Montana Bureau of Mines and Geology

Information Pamphlet 17

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Ground Water Investigation Program

GROUNDWATER INPUTS TO RIVERS AND STREAMS

Using temperature and visual cues on the Big Hole River, southwestern Montana

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INTRODUCTION

Groundwater and surface water are sometimes perceived as two separate entities, but in many cases these water resources are in constant communication. Rivers and streams can lose water to groundwater, or can gain water where groundwater discharges to surface water. Through these interactions, groundwater and surface water influence the quality and quantity of one another. This pamphlet discusses how groundwater discharge can affect stream temperature.

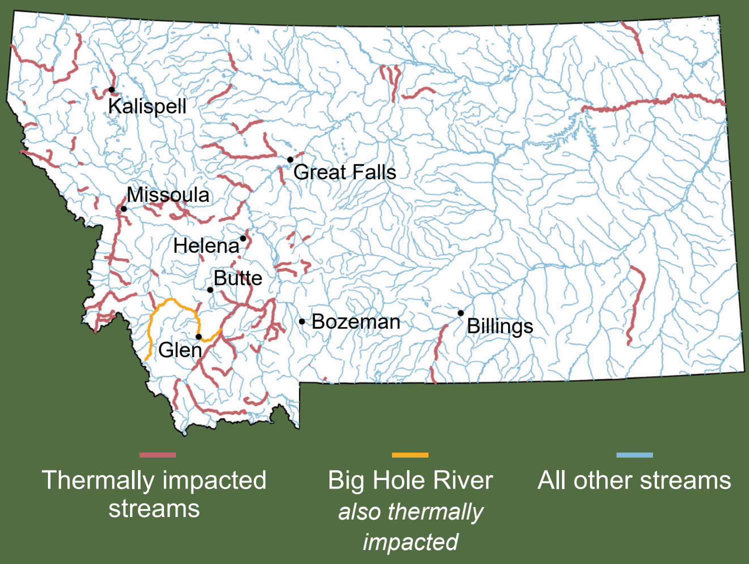
Figure 1. The Big Hole River near Glen, MT.

In late summer, elevated stream temperatures can stress many aquatic organisms. Ideal water temperatures for wild trout range from 55 to 65°F, and prolonged temperatures of 70°F or higher can lead to trout mortalities (Montana Trout Unlimited, 2021). During periods of low streamflow and elevated stream temperature, Montana Fish, Wildlife and Parks will implement “hoot owl” fishing restrictions (where fishing is closed after 2 p.m.) or full-day fishing closures on river sections (Montana FWP, 2023).

The Big Hole River in southwestern Montana (figs. 1, 2) is an important water resource for local agriculture and recreational tourism, and also provides drinking water to the city of Butte, Montana. The river frequently has elevated temperatures in the summer, which compromises this resource (fig. 2). A better understanding of factors that influence temperature changes in the Big Hole will be helpful for maintaining this resource in the future.

MONTANA STREAM STATS

There are nearly **41,000** stream miles in Montana.



2,713 river miles in Montana are thermally impacted, meaning they exceed water-quality standards for temperature.

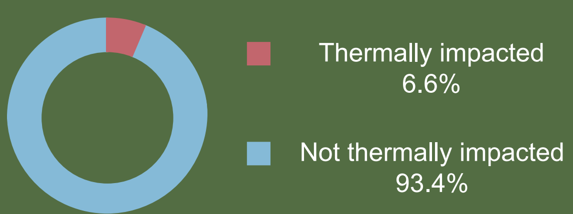


Figure 2. Thermally impacted streams are more common in western Montana. Although only 6.6% of Montana’s waterways are considered thermally impacted, elevated temperatures can have a negative effect on aquatic species in these streams. Data sources: Montana DEQ CWAIC, 2021.

FACTORS THAT AFFECT STREAM TEMPERATURE

To understand the factors that affect stream temperature in the Big Hole River, it is important to look at the entire ecosystem. Factors within and near the stream play a role, but so do factors in the larger landscape and atmosphere.

Figure 3 illustrates the factors that influence stream temperature. Some of these factors can be affected by changes in water management (e.g., irrigation type, reservoirs, stormwater), but most are controlled by the landscape. These factors impact stream temperature by warming or cooling the stream, and/or by changing the volume of streamflow. For example, intense solar radiation can heat up the stream, while increased cloud cover or vegetation can block solar radiation and help keep the stream cooler. Tributaries can provide a cold source of water and also increase streamflow. Having more streamflow means that more solar radiation is required to raise the temperature of the stream. Stream temperature is influenced by a combination of these factors; however, some factors are easier to measure than others.

Atmospheric Conditions	Topography	Stream Discharge	Streambed
Solar radiation/Cloud cover	Geology	Groundwater/Tributaries	Groundwater input
Precipitation/Evaporation	Latitude/Altitude/Aspect	Irrigation	Hyporheic exchange
Relative humidity/Wind speed	Vegetation/Canopy cover	Stormwater/Wastewater	Streambed conduction

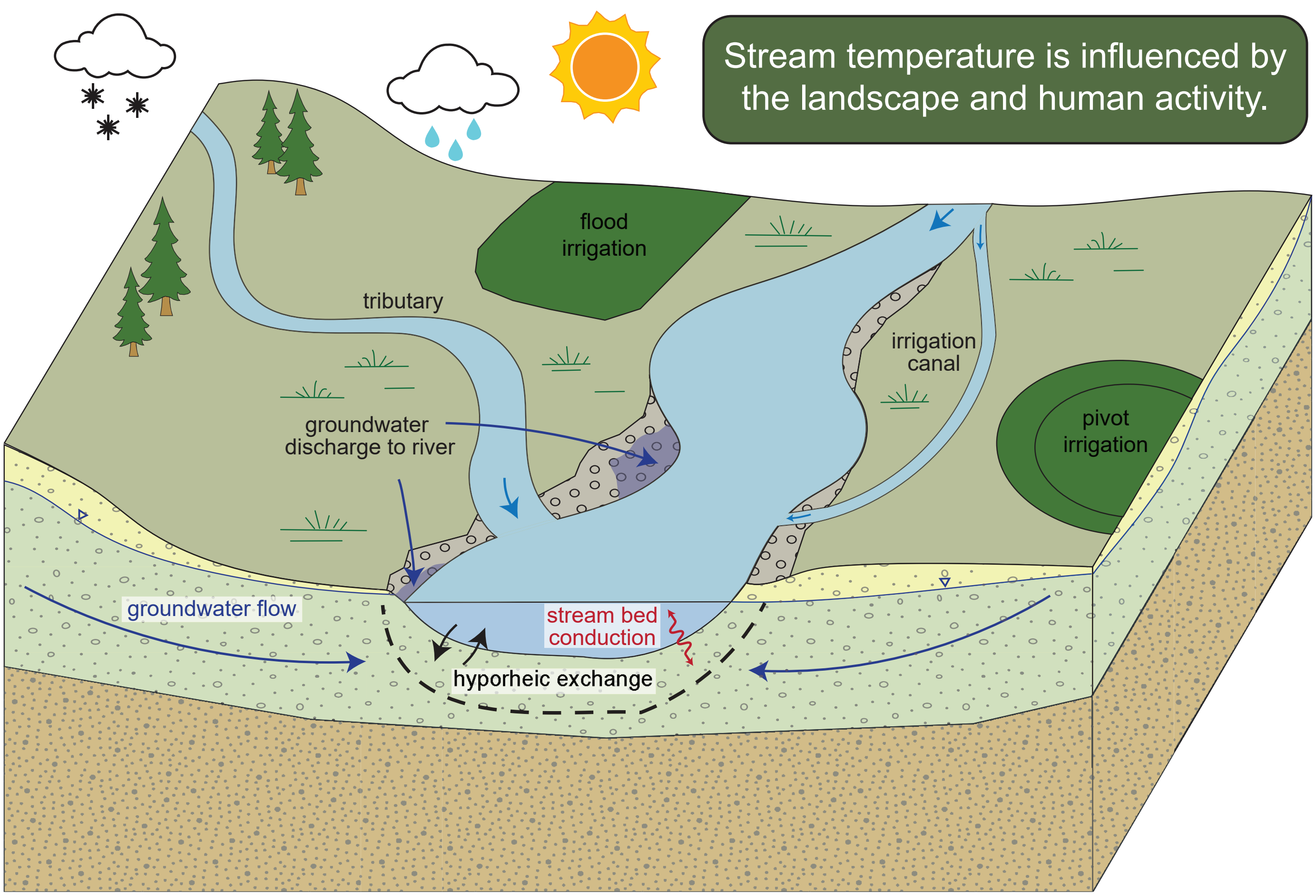


Figure 3. Many components affect stream temperature, as shown in this conceptual model. All components are described in Caissie, 2006. Note: hyporheic exchange involves mixing between surface water and the shallow subsurface.

GROUNDWATER INFLUENCES STREAMFLOW AND TEMPERATURE

Streamflow varies seasonally. In fall and winter in snow-dominated landscapes, rivers and streams are at “baseflow” conditions, meaning they are primarily supported by groundwater inputs. To sustain these inputs, groundwater must be replenished or “recharged.” This occurs when water on the surface of the earth infiltrates down into the ground until it reaches the groundwater table. Groundwater flows through the subsurface and discharges into streams. Without groundwater inputs, many streams would be dry in the late summer and early fall.

In summer, groundwater temperature is generally colder and more stable than surface water.

Groundwater temperatures approximate the average annual air temperature (fig. 4; Heath, 1983). In Montana, this is about 44°F (NOAA, 2023), but groundwater temperature can vary based on local conditions. Both groundwater and surface-water temperature fluctuate on a daily and seasonal basis, but groundwater temperature is more stable and has smaller fluctuations than surface water (fig. 4, inset). Because of this stability, groundwater is generally colder than surface water in the summer and warmer in the winter. Cooler groundwater inputs during the summer can help moderate elevated stream temperatures during late-summer low-flow periods (Mayer, 2012).

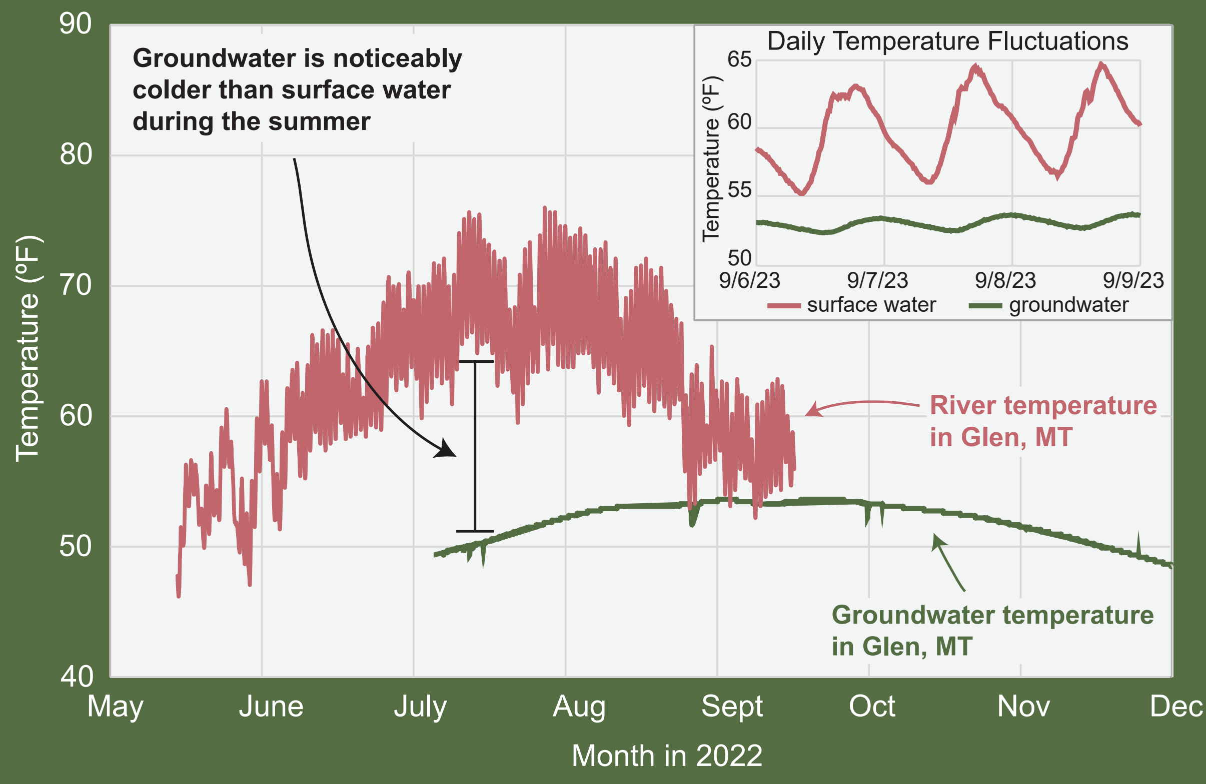


Figure 4. Groundwater near the Big Hole River has smaller temperature fluctuations compared to the seasonal and daily (inset) temperature swing of the river. Data sources: USGS stream gage 06025500, GWIC wells 161775, 327565 (inset), and GWIC surface-water site 327564 (inset). Data source: https://mbmggwic.mtech.edu.

GROUNDWATER AND THE BIG HOLE RIVER

Elevated temperatures are common in the Big Hole River during the summer. To better understand how groundwater might influence temperatures in the Big Hole River, Montana Bureau of Mines and Geology (MBMG) hydrogeologists identified groundwater discharge sites along a 13-mile stretch of the Lower Big Hole River near Glen, Montana.

TOOLS FOR IDENTIFYING GROUNDWATER INPUTS

Groundwater enters streams as diffuse (spread out) flow as well as at discrete (single) points (fig. 5). These groundwater inputs are sometimes visible where they seep or pour out of the stream bank. In most cases, groundwater inputs are not visible to the naked eye. Luckily, other clues and tools can be used to identify these groundwater discharge sites.

Did you know? Distinct temperature differences in a stream can be an indicator of a groundwater discharge site.

Thermal image vs. Regular image

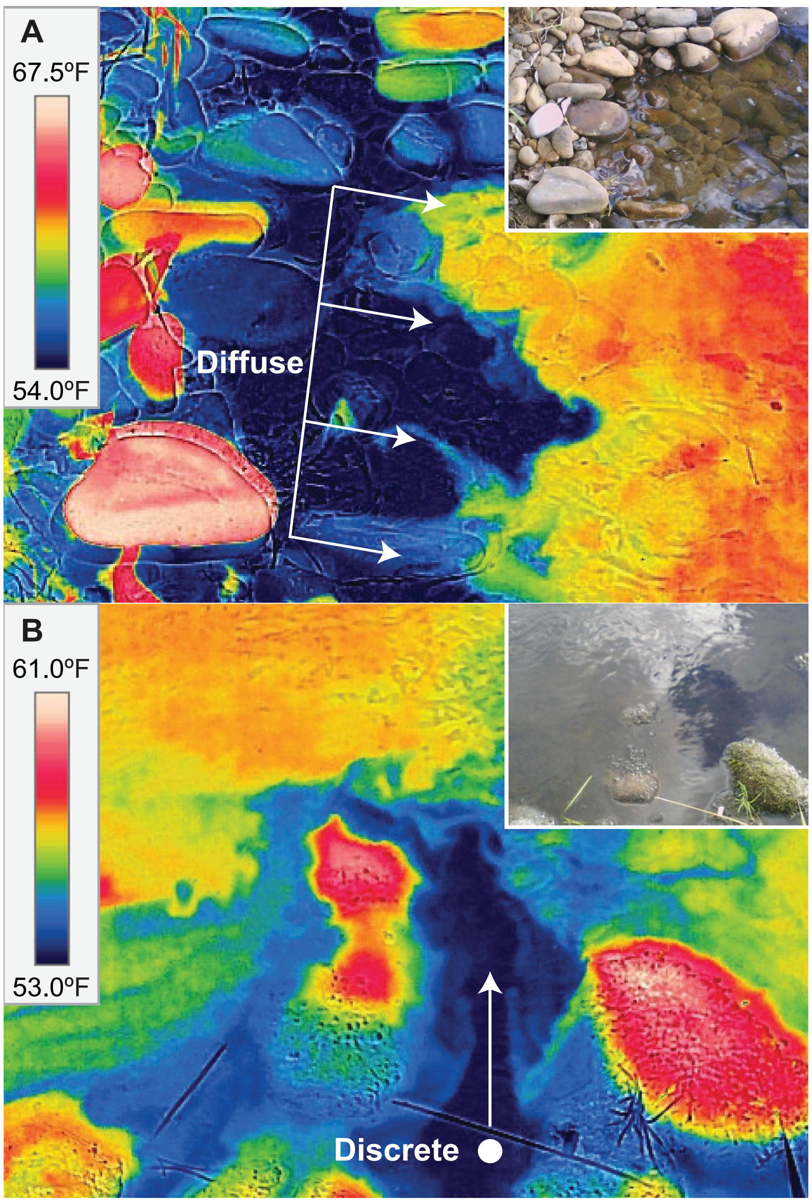


Figure 5. Thermal infrared images show (A) diffuse and (B) discrete groundwater flowing into the Big Hole River. Insets show the corresponding regular camera images. Notably, these groundwater inputs cannot be observed with the naked eye, but the colder temperatures are noticeable by touch.

Cold-Water Inputs

During the summer, when stream temperatures are warmer, areas of cold water along the stream can be an indicator of groundwater discharge. Scientists can use tools such as thermal infrared cameras to find these cold-water inputs (Briggs and Hare, 2018).

The photos to the left (fig. 5) were taken by MBMG scientists on the Big Hole River in August 2023, and illustrate how thermal images can be used to detect cold groundwater discharging to streams. The larger thermal images are paired with their corresponding regular camera images of the same site (insets). In these images, groundwater temperatures are as low as 53–54°F (cool colors), while nearby the stream is 61–67°F (warm colors). That is a difference of 5–14°F warmer in the stream.

Thermal infrared cameras can be used to interpret surface temperatures of streams, but when groundwater discharges from below the water surface, additional clues are needed to identify groundwater inputs.

Visit the MBMG YouTube channel to watch thermal videos of groundwater flowing into the Big Hole River:

https://tiny.cc/mbmgthermal

Did you know? Groundwater discharge sites can sometimes be orange or have an oil-like sheen due to iron in the groundwater.

Iron Precipitate

Iron is a common element in the earth. Groundwater can incorporate iron from the rocks and soils that it moves through. When iron-rich groundwater flows from an underground low-oxygen environment into a surficial high-oxygen environment, the iron oxidizes and leaves a rust-colored deposit (iron precipitate) on rocks (fig. 6A; Emerson and Weiss, 2004).

Naturally occurring iron-oxidizing bacteria can also facilitate iron precipitation through the creation of fibrous, orange mats (fig. 6B; Emerson and Weiss, 2004). These bacteria do not pose any risk to human health or the environment.

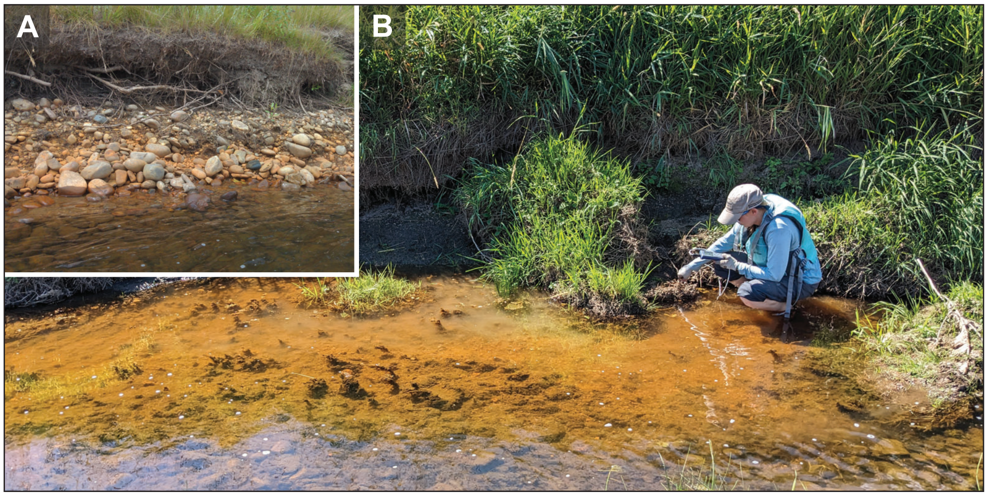


Figure 6. (A) Orange iron-staining and (B) iron-oxidizing bacteria mats were observed at groundwater discharge sites along the Big Hole River.

Iron precipitation occurs both inorganically due to changes in oxygen between the subsurface and surface, and biologically due to oxidizing bacteria.

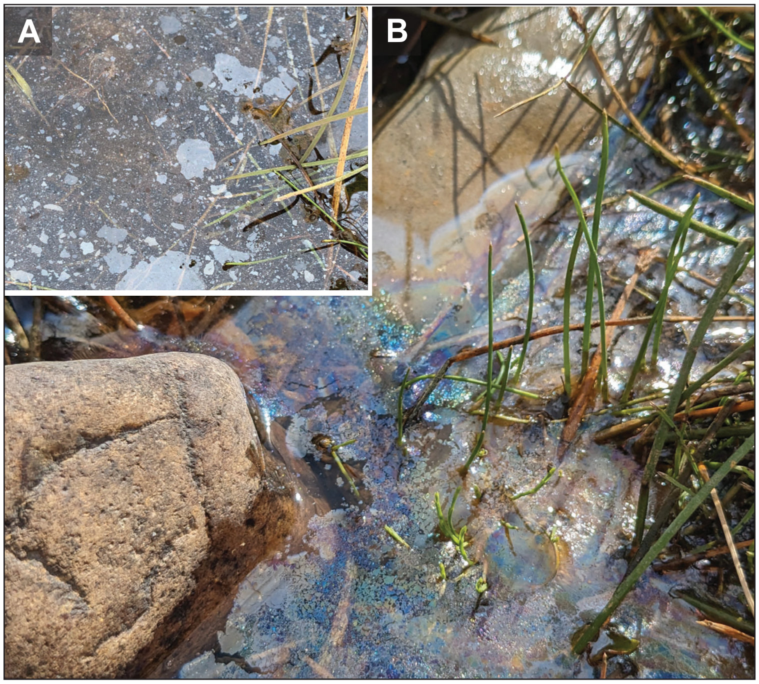


Figure 7. Biofilms with oil-like sheens were observed at groundwater discharge sites on the Big Hole River. These may look like small sheets (A) or similar to a petroleum sheen (B).

Biofilm

Iron-oxidizing bacteria can also produce a biofilm that appears similar to an oil sheen on top of the water (fig. 7). Swirling the water can help differentiate between a petroleum-oil sheen and a biofilm. When disturbed, the biofilm particles will disperse into small sheets (fig. 7A), rather than mixing back together like the petroleum oil would (Robbins and Hayes, 2023).

The presence of iron precipitate or biofilm is a good indicator of groundwater discharge along stream banks. Both of these indicators were observed at groundwater discharge sites along the Big Hole River, though they weren't present at every site. The concentration of iron and dissolved oxygen in the groundwater and the degree of protection from the river affects whether these iron-related clues are present.

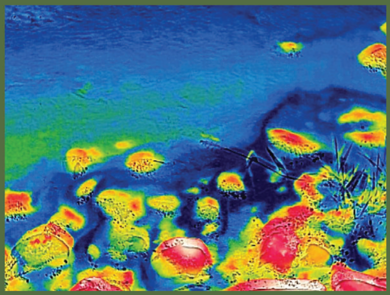
GROUNDWATER INFLUENCES STREAMFLOW AND TEMPERATURE

A number of streams in Montana are considered impaired for elevated temperature.

Groundwater may aid in cooling streams during critical low-flow periods in summer because it can add cool water and increase flow.

Clues for identifying where groundwater is discharging to streams include:

Cold-water inputs



Orange iron deposits

Biofilm

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The Ground Water Investigation Program (GWIP) encompasses site-specific studies of groundwater resource concerns that support statewide and local decisions regarding water. The Montana Legislature established GWIP in 2009, with a design that allows local communities or other stakeholders to nominate projects for study. The interagency Ground Water Assessment Steering Committee ranks and prioritizes project nominations. MBMG hydrogeologists bring data-driven scientific analyses that address important questions to Montana's citizens, business communities, and agricultural and industrial/commercial stakeholders.

MBMG publications can be found on our website: MBMG.mtech.edu