Progress Report:

Yellowstone Controlled Groundwater Area
Technical Oversight Committee
2009 - 2013

Bear Creek Hot Springs Monitoring Site – photo by Alan English

Yellowstone Controlled Groundwater Area

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

> *The parties understand that knowledge of the interrelationship of hydrothermal features within YNP, 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 Yellowstone Controlled Groundwater Area shall be to allow no impact to the hydrothermal system within the reserved land of YNP."

The following are roles of cooperating agencies:

DNRC - administer YCGA and regulate groundwater appropriations in YCGA.
NPS – review and evaluate applications for beneficial groundwater use in YCGA.
Montana University System – advise on inventory and monitoring activities in YCGA.
USGS – conduct hydrologic and geologic studies in the vicinity of YCGA, including stream flow and water quality monitoring and geologic mapping.
MBMG – conduct hydrologic and geologic studies in the vicinity of YCGA, including stream flow and 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 role of the TOC specified by the Compact is reviewing scientific evidence related to the YCGA; advising the Montana Department of Natural Resources and Conservation (DNRC) on administration of the area, including review of applications to appropriate water of 60° F or more; consulting with the Montana Bureau of Mines and Geology (MBMG) on inventory and sampling; and recommending modification of boundaries and restrictions. The Compact specifically outlines tasks and procedures for the TOC in Article IV, section J.1.e. The compact 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 area;
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 on request by the Department as set forth in Article IV, section G.2.c; and
ix. take any additional action necessary to implement Article IV of the Compact.

Members of the TOC are from the NPS, the U.S. Geological Survey (USGS), the DNRC and the Montana University System (Table 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 Tech of the University of Montana. Also, note that David Susong is a USGS employee serving as the NPS representative.

Table 1. The 2013 TOC members and representation:

Member	**Representation**
Steve Custer (Chair)	TOC members
Russell Levens	DNRC
Marvin Miller	Montana University System (MBMG)
David Susong	NPS
John Kirkpatrick	USGS

The past five years saw Bob Fournier retire from his appointment to the TOC and the new appointment of David Susong as the NPS appointment. In addition to David's appointment, all other members of the TOC were formerly reappointed in 2013 by the appropriate official. The Committee expressed their deep appreciation for Bob Fournier's very helpful service.

Bob Fournier and Henry Heasler on October 2, 2012.

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. A subsequent report was completed by the TOC in 2008 covering the years 2000 through 2008. This report covers the five years from 2009 through 2013:

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 a temperature equal to or greater than 60º F. Applicants for uses of water less than 60º F and 35 gpm or less and 10 acre-feet per year or less are subject to standard requirements in §85-2-306, MCA for the exception for small groundwater uses. Applicants for uses of water less than 60º F and greater than 35 gpm or 10 acre-feet 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 60º F are subject to special provisions of Article IV, section G.2.c of the Compact and Administrative Rules of Montana (ARM) 36.12.1201 through 1212. Appropriations ofr groundwater between 60º F and 85º 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 14º F,
ii. The concentration of soluble chloride is less than 10 ppm,
iii. The well does not contain a production zone completed within the Madison Group of formations.

Appropriations of.groundwater with a wellhead water temperature of 85º 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 276 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, 2013 (Tables 2 and 3; Figure 1). There are 3 main areas of higher density (Figure 2): Cooke City area (furthest east), Yellowstone River valley area (north central), and Hebgen Lake/West Yellowstone area (furthest west). One permit has been issued for water of 60°F or greater. 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 and 85 degrees Fahrenheit (° F). Several permits have been issued in the Corwin Springs area for water above 55° F. These warmer-water wells will be monitored periodically for change. All but 6 of the 276 permits issued through December 2013 are for 10 acre-feet or less. The 6 permits for over 10 acre-feet account for 527 acre-feet or 43 percent of the total 1212.9 acre-feet authorized. Two permits for one development issued in 1996 account for 279 acre-feet or 23 percent of the total volume authorized.

The formula used to trigger special review of a proposed well 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/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 Park geothermal system.

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

1995	51	**2002**	8	**2009**	13
1996	23	**2003**	7	**2010**	6
1997	35	**2004**	14	**2011**	9
1998	18	**2005**	13	**2012**	6
1999	15	**2006**	16	**2013**	5
2000	9	**2007**	12		
2001	5	**2008**	11		
Total	276				

Table 3. Number of YCGA permits by hydrologic basin.

41F - Madison River	150
41H - Gallatin River	3
43B - Yellowstone River, Above and Including Bridger Creek	123
Total	276

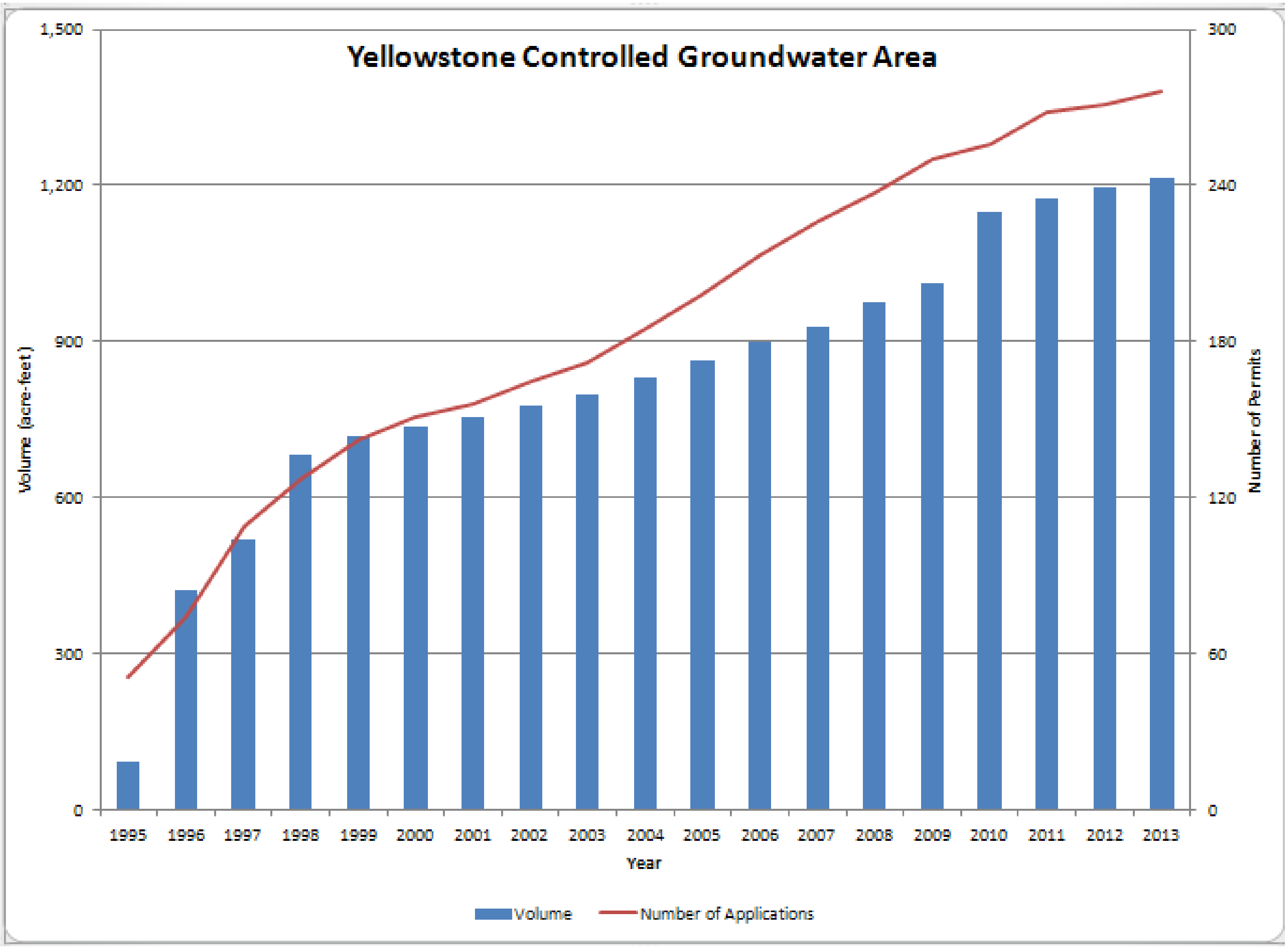

Figure 1. Number of YCGA permits and authorized volumes.

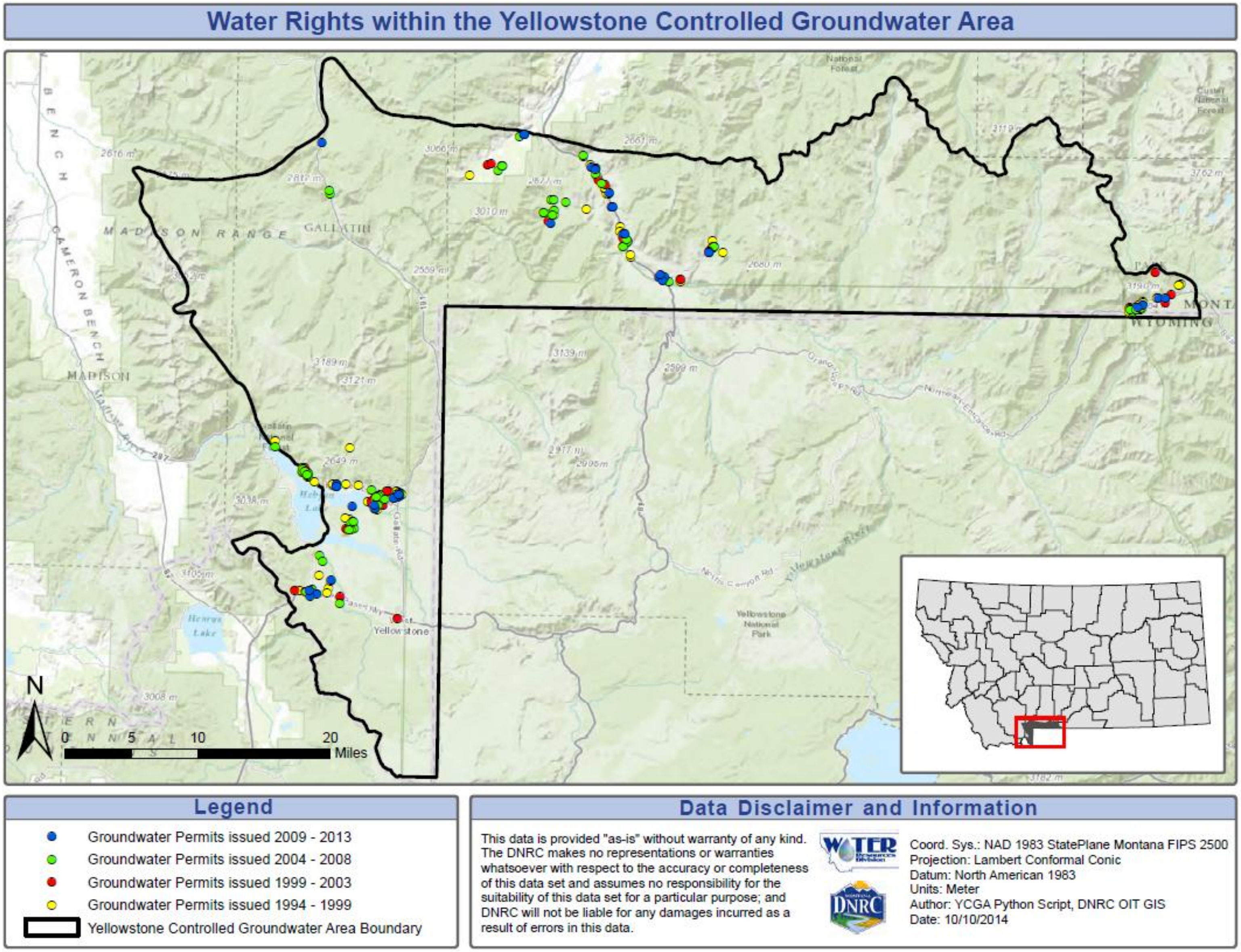

Figure 2. Map showing location of permitted YCGA wells.

TOC Activities Related to Development within the CGWA

The TOC discussed the impacts of development and LaDuke Hot Springs

LaDuke Hot Springs

The TOC spent parts of two annual meetings discussing the implications of a plan by the Church Universal Triumphant (CUT) to put water to use under their water right for LaDuke Hot Springs. The foremost issue considered by the TOC was whether the proposed development could impact the YNP geothermal system. A parallel issue outside the authority of the TOC was whether work completed by the CUT to clean out and divert water from an existing spring box at LaDuke Hot Springs would "enhance" flow as specified in an agreement between the U.S. Forest Service (USFS) and CUT that is described in the abstract for water right number 43B-19412-00. That agreement states that "the flow rate is the entire unenhanced flow of LaDuke Springs collected in the presently existing springbox"

The CUT cleaned out the spring box and reestablished connection between its two chambers, installed a 6-inch discharge line through the north end of the spring box and plugged the discharge line through the south end (Figure 3). In preparation for a 72-hour pumping test, McNabb Engineering installed three shallow (<10 feet deep) groundwater monitoring wells near the spring box to monitor changes. On May 10, 2010, MBMG installed water-level and temperature recorders in the spring box and the three monitoring wells. MBMG also installed a staff gage at a Forest Service spring and collected pre- and post-test water samples from La Duke spring. The 72-hour test was started on Wednesday May 12, 2010. The initial rate of 350 gallons per minute (gpm) resulted in a relatively rapid water-level decline. The successive discharge adjustments and corresponding water-level changes indicate that a stabile water level in the spring box was established at a flow of approximately 145 gpm. At discharge rates greater than 145 gpm, the water level in the spring declined, at flow rates less than 145 gpm, the water level in the spring box recovered. During the test the water temperature in the spring box varied slightly, but the variations appear related to water-level changes. The temperature values were mostly between 146 – 148^{o} F.

Representatives of the CUT, including Vice President Jon Springer, Business Manager Alan Shaw and engineers Jeff McNabb and Willis Weight, presented information on their testing and plan for water from LaDuke Hot Springs to the TOC at their October 2, 2012 meeting. The focus of the discussion was monitoring and how the flow rate was determined. The question of whether the flow rate constituted enhanced flow had been settled between the USFS and CUT per their agreement and was part of the discussion only to determine whether the TOC could or should weigh in on the USFS / CUT decision.

The CUT will control pumping to hold water level in the spring box constant at 2 to 3 inches above the outlet and will monitor for pH, TDS, pipe pressure, flow rate, and volume. They agree to share discharge and pressure data and allow MBMG to record water levels and temperature in the spring box, and periodically obtain grab samples for water chemistry determination.

TOC members discussed the CUT design and plans for monitoring as well as the question of whether the planned flow rate constituted enhanced flow as provided under the agreement between CUT and USFS. Russell Levens indicated that pumping by CUT will reduce head in the spring box as well as the source of the spring which will increase flow from the source. He indicated that the question of whether this would constitute enhanced was a matter between the USFS and CUT and their understanding of their agreement and not a question of hydrology for the TOC to decide. Steve Custer, Marvin Miller, and John Kilpatrick felt that the design as presented appeared to address concerns about maintenance of head in the context of the existing water right. Fournier concurred that we should monitor for temperature and chemical changes as the pumping begins. The vote was unanimous that the design was acceptable but that monitoring is essential.

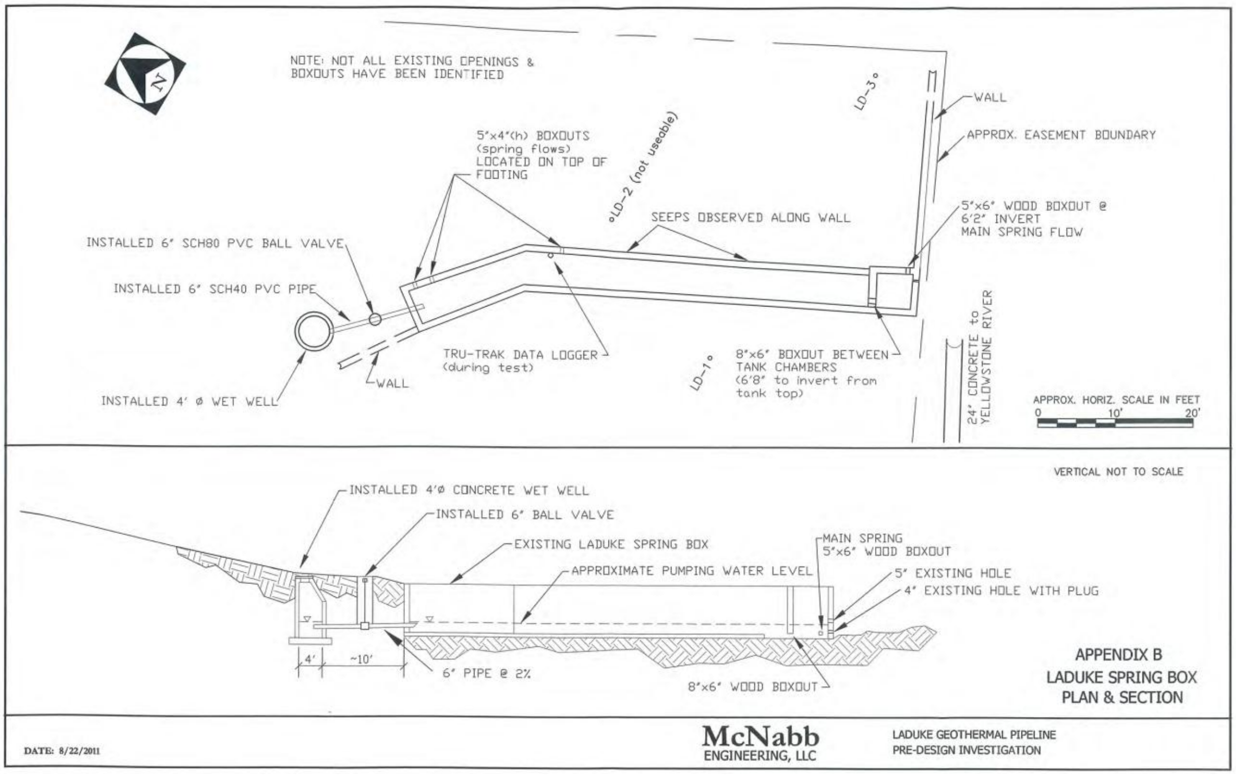

Figure 3. Spring box plan and section by McNabb Engineering

<u>98 Degree Well</u>

A well was drilled to 203 feet near a gravel pit 0.5 miles S-Se of LaDuke hot springs. The water temperature in the well was measured at 98 degrees F (36.6 degrees C) immediately after drilling. MBMG investigated converting the well to a monitoring well; however, heaving sands pushed 70 feet upward in the casing precluding collection of meaningful information and completion of the well. Water in the well was no longer hot upon subsequent visits to the well, possibly because of the blockage by sand. Discussion by the TOC centered on the questions of whether the well should be abandoned, how it could be abandoned, who is responsible for abandonment and the value and potential of completing the well for monitoring. MBMG researched the options and estimated the cost of $1,500 to $2,000 for abandonment and $3,000 to $5,000 to convert the well for monitoring. The TOC discussed the responsibility for abandonment, the value of the well for monitoring, and future access. Action items as of the November 2013 TOC meeting include developing a work plan and cost estimates based on research of expertise with heaving sands, suitable materials for monitoring hot water, and potential sources of financing to complete whatever approach is selected.

Summary of YCGA Monitoring efforts, 2009 to 2013

The YCGA monitoring program is based on the Compact, the Working Group Report (Custer and others, 1993), and information collected in the well and spring inventories (Metesh and others, 1999 and 2000; GWIC, 2002). The Compact states that the Working Group Report will be used as a guide for selection of sampling sites and frequency until superseded by recommendations of the TOC. Critical issues to be addressed through monitoring that were identified by the Working Group include:

- Evaluation of the relationships between warm and cold wells and springs.
- Monitoring encourages discovery, inventory, and assessment of unregistered new wells.
- Identification and evaluation of changes in wells and springs through time.
- Identification and evaluation of spatial relationships of wells and springs through time.

The following are minimum monitoring requirements for wells, springs, and water chemistry outside the Park to address these issues:

Wells with water temperatures greater than or equal to 15 °C (59 °F) shall be monitored. There are 10 known wells with water temperatures greater than 15 °C (59 °F). In addition, the TOC has requested that MBMG select 5 additional wells with water temperatures less than 15 °C (59 °F) for the same monitoring. The “cold water” sites will provide base-line response to climatic and anthropogenic changes and provide insight into changes due to climate or development that might influence warm springs. Field parameters to be collected at the 15 wells shall include:

1) water levels by continuous recorders
2) field specific conductance (SC)
3) field pH
4) water temperature (°C)
5) field alkalinity (as HCO_3)
6) chloride (Cl)
7) field oxidation-reduction potential (ORP)

Field parameters shall be collected three times per year because winter access is too difficult and costly to allow quarterly measurements. The measurements will coincide with the required maintenance of the continuous recorders. Initially, both field and lab chloride will be collected from all wells. When sufficient data are collected, the TOC and MBMG will select a preferred method of analysis.

All springs with water temperatures greater than or equal to 15 °C (59 °F) shall be monitored. At present, there are 15 springs with water temperatures greater than 15 °C (59 °F). The TOC has requested that MBMG select 5 additional springs with water temperatures less than 15 °C (59 °F) for the same monitoring. The “cold water” sites will provide base-line response to climatic and anthropogenic changes. Field parameters to be collected at the 20 springs shall include:

1) discharge by flow metering devices
2) field specific conductance (SC)
3) field pH
4) water temperature (°C)
5) field alkalinity (as HCO_3)
6) chloride (Cl)
7) field oxidation-reduction potential (ORP)

Spring flows shall be monitored using a flume, weir, or similar device in addition to a continuous recorder at each site. As with the wells, field parameters shall be collected three times per year coinciding with the required maintenance of the continuous recorders. Initially, both field and lab chloride will be collected from all springs. When sufficient data are collected, the TOC and MBMG will select a preferred method of analysis.

Table 4. Summary of monitoring status.

GWIC SITE ID	SITE NAME	SITE TYPE	MONITORING STATUS	WATER TEMP*	PERIOD OF RECORD
SODA BUTTE CREEK WATERSHED-*COOKE CITY-SILVER GATE AREA*					
162539	KLOSTER	Domestic Well	Active	Cold	Aug2007-Nov2013
106030	SILVER GATE	Monitor Well	Active	Cold	Sept2006-Present
YELLOWSTONE RIVER WATERSHED-*GARDINER-CORWIN SPRINGS AREA*					
171215	LA DUKE HOT SPRING	Spring	**Active**	**Hot**	Oct2005-Present
197921	BEAR CREEK HOT SPRING	Spring	**Active**	**Hot**	July2009-Present
184260	POWELL	Spring	**Active**	**Warm**	Oct2008-Present
171229	SIRR	Spring	**Active**	**Cold**	April2009-Present
181620	COLE	Spring	**Active**	**Cold**	May2007-Present
138764	COLE IRRIGATION	Irrigation Well	**Active**	**Warm**	Oct 2006-Present
252314	SHOOTING STAR RANCH	Domestic Well	**Active**	**Warm**	Nov2009-Present
145529	YELLOWSTONE BASIN INN	Public Supply Well	**Active**	**Warm**	May2007-Present
105959	STRAUSS	Domestic Well	**Active**	**Warm**	May2007-Present
146967	GALLOWAY	Domestic Well	**Active**	**Cold**	Aug2005-Present
105980	GARDINER AIRPORT	Domestic Well	**Active**	**Cold**	Sept2006-Present
152216	MILLER	Monitor Well	**Active**	**Warm**	March2006-Present
182012	MCPHERSON	Spring	**Discontinued**	**Cold**	April2009-Present
140974	SPHINX MOUNTAIN MOBILE HOME PARK-WELL 2	Public Supply Well	**Discontinued**	**Cold**	May2009-May2011
181621	SPERANO	Spring	**Discontinued**	**Cold**	June2008-May2010
GALLATIN RIVER WATERSHED-*BIG SKY AREA*					
258715	ANCENY SPRING	Spring	**Active**	**Warm**	Oct2010-Present
171216	SNOWFLAKE SPRING	Spring	**Active**	**Cold**	April2010-Present
215333	ALTMAN	Well	**Active**	**Cold (?)**	July 2007-Present
183236	SHEEP CAMP SPRING	Spring	**Discontinued**	**Cold**	July2007-Nov2011
MADISON RIVER WATERSHED-*WEST YELLOWSTONE-HEBGAN BASIN AREA*					
182014	COREY SPRING	Spring	**Active**	**Cold**	July2010-Present
183268	STINKY SPRING	Spring	**Active**	**Warm**	Oct2005-Present
183242	BLACK SAND SPRING	Spring	**Active**	**Cold**	May2010-Present
8930	RYBERG SPRING #4	Spring	**Active**	**Cold**	Aug2010-Present
106775	BAKER'S HOLE CAMP-SOUTH WELL	Flowing Well	**Active**	**Warm**	May2007-Present
8943	BAKER'S HOLE CAMP-NORTH WELL	Flowing Well	**Active**	**Warm**	May2007-Present
106778	KELAND	Flowing Well	**Active**	**Cold**	Nov2006-Present
230654	RYBERG	Flowing Well	**Active**	**Warm**	Nov2011-Present
106842	3 BEARS LODGE	Irrigation Well	**Active**	**Cold**	March2006-Present
165852	WEST YELLOWSTONE KOA-BACKUP WELL	Public Supply Well	**Active**	**Cold**	May2010-Present
8935	WEST YELLOWSTONE KOA MAIN WELL	Public Supply Well	**Sample Only**	**Cold**	March2006-Present
181626	LIONSHEAD SPRING	Spring	**Discontinued**	**Cold**	May 2007 -?
164216	LONESOMEHURST WUA	Spring	**Discontinued**	**Cold**	Aug2008-May2012
181930	BEAVER CREEK	Spring	**Discontinued**	**Cold**	May2007-Nov2011

* Hot > 25° C   Warm > 15° C and ≤ 25° C   Cold ≤ 15° C

Soda Butte Creek Watershed Sites

Kloster Well (162539) ***Mean Temperature*** ***<u>4.5°C</u>*** ***Mean SWL*** ***<u>45.6 ft bgs</u>***
This well was monitored throughout the five-year period but was abandoned by the owner in September 2013. Hourly water-level and water-temperature data were collected from the well using a data-logger. The well was sampled for major ions and trace elements 5 times, and isotopes (^{2}H, ^{3}H and ^{18}O) twice between 2008 and 2013. The owner drilled a replacement well (275365) but has requested that MBMG cease monitoring at the property.

Silver Gate Well (106030) ***Mean Temperature*** ***<u>4.9°C</u>*** ***Mean SWL*** ***<u>10.7 ft bgs</u>***
This well was monitored throughout the five-year period. It is 51 feet deep and is completed in alluvium. Hourly water-level and water-temperature data are collected from the well using a data-logger. The site also has a barologger for correcting water-level data from dataloggers in the area. The well was sampled four times for major ions and trace elements and once isotopes (^{2}H, ^{3}H and ^{18}O) during the five-year period.

Yellowstone River Watershed Sites

LaDuke Hot Spring (171215) ***Mean Temperature*** ***<u>63.8°C</u>*** ***Mean Flow*** ***<u>145 gpm</u>***
This site was monitored throughout the five-year period. The spring box was rehabilitated in 2010 and the discharge from the spring was diverted to Corwin Springs in 2012. These changes eliminated the original monitoring site located across the highway along the east bank of the Yellowstone River. Since 2012 MBMG has collected hourly water-temperature and water-level data from the south end of the spring box and the Royal Teton Ranch (formerly Church Universal and Triumphant) has monitored the discharge from the north end of the spring box. The spring was sampled twelve times during the five-year period for major ions and trace elements, and twice for isotopes (^{2}H, ^{3}H and ^{18}O).

Bear Creek Hot Spring (197921) ***Mean Temperature*** ***<u>32.6°C</u>*** ***Mean Flow*** ***<u>30 gpm</u>***
This site was added to the monitoring network in August 2009. Water temperature is measured hourly. A flume was installed in June 2012 to monitor discharge. The stage of the water in the flume is monitored hourly using a water-level logger, and manual flume readings are taken each time the site is visited. The spring was sampled seven times for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H and ^{18}O) during the five-year period.

Powell Spring (184260) ***Mean Temperature*** ***<u>15.7°C</u>*** ***Mean Flow*** ***<u>7 gpm</u>***
This site is a developed spring that was added to the monitoring network in October 2008. Water temperature is measured hourly using a temperature logger and discharge is measured using an in-line flow meter. The flow meter has a totalizer and a pulse logger to record hourly discharge. However, the pulse logger has provided unreliable data. Manual discharge measurements are made during site visits. Powell Spring was sampled seven times for major ions and trace elements, and twice for isotopes (^{2}H, ^{3}H and ^{18}O) during the five-year period.

Sirr Spring (171229) ***Mean Temperature*** ***<u>11.7°C</u>*** ***Mean Flow*** ***<u>28 gpm</u>***
This site is an undeveloped spring that was added to the monitoring network in March 2009. A small flume is installed on the outlet of the spring site and is equipped with a data logger to collect hourly water-level (flume stage) and water-temperature data. Problems have been encountered with water from an irrigation ditch that floods out the flume during the irrigation

season. Sirr Spring was sampled seven times for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H and ^{18}O) during the five-year period.

Cole Spring (181620) ***Mean Temperature*** ***<u>10.3°C</u>*** ***Mean Flow*** ***<u>2.5 gpm</u>***
This site is a developed spring that has been monitored throughout the five-year period. A temperature logger is installed in the discharge line to obtain hourly water-temperature data and an in-line flow meter is installed to monitor discharge. Like Powell Spring, the flow meter has a totalizer and a pulse logger to record hourly discharge. However, the pulse logger has provided unreliable data. Manual discharge measurements are made during site visits. Cole Spring was sampled five times for major ions and trace elements, and three times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Cole Well (138764) ***Mean Temperature*** ***<u>21.1°C</u>*** ***Mean SWL*** ***<u>106.5 ft bgs</u>***
This well was monitored throughout the five-year period. It is 143 feet deep and is thought to be completed in Archean Bedrock adjacent to the Gardiner Reverse fault. The well is used for irrigation. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. The well was sampled seven times for major ions and trace elements and three times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Shooting Star Ranch Well (252314) ***Mean Temperature*** ***<u>21°C</u>*** ***Mean SWL*** ***<u>111.7 ft ags</u>***
This well is 750 feet deep and is a flowing artesian well that is shut in. The water is used for fire control and domestic purposes. The well is completed in Eocene Absaroka Group volcanic rock. The well was added to the LTMP network in November 2009. Shut-in pressure is monitored each time the site is visited and water temperature is measured when the well is purged for sampling. The well was sampled four times for major ions and trace elements and twice for stable isotopes (^{2}H, ^{18}O) during the five-year period. It was also sampled for tritium ^{3}H in November 2009.

Yellowstone Basin Inn Well (145529) ***Mean Temperature*** ***<u>15.1°C</u>*** ***Mean SWL*** ***<u>68.3 ft bgs</u>***
This well was monitored throughout the five-year period. It is 98 feet deep and is completed in alluvium fan. The well serves as a public water supply for the Inn. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. The well was sampled six times for major ions and trace elements and three times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Strauss Well (105959) ***Mean Temperature*** ***<u>15.2°C</u>*** ***Mean SWL*** ***<u>68.9 ft bgs</u>***
This well was monitored throughout the five-year period and is 140 feet northwest of the Yellowstone Basin Inn well. It is 100 feet deep and is completed in alluvium. The well provides water to a residence for domestic purposes. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. The well was sampled six times for major ions and trace elements and three times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Galloway Well (146967) ***Mean Temperature*** ***<u>13.2°C</u>*** ***Mean SWL*** ***<u>120.0 ft bgs</u>***
This well was monitored throughout the five-year period. It is a 200-foot deep well that provides water for a private residence. The well is completed in an alluvial fan deposit. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. The well was sampled five times for major ions and trace elements and once for isotopes (^{2}H, ^{3}H, ^{18}O) during the five-year period.

Gardiner Airport Well (105980) ***Mean Temperature <u>9.9°C</u>*** ***Mean SWL <u>107.1 ft bgs</u>***
This well was monitored throughout the five-year period. It is a 263-foot deep well that provides water for a residence and several hangers at the airport. The well is thought to be completed in the Cretaceous Landslide Creek Formation. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. The well was sampled six times for major ions and trace elements and three times for once for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Miller Well (152216) ***Mean Temperature <u>23.9°C</u>*** ***Mean SWL <u>9.1 ft bgs</u>***
This well was monitored throughout the five-year period. It is a 200-foot deep well that is not used due to poor water quality. The well is completed in a geothermal flow system within the Corwin Springs Known Geothermal Resource Area. The well is thought to be completed in fluvial deposits under lake sediments or fluvial silt deposits that fill the valley at the site. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. Since the well is not used, the water-temperature measured by the datalogger is not representative of the groundwater temperature. Water temperature is measured when the well is purged for sampling. The well was sampled six times for major ions and trace elements and once for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

McPherson Spring (182012) ***Mean Temperature <u>10.6°C</u>*** ***Mean Flow <u>1 gpm</u>***
This site was dropped in December 2010 at the request of the owner. It was sampled four times for major ions and trace elements, and twice for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

Sphinx Mountain Well #2 (140974) ***Mean Temperature <u>NA</u>*** ***Mean SWL <u>NA</u>***
This well was added to the LTMP network in May 2009 but was dropped in May 2011. The wells is 455 feet deep and is reported to be completed in Archean gneiss and schist. The well serves as a public water supply for a mobile home park. The well was sampled one time for major ions and trace elements during the five-year period.

Sperano Spring (8943) ***Mean Temperature <u>14.4°C</u>*** ***Mean Flow <u>2.5 gpm</u>***
This site was dropped in December 2010 after the flow meter clogged up and was removed by the owner. quest of the owner. The spring was sampled three times for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

Gallatin River Watershed Sites

Anceny Spring (258715) ***Mean Temperature <u>17.3°C</u>*** ***Mean Flow <u>5 CFS</u>***
This site was added to the LTMP network in October 2010. This is a large undeveloped spring that discharges from Madison Group limestone at the Spanish Peaks Fault. Hourly temperature data is collected at the head of the spring using a temperature logger. Discharge is measured in a channel draining the spring. A gauging station consisting of a staff gauge and stilling well with a water-level logger has been established on the spring channel. The spring was sampled four times for major ions and trace elements, and four times for stable isotopes (^{2}H, ^{18}O). A tritium sample (^{3}H) was collected in November 2013.

Snowflake Spring (171216) ***Mean Temperature <u>12.4°C</u>*** ***Mean Flow <u>12.3 CFS</u>***
This site was added to the LTMP network in August 2011. Similar to Anceny Spring, Snowflake Spring is a large undeveloped spring that discharges from Madison Group limestone adjacent to a thrust fault. Hourly water-temperature data is collected at the head of the spring using a temperature logger and discharge is measured by gauging the flow of a channel that drains the

spring area during site visits. The spring was sampled four times for major ions and trace elements, and five times for stable isotopes (^{2}H, ^{18}O), and twice for tritium (^{3}H) during the five-year period.

Altman Well (215333) ***Mean Temperature <u>NA</u>*** ***Mean SWL <u>369.6 ft bgs</u>***
This well was added to the LTMP network in July 2010. It is a 520-foot deep well that is not used and does not have a pump installed. The static water level in the well has been monitored during site visits. The depth to water in the well is too far to allow sampling with a portable sampling pump. The well is thought to be completed in the Jefferson Formation.

Sheep Camp Spring (183236) ***Mean Temperature <u>NA</u>*** ***Mean Flow <u>0-3 gpm</u>***
This site was dropped from the LTMP network in November 2011 because the spring flow was low and the spring only flowed intermittently. The spring was sampled twice for major ions and trace elements during the five-year period.

Madison River Watershed Sites

Corey Spring (182014) ***Mean Temperature <u>7.7°C</u>*** ***Mean Flow <u>10.7 CFS</u>***
This site was monitored throughout the five-year period. Corey Spring is a large spring that discharges from road fill near Hebgen Lake, but is likely sourced from Madison Group limestone just north of the highway. A temperature logger is installed at the head of the spring to obtain hourly water-temperature data, and the discharge from the spring is gauged each time the site is visited. The spring was sampled four times for major ions and trace elements, four times for stable isotopes (^{2}H, ^{18}O), and twice for tritium (^{3}H) during the five-year period.

Stinky Spring (183268) ***Mean Temperature <u>14.2°C</u>*** ***Mean Flow <u>34.2 gpm</u>***
This site was monitored throughout the five-year period. This spring is a geothermal spring but the water has cooled prior to surfacing. The spring is thought to discharge from the Lava Creek Tuff. A flume is installed on the outlet of the small pond at the spring to measure discharge. A datalogger is installed in the flume to obtain hourly discharge (flume stage) and water-temperature data. isited. The spring was sampled six times for major ions and trace elements, and twice for isotopes (^{2}H, ^{3}H,^{18}O), and twice for tritium (^{3}H) during the five-year period.

Black Sand Spring (183242) ***Mean Temperature <u>8.9°C</u>*** ***Mean Flow <u>19.9 CFS</u>***
This site was added to the LTMP network in May 2010. This is a large cold-water spring that is undeveloped. Monitoring has consisted of water-temperature measurement and discharge measurements made by gauging the spring creek that drains the site. These measurements are only made during site visits. The spring was sampled four times for major ions and trace elements, six times for stable isotopes (^{2}H, ^{18}O), and twice for tritium (^{3}H) during the five-year period.

Ryberg Spring #4 (8930) ***Mean Temperature <u>°C</u>*** ***Mean Flow <u>CFS</u>***
This site was added to the LTMP network in August 2010. This spring is thought to be fault controlled and discharges in a small depression, forming a small sand boil. A temperature logger is installed in the spring to record hourly water-temperature data. The discharge from the spring is measured using a gauging station set up on the spring creek that drains the spring area. The spring has been sampled twice for major ions and trace elements, and twice for isotopes (^{2}H, ^{3}H, ^{18}O) during the five-year period.

Baker's Hole Campground S. Well (106775) Mean Temperature <u>22.2°C</u> Mean Flow <u>17 gpm</u>
This well was monitored throughout the five-year period. No well log has been found for the well and the depth is unknown. The well is a flowing artesian well that discharges to the Madison River on a year-round basis. The well serves as a backup public water supply well for the campground. The shut in pressure and the discharge are measured during site visits. A temperature logger is installed on the discharge line from the well to obtain hourly water-temperature data. The well was sampled seven times for major ions and trace elements, and four times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Baker's Hole Campground N. Well (106775) Mean Temperature <u>18.1°C</u> Mean Flow <u>32 gpm</u>
This well was monitored throughout the five-year period. The well is a flowing artesian well that discharges to the Madison River on a year-round basis. The well serves as the main public water supply well for the campground. The shut in pressure can't be measured. An in-line flow meter equipped with a pulse logger is installed on the discharge line to measure flow. The flow meter has a totalizer. The pulse logger has been unreliable. A temperature logger is also installed in the discharge line to measure water-temperature hourly. and the discharge are measured during site visits. A temperature logger is installed on the discharge line from the well to obtain hourly water-temperature data. The well was sampled six times for major ions and trace elements, and three times for stable isotopes (^{2}H, ^{18}O) during the five-year period.

Keland Well (106778) Mean Temperature <u>12.3°C</u> Mean Flow <u>1.5 gpm</u>
The Keland well was monitored throughout the five-year period. The well is located just north of the Baker's Hole Campground and is also a flowing artesian well that discharges to the Madison River on a year-round basis. The well is 48 feet deep and provides water to a cabin for domestic purposes. A temperature logger is installed on the discharge line to obtain hourly water-temperature data and the flow is measured during site visits. The well was sampled twice for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

Ryberg Well (230654) Mean Temperature <u>15°C</u> Mean SWL <u>13 ft ags</u>
This well was added to the LTMP network in November 2009. The well is a flowing artesian well that is shut in. The well is 119 feet deep and is reported to be completed in rhyolite under glacial outwash deposits. The shut-in pressure of the well is monitored during site visits and the water temperature is measured with the well is sampled. The well was sampled five times for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

Three Bears Lodge Well (106842) Mean Temperature <u>6.8°C</u> Mean SWL <u>39.6ft bgs</u>
This well was monitored throughout the five-year period. The well is 140 feet deep and is used for irrigation at the lodge. A datalogger is installed in the well to collect hourly water-level and water-temperature data. re is measured with the well is sampled. The well was sampled six times for major ions and trace elements, and once for isotopes (^{2}H, ^{3}H,^{18}O) during the five-year period.

West Yellowstone KAO Backup Well (165852) Mean Temperature <u>5°C</u> Mean SWL <u>20 ft bgs</u>
This well was added to the LTMP network in May 2010. It is a 260 foot deep well that serves as a backup for the public water supply system at the campground. A datalogger is installed in the well to obtain hourly water-level and water-temperature data. monitored throughout the five-year period. The well is 140 feet deep and is used for irrigation at the lodge. A datalogger is installed in the well to collect hourly water-level and water-temperature data. re is measured with the well is sampled. The well was sampled four times for major ions and trace elements, twice for stable isotopes (^{2}H, ^{18}O), and once for tritium (^{3}H) during the five-year period.

West Yellowstone KAO Main Well (8935) Mean Temperature <u>5°C</u> Mean SWL <u>20 ft bgs</u>
This well was monitored throughout the five-year period. The well is 213 feet deep. It is only used for water quality monitoring since it is in active use during the summer. The well was sampled three times for major ions and trace elements during the five-year period.

Lonesomehurst Spring (164216)   Mean Temperature <u>7.1°C</u>   Mean Flow <u>NA</u>
This site was dropped in May 2012 because there was no practical way to monitor flow. The spring was sampled once for major ions and trace elements during the five-year period.

Beaver Creek Spring (181930)   Mean Temperature <u>7.1°C</u>   Mean Flow <u>0-20 gpm</u>
This site was dropped at the end of 2008 because the flow was low and intermittent.

Summary of Yellowstone National Park Monitoring, 2009 to 2013

Introduction

This brief discussion presents a summary of Yellowstone National Park's hydrothermal monitoring efforts from 2009 to 2013. Topics discussed include the use of chloride flux, helicopter thermal infrared (TIR) condition assessments, temperature monitoring of hydrothermal features, fixed-wing airborne TIR monitoring and additional efforts for protecting hydrothermal systems.

Before discussing monitoring efforts, defining terms for hydrothermal components are presented from 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 5.

Table 5 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

Reasons to monitor vital signs of hydrothermal systems	Explanation
	what are normal changes and what are significant changes that might portend broader geologic events. Short-term (daily, weekly, seasonal, annual) variation needs to be distinguished 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 and others, 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 if anthropogenic impacts stop • 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, 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 Flux for Hydrothermal Monitoring

Since the early 1980s, researchers and the National Park Service have utilized the chloride flux of major rivers exiting Yellowstone National Park (YNP) to estimate hydrothermal activity (see

Friedman and Norton, 2007 and associated references). Between 2009 and 2013, about twenty water samples were collected annually from the Yellowstone, Madison, Snake, Fall, 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. More than 850 chloride samples were analyzed during the 5-year study period. Results of the laboratory analysis through 2010 are available at http://pubs.usgs.gov/ds/2007/278/. Additional analyses for 2011 through 2013 water years will be added to the database pending verification of results.

Although periodic water sampling can yield an estimate of annual hydrothermal trends, including associations between chloride concentration and specific conductivity in major rivers, data acquisition is constrained by the number of site visits. To address this deficiency, in 2010, the NPS Geology program and USGS researchers installed In-Situ Aquatroll continuous recording probes at several of the established chloride flux monitoring sites. The Aquatroll units recorded site-specific water temperature, specific conductivity, and water stage (*i.e.*, water level) at 15-minute intervals (Clor, et. al. 2012., http://pubs.usgs.gov/sir/2007/5234/). Short-term, high-frequency (*e.g.*, hourly) water sampling with an ISCO automated collection unit accompanied a small portion of each Aquatroll deployment. Those samples were extensively analyzed for the purpose of developing accurate chloride concentration-specific conductivity relationships for detecting short-term changes in thermal water chemistry (McCleskey, *et. al* 2012, http://dx.doi.org/10.1016/j.apgeochem.2012.07.019). If specific conductivity proves to be a reliable substitute for chloride content of thermal waters, future studies may rely more on continuous instrumentation with Aquatrolls than periodic water sampling to monitor long term trends in the park's hydrothermal systems.

In August 2012, a localized monitoring effort began in the Mammoth Hot Springs area. The purpose was to describe short-term viability in chloride flux trends within the Gardner River and associated thermal tributaries. Discharge and chemical patterns in the Mammoth area were examined and compared to historical data. Our study was initiated in response to private use of waters from LaDuke Hot Springs north of the park boundary. We sampled bi-weekly or weekly at three main stem sites in the Gardner River, Boiling River, and Bluff Creek (termed "Mammoth Hot Springs outflow" in earlier studies). Sampling began in August 2012 and continued through September 2013.

Helicopter TIR Condition Assessments

Introduction

Helicopter reconnaissance is a cost-effective and rapid method to visually and photographically perform a condition assessment of Yellowstone National Park's (YNP) numerous hydrothermal areas.

Methods

Using Yellowstone National Park (YNP) contract helicopters, portions of thermal areas were flown at 150 to 300 m (500 to 1,000 ft) above ground level, allowing oblique imaging of both visual and thermal infrared spectra. Two Garmin Etrex Vista GPS units document the flight path and altitude every 100 meters, within a ±4 m error. Day-time thermal infrared images were acquired using a FLIR SC640 640 by 480 pixel, 8 to 12 microns from 2009 to 2011. Between 2012 and 2013, a FLIR SC660 640 by 480 pixel, 8 to 12 micron camera was used. For all flights a 38 mm lens acquired both visible and thermal imagery.

Image acquisition targets are chosen based on ground observations or based on unusual characteristics noticed while in flight.

<u>Results</u>

Approximately 2,600 paired images (visible and TIR) have been acquired over multiple targets in the period 2009-2013 (Table 6). An example of a visible and TIR image taken over the Lower Geyser Basin is shown in Figure 4.

Table 6: Helicopter TIR Flights Over Yellowstone National Park, 2009-2013.

Date	Number of images	Areas Imaged
8/20/2009	488	LGB, MGB, UGB, SGB, NGB, Mammoth
8/29/2009	398	WTGB, Heart lake, Turbid Lake, Mud Volcano
8/30/2009	454	Roaring Mtn, NGB, MGB, APP, Nymph Lake
3/1/2010	402	Upper Sentinel Creek, LGB, UGB, NGB
7/3/2010	310	NGB, UGB, Mammoth
10/11/2010	234	Mammoth, Tower, Soda Butte, Death Gulch
10/12/2010	662	LGB, UGB, Violet Springs, Clear Lake, HSB
9/10/2011	376	Mammoth, Terract Spring, SGB, UGB, LGB, APP, NGB
9/11/2011	300	Mud Volcano, Upper Pelican Creek, HSB, Death Gulch, Soda Butte, Tower
10/2/2011	498	Mammoth, NGB, UGB, WTGB, Clear Lake
9/26/2012	408	Mammoth, UGB, Sulfur Hills, HSB, Death Gulch, Soda Butte, Tower
9/27/2012	334	Mammoth, UGB, WTGB, NGB
9/27/2013	386	Mammoth, NGB, LGB, UGB, SGB, WTGB,

Artists Paintpots (APP), Hot Spring Basin (HSB), Lower Geyser Basin (LGB), Monument Geyser Basin (MGB), Norris Geyser Basin (NGB), Shoshone Geyser Basin (SGB), West Thumb Geyser Basin (WTGB).

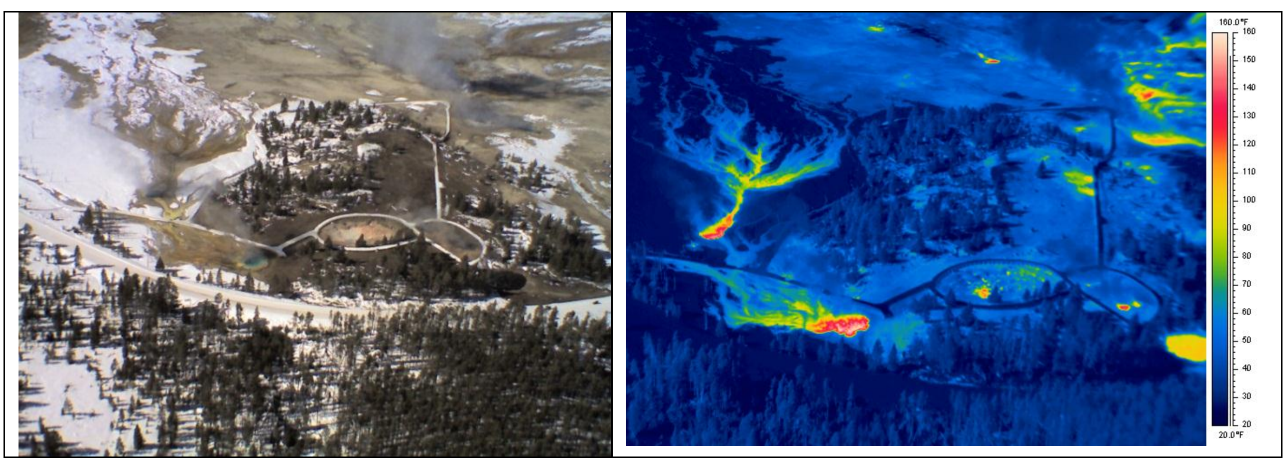

Figure 4. Visible and TIR photo pair taken from a helicopter on 1 March 2010 of the Lower Geyser Basin. Images were acquired at 250 m (800 ft) elevation looking to the west.

Discussion

Aerial condition assessment of numerous hydrothermal areas park-wide have been used for rerouting boardwalks, assessing other park infrastructure and rapidly assessing change though time for visitor and staff safety.

Thermal Feature Temperature Monitoring

Select hydrothermal features are monitored in Yellowstone National Park. Out of the over 10,000 hydrothermal features in the park, temperature is monitored at approximately 35 locations. Monitored sites are chosen based on the cultural significance of the hydrothermal feature, safety of visitors, and potential anthropogenic impacts to hydrothermal features. Temperatures were collected on 16 geysers in the Lower and Upper Geyser Basins (Figure 5).

Onset Computer Corporation temperature loggers measured kinetic surface temperatures using two types of loggers: the Onset Hobo Pro and the Onset Microstation. Both loggers had 2-m length thermistor probes, accurate to within 0.2 ^{o}C. Temperatures were usually collected on a 1 minute interval. (About 536,000 data values per site per year). Approximately 35 locations are monitored which roughly equates to 17.5 million temperature values per year, or 87.5 million over 5 years.

All geyser data is served publically on ***GeyserTimes .org.*** Additional temperature data were gathered for heat flow studies.

Figure 5. Temperature logger locations in the Upper and Lower Geyser Basins.

Fixed-wing Airborne TIR Monitoring

Beginning in 2005, the Yellowstone National Park geology program funded researchers from Montana State University, the University of Montana, and Utah State University. These initial collaborations resulted in the monitoring of hydrothermal areas both park-wide (satellite) and for specific areas (fixed-wing). Final reports from the 2005-2010 cooperative research (fixed-wing and satellite) are publically available at the following web sites:

For the Montana State University park-wide study (satellite)

Final Report entitled " *Evaluating the Use of Landsat Imagery for Monitoring Geothermal Heat Flow in Yellowstone National Park*"
http://www.cfc.umt.edu/CESU/Reports/NPS/MSU/2005/05_07Lawrence_YELL_thermal%20inventory_finl%20rpt.pdf

2005-2006 Final Report
For the University of Montana fixed-wing study entitled "*Thermal Remote Monitoring of Norris Geyser Basin and Associated Geothermal Resources, Yellowstone National Park*"
http://www.cfc.umt.edu/CESU/Reports/NPS/UMT/2005/05_06Sielstad_YELL_thermal_final%20rpt.pdf

For the fixed-wing Utah State University studies entitled

"Monitoring Geothermal Activity in Yellowstone National Park using Airborne Thermal Infrared Remote Sensing"
http://www.cfc.umt.edu/CESU/Reports/NPS/USU/2005/05_08Neale_YELL_%20Thermal_journal%20article.pdf

2008-2009 Final Report:
"Integrated Study of Systematic Monitoring and Mapping Thermal Springs and features in Yellowstone National Park"
http://www.cfc.umt.edu/CESU/Reports/NPS/USU/2005/05_08Neale_YELL_%20Thermal_Final_Report.pdf

2010 Final Report
"*Visualization of the Mammoth Hydrothermal System, Yellowstone National Park Headquarters, and the Controlled Groundwater Area of the Montana Compact*"
http://www.cfc.umt.edu/CESU/Reports/NPS/USU/2010/10Neale_YELL_hydrothermal%20monitoring_fnlrpt.pdf

As part of the existing partnership between Montana Bureau of Mines and Geology and the Yellowstone National Park geology program, the 2010 high-resolution visible and digital elevation data currently is being served for the Mammoth hydrothermal system, the La Duke hydrothermal system north of Yellowstone and other selected areas. The imagery/data can be accessed through the MBMG's ArcGIS Server. Details on how to connect to the server are available on the MBMG Geographic Information Systems (GIS) web page: http://www.mbmg.mtech.edu/gis/gis-server.asp. This collaboration provides a repository for existing data and a platform for the release of future data collected as part of the NPS and MBMG on-going monitoring efforts.

Additional Protection Efforts

Federal Highways – Norris to Grizzly Lake road reconstruction Nymph Lake (2011-2013)
Federal Highways conducted a drilling program in September and October of 2011 to assess profiles of the road structure and the shallow hydrothermal system from Norris to Obsidian Cliff as part of a road reconstruction project scheduled to begin in 2014. Temperatures were measured in 67 of the 71 borings. Geothermal gas concentrations were measured in 62 of the 71 borings. On-site descriptions of cuttings and core were used to assess the hydrothermal fluid flow regime.

Temperature values and gas concentrations were used to quantify locations were thermal road designs should be used. The purposes of the thermal road design was to allow the venting of heat, hydrothermal gasses and moisture from hydrothermal areas to protect the natural processes associated with the hydrothermal area and to increase the functional life span of the road. In one area near Nymph Lake, high subsurface temperatures and high gas concentrations were used to design a road reroute.

Old Faithful Science Review Panel (2013)
A panel of leading experts (The Old Faithful Science Review Panel) was convened by Yellowstone National Park to review and summarize the geological and hydrological understanding that can inform park management of the Upper Geyser Basin area. The report, written by U.S. Geological Survey and park geologists, working with university, and private-sector scientists, includes a discussion of the local rock types, and water chemistry, and the behavior of geysers and other features within the hydrothermal system. The panel of scientists also reviewed the effects of infrastructure (utilities, roads, buildings) on thermal features and vice versa.

The report identifies knowledge gaps and suggests topics for further research. It includes a variety of techniques that can assist park managers as they evaluate options for future management of the Old Faithful area. It also includes suggestions on how to avoid harm to changing and sometimes migrating thermal features during maintenance of critical infrastructure such as the nearby lodging, including the historic Old Faithful Inn.

To balance the protection of the hydrothermal system with infrastructure needs in the Old Faithful area, the report recommends delineating zones of varying degrees of hydrothermal activity, and managing infrastructure accordingly. "Green" zones where there is no evidence of hydrothermal activity might have no constraints on infrastructure, whereas in "red" zones of active hydrothermal activity, building new structures would be prohibited, and special protocols developed for the maintenance of existing infrastructure.

The full report of the Old Faithful Science Review Panel, "Hydrogeology of the Old Faithful Area, Yellowstone National Park, Wyoming, and its Relevance to Natural Resources and Infrastructure," U.S. Geological Survey Open-File Report 2014-1058, is available online at **http://pubs.usgs.gov/of/2014/1058/**

Re-evaluation of CGA Boundary
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 the Park'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.

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