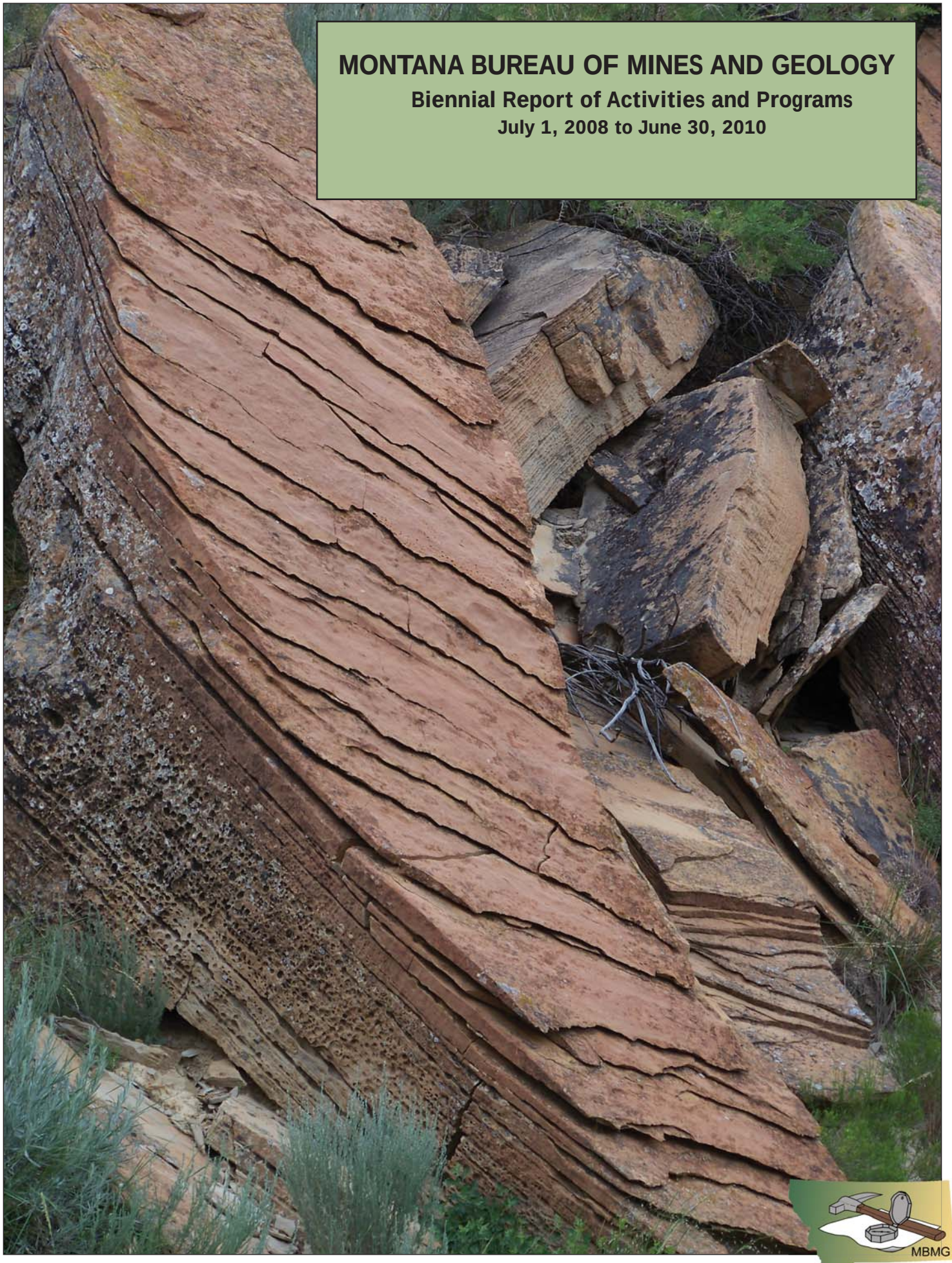
MONTANA BUREAU OF MINES AND GEOLOGY

Biennial Report of Activities and Programs

July 1, 2008 to June 30, 2010



MBMG

A department of Montana Tech of The University of Montana

DIRECTOR'S INTRODUCTION

New building, new programs, new people, new data: change is not an option, it's mandatory.

The just-completed biennium has to be one of the most eventful in the history of the Montana Bureau of Mines and Geology (MBMG). In December 2009 we began moving from Main Hall, the oldest building on Montana Tech's campus and our home since 1919, to the brand new Natural Resources Building on the west side of campus. Part of the MBMG's enabling legislation directed us to collect various things…a task that in some aspects we've done remarkably well, so serious house cleaning was launched well ahead of the move. It still took about a month to complete, plus time for settling in. Considering that we're geologists, there were remarkably few rocks to move, but there were tons of files and documents. We left Main Hall with serious regrets, but we're benefiting from having modern space that was designed with our needs in mind. The Mineral Museum had to remain in its old space, but changes are also happening there with the installation of new cabinets, exhibits, updated lighting, and revised staffing.

Geologic resources were certainly on the mind of the 2009 Legislature, as it established three new programs in the MBMG. HB 333 directs us to conduct research on Montana's geothermal resources and evaluate costs of development, and SB 297 established a sand and gravel evaluation program. Neither bill was funded, but we have obtained external grant funds that enable us to pursue geothermal data collection in a very modest way, and sand and gravel mapping now receives increased emphasis in our yearly STATEMAP grant proposal.

HB 52 established and funded the Ground Water Investigation Program (GWIP). This legislation was driven by growing conflicts over surface water and groundwater rights and resources. The program is directed to provide detailed reports on groundwater resources at the sub-basin level. It complements the long-established Ground Water Assessment Program (GWAP), which more broadly addresses statewide groundwater assessment and monitoring. Unfortunately, the status of future funding for GWIP has been uncertain, and about 20 percent of the anticipated second-year budget was lost as part of university-system budget reductions. This has created problems with attaining intended staffing levels. Despite these obstacles, the program is on track to deliver reports on seven sub-basins as originally planned, although the scope for two sub-basins will have to be somewhat reduced.

With all the changes in 2009, the MBMG's 90th anniversary quietly slipped by with little notice. Our basic mission of mapping and evaluating the State's geologic resources has remained unchanged over the decades. It still holds true that nearly every investigation depends on good geologic maps, whether they depict bedrock, mineralized zones in an ore deposit, or gravels that form aquifers. Not too many years ago, a project ended with a written report and/or geologic map, with or without a few tables of data, and went through technical reviews and editing to become a static paper publication. At this point, past and present operational practices diverge greatly.

We now generate huge amounts of data that cannot fit neatly on geologic maps or adequately in a report. Databases have become just as great a necessity as geologic maps, and the need to connect databases with each other and with geologic maps is a constantly moving and increasingly complex target. By itself a data point is just a number. In our work, successful interpretation requires that it be evaluated with other data points and with respect to the geology of the site or area. Each data point must also have geographic coordinates in three dimensions, so the information can be tied to the real world. In situations such as repeated measurements of water levels or water quality at a particular site, time is added as a fourth dimension. Without computers…where would we be?

Today, rather than a one-time press run of high-cost paper maps, our new geologic maps are digital, printed on demand, and can be updated as new information warrants. We now provide an

unprecedented amount of information, and much of it can be downloaded from our website at no cost.

Our customers have responded. During the FY 2007–08 biennium, we sold 15,788 paper copies of publications and digital copies were downloaded 218,750 times. For the FY 2009–10 biennium, the paper sales dropped to 10,797 copies, but digital copies nearly doubled to 434,357 downloads. Additionally, each month users of our Ground Water Information Center database logged in nearly 3500 times and viewed more than 1.8 million data records in response to their queries.

In the following pages, you will find brief descriptions of the activities of some of our programs and projects. Despite the fact that these are presented separately, all our programs contribute to a common pool of information that is becoming easier to mine for more complete answers to multiple problems. We've again tried to keep this report non-technical, but if you would like more information on any topic, please feel free to contact us.

Edmond G. Deal
Director and State Geologist

Data Preservation Project

It is important to recognize that "old" data may have immense value. Unfortunately over the years great amounts of old geologic data have been lost. For example, many exploration companies went out of business and truckloads of documents as well as cores and cuttings from test wells, costing millions of dollars, simply disappeared; data from many environmental investigations went into reports that were tossed out or relegated to a forgotten shelf; aerial photograph collections that are hugely valuable for documenting changes in the landscape and vegetation over decades of time have been discarded for lack of space. The MBMG is a participant with the Association of American State Geologists and the US Geological Survey in an effort to rescue endangered data and preserve it in the various state geological surveys. This attempt has received a modest amount of federal funding, but far less than needed to secure the data at risk.

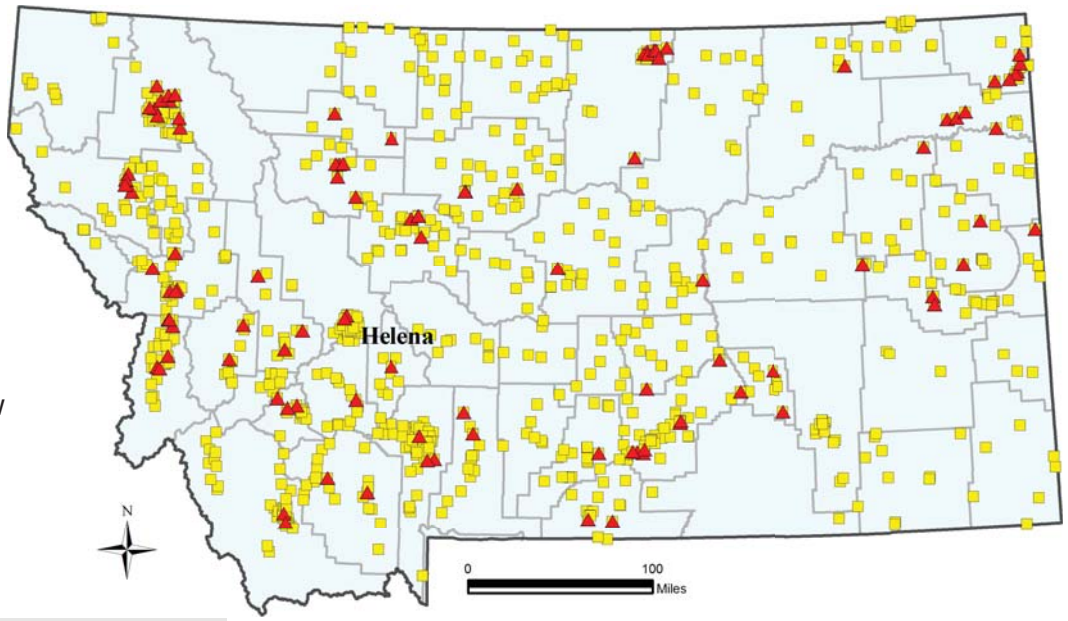
GROUND WATER ASSESSMENT PROGRAM

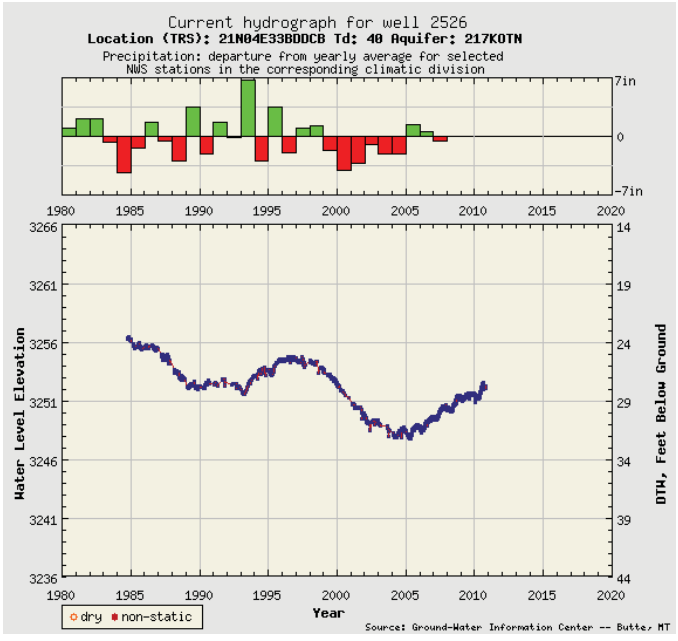
The Legislature established the Ground Water Assessment Program in 1991 after considering the recommendations of a Ground Water Task Force organized by the Environmental Quality Council. Statute specifically requires systematic monitoring and assessment of aquifers to improve understanding of Montana's groundwater resources. As part of a mandate to make groundwater information widely available, the Assessment Program includes the Ground Water Information Center (GWIC) database at the MBMG.

The Legislature also created an interagency Steering Committee that selects study areas, addresses the need for better coordination among State, Federal, and local government units, and oversees Assessment Program progress.

Ground Water Monitoring

The Ground Water Monitoring Program collects quarterly water-level measurements from 954 wells strategically located across the entire State, as shown by the yellow squares on the map at right. Red triangles mark locations of continuous water-level recorders. Long-term groundwater-level records (see hydrograph for well 2526, below) are the only direct measure of how Montana's aquifers respond to seasonal, climatic, developmental, or land-use factors. Long-term groundwater hydrographs are similar to long-term records of stream flow and precipitation, and must be evaluated at decadal scales. For example, information from the Ground Water Monitoring Program helps people understand the impact of drought on groundwater levels. In 2002, almost 85 percent of climate-sensitive network wells were below their seasonal averages; in June 2010 Montana's drought had moderated and only about 60 percent of the wells were below their seasonal averages. Ground Water Monitoring also collects water-quality samples to create long-term records of baseline water quality; the program collected 177 water samples during the biennium.





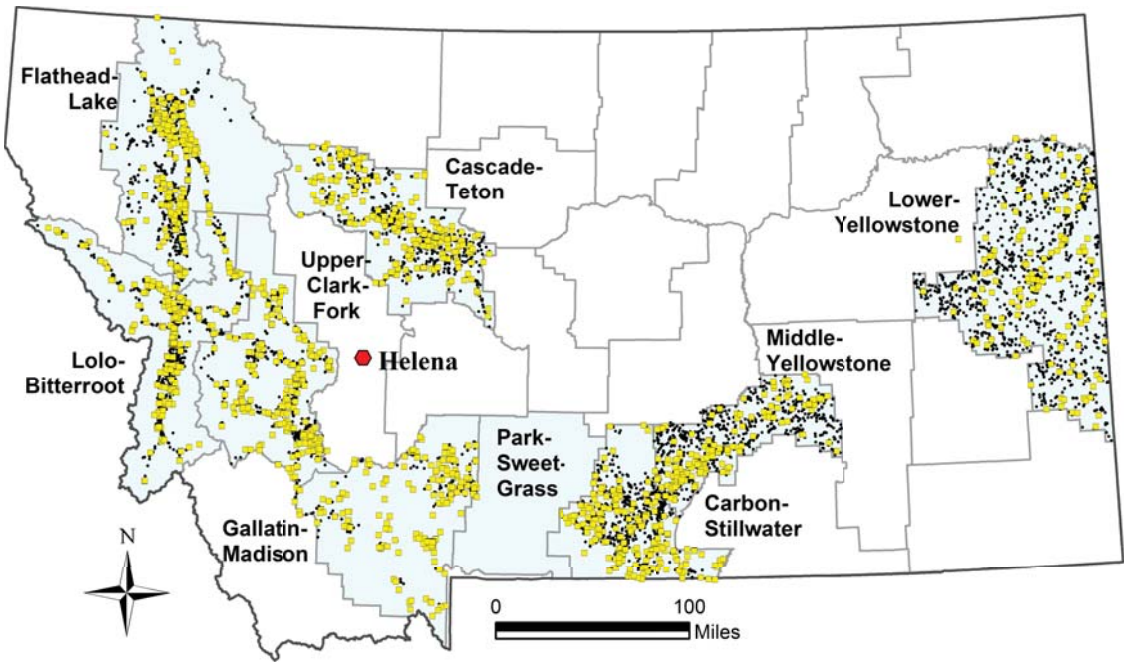
In an effort to improve efficiency and provide more timely water-level data from critical locations, the Ground Water Monitoring Program has installed three telemetry units to gather and send data directly to the Ground Water Information Center database. A photograph of the Deer Lodge Valley telemetry site is at right.

GWIC TICKER:

19,370 registered users...3,500 sessions and 34,000 queries each month...Information on 229,792 wells and boreholes...Scanned

Ground Water Characterization Program

The Characterization Program provides basic information about aquifers within specific areas as prioritized by the Ground Water Assessment Steering Committee. The locations for more than 8,950 site visits (dots) and 2,100 samples (yellow squares) generated by Characterization Program staff are shown on the map at right.



Fieldwork has been completed in the Cascade-Teton characterization area and is ongoing in the Gallatin–Madison area. The Steering Committee has selected the Park–Sweet Grass characterization area for future work. Characterization Program staff have described the hydrogeology of the 22 counties currently covered by active/completed groundwater characterization studies with two atlases, 42 maps, and 10 open-file reports. Between July 2008 and June 2010, customers retrieved 45,516 copies of Characterization Program maps and reports from the GWIC/MBMG websites.

Ground Water Information Center (GWIC)

GWIC customers seek groundwater data generated by MBMG projects, logs from water-well drilling, and results from water-quality sampling. GWIC offers geographic, address, subdivision, drainage basin, aquifer, and county searches, which allow customers broad choice in how to retrieve data. Users can choose from 13 report formats to customize retrievals. During the past biennium GWIC staff completed a 'first pass' through the main body of well logs, scanning and attaching the document images to database records. The scanned images are popular with customers who may prefer to have an image of the well log in addition to GWIC's digital record.

On July 1, 2004 drillers began filing water-well logs directly with the MBMG. Statute also allows the MBMG to accept electronically filed logs. Between July 1, 2008 and June 30, 2010 almost 3,136 water-well logs (almost 30 percent of all logs) were filed electronically through GWIC's "DrillerWeb" tool.

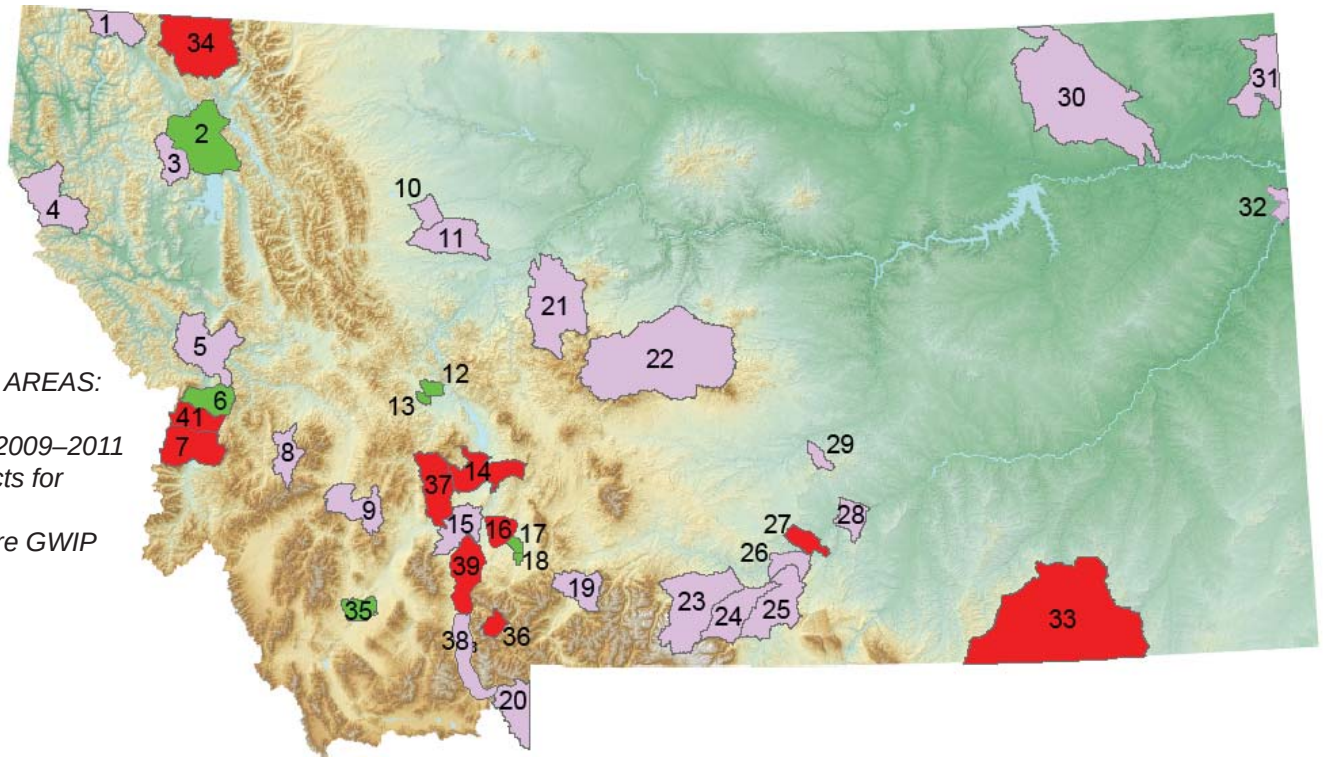
images for 207,496 well logs...Results from 52,617 water-quality analyses for 16,215 sites...6.4 million water-level measurements

GROUND WATER INVESTIGATION PROGRAM

The Legislature's 2007/2008 Water Policy Interim Committee (WPIC) recognized that competition for water resources and the lack of detailed information on groundwater/surface water interaction has challenged informed water-resource management and development in Montana. The WPIC found that "continued and expanded study of groundwater resources is vital to shaping statewide policy as well as providing the data necessary for local decisions regarding water." The Ground Water Investigation Program was funded by the 61st Montana Legislature to complete 6 to 8 projects per biennium, and operates under the oversight of the Ground Water Assessment Steering Committee. Additional information is available at *http://www.mbmg.mtech.edu/gwip/gwip.asp.*

MAP OF PROJECT AREAS:

Green, projects for 2009–2011
Red, planned projects for 2011–2013;
Pink, proposed future GWIP projects.



1 Eureka
2 Flathead Valley
3 Smith Valley
4 Noxon
5 Missoula Valley
6 Florence
7 Hamilton
8 Georgetown Lake, Philipsburg
9 Summit Valley
10 Priest Butte Lk
11 Greenfield Bench
12 North Hills
13 Scratchgravel Hills
14 Townsend, Toston
15 Three Forks
16 Manhattan
17 Belgrade
18 Four Corners
19 Pine Creek
20 W. Yellowstone
21 Belt, Monarch
22 Little Belt Mts
23 Stillwater Valley
24 Rock Creek
25 Pryor Mts
26 Park City
27 West Billings
28 East Billings
29 Roundup
30 Flaxville Gravels
31 Clear Lake
32 Sidney
33 Coalbed methane
34 NF Flathead
35 Lower Beaverhead W.
36 Big Sky
37 Boulder River
38 Madison Valley Quake Lake to Ennis
39 Madison Valley Ennis to Three Forks
40 Jefferson Valley
41 Stevensville Bitterroot

Program Status: Forty-one projects have been nominated and prioritized by the Ground Water Assessment Steering Committee. Prioritization was based on land use changes, anticipated growth in housing, agriculture, industry, and commercial activities. Seven sites were selected for the 2010–2011 biennium, and those projects are expected to be completed by June 2011.

Program Products: Every GWIP investigation is expected to produce: (1) a detailed report on the hydrogeologic system and stresses; (2) a computer model that simulates specific hydrogeologic features and future stresses; and (3) a comprehensive set of hydrogeologic data available online through the Ground Water Information Center.

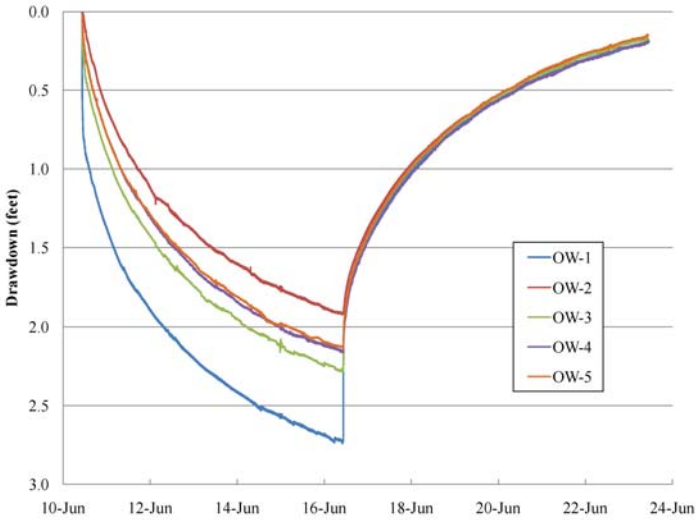
Montana water utilization will be supported by these products, which will be used by scientists and engineers representing agencies, senior water-right holders, new applicants, and other stakeholders. All data that have been collected are currently available to the public at http://mbmggwic.mtech.edu/.

Current Investigations:

1) **North Hills area, Helena**—Increasing groundwater development by subdivisions in this area has raised concerns of impacts to water-rights holders, and concerns about potential impacts from use of individual septic systems in dense housing developments. Computer modeling is being used to interpret declining water levels.

2) **Four Corners area, Bozeman**—Large-scale irrigation has altered a complex interconnection between groundwater and surface water. Changes due to population growth and changing irrigation practices that may affect water availability and senior water rights are being investigated to improve predictability and optimize water-use efficiency.

3) **Belgrade**—New water uses may cause negative impacts on water quality and quantity. A primary question being addressed by GWIP is whether mitigation can be effective in compensating for potential impacts.



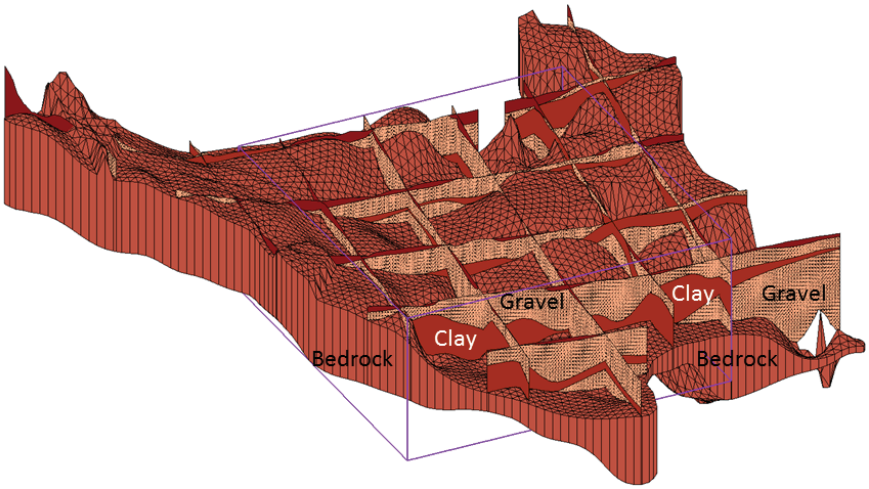
Water levels in observation wells respond to pumping and recovery during aquifer tests. Hydrographs, such as the one shown here, are used to interpret the responses and determine characteristics of the aquifers including transmissivity and storativity.

4) **Lower Beaverhead River West, Dillon**—The increased number of high-volume production wells since the mid-1990s may impact senior water-rights holders and may stress the aquifer beyond sustainability. Understanding the impact of increased groundwater withdrawals on groundwater and surface water availability is the primary focus of this project. A computer model will be used to evaluate the impact of high-capacity wells on potential depletion of water resources.

5) **Scratchgravel Hills, Helena**—Declining water levels concurrent with subdivision growth have been observed in some parts of this project area. This project will provide a better understanding of aquifer recharge and withdrawals.

6) **Florence**—Increasing population density in the Bitterroot Valley has increased the demand on the aquifer and the possibility of inducing contamination of drinking water by septic waste drainage.

7) **Flathead Valley Deep Confined Aquifer**—The increase in high-capacity municipal and irrigation wells, domestic wells, and localized water-level declines in the deep aquifer have raised concerns about the long-term sustainability of this water supply.



Computers are used to integrate detailed geologic and hydrogeologic data into a comprehensive 3-dimensional model of an aquifer.

GEOLOGIC MAPPING

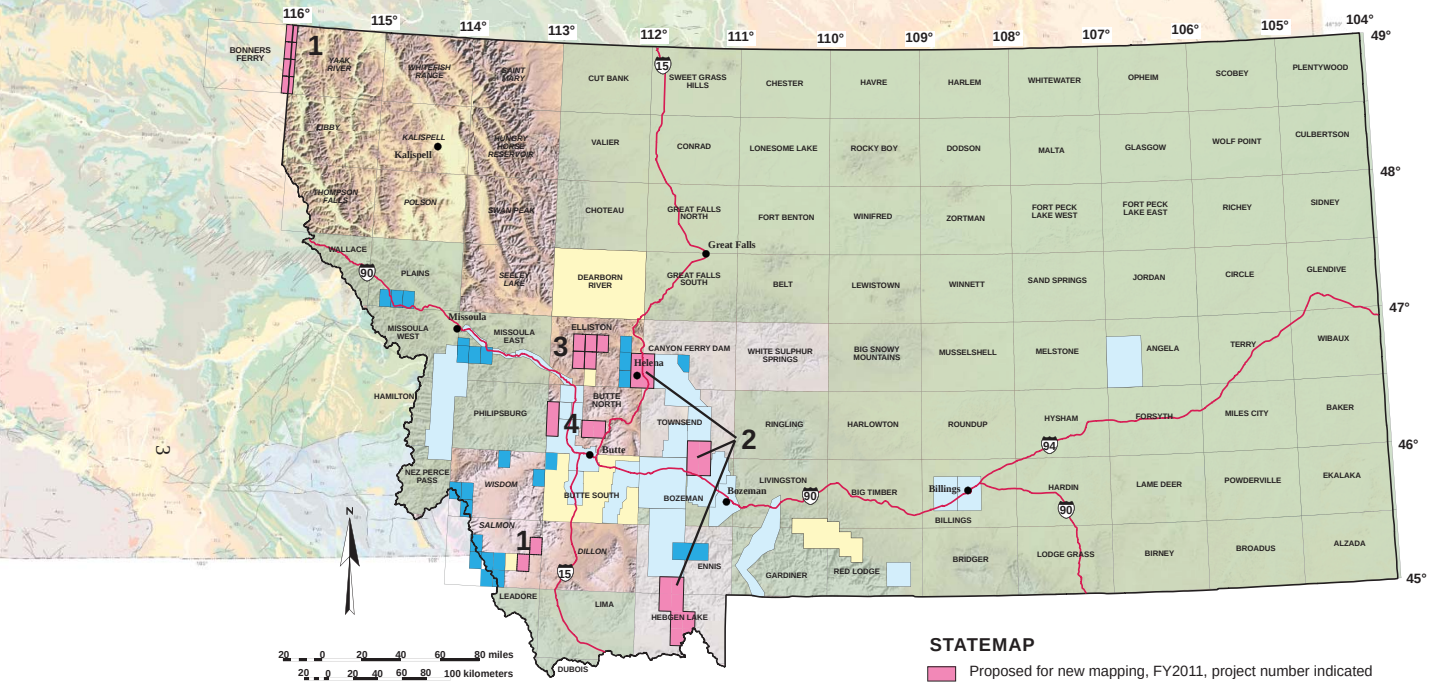
STATEMAP and EDMAP

During the past biennium, the Montana Bureau of Mines and Geology published eight geologic maps of areas of western Montana based on new fieldwork conducted through STATEMAP, a cooperative program with the U.S. Geological Survey. Federal funding for STATEMAP is awarded through an annual competitive grant process that requires matching State dollars.

Map areas are prioritized by an Advisory Committee made up of representatives from Montana universities, industries, and Federal, State, and Tribal agencies. One of the priorities established by the committee is for the MBMG to complete geologic mapping of the entire State at 1:100,000 scale, as 30' x 60' quadrangle geologic maps. Eastern and central Montana have been completed, so the recent focus has been on western Montana. During the past biennium the Missoula East 30' x 60' quadrangle and new versions of the Bozeman and Circle 30' x 60' quadrangles were prepared for publication.

Another goal of the STATEMAP program is to produce larger scale maps that focus on particular geologic issues or areas where development is occurring or is anticipated to occur. During the past biennium, geologic maps were published in the Beaverhead Mountains, Townsend area, and Big Sky–Moonlight Basin area of the Madison Range that meet this goal. Fieldwork was completed in the Canyon Ferry Lake area, Austin–Silver City area, and Beaverhead Range for maps that will be published in 2011.

In addition to the geologic maps produced through the STATEMAP Program, the MBMG released seven maps created by university students funded by EDMAP, a related program that partially funds geologic mapping by students. All of the published STATEMAP and EDMAP products are available for free download from the MBMG website.



Montana Bureau of Mines and Geology
STATEMAP Geologic Map Status
October 2010

STATEMAP

- Proposed for new mapping, FY2011, project number indicated
- In progress FY2010; completion 6/30/11
- Completed 30' x 60' quadrangles (1:100,000 scale)
- Completed 1:48,000 and 1:50,000 scale maps
- Completed 1:24,000 scale maps
- USGS completed 30' x 60' quadrangles (1:100,000 scale)

ENVIRONMENTAL HYDROGEOLOGY: TECHNICAL ASSISTANCE PROGRAMS

The MBMG works in concert with State and Federal agencies, conservation districts, water-quality districts, and local communities to monitor, identify, and propose solutions to groundwater problems. Current projects run the spectrum from environmental problems associated with historic mining practices to water-quality issues related to organic waste-water chemicals in groundwater and waste-water-system effluent.

Montana has a rich history of natural resource development and corresponding environmental problems associated with those practices. Many of these problems are the result of mining practices dating to the late 1800s and early 1900s, which predate environmental and mining regulations. State and Federal agencies have very proactive programs to address these environmental problems, many of which are water-related. Combining state-of-the-art Geographic Information System (GIS) capabilities, historic mine maps, lithologic data, and water-level information, the MBMG has created three-dimensional models of underground mine workings and locations of pooled water within a central Montana abandoned coal mine and the extent and thickness of old smelter and mill tailings adjacent to Silver Bow Creek (see figure below). These models allow researchers to visualize current conditions within mine workings without having to enter them and to assist with remediation options for tailings removal.

Organic waste-water chemicals (OWCs) originate from human or animal waste-water discharges (treated or untreated) to the environment and encompass a wide variety of chemicals, including pharmaceuticals, hormones, fire retardants, industrial chemicals, personal care products, and pesticides.

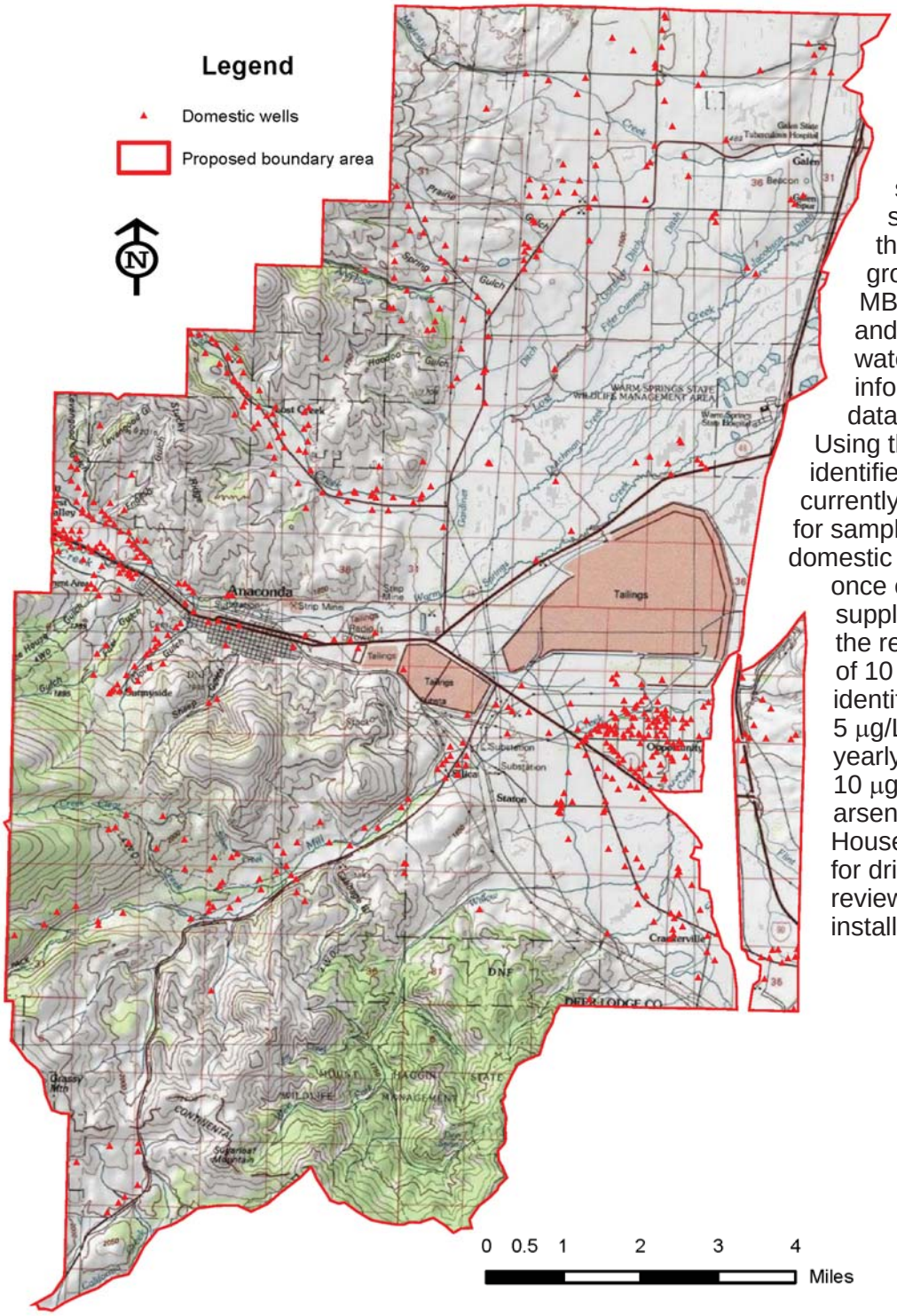
Current Investigations:

- Acid mine-drainage mitigation through land-use changes and source control at an abandoned underground coal mine, Belt
- Identification of recharge areas associated with a reclaimed gold mine leach pad, southwest Montana
- Groundwater monitoring of flooding underground mines and the Berkeley Pit
- Long-term monitoring of groundwater at the Anaconda Smelter Superfund site
- Assisting with evaluation of remediation options in the Upper Clark Fork River Basin
- Long-term monitoring of chromium concentrations in groundwater at the Mouat chromium repository
- Operation and maintenance of a groundwater recovery system and soil and groundwater treatment systems associated with organic contamination of soil and groundwater at a former timber-treatment site

Roughly 369,000 cubic yards of tailings are present in the subsurface of the Parrot Complex. This isopach map combines all existing bore hole and well lithology data. Calculations based upon EPA, 2004a (red boundary) partial removal boundaries; roughly 205,000 cubic yards of tailings are present within the area.

Many of these chemicals have been shown to interfere with the endocrine system of both animals and humans at very low concentrations and are therefore of significant concern. A study completed this biennium of shallow groundwater, surface water, and waste-water sources in Gallatin County (collaborative project with the Gallatin Local Water Quality District, funded by the MT DNRC) showed that 73 percent of the wells and all of the streams sampled had at least one detectable OWC. The study also showed that while the effluent from wastewater treatment plants (WWTPs) discharge a significant amount of OWCs to the environment, the WWTPs effectively removed most of the OWCs from waste-water influent.

Anaconda Smelter Superfund Issues



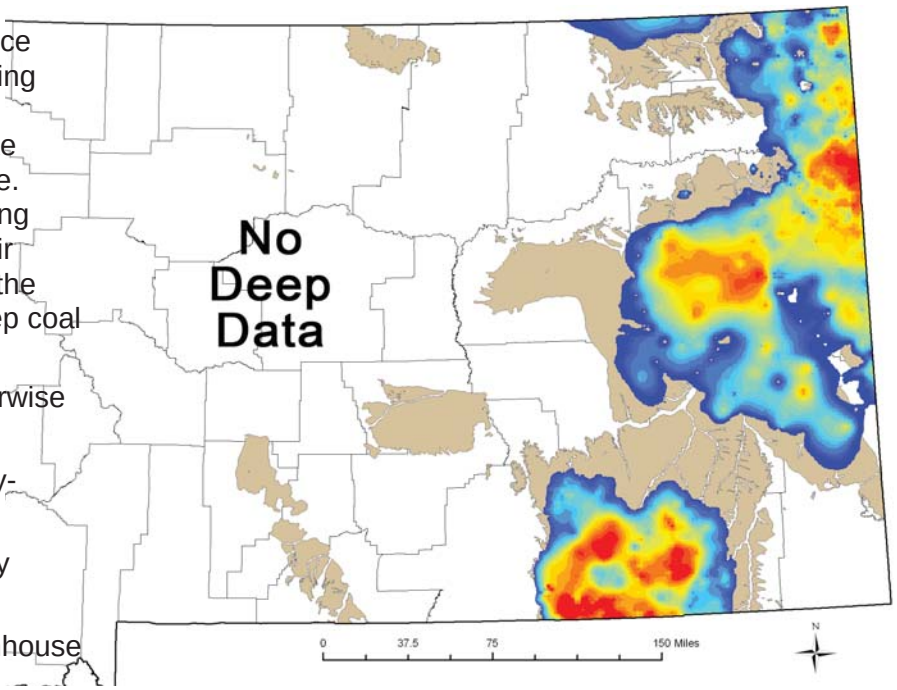
The US Environmental Protection Agency (EPA), Montana Department of Environmental Quality (MDEQ), and Atlantic Richfield Company (ARCO) have identified an area associated with the Anaconda Smelter Superfund site where airborne emissions from the smelter may have deposited arsenic that has the potential to leach into local groundwater aquifers (see figure). The MBMG in cooperation with the agencies and ARCO have implemented a groundwater sampling program that uses existing information contained in the MBMG GWIC database and State Library Cadastral data. Using this information, wells and ownership are identified and plotted within the boundary area; currently over 1200 wells have been identified for sampling. The program is designed to sample domestic wells within the identified boundary once every 5 years to ensure drinking water supplies have arsenic concentrations below the recommended drinking water standard of 10 μg/L (micrograms per liter). If wells are identified having arsenic concentrations above 5 μg/L but less than 10 μg/L, they are sampled yearly. Wells that have concentrations above 10 μg/L are evaluated for replacement if the arsenic source is related to mining activities. Households are provided with bottled water for drinking while well replacement options are reviewed. Wells identified for replacement are installed at no cost to the property owner.

ENERGY RESOURCES

Deep Coal

At least 60 percent of Montana's vast coal resources lie more than 500 feet below the surface and cannot be accessed using conventional mining methods. However, new technologies such as *in situ* or underground coal gasification (UCG) make our "deep coal" resources economically attractive. UCG is a "clean coal" process capable of gasifying deep, unmineable coal seams and capturing their energy content, in the form of product gases, at the surface. Identifiying and mapping Montana's deep coal resources will:

- position Montana to exploit coal which is otherwise "locked up," too deep for conventional mining.
- encourage and facilitate investment by energy-producing companies.
- minimize the environmental footprint of energy development.
- provide potential sequestration sites for greenhouse gases like CO_2.



UCG favorability in the Powder River and Williston Basins.

These same data will also be necessary and applicable as other technologies become available that could exploit the intermediate to deep coal resources of the State. This project is funded, in part, by the Montana Board of Research and Commercialization Technology.

Oil & Gas Activity

In northeastern Montana, drilling activity is increasing again and the Bakken oil play is rapidly expanding into Roosevelt and Sheridan Counties. Horizontal drilling and fracture stimulation play a critical role in the successful production of Montana's largest oil reservoir. The MBMG continues to be involved with the petroleum industry, providing geologic data, maps, and other information to individuals, public agencies, and industry. As an example, the MBMG has worked closely with coal-bed methane (CBM) producers over the past decade to help manage and monitor co-produced water from CBM wells.

Coal Availability Studies

With approximately 120 billion tons, Montana leads the nation in demonstrated coal reserves, consistently produces about 4 percent of the nations supply, and ranks 5th in annual production. Five surface mines and 1 underground mine produced about 45 million short tons in 2008 and 39 million short tons in 2009. The largest coal fields, such as the Otter Creek coal deposit, are found in the Powder River Basin (PRB) in southeastern Montana. Using a methodology developed by the USGS, the MBMG has been conducting coal availability studies to more accurately determine mineable reserves as part of a broad resource evaluation of the entire PRB by the USGS.

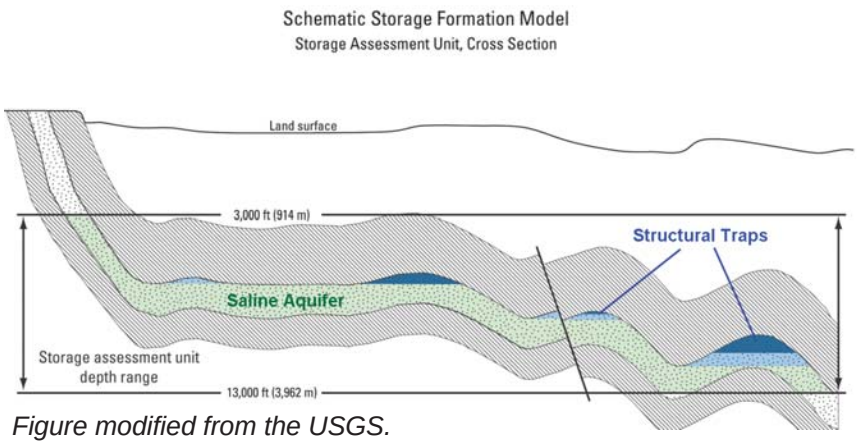


Figure modified from the USGS.

Carbon Sequestration

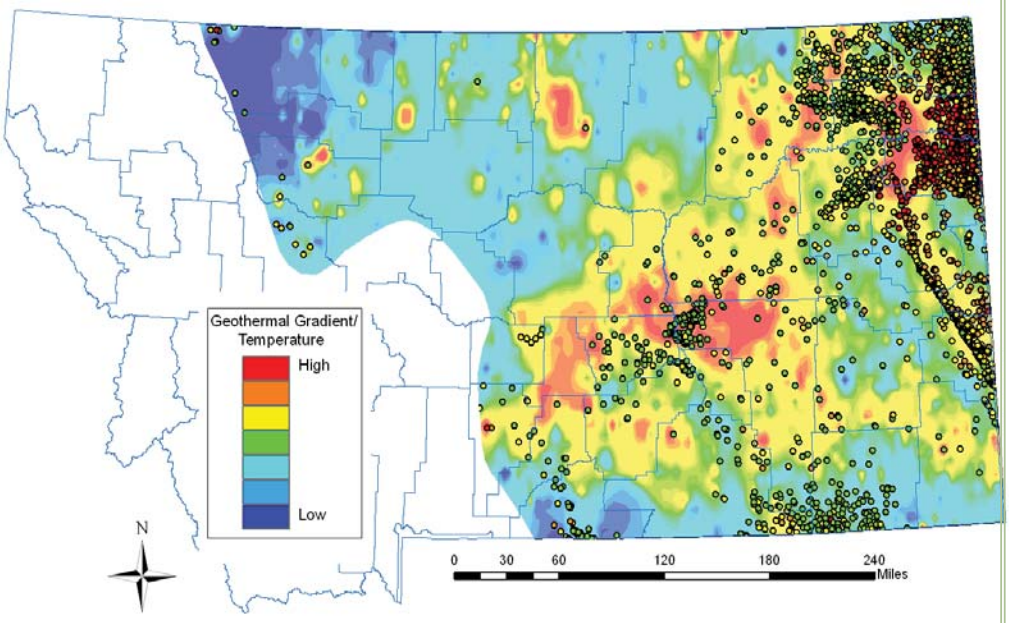
Geologic sites can provide permanent storage of CO_2 to reduce atmospheric concentrations of greenhouse gases. Under a cooperative agreement with the USGS, the MBMG is identifying potential sequestration sites such as existing petroleum traps and deep saline aquifers. Ideal locations would be near large CO_2 sources such as large fossil-fuel power plants to keep transportation costs to a minimum. If CO_2 can be injected into oil reservoirs, the increased recovery of hydrocarbons can offset these costs.

Geothermal Energy

Geothermal energy is heat that radiates from the Earth's interior. Because temperature generally increases with depth, groundwater deep in the subsurface is heated as it migrates through rock layers. Hot water can be produced to the surface and utilized in heat exchangers or steam turbines to generate electrical power. Geothermal energy is an enormous resource that is both clean and sustainable.

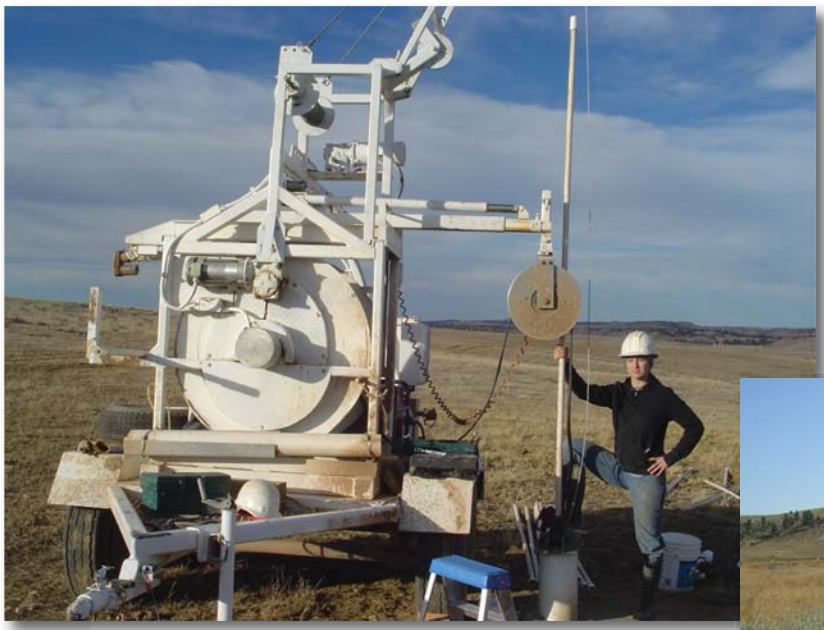
Montana Tech received a grant through the US Department of Energy to evaluate the benefits of using warm mine waters to heat the Natural Resources Building, the new home of the MBMG.The first phase, nearly complete, was to conduct a detailed cost/benefit analysis along with an engineering feasibility study. In phase 2, a heat pump system, using a heat exchanger placed in the shaft of the Orphan Boy mine, will be installed to complement the conventional heating/cooling system that now supplies the new building. In addition to energy savings, the geothermally based system will serve as a large-scale demonstration project that can be used for both teaching and research purposes (phase 3).

One cost-effective way to produce geothermal energy is to utilize the water that is co-produced along with oil from existing oil wells. Wells in depleted oil fields can be converted to water production and used for geothermal energy without additional drilling costs. Temperature measurements from petroleum wells provide information on regional geothermal "hot spots," and can be used to identify specific oil fields with enough high-temperature water production for use as geothermal energy sources (map of regional geothermal temperatures in Montana below).



The MBMG was also awarded funds from the US Department of Energy in cooperation with the American Association of State Geologists to participate in a national effort to compile geothermal data. For more than 30 years, the MBMG has gathered temperature, depth, flow, and chemistry for nearly 300 warm wells and springs throughout Montana and will provide these and new data to be included in a nationwide effort to promote the use of geothermal resources.

EASTERN MONTANA PROJECTS



Water Impact of Coalbed-methane Development

Coalbed-methane (CBM) production began in Montana in 1999, and currently 885 wells are producing methane gas. The process of extracting methane from coalbeds requires pumping large quantities of water to the surface. In 2009, over 4,500 acre-feet of water was extracted from Montana coal aquifers during CBM production, down from over 5,000 acre-feet in 2008. The MBMG regularly monitors 28 springs and over 200 wells within and near areas of CBM development. Additionally, in cooperation with the Big Horn Conservation District, the MBMG is assisting landowners near CBM development to monitor their water resources, including water levels in wells and spring-discharge rates.

Drawdown of water levels in coal aquifers has exceeded 600 feet near some areas of intense CBM development. However, drawdown rarely exceeds 20 feet at distances 1 to 2 miles outside of CBM development. While this drawdown is similar to that predicted by the U.S. Bureau of Land Management Environmental Impact Statement (EIS), the drawdown occurred much faster than the 10-year time frame outlined in the EIS; in some cases it was just 2 years. Water levels in aquifers overlying coalbeds targeted for CBM production are, in general, not impacted. Vertical migration of water tends to be inhibited by shale layers. Similarly, horizontal migration of water is limited by extensive faulting in the region. Records of water levels in CBM wells no longer in use have shown approximately 75 percent recovery after 5 years. Full recovery, however, is likely to be on the order of decades.

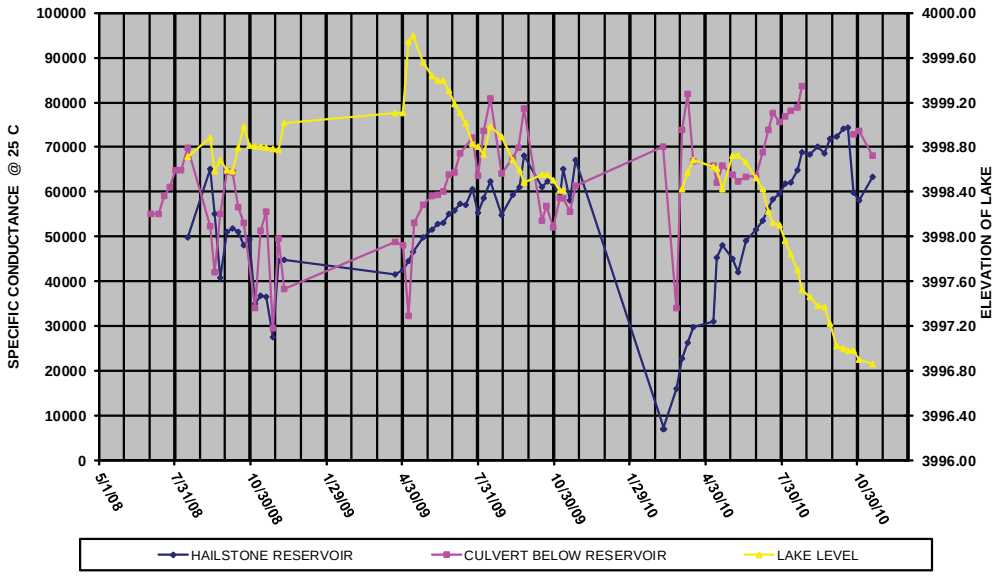
Eastern Montana Hydrology Projects

- **Alzada, Montana:** Predevelopment baseline groundwater evaluation in an area of potential in-situ Uranium mining.
- **Otter, Montana:** Isotopes of carbon and strontium are being used to determine the connection between Otter Creek and the Knobloch coal.
- **Hysham, Montana:** The amount of water consumed by Salt Cedar and Russian Olive trees was determined by removing each species in turn and monitoring the resulting impact on the water table.
- **Absarokee, Montana:** Increasing development in the Stillwater River Valley prompted a study on the availability of water in the aquifers used for domestic and stock water.
- **Great Falls, Montana:** Many of the people who live in the central and eastern part of the state depend upon the same limestone aquifer: the Madison. The Madison, though, is known for having extremely variable water quality and quantity. We are undertaking an extensive examination of the Madison aquifer to better characterize its potential for further development.

Hailstone Reservoir Project

Hailstone Reservoir, located 5 miles northeast of Rapelje, Montana, has high salinity and selenium concentrations. Previous work by the United States Fish and Wildlife Service (USFWS) and the MBMG documented water-quality conditions toxic to migrating birds. The USFWS planned to remove Hailstone Reservoir and convert the watershed back to natural flow-through conditions that existed prior to the construction of the dam.

LAKE LEVEL AND COMPARISON OF SPECIFIC CONDUCTANCE OF WATER IN HAILSTONE RESERVOIR TO WATER BELOW THE RESERVOIR

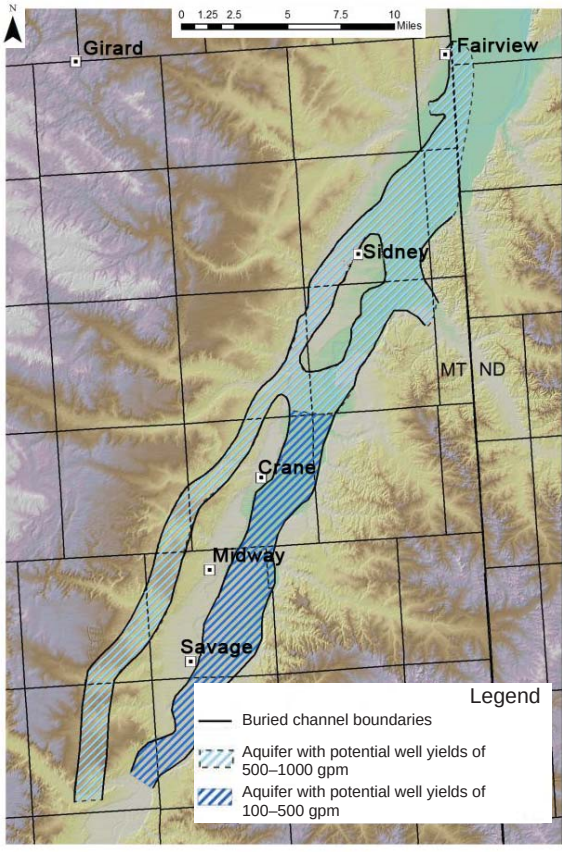


The MBMG and students from Montana State University-Billings (MSU-B) have been monitoring field-water quality and lake levels of Hailstone Reservoir for the past two and half years, and birds using the reservoir were counted and identified. Several wells were constructed by the Montana Salinity Control Association. Water levels and field-water quality are measured at these wells. The USFWS successfully drew down the lake levels over the past summer and fall using a pump and water-spreading system to accelerate evapotranspiration. As lake levels declined, the process to remove the reservoir commenced. This produced the desired result of no downstream drainage of lake water as natural pre-dam conditions were approached. Groundwater and surface-water conditions will be monitored and evaluated until the new equilibrium is reached.

Yellowstone River Buried Channel

An aquifer capable of producing large quantities of very good quality water has recently been identified underlying the Yellowstone River valley (see map, right). Past work on municipal water supplies identified the aquifer as sand and gravel fill in a paleo-river channel. It underlies the city of Sidney, where it provides municipal water for the community. Recent work by the MBMG has traced the aquifer to the North Dakota border near Fairview, where the buried channel underlies the lower reaches of the Yellowstone River valley, and preliminary work indicates it extends further south than previously known. Aquifer tests in this reach recently verified that properly constructed wells are capable of producing 800 to 1000 gallons per minute. These are the pumping rates commonly needed for irrigation development, municipal supplies, and large-scale industry.

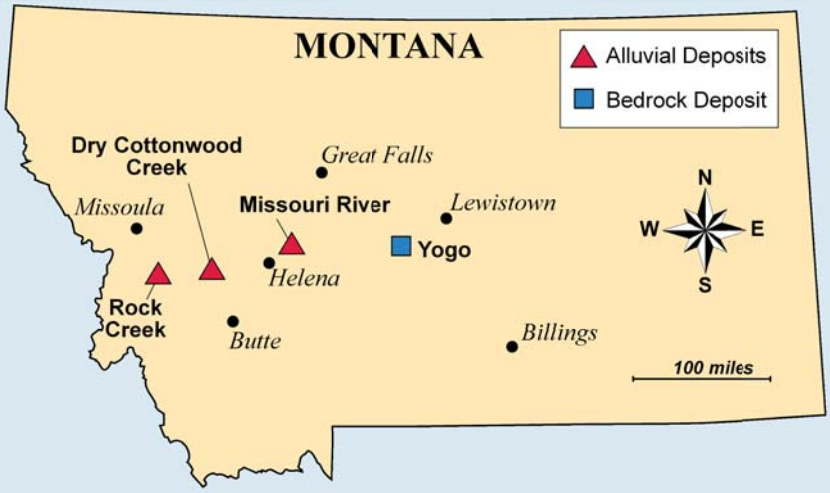
The development capability of this aquifer is very promising, especially for irrigating dry-land valley slopes and terraces that overlie much of the aquifer. Recharge–discharge relationships, maximum pumping rates, and potential impacts to other water resources are being investigated by the MBMG to help the Richland County Conservation District and local landowners determine development potential.

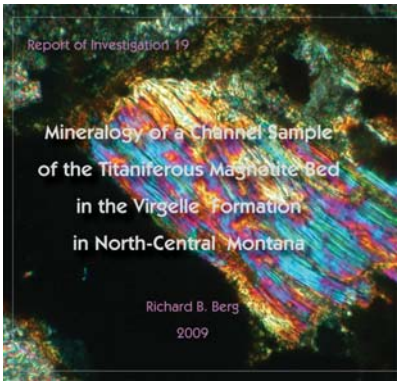


MINERAL RESOURCES

Montana Sapphires

Estimated historic production of sapphires from Montana deposits exceeds 75 tons. Present production is from the Yogo district, Missouri River deposits, and the Rock Creek district, all for the gemstone market. A detailed report on sapphires in the Butte–Deer Lodge area has been published (Bulletin 134, Berg, 2007). Current research is focused on the Rock Creek district. It is surprising that detailed information on the sapphires and geologic setting of this very large deposit (estimated historic production greater than 65 tons) has not yet been published. Study of the Rock Creek district includes detailed mapping of the geology and characterization of sapphires, including examination of surface features by scanning electron microscopy and identification of mineral inclusions usting standard petrographic techniques and energy dispersive x-ray analyses. Results of this work will be published by the MBMG. Future investigation of the Missouri River deposits is planned.





Mineralogy of Titanium Resources

The upper Cretaceous Virgelle Formation contains beds of titanifererous magnetite that stretch from the Canadian border almost as far south as Augusta, east of the Rocky Mountain Front. Standard petrographic methods, x-ray diffraction analysis, and EDX techniques were used to provide semiquantitative chemical analysis of individual grains. Fourteen different minerals were identified. The results of this investigation were published as MBMG Report of Investigation 19.

Photo above left by Jeff Scovill: sapphires from Yogo deposit.

MINERAL EXPLORATION

Mineral commodity prices have continued to rise over the past two years, with gold leading at record high levels. However, high prices alone do not drive the industry to invest in exploration or development. Montana's rich mineral endowment is certainly attractive, but the State also has the reputation as a highly challenging business environment. As a result, venture capital for exploration in the State has remained scarce. However, we seem to be seeing a leveling of the playing field as other states are now tightening their rules, and permitting continues to improve.

The combination of Montana's geology, high gold prices, and opportunity has focused the greatest amount of prospecting interest in "worked out" gold placers and lode deposits. Modern exploration techniques have led to repeated successes in reviving long-abandoned properties, using techniques and processes that meet Montana's environmental standards.

Water treatment plant at the Drumlummon Gold/Silver Mine.

The MBMG develops and maintains files on mineral properties and gathers information on current exploration and mining activities throughout the State. For individuals or companies developing exploration or mine plans, the MBMG has maintained the Small Miners Assistance Program since 1919. This program has assisted thousands of individuals and companies with plans, data interpretation, permitting, advice, short- and long-term planning, and an endless variety of advice on a multitude of subjects. The goal is to assist those intending to develop mineral properties to proceed in an orderly fashion that maximizes the resource and minimizes environmental impacts.

The small MBMG staff has been strained to the limits to meet the demands of the mineral industry, government agencies, landowners, and citizens for mineral data and assistance in mineral-related activities. We provide field assistance, talks for organizations, and advice to the extent our resources and mission allow; customers with requests exceeding those limits are referred to the private sector for additional help.

MINERAL MUSEUM

The Mineral Museum houses one of the finest mineral collections of minerals in the Pacific Northwest. One of the oldest museums in Montana, its history dates back over 100 years, when Montana Tech first opened its doors in 1901.

Estimated attendance for this biennium is 18,000, including at least 2900 individuals, mainly schoolchildren, in formal tours. Three hundred and ten specimens were acquired and accessioned into the permanent collection, including a spectacular cluster of smoky quartz crystals collected in the Butte area (picture below). In addition to offering workshops and several evening lectures, the Mineral Museum hosted the annual meeting of the Crystal Collectors in both years. The Crystal Collectors is a group of serious mineral collectors from Idaho and Montana. The Museum also hosted an evening reception for the annual meeting of the Museums Association of Montana and a reception in connection with the Butte Mineral and Gem Club show. The Friends of the Mineral Museum, a group of supporters of the Museum, was established. Five exhibits were prepared in new custom-built exhibit cases with interior lighting. Temporary exhibits included a lunar specimen in August 2009, a weather exhibit in the summer of 2009, and photos of old Montana mines and mills.

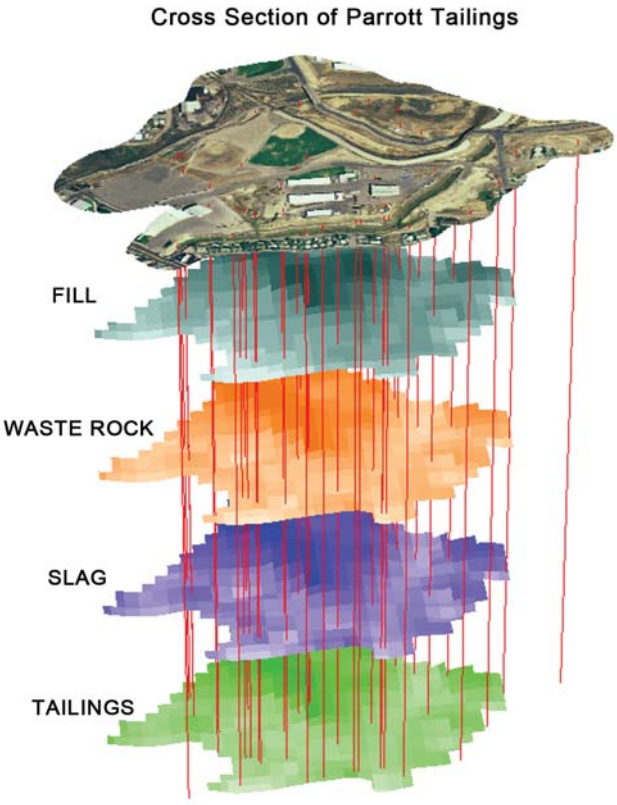
Rhianna's Star, collected near Butte

ANALYTICAL LAB

The Analytical Laboratory provides organic and inorganic analyses in support of the MBMG's research projects. The laboratory has added new capability, with the acquisition of a Thermo iCAP 6000 Inductively Coupled Plasma Optical Emission Spectrometer. This instrument complements the Thermo mass spectrometer to provide analyses of over 30 elements at concentrations ranging from sub-parts per billion to percent levels. The aging Dionex Ion Chromatograph was replaced with a Metrohm 882 with autodilution capability. Very soon, all transfer of data will be handled within a Laboratory Information Management System acquired from Systat Software.

The MBMG's new ICP spectrometer.

Our new Ion Chromatograph.



GIS LAB

The staff in the GIS Lab are actively engaged in a number of projects. The STATEMAP program continues to be the largest single project while many other projects are active. STATEMAP products are frequently updated to reflect new information or to integrate other data.

Other assignments include Superfund remediation/monitoring projects, geothermal heat reservoir modeling, and the Ground Water Investigation Program (GWIP), all programs or projects with an active GIS component. Efforts are underway to enable web delivery of GIS data and imagery.

EARTHQUAKE STUDIES

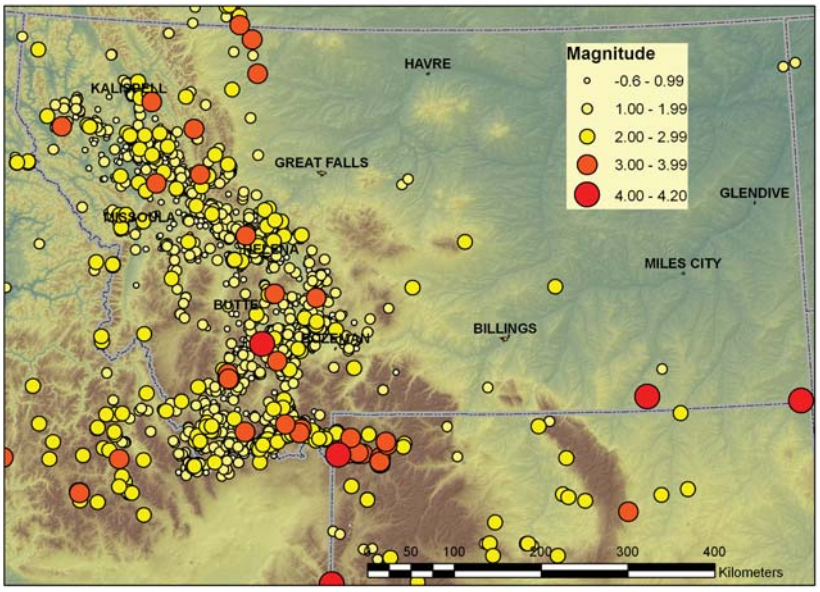
Western Montana has a history of large, damaging earthquakes and remains seismically active. Most of these earthquakes (including the 1925 magnitude 6.6 Clarkston earthquake centered north of Three Forks, and the magnitude 6.3 and 6.0 Helena earthquakes in 1935) occur 3 to 10 miles deep along faults that do not extend to the Earth's surface. The seismic hazards associated with these "blind" faults cannot be evaluated with traditional surficial mapping of faults and are best studied with data from a permanent network of seismograph stations. As the population and infrastructure of earthquake-prone western Montana continues to grow, the exposure to seismic hazards—the risk—increases.

The MBMG operates a network of 38 seismic monitoring stations throughout western Montana, the most seismically active region of the State. Four additional stations operate in less active eastern Montana. Other regional seismic monitoring centers in Yellowstone National Park, central Idaho, and southern Canada exchange seismic data with the MBMG and provide additional monitoring coverage near Montana's borders. In cooperation with the U.S. Geological Survey, the MBMG will be incorporating seven strong-motion seismic monitoring instruments previously operated by the USGS into the Montana seismic network and also upgrading three analog seismograph stations to digital instrumentation.

The MBMG currently records a total of 167 channels of seismic data from 98 local and regional stations. Data from this network are used to detect and report earthquake locations and magnitudes for significant earthquakes within 2½ to 3 minutes of their occurrence to the National Earthquake Information Center. State and Federal agencies (Montana Disaster and Emergency Services, Montana Dam Safety Program, Confederated Salish and Kootenai Tribes Safety of Dams Program, and the U.S. Geological Survey), the media, and the public use this information. As part of its routine earthquake cataloging procedure, the MBMG determined times, locations, and magnitudes for 2,964 earthquakes with magnitudes ranging from -0.6 to 4.2 from July 1, 2008 to June 30, 2010.

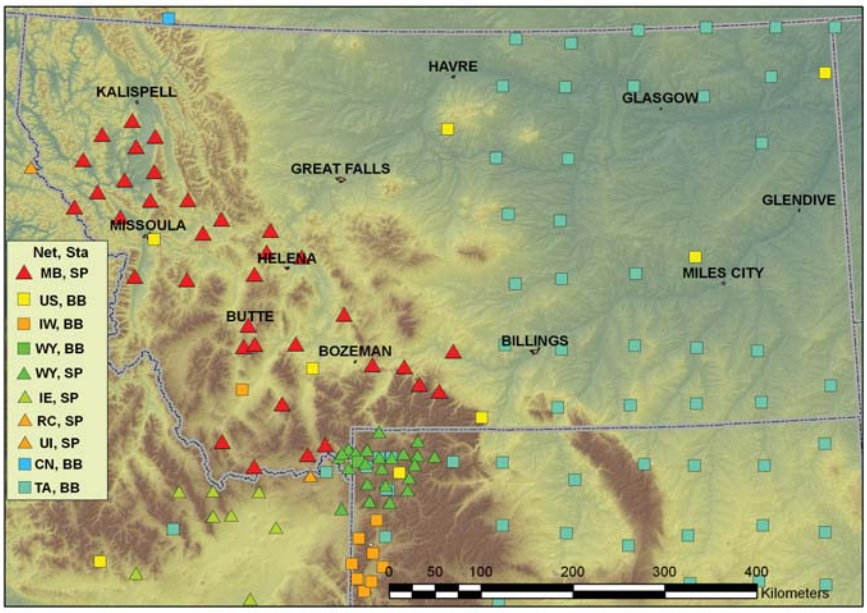
Real-time views of seismograms from the MBMG network are available on the MBMG Earthquake Studies Office website (http://mbmg-quake.mtech.edu/), along with a listing of recent earthquakes and other information about seismic hazards in Montana.

Earthquakes July 1, 2008-June 30, 2010



Epicenter locations for 2964 earthquakes located by the MBMG from July 1, 2008 – June 30, 2010.

2010 Seismograph Stations



Seismograph stations used to locate earthquakes during 2010. Square symbols indicate digital broadband seismographs and triangles indicate short-period seismographs. Network codes are: MB, MBMG; US, USGS National; IW, USGS Intermountain West; WY, University of Utah Yellowstone; IE, Idaho National Labs; RC, BYU Idaho; UI, University of Idaho; CN, Canadian national; TA, NSF-funded Earthscope Transportable array. The TA stations that operated in eastern Montana through September 2010 have since been moved eastward as part of this mobile deployment.

INFORMATION SERVICES

The Information Services Division is responsible for creating, editing, and distributing MBMG publications and reports to the public, both through our Publication Sales office and the MBMG's website. During this biennium we greatly increased the amount of material available for digital download.

Visit the MBMG site, http://www.mbmg.mtech.edu, or at our new office in the Natural Resources Building!

New publications in this biennium:

Geologic Maps

GM 62E, Geologic map of Montana field notebook, 59 p., 1:500,000, Vuke, S. M., Porter, K.W., Lonn, J.D., and Lopez. D.A., 2009.

Ground-Water Atlas Series

GWAA 7B-03, Altitude of the top of the Madison Group, Cascade County, Montana, 1 sheet(s), 1:75,000, Smith, L.N., 2008.

Ground-Water Open Files

Ground-Water Open-File Report 22, Nitrate in the ground water and surface water of the Summit Valley near Butte, Montana, 35 p., LaFave, J.I., 2008.

Open Files

MBMG 519E, Minerals of Montana, Part V, 176 p., French, L.B., 2009.

MBMG 572, Ground water and surface water in a study area within the upper Big Hole River basin, 85 p, Abdo, G.A., and Roberts, M., 2008.

MBMG 573, Geologic map of the Porcupine Dome area, Rosebud and Garfield counties, Montana, 9 p., 1 sheet, 1:48,000, Lopez, D. A., 2008.

MBMG 574, Geologic map of the Helmville basin, west-central Montana, 10 p., 2 sheets, 1:24,000, McCune, J.G., and Hendrix, M.S., 2009.

MBMG 575, Geologic map of the Homer Youngs Peak quadrangle, Lemhi County, Idaho, Beaverhead County, Montana, Montana Bureau of Mines and Geology: Open-File Report 575, 1 sheet, 1:24,000, Lonn, J.D., Burmester, R.F., Lewis, R.S., and Stanford, L.R. , 2008.

MBMG 576, 2007 Annual coalbed methane regional ground-water monitoring report: Northern portion of the Powder River Basin, 99 p., 6 sheets, Wheaton, J.J., Reddish-Kuzara, S., Meredith, E., and Donato, T. A., 2008.

MBMG 577, Butte Underground Mines and Berkeley Pit Water-Level Monitoring and Water-Quality Sampling 2007 Consent Decree Update Butte, Montana 1982–2007, 164 p., Duaime, T.E., and Tucci, N.J., 2009.

MBMG 578, 2008 Water Year Annual Coalbed Methane Regional Ground-Water Monitoring Report: Powder River Basin, Montana, 99 p., 2 sheets, Meredith, E., Wheaton J., Kuzara, S., and Donato,T., 2009.

MBMG 579, Geologic map of the Iris Point 7.5' quadrangle, western Montana, 14 p., 1 sheet, 1:24,000, Lonn, J., 2009.

MBMG 580, Geologic map of the Laurel area, Yellowstone County, Montana, 1 sheet, 1:48,000, Lopez, D.A., 2009.

MBMG 581, Geologic map of landslide and other Cenozoic deposits, Big Sky-Moonlight Basin-Lost

Lake area, Madison Range, Montana, 11 p., 1 sheet, 1:24,000, Vuke, S.M., 2009.

MBMG 582, Geologic map of the Kitty Creek quadrangle, Lemhi County, Idaho, and Beaverhead County, Montana, 1 sheet, 1:24,000, Lewis, R.S., Burmester, R.F., Stanford, L.R., Lonn, J.D., McFaddan, M.D., and Othberg, K.L., 2009.

MBMG 583, Geologic map of the Bohannon Spring quadrangle, Lemhi County, Idaho, and Beaverhead County, Montana, 1 sheet, 1:24,000, Lewis, R.S., Burmester, R.F., Stanford, L.R., Lonn, J.D., McFaddan, M.D., and Othberg, K.L., 2009.

MBMG 584, Geologic map of the Goldstone Pass quadrangle, Lemhi County, Idaho,and Beaverhead County, Montana, 1 sheet, 1:24,000, Lonn, J.D., Stanford, L.R., Burmester, R.F., Lewis, R.S., and McFaddan, M.D., 2009.

MBMG 585, Geologic map and geohazard assessment of Silver Bow County, Montana, 88 p., 3 sheets, 1:50,000, Elliott, C.G., and McDonald, C., 2009.

MBMG 586, Geologic map of the southern Townsend basin, Broadwater and Gallatin counties, Montana, 22 p., 1 sheet, 1:24,000, Vuke, S.M., 2009.

MBMG 587, Geologic map of the Black Mountain 7.5´ quadrangle southwestern Montana, 12 p., 1 sheet, 1:24,000, Berg, R.B., 2009.

MBMG 588, Hydrogeology of the northern Bighorn River Valley, 45 p., 3 sheets, Meredith, E.L., Wheaton. J.R., Kuzara, S.L., 2009.

MBMG 589, Butte Mine Flooding Operable Mine Unit Water-Level Monitoring and Water-Quality Sampling 2008 Consent Decree Update, Butte, Montana 1982–2008, 157 p, Duaime, T.E., and Tucci, N.J., 2009.

MBMG 590, The Parrot complex: A drilling investigation of historic mine waste left in place; tailings and overburden volumes, leachability and economic feasibility for recovery, and water quality along the upper metro storm drain in Butte, Montana, 127 p., Tucci, N.J., 2010.

MBMG 591, 2009 Annual Coalbed Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana, 94 p., 6 sheets, Meredith, E., Wheaton, J., Kuzara, S., Bierbach, S., and Schwartz. C., 2009.

MBMG 592, Aquifer Test Evaluation conducted on the middle gravel unit of the alluvial aquifer in Upper Metro Storm Drain area, Butte, Montana, 47 p., 1 sheet, Tucci, N.J., and Icopini, G.A., 2010.

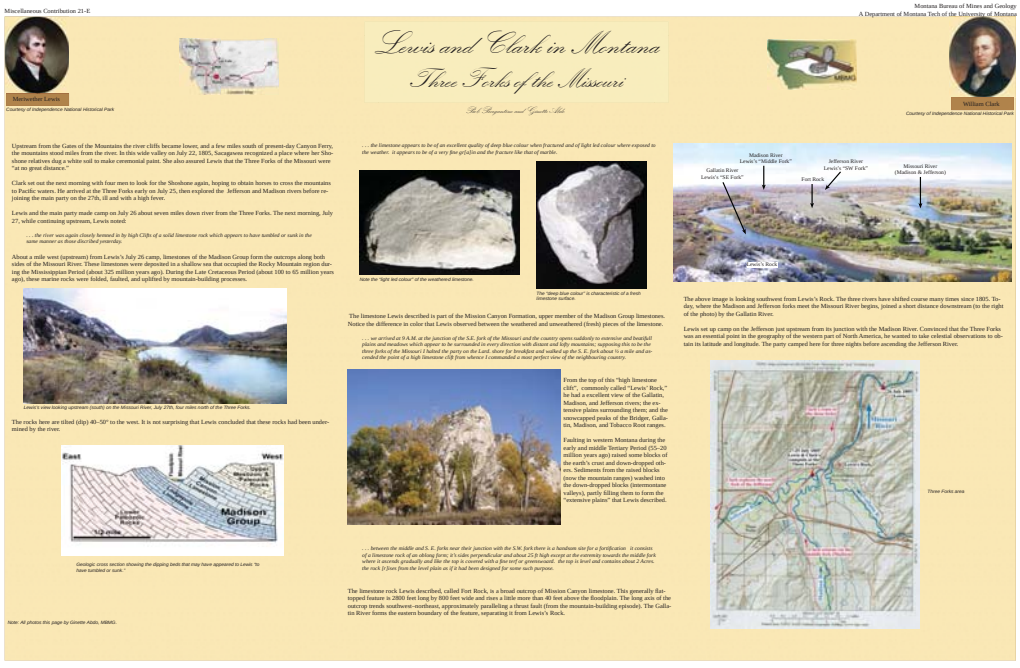
MBMG 593, Geologic map of the Missoula East 30' x 60' quadrangle, western Montana, 2 sheets, 1:100,000, Lonn, J.D., McDonald, C., Sears, J.W., and Smith, L.N., 2010.

Miscellaneous Contributions

MC 21A, Lewis and Clark in Montana: Entering Montana, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21B, Lewis and Clark in Montana: The White Cliffs of the Missouri, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21C, Lewis and Clark in Montana: Great Falls of the Missouri, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.



MC 21D, Lewis and Clark in Montana: Gates of the Mountains, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21E, Lewis and Clark in Montana: Three Forks of the Missouri, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21F, Lewis and Clark in Montana: Beaverhead Rock, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21G, Lewis and Clark in Montana: Pompeys Pillar, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21H, Lewis and Clark in Mon-

tana: Powder River Area, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21I, Lewis and Clark in Montana: Scientific equipment of the Expedition, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21J, Lewis and Clark in Montana: Finding the Latitude, 1 sheet, Bergantino, R.N. and Abdo, G., 2010.

MC 21K, Lewis and Clark in Montana: Includes Posters A-J plus SP 116 (The Route and Campsites of Lewis and Clark in Montana : A Geologic Perspective), 11 sheets, Bergantino, R.N. and Abdo, G., 2010.

Reports of Investigation

Report of Investigation 19, Mineralogy of a channel sample of the titaniferous magnetite bed in the Virgelle Formation in north-central Montana, Berg, R. B., 2009.

Miscellaneous Publications

MISC 33, Montana Bureau of Mines and Geology 2009 Calendar: Madison Limestone, Montana, 2008.

MISC 34, Montana Bureau of Mines and Geology 2010 Calendar: Glacier National Park Centennial, 2009.

EDMAP Series*

*****_The EDMAP series is part of the USGS National Cooperative Geologic Mapping Program. The maps are produced by geology students from various colleges and universities. MBMG staff may provide mentoring and assistance._

EDMAP 1, Geologic map of the Bailey Mountain and Griffin Creek 7.5' quadrangles, Montana, 2 sheets, 1:24,000, Brooks, J.A., and Sears, J.W., 2009.

EDMAP 2, Geologic Map of the Rock Creek 7.5' quadrangle, Powelll County, Montana, 6 p., 2 sheets, 1:24,000, Feeney, C.M., Ryan. C.B.., O.Connell, M., and Hendrix, M.S., 2009.

EDMAP 3, Surface geologic map of the confluence of the Swan and Flathead valleys, western Montana, 1 sheet, 1:24,000, Skudder III, P.A., and Hendrix, M.C. , 2010.

EDMAP 4, Geologic map of parts of the Carlton Lake, Dick Creek and West Fork Butte 7.5' quadrangles, western Montana, 14 p., 2 sheet(s), 1:24,000, Brown, C., Fitzpatrick, C., and Baldwin, J.A., 2009.

EDMAP 5, Bedrock and surficial geologic map ot the Snowline 7.5' quadrangle, Beaverhead County, southwest Montana, 3 p., 1 sheet, 1:24,000, Abrahamson, I.S., and Schmitt, J.G., 2010.

EDMAP 6, Geologic map of the Nez Perce drainage basin, southwestern Montana, 9 p., 1 sheet, 1:24,000, Feinstein, R.A., Reid, C.A., 2010.

EDMAP 7, Bedrock and surficial geologic map of the Lima Dam 7.5' quadrangle, Beaverhead County, southwest Montana, 17 p., 2 sheet(s), 1:24,000, Majerowicz, C.N., Troy, J.K., Anastasio, D.J., and Pazzaglia, F.J., 2010.

Information Services Statistics for this Biennium

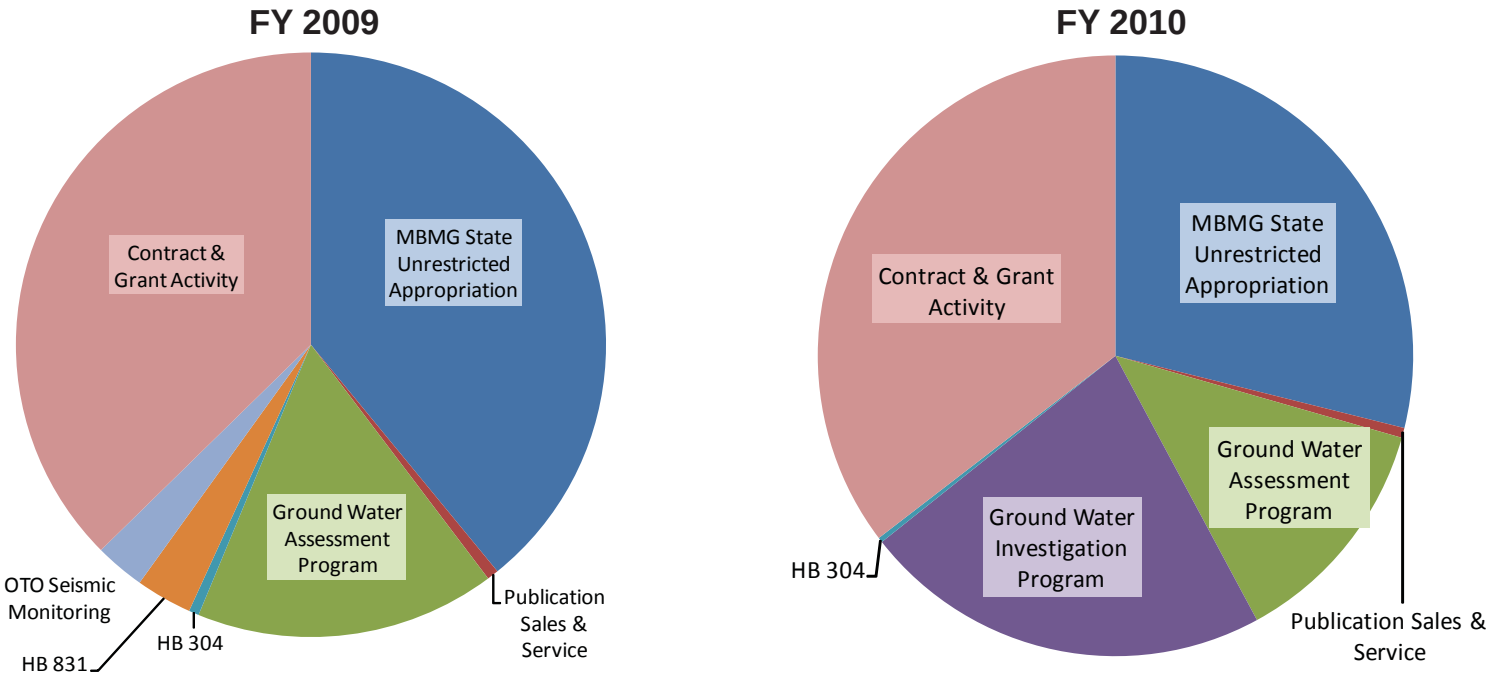
Publication Sales:

- 1553 titles
- 10,979 items sold

Data downloaded:

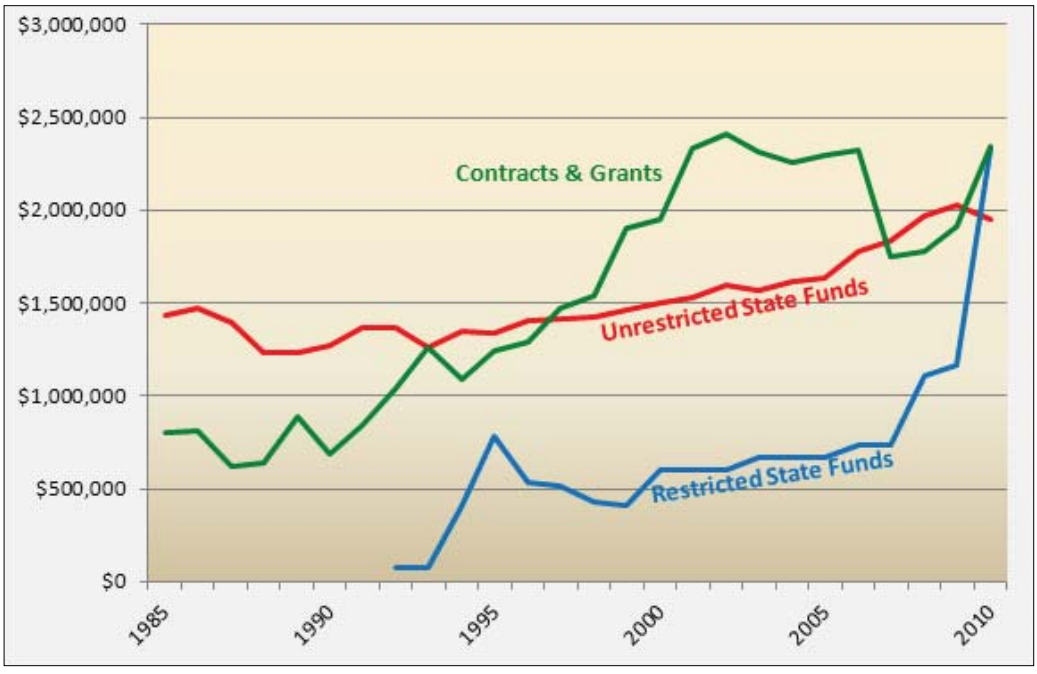
- 643 titles
- **434,357 files (almost double last biennium!)**

MBMG FINANCES



The Montana Bureau of Mines and Geology was established in 1919 as a non-regulatory, applied-research agency mandated to provide reliable and unbiased earth-science information for the State. Administratively, the MBMG is a department of Montana Tech of The University of Montana. Our main office is located in Butte on the campus of Montana Tech and a smaller office is located on the Montana State University-Billings campus. Our staff is composed of about 65 permanent employees and additionally we hire 25–30 students on a part-time basis.

Funding falls into three major categories: **Unrestricted State funds** are a biennial appropriation from the State's general fund and are used to maintain core programs fundamental to all our research, and to provide matching requirements for contracts and grants. **Restricted State funds** may come from the State's general fund or other accounts, but can be used only for designated purposes, such as the Ground Water Assessment Program and Ground Water Investigation Program. **Contracts and grants** are derived through agreements with variety of Federal, State, and local organizations; these agreements address specific issues of interest to the sponsoring organization and use of the funds is limited to that project.



The graph at left shows historic trends in funding from various sources. The roughly parallel level of unrestricted State funds and contracts and grants is inherent because many grants require a 1:1 match, which is derived mostly from unrestricted State funds. It is apparent that real growth in the MBMG budget has historically been in contracts and grants, and more recently in restricted State funding.

MBMG STAFF

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Stacey Konda, GWIC Lab Manager
Jeffrey D. Lonn, Associate Research Geologist
James Madison, Associate Research Hydrogeologist
Jane Madison, Professional Scientist
Donald C. Mason, Research Specialist
Robin B. McCulloch, Associate Research Mining Engineer
Catherine McDonald, Associate Research Geologist
Thomas Michalek, Senior Research Hydrogeologist
Todd Myse, Assistant Research Hydrogeologist
Thomas W. Patton, Senior Research Hydrogeologist, Program Manager–Ground Water Assessment Program
Mike Richter, Research Specialist
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Deborah Smith, Professional Scientist (Seismic Analyst)
Garrett Smith, Professional Scientist
Dean Snyder, Professional Scientist
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Kirk Waren, Senior Research Hydrogeologist
John Wheaton, Senior Research Hydrogeologist, Program Manager–Ground Water Investigation Program (GWIP)

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Jay Gunderson, Research Geologist
Shawn Kuzara, Professional Scientist
Elizabeth Meredith, Assistant Research Hydrogeologist
Jon C. Reiten, Senior Research Professor/Hydrogeologist
Clarence Schwartz, Groundwater Specialist

MBMG GRANTS AND CONTRACTS
in effect during this biennium

Abdo, G., *Investigative Studies of the Hydrology in Beaverhead River Basin*, US Bureau of Reclamation

Bowler, T., *Montana Pole Superfund Site Remedial Action*, MT Dept. of Environmental Quality

Delaney, M., *National Geological & Geophysical Data Preservation Program: Inventory of Geological Data*, Phase I, US Geological Survey

Delaney, M., *National Geological & Geophysical Data Preservation Program: Phase II*, US Geological Survey

Delaney, M., *National Geological & Geophysical Data Preservation Program: Phase IV*, US Geological Survey

Duaime, T., *Agricultural Practices Used in Source Control of AMD Problems in Central Montana (Belt-Anaconda Mine)*, MT Dept. of Environmental Quality

Duaime, T., *Agricultural Practices Used in Source Control of AMD Problems in Central Montana (Belt-Anaconda Mine)*, MT Dept. of Environmental Quality; US Natural Resource Conservation Service

Duaime, T., *Anaconda Regional Water, Waste and Soils Groundwater Monitoring, 5-yr Review, 2009*, Atlantic Richfield Company

Duaime, T., *Butte Mine Flooding Consent Decree Monitoring*, MT Dept. of Environmental Quality

Duaime, T., *Butte Mine Flooding Long-Term Monitoring Program*, MT Dept. of Environmental Quality

Duaime, T., *TO-5, Butte Area One-Silver Bow Creek-Technical Assistance, Groundwater and Surface Water Monitoring*, MT Dept. of Justice; Natural Resource Damage Program (NRDP)

Duaime, T., *Upper Blackfoot Mining Complex Drill Core Relocation*, MT Dept. of Environmental Quality

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