

Progress Report: Yellowstone Controlled Groundwater Area Technical Oversight Committee 2019 - 2023



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Yellowstone Controlled Groundwater Area

The Yellowstone Controlled Groundwater Area (YCGA) was established on January 31, 1994 under Article IV of the Water Rights Compact (Compact) between U.S. National Park Service (NPS) and the State of Montana (Montana Water Law: [§85-20-401](#) Montana Code Annotated (MCA)). Article IV, section A of the Compact states in part:

The parties understand that knowledge of the interrelationship of hydrothermal features within YNP [Yellowstone National Park], the hydrothermal system that supports those features, and groundwater in surrounding areas of Montana will benefit from increased study. The parties agree that the hydrothermal features of YNP are a unique and irreplaceable resource and represent one of the few undisturbed hydrothermal systems in the United States.

The Compact further states that “the goal of establishment and administration of the YCGA shall be to allow no impact to the hydrothermal system within the reserved land of YNP.”

The following are roles of cooperating agencies:

- *Department of Natural Resources and Conservation (DNRC)* – administer YCGA and regulate groundwater appropriations in YCGA.
- *U.S. National Park Service (NPS)* – review and evaluate applications for beneficial groundwater use in YCGA and responsible for monitoring geothermal systems in YNP.
- *Montana University System* – advise on inventory and monitoring activities in YCGA.
- *U.S. Geological Survey (USGS)* – conduct hydrologic and geologic studies in the vicinity of YCGA, including streamflow, water quality monitoring, and geologic mapping.
- *Montana Bureau of Mines and Geology (MBMG)* – conduct hydrologic and geologic studies in the vicinity of YCGA, including streamflow, water quality monitoring, geologic mapping, data management, and mails, handles and tracks meter cards.

Technical Oversight Committee

The Technical Oversight Committee (TOC) for the YCGA was established in Article IV, section J.1.a to the Compact. The Compact specifically outlines tasks and procedures and states that “the TOC shall”:

- i. Review the boundaries of the Area and the Subareas.
- ii. Review the initial restrictions on groundwater development imposed pursuant to Article IV, and future modifications of those restrictions.
- iii. Assess the cumulative impact of all development in the Area.
- iv. Review changes in groundwater and hydrothermal systems revealed by inventory and analyses done by MBMG, and any other pertinent scientific evidence.
- v. Review new scientific evidence pertinent to the YCGA.
- vi. Consult with MBMG or the DNRC on request.
- vii. Present evidence and make recommendations to DNRC in accordance with Article IV, section J.2.
- viii. Review applications for a permit to appropriate groundwater with a temperature greater than 60 degrees Fahrenheit (°F) or on request by the DNRC as set forth in Article IV, section G.2.c.
- ix. Take any additional action necessary to implement Article IV of the Compact.

Members of the TOC are from the NPS, USGS, DNRC and Montana University System (Table 1 and Figure 1). An additional at large member is selected by the other members. The representative for the Montana University System is appointed by the Montana State Geologist and typically is from MBMG, part of Montana Technological University.

Table 1. The 2023 TOC members and representation.

Member	Representation
Attila Folnagy (Chair)	DNRC
Marvin Miller	Montana University System
John Kilpatrick	USGS
Jefferson Hungerford	NPS
Kirk Waren	TOC members

The past five years saw Dr. Stephan Custer resign from his appointment to the TOC and the appointment of Kirk Waren as the At-large member. Dr. Custer was on the working group that established the YCGA boundary prior to the compacts passage in 1994. He served as Chair of the TOC from 2001 to 2022. David Susong also resigned from the TOC and Dr. Jefferson Hungerford was appointed by NPS as their new member. Mr. Susong has completed significant research projects and has a wealth of knowledge regarding the thermal systems of YNP. In addition to Mr. Waren's and Dr. Hungerford appointments, all other members of the TOC were formerly reappointed to five-year terms in 2023 by the appropriate official. The Committee expressed their deep appreciation for Dr. Custer and Mr. Susong's service and dedication to seeing that the TOC complete its work. Attila Folnagy was elected to serve as the Chair of the TOC on October 4, 2022.

TOC Reporting Requirements

Article IV, section J.1.g. of the Compact states that an initial review shall take place within one year of the inventory report done by the Montana Bureau of Mines and Geology followed by subsequent reviews every five years. The initial report was completed in 2001 covering the period from 1994 through 2000. Subsequent reports were completed by the TOC in 2008, 2013 and 2018. This report covers the five years from 2019 through 2023.



Figure 1. Left to Right: DNRC TOC member Attila Felnagy, former TOC Chair Dr. Stephan Custer, former NPS TOC member David Susong, USGS TOC member John Kilpatrick, and Montana University System TOC member Marvin Miller. Photo by Kerri Strasheim.

Water Permitting in the YCGA

Applicants wishing to appropriate water in the YCGA must apply for a Permit for Beneficial Water Use from the DNRC and have a meter installed to measure total volume of water used. The meter is provided by DNRC, made possible with funding from the NPS. MBMG performs the lead role in monitoring, by inventorying wells and collecting the meter data.

All permit applications must include a statement of whether the proposed water use will be at a temperature equal to or greater than 60 °F. Applicants for uses of water less than 60 °F and 35 gallons per minute (gpm) or less and 10 acre-feet (AF) per year or less are generally subject to standard requirements in [§85-2-306](#), MCA for the exception for small groundwater uses.

Applicants for uses of water less than 60 °F and greater than 35 gpm or 10 AF per year are subject to requirements of [§85-2-311](#), MCA for issuance of a provisional permit.

Appropriations of groundwater with a temperature of greater than 60 °F are subject to special provisions of Article IV, section G.2.c of the Compact and Administrative Rules of Montana ([ARM](#)) [36.12.12](#). For subareas # 1 and 2 (Figure 2), water between 60 °F and 85 °F and greater than 85 °F are permitted under each's respective compact criteria and procedures, except more monitoring is required, as described in Custer et al. (1993), for permits issued in sub area #2.

Appropriations for groundwater between 60 °F and 85 °F must meet the following criteria:

- i. The wellhead water temperature is the result of the normal thermal gradient of the earth, plus the mean annual air temperature at the site, plus 14 °F,
- ii. The concentration of soluble chloride (Cl) is less than 10 parts per million (ppm),
- iii. The well does not contain a production zone completed within the Madison Group.

Appropriations of groundwater with a wellhead water temperature of 85 °F or more is presumed to be hydrothermal discharge water. DNRC will not process or grant an application for a permit unless the application contains credible information that the proposed appropriation does not include contribution by hydrothermal discharge water, is reviewed and approval recommended by the Technical Oversight Committee, and a contested-case hearing is held with the application approved by the hearings officer. If the application is denied, the well must be temporarily or permanently abandoned according to the Montana Board of Water Well Contractors Rules in [ARM 36.21.670](#).

Water Permitting Activities in YCGA

A total of 389 permits for the use of groundwater in the YCGA have been issued through the DNRC Office in Bozeman from the January 31, 1994, effective date of the compact, through December 31, 2023 (Tables 2 and 3; Figure 3). As of the end of 2023, there are 19 pending permits being processed by DNRC. There are 3 main areas of higher well permit density (Figure 2): Cooke City area (furthest east), Yellowstone River valley area (north central), and Hebgen Lake/West Yellowstone area (furthest west).

All but 6 of the 389 permits issued through December of 2023 are for 10 AF or less. The 6 permits for over 10 AF account for 527 AF or 35 percent of the total 1,496.8 AF authorized. Two permits for one development issued in 1996 account for 279 AF or 19 percent of the total volume authorized.

There is one permit (provisional permit # 43B 30048372), issued in 2010, that is for an appropriation with a water temperature between 60 °F and 85 °F. Using the Compact criteria (see below for geothermal gradient criteria), well data were analyzed by MBMG staff and the TOC and found to meet criteria for use of water between 60 °F and 85 °F. Several permits have been issued in the Corwin Springs area for water above 55 °F. Monitoring of these warmer-water wells is described in the YCGA Long-Term Monitoring Activities 2019 through 2023.

The formula used to trigger special review of a proposed appropriation uses a representative geothermal gradient for the stable craton to compute the expected temperature and a representative mean air temperature for recharge and computes whether the temperature is higher than the expected threshold.

Formula: Geothermal Gradient x Depth + Mean Air Temp + 14 °F
 0.01646 °F/feet (ft) x Depth (ft) + 45.3 °F + 14 °F

The 14 °F is an adjustment factor to allow for error in the geothermal gradient and/or mean annual temperature so that the trigger temperature for action is reasonable, but protective. This equation is used to evaluate whether the ground-water temperature is substantially above the temperature expected at the bottom of a well without the influence of heat from the YNP geothermal system.

Table 2. Number of permits issued in YCGA by year received.

1995	51	2005	13	2015	4
1996	23	2006	16	2016	13
1997	35	2007	12	2017	5
1998	18	2008	11	2018	10
1999	15	2009	13	2019	9
2000	9	2010	6	2020	8
2001	5	2011	12	2021	21
2002	8	2012	3	2022	17
2003	7	2013	5	2023	11
2004	14	2014	15		
Total	389				

Table 3. Number of YCGA permits by hydrologic basin.

41F - Madison River	202
41H - Gallatin River	6
43B - Yellowstone River, Above and Including Bridger Creek	181
Total	389

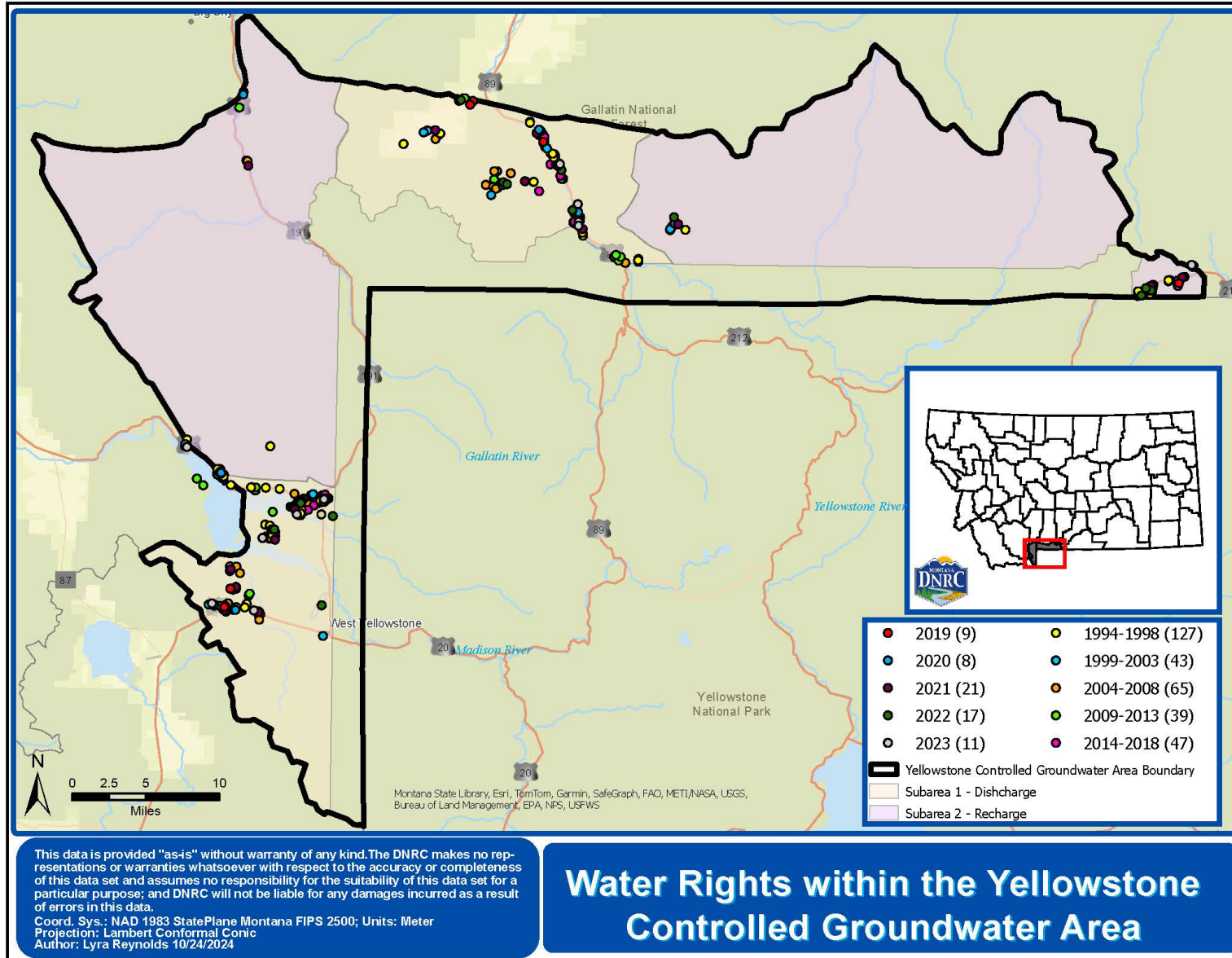


Figure 2. Map showing the location of subareas and permitted YCGA wells by year permitted.

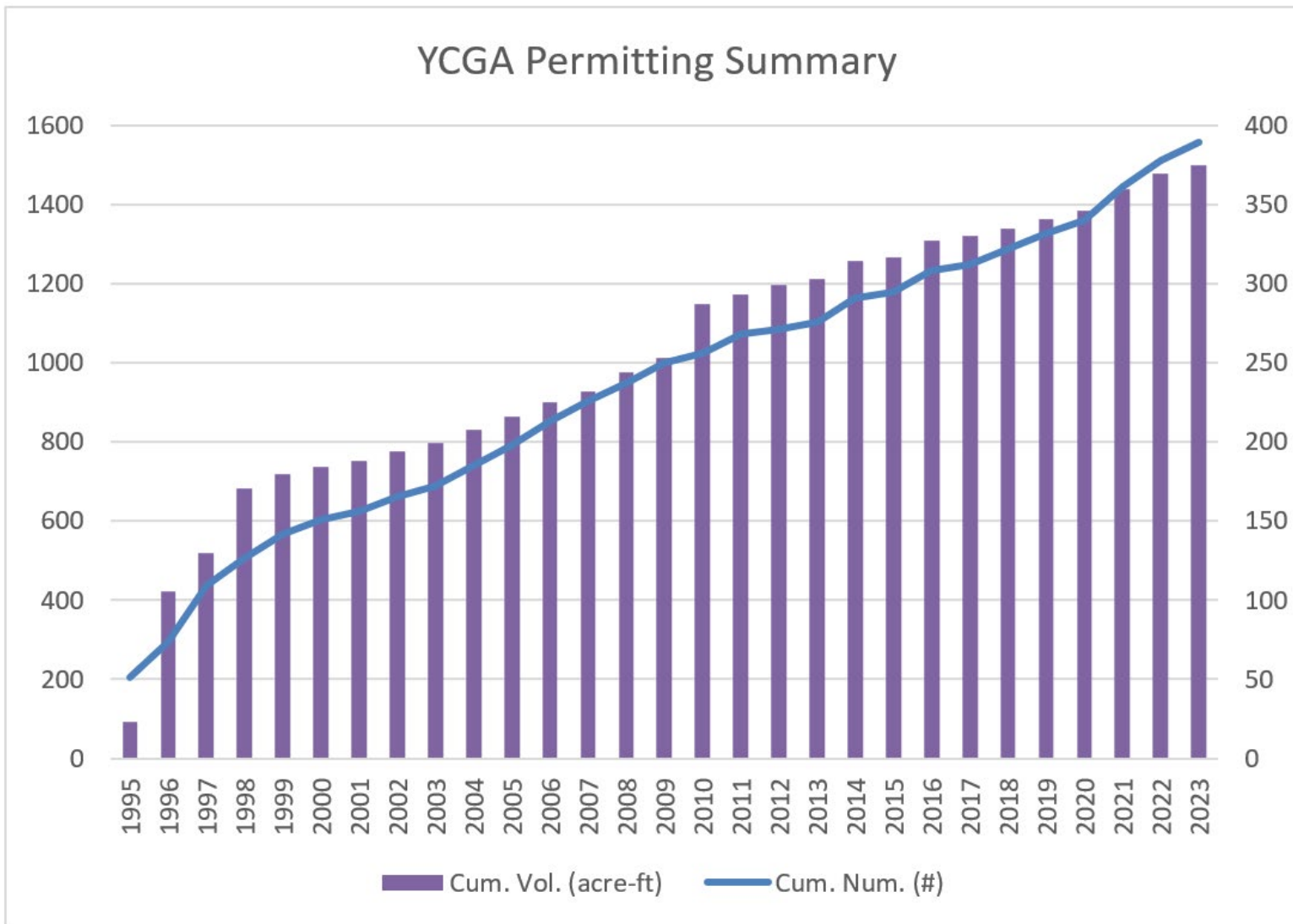


Figure 3. Number of YCGA permits (right axis) and authorized cumulative volume in AF (left axis).

Overview of YCGA Long-Term Monitoring Sites

Active and Discontinued Monitoring Sites

The MBMG established the YCGA Long-Term Monitoring Program (LTMP) in 2005 to 2007. The LTMP monitoring sites include wells, springs, spring creeks, and one river site (South Fork of Madison River). Sites are classified, based on water temperature, as cold ($<15^{\circ}\text{C}$), warm (15° to 25°C), or hot ($>25^{\circ}\text{C}$). Currently 37 monitoring sites are active. A summary of all sites that MBMG has monitored since the LTMP was initiated, and the types of monitoring data collected, is provided in Appendix A. Links to the data for the monitoring sites are included in the text and Appendix A. Most sites are visited at least three times per year, typically in May, August, and November. Some monitoring sites are visited more often to maintain or repair monitoring equipment. Almost all of the sites have data loggers that record water levels and/or water temperature on an hourly basis.

Inorganic water-quality samples are collected annually, in August-September, at the active LTMP sites. Water quality field parameters (temperature, pH, specific conductance, oxidation-reduction potential, and dissolved oxygen) are measured while collecting samples. All of the monitoring data collected are available to the public via the MBMG Ground Water Information Center (GWIC) website at <http://mbmggwic.mtech.edu>. A data summary report for monitoring data collected from the long-term monitoring network from inception through 2013 was published in 2021 (English et al. 2021). A data summary report for data collected from 2014 through 2020 is currently in draft.

Soda Butte Creek Watershed Monitoring Sites-Cooke City and Silver Gate

Surface water and groundwater flow into YNP from the upper Soda Butte Creek Basin, entering YNP at the Northeast Entrance, near Silver Gate, Montana. The bedrock geology consists of gently dipping Paleozoic sedimentary formations overlying Archean metamorphic basement rocks, intruded by Tertiary igneous bodies and covered by a thick sequence of andesitic volcanoclastic deposits. Glacial till covers the bedrock along the valley sidewalls and alluvium and glacial outwash deposits cover the valley floor. A hydrogeologic assessment of the area (Metesh et al., 1999) found no evidence of geothermal resources in the area, and all surface water and groundwater sites that have been visited by MBMG produce cold water. The closest known geothermal feature is Soda Butte, located 12 miles southwest of the Northeast Entrance. There are currently three wells monitored in this basin. Three wells are monitored in the Upper Soda Butte watershed. Of these, the Silver Gate well ([106030](#)) has the longest record.

Yellowstone River Watershed Monitoring Sites-Gardiner and Corwin Springs Area

Surface water and groundwater flow into the Gardiner Basin from YNP at the North Entrance. Additional groundwater and surface water flow into the Gardiner Basin from the mountains surrounding the basin inside and outside YNP. The geology of the Gardiner Basin is complex, with bedrock that includes Archean metamorphic basement, Paleozoic sedimentary rocks, Mesozoic sedimentary rocks, Tertiary volcanic rocks, Tertiary intrusive rocks, Quaternary volcanic rocks, and Quaternary travertine deposits. Surficial geology units include Quaternary glacial moraine, glacial outwash, landslide deposits and alluvium. The long-term monitoring sites include sites in most of these geologic units. Currently 13 sites are monitored in the Gardiner Basin, which include a mix of cold and geothermal springs and wells, which reflect the complex geology of the area.

Gallatin River Watershed Monitoring Sites-Big Sky Area to Park Boundary

Monitoring in the Upper Gallatin River watershed is focused along the Upper Gallatin River after it flows out of YNP. The monitoring sites are focused on Paleozoic carbonate bedrock aquifers (Cambrian and Mississippian). Two wells and three large discharge springs are currently being monitored. All the monitored sites produce cold water and no geothermal resources have been identified in the monitored watershed area. The two monitored wells are completed in the Cambrian Pilgrim formation ([215333](#)) and the Mississippian Madison Group ([259697](#)). Both wells show annual water-level fluctuations of about 5 to 30 feet, and groundwater levels in both wells have increased since the spring of 2017. Two of the monitored springs, Slow Vehicle ([255289](#)) and Anceny ([258715](#)), discharge along a major reverse fault, where Archean basement rock has been faulted over the Madison Limestone. Snowflake Spring ([171216](#)) discharges along a thrust fault where the Madison Limestone is thrust over Cretaceous sedimentary bedrock. All the springs have large seasonal fluctuations in discharge that are most likely associated with annual changes in snowpack and precipitation as rain. For example, the measured discharge of Anceny Spring ranges from 1,719 to 2,767 gpm). While the discharge at Anceny Spring fluctuates, the total dissolved solids concentrations are consistently about 300 mg/L, indicating the water chemistry is relatively stable.

Madison River Watershed Monitoring Sites-West Yellowstone-Hebgen Basin

Surface water and groundwater flows into the Hebgen Basin from YNP at the West Entrance, and also from the Mountains that bound the basin on the south and east. There are warm-water springs and wells in the area which may be due to some geothermal activity in the area. A confined aquifer underlies the basin between West Yellowstone and Hebgen Lake. MBMG currently monitors 11 sites in the Hebgen Basin that include three flowing-artesian wells, three cold water springs, and a warm water spring that produces hydrogen sulfide gas. Most of the monitored wells and springs appear to show seasonal and annual fluctuations that generally follow snowpack and precipitation patterns. However, one flowing artesian well ([230654](#)) does not follow annual precipitation patterns and may reflect longer-term changes in groundwater recharge. Two large-discharge cold water springs Corey Spring ([182014](#)), and Black Sand Spring ([183242](#)) show a pattern similar to Snowflake Spring ([171216](#)) in the Gallatin River basin.

Summary of YCGA Long-Term Monitoring Activities, 2019 through 2023

U.S. Forest Service Special Use Permit Amendment

Many of the long-term monitoring sites are located on U.S. Forest Service (USFS) land. The MBMG maintains a Special Use Permit, issued by the USFS, to allow monitoring activities on public lands managed by the USFS. The current permit was issued in 2017 and allows monitoring of 10 sites on USFS land. In 2021 MBMG obtained an amendment to the current permit to add 5 additional wells to the permit. The added wells include a USFS owned well at the Cooke Pass Administrative Site/Colter Campground, a deep-shallow well pair to be drilled at the USFS Fire Center at the West Yellowstone Airport, and a deep-shallow well pair to be drilled west of the West Yellowstone Airport. The deep-shallow well pair at the Fire Center were completed in 2020, but due to drilling difficulties, the second deep-shallow well pair to the south were never drilled.

Modifications to the Long-Term Monitoring Network

Significant modifications to the monitoring network over the 5-year period from January 1, 2019 to December 31, 2023 included the following:

USFS well 106074-Located at the Cooke Pass Administrative Site/Colter Campground, east of Cooke City, this well was added to the network in September 2019. A water-level data logger and barometric pressure data logger are being maintained in the well, and water-quality samples have been collected annually since August 2020.

Spring 181620-Located in the Gardiner Basin, northwest of Gardiner, this monitoring site consists of a developed spring within an area of diffuse discharges from colluvial material on a hillside. The site was dropped due to difficulties with obtaining accurate or meaningful discharge measurements, and difficulties in collecting water-quality samples.

Spring 184260-Also located in the Gardiner Basin, about 500 feet northwest of Spring 181620 (see above) has the same hydrogeologic setting as spring 181620 and was dropped for the same reasons.

Spring 183268 (AKA Stinky Spring)-This warm-water spring has interesting water chemistry, forms a small pond, and has been monitored since 2005. Discharge is measured using a small flume at the outlet of the pond, and water temperature is measured with a logger deployed in the upwelling area within the pond. Numerous attempts at maintaining a water-level logger at the flume to measure stage and obtain hourly discharge data have failed. Problems include bio-fouling of the flume mouth by aquatic plant debris, which backs up water and changes the pond stage, and issues with the accuracy of the water-level data loggers to track changes in pond stage that are generally less than 1 cm. For these reasons use of a water-level logger to obtain discharge data has been dropped and only manual flume measurements are obtained after cleaning the flume and allowing the pond level to stabilize. All other monitoring activities at this spring continue.

Wells 316112 (shallow) and 316315 (deep)-This deep-shallow well pair was installed in the summer of 2020 at the USFS Fire Center at the West Yellowstone Airport and added to the long-term monitoring network. These wells are also part of the USGS National Groundwater Monitoring Network (NGWMN). The wells were installed, in part, to obtain more information on groundwater near the Madison River in the Bakers Hole area, where there are several flowing wells, including wells that have been monitored for the YCGA (8943, 106775, 106778).

South Fork of the Madison River at Highway 20 (327883)-This surface-water monitoring site was added to the monitoring network in 2023 to obtain discharge measurements to aid in understanding the water budget in the Hebgen basin. The USGS maintains a gage site on the Madison River at the YNP boundary, but the South Fork of the Madison is the second largest surface water source flowing into the Hebgen basin, and there is limited information on the quantity of water it contributes to the basin.

Well 266377-When this well was drilled in 2012, the driller reported hitting groundwater with a temperature of 37 °C (98 °F) at a depth of 282 feet below ground surface and reported the following unusual drilling conditions: “*stopped under ream drilling @ 282 feet due to hot water and heaving sands came back up casing to 201 feet.*” The TOC discussed this well in 2013, and it is referred to as the “98 Degree Well” in the 2009 – 2013 TOC 5-year report. It has also been referred to as the “Hot Well”. The well was never completed or properly abandoned. MBMG

evaluated rehabilitating the well as a geothermal monitoring well but determined the risks of trying to remove the heaving sands to recover the well were too great. MBMG has periodically measured the water level in the well since June 2012, and the TOC agreed to adding the well to the long-term monitoring network at the 2023 annual meeting. MBMG has made numerous attempts to contact the property owner, including sending a letter to the address on record for the property owner. However, the owner has never responded to phone calls or the letter, and permission to use the well as part of the long-term monitoring network are still pending.

Other MBMG Activities in the YCGA

Upper Gallatin River Stream Gaging and Specific Conductance Monitoring

The MBMG, with funding support from DRNC, conducted seepage runs along the Gallatin River in October of 2021 and April of 2022. The seepage runs were conducted to determine if the Gallatin River was gaining or losing water as it flowed across an extensive area of outcropping Madison Group Limestone in the northwest corner of the YCGA. Discharge measurements were made at five stations along the river, from just below Cinnamon Creek downstream to below Twin Cabin Creek. The river bed along this reach of the Gallatin River consists of cobbles and boulders, and the discharge measurements were inconclusive for determining gains or losses within the range of error of the measurements.

Lucky Minerals Drilling Proposal-Emigrant Gulch

In June 2015, Lucky Minerals, Inc. submitted a Mineral Exploration Plan to Montana Department of Environmental Quality (DEQ) to complete exploration drilling in the Emigrant Creek watershed for base and precious metals deposits. The proposed exploration area is in Park County and is located about 7 mi SE of Emigrant, Montana and 19 miles due north of the YNP boundary. The Mineral Exploration Plan originally called for exploratory drilling on public land managed by USFS and private land. To help address the public concerns the USFS provided funding to MBMG to complete an investigation (LaFave, 2016) to characterize the water quality in the Emigrant Creek watershed. In 2019, the Yellowstone Gateway Protection Act permanently withdrew the federal mineral rights in this area which made the project not profitable for continued exploration.

Crevice Mountain Mining Exploration Proposal

In 2019, Yellowstone Gateway Protection Act permanently withdrew federal mineral rights in the Crevice Mining District. This will prevent proposed mines from expanding onto unclaimed public land adjacent to YNP. Due to the proximity of the project to YNP, NPS, with assistance from MBMG, planned to collect baseline water-quality samples during the 2019 field season in the area. Surface-water samples were collected from Bear Creek and the Yellowstone River just above the confluence with Bear Creek in 2019, but no additional samples were collected because the proposed mining activities were dropped. In 2021, DNRC terminated a pending application # 43B 30072675 for the purpose of dust suppression from a proposed well that had not been drilled. In 2023, the Greater Yellowstone Coalition purchased the land, mining claims, and all associated mineral rights that had been proposed to be used for exploration by the Crevice Mining Group LLC. The Greater Yellowstone Coalition plans to sell these holdings to the USFS. This effectively ends the feasibility of future large-scale mining in this area.

Groundwater Quality Investigation in the West Yellowstone Basin

Groundwater quality was investigated in the West Yellowstone basin in the summer of 2021. Samples were collected from 42 wells for inorganic analysis (major ions, trace elements, radon, and strontium 86/87 isotopes). In addition, sampling data from 24 wells that MBMB sampled between 2010 and 2021 were compiled to aid in evaluating groundwater quality in the area. The results of this investigation were published in 2023 (Hanson and English, 2023). While conducting the field work, well inventories were completed for numerous wells that were drilled after the original YCGA well inventories were completed.

Summary of Yellowstone National Park Monitoring, 2019 to 2023

Introduction

This brief discussion presents a summary of YNP's hydrothermal monitoring efforts from 2019 to 2023. Topics discussed include the use of CI flux, fixed-wing airborne thermal infrared (TIR) condition assessments, temperature monitoring of hydrothermal features and additional efforts for protecting hydrothermal systems.

Terms used to describe hydrothermal systems are defined by Jaworowski (2010):

A hydrothermal area is a contiguous geologic unit generally including one or more hydrothermal features, bounded by the maximum aerial extent of hydrothermally altered ground, thermal deposits, geothermal gas emissions, or heated ground. A thermal group is a subdivision of a thermal area that contains one or more hydrothermal features and can be isolated from other groups based on physiographic, hydrologic, or geochemical parameters. A thermal feature is a vent, or small cluster of related vents, emitting gases and/or hot water. A thermal drainage is a physiographic/hydrologic drainage to which heated waters are contributed by adjacent thermal areas. For example, Wall Pool and Black Opal Pool are thermal features in the Biscuit Basin thermal group, which is part of the Upper Geyser Basin thermal area; and these features contribute thermal waters to the Firehole River thermal drainage.

Reasons to monitor hydrothermal systems are presented in Table 4.

Table 4. Reasons to monitor hydrothermal systems (from Heasler et al., 2009).

Reasons to monitor vital signs of hydrothermal systems	Explanation
Human health and safety	• Hot systems can cause thermal burns (and death) • Some systems may cause chemical burns (acid waters, vapors or rocks) • Some systems concentrate toxic chemicals (mercury, arsenic, etc.) • Some systems produce toxic gases (hydrogen sulfide, carbon dioxide) • Some systems may have the potential for hydrothermal explosions
Baseline data	• Without baseline data, natural variation in heat, water and chemistry cannot be assessed, and potential impacts from human activities, seasonal variation, climate change, etc., cannot be determined. Without baseline data, it is difficult to determine what normal changes are and what significant changes are that might portend broader geologic events. Short-term (daily, weekly, seasonal, annual) variation needs to be distinguished

Reasons to monitor vital signs of hydrothermal systems	Explanation
	from long-term trends (are systems getting larger or smaller; hotter or cooler?). • Baseline data are also critical for scientific researchers to be able to test hypotheses about hydrothermal systems and their components. • Baseline data may be useful to researchers in other fields (e.g., seismicity, geomicrobiology) • Baseline data may help clarify the interaction of thermal water with local cold groundwater.
Environmental impacts	• Hydrothermal systems may be having an impact on wildlife (Chaffee et al., 2007; Varley and Schullery, 1998) or on water quantity and/or quality of adjacent streams • Gases may produce indoor air pollution where there are buildings (Durand, 2006)
Development of local or neighboring resources	• Water (even local cold), geothermal, oil, gas, or mineral production may influence underground water flow path characteristics and therefore ultimately the resulting surface hydrothermal feature; springs may dry up, or change from hot spring to fumaroles as water table drops (Allis, 1983; USGS, 2003; Barrick, 2007) • Monitoring can also help document recovery of hydrothermal features from anthropogenic impacts • Monitoring elevation data can detect subsidence from nearby fluid production
Planning, development or construction activities	• Geothermal features may be impacted by development or construction, or the thermal features may impact managerial decisions (e.g., road construction in thermal areas)
Research and education activities	• Research and education activities can be a source of data for monitoring efforts (see discussions of vital signs later in this chapter), but if conducted improperly, research and education may have a detrimental impact on geothermal features.
Vandalism	• Vandalism cannot be documented without baseline information about what existed before damage
Interpretation activities	• Monitoring data can provide data for local interpretation activities
Volcano monitoring	• Chemical changes may indicate impending hydrothermal explosion (Fournier et al., 1991) • Changes in physical appearance of spring may mean other hazards exist, such as landslides (springs reportedly became cloudy prior to a landslide in a Guatemala thermal area) • Changes may be indicator of magmatic activity (see discussion of fumarole gasses in volcano chapter)

Use of Chloride (Cl) Flux for Hydrothermal Monitoring

Since the early 1980s, researchers and the NPS have used Cl flux of major rivers exiting YNP to estimate hydrothermal activity (see Friedman and Norton, 1990 and associated references). Through 2010, approximately twenty water samples were collected annually at each monitoring site on the Yellowstone, Madison, Snake, Falls, and Henry's Fork rivers. Large tributaries with substantial thermal inflows were also sampled in the Yellowstone and Madison River basins to examine hydrothermal trends at a finer resolution including the Firehole, Gibbon, and Gardner rivers. Although periodic water sampling can yield an estimate of annual hydrothermal trends, including associations between Cl concentration and specific conductivity (SC) in major rivers, data acquisition is constrained by the number of site visits and analytical costs.

Beginning in 2010, SC, which is relatively easy to measure and can be automated, has been used as a proxy for Cl. The NPS Geology program and USGS researchers have installed In-Situ Aqua TROLL[®] 100 continuous recording probes which records water temperature and SC at 15-minute intervals at nine Cl flux monitoring sites (Clor et al., 2012).

From 2019 to 2023, the following CS stations were operating and continue to operate.

- Madison River near West Yellowstone (44°39'25.46", -111°04'04.67");
- Firehole River near West Yellowstone (44°37'12.66", -110°51'48.61");
- Gibbon River at Madison Junction (44°38'26.88", -110°51'39.83");
- Tantalus Creek at Norris (44°43'57.81", -110°42'47.71");
- Gardner River (45°1'2.4", -110°41'37.2");
- Firehole River at Old Faithful, YNP (44°27'33.60", -110°49'20.18");
- Yellowstone Lake Outlet/Fishing Bridge (44°34'01.53", -110°22'49.46");
- Yellowstone River at Corwin Springs (45°06'43.63", -110°47'37.20");
- Snake River above Jackson Lake at Flagg Ranch (44°6.0178', -110°40.2005');)
- Fall River in Caribou-Targhee National Forest (44°3.4474', -111°11.1462').

Between 2019 and 2023, SC monitoring stations on the Yellowstone River at Corwin Springs, Madison River near West Yellowstone, Firehole River, Gibbon River at Madison Junction and Tantalus Creek at Norris Geyser Basin were upgraded with In-Situ telemetry systems to deliver data daily to NPS and USGS servers.

These higher resolution data yield a wealth of hydrologic information compared to the 28 samples per year for each river under the sample plan used prior to 2010 (Norton and Friedman, 1985; Friedman and Norton, 2007; McCleskey et al., 2017). On an annual basis, the NPS Geology program and USGS researchers collect 2-3 samples per site to verify and improve the SC-solute correlations.

The use of SC probes at the various monitoring sites enables a more consistent estimation of Cl flux and can be used to identify changes in river chemistry as a result of geyser eruptions, rain events, or changes in thermal inputs as a result of earthquakes or other natural events. The use of SC as a proxy for Cl requires quantification of the relationship between SC, Cl, and other geothermal solutes (SO₄, F, HCO₃, SiO₂, K, Li, B, and As). At each monitoring site, numerous

water samples were collected over a wide range of hydrological conditions and analyzed for Cl concentration-SC relationships which are used to determine short- and long-term Cl flux (McCleskey et al., 2012; McCleskey et al., 2016).

Thermal Infrared (TIR) Imagery Acquisition of Hydrothermal Areas

Fixed-wing Airborne TIR Monitoring

Beginning in 2005, the YNP Geology Program funded researchers from Montana State University, University of Montana, and Utah State University to collect and manage thermal imagery. These initial collaborations resulted in the monitoring of hydrothermal areas both park-wide (satellite) and for specific areas (fixed-wing). Acquisition of fixed-wing thermal imagery continued under an agreement with Utah State University until September 2015. The current YNP Geology Program staff was prohibited from seeking funding to reinstate the fixed-wing thermal infrared acquisition program.

In 2024, Geology Program staff was able to secure funding from Yellowstone Forever, the philanthropic entity supporting Yellowstone National Park programs, to re-establish the acquisition of IR image data from fixed-wing mounted sensors. Working closely with USGS Astrogeology Program staff we will acquire and analyze thermal infrared imagery that will be assessed against earlier imagery for temporal variations in heat output in the thermal basins. YNP Geology Program staff have also processed imagery acquired since 2005 with structure from motion (SfM) techniques to render 3-dimensional models of 2-dimensional image sequences. These analyses more effectively indicate temporal variations between geo-rectified image datasets.

Ground-based Thermal Feature Temperature Monitoring

The YNP Geology Program and its research partners, which include the USGS, monitor select hydrothermal features in YNP with temperature loggers. Temperature loggers comprise a thermistor and a data logger and are in a thermal pool or, in the runoff channel of a hydrothermal feature. In 2023, there are 90 temperature loggers deployed in hydrothermal features in YNP. The temperature loggers are not calibrated, and, therefore, the data collected with these loggers are treated as relative information; the system is comparatively erupting/overflowing or not. Monitored features are chosen based on their significance to the hydrothermal system, cultural significance, safety of visitors and/or potential anthropogenic impacts to the hydrothermal feature. For example, temperature loggers exist on 14 thermal features in the Norris Geyser Basin, 30 features in the Lower and Upper Geyser Basins (Figure 4), 3 features in West Thumb and Dragon's Mouth in Mud Volcano.

Onset[®] Computer Corporation temperature loggers were used to measure kinetic surface temperatures. Onset[®] loggers are paired with thermistors of cable lengths that vary from 2 m. to 17 m. in length, and temperatures readings were usually collected on a 1-minute interval. (About 536,000 data values per site per year).

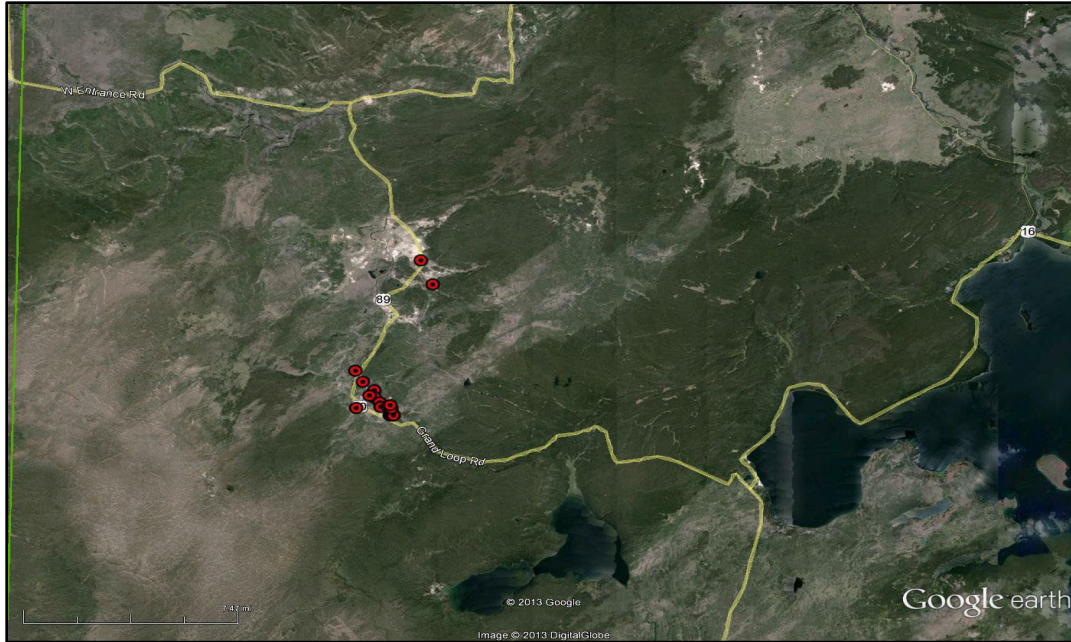


Figure 4. Temperature logger locations in the Upper and Lower Geyser Basins.

Future Protection Efforts

Federal Highways – Canyon to Fishing Bridge Road Replacement Project

Federal Highways is conducting preliminary drilling programs during the summer months of 2022 to 2025 to assess road alignment options in the area of the Mud Volcano Hydrothermal Basin. Currently, the road lies within the Mud Volcano hydrothermal area and has been degraded by the underlying hydrothermal system. Field mapping of the area's active and relic hydrothermal ground also indicate impingement and degradation from the hydrothermal system to the existing road prism. Remotely sensed IR data has been acquired and continues to be acquired to determine spatiotemporal variations heat output by the hydrothermal system. Because of these degradational factors to the existing road prism, we are looking at potential new road alignments to the west of the existing alignment that will continue to provide visitor access to the hydrothermal features in the Mud Volcano area.

Climate Change and the fate of Yellowstone's Hydrothermal Systems

The YNP Geology Program is initiating an important effort to raise funds to study the effects that climate change will have on hydrothermal system recharge and its effect on hydrothermal feature activity. This effort will be informed by Montana Water Compact TOC project initiatives as well as efforts by Yellowstone Volcano Observatory cohort programs.

Thermal Area Preservation Program

The YNP Geology Program created the Thermal Area Preservation Program (TAPP) in 2018 to mitigate, rehabilitate and gather spatiotemporal degradation information in front country hydrothermal areas in YNP. The trails and boardwalks of Yellowstone's front country hydrothermal areas are used by millions of visitors every year, and unfortunately, they carelessly leave their mark on their visits. The TAPP team works all summer to rehabilitate hydrothermal features that incur damage from poor or careless visitor behavior as well as performing damage assessments for law enforcement officers prosecuting cases against people who commit resource damage and trespass in hydrothermal areas.

Stream gaging in YCGA and YNP

The USGS, DNRC, MBMG, and Montana Fish Wildlife and Parks (FWP) have gaged continuous flows within the YCGA and YNP at the locations shown in Table 5. These federal and state networks collectively serve a diverse array of water managers and water users in the YCGA. As demand for water grows, effective water right administration will increasingly depend on accurate real-time measurements of streamflow. Data from stream gages inform real-time decision making and long-term planning on water issues, such as water management, economic development, infrastructure design, water compacts, municipal growth, flood forecasting, water quality, aquatic ecosystem management, and recreational safety (Stream Gage Oversight Work Group, 2022). The real-time streamflow data from the gages in Table 5 were critical for real-time response to the June 2022 floods.

Table 5. List of stream gages, link to the data, and period of record within YCGA and YNP.

Gage # and Link to Data	Gage Name	Period of Record
Yellowstone River Basin		
06191500	Yellowstone River at Corwin Springs	1990-present
06191000	Gardiner River near Mammoth	1989-present
06190540	Boiling River at Mammoth	1991-present
06188000	Lamar River near Tower Ranger Station	1989-present
06187915	Soda Butte Creek at Park Boundary	1998-present
06186500	Yellowstone River at Yellowstone Lake Outlet	1991-present
DNRC/FWP Seasonal Gages		
43B 91620	Cedar Creek at Mouth near Corwin Springs	2005-2023
43B 91550	Mulherin Creek near Corwin Springs	2007-2023
43B 89500	Bear Creek at Jardine	2022-2023
43B 89490	Pine Creek near Jardine	2023
43B 01990	Tom Miner Creek near Mouth	2023
327883	South Fork of the Madison River at Hwy 20	2023
Madison River Basin		
06036940	Tantalus Creek at Norris Junction	2004-present
06036805	Firehole River at Old Faithful	2007-present
06036905	Firehole River near West Yellowstone, MT	2003-present
06037100	Gibbon River at Madison Junction,	2002-present
06037500	Madison River near West Yellowstone, MT	1994-present

Water Use Data and Analysis

Montana statutes for the requirement of meters on wells permitted within the YCGA ([§85-20-401](#) MCA, Article IV, G,2,a,I,(1) state that “*On or before January 15 of each year, the permittee shall report annual use to the Bureau at: Montana Bureau of Mines and Geology, Main Hall, Montana Tech, Butte MT, 59701.*” The Administrative Rules of Montana dealing with water meters within the YCGA ([ARM 36.12.1211](#)) states more specifically that the reporting of meter readings must be on a form provided by MBMG, stating “*On or before January 15 of each year and upon request, the permittee shall report the annual metered water use to the MBM&G. The water use must be recorded on a form provided by the MBM&G.*”

The MBMG has been mailing meter cards (post cards) to permitted well owners since 2002 using permit records provided by DNRC. However, this process has been challenging for the following reasons:

- The return rate for mailed meter cards has always been low (20-25%).
- Permitted well owner records provided by DNRC include all owners of record for a water right, and in many cases, there are multiple owners listed with the same address for a water right ID, so duplicate records have to be removed to avoid mailing multiple meter cards to the same address.
- Many of permitted wells are for vacation cabins or summer homes, but the mailing address of record is primary residence for the permittee. When the meter cards are mailed, the permittee may be at the well address and not get the card, or at the primary residence and not have access to the meter to record a reading.
- Many well owners have difficulty reading the meter correctly. In an attempt to help with this issue, MBMG has been including a letter along with the meter cards, that states the well owner simply email or text a photo of the meter dial to MBMG.

Due to staffing changes and the coronavirus pandemic, meter cards were not mailed out in 2020. While collecting water samples in the West Yellowstone area, MBMG offered assistance to cooperating well owners on obtaining meter readings.

In 2021, DNRC analyzed 307 GWIC records to calculate the mean annual water use from the meter data compared to the permitted volume. One hundred sixty-two GWIC records did not have adequate or had incomplete data and were not used. DNRC analyzed 145 permits with a GWIC record with the statistics shown in Table 6. For these records, DNRC found the total mean annual water use to equal 63.1 AF compared to the 325.9 AF permitted. There are 5 permits that exceed their permitted volume. DNRC has permitted a total of 1,496.8 AF in the YCGA between 1995 and 2023.

Table 6. Mean annual water use statistics for 145 permit records with a variable period of record.

	Data Record (Years)	Permitted Mean Annual Water Use (AF)	Mean Annual Water Use (AF)
Min.	1	0.2	0.002
Max.	23	10.0	13.452
Mean	11	2.2	0.435
Median	11	1.6	0.125

Education and Public Outreach

The following are highlights from the education and public outreach related to the YCGA.

- The Montana State Library published Lidar project data from 2020 for YNP, West Yellowstone area, and the entirety of Park County.
- YNP Geology Program staff speak to university and other educational groups as well as park stakeholders, philanthropic and visitor groups on a yearly basis.
- The YNP Geology staff edit and review publications and exhibits for visitors and other stakeholders as part of their regular responsibilities.

- YNP Geology Program staff train other YNP staff on how to safely work in hydrothermal areas if hydrothermal area operations are within their scope of work. Examples of work groups needing to work in hydrothermal areas are search and rescue staff and trail and boardwalk construction staff.
- In May 2022, DNRC gave a presentation about protecting geothermal features by regulating groundwater at the Biennial Scientific Conference on the Greater Yellowstone Ecosystem (DNRC, 2022).
- The DNRC has worked with the Board of Water Well Contractors (BWWC) to provide information to their members of the YCGA drilling and measurement requirements through a newsletter (BWWC, 2023).
- The DNRC has also published an informational flyer to help applicants navigate the YCGA application process (DNRC, 2023).
- The MBMG has included a letter to permitted well owners along with the annual meter reading cards that explains the purpose of the meter reading requirements and offers assistance to well owners with meters.
- MBMG published a report presenting, compiling, and summarizing YCGA data through 2013 (English et al. 2021).
- MBMG published a report presenting results from 66 sites sampled for total dissolved solids, inorganic parameters, radon, and strontium 86/87 isotopes (Hanson and English, 2023).
- In May 2023, MBMG submitted an abstract and presented on the YCGA History, Purpose, and Long-term monitoring at the 2023 annual meeting of the Rocky Mountain Section of the Geological Society of America, held in Fort Collins (English, 2023).

Recommendations

The Compact was established to protect the geothermal resources of YNP. Long-term monitoring of wells and springs necessary to assess impacts of future development on YNP's geothermal system is the most important means to meet this goal. The TOC will continue to proactively encourage data collection, analysis and review to protect the hydrothermal flow system of YNP.

The YCGA TOC recommends the following:

- No action be taken on modifying the YCGA boundary as no evidence has been reviewed that supports a change at this time (Article IV, section J).
- No action be taken at this time on modifying the criteria for proposed appropriations greater than 60 °F but less than 85 °F (Article IV, section G.2.c.ii.(1)(b)).
- Consider additional criteria for evaluating proposed appropriations.

The YCGA TOC will evaluate the following priorities:

- DNRC establish a notice of intent to drill prior to permit applicants drilling a proposed well(s) in known geothermal resource areas within the YCGA.
- DNRC build a database or write programming code to generate a mailing list with one primary address for all perfected permits issued within the YCGA.
- NPS, MBMG, USGS, and TOC work with YNP to implement Healser et al. (2004) who recommended 20 monitoring wells in YNP be instrumented and the USGS proposal that

one of the proposed monitoring wells be a climate response network well in the National Oceanic and Atmospheric Administration climate division 1 (Article IV, section H.2.a).

- MBMG complete the monitoring project and report the results described under Memorandum of Understanding (# WRD-MBMG-001 Amend. 1) by June 30, 2025 (Article IV, section H.2.a).
- MBMG contact the landowner of the “hot well” also known as the “98 degree well” ([266377](#)) and request to monitor the well with a transducer (Article IV, section H.2.a).
- MBMG and DNRC develop and submit a plan to the TOC on alternative methods to collect and estimate water use within the YCGA, and share their findings with TOC (Article IV, section H.2.a).
- MBMG work with Western Shambala Inc. to install an inline flow meter on the pipeline from LaDuke Hot Springs near Yellowstone Hot Springs (Article IV, section H.2.a).
- MBMG explore incorporating a groundwater trend analysis as part of their five-year data summary report (Article IV, section H.2.a).
- Parties to the compact continue to advocate for a sustainable federal investment in the USGS stream gage network.

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Appendix A: YCGA-Active and Discontinued Long Term Monitoring Program Sites (as of 1/1/2024)

GWIC ID	SITE NAME	SITE TYPE*	MONITORING STATUS	WATER TEMP**	PERIOD OF RECORD	WATER QUALITY	LOGGERS*** <i>Manual Data</i>
GALLATIN RIVER WATERSHED-BIG SKY AREA							
258715	ANCENY	Undeveloped Spring	Active	Warm	Nov 2010→Present	Yes	Spring Head, TEMP
304093	ANCENY SPRING CREEK	Stream	Active	Cold	May 2012→Present	No	Discharge
171216	SNOWFLAKE SPRING	Spring & Stream	Active	Cold	Aug 2011→Present	Yes	TEMP, Discharge
255289	SLOW VEHICLES DISCHARGE SPRING CK	Undeveloped Spring	Active	Cold	April 2010→Present	Yes	Spring Head, TEMP
303411	BIG SKY SPRING CREEK	Stream	Active	Cold	Sept 2019→Present	No	Discharge
215333	ALTMAN	Domestic Well	Active	Cold	July 2010→Present	Yes	WL, SC, BARO
259697	USFS RED CLIFF CAMPGROUND	PWS Well	Active	Cold	Dec 2014→Present	Yes	WL, SC
183236	SHEEP CAMP SPRING	Undeveloped Spring	Discontinued/Ephemeral	Cold	July 2007→Nov 2011		
YELLOWSTONE RIVER WATERSHED-GARDINER-CORWIN SPRINGS AREA							
171215	LA DUKE HOT SPRING	Developed Spring	Active	Hot	Oct 2005→Present	Yes	HIGH TEMP
256421	LA DUKE HOT SPRING LD 1	Monitor Well	Active	Hot	May 2010→Present	No	HIGH TEMP, Level
280402	USFS SPRING AT LA DUKE HOT SPRING	Undeveloped Spring	Active	Hot	Oct 2014→Present	Yes	TEMP
197921	BEAR CREEK HOT SPRING	Undeveloped Spring	Active	Hot	July 2009→Present	Yes	TEMP, Discharge
171229	SIRR	Undeveloped Spring	Active	Cold	April 2009→ Present	Yes	WL, TEMP
138764	DEMAREE	Irrigation Well	Active	Warm	Oct 2006→ Present	Yes	WL
252314	SHOOTING STAR RANCH	Fire Supply Well	Active	Warm	Nov 2009→ Present	Yes	Pressure
105959	MIKOS	Domestic Well	Active	Warm	May 2007→ Present	Yes	WL
146967	GALLOWAY	Domestic Well	Active	Cold	Aug 2005→ Present	Yes	WL
105980	GARDINER AIRPORT	Domestic Well	Active	Cold	Sept 2006→ Present	Yes	WL
152216	MILLER	Monitor Well	Active	Warm	March 2006→ Present	Yes	WL, BARO
287868	NPS CSCS-1	Monitor Well	Active	Cold	June 2016→ Present	Yes	WL, BARO
287867	NPS-STEVENS CREEK CORRAL RESIDENCE	Unused Domestic	Active	Cold	June 2016→ Present	Yes	WL
266377	HOT WELL	Undeveloped Well	Pending Permission	Hot	June 2012→ Present	No	WL
181620	DEMAREE	Developed Spring	Discontinued-Poor Data	Cold	May 2007→Aug 2023	Yes	TEMP, Discharge
184260	POWELL	Developed Spring	Discontinued-Poor Data	Warm	Oct 2008→Sept 2022	Yes	TEMP, Discharge
145529	YELLOWSTONE BASIN INN	PWS Well	Discontinued/Redundant	Warm	May 2007→Aug 2014		
182012	MCPHERSON	Developed Spring	Discontinued/Owner Request	Cold	April 2009→Dec 2010		
140974	SPHINX MOUNTAIN MOBILE HOME PARK	PWS Well	Discontinued/Owner Request	Cold	May 2009→May 2011		
181621	SPERANO	Developed Spring	Discontinued/Owner Request	Cold	June 2008→May 2010		

Data for sites with loggers are obtained on an hourly basis. *[PWS=Public Water Supply] **[Sites are classified as cold (<15°C), warm (15° to 25°C), or hot (>25°C).]

*** WL=water level and water temperature logger, TEMP=water-temperature logger, BARO=barometric pressure logger, SC=specific conductance

YCGA-Active and Discontinued Long Term Monitoring Program Sites (as of 1/1/2024)

GWIC ID	SITE NAME	SITE TYPE*	MONITORING STATUS	WATER TEMP**	PERIOD OF RECORD	WATER QUALITY	LOGGERS*** (Manual Data)
SODA BUTTE CREEK WATERSHED-COOKE CITY-SILVER GATE AREA							
234520	LYMAN	Domestic Well	Active	Cold	August 2015→Present	No	WL
106030	SILVER GATE	Monitor Well	Active	Cold	Sept 2006→ Present	Yes	WL, BARO
106074	USFS ADMINISTRATIVE SITE (Colter C.G.)	PWS Well	Active	Cold	Sept 2019→ Present	Yes	WL, BARO
162539	KLOSTER	Domestic Well	Well Abandoned by Owner	Cold	Aug 2007→Nov 2013		
MADISON RIVER WATERSHED-WEST YELLOWSTONE-HEBGAN BASIN AREA							
182014	COREY SPRING	Undeveloped Spring	Active	Cold	July 201→ Present	Yes	TEMP
183268	STINKY SPRING	Undeveloped Spring	Active	Warm	Oct 2005→ Present	Yes	WL, TEMP
183242	BLACK SAND SPRING	Undeveloped Spring	Active	Cold	May 2010→ Present	Yes	TEMP
8930	RYBERG SPRING	Undeveloped Spring	Active	Cold	Aug 2010→ Present	Yes	TEMP
277397	RYBERG SPRING CREEK	Stream	Active	Cold	Aug 2011→ Present	No	WL, <i>Discharge</i>
106775	BAKER'S HOLE C.G SOUTH WELL-BACKUP	Flowing Well-PWS	Active	Warm	May 2007→ Present	Yes	TEMP
8943	BAKER'S HOLE C.G. NORTH WELL	Flowing Well-PWS	Active	Warm	May 2007→ Present	Yes	TEMP
230654	RYBERG	Flowing Well	Active	Warm	Nov 2011→ Present	Yes	<i>Pressure</i>
106842	3 BEARS LODGE	Irrigation Well	Active	Cold	March 2006→ Present	Yes	WL, BARO
165852	WEST YELLOWSTONE KOA-BACKUP WELL	PWS Well	Active	Cold	May 2010→ Present	Yes	WL
247335	HEBGAN BASIN FIRE STATION 3	Domestic Well	Active	Cold	July 2010→ Present	Yes	WL, BARO
316115	USFS FIRE CENTER-SHALLOW	Monitor Well	Active	Cold	July 2021→ Present	Yes	WL
316112	USFS FIRE CENTER-DEEP	Monitor Well	Active	Cold	July 2021→ Present	Yes	WL, BARO
327883	SOUTH FORK MADISON RIVER @ HWY 20	River	Active	Cold	Aug 2023→ Present	Yes	<i>Discharge-Staff Gage</i>
8935	WEST YELLOWSTONE KOA MAIN WELL	PWS Well	Discontinued/Redundant	Cold	Mar 2006→Aug 2010		
106778	KELAND	Flowing Well	Discontinued/Redundant	Cold	Nov 2006→Aug 2014		
181626	LIONSHEAD SPRING	Developed Spring	Discontinued	Cold	May 2007→Aug 2008		
164216	LONESOMEHURST WUA	Developed Spring	Discontinued	Cold	Aug 2008→May 2012		
181930	BEAVER CREEK	Undeveloped Spring	Discontinued/Ephemeral	Cold	May 2007→Nov 2011		

*[PWS=Public Water Supply] **[Sites are classified as cold (<15°C), warm (15° to 25°C), or hot (>25°C).]

*** WL=water level and water temperature logger, TEMP=water-temperature logger, BARO=barometric pressure logger

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Yellowstone Controlled Groundwater Area • Technical Oversight Committee

More information about the YCGA and previous progress reports can be found at <http://dnrc.mt.gov/ycga>
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