HYDROGEOLOGIC INVESTIGATION OF THE UPPER GALLATIN RIVER CORRIDOR, BIG SKY, MONTANA

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Ground Water Investigation Program

MBMG
Montana Bureau of Mines and Geology

Front photo: Twin Cabins gaging station on the Gallatin River. Photo by Todd Myse.

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TABLE OF CONTENTS

FIGURES

TABLES

PREFACE

The Ground Water Investigation Program (GWIP) at the Montana Bureau of Mines and Geology (MBMG) investigates areas prioritized by the Ground Water Assessment Steering Committee (MCA 2-15-1523). Prioritization is based on such factors as current and anticipated growth of agriculture, industry, housing, and commercial activity. Additional program information and project-ranking details are available on the MBMG GWIP website (https://mbmg.mtech.edu).

The Gallatin River Task Force (GRTF), a local nonprofit organization, proposed this GWIP project to better understand the effects of continued growth and future development on water quality and quantity.

Products of the Upper Gallatin River Corridor GWIP project include:

- A hydrogeologic investigation summary report (this report) that presents the study scope, data, and interpretations that focus on the hydrogeologic framework, surface-water budget, and water chemistry.
- A groundwater-flow modeling report (Zeiler and others, 2025) that presents details on model construction, groundwater flowpaths, and results of groundwater modeling scenarios for a subarea within the Upper Gallatin River Corridor study area.
- An aquifer test report (Rose, 2022) that summarizes the results of aquifer tests performed in the study area.
- All data are available on the Ground Water Information Center database (MBMG, 2024).

ABSTRACT

In recent years, the area around Big Sky, Montana, including the Upper Gallatin River Corridor (UGRC) east of Big Sky, has undergone rapid growth and development with increases in short-term, seasonal, and year-round residency. The area is serviced by private wells, public water supply wells, and individual and community sewage disposal systems. The increased growth in the area prompted this study to better understand the quantity and quality of water resources in the study area, understand the interaction between groundwater and surface water, and examine the potential for water-quality degradation in the Gallatin River associated with septic effluent discharge. Periodically since 2018, algal blooms in the Gallatin River have occurred in late summer. Algal blooms can result from excess nutrients in combination with warmer temperatures.

The UGRC study area is about 5 square miles and includes a 7-mile reach of the Gallatin River. The primary focus of this study is the shallow, unconfined, sand and gravel alluvial aquifer. This alluvial aquifer has an average thickness of approximately 35 ft but ranges up to 60 ft thick; it is underlain by bedrock. The aquifer is recharged by snowmelt from the surrounding mountains, losses from the Gallatin River, and losses from tributaries. Some recharge also occurs through rainfall, inflow from the underlying bedrock, and spring discharges. Groundwater levels fluctuate seasonally on the order of 1–3 feet. Long-term water-level measurements from the alluvial aquifer indicate no significant increasing or decreasing trends. One well completed in bedrock (Madison Formation) showed a statistical increase in groundwater levels of about 0.3 ft over a 16-year period.

The Gallatin River and the alluvial aquifer are interconnected and exchange water. This exchange varies seasonally and with climatic conditions. In the upstream section of the study area, groundwater was either at equilibrium with the river (no loss or gain in river flow from the alluvial aquifer) or the river was losing water, thereby providing recharge to the aquifer during low-flow periods. In the downstream section of the study area, the Gallatin River gains water from groundwater and Madison aquifer spring discharge. This gain was consistent in both 2020 and 2021.

Water quality in the study area is generally suitable for human consumption, with a few sites exceeding the primary infant drinking water recommendation for manganese (four sites). Nitrate concentrations increase along the groundwater flowpath through the developed portion of the UGRC. The highest groundwater nitrate concentration was 5.84 mg/L, below the 10 mg/L drinking water standard but elevated above concentrations measured east of the river, outside of development. Most surface-water samples had nitrate concentrations below 0.2 mg/L, with a few exceptions, including several samples collected from Michener Creek. Michener Creek is a small tributary stream that gains flow and had nitrate concentrations ranging from non-detect to 1.87 mg/L.

INTRODUCTION

Background

In recent years, Big Sky, Montana has undergone rapid growth and development with increases in short term, seasonal, and year-round residency; the population grew from 2,308 in 2010 to 3,591 in 2020 (U.S. Census, 2024). During peak periods throughout the year, Big Sky's population is upwards of 15,000 (Big Sky Chamber of Commerce; https://www.visitbigsky.com/live-work/). This rapid growth has challenged the ability of resource managers to supply enough water to, and manage wastewater from, the growing population. To address information needs regarding water resources, the Montana Bureau of Mines and Geology (MBMG) Ground Water Investigation Program (GWIP) completed a hydrogeological investigation of a rapidly developing reach of the Upper Gallatin River Corridor (UGRC) near Big Sky, approximately 40 mi south of Bozeman (fig. 1). The UGRC is locally known as the canyon area.

The UGRC study area is serviced by private wells, public water supply (PWS) wells, and individual and community sewage disposal systems. The increasing number of septic drain fields prompted concerns about groundwater and surface-water degradation. Since 2018, algal blooms in the Gallatin River have occurred in late summer (GRTF, 2022); excess nutrients (e.g., nitrates) from septic effluent and warmer water temperatures are potential contributing factors. Montana DEQ has listed the middle stretch of the Gallatin River (which includes the study area) as impaired due to recurrent algal blooms affecting aquatic life and recreational uses (MT DEQ, 2020). A Total Maximum Daily Load (TMDL) study is underway by the Montana Department of Environmental Quality to determine the causal pollutants causing or contributing to recurrent algal blooms. The Gallatin Canyon County Water and Sewer District (GCCWSD) was formed in

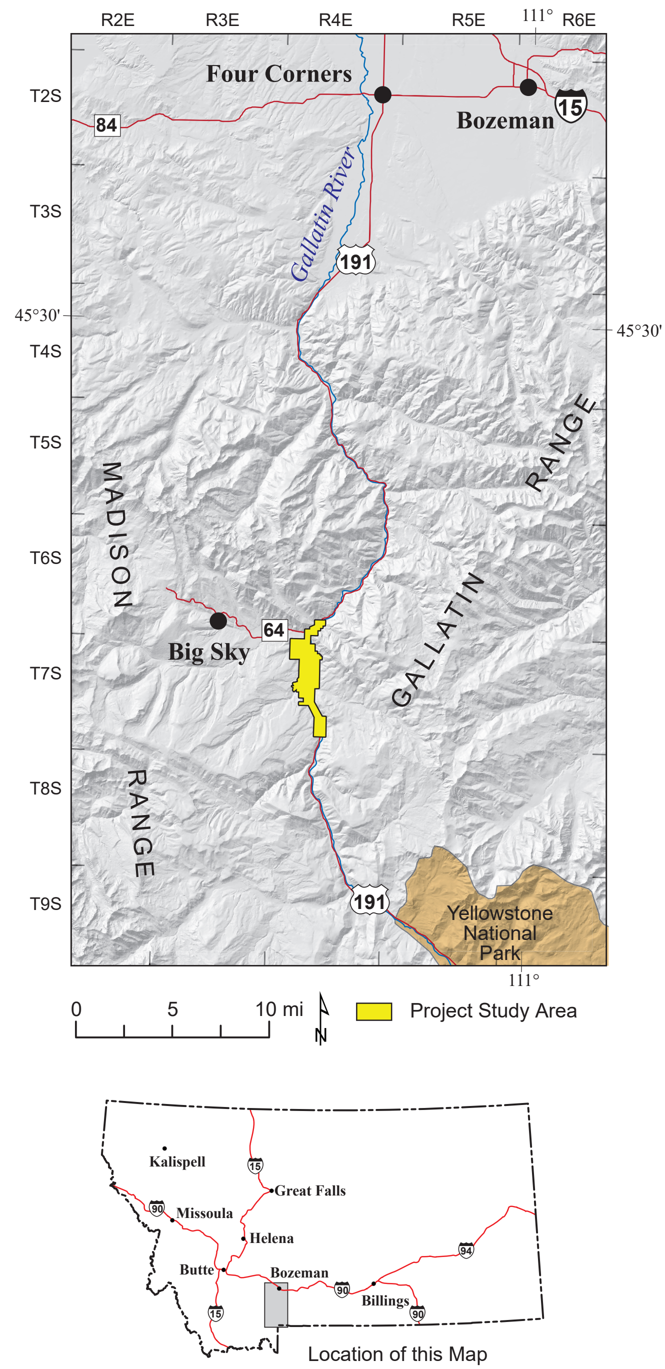

Figure 1. The study area is located about 40 mi south of Bozeman in the Big Sky, Montana area. In recent years, the area around Big Sky, including the Upper Gallatin River Corridor (UGRC), has undergone rapid growth and development with increasing short-term, seasonal, and year-round residency.

2020 with the goal of centralizing sewer collection for treatment at the Big Sky Waste Water Reclamation Facility (BSWWRF) via a lift station and pipeline. Construction on the Sewer District is anticipated to begin in 2026 (https://www.gallatincanyonwsd.com/).

Purpose

The primary purpose of this study was to:

- Describe the hydrogeologic conditions, specifically the quality and quantity of alluvial groundwater used for domestic and commercial supplies in the study area.
- Understand the groundwater and surface-water interaction, specifically focusing on groundwater/surface-water exchange between the shallow, unconfined alluvial aquifer and the Gallatin River.
- Examine the potential for water-quality degradation in the Gallatin River associated with septic effluent discharge to the shallow alluvial aquifer.

This work is presented in two reports. This report focuses on the overall hydrogeology and water-quality aspects of the UGRC project area with data collection focused to support model development. The groundwater model developed for the project is published as a companion report and addresses model construction and groundwater quantity, presents a groundwater budget, and identifies groundwater flowpaths to the river (Zeiler and others, 2025).

Project Area

The UGRC study area is about 5 mi^2 and includes a 7-mi reach of the north-flowing Gallatin River between the confluence with Twin Cabins Creek in the south and Dudley Creek in the north (fig. 2). The Gallatin River alluvial valley is topographically flat (elevation 6,000 to 6,200 ft) and surrounded by high-elevation mountains (up to 8,000 ft), with the Gallatin Range on the east and the Madison Range to the west (fig. 1).

There are seven tributary streams to the Gallatin River in the study area. These include Twin Cabins Creek, Beaver Creek, Porcupine Creek, Michener Creek, the West Fork of the Gallatin River (referred to as the West Fork), Levinski Creek, and Dudley Creek (fig. 2). These tributaries drain a total area of approximately 90,000 acres of mostly undeveloped mountainous terrain.

Most of the residential, commercial, and industrial development occurs on the west side of the river (fig. 3); the east side of the river is mostly undeveloped and includes a large track of public land maintained by Montana Fish, Wildlife and Parks (FWP) and the U.S. Forest Service (USFS). FWP land includes the Porcupine Unit of the Gallatin Wildlife Management Area.

The development along the west side of the river includes four existing and/or platted residential subdivisions (fig. 3):

1. Ramshorn View Estates (Ramshorn Subdivision) includes 90 small (typically <1 acre) platted lots, over 90 percent built out with single-family residences.
2. Blackfoot Hills Subdivision, platted at less than 20 large lots (generally >1 acre), under construction.
3. San Marino Subdivision includes eight smaller (approximately ¾ acre) lots with 7 acres of undeveloped community space, appears to be fully built out.
4. Rimrock Meadows Subdivision includes 18 undeveloped, platted lots (about 1 acre each) that was undeveloped as of 2022.

There are also plans for a phased subdivision at a former gravel pit (Quarry subdivision; fig. 3). The first phase will include 90 single family homes; the proposed second phase consists of 135 single family homes, 130 apartments, and commercial spaces (Reaney, 2024). There are other large-lot residential properties (about 1 acre or larger) outside of the platted subdivisions.

The Big Sky elementary, middle, and high schools are located together near Beaver Creek (fig. 3). Commercial properties include gas stations, restaurants, hotels, outfitters, public storage, and other seasonal and small, service-sector businesses (fig. 3). The only industrial property, a former sand and gravel mining operation, is located in the northwest part of the study area.

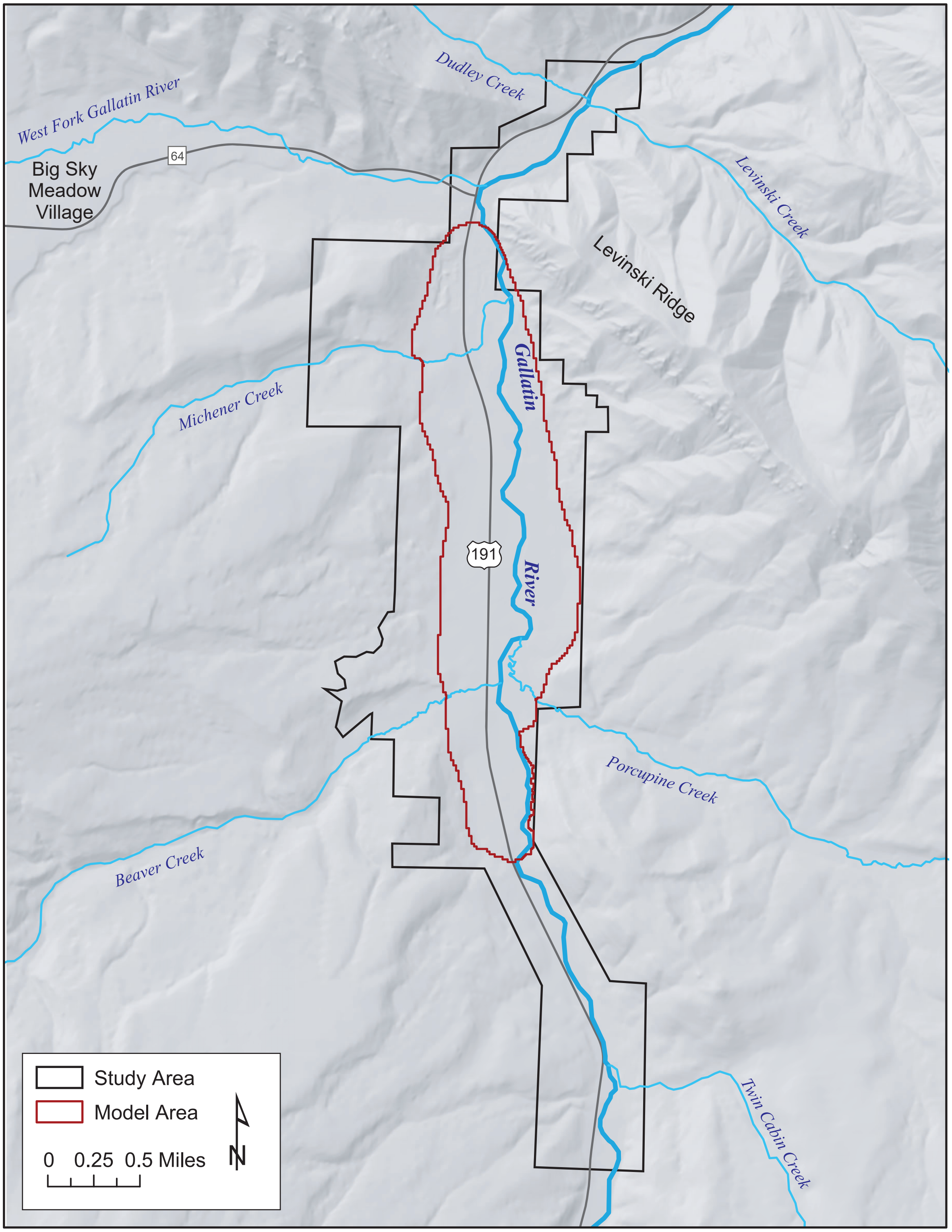

Figure 2. The study area is about 5 mi^2. The model area includes the most developed portion within the UGRC and is about 2 mi^2. The study area is about 9 mi east of Big Sky Mountain Village and Big Sky Resort and 2.5 mi east of Big Sky Meadow Village.

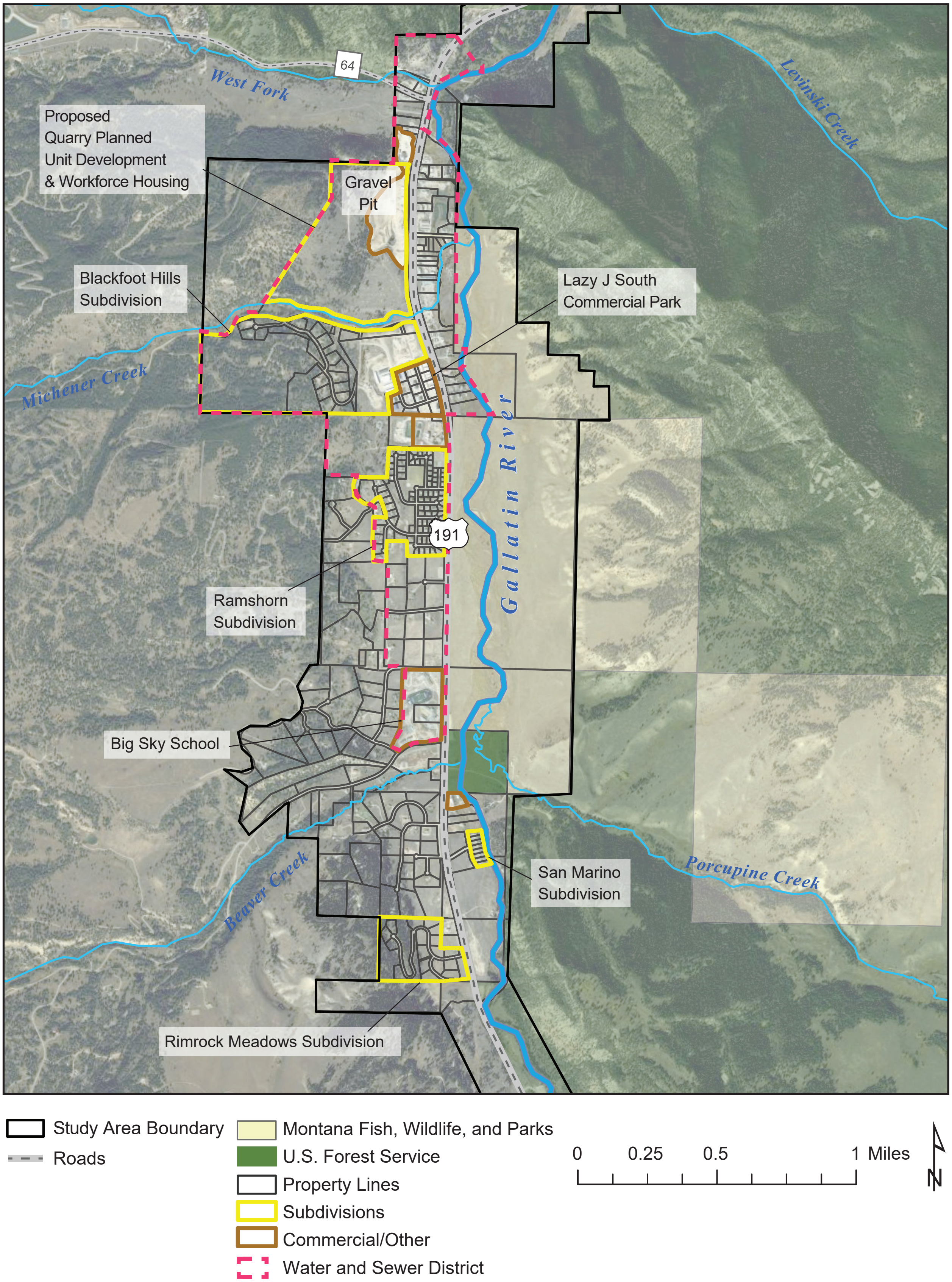

Figure 3. The development in the study area is west of the river. East of the river is mainly the Porcupine Unit of the Gallatin Wildlife Management Area (FWP) and Forest Service land.

Public water supply wells (PWS) serve the Ramshorn, San Marino, and Blackfoot Hills subdivisions. The undeveloped Rimrock Meadows subdivision will eventually be served by a PWS well. Some existing PWS wells are completed at depths greater than 1,000 ft in bedrock beneath the alluvial valley. Currently, there is no centralized wastewater collection and treatment system. Wastewater is treated onsite via septic tanks, leach-field systems, lagoons, infiltration ponds, and land application. In December 2020, the Gallatin Canyon County Water and Sewer District was formed with the goal of routing much of the area's wastewater to the Big Sky Water and Sewer District treatment plant via a lift station.

Previous Studies

The MBMG has conducted regional groundwater evaluations in Gallatin County that, while not focused on the UGRC, include the greater Big Sky area and the UGRC. English and others (2021) provide information on the water quality of wells and springs within the Yellowstone Controlled Groundwater area, part of which encompasses the UGRC study area. The groundwater resources of Gallatin and Madison Counties are presented by the MBMG's Groundwater Characterization Program (GWCP) in a series of three reports that describe the regional hydrogeologic framework, groundwater flow systems, and water quality (Carstarphen and others, 2015; Carstarphen and LaFave, 2018; Madison, 2022). Suitable sites for long-term monitoring were identified and added to the MBMG's long-term groundwater monitoring network during the GWCP characterization, including four wells and two springs within the UGRC study area (see Methods, Groundwater Monitoring section).

The Big Sky Mountain Village and Meadow Village community, located west of the UGRC, were the focus of an MBMG GWIP groundwater availability investigation, which included the development of a numeric groundwater model (Waren and others, 2021) and a report on the hydrogeology and groundwater availability (Rose and Waren, 2022). Groundwater sampling from five sites in the Meadow Village area showed nitrate concentrations elevated above baseline, generally ranging from 2 to 6 mg/L, with one sample as high as 12.4 mg/L.

WGM Group (2020) provided a limited evaluation of potential septic effluent impacts to the Gallatin River and the effect of potential sewer infrastructure projects. This report presented a simplified groundwater flowpath map that illustrated areas where septic effluent could potentially discharge through groundwater to the Gallatin River.

Water-quality sampling and streamflow-stage monitoring by the GRTF in the Gallatin Canyon (Gardner and Buban, 2023) includes collecting monthly water-quality samples during the summer on the Gallatin River and selected tributaries. Samples for nitrate analysis have been collected since 2000.

Montross and others (2013) investigated the role of geology in the nitrate cycle in the West Fork of the Gallatin River watershed. Through laboratory weathering of rock samples and isotope analysis, they found that nitrate in waters upgradient from developed areas is likely geogenic, as nitrate samples collected downgradient from development differed isotopically from geologic-sourced nitrate.

Geologic Setting

The bedrock lithology underlying the UGRC alluvial valley is variable and the geologic structure is complex. Bedrock units include Archean metasediments and Cambrian through Cretaceous sedimentary formations (fig. 4; Kellogg and Williams, 2006; Vuke, 2013). The Spanish Peaks fault is a major northwest-striking fault with at least 10,000 ft of offset that crosses the northern part of the study area. Northeast of the fault, the bedrock is Archean metasedimentary rock; south of the fault are carbonate sedimentary rocks that strike parallel to the fault and dip steeply to the southwest near the fault and dip more moderately further away. A prominent ridge, Levinski Ridge, with near-vertical beds of the Madison Limestone, occurs next to the fault where the alluvial valley narrows near the confluence with the West Fork. To the south, most of the alluvial valley is underlain by the Cretaceous and Upper Jurassic-aged Frontier, Kootenai, and Morrison Formation bedrock formations that occupy a northeast-striking asymmetrical synclinal fold (Big Sky Syncline; fig. 4). These bedrock units are composed of thick sequences of shale with thin interbeds of sandstone, siltstone, mudstones, and limestone.

In the southern part of the study area, where the canyon narrows, the Cretaceous Kootenai Formation is exposed along the steep canyon walls (fig. 4). Further

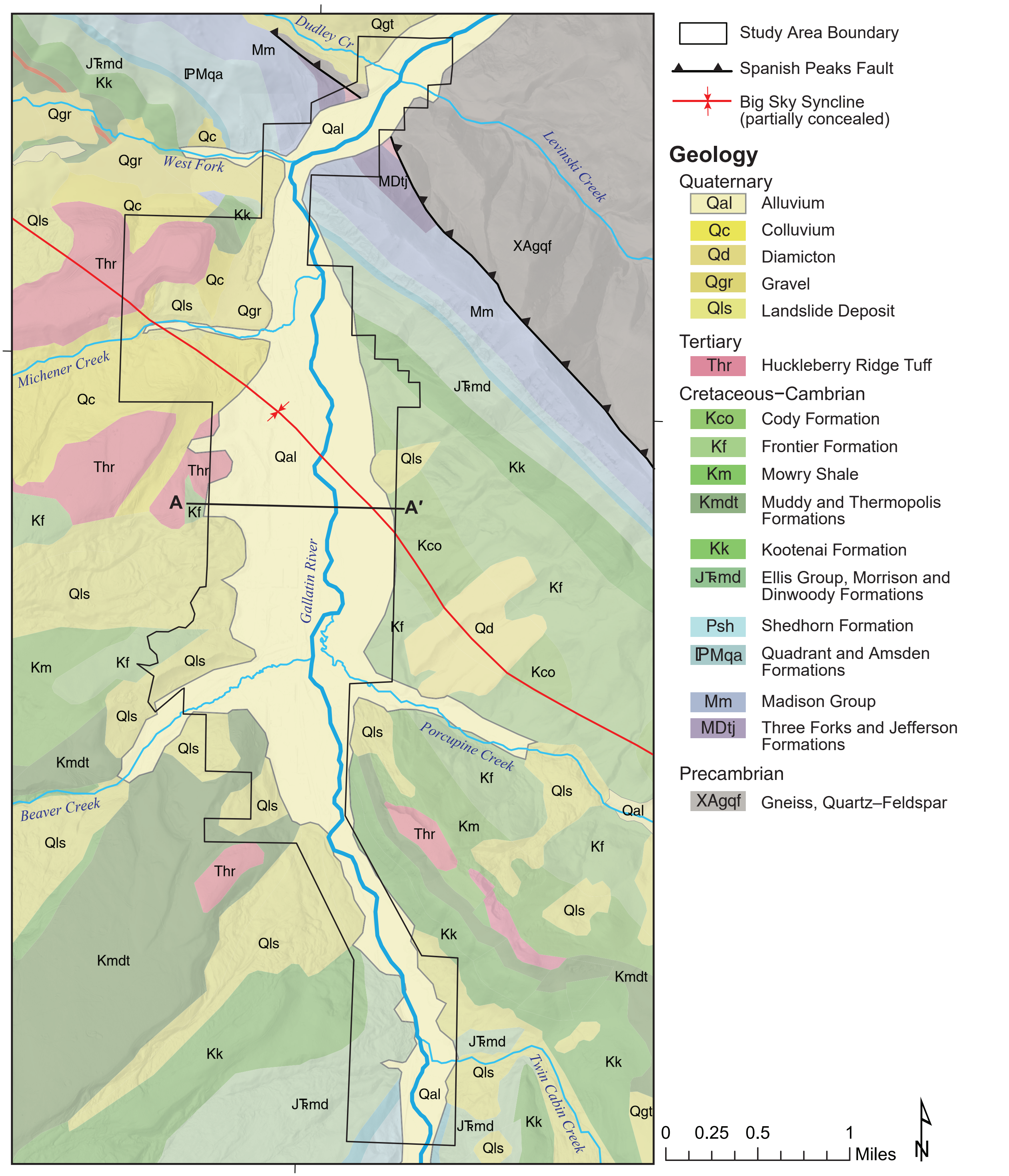

Figure 4. The study area encompasses the alluvial aquifer (Qal). Relatively impermeable Cretaceous Shale underlies most of the Qal. The Spanish Peaks fault has resulted in upturned nearly vertical beds south of the fault. Bedrock is exposed in the northern and southern sections of the study area. Cross section A–A' is shown in figure 8.

south, out of the study area, Madison Limestone is exposed along Highway 191 and the Gallatin River.

The Upper Gallatin alluvial valley is filled with Quaternary-aged sand and gravel deposits (Qal; fig. 4) that range up to 80 ft thick based on well-log data, with an average thickness of around 35 ft. Landslide and colluvial deposits locally cover the alluvium along the valley margins at the surrounding east and west hillslopes (fig. 4).

Climate

The climate in the UGRC is typical of high-elevation alpine areas in southwestern Montana, characterized by winter snowpack accumulation in the upper portions of watersheds, spring rains, and summer thunderstorms. All climate data were evaluated by water year (WY; October 1 to September 30 the following year). Water years are identified by the ending year. For example, WY 2020 began on October 1, 2019 and ended on September 30, 2020.

Snowpack

The mountains around Big Sky and the UGRC receive most of its annual precipitation as winter snowfall. Snowpack typically begins accumulating in October and continues to accumulate until the spring thaw in April or May. Snow-water equivalent (SWE) is a measure of the amount of water stored in the snowpack. As the snowpack melts, infiltration and runoff provide a source of recharge to groundwater and surface water. Historic peak Gallatin River flows at USGS Gallatin Gateway gage occur in early June.

The Lone Mountain SNOTEL (site 590; NRCS, 2024), at an elevation of 8,880 ft, is less than 10 mi from the UGRC in the Madison Range and provides a reasonable estimate of high-elevation snowpack conditions for the study area; the median annual peak SWE is 21.8 in for this station (30-yr average from 1993 to 2022). During this study, the peak SWE of 22.2 in. occurred in mid-April for WY 2020; in WY 2021, the peak SWE was 19.2 in. in early May. A rapid, early runoff and low precipitation in 2021 resulted in a drought year (NRCS, 2024).

Low-elevation snowpack is measured at the West Yellowstone SNOTEL (6,700 ft elevation, site 924; NRCS, 2025), located 43 mi south of the study area, and while not in the UGRC catchment area, it provides a long-term record of lower elevation SWE. Based on a 30-yr record, West Yellowstone SNOTEL has a median annual peak SWE of 11.6 in. In WY 2020, the peak SWE was 11.9 in, and in WY 2021, the peak SWE was 10.5 in.

Precipitation and Temperature

The UGRC receives an average of approximately 21.6 in/yr of precipitation, primarily as winter snowfall, based on the 30-yr average of water years 1993–2022 (Abatzoglou, 2013; https://www.climatologylab.org/gridmet.html). Water years 2020 and 2021 (roughly the duration of this study) were compared to the 30-yr precipitation average. Precipitation over the study area during WY 2020 was 8 percent (1.7 in) below average at 19.9 in, and during WY 2021 was 16 percent (3.5 in) below average at 18.1 in (Abatzoglou, 2013; https://www.climatologylab.org/gridmet.html; fig. 4).

Highest average maximum temperatures occur in August at 77.8°F, and average minimum temperatures occur in January at 7.5°F (WRCC, 2024; based on a period of record from 1967 to 2016).

METHODS

Groundwater Monitoring

To assess seasonal changes in water levels and groundwater flow, a network of 49 wells were monitored between 2019 and 2021 (fig. 5; appendix A, table A1). Ten alluvial aquifer monitoring wells were drilled for this project; seven were drilled on the undeveloped east side of the river in the wildlife management area to establish the base of the alluvial aquifer, monitor groundwater elevations, and establish baseline groundwater quality.

Other monitored wells included a mix of domestic, public water supply, commercial, monitoring, and unused wells. Monitoring well selection was based on well construction details, hydrogeologic setting, geographic distribution, existing measurements, and accessibility.

Water levels were measured monthly in all wells, and 31 wells were equipped with pressure transducers to get hourly measurements (appendices A and B). Access to some well locations was occasionally limited due to weather, landowner permission, or other restrictions.

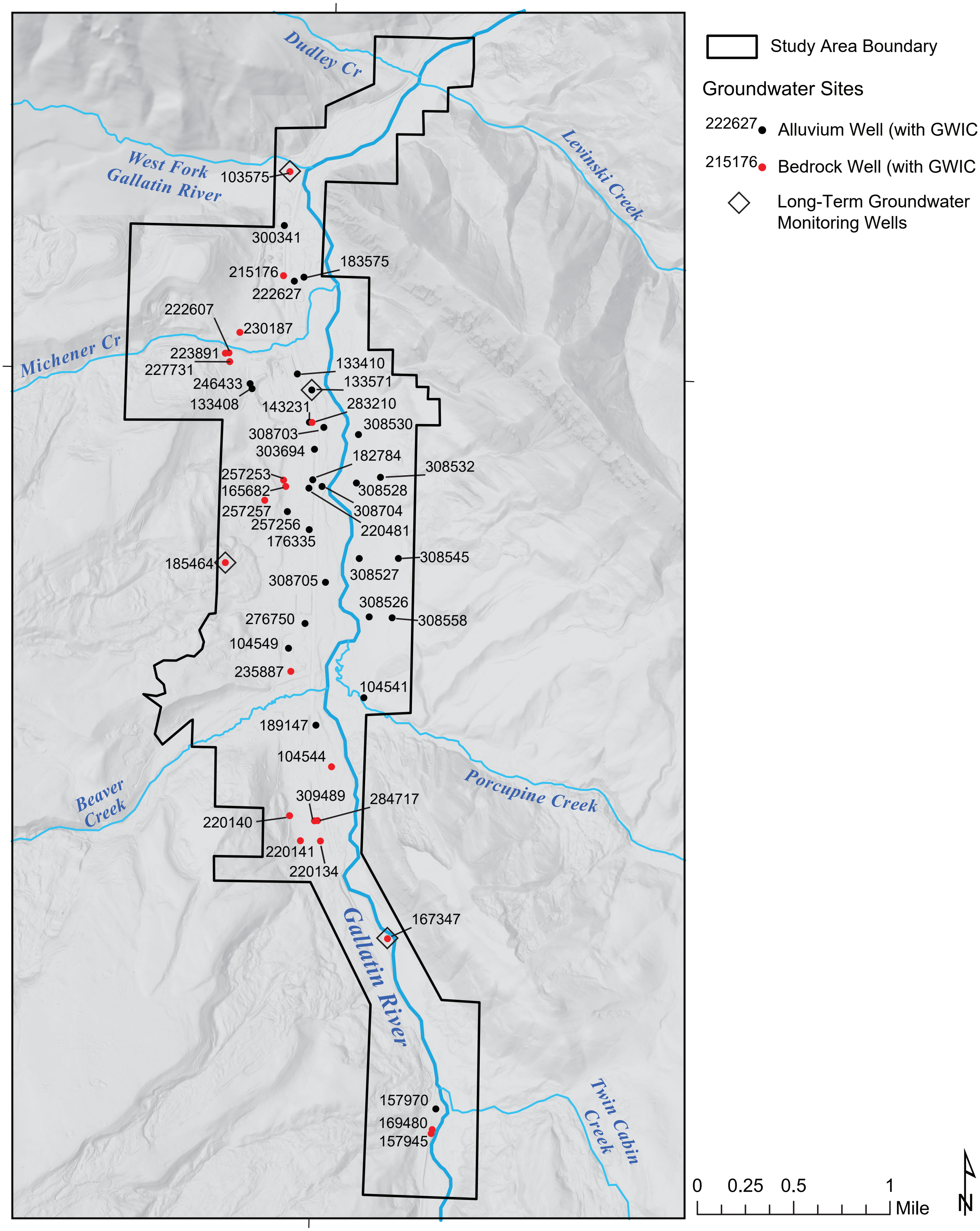

Figure 5. The groundwater monitoring network consisted of 49 wells completed in the alluvial and bedrock aquifers. Thirty-one of these wells were equipped with pressure transducers to record hourly water levels (appendix A, table A1; appendix B).

To characterize the alluvial aquifer hydrologic properties (hydraulic conductivity), aquifer tests were conducted at two wells installed for this project on the east side of the valley. Constant flow rate and single-well tests were conducted; test details and results are presented in Rose (2022).

Surface-Water Monitoring

Surface water was monitored at 20 sites (fig. 6); seven were springs (site details are included in appendix A, table A2). Stage and discharge measurements were collected monthly at 13 sites between September 2019 and June 2021, when the rivers and streams were ice-free. Measurements were obtained using handheld (acoustic Doppler velocimeter or electromagnetic current meter) or boat-mounted flow (acoustic Doppler current profiler) meters with assumed measurement errors of 5 and 3 percent, respectively. However, high-stage field measurements were less reliable due to poor channel constraints, flooding, and unsafe flow conditions.

Hourly stage measurements were also collected at 11 of the sites using a staff gage and pressure transducer. Four of these sites were on the Gallatin River, and the other six were on major tributaries: Beaver Creek, Dudley Creek, Levinski Creek, Porcupine Creek, and the West Fork of the Gallatin (fig. 6). Stage-discharge rating curves were developed for all the sites except one on the Gallatin River (site 303406) because the high and low flows resulted in large errors.

Discharge from two springs issuing from the Madison Limestone at the north end of the study area—Anceny (sites 258715, 303412 and 304093) and Big Sky Spring Creek (sites 255289, 303411)—were also monitored (fig. 6). These springs have been monitored long-term since 2011 for discharge, temperature, and water quality (MBMG, 2024). These and many other Madison Limestone springs occur in the area, discharging directly into the Gallatin River where the alluvial deposit has pinched out and limestone bedrock is exposed at the land surface and underneath the river channel (Vuke, 2013).

To quantify streamflow gains and losses to and from the alluvial aquifer, the stream-discharge data were used to develop a surface-water budget for two reaches along the Gallatin River between May and October 2021. The first reach (between sites 303405 and 303409; fig. 6) covers about 4.5 mi of the upper part of the study area, and the second reach covers about 1.5 mi of the lower part (between sites 303409 and 303415, fig. 6).

The net streamflow gain or loss was calculated as the difference between the inflows and the outflows in each reach and is expressed as:

$$GR_{Flow\ out} - Trib_n - \mathrm{GR}_{Flow\ in} = GR_{loss/gain},$$

where GR_{out} is outflow of the Gallatin River; $Trib_n$ is tributary inflow from n sites; GR_{in} is inflow of the Gallatin River; for $GR_{gain/loss}$ river gain is groundwater discharge from the alluvial aquifer to the Gallatin River, and river loss is groundwater recharge to the alluvial aquifer from the Gallatin River.

The error for $GR_{gain/loss}$ was calculated as the root of the squared sum of the discharge errors.

Water-Quality Sampling

Water samples were collected from groundwater and surface-water sites to characterize the water chemistry and assess the effects of septic effluent on water quality. Thirty-two groundwater sites (appendix A, table A1; appendix C, table C1, available online) were sampled for major ions, trace metals, nitrate (and total nitrogen), and water isotopes ($\delta^{18}O$ and δD; appendix C, table C2, available online). A subset of samples was analyzed for nitrate only (see below). One-time samples were collected from bedrock wells. Well locations and the number of samples collected at each site are shown in figure 7 and appendix A (table A1).

Seventeen wells and one spring were sampled between 8 and 14 times to evaluate nitrate trends. Monthly samples were collected from January 2020 through August 2021 (COVID-19 suspended field investigations in March and April 2020).

Surface-water samples were collected at all monitored sites for major ions, trace metals, and nitrate (appendix A, table A2). Samples were collected periodically during low-flow conditions in July, August, and October 2020. Sites with detectable nitrate underwent additional sampling in November 2020 and January–July 2021.

Samples were collected in accordance with MBMG Standard Operating Procedures (Gotkowitz, 2023) and analyzed by the MBMG Analytical Laboratory per methods outlined in Timmer (2020).

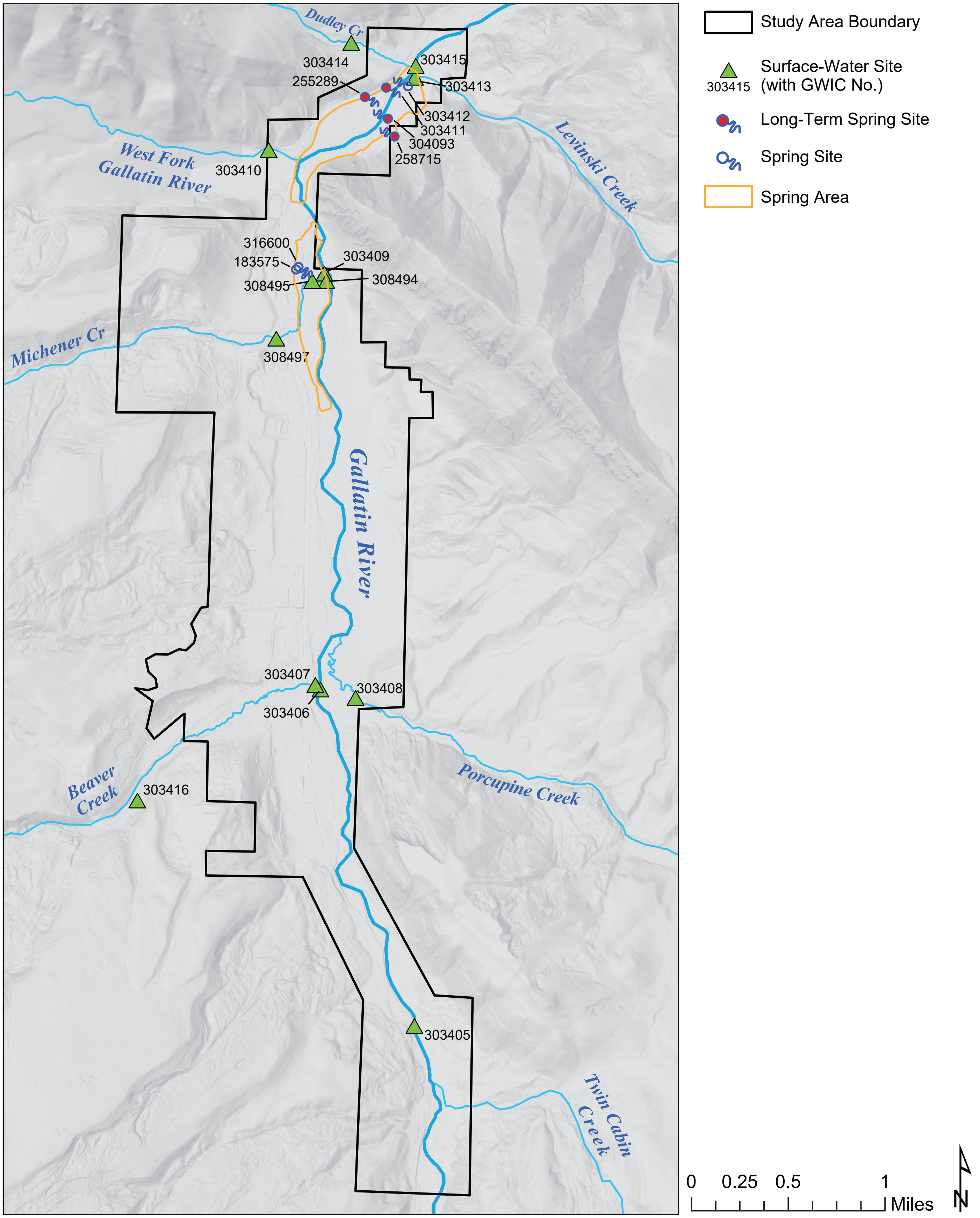

Figure 6. Twenty surface-water sites were monitored for stage and discharge. Eleven sites were equipped with pressure transducers during this study (appendix A, table A2).

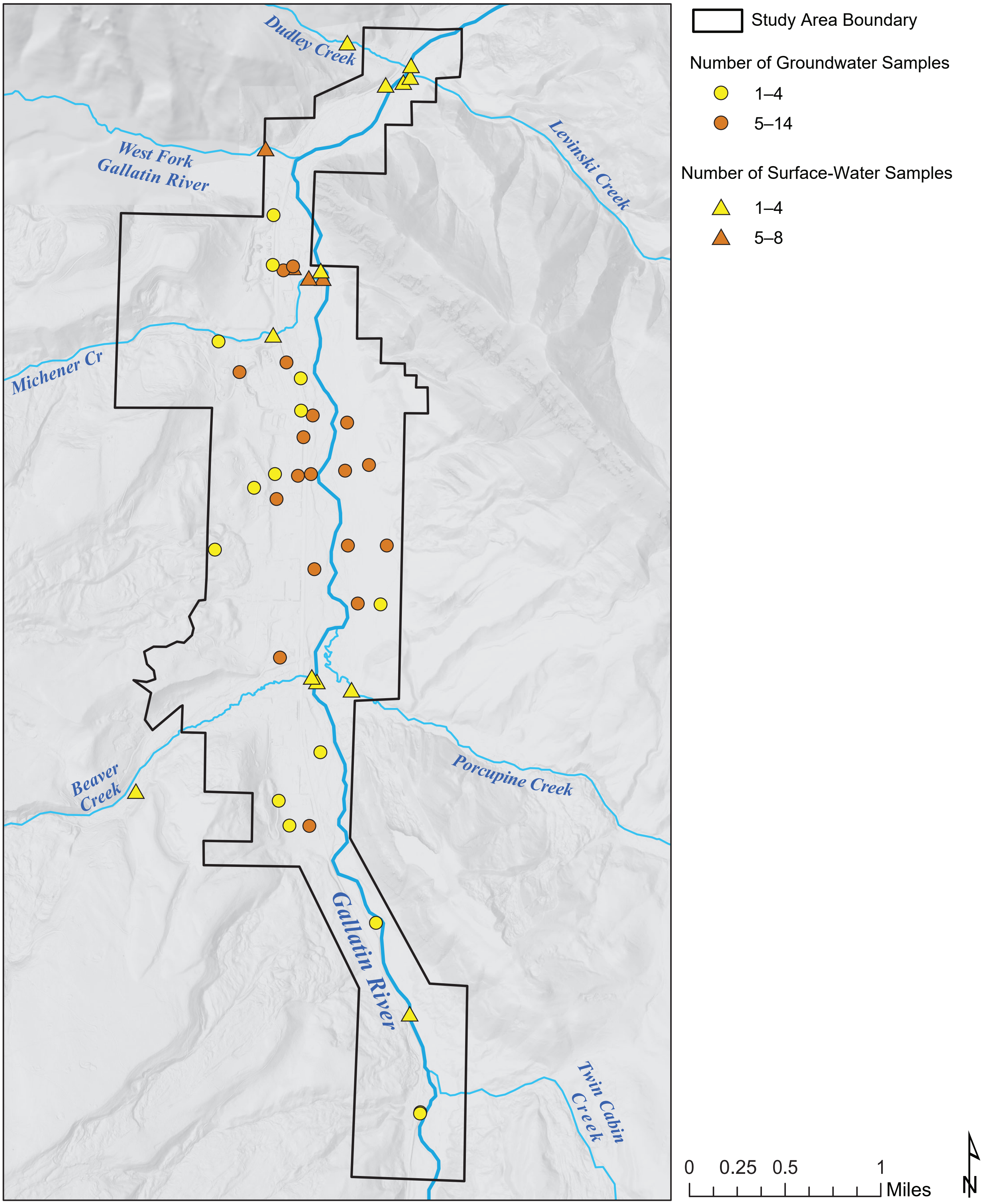

Figure 7. Thirty-two groundwater and all surface-water sites were sampled for major ions, trace elements, nitrate/nitrite, total nitrogen, and water isotopes.

Duplicate samples for quality analysis and control were collected approximately every tenth sample. Field measurements of temperature, pH, and specific conductance were recorded at the time of collection. Water chemistry results and field parameters are presented in appendix C (online at the website for this publication) and available from the Ground Water Information Center (GWIC) database (MBMG, 2024).

Nitrate Laboratory Analysis

Two analytical methods were used to measure nitrate concentrations: ion chromatography (IC; method EPA 300, detection limit 0.01 mg/L) and a spectrophotometer (detection limit 0.2 mg/L). The spectrophotometer method was used on every sample; however, the IC method was only used on samples where the total anion/cation composition of the sample was analyzed. While the IC can measure the concentration of nitrate (NO_3) and nitrite (NO_2) separately, the spectrophotometer measures total nitrate and nitrite. Because there is rarely any measured nitrite, the two methods provide similar results for the concentration of nitrate as nitrogen (reported here as nitrate in mg/L). However, the spectrophotometer method generally reported nitrate concentrations approximately 85 percent that of the reported concentration from the IC method for the samples collected in this study. When results from both methods are available, this report quotes the result from IC; when a range is reported, both methods are considered.

Data Management

All data collected for this project are archived in the MBMG GWIC database (MBMG, 2024) and can be obtained from the "Upper Gallatin project" page within the GWIP section of the MBMG website (https://mbmg.mtech.edu). The groundwater and surface-water sites monitored for this study are assigned GWIC ID numbers (i.e., well 235887 or site 308497, respectively). The database archives information on well completions, groundwater levels, water chemistry, aquifer test analyses, and other hydrological or geological data.

RESULTS

Hydrogeologic Framework

The unconsolidated Upper Gallatin River aquifer (UGA) is shallow and unconfined, consisting of unconsolidated sands and gravels. The UGA includes the extent of the Quaternary alluvium deposited by the Gallatin River and its tributaries (Qal; fig. 4). Much of the Quaternary alluvium is less than 30 ft thick, limiting its storage capacity and ability to provide sufficient water for domestic purposes. The underlying bedrock units contain four sandstone and shale aquifers within the Cretaceous-aged Frontier, Muddy, Kootenai, and Morrison Formations. The Madison Limestone forms a fifth bedrock aquifer. These bedrock aquifers are described in Rose and Waren (2022).

There are about 250 wells completed in the UGA and bedrock aquifers within the study area; there are nearly twice as many bedrock wells as alluvial wells. Table 1 lists the well use by aquifer (UGA or bed-

Table 1. Well use by aquifer (percent).

Upper Gallatin Aquifer		Bedrock		Unknown Aquifer[1]	
n = 62	Percent	*n* = 135	Percent	*n* = 52	Percent
Domestic	44	Domestic	72	Domestic	79
Monitoring	32	Monitoring	7	Monitoring	2
PWS	11	PWS	9	PWS	4
Irrigation (lawn and garden)	3	Irrigation (lawn and garden)	3	Irrigation (lawn and garden)	2
Unused	3	Unused	0	Unused	4
Other (commercial, test well)	7	Other (commercial, industrial, stock, unknown)	9	Other (commercial, fire protection, test, other)	10

[1]No geologic description in the drillers' log.

rock); most wells have a reported use of domestic for both aquifers followed by monitoring and public water supply.

Upper Gallatin Aquifer

Based on available well log data and MBMG test drilling, the UGA has an average thickness of approximately 35 ft and reaches a thickness of about 60 ft. The thickest and most productive part of the aquifer is found just west of the Gallatin River (fig. 8; Zeiler and others, 2025). The alluvium thins and pinches out along the margins of the valley (fig. 8) and in the northern and southern ends of the study area where bedrock is closer to the surface. East of the Gallatin River, the saturated thickness is less than 30 ft (Zeiler and others, 2025), limiting its use as an aquifer. The water table is generally between 5 and 40 ft below ground surface. Well yields in the UGA range from about 3 to 75 gpm and average 29 gpm (MBMG GWIC, 2025). Relatively impermeable shale underlies a large portion of the UGA. In the northern end of the study area, the alluvial deposit thins as steeply dipping bedrock becomes closer to the land surface.

Snowmelt, surface-water losses, and precipitation recharge the UGA. The Gallatin River is generally gaining, indicating the groundwater discharges to the river. The aquifer is directly connected to the Gallatin River and its tributaries. Synoptic measurements from sites on Beaver Creek generally show losing conditions where it leaves the impermeable Cretaceous bedrock and flows across the highly permeable alluvium, near the confluence with the Gallatin River (see fig. 6 for location; see the Tributary Streams section for gain/loss calculations).

Groundwater flow from the underlying bedrock aquifer into the alluvial aquifer occurs in the northern section of the study area and along the eastern edge of the valley near the Wildlife Management Area (discussed in the Bedrock Aquifer and Water Chemistry sections). The bedrock PWS wells also discharge to the alluvial aquifer via septic systems. Large rainfall events recharge the aquifer, observed as water-level rises in hourly hydrographs (Groundwater Fluctuation section). The response to rainfall, as well as the shallow, unconfined nature of the aquifer, indicate its vulnerability to contamination from the land surface.

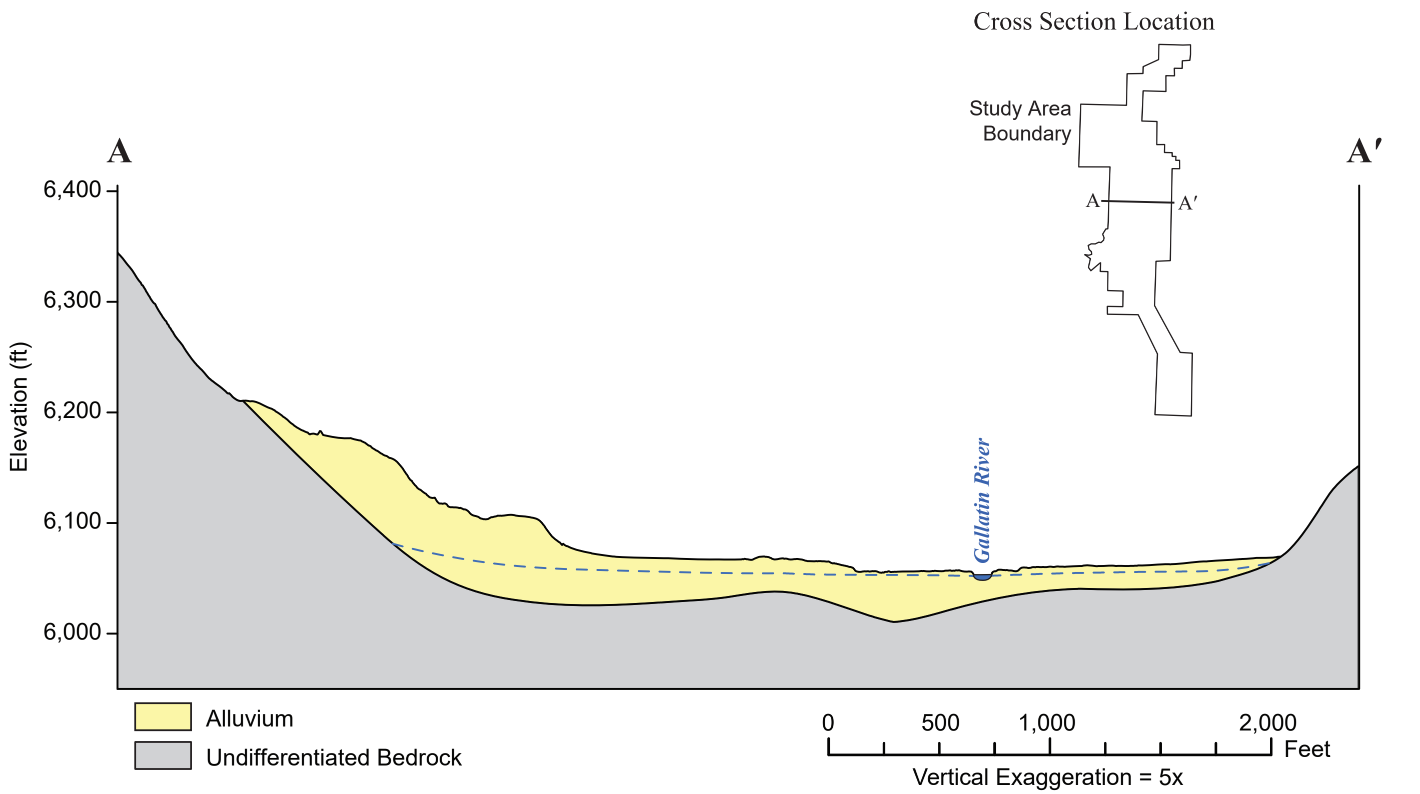

Figure 8. Schematic cross section of the Gallatin River Valley. The saturated thickness of the aquifer is thickest west of the Gallatin River. The aquifer pinches out along the valley margins. The cross section line is also shown on the geology map (fig. 4).

The alluvial aquifer potentiometric surface during low-flow conditions (October 2020) shows that groundwater flows to the north parallel to or towards the river (fig. 9). The hydraulic gradient near the river is around 0.008 ft/ft, and the contours indicate that the river is generally gaining during low-flow periods. In the north, the aquifer discharges into lower Michener Creek, several springs and spring fed ponds, and the Gallatin River. The river gains a significant amount water from the UGA as the alluvial deposits thin (see Gallatin River Water Budget section).

Transmissivity, estimated from aquifer tests on the east side of the Gallatin, ranges from 5,300 to 7,500 ft^2/d, and the estimated hydraulic conductivity ranges from 380 to 360 ft/day (Rose, 2022). Although the hydraulic conductivity estimates fall within the range of expected values for alluvial aquifers (Driscoll, 1995), the aquifer was not sufficiently stressed due to low pumping rates.

<u>Bedrock Aquifers</u>

Bedrock units include Archean metasediments and Cambrian through Cretaceous sedimentary formations (fig. 4; Kellogg and Williams, 2006; Vuke, 2013). Adjacent to and underlying the alluvial aquifer, in the Cretaceous and Jurassic formations groundwater occurs in thin sandstone layers (~ 10 ft thick) within the much thicker shale units (hundreds to thousands of feet thick). Bedrock wells monitored for this study ranged from 40 to 1,490 ft deep.

Bedrock aquifer well yields range from <1 gpm to 180 gpm and average about 34 gpm (MBMG GWIC, 2025). Bedrock public water supply wells provide water for most of the larger subdivisions. Public water supply wells for the Blackfoot Hills and Ramshorn subdivisions are completed in the Kootenai and upper Morrison aquifers; the wells range from about 1,300 to 1,500 ft deep (see fig. 5 for well locations) and yield between 120 and 180 gpm. However, other reported Kootenai well yields are as low as 14 gpm (227731, PWS well for Lazy J subdivision, 1,325 ft deep). There are also records of individual domestic wells that range from 26 to 490 ft deep and yield between < 1 and 125 gpm. Water pumped from the bedrock aquifers discharges to the alluvial aquifer via septic systems. While not volumetrically significant, the discharges may affect water quality in the UGA.

The deep Kootenai wells in the central part of the study area are flowing artesian with reported heads as much as 369 ft above the land surface (e.g. 227731). Despite the upward gradient between the Kootenai aquifer and the alluvium, the lithologic data show over 1,000 ft of shale separating the two aquifers, preventing any direct hydraulic connection in this part of the study area.

Within most of the study area, the Madison Limestone occurs at depths greater than 1,000 ft. However, south of the study area it crops out along the southern limb of the Big Sky anticline, and the Gallatin River flows over the exposed limestone. In the northern end of the study area, the Madison is exposed at the land surface along the Spanish Peaks fault. A series of large springs issues from the Madison Limestone on both sides of the river, upwelling into the river itself. The average discharge from the Madison Limestone to the Gallatin River is estimated to be 66 cfs for 2020 and 116 cfs for 2021 (see Gallatin River Water Budget section), contributing to river flow and benefiting the fishery. Wells drilled into the Madison Limestone in this area are shallow, typically less than 100 ft total depth. Several domestic and one PWS well have been completed in the Madison Limestone in the area. Increased pumping from these or any new high-capacity Madison Limestone wells may reduce area spring flow and flow into the Gallatin.

Groundwater Fluctuations

<u>Alluvial Aquifer</u>

Hydrographs for wells equipped with pressure transducers recording hourly levels are included in appendix B. Water levels in the alluvial aquifer rise in the spring, usually peaking between April and June, in response to recharge from snowmelt. Several wells exhibited a bi-modal spring peak response, with water-level highs occurring in early April and late May coinciding with low- and high-elevation snowmelt events (fig. 10A). The timing of stage increases on the Gallatin River coincides with the groundwater level increases and follows the snowpack melt (fig. 10B). The groundwater-level and stream-stage data confirm that the groundwater/surface-water system is dominated by snowmelt.

Following the spring runoff peak, groundwater levels decline through the summer and typically reach

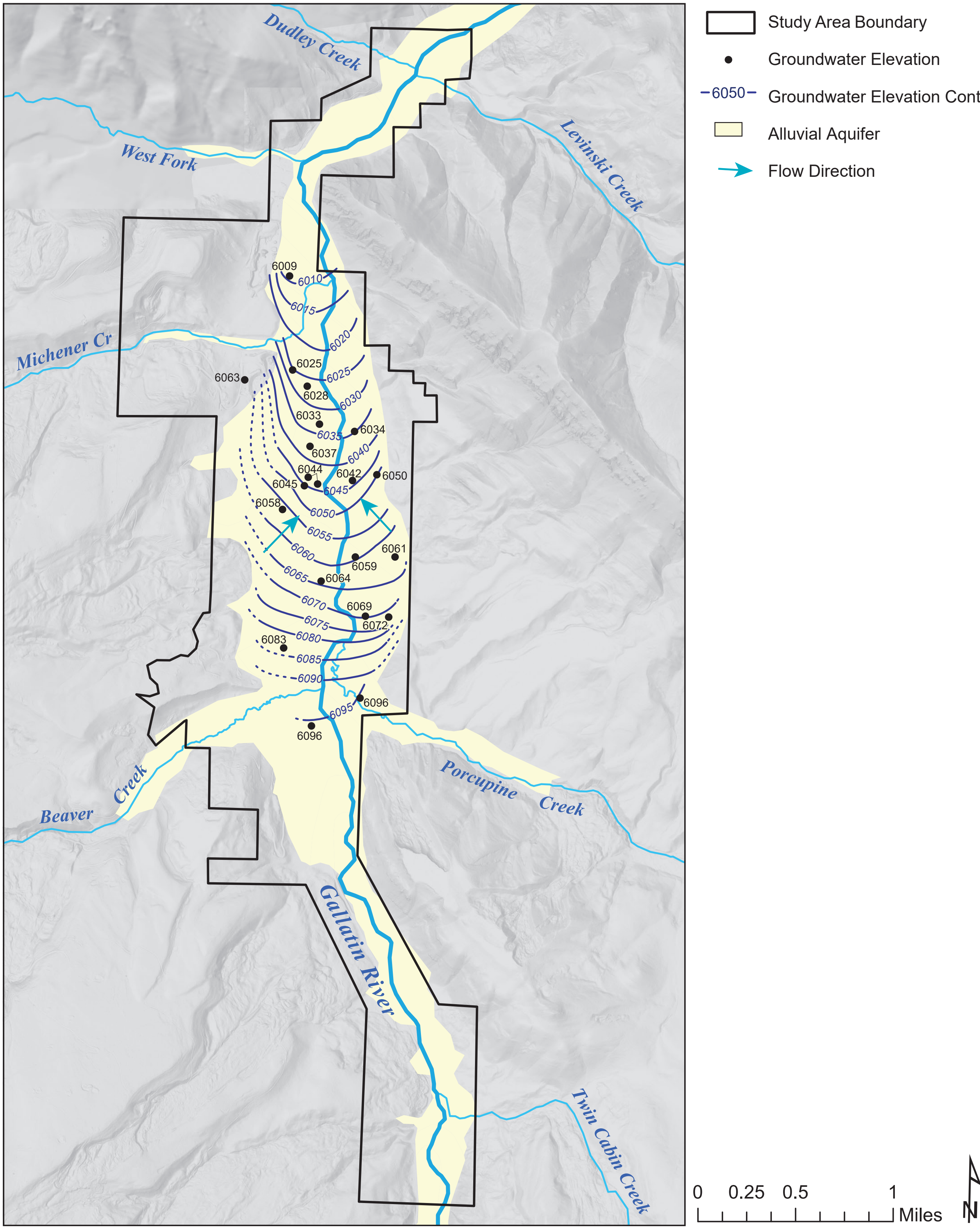

Figure 9. Average groundwater elevations from October 2020 indicate that groundwater flows from south to north nearly parallel or towards the river.

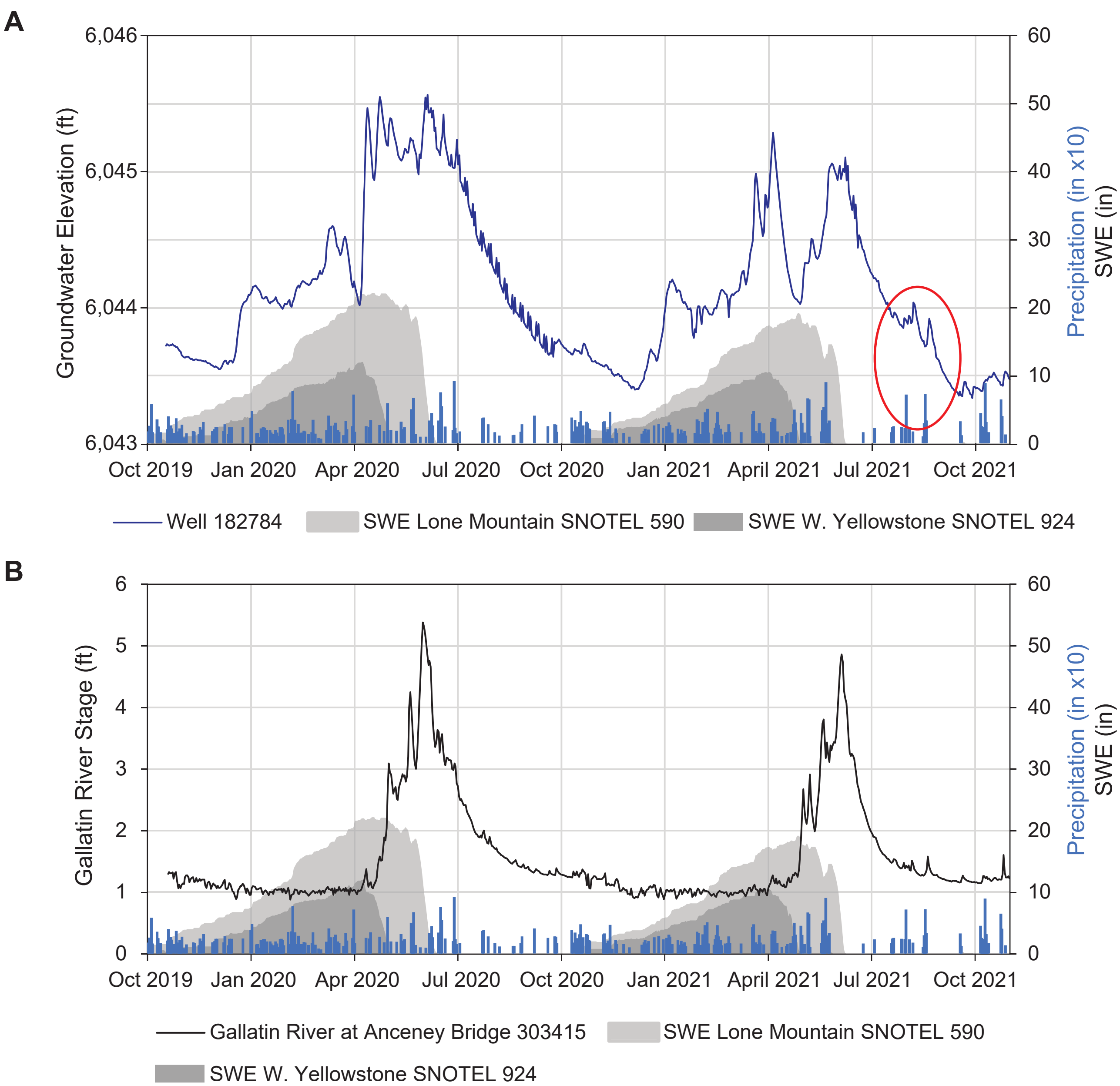

Figure 10. The hydrograph for well 182784, completed in the alluvial aquifer, shows a bimodal spring in both 2020 and 2021. These peaks correspond to the timing of low- and high-elevation snowmelt (SWE; A) and also correspond to an increase in stream stage (B). Circled area on hydrograph for well 182784 is an example of precipitation influencing groundwater levels.

minimum levels between October and November (fig. 10A). Small water-level increases in the late fall and winter months are likely associated with the cessation of evapotranspiration, ice jams in the river causing groundwater levels to rise, or direct infiltration from Chinook weather patterns (Glenn, 1961; Oard, 1993). Chinook weather patterns often result in intermittent, temporary warming and snowmelt, usually occurring in January. The timing of these processes may coincide, and therefore no single cause can be isolated for late-season water-level increases.

High-frequency (hourly), low-magnitude (< 1 ft) water-level fluctuations were observed in a subdivision irrigation well (18274; fig. 10A). These are localized effects that occur daily from 4 am to 7 am and do not affect the overall seasonal decline in the hydrograph from June through December (fig. 10A). Declining groundwater levels are evident throughout the alluvial aquifer during this period (app. B) and are attributed to drier climatic conditions after spring runoff, not domestic well usage.

Across the alluvial aquifer, groundwater levels rose between 1 and 3 ft in the spring and early summer. The largest increase was observed in well 104541 (appendix B) located near Porcupine Creek, where water levels rose about 6 ft in 2020 and about 4 ft in 2021.

Long-term water-level data (since 2005) are available from a 31-ft-deep alluvial well located on the west side of the Gallatin River, south of Michener Creek (well 133571; fig. 11A). The measurement frequency varies over the period of record (quarterly, monthly, and hourly), but the data show a regular seasonal response. A Seasonal Kendall trend test (Helsel and others, 2020) using average monthly elevations indicated there were no significant water elevation trends (*p*-value = 0.88). A *p*-value ≤0.05 was considered statistically significant. Note that the period of hourly data from May 2019 through June 2022 coincides with a period of below average precipitation (fig. 11D). The difference in the water-level high in 2020 compared to 2021 was less than a foot. During 2020, the SWE was higher at both high elevations (Lone Mountain SNOTEL) and low elevations (West Yellowstone SNOTEL) compared to 2021.

Bedrock Aquifers

Data from two shallow Kootenai bedrock wells (220134 and 167347) show seasonal water-level variations, similar to the alluvial aquifer, with highs occurring between April and June and lows in February and March (fig. 12). Generally, bedrock water levels rise quickly in the spring during snowmelt, then decrease slowly back to a minimum over the summer and fall; the magnitude of fluctuation was 3 to 6 ft during the study period. In general, the bedrock groundwater peaks were delayed compared to the alluvial groundwater peaks, and they do not show the same high-frequency water-level changes (fig.12A).

Two other bedrock wells, one completed in the Frontier Formation (185464, 115 ft deep, measured since 2001) along the western border of the study area and one completed in the Madison Limestone (103575, 40 ft deep, measured since 2008) near the confluence of the West Fork (see fig. 5 for location) have long-term water-level data. Statistical analysis of groundwater data from well 185464 using the Seasonal Kendall trend test and average monthly elevations indicated no significant water-elevation trend (*p*-value = 0.24). Statistical analysis of groundwater-level data in well 103575 showed a statistically significant trend (*p*-value = 0.015). A Sen Slope (Helsel and others, 2020) was calculated to provide a linear estimate of the groundwater trend. The Sen Slope (Helsel and others, 2020) estimated an increasing water-level trend of 0.015 ft/yr (fig. 11C). Over the period of record, this would account for an increase of approximately 0.3 ft.

Surface Water

Data from the surface-water monitoring (Gallatin River and tributary streams) show characteristic snowmelt-dominated hydrographs with high flows and stages occurring in the spring and early summer (April –June) and the lowest flows occurring from mid-summer (late July) through the fall and winter. The Lone Mountain and West Yellowstone SNOTEL sites clearly show the relationship between snowmelt (observed decrease in SWE) and stream flow (fig. 10B).

Gallatin River

Summary flow statistics for 11 surface-water sites (Gallatin River and tributaries) are presented in table 2. On the Gallatin River, flow was monitored at the upstream and the downstream study area boundaries (sites 303405 and 303415, respectively, fig. 6); the total area drained by these sites is 533 mi^2 (USGS, 2019). Flow on the Gallatin River entering the study area ranged from 75 to 2,000 cfs; flow leaving the study area ranged from 175 to 3,610 cfs (table 2).

Tributary Streams

Seven tributary streams originating outside the study area contribute flow to the Gallatin River. These streams have a similar observed hydrograph pattern as the Gallatin River, except for Michener Creek, which is dam-controlled.

The West Fork is the largest tributary, entering the Gallatin River north of the extent of the UGA. Flows ranged from 10.7 to 1,060 cfs (table 2), and nitrate values at times exceeded the aquatic life standard (see Chemistry section).

Beaver and Michener Creeks, on the west side of the valley, flow over relatively impermeable bedrock before flowing onto the highly permeable alluvium, where they lose water into the UGA. Beaver Creek loses water into the alluvium recharging the southern portion of the UGA. Our manual measurements

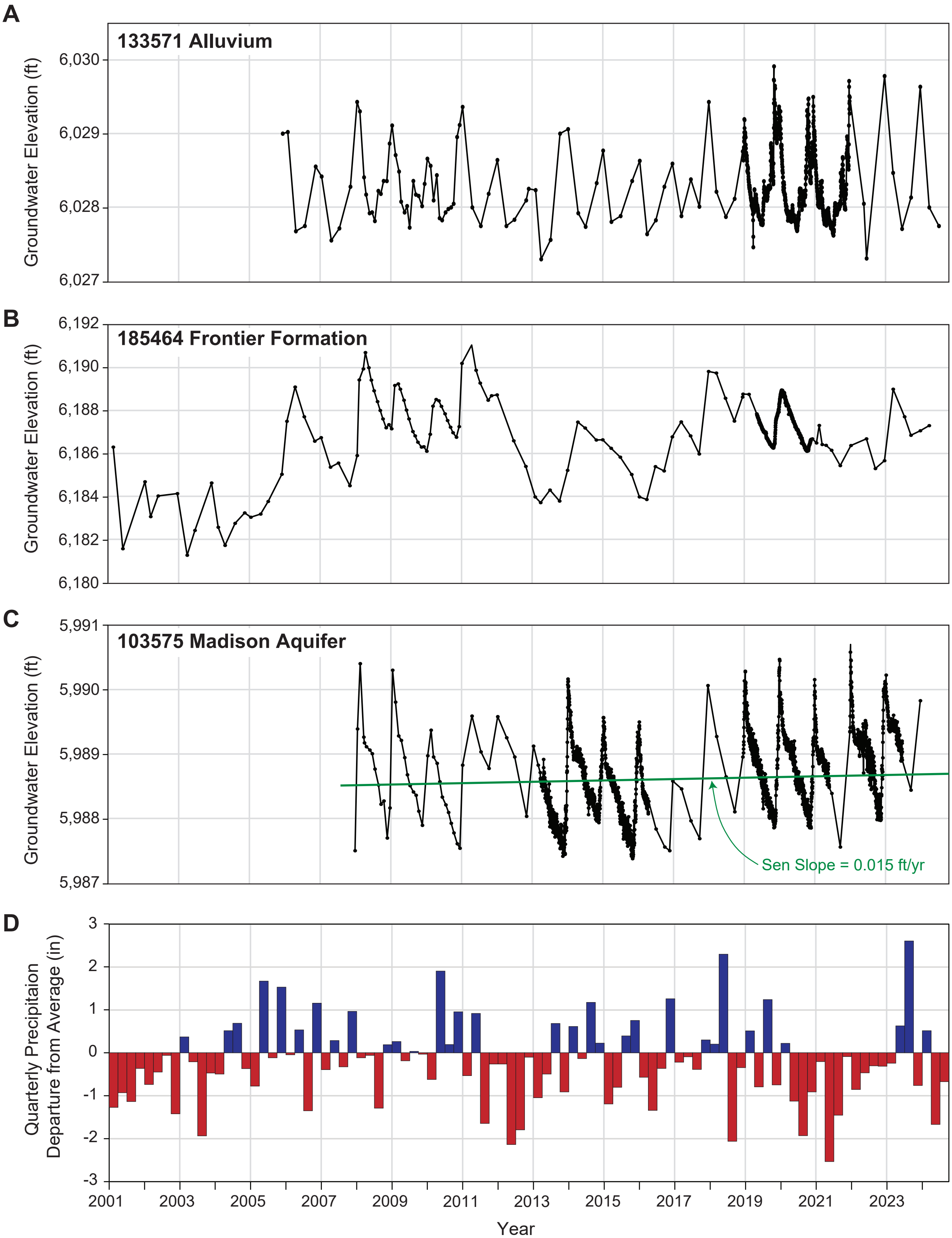

Figure 11. Groundwater levels in wells 133571 and 103575 showed no significant trends. Statistical analysis of groundwater levels in well 103575 indicate an increasing trend of 0.015 ft/yr. Groundwater-level fluctuations are driven by climate, including precipitation and melting of mountain snowpack. Note vertical scale difference in A, B, and C. Precipitation data from MBMG (2025).

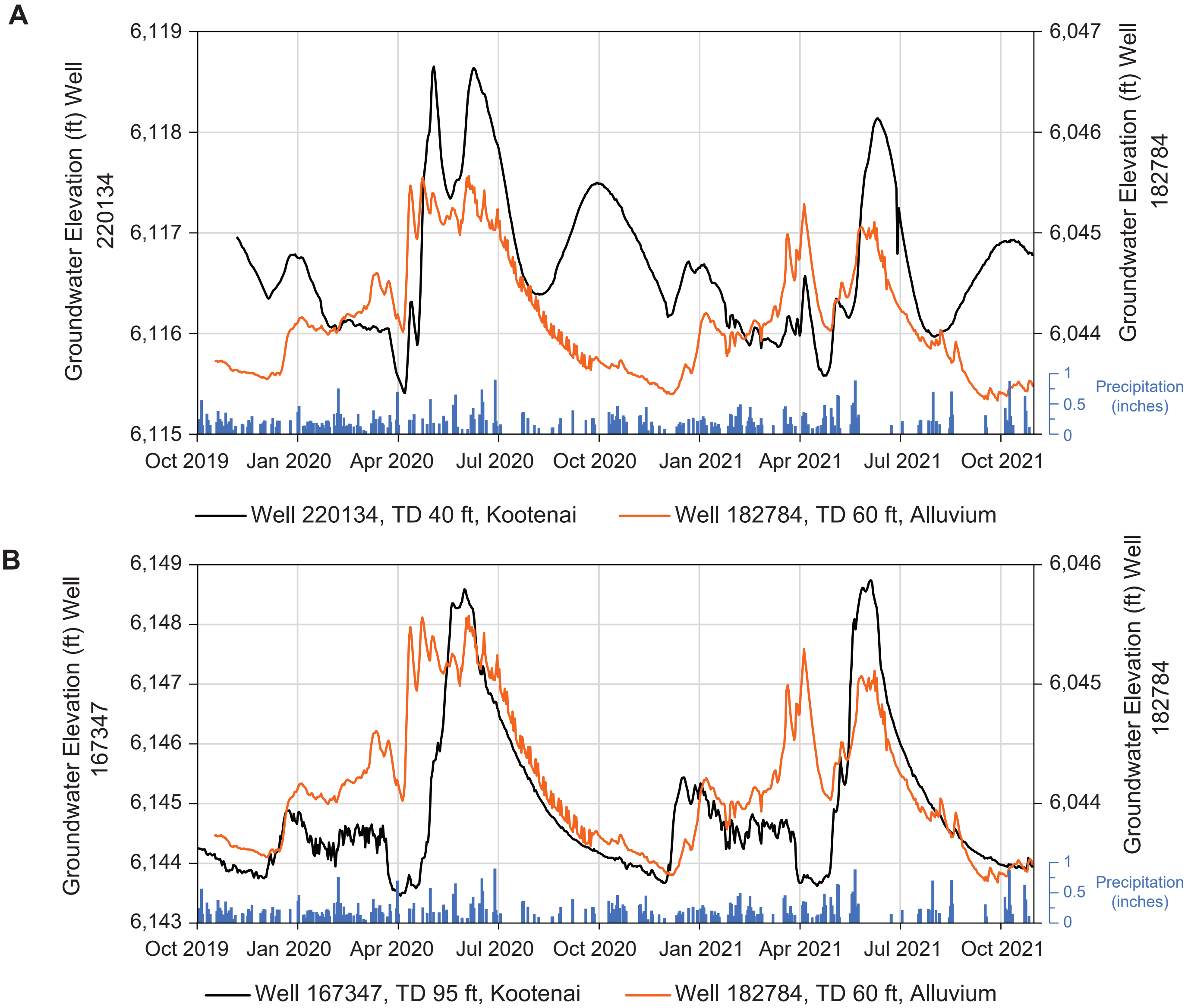

Figure 12. The groundwater peaks are delayed in bedrock wells 220134 (A) and 167347 (B) when compared to groundwater in well 182784, completed in the alluvial aquifer.

calculated an average loss of 1.50 cfs between sites 303416 and 303407 (approximately a 1.3-mi reach); however, calculated gain/loss ranged between a gain of 1.04 cfs and a loss of 7.15 cfs (table 3). Of the 10 synoptic measurements that had calculated gains or losses that exceeded measurement error, seven of those calculations indicated a loss to the aquifer.

Michener Creek flows under Hwy 191, where it begins to act as a groundwater drain, gaining flow and nutrients from the UGA as it winds through a wetland area before discharging to the Gallatin River. Periodic manual discharge measurements ranged from less than 1 cfs to about 2 cfs.

Springs

In the northern part of the study area, springs issue from the UGA in the area west of the river on the floodplain, south of the juncture of the West Fork and the Gallatin River (sites 183575 and 316600; fig. 6); there are several spring-fed ponds. Springs discharge water to the Gallatin River, where the alluvial sand and gravel thins and upturned bedrock becomes closer to the land surface.

North of the West Fork, the Madison Limestone aquifer springs, near the Spanish Peaks fault, discharge large amounts of water to the Gallatin River. Two of the springs, Big Sky Spring (sites 303411 and 255289) and Anceny Spring (sites 258715, 316600,

Table 2. Discharge ranges for the Gallatin River and its tributaries.

Site Name	GWIC No.	Period of Record	Drainage Area[1] (mi²)	WY 2020 (cfs) Min	WY 2020 (cfs) Max	WY 2020 (cfs) Ave	WY 2021 (cfs) Min	WY 2021 (cfs) Max	WY 2021 (cfs) Ave
Gallatin River below Twin Cabin Creek	303405	Jul–Nov 2019, Mar–Oct 2020, May–Nov 2021	390	74.8	2,000	418	108	1,530	359
Gallatin River at Wildlife Management Area	303409	Jun–Oct 2020, May–Nov 2021	440	175	1,100	339	81.0	2,110	438
Gallatin River at Anceny Bridge	303415	Oct 2019–Nov 2021	533	175	3,610	544	176	2,970	438
Porcupine	303408	Oct 2019–Oct 2020, Apr–Oct 2021	26.0	5.04	148	15.9	5.68	157	36.3
Beaver Creek	303407	Oct 2019–Oct 2020, Apr–Oct 2021	14.9	0.32	100	9.01	5.34	149	27.9
Michener Creek	308497		2.00	(see report text)					
West Fork Gallatin River	303410	Oct 2019–Oct 2020, Apr–Oct 2021	80.1	10.7	1,030	88.0	19.4	1,060	143
Levinski Creek	303413	Oct 2019–Oct 2020, May 2021–Oct 2021	4.30	1.22	17.7	2.32	0.72	9.41	1.58
Dudley Creek	303414	Jun 2020–Oct 2020, Apr–Oct 2021	7.60	4.65	36.8	9.08	0.00	29.3	2.90
Big Sky Springs Channel	303411	Oct 2019–ongoing	NA	11	11.7	11.25	10.9	11.7	11.3
Anceny Spring Pond Outlet	303412	Sep 2019–Oct 2020	NA	4.14	4.92	4.31	3.88	4.85	4.17

[1]Data obtained from USGS StreamStats (https://streamstats.usgs.gov/ss/).

Note. Spring sites 183575 and 316600 are not listed in the this table. Site 183575 only had four manual measurements and site 316600 is a pond in which only stage was measured. For Beaver Creek and Michener Creek, only the the downstream gage site is listed in this table. For a full list of sites, see appendix A, table A2.

and 393412; appendix A, table A2; fig. 6), discharge into discrete spring creek channels. Flow at Big Sky Spring Creek site 303411 was consistent throughout 2020 and 2021, ranging from 10.8 to 11.8 cfs and averaging about 11.2 cfs. Hourly temperature data from long-term monitoring site 255289 at the head of Big Sky Spring Creek shows an average temperature of around 57°F (14°C).

East of the Gallatin River, flow at Anceny Springs (site 303412) was fairly consistent throughout the year, averaging about 4.2 cfs and ranging between 3.9 to 4.3 cfs, with an increase in late summer and fall. Hourly temperature data from long-term monitoring site 258715 at the head of the Anceny Spring shows an average temperature of around 63ºF (17ºC). The warm temperatures and consistent flow of these springs indicate a long flowpath with deep circulation. The somewhat lower temperatures recorded at 255289 (Slow Vehicle Spring) on the west side of the river may indicate some localized recharge where upturned Madison Limestone outcrops at higher elevation.

Gallatin River Water Budget

A surface-water budget was developed for two reaches of the Gallatin River to assess the relationship of surface water to groundwater. For each reach, the flow leaving the study area was subtracted from tributary inflows and the difference was then subtracted from the flow entering the study area. The difference in flow was attributed to groundwater discharge to the river (a gain in river flow if flow leaving was greater than flow entering) or groundwater recharge from the river to the aquifer (a loss in river flow if flow leaving was less than flow entering).

The upstream reach between sites 303405 and 303409, and the downstream reach between sites 303409 and 303415 (see fig. 6), were monitored from late June to late October 2020, and from May through October 2021. Sites 303405 and 303415 recorded discharge coming into and out of the study area, respectively. Site 303409 is located between sites 303405 and 303415 before a pinch point where the Madison Limestone outcrops in the northern section of the study area.

Table 3. Manual discharge measurement (cfs) and gain (+)/losses (-) calculated on Beaver Creek.

	Site 303416		Site 303407		Gains/Loss	
Date	Discharge	Error	Discharge	Error	Loss	Error
9/18/2019	2.37	0.12	2.56	0.13	**0.19**	0.17
5/20/2020	54.1	2.71	48.4	2.42	**-5.71**	3.63
6/25/2020	20.2	1.01	18.4	0.92	**-1.85**	1.37
7/9/2020	8.67	0.43	8.57	0.43	-0.10	0.61
7/21/2020	4.08	0.20	4.46	0.22	**0.38**	0.30
8/26/2020	1.99	0.10	1.67	0.08	**-0.32**	0.13
9/30/2020	1.41	0.07	1.28	0.06	**-0.13**	0.10
10/19/2020	2.14	0.11	1.65	0.08	**-0.49**	0.14
4/27/2021	2.72	0.14	2.76	0.14	0.04	0.19
5/5/2021	13.2	0.66	14.2	0.71	**1.04**	0.97
5/18/2021	37.9	1.90	38.8	1.94	0.93	2.71
6/8/2021	67.5	3.37	60.3	3.02	**-7.15**	4.53
6/30/2021	8.6	0.43	7.69	0.38	**-0.91**	0.58

Note. 5% error was used for hand-held manual measurements. Bolded numbers represent value outside the calculated error.

Rivers are dynamic, complex systems and can be gaining in one section of a reach and losing in another. They can also change from gaining to losing in the same reach depending on the time of year and climatic patterns. The distance of the upstream reach (between sites 303405 and 303409, fig. 6) is about 4.5 mi; the gains/losses for 2020 and 2021 are presented in figure 13. During the 2020 runoff period, there was a gain in the Gallatin River calculated during the end of the spring runoff (June–mid-July; fig. 13A). From mid-July through mid-October, although within the margin of error, the data suggest that the Gallatin River was in equilibrium with no measurable gains/losses. For 2021, besides one large spike in river gains during spring runoff (early June), there was a consistent calculated loss of about 50 cfs (fig. 13B). In 2021, recharge from mountain snowpack was less than in 2020, possibly contributing to the loss in river flow from July to November 2021. After the Gallatin River flows past site 303405, the valley widens and the alluvial sediments thicken. This is most likely where the river loss is occurring. During higher flows, such as 2020, the loss can still occur in this area, but the flows in the river are high enough to mask it.

The gains/losses of the downstream reach (approximately 1.5 mi) for 2020 and 2021 are presented in figure 14. The results show that after the spring runoff (late July), there was a consistent gain in flow of approximately 60–70 cfs (average of 65 cfs) in 2020 and about a 105–120 cfs (about 116 cfs) gain in 2021 (figs. 14A, 14B). In 2020, the gains represented approximately 10–23 percent of the total flow at site 303415 and averaged about 21 percent during baseflow. In 2021, the gains represented approximately 10–48 percent of the total flow at site 303415 and averaged around 45 percent during baseflow. The higher calculated gains in 2021 were not expected as it was a lower SWE year. These gains occur as the UGA thins in its northern extent and discharges water into floodplain springs and the Gallatin River channel. Further north, near the Spanish Peaks fault, the Madison Limestone is brought to the surface, discharging bedrock groundwater into large springs and the river channel. The measured gains are attributed to a combination of alluvial groundwater entering the river and groundwater issuing from the Madison Limestone.

Overall, the data indicate that gaining/losing conditions can depend on the reach and vary temporally. Factors such as stream morphology, geology, and climatic conditions can affect losing/gaining river conditions.

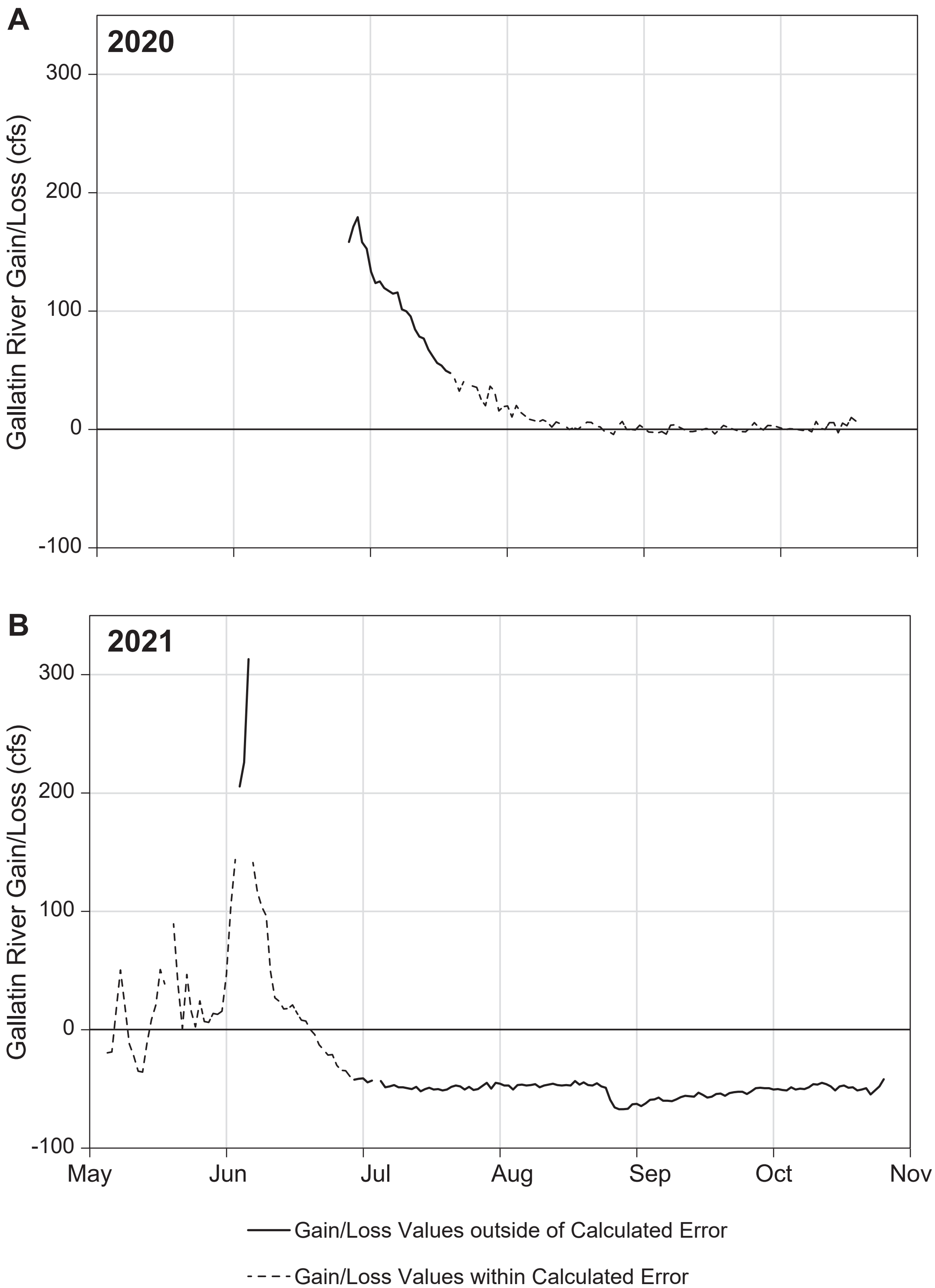

Figure 13. Gain and loss to the Gallatin River between sites 303405 and 303409 for 2020 (A) and 2021 (B). Values above 0 indicate a gain in river flow and values below zero indicate a loss.

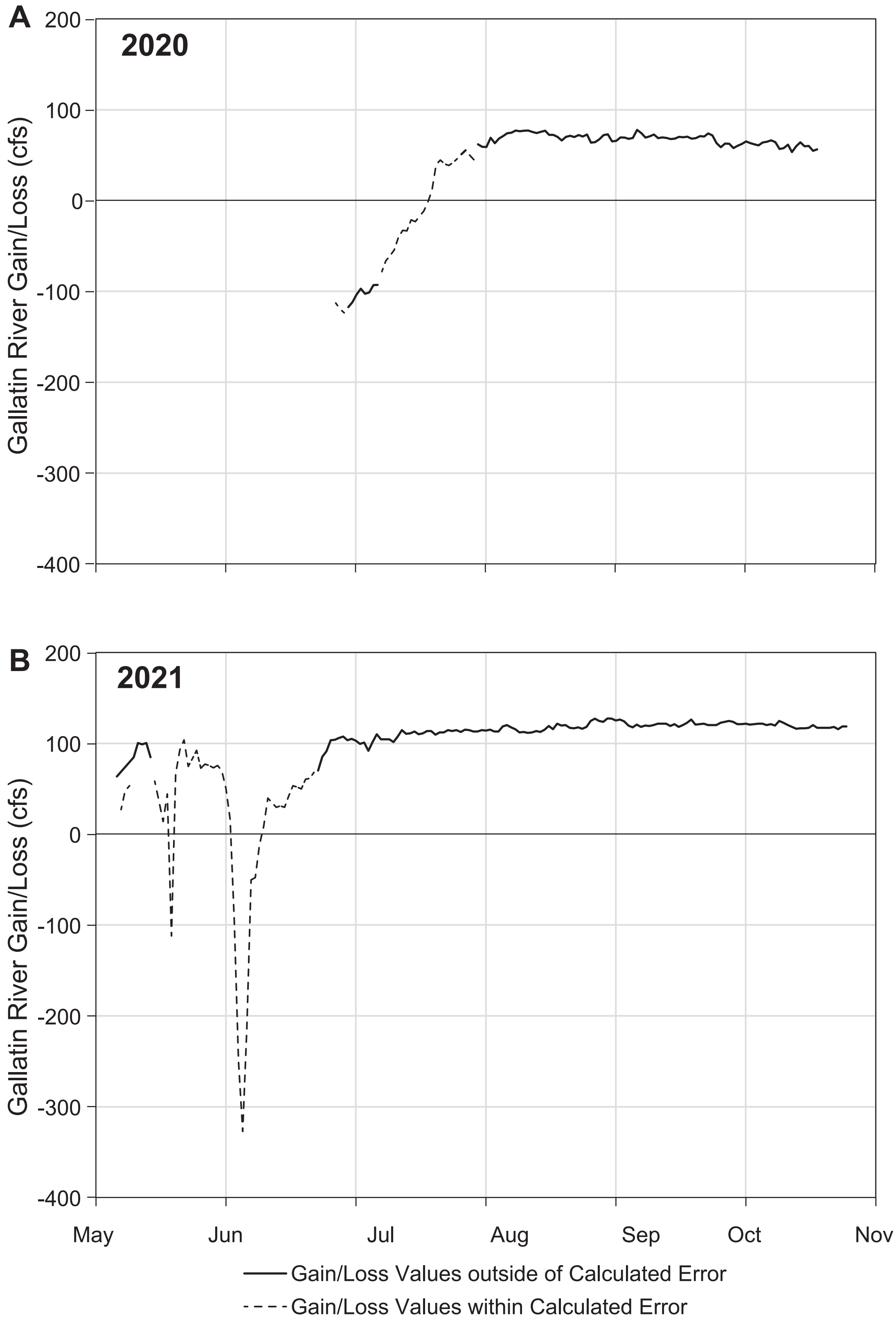

Figure 14. Gain and loss to the Gallatin River between sites 303409 and 303415 for 2020 (A) and 2021 (B). Values above 0 indicate a gain in river flow (groundwater discharge to the river) and values below zero indicate a loss (groundwater discharge from the river).

Water Chemistry

In order to assess the occurrence of inorganic constituents in the groundwater and surface water, 229 samples from 50 unique sites were collected and analyzed (appendix C). Samples were obtained from 13 surface-water sites, 3 springs, and 32 wells (fig. 7); the samples were analyzed for major ions, trace metals, nutrients, and total dissolved solids (TDS, an indicator of water quality; fig. 15). Because groundwater is the primary source of drinking water in the study area, the results were compared to human health and aesthetic standards to assess the suitability for use. The U.S. Environmental Protections Agency has established maximum contaminant levels (MCLs) for many constituents in drinking water to protect human health, and secondary maximum contaminant levels (SMCLs) for constituents that pose no known health risk but may have adverse aesthetic effects, such as staining or undesirable taste or odor (US EPA, 2024). The state of Montana recently set a primary standard for manganese in drinking water to 0.1 mg/L for infants and 0.3 mg/L for adults (MT DEQ, 2024).

The quality of the sampled groundwater and surface water was generally within drinking water standards; however, the manganese health standard (for infants, 0.1 mg/L) was exceeded in two samples from Michener Creek collected in July 2020 (0.121 mg/L and 0.126 mg/L; sites 308494 and 308495, respectively) and from wells completed in the Kootenai aquifer (0.119 mg/L and 0.121 mg/L; sites 220134 and 220140, respectively), the Frontier aquifer (0.189 mg/L; site 185464), and the alluvial aquifer (0.109 mg/L; site 257256). However, one of the Kootenai aquifer wells that had manganese over 0.1 mg/L was sampled ten times from May 2020 through February 2021 and the manganese standard was only exceeded once; the remaining samples were generally near or less than 0.02 mg/L (fig. 15).

The SMCL for TDS is 500 mg/L; concentrations ranged from 45.8 to 942.8 mg/L (fig. 15). The only samples that exceeded 500 mg/L were from the two wells completed in the Shedhorn Formation, one well each in the Muddy, Morrison, and Kootenai Formations, an alluvial aquifer well (133410) on the west side of the river, and two alluvial wells on the east side of the river. The two east-side alluvial wells had the highest measured TDS concentrations (approximately 900 and 700 mg/L from wells 308545 and 308532, respectively). Iron concentrations ranged from non-detect to 0.649 mg/L. The SMCL for iron (0.3 mg/L) was exceeded in samples collected from two alluvial wells on the west side of the river and one well each in the Frontier and Morrison Formations. The SMCL for sulfate is 250 mg/L; concentrations ranged from 2.89 to 433 mg/L. Sulfate concentrations exceeded the SMCL in samples collected from two alluvial wells on the east side of the river and the two wells completed in the Shedhorn Formation.

Major Ion Chemistry

The relative composition of major cations and anions for groundwater and streams were plotted on Piper diagrams (figs. 16, 17) where data-point groupings indicate distinctions in major ion chemistry. The relationship between groupings can illustrate mixing between different aquifers and between groundwater and surface water.

Alluvial Groundwater

The alluvial aquifer is predominantly calcium-bicarbonate type water, but shows variability. Groundwater west of the river and samples collected near the river on the east side are calcium-bicarbonate type; however, along the eastern valley edge, up to 60 percent of anions in the groundwater are sulfate. Additionally, the eastern edge of the aquifer had elevated TDS of approximately 700 and 900 mg/L, as compared to an average TDS of 360 mg/L near the river (fig. 15). Higher sulfate and TDS along the eastern valley edge as compared to along the river and the alluvium west of the river likely reflects the inflow of bedrock groundwater (fig. 16).

Alluvial groundwater on the west side of the river, which is where residential and commercial development is concentrated, generally has higher TDS with more sodium and chloride than the alluvial groundwater on the east (fig. 16). The elevated sodium and chloride in the west-side alluvial groundwater (fig. 15) could reflect the influence of septic effluent, which tends to have high proportions of sodium and chloride (Robertson, 2021), and/or groundwater from bedrock units, such as PWS sourced from the Morrison aquifer, which is sodium dominated.

Bedrock Groundwater

Wells completed in the Frontier Formation, Kootenai Formation, Muddy Sandstone member of the

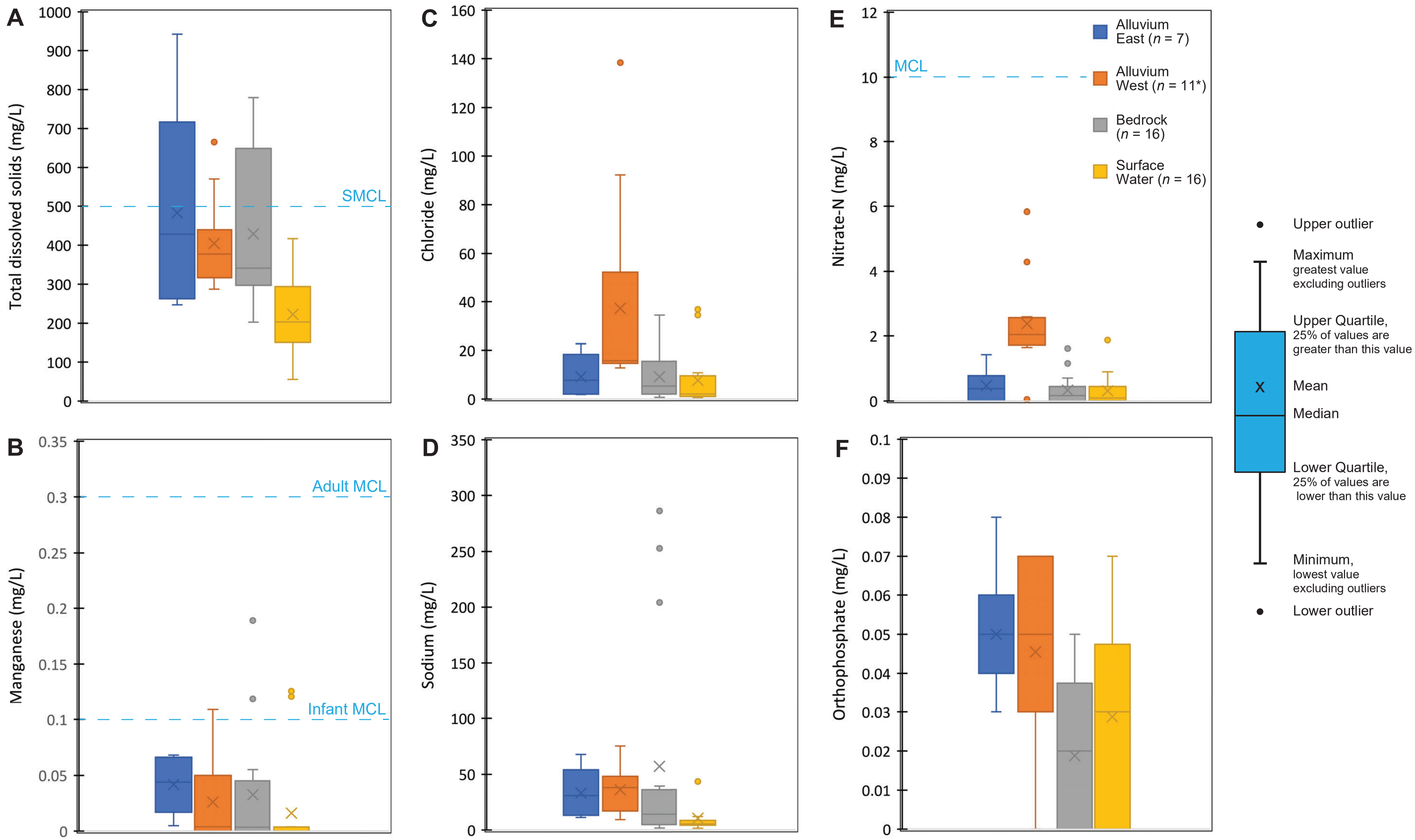

Figure 15. The highest measured constituent from each sample site is displayed on a box plot to show variability between aquifers and surface water. Alluvial samples were separated into samples collected east and west of the Gallatin River. *n = 11 for alluvial sites west of the Gallatin River except for nitrate, which has n = 12.

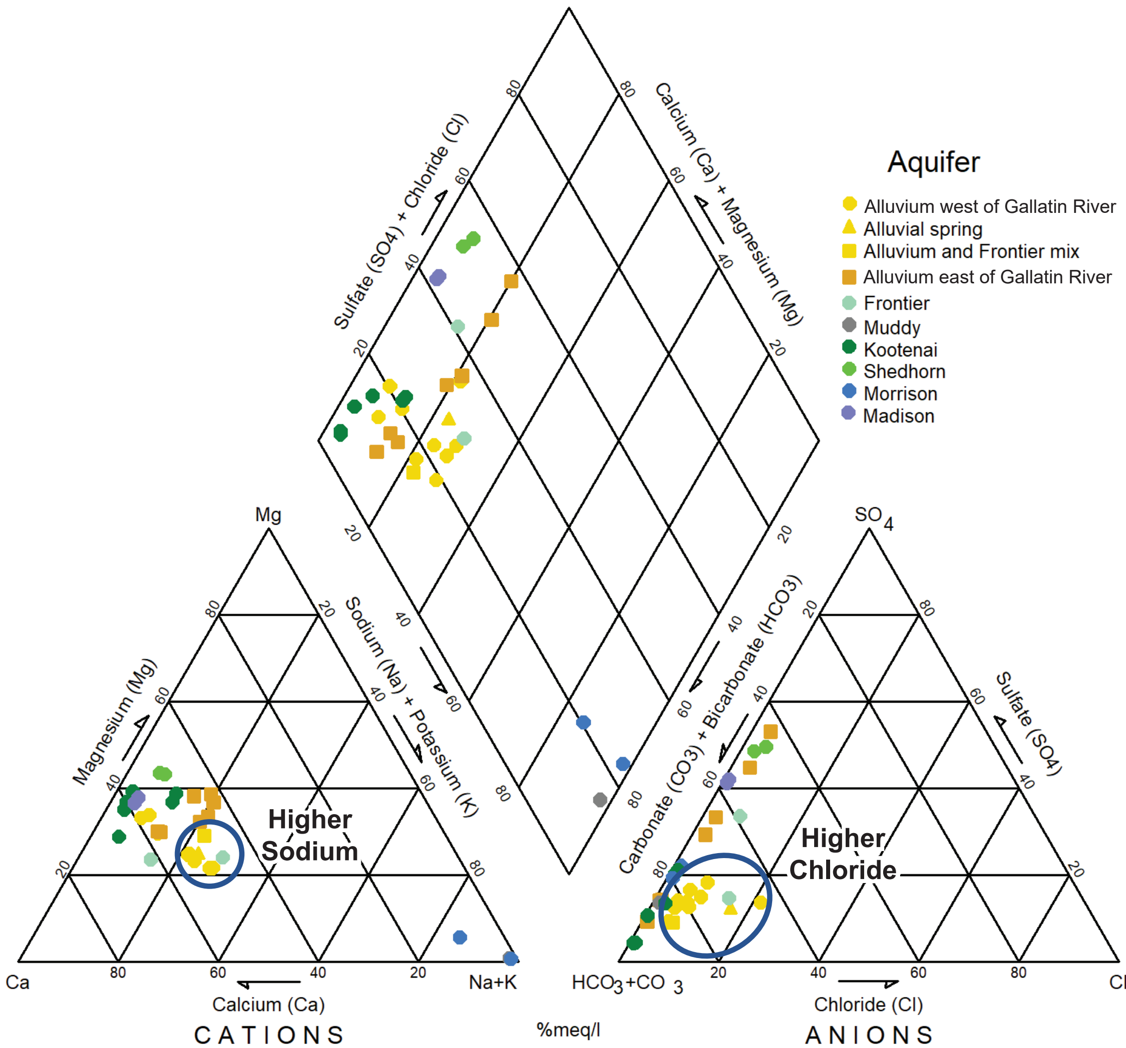

Figure 16. Bedrock aquifers in the study area tend to have distinctive major ion chemistry types. The alluvial aquifer reflects the contributions from bedrock aquifers (e.g., the prevalence of sulfate) and septic return flows (e.g., the presence of chloride elevated above what is naturally contributed by the geology). For sites with multiple samples, the most recent is displayed.

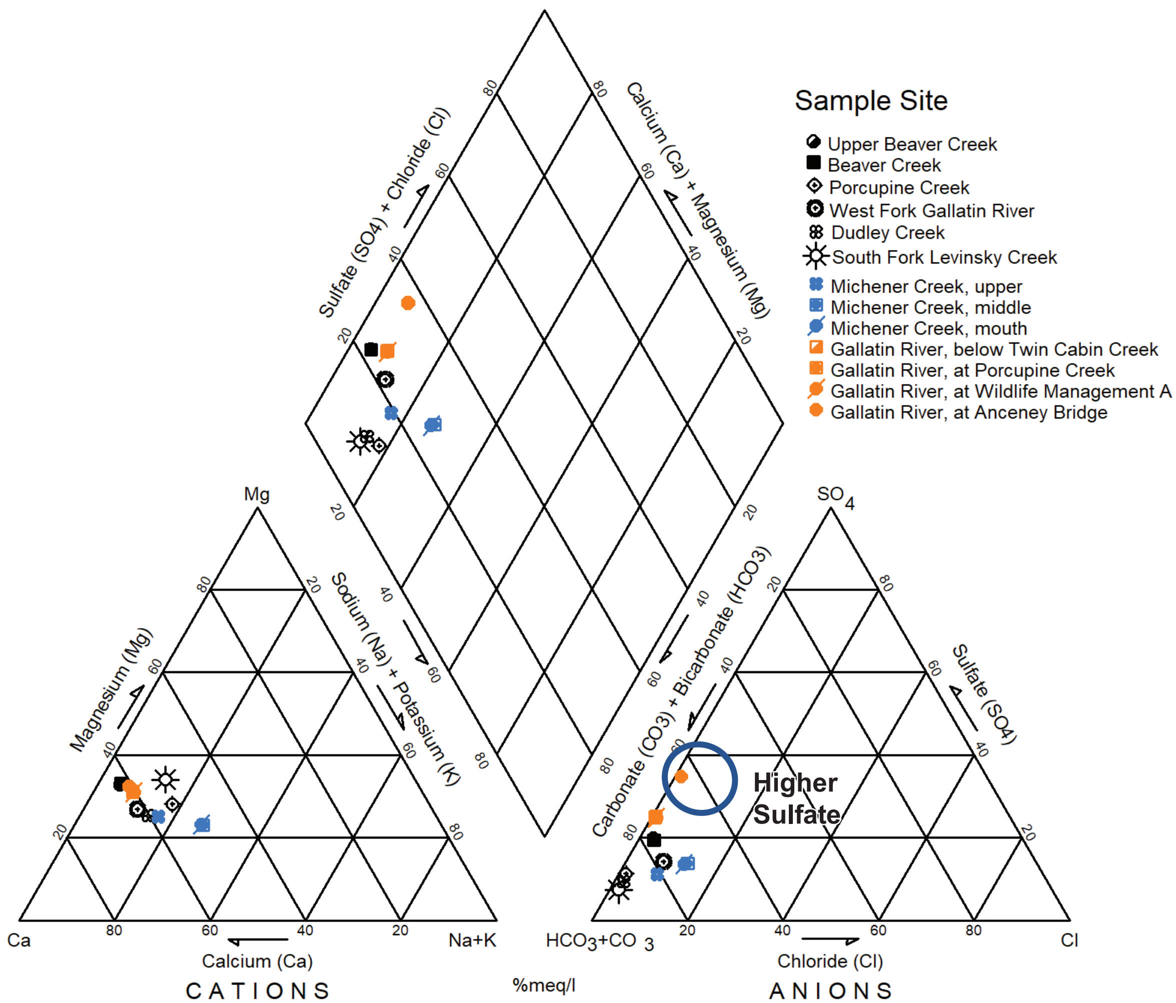

Figure 17. All surface water is calcium-bicarbonate type; however, the sample collected from the downgradient Gallatin River site at Anceny Bridge has a slightly higher proportion of sulfate that may come from groundwater recharge from the Madison Aquifer. Additionally, the samples collected downgradient from development along Michener Creek have somewhat higher proportions of sodium and chloride, which can indicate septic return flow. Displayed samples are from the synoptic sampling in October 2020 except Michener Creek samples, which were collected in August 2020.

Thermopolis Shale, Morrison Formation, Shedhorn Formation, and Madison Limestone springs were sampled.

There is a range of water types in the bedrock aquifers. The Kootenai aquifer is consistently calcium-bicarbonate type. The Morrison and Muddy aquifers are sodium-bicarbonate type. The Madison and Shedhorn aquifers are calcium-sulfate type. However, the two samples from wells completed in the Frontier Formation do not have the same major ion chemistry; well 215176 has a chemical signature similar to the alluvial aquifer (fig. 16). This well is completed through the alluvium to a total depth of 100 ft with a surface casing that extends 5 ft into the underlying shale. It is possible this well accesses water from both the alluvium and the Frontier Formation. On the east valley margin, groundwater from bedrock aquifers discharging to the alluvial aquifer may account for the relative increase in sulfate concentrations.

<u>Surface Water</u>

Results from a synoptic sampling event in October 2020 on the Gallatin River and the tributaries show that the baseflow water quality is predominantly calcium-bicarbonate type (fig. 17). The three Gallatin River sample sites upgradient from Levinski Ridge are nearly identical; the downgradient sample point at Anceny Bridge (site 303415) has a slightly higher proportion of sulfate and slightly higher TDS than the upgradient sites. This is likely a reflection of the influence of groundwater and spring discharge to the river (fig. 17), including the sulfate-enriched Madison aquifer-sourced springs present in the northern portion of the study area.

The major ion chemistry is similar for Porcupine, Dudley Creek, and South Levinski Creek. These creeks flow into the north and south parts of the study area, which are relatively unaffected by development. Beaver Creek, Upper Beaver Creek, and the West Fork all have major ion chemistry similar to the Gallatin River; however, the West Fork (which drains the Big Sky Mountain and Meadow Villages) has more chloride than tributaries flowing through undeveloped areas. Michener Creek, which flows through a developed area in the study area, contains more sodium, sulfate, and chloride than the other tributaries. Elevated chloride and sodium concentrations in an aquifer can indicate septic discharges (Robertson, 2021). The higher chloride in the West Fork and slightly higher sodium and chloride in Michener Creek may indicate the presence of septic effluent in these streams (Robertson, 2021; fig. 15).

<u>Stable Isotope Chemistry</u>

Isotope ratios of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) within the water molecule (water isotopes) can be used to trace the seasonality and elevation of precipitation in addition to evaporation (Rozanski and others, 1993). Lower, or more negative, isotope values indicate higher elevation or cold-season precipitation while higher, or less negative, isotope values indicate lower elevation or warm-season precipitation (Landwehr and Coplen, 2006). Oxygen and hydrogen isotopes in precipitation covary, resulting in a linear relationship when plotted against each other. This relationship, on a global scale, is defined as the global meteoric water line (Craig, 1961); samples collected in a localized area can be used to define a local meteoric water line (LMWL; Putman and others, 2019). A weighted LMWL from the Basin Creek SNOTEL, approximately 70 mi from Big Sky, was used to represent the expected isotopic signature of meteoric waters in the study area (eq. 1; Carstarphen and others, 2024).

$$\delta^2H = 7.8\,\delta^{18}O + 3.98 \qquad \text{eq.1}$$

The isotope results show some distinct groupings among the groundwater and surface-water samples (fig. 18). Samples from the bedrock wells (Muddy Sandstone of the Thermopolis Formation, Morrison Formation, Thermopolis Shale, and Kootenai Sandstone) were generally the most negative, suggesting recharge from higher elevation and/or lower temperature precipitation. Variability in the results from alluvial aquifer samples suggest a mix of distinct recharge from underlying or lateral bedrock inflows, surface water, or direct infiltration through soils.

In general, the surface-water samples were less negative than the alluvial aquifer samples (fig. 18). This could reflect the summer timing of the surface-water sample collection or it could indicate that the alluvial aquifer receives a higher proportion of more isotopically negative bedrock inflows or higher elevation snowmelt than the broader Gallatin River watershed above Big Sky. Slightly more negative water isotope values in the tributaries compared to the Gallatin River may again indicate a greater contribution of bedrock-derived groundwater.

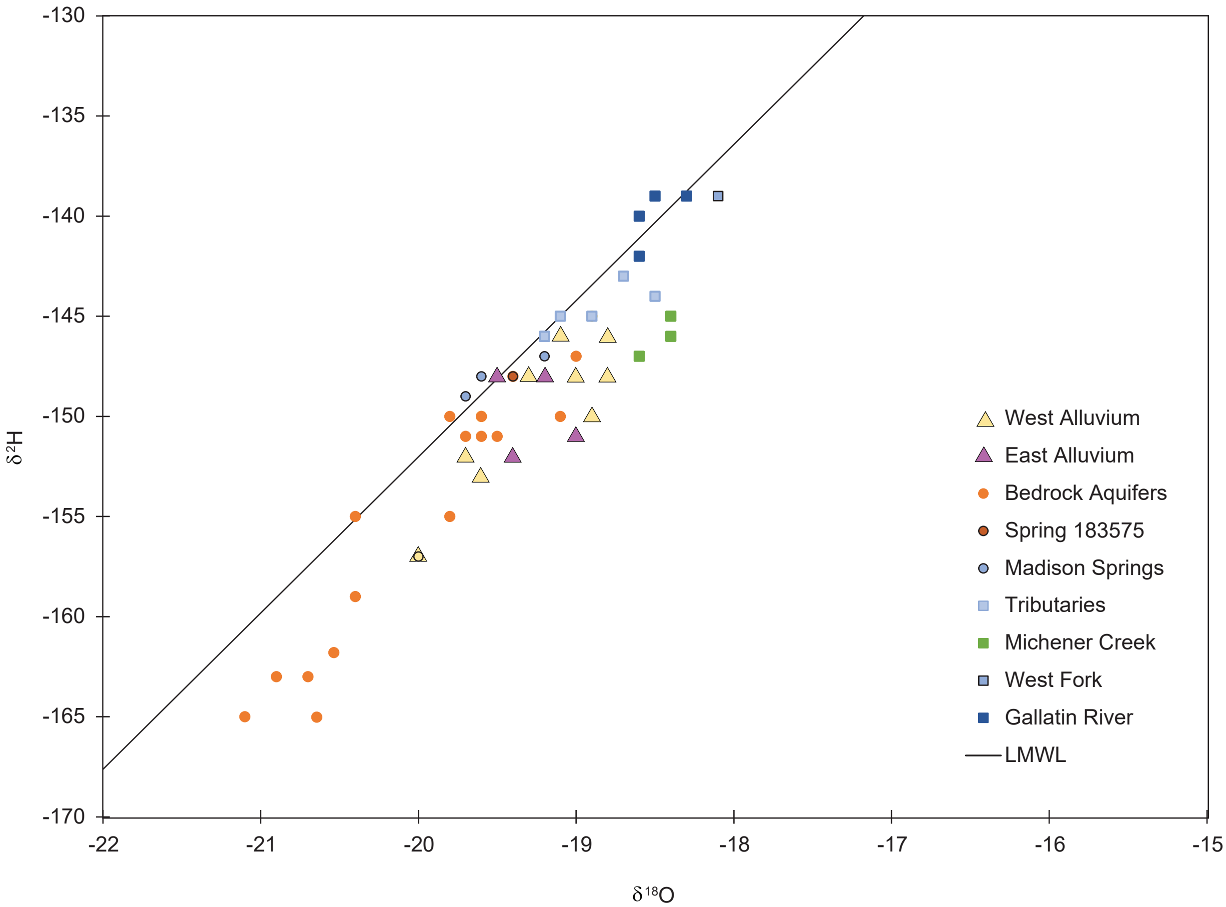

Figure 18. Water isotope ($\delta^{18}O$ and $\delta^{2}H$) values show alluvial groundwater is more similar to bedrock aquifers than to surface water. The isotope signature of tributaries show contributions from groundwater. Values fall near the expected range for precipitation defined by the local meteoric water line (LMWL, eq. 1; Carstarphen and others, 2024). Where multiple groundwater samples were available from a single sample site, the sample collected close to the lowest point in the hydrograph (winter) is displayed. Surface-water samples collected during August 2020 are displayed. Samples from sites 143231 and 104544 are not displayed because they were only sampled once and exhibit evidence of evaporation post sample collection.

Nitrate Concentrations

Nitrate has a drinking water MCL of 10 mg/L (U.S. EPA, 2019). Nitrates can be deadly to infants at concentrations of 10 mg/L or higher, but also may indicate that other contaminants such as *E. coli* bacteria or pharmaceuticals may be present in domestic water. Potential anthropogenic sources of nitrate in surface water and groundwater include septic systems, agricultural and landscaping fertilizers, and livestock manure. The study area does not have large areas of agricultural land or large livestock operations, but does have some horse corrals whose manure piles may contribute nitrate. Lawn fertilizer, if not applied in appropriate amounts, could also contribute nitrate to the groundwater. Homes, businesses, and facilities are served by individual or community septic systems. Rock weathering has been shown to be a natural source of nitrate (Montross and others, 2013), especially from the Kootenai Formation. Therefore, nitrate concentrations in groundwater and baseflow-supported streams is a combination of septic discharges, natural mineral weathering, and, potentially, stock waste and lawn fertilizers. The monitoring wells installed in the undeveloped area on the east side of the river had nitrate concentrations ranging from non-detect to 1.43 mg/L (well 252822), with the highest values measured along the eastern valley edge where bedrock geochemistry also influences the TDS and sulfate concentrations.

The aquatic standard for nitrate is ecosystem dependent and based on the potential for excessive algal and plant growth (MT DEQ, 2019). Numeric standards are generally not set for large streams in Montana; however, numeric standards for wadeable streams in the Northern Rockies for the summer months (July–September) is 0.275 mg/L (some specific streams vary from this standard; MT DEQ, 2014).

Groundwater

For this project, 204 water samples from 32 wells and 3 springs were analyzed for nitrate (17 wells and one spring were sampled 7–14 times to evaluate temporal variation); concentrations ranged from non-detect to 5.84 mg/L (well 133410). The maximum concentration detected at each site is represented in figure 19.

All 10 wells and one spring sampled from the alluvial aquifer on the west side of the river had detectable nitrate at concentrations greater than 1.5 mg/L, and seven had nitrate greater than 2.0 mg/L (fig. 19). Septic effluent, stock waste, and lawn fertilizers are the potential sources of the elevated nitrate. Of the sites with concentrations above 2.0 mg/L, five also had detectable bromide (Br); elevated bromide concentrations can be an indicator of septic effluent (Dumouchelle, 2006).

On the undeveloped east side of the river, nitrate concentrations were lower, ranging from non-detect to 1.43 mg/L. Of the four sample sites closest to the river, only one (308530) had detectable nitrate at a concentration of 0.07 mg/L (fig. 19). Nitrate was detected in the wells along the eastern edge of the valley that had elevated TDS and were enriched with sulfate (fig. 16), suggesting a potential geogenic source of nitrate.

Temporal Evaluation of Groundwater Samples

Repeated sampling from 17 wells and one spring occurred throughout 2020 and the first half of 2021. Samples from three wells and a spring had nitrate that consistently exceeded 2 mg/L: wells 133410 (sampled 13 times), 222627 (sampled 14 times), and spring 183575 (sampled 7 times; fig. 20).

Spring 183575 is likely sourced from shallow alluvial UGA groundwater and is less than 300 ft east of well 222627, so both sample sites likely represent similar alluvial groundwater and nitrate sources. Similarly, well 133410 is also close to these sample sites, at approximately 0.5 mi upgradient from the spring. These sites are near residential and commercial development and associated septic drainfields on the west side of the river.

The nitrate concentrations at these three sites are not consistent, but generally peaked in the fall and winter when groundwater levels were at their lowest point. Snowmelt recharge appears to have a diluting effect (fig. 20).

Surface Water

Fifty-three samples were collected from 13 surface-water sites. The maximum measured nitrate concentration for each site is represented in figure 19. Concentrations ranged from non-detect to 1.87 mg/L (Michener Creek site 308495). The aquatic life standard for wadeable streams (0.275 mg/L; MT DEQ, 2014) was exceeded on 2 streams: Michener Creek at three locations (308494, 308495, and 308497; 9 out of 11 total samples) and the West Fork of the Gallatin River (303410; 1 out of 5 samples). One sample collected on the Gallatin River at Porcupine Road (303406; 10/21/2020; 0.76 mg/L) had a nitrate concentration that exceeded 0.275 mg/L as measured on the IC (0.76 mg/L); the spectrophotometer method measured non-detectable nitrate on the same sample.

Michener Creek gains flow from the alluvial aquifer in its lower reach east of Highway 191; therefore, groundwater potentially influences the surface-water nitrate concentration. During sample collection on August 28, 2020, the nitrate concentration increased between the upper sample site (308497; 0.06 mg/L) and the sample site approximately 0.43 mi downstream (308495; 0.64 mg/L). The increase in nitrate is likely due to the influence of UGA groundwater with elevated nitrate discharging into Michener Creek. Samples collected from site 303409 on the Gallatin River, just downstream from the confluence with Michener Creek, had non-detect nitrate concentrations during the four times it was sampled, likely due to dilution by the large flow volume in the Gallatin.

The samples from the Gallatin River were all non-detect for nitrate except for the previously discussed sample at Porcupine Bridge (303406) and three samples collected at the downstream site at Anceny Bridge (site 303415; all samples were 0.06 mg/L using the IC method, non-detect using the spectrophotometer method).

Phosphate Concentrations

Phosphate, like nitrate, is a nutrient that, if present in surface waters at elevated concentrations, can lead to undesirable algae growth. To limit the growth of nuisance algae, Dodds and Welsh (2000) recommend

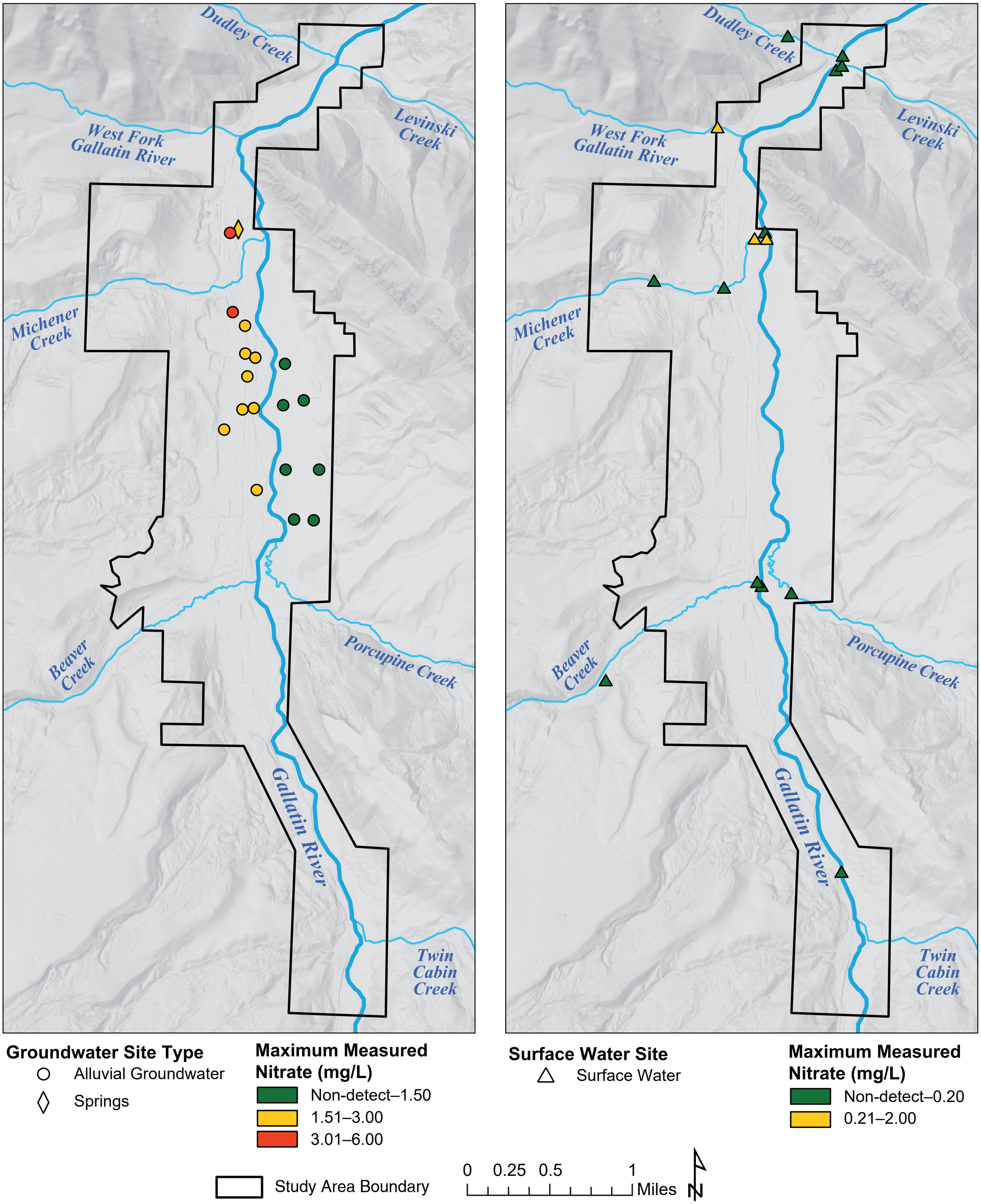

Figure 19. The highest measured maximum nitrate-N concentrations are from samples collected near septic systems.

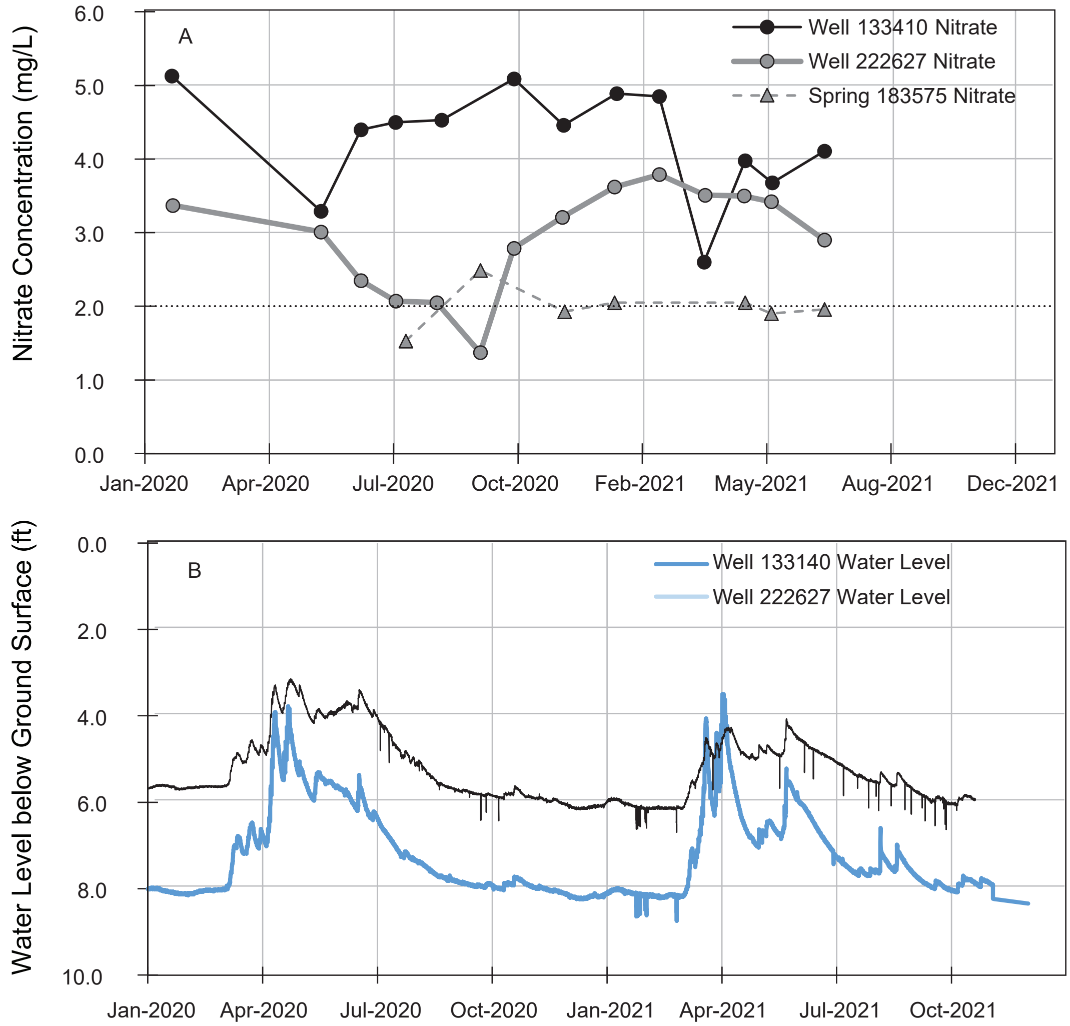

Figure 20. The temporal changes in nitrate concentrations differ among the three sites, but the highest measured nitrate concentrations occur (A) when water levels are at or near their lowest (B).

total phosphorus in streams be limited to 0.4 mg/L and the U.S. Environmental Protections Agency criteria for total phosphorus in mountain streams is 0.01 mg/L (U.S. EPA, 2000). Criteria are set for total phosphorus, whereas the analytical method for dissolved constituents in groundwater measures dissolved orthophosphate as phosphate. Total phosphorus includes dissolved orthophosphate and phosphorus found in particles and bound to sediment; the bioavailability of organic and mineral phosphorus fractions varies widely. In groundwater, dissolved orthophosphate is approximately equal to total phosphate (Domagalski and Johnson, 2012).

While not the focus of this study, phosphate was measured (as orthophosphate; OPO_4-P) in the 228 samples that were analyzed for major and minor inorganic constituents. Of these samples, orthophosphate was at or below the 0.03 mg/L detection limit in 128 samples (56 percent; appendix C). There is no apparent correlation between phosphate concentrations and nitrate concentrations in the surface and groundwater (fig. 21). The wells and spring with elevated nitrate (wells 133410, 222627, and spring 183575) have OPO_4-P concentrations ranging from 0.02 to 0.07 mg/L. However, samples collected from monitoring wells on the east side of the river, isolated from development, also have OPO_4-P concentrations ranging from non-detect to 0.08 mg/L (appendix C). Therefore, phosphate is not considered a definitive indicator of septic influences.

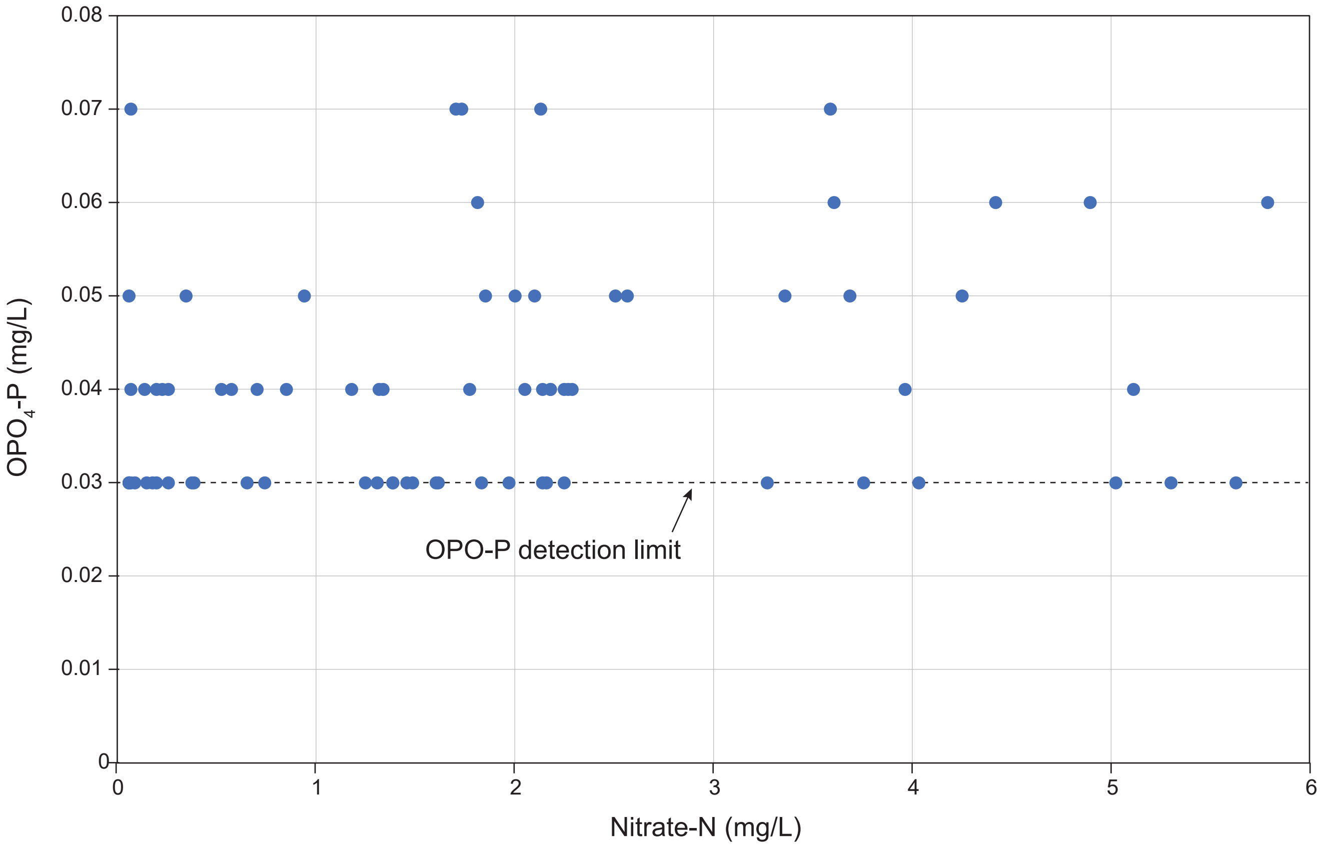

Figure 21. There is no apparent correlation between phosphate and nitrate concentrations.

DISCUSSION

The UGRC is experiencing rapid growth and development that is dependent upon wells for domestic water supplies and septic tanks for wastewater treatment. Within the alluvial valley, groundwater flows either parallel to or towards the river. Flows in the river are primarily derived from snowmelt, surface-water flow from tributaries, alluvial groundwater inflows, bedrock contributions mainly along the valley margins, and springs that are sourced from bedrock.

The UGA is shallow, unconfined, and vulnerable to contamination. The UGA has low TDS (<360 mg/L), low nitrate (<2.0 mg/L), and is calcium-bicarbonate type. In developed areas west of the river, the UGA nitrate concentration is elevated above concentrations found east of the river and has slightly higher TDS, sodium, chloride, and bromide—most likely reflecting the influence of septic effluent. In the developed part of the valley, concentrations of nitrate in the UGA ranged up to 5.84 mg/L. Elevated nitrate concentrations are likely sourced from septic effluent, but also potentially fertilizers and stock waste.

The Gallatin River and the UGA are a connected system. Synoptic flow measurements on the river indicate that the river and alluvial aquifer exchange water; the magnitude of gains and losses vary between the upper and lower portions of the UGA seasonally and with annual snowpack and precipitation. During the low-flow period in 2020, the upstream river reach (between sites 303405 and 303409) was in a state of equilibrium with the groundwater, neither gaining nor losing flow. During 2021, when the snowpack was lower, the river lost water to the alluvial aquifer in the upstream reach. During the high-flow period of spring runoff, the river gains through this section. The southern, upgradient portion of the aquifer is recharged by stream losses from the Gallatin River and Beaver Creek. In the downstream reach of the river (between sites 303409 and 303415), there was a consistent gain in Gallatin River flow in 2020 and 2021 during the low-flow period. This gain is attributed to groundwater discharge from the UGA, supplemented by the upwelling of water from large Madison-sourced springs near the Spanish Peaks fault.

Elevated nitrate levels in UGA groundwater that discharges to the Gallatin River may contribute to harmful algal blooms in the Gallatin River. On the Gallatin River there were no exceedances of the aquatic life standard for nitrate (approximated at 0.275 mg/L) except at site 303406, just upstream from Beaver Creek. However, the IC and spectrophotometer methods that were used to analyze this sample had conflicting results, with the spectrophotometer method showing non-detectable nitrate.

The aquatic life standard for nitrate was exceeded at three locations on Michener Creek (308497, 308495, and 308494). Michener Creek gains about 1 cfs flow between the upstream (303497) and the downstream (308494) gaging sites. Nitrate concentrations in Michener Creek also increased from 0.06 to 0.64 mg/L along its flowpath through the developed portion of the study area. Multiple samples collected on the Gallatin River just downstream from Michener Creek did not have detectable nitrate, indicating that nitrate contributed to the Gallatin from Michener Creek is diluted below detection limits.

The West Fork samples exceeded the nitrate aquatic life standard once (out of 5 samples) in February 2021 during baseflow conditions. The West Fork flows through Meadow Village, where elevated nitrate concentrations (in the range of 2–6 mg/L; Rose and Waren, 2022) have been measured. A similar seasonal trend of higher nitrate concentrations in the winter was also measured in the two groundwater sample sites that showed temporal nitrate variability (wells 133410 and 222627), perhaps indicating less dilution from snowmelt recharge.

The effects of septic effluent in the UGA on the Gallatin River depends upon a number of factors, including the nitrate concentration of the effluent, groundwater flowpath length, attenuation, denitrification, and dilution. Flowpath length is discussed in the companion report on numeric flow modeling of the study area (Zeiler and others, 2025). Algal blooms that began impacting the Gallatin River mainstem in 2018 are undesirable and can be harmful to existing aquatic life. Factors contributing to excessive algal blooms include dissolved nutrients like nitrate and phosphorus, water temperature, solar input, river flow, sediment, and background water chemistry (MT DEQ, 2019). The nitrate concentration that triggers an algal bloom in the Gallatin River is unknown and will vary with changing local conditions. Measures to reduce sources of nutrients, specifically nitrates, entering the UGA may also lower nutrients in surface waters, reducing the occurrence of algal blooms while also protecting local residents' drinking water quality.

RECOMMENDATIONS

The results from this study can inform future decisions regarding groundwater use, wastewater treatment, and continued groundwater monitoring. Long-term groundwater monitoring is recommended for wells 308526, 308703, 133410, and 222627 to measure trends in water level and nitrate concentrations (fig. 5). Seasonal sampling and instrumenting the wells to collect continuous water levels and specific conductance (SC, a proxy to TDS), or equipping sites with continuous nitrate data loggers, would provide information on the timing of seasonal water-quality changes and long-term water-quality trends.

Long-term monitoring of discharge at key locations on the Gallatin River will help identify seasonal and annual patterns of loss/gains. This will be instrumental in understanding how groundwater interacts with surface water and can provide additional insight on where nutrients from wastewater can potentially impact the river.

Michener Creek had the highest surface-water nitrate concentrations. Developing a way to slow the flow through the soil and alluvium with engineered wetlands, where plant uptake and denitrification may occur, can help reduce nitrate concentrations in the stream. This may be applicable to other small streams that act as groundwater drains.

The results from this study show that the alluvial aquifer in the developed part of the valley west of the river has nitrate concentrations elevated above concentrations measured outside of developed areas. People consuming water from the aquifer in this area should regularly test their water and consult the County health department as to when to consider point-of-use treatment, such as reverse osmosis systems.

Outreach to owners of horse corrals explaining the importance of frequently removing manure for off-site composting could help reduce stock-related sources of nitrate to the groundwater. Also, outreach regarding lawn fertilizer use and its potential as a source of nutrients to groundwater and surface water is recommended. Preventive measures that keep contaminants and nutrients from entering the aquifer can go a long way to protect groundwater and surface-water quality.

A centralized, community sewer system, which has a higher level of treatment then a traditional septic system, is under consideration in the UGRC area. In 2020, the Gallatin Canyon County Water and Sewer District (GCCWSD) was formed with the goal of installing a sewer collection system to transport sewage to the Big Sky Waste Water Reclamation Facility. This professional management of wastewater may more effectively protect water quality in the UGA, connected surface waters, private and public wells, and public health (GRTF, 2024). If implemented, this will likely reduce groundwater nitrate concentrations and potential impacts to the river as the UGRC population grows. In lieu of centralized treatment, stakeholders should consider a community-wide evaluation of the age and effectiveness of existing septic systems. New building permits should encourage modern septic systems that maximize treatment and filtration of wastewater. Older, existing septic systems should be prioritized for annexation into the new sewer district or incentivized to upgrade to level 2 systems based on size and proximity to surface water or PWS wells.

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APPENDIX A

GROUNDWATER AND SURFACE-WATER MONITORING SITES

Table A1. Groundwater monitoring sites.

GWIC ID	Latitude	Longitude	Elevation (ft)	Use	Total Depth (ft)	Aquifer	Average SWL[1] Oct 2020 (ft)	Transducer	No. Water-Quality Samples Collected for This Study[4]
103575	45.26509	-111.25451	5,998.38	Domestic	40	Madison		Yes	0
104541	45.22572	-111.24540	6,106.79	Domestic	50	Alluvium	6,096	Yes	0
104544	45.22048	-111.24867	6,114.47	Domestic	102	Kootenai		No	1
104549	45.22930	-111.25353	6,112.21	PWS[2]	43	Alluvium	6,083	Yes	0
133408	45.24873	-111.25802	6,099.83	Monitoring	50	Alluvium		No	0
133410	45.24991	-111.25324	6,032.77	Monitoring	14	Alluvium	6,025	Yes	13
133571	45.24874	-111.25167	6,035.00	Domestic	31	Alluvium	6,028	Yes	3
143231	45.24629	-111.25156	6,046.27	Domestic	60	Alluvium		No	1
157945	45.19341	-111.23712	6,195.21	PWS	80	Shedhorn		No	1
157970	45.19497	-111.23678	6,189.39	PWS	32.5	Alluvium		No	0
165682	45.24145	-111.25420	6,060.12	PWS	1490	Kootenai /Morrison		No	1
167347	45.20764	-111.24227	6,146.50	Domestic	95	Kootenai		Yes	1
169480	45.19331	-111.23714	6,197.92	PWS	140	Shedhorn		No	1
176335	45.23825	-111.25161	6,066.71	Irrigation	40	Alluvium		No	0
182784	45.24200	-111.25135	6,054.94	Irrigation	60	Alluvium	6,044	Yes	0
183575	45.25719	-111.25277	6,003.87	Spring	NA	Alluvium		No	7
185464	45.23563	-111.26045	6,266.00	Domestic	115	Frontier		Yes	2
189147	45.22357	-111.25043	6,119.23	Domestic	37	Alluvium	6,096	Yes	0
215176	45.25727	-111.25494	6,014.88	Monitoring	100	Frontier		No	1
220134	45.21489	-111.24968	6,135.76	Monitoring	40	Kootenai		Yes	13
220140	45.21674	-111.25302	6,142.58	Monitoring	92	Kootenai		Yes	1
220141	45.21488	-111.25181	6,138.35	Monitoring	55	Kootenai		Yes	1
220481	45.24137	-111.25175	6,057.13	Monitoring	20	Alluvium	6,045	Yes	14
222607	45.25139	-111.26056	6,127.47	Monitoring	420	Morrison		No	1
222627	45.25687	-111.25378	6,014.38	Domestic	35	Alluvium	6,009	Yes	14
223891	45.25135	-111.26075	6,130.24	PWS	1278	Kootenai		No	0
227731	45.25072	-111.26046	6,123.14	PWS	1325	Kootenai		No	0
230187	45.25294	-111.25945	6,117.65	Monitoring	100	Frontier		No	0
235887	45.22757	-111.25323	6,128.91	Monitoring	50	Kootenai		Yes	12
246433	45.24910	-111.25824	6,102.49	Monitoring	91	Alluvium/Frontier	6,063	Yes	8
257253	45.24192	-111.25445	6,061.92	Unused	1320	Kootenai		No	0
257256	45.23956	-111.25397	6,068.30	Unused	17.25	Alluvium	6,058	Yes	14
257257	45.24038	-111.25641	6,127.60	Unused	150	Thermopolis shale		Yes	1
276750	45.23119	-111.25183	6,103.98	PWS	50	Alluvium		No	0
283210	45.24709	-111.25685	6,090.00	Monitoring	70.6	Frontier		No	0
284717	45.21639	-111.25036	6,128.94	Domestic	58	Thermopolis Shale		Yes	0
303694	45.24429	-111.25124	6,049.43	Monitoring	25.1	Alluvium	6,037	Yes	13
304340	45.24625	-111.25155	6,046.00	Commercial	42	Alluvium		No	0
308526	45.23179	-111.24503	6,076.45	Monitoring	21	Alluvium	6,069	Yes	8
308527	45.23616	-111.24622	6,062.53	Monitoring	18	Alluvium	6,059	Yes	8
308528	45.24182	-111.24670	6,048.46	Monitoring	23	Alluvium	6,042	Yes	8
308530	45.24546	-111.24660	6,040.69	Monitoring	26	Alluvium	6,034	Yes	8
308532	45.24229	-111.24416	6,063.26	Monitoring	31	Alluvium	6,050	Yes	8
308545	45.23623	-111.24206	6,099.21	Monitoring	46	Alluvium	6,061	Yes	8
308558	45.23177	-111.24258	6,107.41	Monitoring	45	Alluvium	6,072	Yes	4
308703	45.24595	-111.25030	6,045.57	Monitoring	33	Alluvium	6,033	Yes	8
308704	45.24151	-111.25035	6,057.26	Monitoring	25	Alluvium	6,044	Yes	8
308705	45.23432	-111.24975	6,079.36	Monitoring	38	Alluvium	6,064	Yes	8
309489	45.21641	-111.25023	6,128.96	Domestic	58	Thermopolis Shale		Yes	0

Note. NA, not available.

[1]SWL, surface water level.
[2]PWS, public water supply.
[3]Average SWL only determined for sites with pressure transducers.
[4]Either a full suite was collected (major ions and trace metals) or just nitrate. See GWIC database for samples collected outside the timeframe of this study.

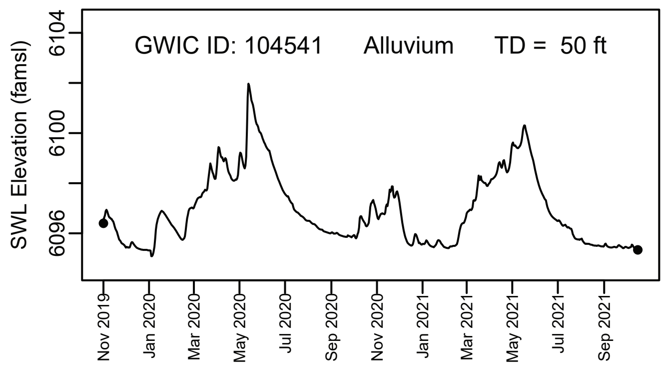
Table A2. Surface-water and spring sites monitored for this investigation.

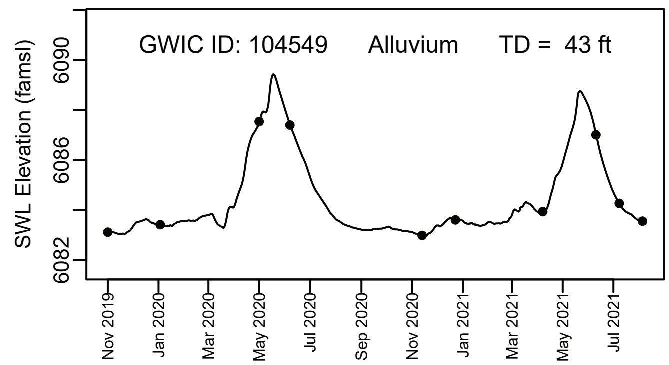
GWIC ID	Latitude	Longitude	Site Name	Transducer Installed	No. Water Quality Samples
Surface-Water Sites					
303405	45.20092	-111.23850	Gallatin River at Twin Cabin Creek	Yes	4
303406	45.22590	-111.24922	Gallatin River at Porcupine Bridge	Yes	4
303407	45.22624	-111.24978	Beaver Creek	Yes	4
303408	45.22533	-111.24550	Porcupine Creek	Yes	3
303409	45.25700	-111.24979	Gallatin River at Wildlife Management Area	Yes	4
303410	45.26614	-111.25599	West Fork of the Gallatin River	Yes	4
303413	45.27179	-111.24066	Levinski Creek	Yes	3
303414	45.27429	-111.24749	Dudley Creek	Yes	3
303415	45.27267	-111.24061	Gallatin River at Anceny Bridge	Yes	3
303416	45.21730	-111.26834	Upper Beaver Creek	No	3
308494	45.25643	-111.24956	Michener Creek confluence of Gallatin River	No	5
308495	45.25642	-111.25106	Michener Creek at Frenchmans Bridge	No	5
308497	45.25205	-111.25473	Michener Creek upstream of Highway 191	No	2
Spring Sites					
183575	45.25719	-111.25277	Ainsworth Walter/Big Sky Spring	No	7
255289	45.27021	-111.24568	Slow Vehicles Spring	No	0
258715	45.2673	-111.2427	Anceny Spring #1	No	0
303411	45.27115	-111.24328	Big Sky Springs Creek	Yes	1
303412	45.27140	-111.24140	Anceny Spring Pond Outlet	Yes	3
304093	45.2686	-111.2434	Anceny Spring Creek	No	0
316600	45.25735	-111.25261	Ainsworth Spring Pond	No	0

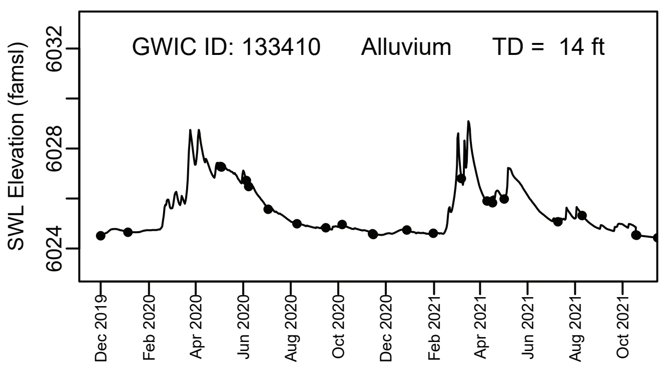
APPENDIX B

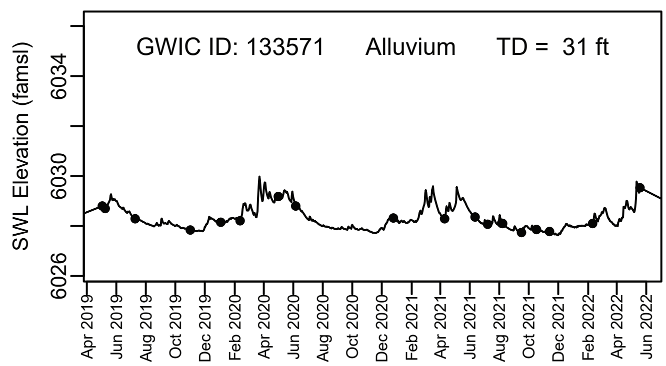
GROUNDWATER HYDROGRAPHS

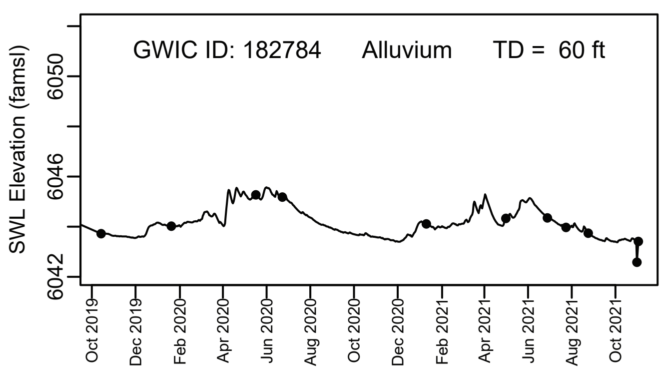
Alluvial Aquifer

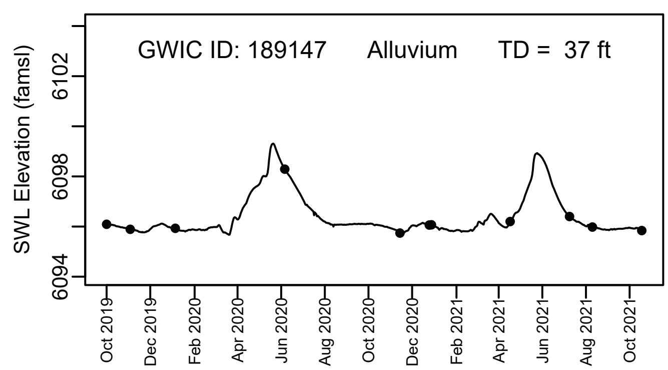


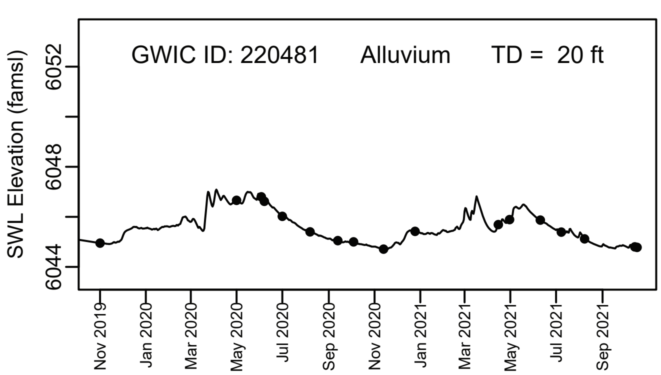


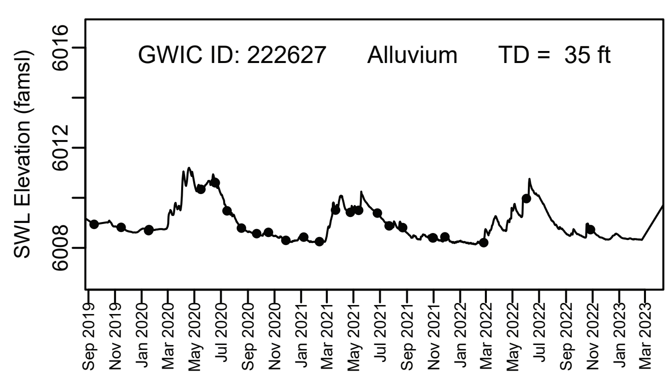




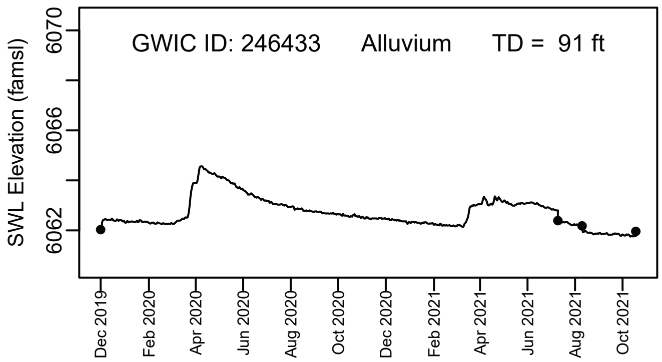


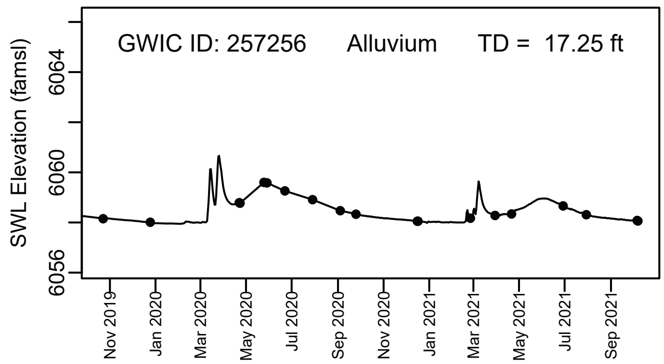


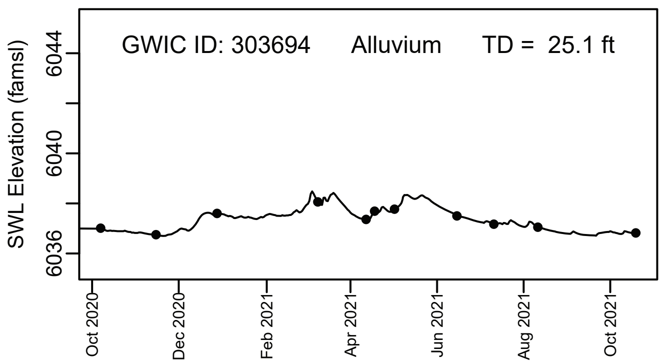


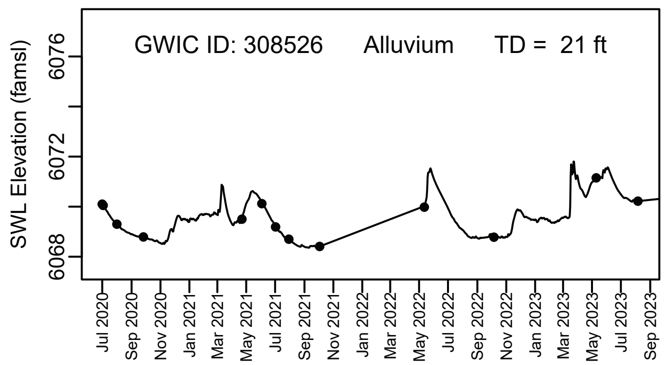


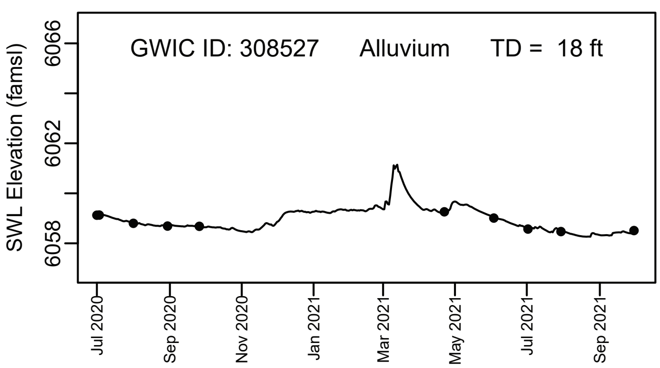
Alluvial Aquifer

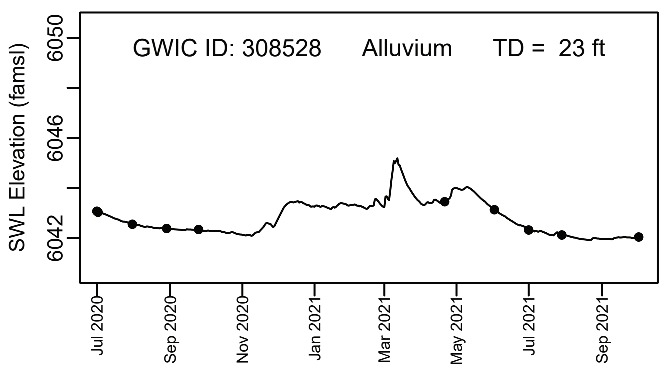


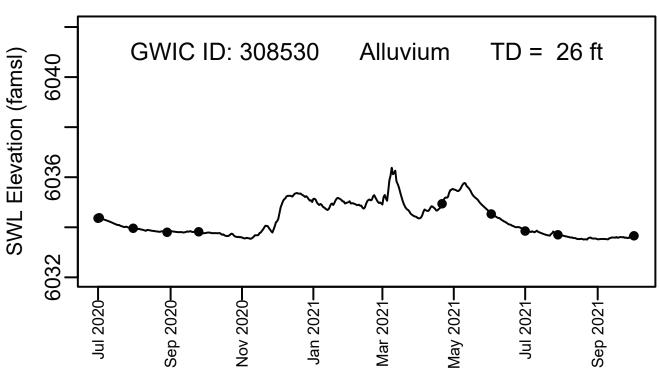


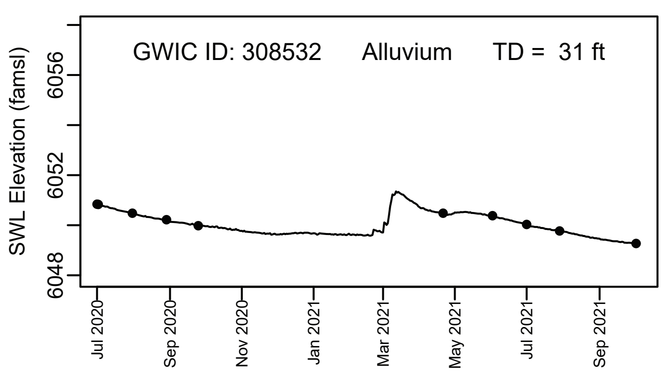












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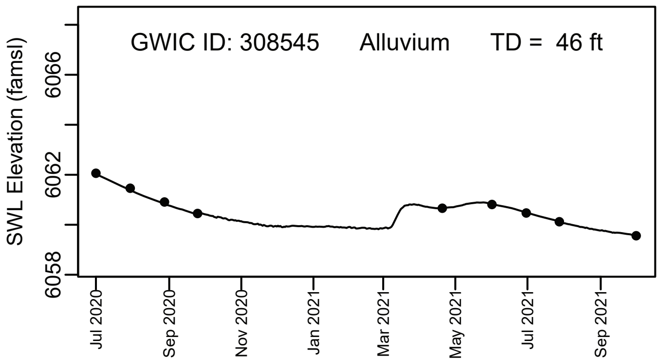

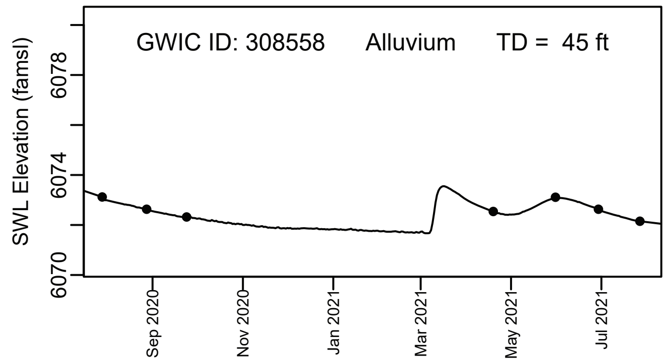

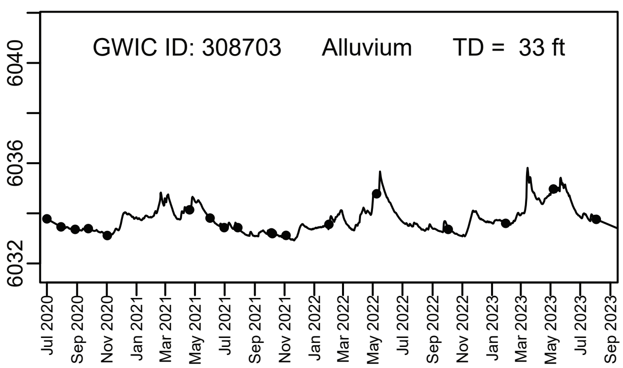

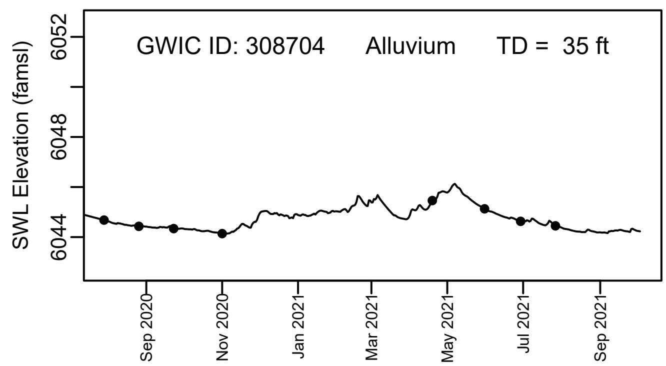

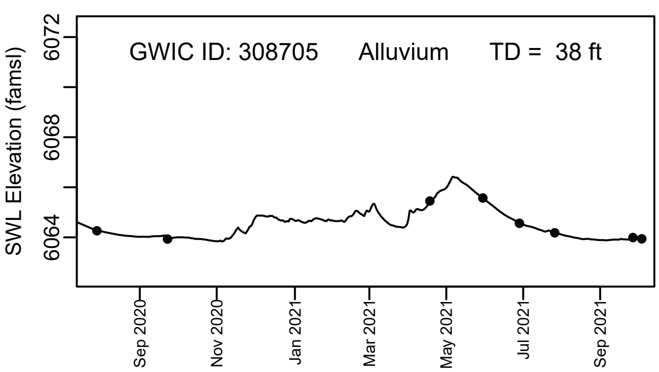

Bedrock Aquifers