from groundwater.

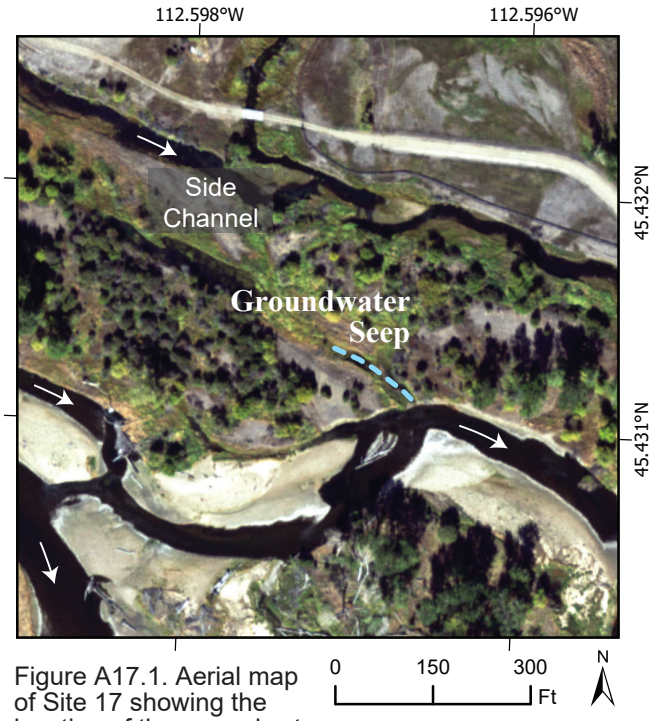


Figure A17.1. Aerial map of Site 17 showing the location of the groundwater seep (dashed blue line).

Table A17.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/23/2023 3:45 PM	22.2	7.85	235.7	10.1	31.0
River	8/23/2023 3:45 AM	20.9	8.90	198.3	9.1	43.1
Groundwater	9/13/2023 1:29 PM	15.2	7.87	220.8	7.7	-108.0
River	9/13/2023 1:48 PM	15.8	8.72	209.3	9.3	25.1
Groundwater	9/28/2023 1:45 PM	11.9	8.69	210.2	8.9	-92.1
River	9/28/2023 1:40 PM	11.8	8.76	194.2	10.7	50.1
Groundwater	10/19/2023 2:13 PM	8.3	7.44	271.4	3.0	-45.6
River	10/19/2023 2:32 PM	10.1	8.67	195.8	9.0	1.8
Groundwater	11/2/2023 1:52 PM	4.9	8.20	196.2	10.2	123.1
River	11/2/2023 1:56 PM	3.8	8.39	179.7	12.1	104.8

Figure A17.2. The ponded water where discrete areas of groundwater were seeping (left). Both iron-oxide and manganese-oxide were deposited in the ponded area (right).

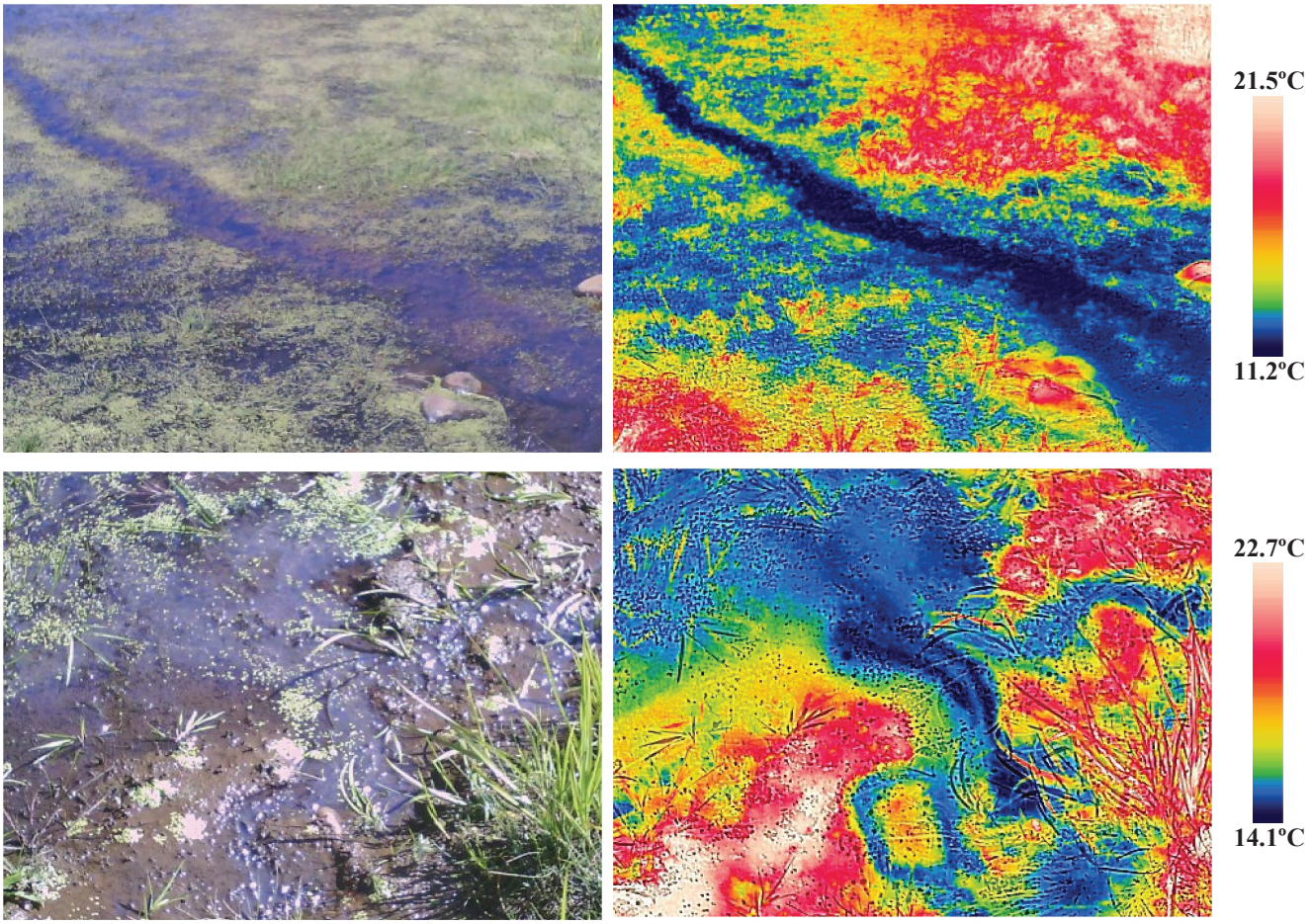


Figure A17.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 17. Vegetation, which warmed in sunlight, often masked the thermal signal at this site (top). Discrete groundwater seeps could be seen on the edges of the ponded area (bottom).

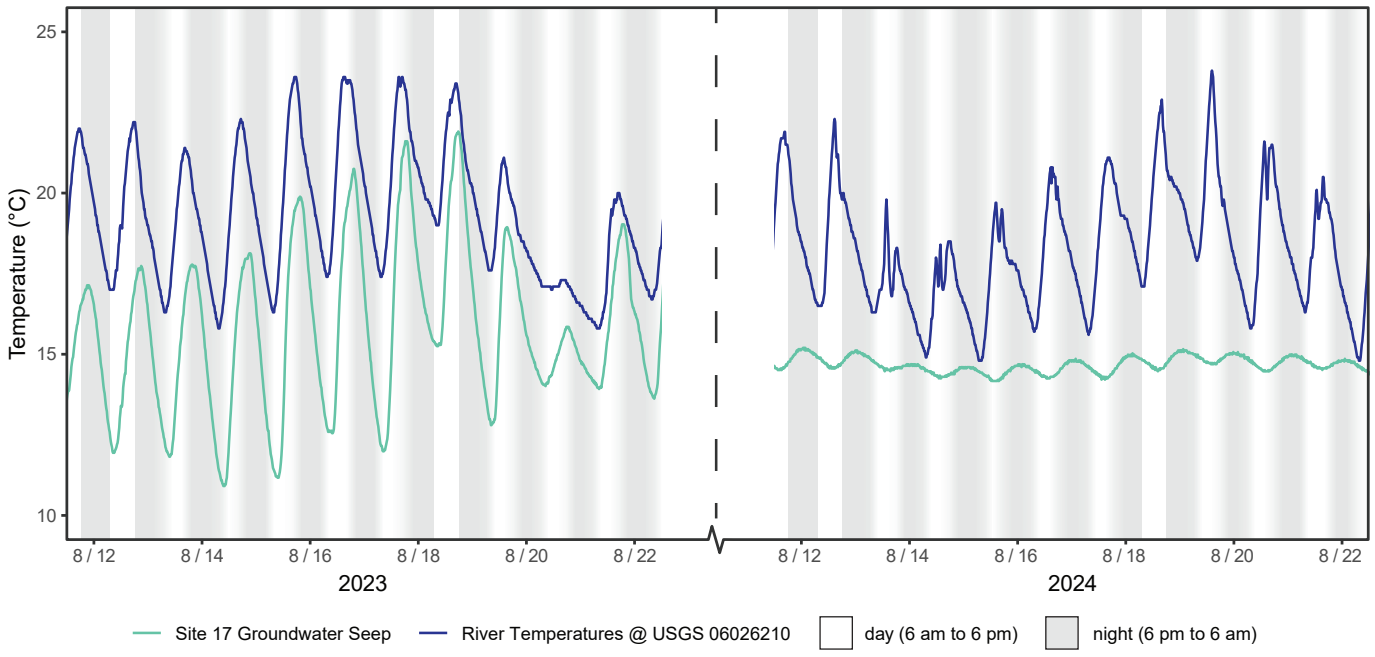


Figure A17.4. Comparison of August 2023 and 2024 logged temperatures at Site 17 groundwater seep (334302) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). Diel fluctuations of the groundwater seep changed between 2023 and 2024; this was likely due to where the groundwater seep was measured.

Site 18

GWIC #: 334303 (groundwater seep), 334338 (seep joins river)

Latitude/Longitude: 45.42973, -112.58296

Description: Site 18 had groundwater discharging for ~170 ft along a gravel bar on the outside of a river meander (fig. A18.1). Similar to site 16, the groundwater became shallowly ponded and flowed across the land surface before entering the river (fig. A18.1, A18.2). Vibrant iron-oxide deposition and microbial mats were present at the site (fig. A18.2). The pH, DO, and ORP of the groundwater seep were less than those measured for the river; groundwater SC was similar to or greater than the river (table A18.1). Thermal infrared showed the groundwater was cooler than the river (fig. A18.3). Logged groundwater temperatures were consistent around 10−12ºC (fig. A18.4). However, relative to the groundwater seep, the ponded groundwater that flows along the gravel bar warmed up during midday and cooled down during the night and early morning (fig. A18.4).

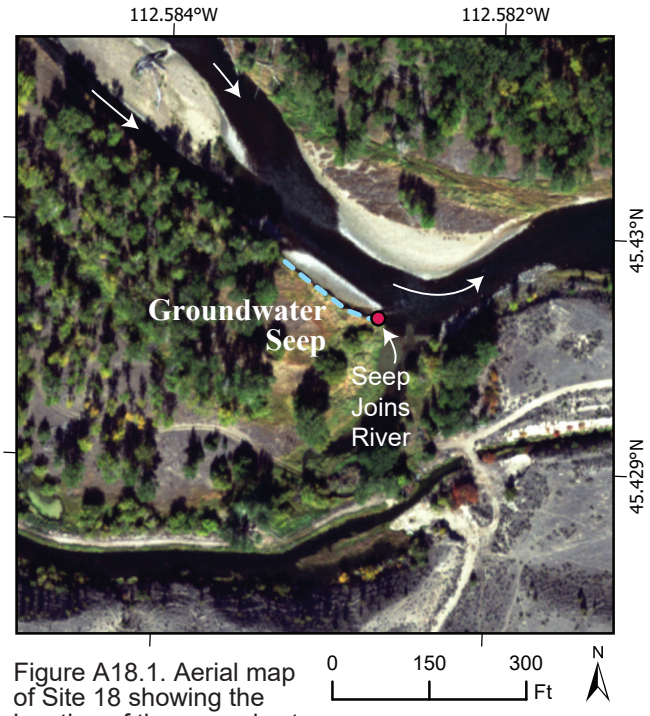


Figure A18.1. Aerial map of Site 18 showing the location of the groundwater seep (dashed blue line).

Table A18.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/24/2023 1:09 PM	11.8	7.00	234.8	0.8	-34.0
River	8/24/2023 1:22 PM	18.7	8.60	197.4	9.2	58.9
Groundwater	9/13/2023 1:48 PM	11.7	7.15	223.9	0.5	-66.8
River	9/13/2023 1:48 PM	15.8	8.72	209.3	9.3	25.1
Groundwater	9/28/2023 2:13 PM	12.1	7.37	198.9	3.1	-56.0
River	9/28/2023 2:03 PM	12.1	8.80	194.3	10.5	22.0
Groundwater	10/19/2023 2:36 PM	10.3	7.27	202.9	0.9	-71.0
River	10/19/2023 2:32 PM	10.1	8.67	195.8	9.0	1.8
Groundwater	11/2/2023 2:10 PM	4.2	8.38	180.1	11.5	-48.4
River	11/2/2023 2:15 PM	4.1	8.42	180.0	12.0	17.9

Figure A18.2. Bright orange iron-oxidizing microbial mats at the groundwater seep (left) and a close-up of the iron-oxidizing microbial mats (right).

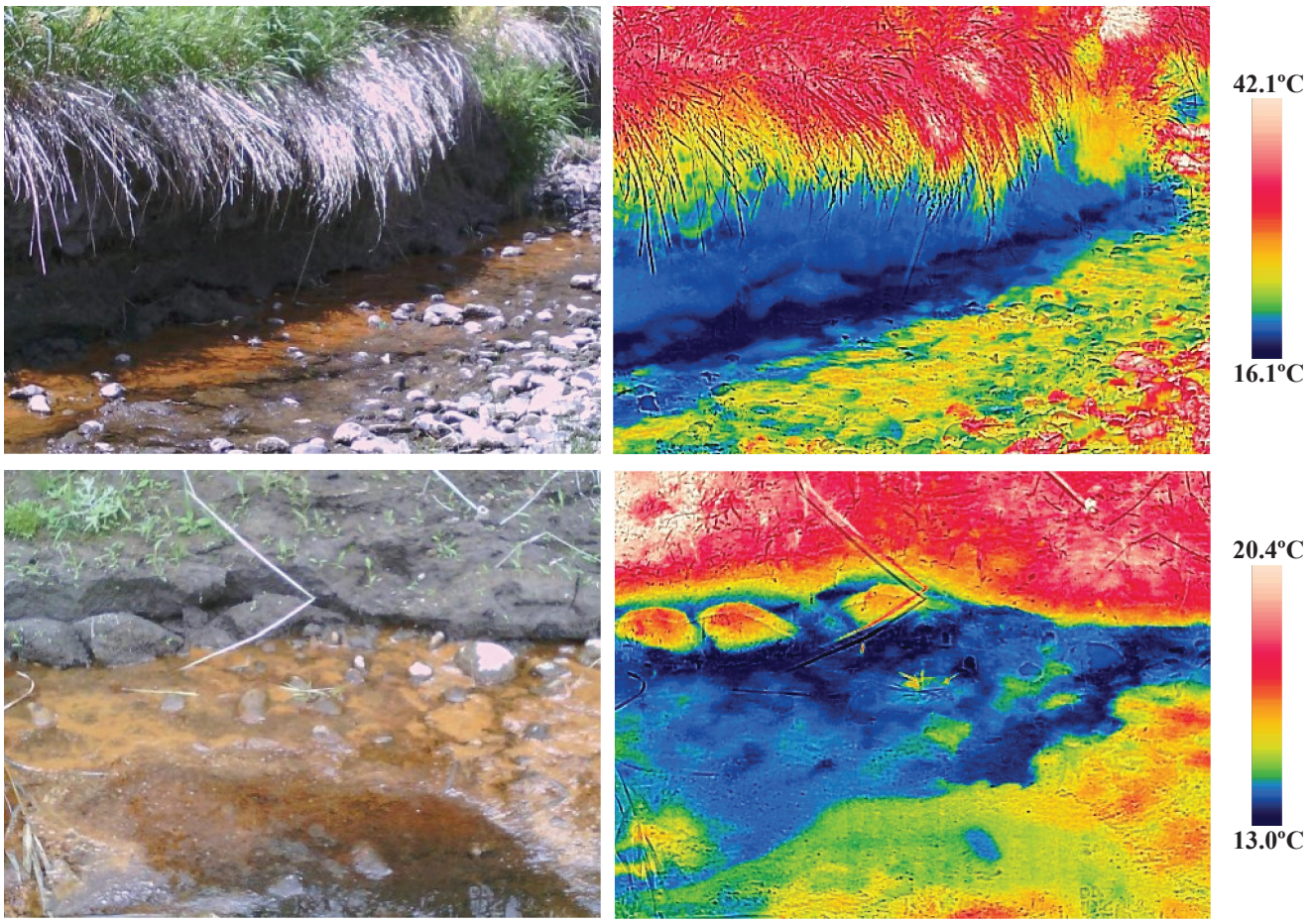


Figure A18.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 18. This site commonly had cool groundwater (dark blue, ~13-16ºC) seeping from the edge and ponding.

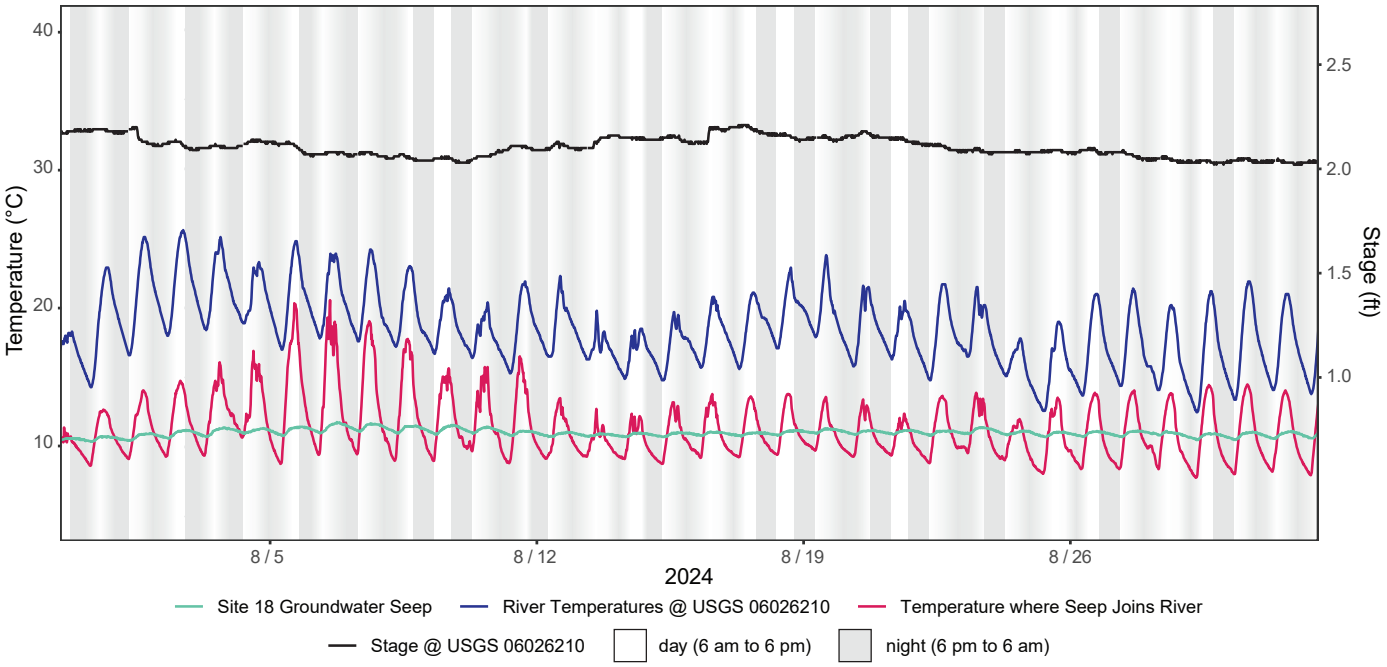


Figure A18.4. August 2024 logged temperatures at Site 18 groundwater seep (334303) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). Temperature was also monitored where the ponded groundwater reached the river (~200 ft away; 334338; see fig. A18.1). As the discharged groundwater flowed over the gravel bar it warmed as much as 10ºC during midday.

Site 19

GWIC #: 334304 (seep), 334308 (lower tailwater)
Latitude/Longitude: 45.43484 -112.56904
Description: Site 19 had water discharging for ~100 ft along a riverbank that was adjacent to a dammed tailwater pond and outlet (fig. A19.1−A19.2). The tailwater is discussed in the "lower tailwater" surface-water site. The water quality parameters of the seep were very similar to the river with slightly lower pH, DO, and ORP and slightly higher SC compared to the river (table A19.1). Iron-oxide deposition and algae growth were present along the riverbank (fig. A19.2). Thermal infrared of the water seeping from the riverbank often showed it slightly warmer than the river (fig. A19.3). However, the logged temperatures of the seep varied through time. Sometimes the seep was similar to the temperatures of the tailwater pond outlet; other times the seep was more similar to the river (fig. A19.4). The proximity and similarity in temperature of the seep to the tailwater pond suggests some of the dammed tailwater flowed subsurface to the riverbank.

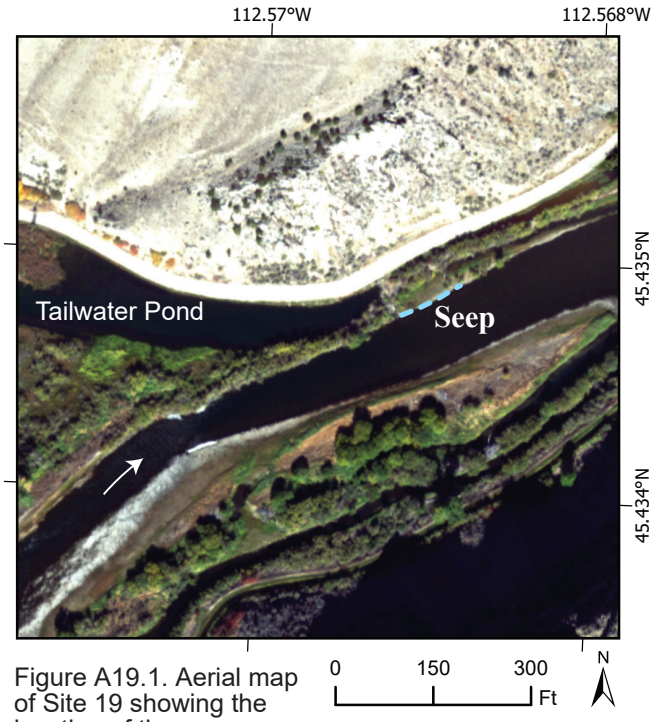


Figure A19.1. Aerial map of Site 19 showing the location of the seep (dashed blue line) derived from the tailwater pond.

Table A19.1. YSI water quality parameters measured during site visits of the seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Seep	8/24/2023 1:46 PM	18.8	8.08	221.0	7.1	30.4
River	8/24/2023 1:22 AM	18.7	8.60	197.4	9.2	58.9
Seep	9/13/2023 2:22 PM	16.5	8.21	224.6	7.2	-24.2
River	9/13/2023 1:48 PM	15.8	8.72	209.3	9.3	25.1
Seep	9/28/2023 2:41 PM	13.4	8.47	213.3	8.9	-31.6
River	9/28/2023 2:33 PM	12.4	8.67	204.1	10.1	19.3
Seep	10/19/2023 2:58 PM	10.4	8.39	195.8	9.0	1.8
River	10/19/2023 3:16 PM	10.6	8.64	189.2	10.7	14.6
Seep	11/2/2023 2:31 PM	3.9	8.32	194.0	11.3	51.0
River	11/2/2023 2:55 PM	4.3	8.34	188.8	11.7	54.3

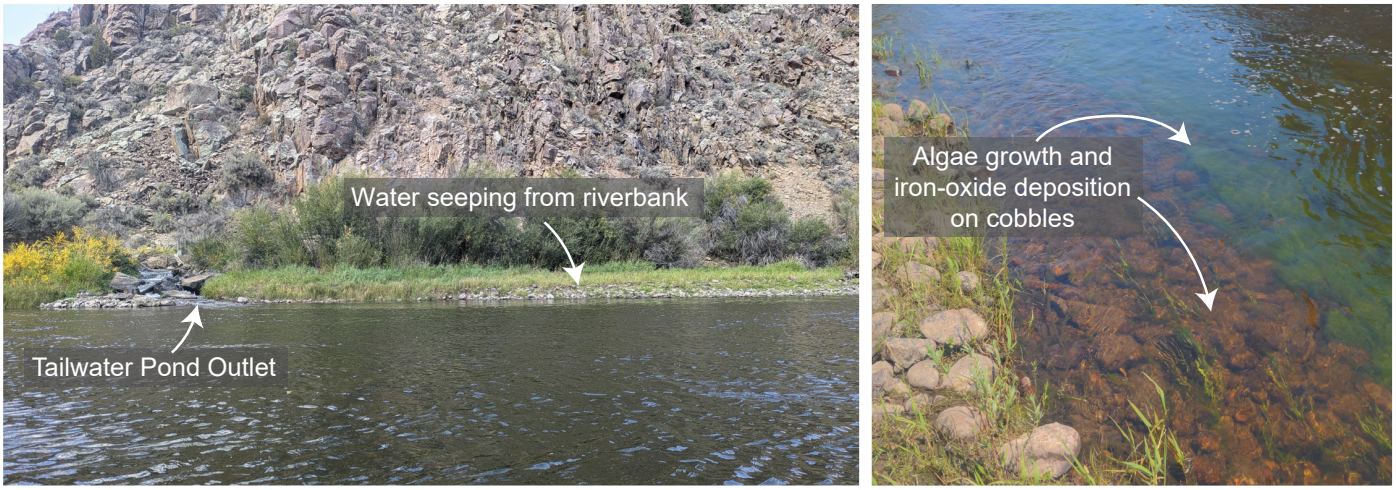


Figure A19.2. The groundwater seep is downstream of the outlet for the tailwater pond (left). Iron-oxide deposition and algae growth was commonly seen along the seep (right).

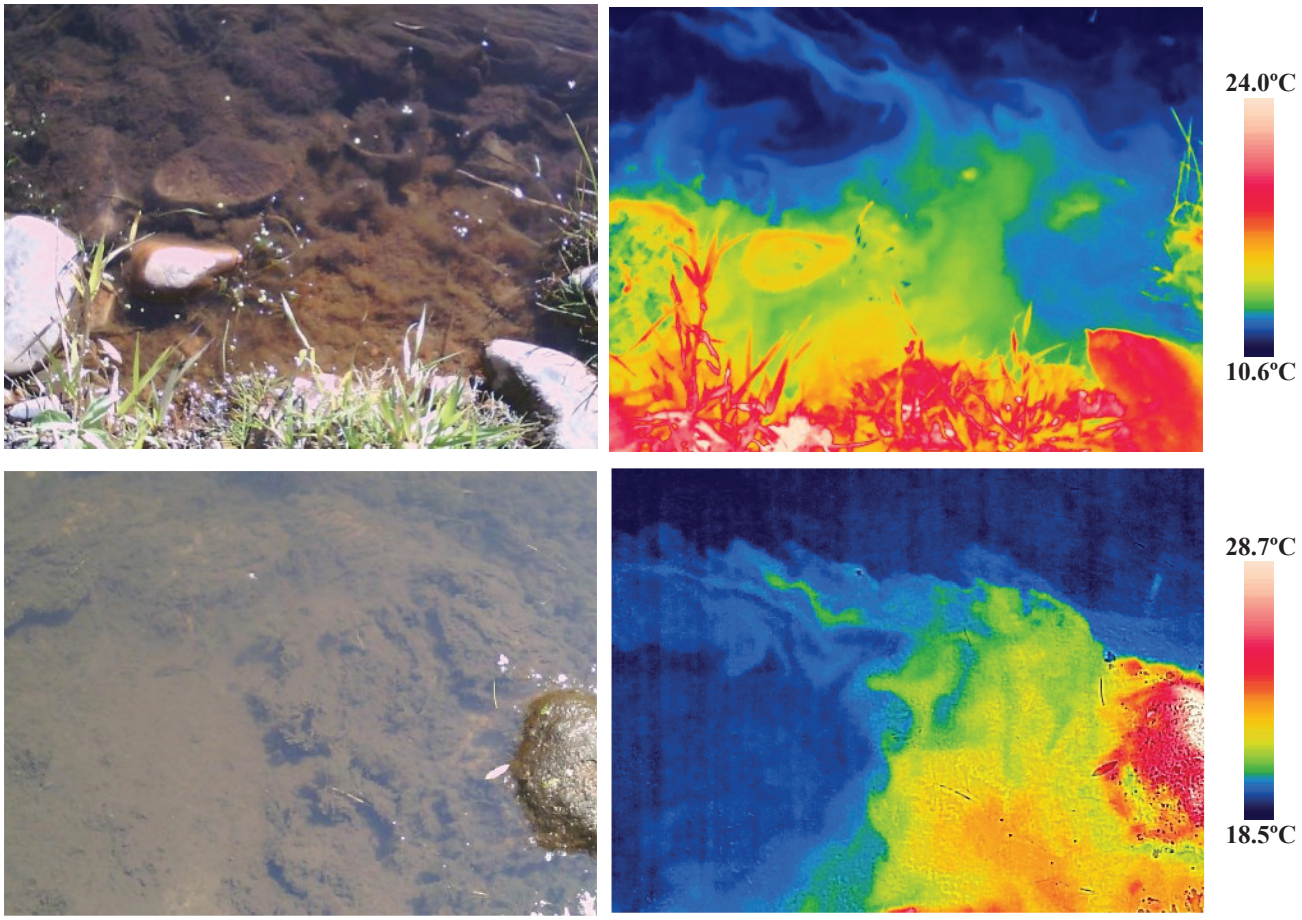


Figure A19.3. Visible light (left) and thermal infrared (right) photos of the seep at Site 19. This site often showed the water seeping from the riverbank to be slightly warmer (yellow, ~16-20ºC) than the river.

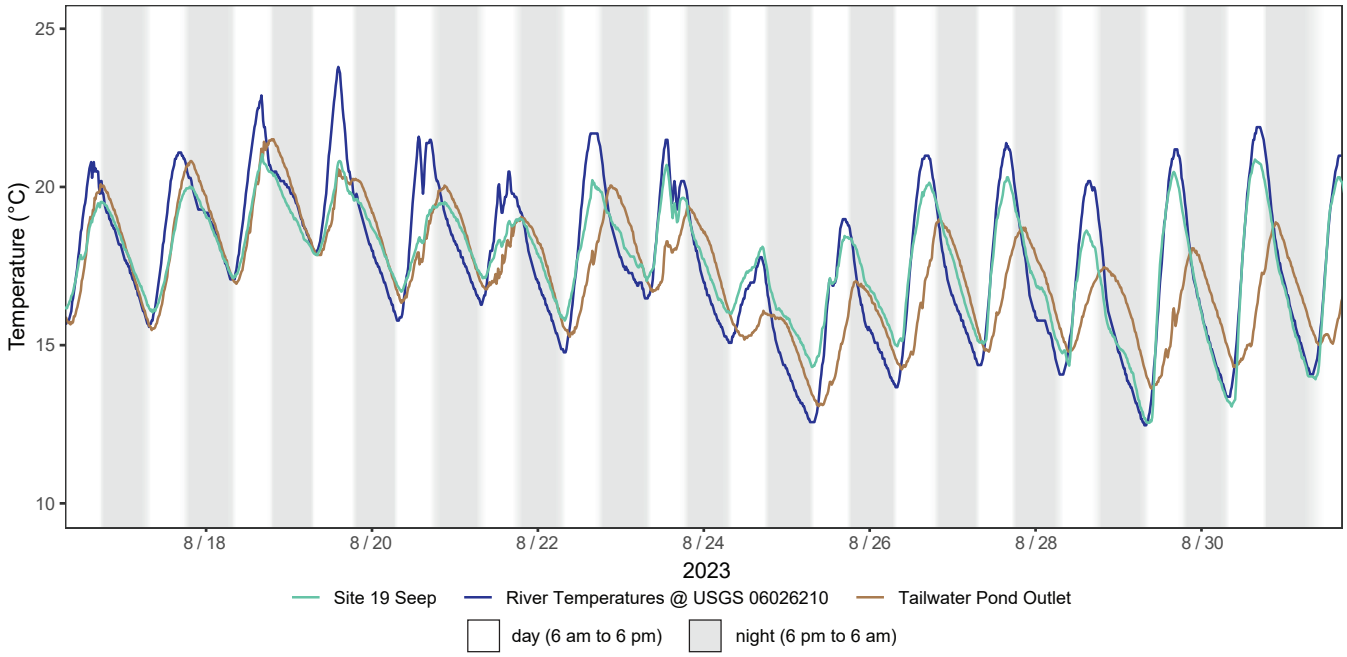


Figure A19.4. Late August 2023 logged temperatures at Site 19 seep (334304) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210) and the adjacent tailwater pond outlet (334308) temperatures. The seep temperatures are more similar to the tailwater pond outlet from 8/17 to 8/22 and more similar to the river temperatures from 8/23 to 8/31, suggesting the amount of water seeping through the riverbank from the tailwater pond varied with time.

Site 20

GWIC #: 327511 (deep drive point), 327512 (shallow drive point)
Latitude/Longitude: 45.43713, -112.56482
Description: Site 20 had groundwater discharging along the riverbank for ~80 ft (fig. A20.1). Two drive points were installed: one that was "deep" at ~5.06 ft deep to the middle of the screen and one that was "shallow" at ~1.96 ft deep to the middle of the screen. The pH and DO of the groundwater were less than those measured for the river; SC was similar to slightly higher in the groundwater than the river and ORP varied on different visits (table A20.1). The riverbank was consistently saturated and showed cooler thermal infrared temperatures compared to the river (figs. A20.2, A20.3). Temperatures in the drive points showed the groundwater was cooler than the river during early August, but transitioned to warmer than the river by mid-September. The deeper drive point showed more consistent daily and annual temperatures compared to the shallow drive point (fig. A20.4).

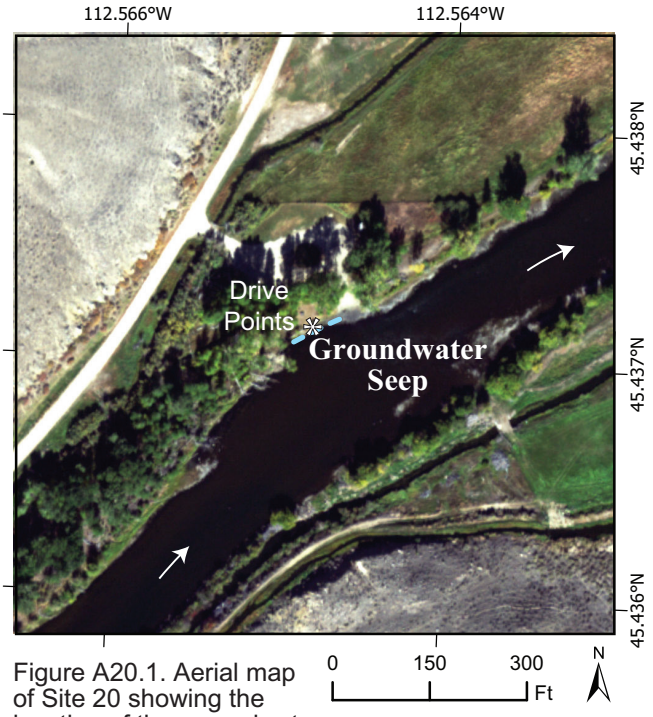


Figure A20.1. Aerial map of Site 20 showing the location of the groundwater seep (dashed blue line).

Table A20.1. YSI water quality parameters measured during site visits of the groundwater seep compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Groundwater	8/24/2023 2:33 PM	22.5	7.31	261.0	5.6	23.3
River	8/24/2023 2:25 AM	19.5	8.38	213.6	9.0	54.0
Groundwater	9/13/2023 2:53 PM	19.4	7.99	233.2	8.5	16.3
River	9/13/2023 3:04 PM	16.8	8.69	219.0	9.6	9.6
Groundwater	9/28/2023 3:11 PM	14.8	8.41	214.1	8.6	17.0
River	9/28/2023 3:03 PM	13.4	8.74	213.3	8.9	-31.6
Groundwater	10/19/2023 3:22 PM	12.3	8.26	196.8	8.6	12.1
River	10/19/2023 3:16 PM	10.6	8.64	189.2	10.7	14.6
Groundwater	11/2/2023 2:51 PM	4.8	8.26	190.6	11.0	43.3
River	11/2/2023 2:55 PM	4.3	8.34	188.8	11.7	54.3

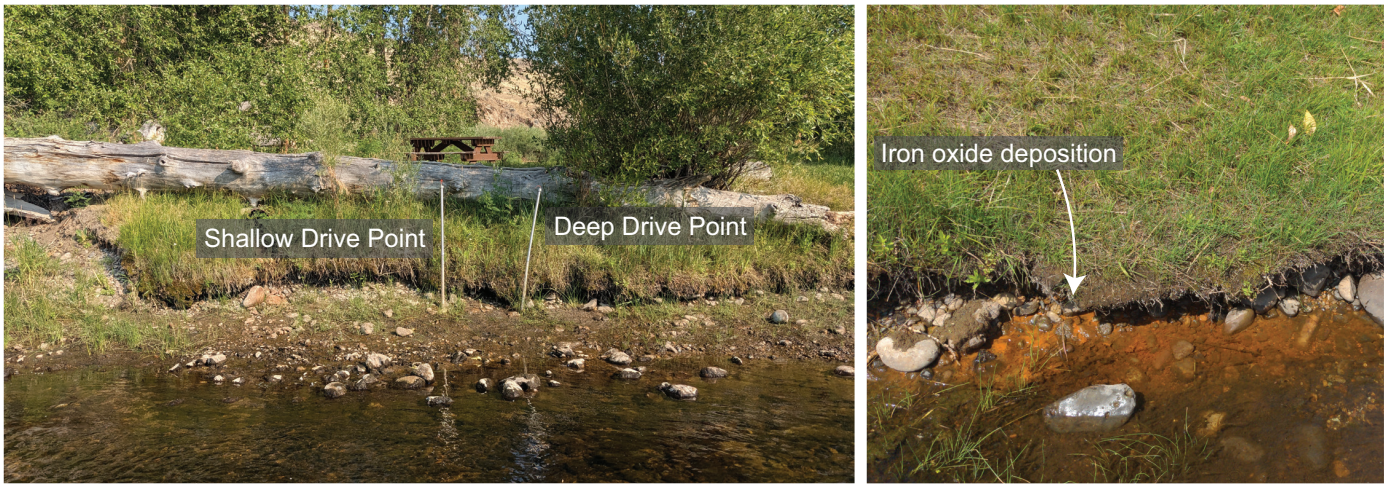


Figure A20.2. The shallow (~1.96 ft deep) and deep (~5.06 ft deep) drive points in the saturated riverbank of the groundwater seep (left). Iron-oxide deposition was commonly seen along the riverbank (right).

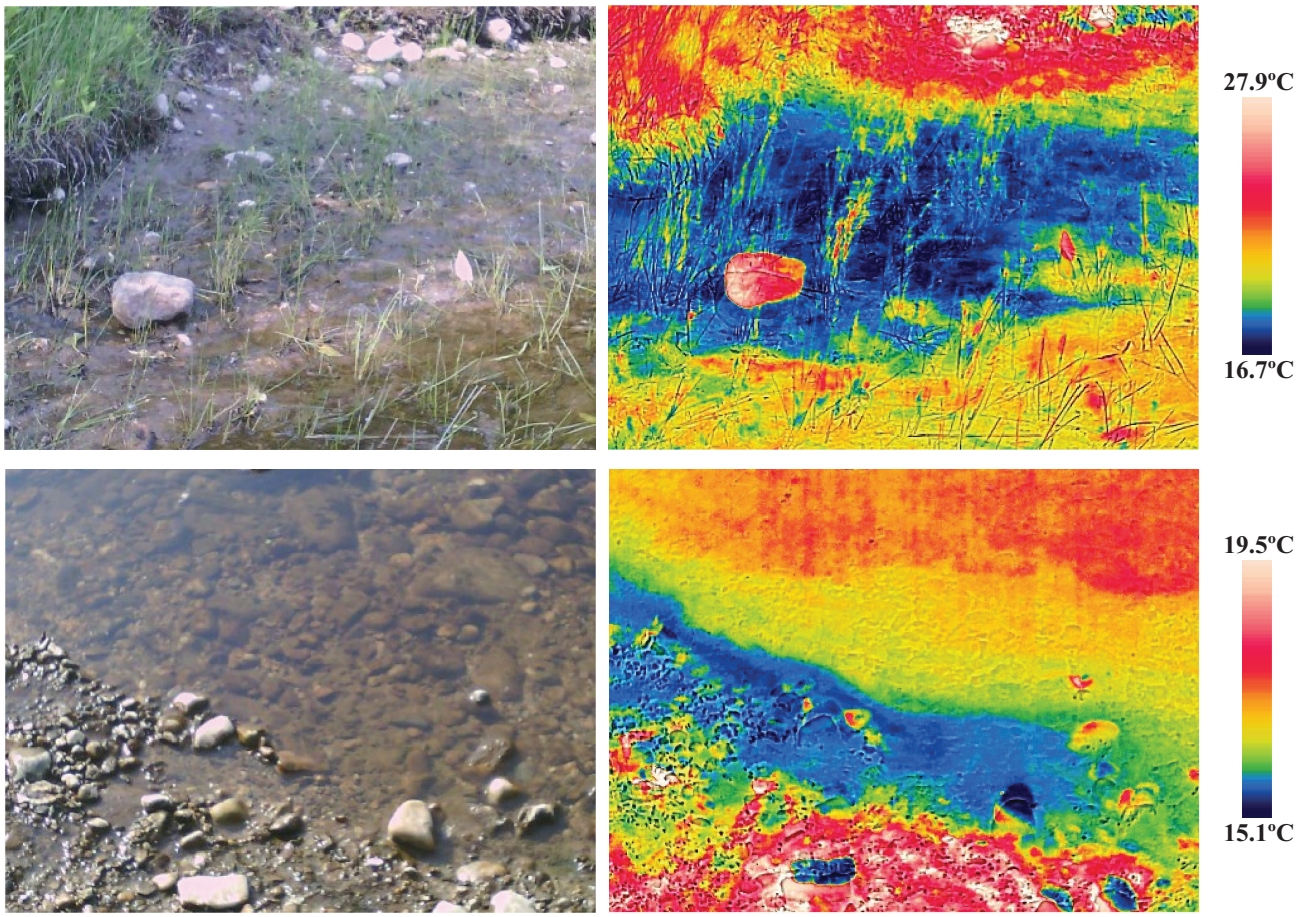


Figure A20.3. Visible light (left) and thermal infrared (right) photos of the groundwater seep at Site 20. Cool (blue, ~15-17ºC) groundwater could be seen discharging from the saturated riverbank (top) and into the river (bottom).

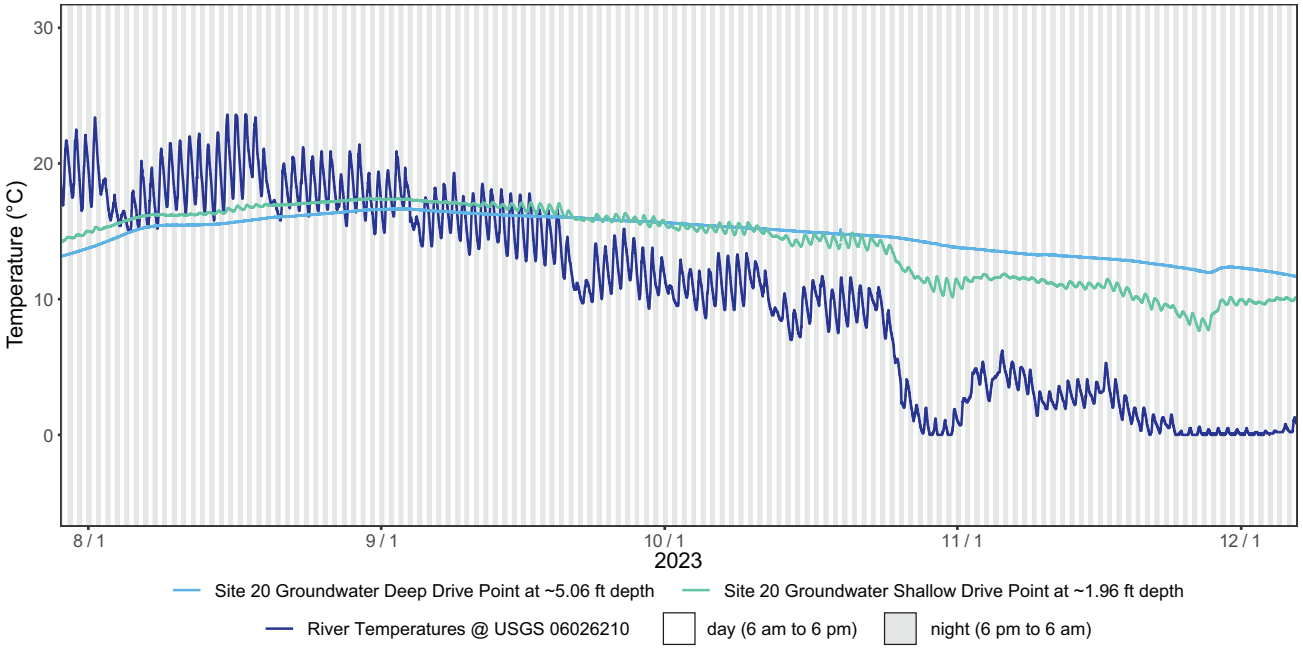


Figure A20.4. August-December 2023 logged temperatures at Site 20 groundwater seep. The groundwater seep (327512, 327511) is cooler than the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210) during early August, but warmer than the river by mid-September. The deeper drive point has more consistent temperatures (less daily and annual fluctuations) compared to the shallow drive point that is more affected by heat transfer with the ground surface.

APPENDIX B

DESCRIPTIONS OF SURFACE-WATER SITES

Northern Tailwater Return

GWIC #: 334305

Latitude/Longitude: 45.51337, -112.69182

Description: The northern tailwater return is a surface-water discharge (0.29–0.55 cfs) to the Big Hole River (see study map in fig. 1). An artificial stick dam backs up water in a large pond (fig. B1.1) that was deepened to allow groundwater to mix with the tailwater before being released into the river. The tailwater return has lower pH, DO, and ORP and higher SC compared to the river (table B1.1). Continuous temperatures showed the water from the tailwater return could be up to 7ºC cooler than the river (fig. B1.2).

Figure B1.1. The northern tailwater return is ponded behind a stick dam.

Table B1.1. YSI water quality parameters measured during site visits of the tailwater return compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Tailwater	8/22/2023 11:44 AM	17.0	7.37	367.5	3.6	-52.3
River	8/22/2023 10:44 AM	17.1	8.45	188.9	8.5	147.4
Tailwater	9/12/2023 11:34 AM	14.9	7.42	428.0	0.0	-167.2
River	9/12/2023 10:21 AM	14.8	8.56	189.5	9.6	57.6
Tailwater	9/27/2023 11:02 AM	11.6	7.44	373.3	1.8	-71.0
River	9/27/2023 11:28 AM	11.5	8.58	183.1	9.4	32.0
Tailwater	10/18/2023 10:35 AM	9.3	7.52	362.6	3.0	-57.0
River	10/18/2023 9:49 AM	7.1	8.27	172.8	9.4	180.1
Tailwater	11/1/2023 11:24 AM	5.4	7.66	382.0	5.2	-59.2
River	11/1/2023 10:27 AM	0.1	7.98	182.0	12.5	133.1

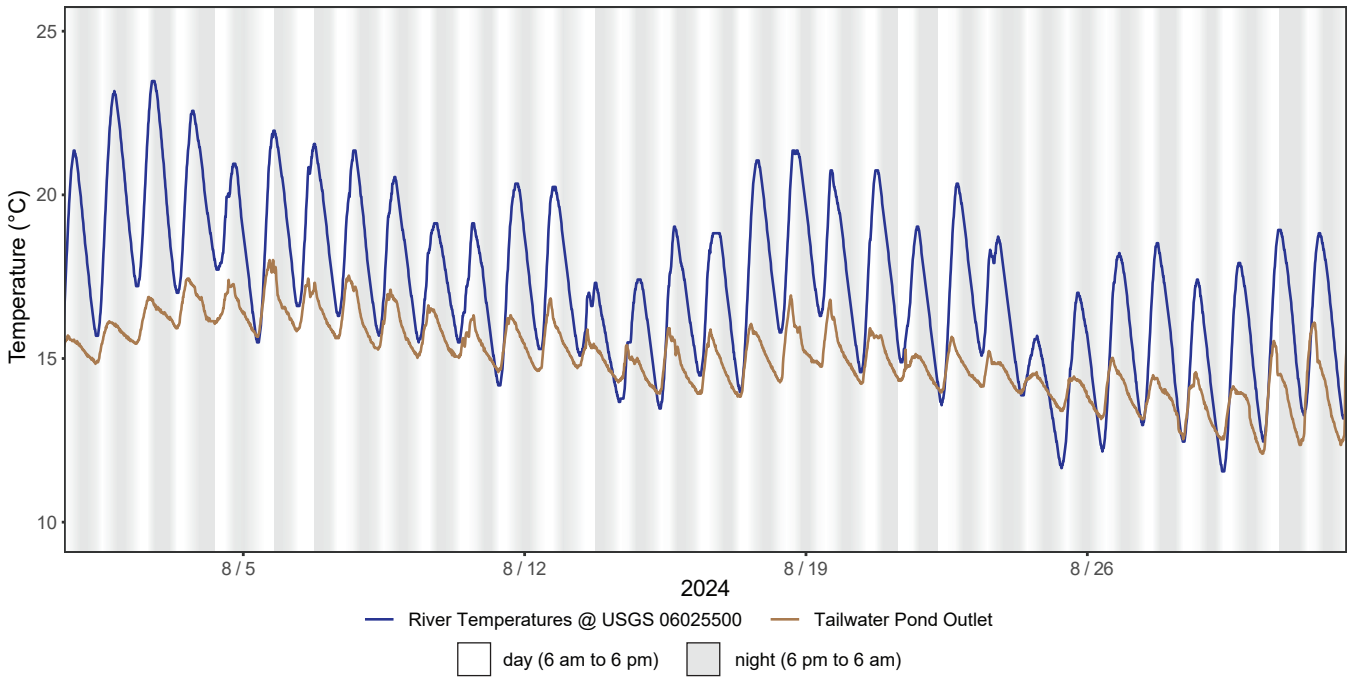


Figure B1.2. August 2024 logged temperatures from the northern tailwater return (334305) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). The northern tailwater return was generally cooler (up to 7ºC cooler) than the river except in the early morning.

Willow Creek

GWIC #: 334306
Latitude/Longitude: 45.45726, -112.65958
Description: Willow Creek is a tributary (9.5–13 cfs) of the Big Hole River (see study map in fig. 1; fig. B2.1). Willow Creek generally had slightly lower pH, DO, and ORP and higher SC compared to the river. However, DO and ORP were higher in Willow Creek compared to the river during some site visits (table B2.1). Willow Creek was consistently cooler than the river during the summer, having temperatures up to 5ºC cooler than the river (fig. B2.2).

Figure B2.1. The confluence of Willow Creek with the Big Hole River.

Table B2.1. YSI water quality parameters measured during site visits of Willow Creek compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Willow	8/23/2023 11:37 AM	14.9	8.12	303.1	8.4	72.7
River	8/23/2023 11:17 AM	17.5	8.40	194.6	8.6	96.7
Willow	9/13/2023 10:11 AM	11.4	8.00	351.8	8.4	21.2
River	9/13/2023 9:24 AM	14.4	8.17	203.9	7.9	34.2
Willow	9/28/2023 10:37 AM	7.7	8.19	349.0	10.2	13.8
River	9/28/2023 9:54 AM	10.0	8.36	190.0	9.9	34.7
Willow	10/19/2023 10:35 AM	6.4	7.91	319.5	8.8	1.0
River	10/19/2023 10:11 AM	7.4	8.21	168.2	9.6	17.0
Willow	11/2/2023 11:11 AM	4.2	7.95	283.0	9.8	15.8
River	11/2/2023 11:29 AM	3.1	8.23	181.7	10.8	-28.1

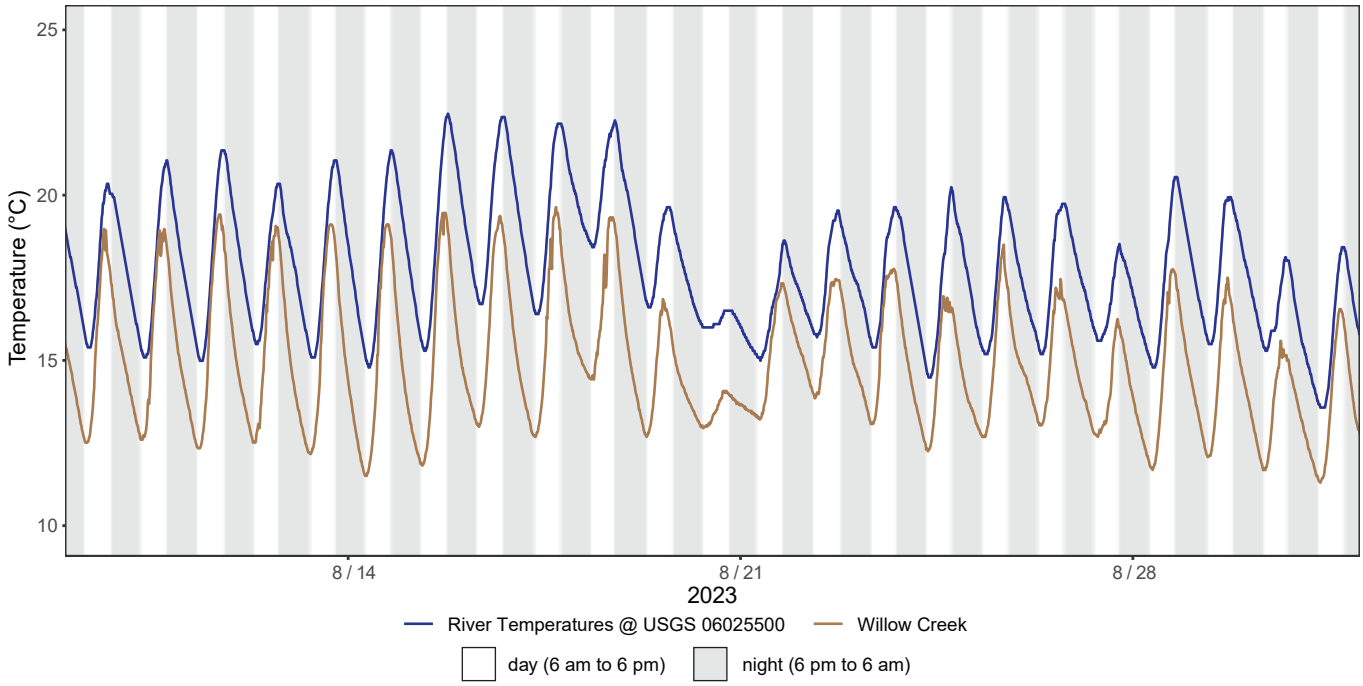


Figure B2.2. Mid- to late-August 2023 logged temperatures from Willow Creek (334306) compared to the river temperatures at the USGS gaging station Big Hole River near Melrose, MT (06025500). Willow Creek is cooler than the river except during early afternoon when the temperature was very similar to the river.

Birch Creek

GWIC #: 334307
Latitude/Longitude: 45.44666, -112.63607
Description: Birch Creek is a tributary of the Big Hole River (see study map in fig. 1; fig. B3.1). Prior to joining the Big Hole River, Birch Creek mixes with canal water and/or groundwater (1.76–1.99 cfs). The pH and DO of Birch Creek were lower than the river; ORP could be higher or lower than the river; SC was generally higher in Birch Creek than the river (table B3.1). Birch Creek commonly had warmer temperatures during the late afternoon and cooler temperatures during the early morning compared to the river (fig. B3.2).

Figure B3.1. The confluence of Birch Creek and the Big Hole River.

Table B3.1. YSI water quality parameters measured during site visits of Birch Creek compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Birch/Tailwater	8/23/2023 3:00 PM	22.1	8.88	321.3	11.2	45.3
River	8/23/2023 2:00 PM	19.9	8.82	197.0	9.5	19.2
Birch/Tailwater	9/13/2023 11:37 AM	14.6	8.04	368.9	7.7	30.7
River	9/13/2023 11:00 AM	14.5	8.42	208.3	8.9	12.6
Birch/Tailwater	9/28/2023 12:23 PM	12.0	8.16	331.4	9.0	9.3
River	9/28/2023 12:32 PM	11.1	8.65	195.0	10.6	19.5
Birch/Tailwater	10/19/2023 12:46 PM	9.8	8.15	320.6	10.1	12.9
River	10/19/2023 12:08 PM	8.4	8.43	180.8	10.6	20.9
Birch/Tailwater	11/2/2023 12:32 PM	3.8	8.04	322.4	11.0	68.8
River	11/2/2023 12:36 PM	3.1	8.27	178.0	12.0	59.8

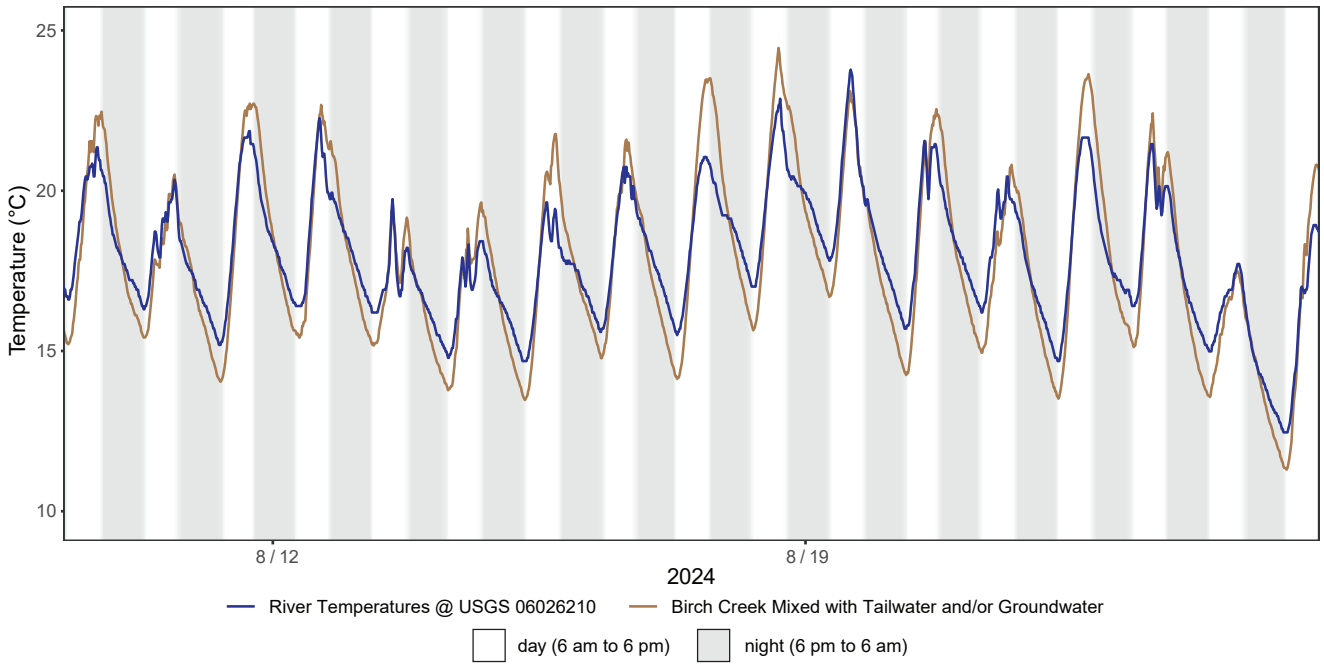


Figure B3.2. Mid- to late-August 2024 logged temperatures from Birch Creek (334307) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). The water from Birch Creek is generally warmer than the river during late afternoon and cooler than the river during early morning.

Southern Tailwater Return

GWIC #: 334308
Latitude/Longitude: 45.43476, -112.56920
Description: The southern tailwater return is a surface-water discharge (1.05–4.35 cfs) to the Big Hole River (see study map in fig. 1). Tailwater is ponded and flows over a spillway down a series of boulders to the river (fig. B4.1). The tailwater return generally had lower pH and DO, similar ORP, and higher SC compared to the river (table B4.1). The tailwater return had similar temperatures to the river, but did not reach as high of maximums (fig. B4.2).

Figure B4.1. Tailwater is ponded and flows over a spillway to the river.

Table B4.1. YSI water quality parameters measured during site visits of the tailwater return compared to the river.

Location	Date and Time	Temperature (°C)	pH	SC (µS/cm)	DO (mg/L)	ORP (mV)
Tailwater	8/24/2023 2:33 PM	18.0	7.91	236.0	7.6	57.7
River	8/24/2023 2:25 PM	19.5	8.38	213.6	9.0	54.0
Tailwater	9/13/2023 2:39 PM	15.4	8.13	242.9	8.4	14.0
River	9/13/2023 3:04 PM	16.8	8.69	219.0	9.6	9.6
Tailwater	9/28/2023 2:46 PM	12.0	8.27	229.2	9.6	9.6
River	9/28/2023 2:33 PM	12.4	8.67	204.1	10.1	19.3
Tailwater	10/19/2023 3:02 PM	9.2	8.27	203.4	10.0	9.5
River	10/19/2023 3:16 PM	10.6	8.64	189.2	10.7	14.6
Tailwater	11/2/2023 2:34 PM	3.3	8.19	209.1	11.1	53.3
River	11/2/2023 2:55 PM	4.3	8.34	188.8	11.7	54.3

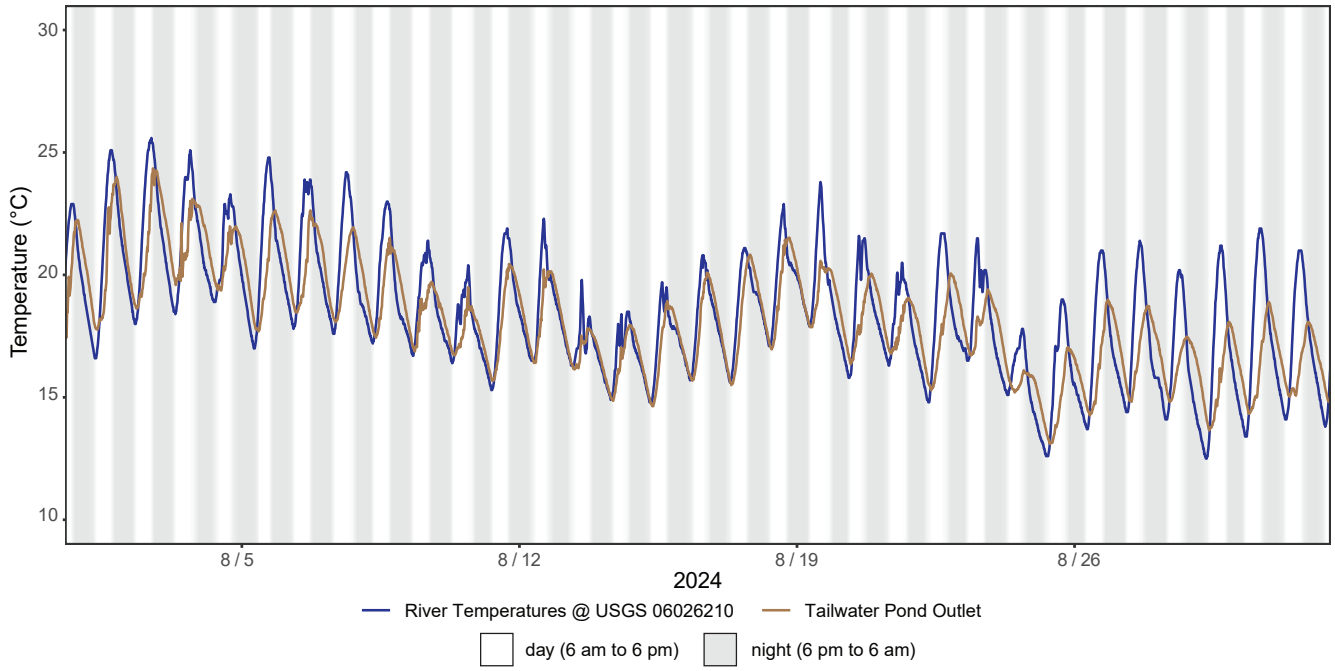


Figure B4.2. August 2024 logged temperatures from the southern tailwater (334308) compared to the river temperatures at the USGS gaging station Big Hole River near Glen, MT (06026210). The ponded tailwater had smaller diel fluctuations compared to the river and generally reached minimum and peak temperatures a couple hours later than the river.

APPENDIX C
GLOSSARY AND ABBREVIATIONS

GLOSSARY AND ABBREVIATIONS

Below we provide definitions of words and abbreviations that occur throughout this report. These definitions are for less common words/abbreviations or words that vary in meaning depending on the perspective of the research and/or source. The definitions provided are summarized, simplified, and/or expanded from multiple sources to best explain how they are used in this report.

Backwater—A part of the river with minimal to no flow, commonly formed from an abandoned side channel or groundwater seep a short distance away from the main river channel. Backwaters can be connected or disconnected from the river depending on river stage.

Biofilm—An oil-like sheen on the surface of the water that is produced by bacteria (e.g., iron-oxidizing bacteria). When swirled, biofilm will break into sheets, unlike oil that will coalesce back together.

Diel fluctuations—A daily cyclic change in a physical parameter that is commonly due to changes between night and day. Diel groundwater temperature fluctuations at seeps commonly have lower minimum temperatures, smaller amplitudes, and a time lag from air temperatures and surface-water temperatures.

Dissolved oxygen (DO)—A measurement of the oxygen concentration in water, commonly measured in milligrams per liter (mg/L). Low DO concentrations (≤5 mg/L) are stressful for aquatic organisms, such as fish.

Drive-point piezometer—A small-diameter well consisting of a perforated steel screen and steel pipe that is driven into the ground to shallow depths (<5 ft) to measure water levels and temperature.

Hyporheic water—Water that flows from the stream, through the alluvial aquifer, and back to the stream; where this occurs is called the hyporheic zone. Hyporheic water has similar average temperatures to the river; however, the diel temperature fluctuations of the hyporheic water may be smaller or lagged from river temperatures.

Iron staining/iron-oxide deposition—An orangish-red coating (rust) on rocks and riverbanks produced by iron precipitating out of solution. This can occur where iron-rich groundwater is exposed to atmospheric oxygen.

Iron-oxidizing microbial mats—Orange masses created by naturally occurring, iron-oxidizing bacteria where iron-rich groundwater flows to the ground surface.

pH—A measurement of the hydrogen ion (H^+) concentration in water that describes whether the water is acidic (<7) or basic (>7); pH 7 is considered neutral.

Oxidation-reduction potential (ORP)—A measurement of the ability of water to transfer electrons from one compound to another in a chemical reaction. Generally, lower ORP values are correlated with lower DO and higher concentrations of dissolved metals (iron, manganese, etc.). ORP was measured with an Ag/AgCl electrode in this study.

Seep—An area where groundwater or hyporheic water discharges to the surface. In this study, temperature was used to distinguish groundwater seeps from hyporheic water. If water discharging from a seep was cooler than the river during the summer, it was considered a groundwater seep even though hyporheic water could have been intermixed.

Specific conductivity (SC)—A measure of the ability of water to transmit an electrical current at 25°C. SC increases with increased concentrations of dissolved salts.

Tailwater return—Excess water remaining in the lower end of an irrigation canal that is discharged back into the river.