



A preliminary investigation of the Madison aquifer for a drinking water supply in Bozeman, Montana
by Karin Bohacek Kirk

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Earth Sciences

Montana State University

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Abstract:

The purpose of this study was to perform a preliminary assessment of the potential of the Madison aquifer in Sourdough Canyon for use as a supplement to the municipal water supply of Bozeman, Montana. The Paleozoic rock units in the upper Sourdough Creek drainage basin were mapped and a geologic cross section was constructed. The Mississippian Madison Group is comprised of the lower Lodgepole Limestone and the upper Mission Canyon Formation, and is 430 meters (1420 feet) in total thickness. Karst features and fractures were common in the Mission Canyon Formation and enhance the permeability of the formation. Recharge to the aquifer was estimated by measuring stream losses where streams flowed across the Madison Group rocks. Each of the streams in the Sourdough Creek watershed was found to be losing water and the estimated stream loss is 3,200,000 m³/year (2,600 acre-feet/year). One spring was found that was discharging from the Lodgepole Limestone. The spring stage was measured by a data logger within a stilling well from October 2000 to October 2001. During this period, the annual spring discharge was 1,100,000 m³/year (900 acre-feet/year). Correlation of a peak in the spring discharge with an isolated precipitation event revealed a response time of 5 days, suggesting a rapid connection between the surface water and the spring discharge. The water temperature, ion chemistry and tritium concentration all indicate the spring has a shallow circulation pattern, and a short residence time. Hence the spring is not representative of a deep, regional aquifer system within the Madison aquifer, and the depth to the regional saturated zone is unknown. The City should not drill a production well without further investigation of the depth to the saturated zone. By drilling a test well, the depth to saturation, well yield and subsurface geology could be determined. This is recommended if the City chooses to pursue the development of groundwater resources in the Sourdough Creek drainage. Other options for water development include the prevention of stream losses in order to provide a net gain to Sourdough Creek, and an assessment of the Madison aquifer in the Hyalite Creek drainage.

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of the requirements for the degree
of
Master of Science
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Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2002

N378
K6349

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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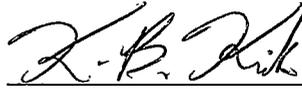
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ACKNOWLEDGEMENTS

This research project was made possible with funding and cooperation from the City of Bozeman, Montana. The U.S. Forest Service granted access to the study area and gave permission to conduct the field research on Forest Service land. The Rosenstiel School of Marine and Atmospheric Science donated free tritium analyses. The Donald Smith memorial scholarship provided additional funding for this research.

The hard work of field assistants Linda Lennon and John Paterson was invaluable, and they were tremendous assets to the project. Thanks also go to Chris Landry, Zack Mercer and Stefan Mitrovich for field help.

I would like to recognize the contributions made by my graduate committee, especially my committee chairman Dr. Stephan Custer, whose expertise was invaluable. Committee members Dr. William Locke and Dr. James Schmitt provided feedback and insight. Thanks also to John Mills for continued advice throughout the project.

Special thanks go to my husband Dave for his constant encouragement and support throughout this project, and for being a wonderful field partner.

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ABSTRACT

The purpose of this study was to perform a preliminary assessment of the potential of the Madison aquifer in Sourdough Canyon for use as a supplement to the municipal water supply of Bozeman, Montana. The Paleozoic rock units in the upper Sourdough Creek drainage basin were mapped and a geologic cross section was constructed. The Mississippian Madison Group is comprised of the lower Lodgepole Limestone and the upper Mission Canyon Formation, and is 430 meters (1420 feet) in total thickness. Karst features and fractures were common in the Mission Canyon Formation and enhance the permeability of the formation. Recharge to the aquifer was estimated by measuring stream losses where streams flowed across the Madison Group rocks. Each of the streams in the Sourdough Creek watershed was found to be losing water and the estimated stream loss is 3,200,000 m³/year (2,600 acre-feet/year). One spring was found that was discharging from the Lodgepole Limestone. The spring stage was measured by a data logger within a stilling well from October 2000 to October 2001. During this period, the annual spring discharge was 1,100,000 m³/year (900 acre-feet/year). Correlation of a peak in the spring discharge with an isolated precipitation event revealed a response time of 5 days, suggesting a rapid connection between the surface water and the spring discharge. The water temperature, ion chemistry and tritium concentration all indicate the spring has a shallow circulation pattern and a short residence time. Hence the spring is not representative of a deep, regional aquifer system within the Madison aquifer, and the depth to the regional saturated zone is unknown. The City should not drill a production well without further investigation of the depth to the saturated zone. By drilling a test well, the depth to saturation, well yield and subsurface geology could be determined. This is recommended if the City chooses to pursue the development of groundwater resources in the Sourdough Creek drainage. Other options for water development include the prevention of stream losses in order to provide a net gain to Sourdough Creek, and an assessment of the Madison aquifer in the Hyalite Creek drainage.

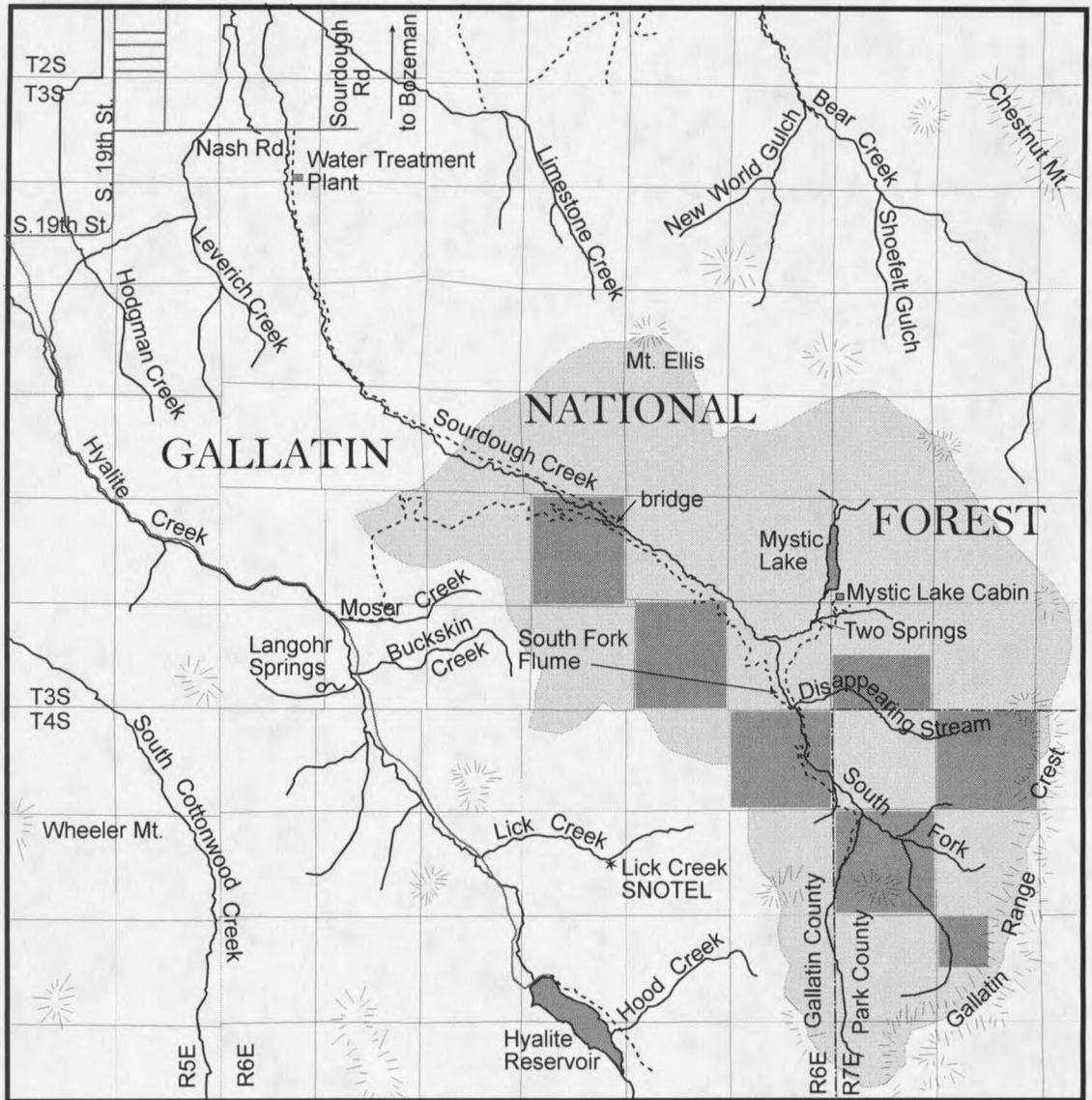
INTRODUCTION

Problem

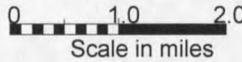
The City of Bozeman, Montana is seeking an additional source of municipal drinking water to meet the needs of its growing population. Water supply wells in the Madison aquifer in the northern Gallatin Range near Sourdough Creek may provide a viable groundwater source of drinking water for the City, but the aquifer potential has not yet been studied.

Bozeman receives its drinking water from three sources: Sourdough Creek, Hyalite Creek and Lyman Creek. Until the early 1980s water from Sourdough Creek had been stored behind the Mystic Lake Dam (Fig. 1-1). In 1984 – 1985 the Mystic Lake Dam was intentionally breached due to concerns over the dam's integrity. With the loss of the Mystic Lake Dam, the City lost the ability to store approximately 7,400,000 cubic meters (6,000 acre-feet) of water (URS Greiner Woodward Clyde, 1999).

The estimated safe yield of the City's current water supplies is 13,300,000 cubic meters per year (10,795 acre-feet per year), not including Mystic Lake (URS Greiner Woodward Clyde, 1999). Based on an estimated water use of 200 gallons per day per capita, Bozeman's current water supply can meet the needs of 48,000 people (URS Greiner Woodward Clyde, 1999). Depending on the rate of population growth in Bozeman, it is predicted that the City will need to expand its water supply in as little as 20 years.



-  Stream Channel
-  Paved Road
-  Dirt Road
-  Primary Study Area
-  City of Bozeman Land



Study Area Location

Map Source:
 USGS 7.5 minute series
 Wheeler Mt. Quadrangle, 1987
 Mt. Ellis Quadrangle, 1987
 Mt. Blackmore Quadrangle, 1988
 Fridley Peak Quadrangle, 1988

Figure 1. The study area.

Although it may be 20 years before Bozeman needs an additional source of water, it is prudent that a thorough search for the best alternative begin well in advance of the need. Most water development projects take 20 years or more from conception to completion. By allowing ample time for planning, there will be time to investigate all of the available options, make a well-informed decision, acquire land and water rights, and construct the infrastructure necessary for an expansion of the public water supply. This proactive planning should save money for the city and will avoid the need for crisis management should the problem be left unanswered. This research on the Madison aquifer potential is a preliminary step in the important process of assessing Bozeman's water supply options.

Background

In June 1999 the Bozeman Broad Spectrum Task Force issued recommendations to the Bozeman City Commission regarding Bozeman's future water needs. The task force recommended that the potential use of groundwater as a water supply "warrants immediate investigation and action" (Bozeman Broad Spectrum Task Force, 1999). Specifically, the Task Force recommended the following specific goals regarding the Madison aquifer.

- Determine water yield potential of the Madison aquifer.
- Determine water storage potential of the Madison aquifer (Bozeman Broad Spectrum Task Force, 1999).

A report submitted to the City by URS Greiner Woodward Clyde in January 1999 investigated the feasibility of building another dam in Sourdough Canyon. However, there are several concerns associated with the construction of a new dam. According to the URS

Greiner Woodward Clyde report, there are seven threatened or endangered animal species that may be present in the area. These species are the bald eagle, American peregrine falcon, grizzly bear, gray wolf, lynx, fluvial Montana arctic grayling, and the western toad (URS Greiner Woodward Clyde, 1999). There are also 35 species that may occur in the area that are listed as Montana threatened, endangered or of special concern (URS Greiner Woodward Clyde, 1999). Another concern regarding the construction of a reservoir is the loss of recreational areas for hiking, horseback riding, fishing, biking, ski touring and hunting. Due to these environmental and recreational concerns, other options for a water supply should be investigated before plans for a new dam are pursued.

URS Greiner Woodward Clyde (1999) found that the development of the Madison aquifer as a water supply “merits future evaluation due to its use in other areas as a groundwater resource and [its] proximity to the Sourdough Creek drainage” (URS Greiner Woodward Clyde, 1999). Several recommendations for further investigation were put forth in the report, including, “detailed geologic field characterization and mapping of outcrops of the Madison Formation should be performed in the Mystic Lake area to provide further information on structural, stratigraphic, and secondary porosity characteristics of the formation” (URS Greiner Woodward Clyde, 1999).

This study assesses the groundwater potential of the Madison aquifer in the Sourdough Creek watershed (Figure 1-1). This drainage area was selected because it contains large exposures of the Madison Group which may serve as recharge areas for the aquifer, because Bozeman’s water treatment facility is at the base of Sourdough Canyon, and because the ideal water source would be located proximal to and uphill from the water

treatment plant to minimize conveyance losses and to avoid the need to pump the water uphill to the city.

Goals and Objectives

This research addresses several questions that are listed below.

1. Is the karst porosity and permeability that has been documented in the Mission Canyon Formation near Livingston present in the Sourdough Creek watershed?
2. Is there dolomite porosity and permeability in the Madison Group rocks in the Sourdough Creek watershed?
3. Do streams recharge the Madison aquifer in the study area? If so, at what rate? Are the springs ephemeral or perennial?
4. Does the Madison aquifer discharge into springs and streams in Sourdough Canyon? If so, at what rate?
5. Do fold-axis fractures or faults affect recharge potential, direct or control the groundwater flow, or control the locations of springs?
6. Is the water quality from the Madison aquifer suitable as a raw drinking water source?
7. Can suitable locations for drilling a test well be determined?
8. Are there known water rights issues pertaining to large-scale use of Madison aquifer water in Montana?

Anticipated Outcomes

There are several anticipated outcomes that arise from the questions above.

1. Karst features are present and do allow rapid transmission and storage of groundwater.
2. Dolomite porosity is present in the Mission Canyon Formation of the Madison Group and represents storage capacity.
3. Streams recharge the Madison aquifer.
4. Springs discharge the Madison aquifer, especially along faults and at the contact between the Madison Group rocks and underlying formations.
5. Additional recharge and discharge areas exist along fracture zones at the crest of anticlines.
6. Water from springs discharging the Madison aquifer may be high in hardness and sulfate, but the water quality will be acceptable for a raw water source for a public drinking water supply.
7. There are suitable locations for drilling a test well in the Madison aquifer in Sourdough Canyon.
8. Water rights issues have been encountered for other large-scale users of Madison aquifer water, and water rights must be considered before Bozeman pursues groundwater development in Sourdough Canyon.

Previous Work

Regional Stratigraphy of the Madison Group

The Mississippian Madison Group rocks are cyclically deposited, fine to medium grained limestones and dolomites with evaporite units. The Madison Group is made up of three formations, the basal Lodgepole Limestone, the Mission Canyon Formation, and the Charles Formation. The Lodgepole Limestone is further subdivided into the Paine Shale and the Woodhurst Limestone. The Mission Canyon Formation has been divided into an upper and lower member. The Charles Formation consists largely of evaporite rocks and is often not present at the surface, presumably due to dissolution of the evaporites. The Charles Formation is present in the subsurface of the Williston Basin (Aram, 1981).

The thickness of the Madison Group rocks ranges from 210 meters (700 feet) in the Bighorn Mountains, to 610 meters (2000 feet) in the Williston Basin (Miller, 1976). The depth of the formation ranges from surface outcrops in mountainous regions, to 3000 meters (10,000 feet) along the Montana – Wyoming border (Miller, 1976). Madison Group rocks lie conformably over the upper Devonian to lower Mississippian Sappington Formation. The uppermost unit of the Sappington Formation is the Bakken shale, which is an organically rich, black shale and is a confining layer below the Madison aquifer. The Bakken Shale also is the source of much of the petroleum and natural gas found within the Madison aquifer (Downey, 1984). Within the study area, the Sappington Formation was not recognized by Roberts (1964) and the Madison Group directly overlies the Three Forks Formation, which is comprised of shale and fine-grained limestone and also acts as a confining layer. The rocks of the Madison Group are overlain unconformably by the upper Mississippian Big Snowy Group or the lower Pennsylvanian Amsden Formation, both of

which are confining layers. Where present, the uppermost member of the Madison Group, the Charles Formation, can act as a confining layer as well.

Local Stratigraphy of the Madison Group

The rocks in the Madison Group near Livingston, Montana were studied by Roberts (1966). The unit was measured to be 346 meters (1,136 feet) thick and is divided into two formations, the Lodgepole Limestone and the Mission Canyon Limestone (Figure 1-2; Roberts, 1966). The Lodgepole Limestone consists of the Paine Shale Member and the Woodhurst Limestone Member. The Paine Shale is 102 meters (334 feet) thick and is generally limestone and dolomite but contains some silty units. The Woodhurst Limestone is 45 meters (146 feet) thick and is comprised of thin-bedded limestone and dolomite (Roberts, 1966). The Mission Canyon Limestone is further subdivided into a lower and upper member. The lower member is 100 meters (330 feet) thick and consists of massive, medium to fine grained limestone and dolomite. The upper member of the Mission Canyon Limestone is 99 meters (326 feet) thick and is comprised of finely crystalline limestone and dolomite interbedded with dolomitic solution-breccia (Roberts, 1966). The Charles Formation is comprised primarily of evaporite deposits and is typically absent at the surface. In some localities, a solution breccia is present in the same stratigraphic position as the Charles Formation.

The limestone units of the Madison Group were described as massive or thickly bedded with some fossils and fossil debris. Oolites and pelletal material are minor constituents and a small percentage of the rock is comprised of clastic material. The dolomite units are either fine-grained or medium-grained and are a product of recrystallization of limestone. Roberts (1966) observed that the limestone units are resistant

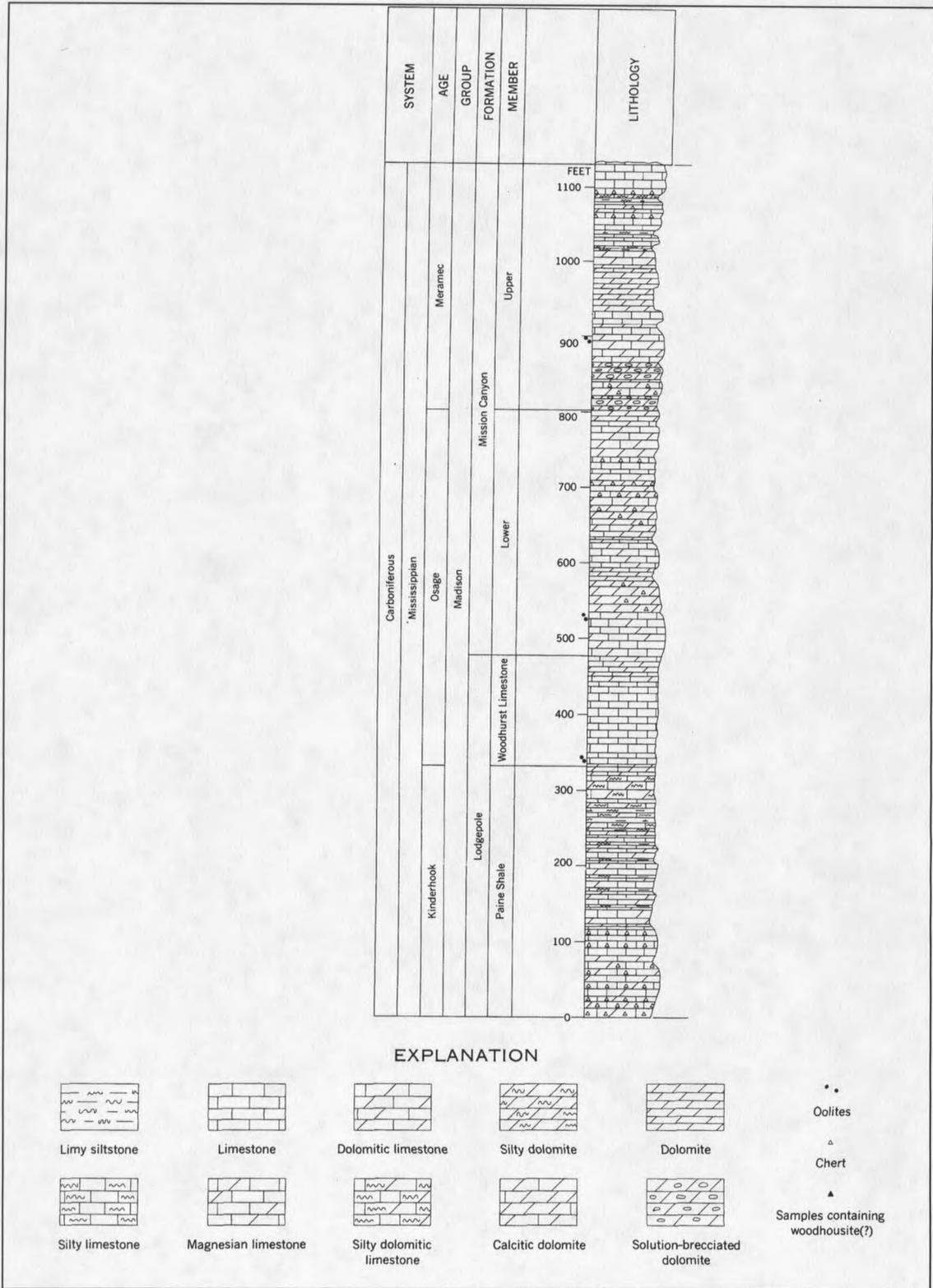


Figure 1-2. Stratigraphic column of the Madison Group, from Roberts (1966).

to erosion and form cliffs and ridges while the dolomites weather more rapidly and create indentations in the profile of the outcrop.

Tectonic Setting for the Deposition of the Madison Group

During the Antler Orogeny in late Devonian and early Mississippian time, a volcanic arc was converging with western North America (Reid and Dorobek, 1989). This created a foreland basin east of the orogenic zone. The foredeep was located in east-central Idaho, and an extension of the foredeep extended into western and central Montana. On the eastern margin of the foredeep, a broad shallow platform developed. The North American continent was positioned so the paleoequator was 5 to 10 degrees south of Montana, thus the area experienced a warm climate. This combination of shallow water and warm climate set the stage for carbonate deposition of the Madison Group rocks (Reid and Dorobek, 1989).

Depositional History

The rocks within the Madison Group were deposited in the Madison Sea during the late Mississippian period (Reid and Dorobek, 1989). Cyclical beds of limestone, dolomite and evaporites represent alternating environments of deep marine and shallow marine, restricted circulation environments. The Antler foreland basin filled with thick deposits of siliciclastic sediments eroding from the Antler highlands, but the western part of the basin was dominated by carbonate deposition. The Lodgepole Limestone was deposited in a subtidal environment on the carbonate ramp (Reid and Dorobek, 1989). This produced thin-bedded, fine to coarse grained, fossiliferous limestones with occasional silty horizons.

The Mission Canyon Formation was deposited conformably above the Lodgepole Limestone in a shallow subtidal to peritidal environment. This setting allowed for subaerial exposure and the precipitation of evaporite minerals (Reid and Dorobek, 1989). Many of the parasequences show a shallowing-upward trend and there is evidence for subaerial exposure during deposition, such as desiccation features, pseudomorphs after evaporite minerals, vadose diagenetic fabrics and cryptalgal laminae. The subaerial exposure was caused by aggradation of the platform deposits and relative drops in sea level (Reid and Dorobek, 1989). These parasequences are regionally correlated. The top of the Mission Canyon Formation represents a regional unconformity that spanned 9 to 14 million years of subaerial exposure (Reid and Dorobek, 1989).

The depositional setting of the Mission Canyon Formation was a gradual inundation of the Wyoming shelf to create a broad and shallow sea (Vice and Utgaard, 1989). Individual microfacies in the Mission Canyon Formation were examined in the northern Bighorn Basin region of Montana and Wyoming, and evidence of subaerial exposure was recognized. Evidence of desiccation and a hypersaline environment include sparse biota with low diversity, bird's eye limestone structures, pseudomorphs after evaporite minerals and cryptalgal laminae. These features were characteristic of supratidal and upper intertidal zones. The hypersaline environment in the supratidal zones on the edge of the platform allowed for precipitation of evaporite facies such as gypsum and anhydrite. These units may become dissolved, leaving large secondary pore spaces. If the voids are large enough, collapse breccias may form (Vice and Utgaard, 1989).

Development of Solution Breccias and Karst Features

The Madison Group is often characterized by the presence of solution breccias and karst features (Sando, 1988). The majority of these features are near the top of the Mission Canyon Formation and its stratigraphic equivalents. The development of these secondary pore spaces has created large voids within the rock, and has increased the permeability of the formation in some cases. There have been at least two episodes of karst development in the Mission Canyon Formation (Sando, 1988). The depositional and post-depositional history of the Mission Canyon Formation has contributed to the formation of karst features and solution breccias and will be discussed below.

Paleokarst. Deposition of Madison sediments ceased during early Meramecian time in the mid-Mississippian (about 345 m.y. BP). The craton was uplifted and sea level fell (Gutschick et al., 1980). The Madison shelf became exposed and was subject to subaerial weathering and the development of karst (Sando, 1988, Roberts, 1966). Many of these caves subsequently collapsed or filled with sediments as the overlying formations were being deposited. Beginning in late Meramecian time the Amsden-Big Snowy transgression began and the Darwin Sandstone member of the Amsden Formation was deposited from west to east in Wyoming. In southwestern Montana the Kibbey Formation of the Big Snowy Group was deposited instead of the Darwin Sandstone. The Kibbey Formation consists of red shale, siltstone, fine sand and small amounts of evaporites. The transgression proceeded from west to east, thus the western portions of the Madison shelf were exposed for a shorter length of time than the areas to the east. It has been estimated that the Madison shelf was exposed for between 9 and 34 million years (Reid and Dorobeck, 1989, Sando, 1988). Sando

(1988) concluded that the karst developed before the deposition of the Amsden Formation because many of the karst features are filled with deposits from the Amsden Formation. These karst fillings appeared to have been deposited as unconsolidated sediments rather than fragments of the overlying formations that collapsed after deposition. The maximum depth of this paleokarst is 60 to 105 meters (200 to 350 feet) below the top of the Mission Canyon Formation (Aram, 1981, Sando, 1988).

Four types of paleokarst features that have been described by Sando (1988) in north-central Wyoming. These are enlarged joints, sinkholes, caves and evaporite solution zones. The enlarged joints are either perpendicular or parallel to the bedding planes and can be up to one foot wide. Enlarged joints are most common in the uppermost 28 meters (93 feet) of the Mission Canyon (or Bull Ridge Member). The enlarged joints were formed by meteoric water passing through fractures in the rock when the Madison was exposed above sea level. Sediments from the Darwin Sandstone member of the Amsden Formation fill the enlarged joints (Sando, 1974).

Sinkholes have been observed in the upper Bull Ridge Member (Mission Canyon equivalent) in Wyoming and may be as much as 15 meters (50 feet) wide and 27 meters (90 feet) deep. The sinkholes have steep sides with nearly parallel walls. The sinkholes formed from solution by meteoric water along fractures. The primary filling of the sinkholes is sand that was deposited during deposition of the overlying Darwin Sandstone. Some of the filling is carbonate and chert breccia from the walls of the sinkholes (Sando, 1974).

Caves are described by Sando (1974) as irregularly shaped solution cavities and were most commonly observed in the Bull Ridge Member to a depth of 60 to 105 meters (200 to 350 feet) below the top of the Madison Group. Many of the caves are tubular and their

shape is strongly controlled by the bedding planes. The cave filling is similar to that found within the sinkholes. There are no flowstones or dripstones within the caves, which suggests that the caves were formed below the vadose zone (Sando, 1988). Some of these paleocaves may have been re-excavated during Tertiary and Holocene time (Sando, 1988).

Two prominent zones of leached evaporites occur in the Mission Canyon Formation in northern Wyoming and Southern Montana. The lithology is brecciated carbonate rock within a matrix of poorly bedded siltstone and shale (Sando, 1974). The origin of the solution zones has been debated in the literature. They have been interpreted as unconformities within the Madison Group (Strickland, 1960), collapse of karst (McCaleb and Wayhan, 1969), or as leaching and collapse of evaporite deposits (Roberts, 1966). The breccias may have formed during the post-Madison, pre-Amsden karst episode or during late Cretaceous or early Tertiary uplift (Sando, 1974).

Miller (1976) describes "lost circulation zones" recorded on drilling logs in the southern and central parts of Montana, indicating areas of high porosity which may be attributed to collapse or solution breccia or karst porosity. Solution breccia features are generally laterally continuous within the rocks and have a clearly defined lower surface and a poorly defined upper surface (Miller, 1976). A laterally continuous solution breccia marks the base of the upper member of the Mission Canyon Formation. Roberts (1966) describes this unit as containing "many cavities ranging from a few inches to several feet wide." This basal unit of solution breccia is observed in several localities where the rocks are exposed at the surface. Below the surface, a unit of anhydrite is present at the same stratigraphic position. Thus it is proposed that the solution breccia was formed by the dissolution of the anhydrite when the unit was exposed at the surface. In addition to the prominent solution

breccia at the base of the upper member of the Mission Canyon Formation, several other solution breccia units were reported by Roberts. Typically the units are from 5 to 6 feet thick (Roberts 1966).

In contrast to the solution zones discussed above, Roberts (1966) described the karst features as laterally discontinuous, with both the upper and lower surfaces poorly defined. Karst topography is present on the upper surfaces of the Mission Canyon Formation. Solution channels and collapsed cavities are filled with material from the overlying Amsden Formation as well as with reworked Mission Canyon Limestone (Roberts, 1966).

Clay mineralogy has also been used to attempt to determine the origins of collapse or solution breccias in the Madison Group. Roberts found that kaolinite was present in some breccias and illite was associated with others. The kaolinite was thought to be attributable to the formation of paleosol during the paleokarst episode, prior to the deposition of the Amsden Formation. Illite has marine origins and may have been derived from the overlying Amsden Formation. Thus the kaolinite-bearing deposits are thought to be representative of paleokarst features while the illite deposits are associated with the dissolution of evaporites (Roberts, 1966, Sando, 1974, Sando, 1988).

While the paleokarst features described in the Madison Group rocks have increased the formation's permeability somewhat, the post-Laramide karst and the Laramide or post-Laramide fracturing impart substantially greater permeability to the aquifer (Huntoon, 1985). This conclusion is based on observations that the paleokarst features are poorly interconnected and that the fillings of the paleokarst cavities are either fine-grained or well cemented. Moreover, springs discharging from paleokarst features have not been documented (Huntoon, 1985).

Post-Laramide Karst. Tectonic stresses during the Laramide Orogeny created faults, fractures and folds in the Madison Group rocks in western Montana and Wyoming. The secondary porosity created by the Laramide deformation of the rocks has allowed for infiltration of groundwater and channeling of water through the formation, thus increasing the permeability of the aquifer and promoting dissolution of the carbonates and the development of more recent karst features in the Madison aquifer. Huntoon (1993) attributes the largest permeabilities in the Madison aquifer to be associated with modern karst that has developed on the flanks of mountain ranges or with the extensional fractures along the crests of anticlines.

Lewis and Clark Caverns is an outstanding example of the development of post-Laramide karst within the Madison Group. Some of the large rooms in Lewis and Clark Caverns formed along the axis of an anticline, where fracturing was most prominent (Figure 1-3; Aram, 1981). The fractures allowed for high permeability and dissolution of the limestone along the hinge line. Fractures also weakened the ceilings of the rooms, causing boulders to fall from the ceiling. Faulting too, contributed to the development of the karst. Many of the cave passages have developed along intersections of bedding planes and faults (Aram, 1981).

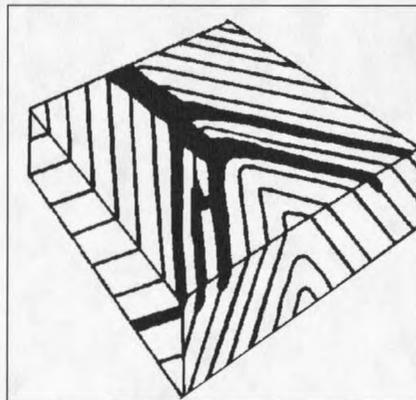


Figure 1-3. Schematic diagram of Lewis and Clark Caverns (from Aram, 1981).

Lewis and Clark Caverns developed within the Mission Canyon Formation, as is the case with most caves in Montana. The Mission Canyon Formation contains only 1 to 6% insoluble material, compared to up to 25% insoluble material in the Lodgepole Limestone (Aram, 1981). The thick beds of the Mission Canyon Formation also help to concentrate groundwater along the bedding planes, creating large conduits in thick beds where the limestone was removed by dissolution.

Regional Hydrology of the Madison Aquifer

Some authors consider the Madison aquifer to be comprised of the Mississippian Madison Group, the Ordovician Bighorn Dolomite and the Devonian Jefferson Dolomite, which are interconnected by fractures that cross-cut the formations (Huntoon, 1976). However, in this research, the Madison aquifer is considered only to be the Madison Group rocks with particular focus on the Mission Canyon Limestone because that is where the post-Laramide karst is most prevalent.

The Madison aquifer is part of the Northern Great Plains regional aquifer system (Figure 1-4). The U.S. Geological Survey has recognized five major subdivisions of the aquifer system. They are the Cambrian-Ordovician, the Madison, Pennsylvanian, Lower Cretaceous and Upper Cretaceous aquifers (Downey, 1984). Collectively, these aquifers make up one of the largest confined aquifer systems in the United States. Regional flow is generally from west to east, with recharge areas in the mountainous areas of Montana, Wyoming and western South Dakota, and discharge areas in the eastern Dakotas and Manitoba, Canada. The aerial extent of this aquifer system is 300,000 square miles (Downey, 1984).

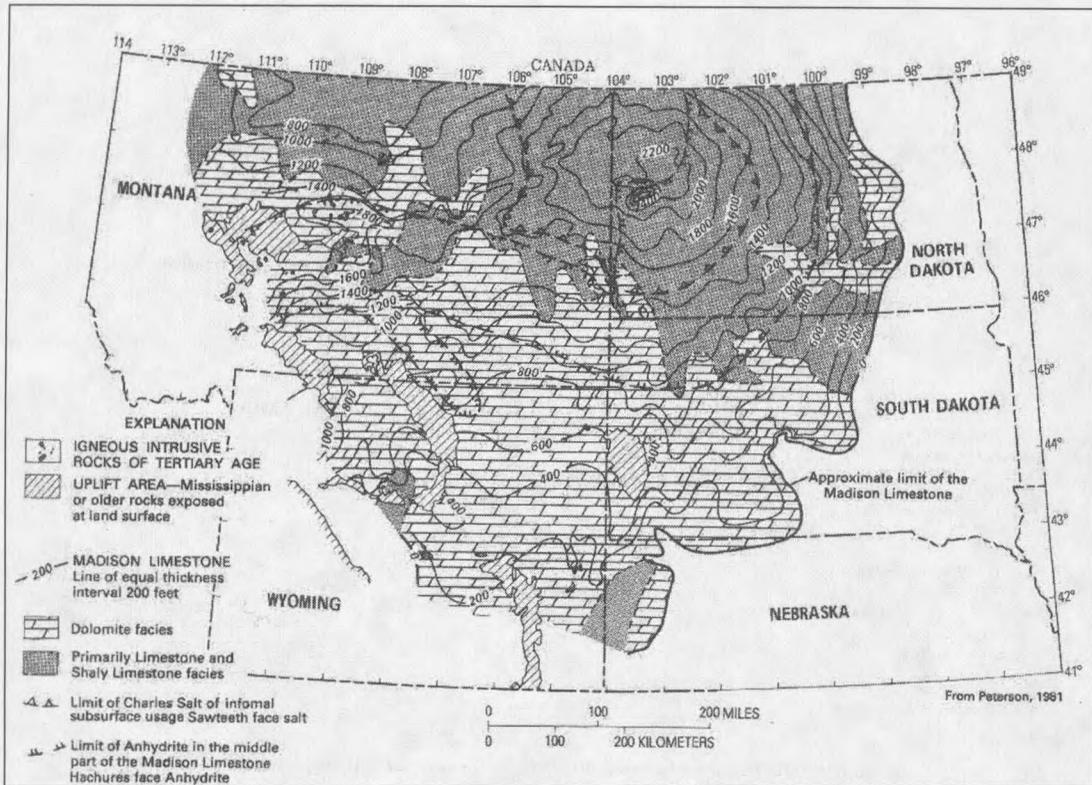


Figure 1-3. Thickness and lithology of the Madison aquifer in the Northern Great Plains (from Downey, 1984).

The hydrologic properties of the Madison Group rocks in southeastern Montana were studied by Miller in 1976. The purpose of this study was to assess the potential for using the Madison aquifer as a water supply for the processing of coal from the Fort Union coal beds in southeastern Montana. Miller reported four types of voids that create high porosity within Madison Group rocks.

- 1) Primary pores between individual grains.
- 2) Dolomite porosity caused by the diagenesis of limestone to dolomite, which decreases the rock volume and thus increases the pore volume.
- 3) Fracturing induced by folding or faulting.
- 4) Dissolution of carbonate or evaporite rocks.

Similarly, Huntoon (1985) lists the two important types of secondary porosities as (1) the enlargement of pore spaces through solution and (2) the fracturing along foreland basin perimeters associated with the uplift of the mountain ranges.

In most localities, water within the Madison aquifer was reported to be under artesian pressure, causing flowing wells in most areas of eastern Montana (Miller, 1976). The aquifer is unconfined in places where it outcrops on the surface. The potentiometric surface ranges from 300 meters (1,000 feet) above the land surface near the Yellowstone River, to 365 meters (1,200 feet) below the land surface in topographically high areas in southern Montana. Reported well yields range from 0.003 m³/sec to 0.09 m³/sec (50 gallons per minute to 1,400 gallons per minute) from a flowing artesian well on the flank of the Porcupine Dome. Transmissivities estimated from drill stem tests range from 500 m²/day to 0.001 m²/day (5,400 ft³/day/ft to 0.01 ft³/day/ft) (Miller, 1976).

Huntoon (1993) reports that the permeability of the Madison aquifer is not uniform throughout the uplifted mountain ranges and foreland basins of Wyoming. The greatest permeabilities were reported in the recharge areas near the flanks of mountain ranges. This permeability is due to the fracturing of the rocks associated with their uplift and to the development of post-Laramide karst in the exposed sections of Madison rock. Within the foreland basins, the permeability of the formation has been shown to decrease sharply due to recrystallization, cementation and compaction (Huntoon, 1985). Recharge water that enters the aquifer in the mountains has been observed to discharge from the aquifer at the toe of the range and does not enter the confined aquifer within the basin. Where the ranges are severed by faults at their margins, the faults do not allow for transmission of groundwater into the basin (Huntoon, 1993, Huntoon, 1985).

Groundwater circulation through karst is also discussed by Mills (1981). According to Mills, karst develops along fractures and bedding planes in foreland uplifts where the Madison aquifer outcrops and recharges. Groundwater flow is rapid and does not typically reach the basinal portion of the aquifer. Instead, most of the groundwater is discharged from springs that are commonly found at the lowest elevation of the Madison aquifer along the mountain front. Mills found that groundwater can travel more than 3 miles per day in these foreland karstic aquifers, with flow directions that are different from surface water drainage patterns. Discharge from karstic springs is continuous throughout the year but increases during the late spring and early summer as the snowpack melts. These flows can be large enough to sustain agricultural and municipal water users near the foreland ranges (Mills, 1981).

Recharge to the Madison Aquifer

Recharge for the Madison aquifer is provided by streams that cross the outcrop areas, and by infiltration within the interstream areas of the outcrops (Miller, 1976). Unknown amounts of recharge also occur from subsurface leakage from overlying and underlying formations or through fractures and faults. Discharge is via springs, gaining streams, leakage through adjacent formations, and pumping wells (Miller, 1976).

Feltis and Shields (1982) measured stream losses where selected streams cross the Madison Group rocks in the Little Belt and Big Snowy Mountains of Montana. They determined the amount of stream losses by establishing long-term gauging stations and also by doing instantaneous measurements during various times of the year. The study indicated that nearly every reach of stream that flowed across the Madison aquifer lost water. At several streams there was no flow at the downstream gauging station because all of the water

from the stream had drained into the Madison aquifer. Stream losses ranged from 0.22 m³/sec (7.6 cfs) on the South Fork Judith River to as much as 1.8 m³/sec (64 cfs) in Dry Wolf Creek. The stream losses were generally greatest in the spring (Feltis and Shields, 1982).

Stream loss was the major source of recharge to the Madison aquifer in the Black Hills of South Dakota (Greene, 1997). Stream losses were greatest in the spring, and there appeared to be a maximum, or 'cap' on the amount of stream loss that was associated with each of the streams measured. Even during times of peak stream discharge the stream losses did not exceed the maximum loss. Presumably this maximum loss is determined by the permeability of the aquifer. Isotopic analysis of hydrogen and oxygen was performed to trace the contributions from losing streams to discharge points such as wells and springs. This analysis indicated that there was significant lateral migration of groundwater beneath adjacent surface water drainage basins (Greene, 1997).

Sinking streams have also been documented by Huntoon (1985) along the eastern perimeter of the Bighorn Basin where streams flow from Precambrian highlands onto the Madison aquifer. This water discharges from the aquifer at the toe of the recharge area, via springs and gaining reaches of streams. Some of the water lost from the streams was found to migrate beneath topographic divides and discharge into streams in an adjacent drainage basin (Huntoon, 1985).

Study Area Description

General

The study area is the drainage basin of Sourdough Creek from the headwaters to a point approximately 8 km (5 miles) downstream from Mystic Lake (Figure 1-1). The study area covers approximately 40 square kilometers (25 square miles) and ranges in elevation from 1722 meters to 2664 meters (5650 feet to 8740 feet). The study area lies within the Gallatin National Forest, with 7 sections of land owned entirely or partially by the City of Bozeman (Figure 1-1). These are sections 27 and 35 in T3S, R6E; the southern half of section 31 in T3S, R7E; section 1 of T4S, R6E; sections 5, 7 and the NW $\frac{1}{4}$ of section 17 in T4S, R7E.

Hydrology

Three major streams flow within the study area. Sourdough Creek drains Mystic Lake near its headwaters and flows southwest for 1.6 km (1 mile) before bending to the northwest and flowing down Sourdough Canyon. Sourdough Creek is also called Bozeman Creek. The South Fork of Sourdough Creek drains the southern portion of the study area and joins Sourdough Creek 1.3 km (0.8 miles) downstream from Mystic Lake. The Disappearing Stream is a tributary to the South Fork of Sourdough Creek and generally flows only in its upstream portion; the downstream portion of the Disappearing Stream is dry.

A major spring is located in the study area, and has been named Two Springs (Figure 1-1). The springs are located on the southeast bank of Sourdough Creek, 0.6 km (0.35 miles)

downstream from Mystic Lake at an elevation of 1887 meters (6190 feet). Two Springs consists of two individual discharge points emanating from the Lodgepole Limestone. The two components of Two Springs have been named Upper Spring and Lower Spring.

Three minor springs were seen within the study area. There is a spring discharging from volcanoclastic landslide debris adjacent to Sourdough Creek approximately 130 meters (400 feet) upstream from Two Springs. There are two ephemeral springs along the South Fork, both of which appeared to be discharging from surficial deposits adjacent to the creek.

Geology

The geology of the study area consists primarily of folded Paleozoic and Mesozoic rocks (Roberts, 1964). The folds plunge gently to the southeast. A large anticline is located in the center of the study area, with the South Fork of Sourdough Creek flowing along its axis. Precambrian gneisses outcrop within the study area along Sourdough Creek approximately 1.6 km (1 mile) downstream from Mystic Lake. Eocene volcanic rocks overlie Mesozoic sedimentary rocks in the southeast portion of the study area, forming the high peaks of the Gallatin Range. Volcanic breccias and unconsolidated volcanic deposits overlie much of the area in the headwaters of the South Fork of Sourdough Creek. An extensive Quaternary landslide deposit forms the eastern edge of Mystic Lake. The original geologic mapping of the area was done by Roberts in 1958, and was published in 1964 as part of an 8-quadrangle study of the region.

METHODS

Forest Service Permits

The field research was conducted within the Gallatin National Forest and was authorized under Special Use Permit # BOZ5556. The permit granted permission to collect water and rock samples, and allowed for motorized use of Bozeman Creek Road on weekdays, prior to 4:00 pm. Motor vehicle use was not permitted during rifle hunting season or when the road was wet.

Geologic Mapping

Geologic field mapping was carried out in selected locations within the field area. This was done in order to provide structural data for the construction of geologic cross sections. Rock formations from the Precambrian through the Jurassic Ellis Group were mapped in a 15.5 square kilometer (6 square mile) area centered on the South Fork drainage. This area was selected because it had the largest extent of Madison Group exposures within the study area. Mapping was performed by identifying rock formations, locating contacts between rock units and measuring strike and dip angles. The stratigraphy and formation names from Roberts' 1964 map were used on the new geologic map created in this study. During the course of the mapping, information from 224 individual sites was recorded and 160 strike and dip measurements were taken. Aerial photos, topographic maps and a global positioning system unit were used to identify field locations. This work took place in June and July of 2001.

Thin Sections

Thin sections of rock samples from the Madison Group were examined to determine their lithology and porosity. A sample from the Mission Canyon Formation at Bozeman Pass was included to compare the rocks in the study area to the highly karstic rocks observed at Bozeman Pass. Eight samples from the Madison Group (5, 90, 93, 94, 95F, 95 NF, 103, 103B) were selected to represent a vertical section of the Madison Group, from the Lodgepole Limestone to the top of the Mission Canyon Formation. Samples 95 F and 95 NF were taken from the same outcrop, but unit 95 F was highly fractured, while unit 95 NF had only minor fracturing. Samples 103 and 103B were both collected from the upper Mission Canyon Formation, but sample 103 was slightly brecciated while 103 B was highly brecciated. A sample from the Lodgepole Limestone at Two Springs was also included to determine the porosity and lithology at the springs. For sample locations, please refer to Appendix A.

Thin sections from 10 different rock samples were prepared by Wagner Petrographic in Salt Lake City, UT. Each thin section was impregnated with blue epoxy to show the pore spaces within the rock. A red calcite stain and a blue iron/magnesium stain were applied to each sample to aid in mineral identification. The mineral content and the percentage of porosity of each sample were determined visually with a petrographic microscope.

Stream Discharge Measurements

The stream discharge of Sourdough Creek and the South Fork of Sourdough Creek was measured three times during the study. Stream discharge measurements were performed according to the velocity-area method (Dingman, 1994). Measurements were

taken using a Marsh-McBirney Flo-Mate Model 2000 portable flow meter with a top-setting wading rod. The criteria for selection of stream discharge measurement sites were safe access to the stream, a relatively straight reach of the stream with little observable backflow, and stream banks that were not undercut. The flow meter measured velocity readings averaged over a 30 second interval. The water velocity was measured at 0.6 of the total water depth, measured from the top of the water surface. Readings of depth and velocity were taken at horizontal intervals between 0.03 and 0.12 meters (0.1 and 0.4 feet). Readings were taken closer together in areas where the flow was faster or the water was deeper. Typically 30 to 60 readings were taken for each stream discharge measurement.

In order to determine the repeatability of manual stream flow measurements, three successive measurements were made in the same location on the same day. This was performed on October 17, 2000 at the South Fork of Sourdough Creek. The results of the reproducibility measurements are in Table 2-1. The measurement error was determined by dividing the standard deviation by the average, and multiplying by 100, yielding +/- 6.4 %.

Table 2-1. Stream discharge reproducibility measurements.

	Discharge (m ³ /sec)
1 st Measurement	0.065
2 nd Measurement	0.060
3 rd Measurement	0.057
Average	0.061
Standard Deviation	0.0039
Measurement Error = +/- 6.4%	

Stream Gain/Loss Measurements

One method to estimate recharge into the Madison aquifer is to measure stream losses. A stream loss is the amount of water that is being drained from a stream into its stream bed over a given reach. Where the stream channel is bedrock or covered by only a thin layer of alluvium, it is likely that the water lost from the stream is recharging the aquifer below. Stream losses are a common occurrence on the Madison aquifer and have been used as an estimate of recharge to the Madison aquifer by Feltis and Shields (1982) and Greene (1997).

There are three locations within the study area where streams flow across the Madison Group rocks: at Sourdough Creek, the South Fork and the Disappearing Stream. Stream losses were measured at two locations outside the study area, at Hyalite Creek and at Bear Creek (Figure 1-1).

Stream loss measurements on Sourdough Creek and the South Fork were made in July 2000, October 2000 and May 2001 in order to identify seasonal changes. The location where the creek flowed across the upper Mission Canyon Formation was located and a suitable stream gauging location was selected within 20 meters (65 feet) downstream from the contact. The stream discharge was measured. Working in a downstream direction, the discharge of each tributary to the creek was measured in a location slightly upstream from where the tributary joined the main creek. On Sourdough Creek the only tributary was Two Springs. On the South Fork there were two flowing tributaries and one dry tributary. The dry tributary was observed to be losing all of its water into the Madison Group rocks prior to flowing into the South Fork. The stream losses in this tributary were estimated by recording the time it took to fill a one-liter bottle because the channel was too small to be

measured by the velocity-area method. Lastly, a downstream discharge measurement was taken at the lower Lodgepole Limestone contact. The discharge measurement was taken at a suitable location slightly upstream from the contact, thus all discharge measurements were taken within the Madison Group. The downstream discharge measurement was subtracted from the sum of the upstream measurement plus the tributaries. The resulting number was the stream loss or gain.

In the case of the Disappearing Stream (Figure 1-1), the creek lost all of its water. Hence the stream loss measurement consisted only of the stream discharge at the upper Madison Formation contact. There were no tributaries to the Disappearing Stream. The location where the stream flow ceased was noted on a topographic map. The Disappearing Stream was measured in July 2000, August 2000, May 2001 and July 2001.

Bear Creek and Hyalite Creek, which are outside the study area, were also gauged. At Bear Creek the stream was measured at the upstream and downstream contacts of the Madison Group, and there were no tributaries along this reach. At Hyalite Creek, the discharge was measured at the upstream Madison contact and at the contact of the Madison Group and a large alluvial deposit. The downstream Madison contact could not be located because it was covered by the alluvial deposit. There were no tributaries along this reach.

Stream loss measurements typically took an entire day for each stream, during which evapotranspiration was also occurring. Evapotranspirative losses were estimated from a flume on the South Fork (Figure 1-1). The stage of the water in the flume was manually read in the morning and in the afternoon of each day of field work. This provided for an average stream loss during the day, presumably due to evapotranspiration.

Spring Location

Each of the major drainages within the study area was visited to check for the presence of springs discharging from Madison Group rocks. Possible locations for springs were in areas where the Madison Group outcropped at low elevations, such as along stream channels. These areas were checked by hiking the length of each of the stream channels that cross Madison Group rocks. The areas around faults mapped by Roberts (1964) were also checked for the presence of springs.

Spring Temperature Measurements

The water temperature of Two Springs was measured several times throughout the study. A VWR Scientific Digital Thermometer 500 was used for all the measurements. The measurements were made at the orifices of both the upper spring and the lower spring.

Spring Discharge Measurements

Manual Measurements

Two Springs discharges from two orifices, the Upper Spring and the Lower Spring. Water flows away from each spring as a small creek. The two creeks join and flow together for approximately 2 meters (6 feet), then discharge into Sourdough Creek. Measurements of the spring discharge were made at the point where the two spring creeks join. Spring discharge measurements were made several times throughout the study to determine the seasonal fluctuations in flow. The discharge measurements were performed as described previously. The ground around Two Springs was saturated and water was also discharging

from the springs directly into Sourdough Creek via shallow groundwater flow. This flow could not be measured and was not accounted for in the discharge measurements. Thus, the actual spring discharge is likely greater than the discharge measurements.

Data Logger Measurements

A stilling well and data logger were used to provide continuous measurements of the stage of Two Springs. The stilling well was located at the confluence of the two small creeks flowing from Upper and Lower Springs. A small hole was dug at the edge of the creek, and the stilling well was anchored within this hole. The stilling well consisted of a 3.2 cm (1.25 inch) diameter, schedule 40 PVC vertical pipe with a 1.3 cm (0.5 inch) diameter horizontal pipe attached to it (Figure 2-1). The horizontal pipe was perforated with 0.95 cm (3/8 inch) diameter holes to allow water to enter the pipe.

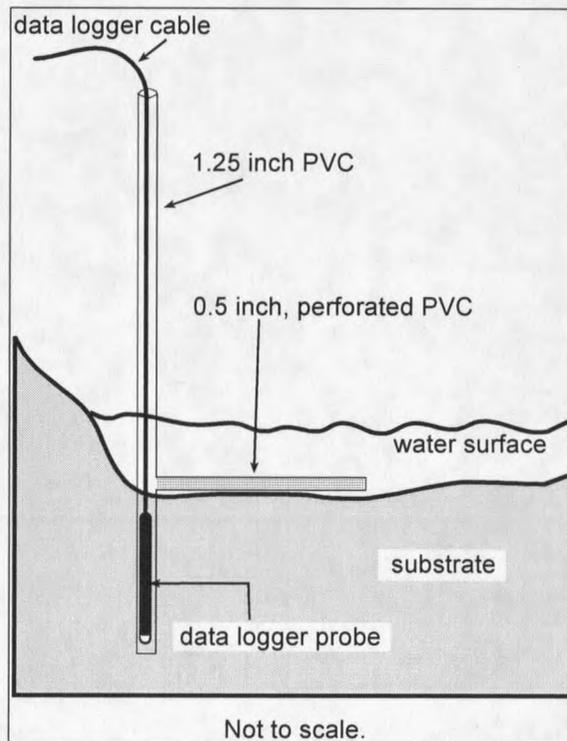


Figure 2-1. Stilling well schematic.

On July 27, 2000 the stilling well was installed at the confluence of the two discharge channels flowing from Two Springs. The horizontal pipe was positioned so that it lay on the bottom of the creek bed. A steel fencepost was driven into the ground adjacent to the stilling well and the stilling well was fixed to the fencepost with copper wire. A meter stick was attached to the stilling well to provide a means to read the stage of the creek manually.

On July 28, 2000 a Global Water WL-14 data logger was deployed inside the stilling well. The probe of the data logger was inserted into the stilling well so that it was below the bottom of the channel. The sampling interval was set so that the data logger took a water level reading every 15 minutes. Downloading the data logger proved to be problematic, so the data logger was removed for data retrieval on August 7, 2000. The data logger was reinstalled on August 21, 2000 and was set for a sampling interval of 20 minutes. The batteries failed on September 19, 2000 and a short circuit was suspected so the data logger was removed again and sent back to the manufacturer for service. On October 19, 2000 the data logger was reinstalled and was set for a one-hour sampling interval. The data logger remained in service for the duration of the project.

On October 10, 2001 the data logger was removed from the stilling well and the stilling well was dismantled. All components of the stilling well were removed so no visible impact remained at the spring.

Water Sampling

Major Ions

Samples were collected from Two Springs on April 29, 2001 and October 1, 2001 for analysis of calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate, carbonate,

specific conductance, total dissolved solids and pH. A sample was taken from both the Upper Spring and the Lower Spring. The samples were collected in 500 ml polyethylene bottles with no filtering and no preservatives added, according to the protocol specified by Energy Laboratories, Inc. The samples were kept cold and shipped on ice to Energy Laboratories in Billings, MT within 24 hours of sample collection.

Tritium

Tritium is a radioactive isotope of hydrogen that decays at a known rate and thus can be used for dating water. Samples were collected from Two Springs on April 29, 2001 for analysis of tritium. One sample was obtained from the Upper Spring and one from the Lower Spring. Samples were collected in one-liter polyethylene bottles with no filtering and no preservatives added. The samples were obtained by holding the sample bottle directly under the spring discharge, as close to the orifice as possible. The sampler did not carry or wear a wristwatch or a compass with a luminescent dial, which can create artificially high tritium concentrations.

A sample of snow at Two Springs was also collected for tritium analysis, to provide a baseline tritium value for winter precipitation. A column of snow was cut from the wall of a snow pit to obtain a vertically integrated sample from the snow surface to the ground. The snow was placed in two one-gallon plastic bags for transportation. The following day, the melted snow was poured into a one-liter sample bottle. The transfer of snowmelt from the plastic bags to the bottle was done outdoors to prevent mixing with indoor air, which may have a higher tritium concentration due to the presence of luminescent dials. The sampling protocol was provided by the Tritium Laboratory at the University of Miami Rosenstiel

School. The samples were shipped via UPS within 24 hours of sample collection to the Tritium Laboratory at the University of Miami Rosenstiel School, where the analyses were performed on June 26, 2001.

Drinking Water Quality

Water samples for water quality analyses were collected from Two Springs on October 1, 2001. The sampling protocol recommended by Energy Laboratories, Inc. was followed and all sample bottles and preservatives were provided by the laboratory. All samples were collected from the lower spring of Two Springs.

One sample was collected in a 500 ml plastic bottle for analyses of potassium, sodium, calcium, magnesium, sulfate, chloride, total dissolved solids, alkalinity, conductivity, pH, nitrate plus nitrite, total iron, fluoride and turbidity. No preservatives were added to this sample. One sample was collected in a 250 ml plastic bottle for analysis of antimony, arsenic, barium, beryllium, cadmium, chromium, mercury, nickel, selenium, thallium, lead and copper. This sample was filtered with 0.45-micron filter paper and was preserved with nitric acid. One sample was collected for coliform bacteria analysis in a sterile container with powdered sodium thiosulfate that had been provided by the laboratory. All samples were packed in a cooler with ice and were shipped on October 1, 2001 via UPS to Energy Laboratories in Billings, Montana.

A water sample for cryptosporidia and giardia analysis was collected on October 10, 2001. The sample was collected from the upper spring of Two Springs in a 20-liter plastic jug. No preservatives were added. The water sample was delivered to Montana Microbiological Services in Bozeman, MT on the same day.

Water Rights

A survey of communities in Montana that use Madison aquifer water for their municipal water supplies was performed in April and May of 2001. Tom Patton, Director of the Groundwater Information Center of the Montana Bureau of Mines and Geology identified the known municipal users of Madison aquifer water within Montana. Telephone interviews were conducted with water system operators or City Clerks with knowledge of the community water system. The following issues were discussed with each person:

- Population served by the water supply
- Well depth
- Flow rate of well or spring
- Fluctuations in flow rate or water level
- General water quality and water treatment
- Water rights.

Water analysis reports were obtained from personnel at Giant Springs and Big Springs in order to provide a comparison of spring waters from the Madison aquifer.

Scott Compton, Regional Manager of the Montana Department of Natural Resources Conservation, was consulted regarding potential water rights conflicts if Madison aquifer water from the Sourdough drainage were used for the Bozeman public water supply.

RESULTS

Geologic Mapping

The geology of area around the Sourdough Creek anticline was mapped in order to observe the lithologic features of the Madison Group rocks, to gather structural data of the area, and to confirm or redraw the formation contacts on the existing geologic map by Roberts (1964). Plate 1 is a geologic map which integrates the results of the mapping. The primary area that was mapped was the drainage basin of the South Fork and the Disappearing Stream. This area was mapped because it contained the largest area of Madison Group bedrock on Roberts' map, because Roberts' map provided few strikes and dips, and because the contacts for the Madison Group were believed to potentially be inaccurate. A table of all data compiled during geologic mapping is presented in Appendix A.

Outcrop exposure in the study area was generally poor. There is extensive tree cover and colluvial cover over most of the study area, making it difficult to find outcrops. Near the headwaters of the South Fork, surficial deposits cover the bedrock. These factors made it difficult to trace the contacts over long distances. Thus, the contacts are dashed where their locations are uncertain.

Thin Sections

Thin sections of rock samples from the Madison Group were examined to determine their lithology and porosity. Rock samples were selected to represent a vertical section of the Madison Group. A sample from the Lodgepole Limestone at Two Springs was selected

to determine the porosity and lithology at the springs. One sample from the Mission Canyon Formation at Bozeman Pass was also included to provide a comparison to the rocks in the study area. For sample locations, please refer to Appendix A.

Two types of porosity were recorded for each sample (Table 3-1). Dolomite porosity was characterized by intercrystalline pore spaces with angular boundaries. Fractures were linear voids that cut across many grains. The small scale of the thin sections precluded the measurement of large-scale fracturing. Thus the thin sections were primarily used to measure dolomite porosity, while visual estimates of the fracture intensity were made on the outcrops.

Table 3-1. Comparison of lithology and porosity from thin sections.

Sample Location	Formation	% Calcite	% Dolomite	% Other	% Dolomite Porosity	% Fracture Porosity	% Total Porosity
Bozeman Pass	Mission Canyon	15	85	0	5	2	7
Two Springs	Lodgepole	39	60	1 (clay)	0	0	0
5	Lodgepole	50	50	0	0	0	0
90	Mission Canyon	5	94	1 (clay)	7	1	8
93	Mission Canyon	0	95	5 (quartz)	1	0	0
94	Mission Canyon	0	100	0	2	3	5
95 F (fractured)	Mission Canyon	0	100	0	2	15	17
95 NF (not fractured)	Mission Canyon	0	100	0	1	0	1
103	Mission Canyon	0	99	1 (quartz)	1	5	6
103 B (breccia)	Mission Canyon	0	75	25 (quartz)	0	1	1

Stream Gains and Losses

Stream discharges were measured where streams flow across the Madison Group in order to determine whether the streams were gaining water from the Madison aquifer or losing water to the Madison aquifer. This helped define areas where groundwater was recharging to or discharging from the aquifer. These measurements were performed on Sourdough Creek, the South Fork, the Disappearing Stream, Hyalite Creek and Bear Creek. Figure 3-1 shows the locations of the stream discharge measurements.

Sourdough Creek

Sourdough Creek was gauged at the upstream and downstream Madison contacts. Two Springs flows into Sourdough Creek between these measuring points, so the discharge of Two Springs was gauged as well. The results of the stream discharge measurements for Sourdough Creek are given in Table 3-2 below. Spreadsheet calculations for each stream discharge measurement are provided in Appendix B.

Table 3-2. Sourdough Creek stream losses.

Date	Upstream Madison Contact (m ³ /sec)	Two Springs (m ³ /sec)	Downstream Madison Contact (m ³ /sec)	Stream Loss		
				(m ³ /sec)	(cfs)	%
July 11, 2000	0.16	0.09	0.22	0.03	1.2	13.9
Oct. 10, 2000	0.14	0.02	0.09	0.07	2.3	40.3
May 23, 2001	0.37	0.10	0.43	0.04	1.5	9.0

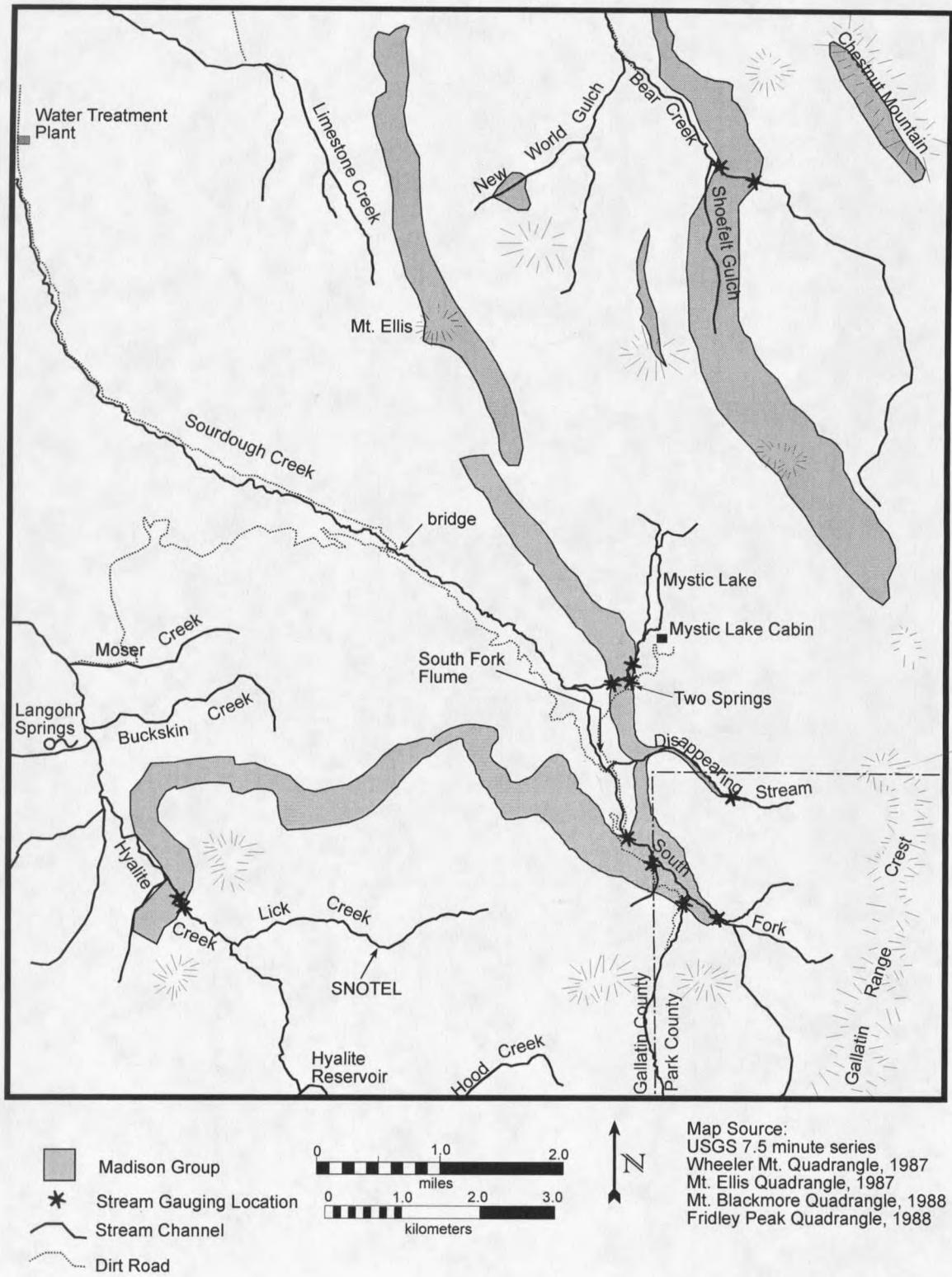


Figure 3-1. Locations of stream discharge measurements.

The South Fork

The stream discharge of the South Fork was measured at the upstream and downstream Madison contacts. The discharges of two tributary streams were also measured. The results from the stream discharge measurements are shown in Table 3-3. During the May 2001 stream discharge measurements, two ephemeral springs were found discharging near the banks of the South Fork. The combined discharge of these springs was estimated to be 0.02 m³/sec. One of the tributaries to the South Fork was dry where the tributary flowed into the South Fork, but it was flowing at the upstream Madison contact. The estimated discharge of this tributary was 0.0003 m³/sec (0.01 cfs). These numbers are not reflected in the stream losses in Table 3-3.

Table 3-3. South Fork stream losses.

Date	Upstream Madison Contact (m ³ /sec)	First Tributary (m ³ /sec)	Second Tributary (m ³ /sec)	Downstream Madison Contact (m ³ /sec)	Stream Loss		
					(m ³ /sec)	(cfs)	%
July 14, 2000	0.06	0.07	0.01	0.13	0.01	0.4	7.8
Oct. 3, 2000	0.03	0.04	0.002	0.06	0.01	0.6	21.1
May 25, 2001	0.13	0.12	0.01	0.25	0.01	0.5	5.8

The Disappearing Stream

The results for the stream discharge measurements on the Disappearing Stream are shown in Table 3-4. The Disappearing Stream lost all of its water as it flowed across the Madison Group rocks, so the stream discharge at the upstream measuring point was equal to the stream loss.

Table 3-4. Disappearing Stream losses.

Date	Upstream Madison Contact (m ³ /sec)	Downstream Madison Contact (m ³ /sec)	Stream Loss		
			(m ³ /sec)	(cfs)	%
July 25, 2000	0.03	0	0.03	1.0	100
Aug. 18, 2000	0.02	0	0.02	0.6	100
May 31, 2001	0.06	0	0.06	2.0	100
July 19, 2001	0.03	0	0.03	1.1	100

Bear Creek

The discharge of Bear Creek was measured at the upstream and downstream contacts of the Madison Group. In this location Bear Creek intersects the Madison Group at the crest of the Bear Creek anticline, so both of the Madison contacts are the upper Madison contact. The results of stream gauging are shown in Table 3-5 below.

Table 3-5. Bear Creek stream discharges.

Upstream Madison Contact (m ³ /sec)	Downstream Madison Contact (m ³ /sec)	Stream Loss		
		(m ³ /sec)	(cfs)	%
0.044	0.037	0.007	0.24	15.3

Hyalite Creek

The discharge of Hyalite Creek was measured at the upper Madison contact, but the lower Madison contact was obscured by a large alluvial deposit. Therefore the downstream

gauging point was not the lower Madison contact, rather it was the point at which the Madison became covered by alluvium. Table 3-6 provides the stream discharge results for Hyalite Creek.

Table 3-6. Hyalite Creek stream discharges.

Upstream Madison Contact (m ³ /sec)	Downstream Gauging Location (m ³ /sec)	Stream Gain		
		(m ³ /sec)	(cfs)	%
0.78	0.82	0.04	1.4	5.0

Spring Discharge

The discharge of Two Springs was determined by manual discharge measurements as well as by stage recordings with a data logger. The results yielded by each method are given separately.

Manual Measurement of Spring Discharge and Water Temperature

When Two Springs was visited during field work, the spring discharge was measured manually, the water temperature was measured and the stage was recorded. The stage was determined with a meter stick attached to the outside of the stilling well. The ruler was positioned so that the 14 cm mark was at the bottom of the channel. Thus a ruler stage of 14 cm would represent zero discharge. The results of these measurements are given in Table 3-7 below.

Table 3-7. Summary of measured discharge, stage and temperature at Two Springs.

Date	Discharge		Ruler Stage (cm)	Temp. (C)
	(m ³ /sec)	(cfs)		
11-Jul-00	0.09	3.1	NM	NM
18-Jul-00	0.06	2.2	NM	NM
28-Jul-00	0.04	1.3	20	4.4
7-Aug-00	0.04	1.4	18.75	4.5
21-Aug-00	0.03	1.2	18.5	4.5
10-Oct-00	0.02	0.8	18	4.3
29-Apr-01	NM	NM	21.75	3.4
23-May-01	0.10	3.6	22.25	3.4
24-Jul-01	0.05	1.9	19.5	4.3
01-Oct. 01	0.02	0.8	17.5	4.4
10-Oct-01	NM	NM	17.2	4.3

NM – Not measured.

Data Logger Stage Measurements

A data logger was installed at Two Springs to provide a continuous record of the stage of the springs. The data logger record begins in July 2000 and goes through October 2001, with two gaps in the data due to equipment malfunctions. The stage measurements as recorded by the data logger are plotted in Figure 3-2. The average discharge from Two Springs between October 2000 and October 2001 was 0.035 m³/sec (1.23 cfs), and the total discharge over that same period was 1,100,000 m³/yr (900 acre-feet/yr). The complete data set is provided in Appendix C.

Comparison of Stage Measurements with Weather

Data from a SNOTEL site located near Lick Creek was used to provide daily precipitation and average daily temperature in the area (http://mt.nrcs.usda.gov/swcs/snow/table_mt.html). This allowed for the correlation of changes in the spring stage with local weather events. The Lick Creek SNOTEL site is approximately 5 km (3 miles) from Two Springs and is shown on Figure 3-1. The Lick Creek site is at an elevation of 2090 meters (6860 feet), while Two Springs is at an elevation of 1890 meters (6190 feet). Due to the proximity of the SNOTEL site to the springs, it is reasonable to assume that the temperature and precipitation of the SNOTEL site are similar to the conditions experienced at Two Springs. Temperature and precipitation at Lick Creek are plotted in Figure 3-3, and the complete data set is provided in Appendix D.

Spring Water Chemistry

Major Ions

Water from Two Springs was sampled for major ion analysis during the spring and fall of 2001. The results from these analyses are summarized in Table 3-8. Laboratory analytical reports can be found in Appendix E.

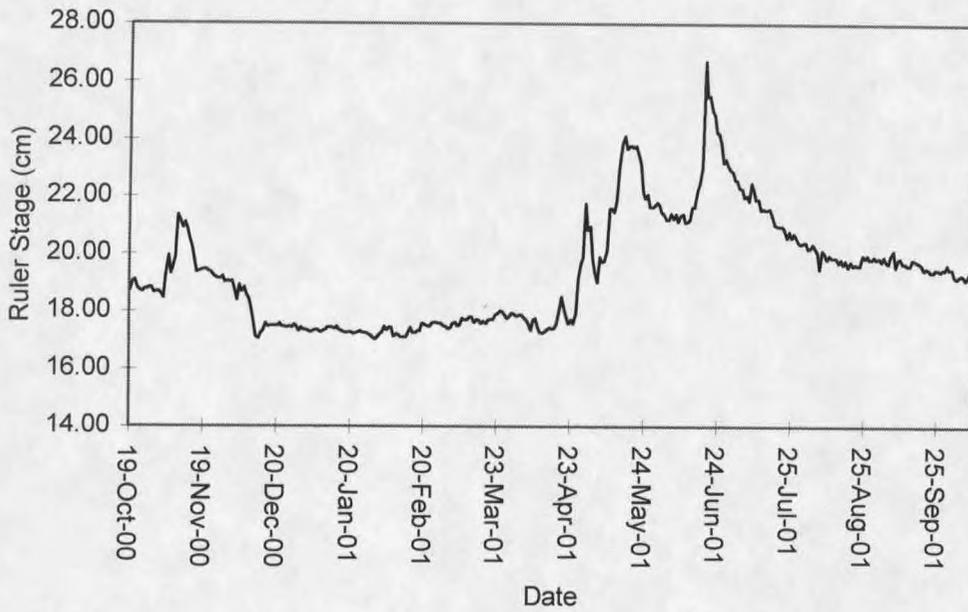


Figure 3-2. Stage of Two Springs as recorded by data logger.

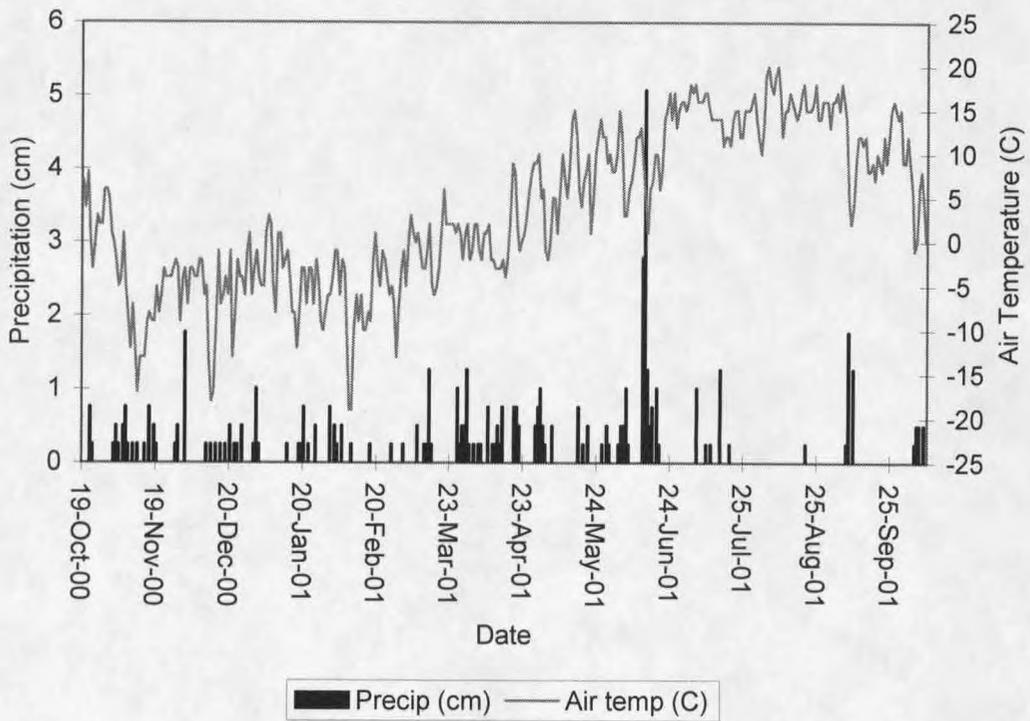


Figure 3-3. Precipitation and air temperature from the Lick Creek SNOTEL site.

Table 3-8. Major ion analyses from Two Springs.

Parameter	April 29, 2001		Oct. 1, 2001	Analytical Method
	Upper Spring	Lower Spring	Lower Spring	
Calcium	20 mg/l	20 mg/l	25 mg/l	EPA 200.7
Magnesium	7 mg/l	7 mg/l	8 mg/l	EPA 200.7
Potassium	2 mg/l	2 mg/l	2 mg/l	EPA 200.7
Sodium	2 mg/l	2 mg/l	2 mg/l	EPA 200.7
Chloride	<1 mg/l	<1 mg/l	>1 mg/l	EPA 300.0
Sulfate	4 mg/l	4 mg/l	5 mg/l	EPA 300.0
Bicarbonate	87 mg/l	88 mg/l	117 mg/l	SM2320B
Carbonate	<1 mg/l	<1 mg/l	<1 mg/l	SM2320B
Specific Conductance at 25 C	147 μ mohs/cm	142 μ mohs/cm	178 μ mohs/cm	SM2510B
Total Dissolved Solids	56 mg/l	65 mg/l	159 mg/l (calculated)	SM2540C
pH	7.7	7.7	8.0	EPA 150.1

Drinking Water Quality

Water from Two Springs was analyzed to determine if it met EPA drinking water standards. The results of these analyses are provided in Table 3-9. Complete laboratory reports are included in Appendix E.

Table 3-9. Drinking Water Quality Analyses of Two Springs.

Parameter		Two Springs (Lower Spring) Oct. 1, 2001	Analytical Method	EPA Standard
General Water Quality	Hardness, Total	95 mg/l	calculated	--
	Calcium	25 mg/l	EPA 200.7	--
	Magnesium	8 mg/l	EPA 200.7	--
	Sodium	2 mg/l	EPA 200.7	--
	Sulfate	5 mg/l	EPA 300.0	250 mg/l*
	Chloride	< 1 mg/l	EPA 300.0	250 mg/l*
	Alkalinity	96 mg/l	SM2320B	--
	Iron	< 0.03 mg/l	EPA 200.7	0.3 mg/l*
	Fluoride	0.10 mg/l	SM4500FC mod	4.0 mg/l
	Nitrate + Nitrite	0.06 mg/l	EPA 353.2	10 mg/l
	Total Dissolved Solids	159 mg/l	calculated	500 mg/l*
	Turbidity	0.33 NTU	EPA 180.1	1 NTU
	pH	8.0	EPA 150.1	6.5 – 8.5*
Microbiological	Total Coliform	Present	SM 9223	95% of samples must be negative
	E. Coli	Absent	SM 9223	0
	Giardia	< 0.05/l		99.9% removal
	Cryptosporidia	< 0.05/l		99.9% removal
Trace Metals	Lead	< 0.005 mg/l	EPA 200.8	0.015 mg/l**
	Copper	< 0.01 mg/l	EPA 200.7	1.3 mg/l**
	Antimony	< 0.003 mg/l	EPA 200.8	0.006 mg/l
	Arsenic	< 0.005 mg/l	EPA 200.8	0.05 mg/l
	Barium	< 0.1 mg/l	EPA 200.7	2 mg/l
	Beryllium	< 0.001 mg/l	EPA 200.7	0.004 mg/l
	Cadmium	< 0.001 mg/l	EPA 200.7	0.005 mg/l
	Chromium	< 0.01 mg/l	EPA 200.7	0.1 mg/l
	Mercury	< 0.0002	EPA 200.8	0.002 mg/l
	Nickel	< 0.01 mg/l	EPA 200.7	0.1 mg/l
	Selenium	< 0.005 mg/l	EPA 200.8	0.05 mg/l
Thallium	< 0.001 mg/l	EPA 200.8	0.002 mg/l	

Note: EPA standards are the National Primary Drinking Water Regulations (MCLs) except where otherwise noted.

* National Secondary Drinking Water Regulations ** EPA Action Level

Tritium

Tritium analyses were performed in order to provide an estimate of the residence time of groundwater discharging at Two Springs. Table 3-10 below contains the results of tritium analysis on the water from Two Springs and from the snowpack. The results are expressed in tritium units (TU), where 1 TU equals a tritium to hydrogen ratio of 10^{-18} . The tritium analytical reports are included in Appendix E.

Table 3-10. Tritium concentrations from Two Springs and snowpack.

Location	Tritium Concentration (TU)	Reported Error (TU)
Upper Spring	14.9	0.5
Lower Spring	13.8	0.5
Snowpack	10.7	0.4

Water Rights

In order to determine how water rights issues may affect Bozeman's potential use of the Madison aquifer, the major users of Madison aquifer water in Montana were identified. These entities were identified by the Montana Bureau of Mines and Geology Groundwater Information Center staff from their database and included four municipalities and two bottling companies. The locations of the municipalities and bottling companies that use the Madison aquifer are shown in Figure 3-4.

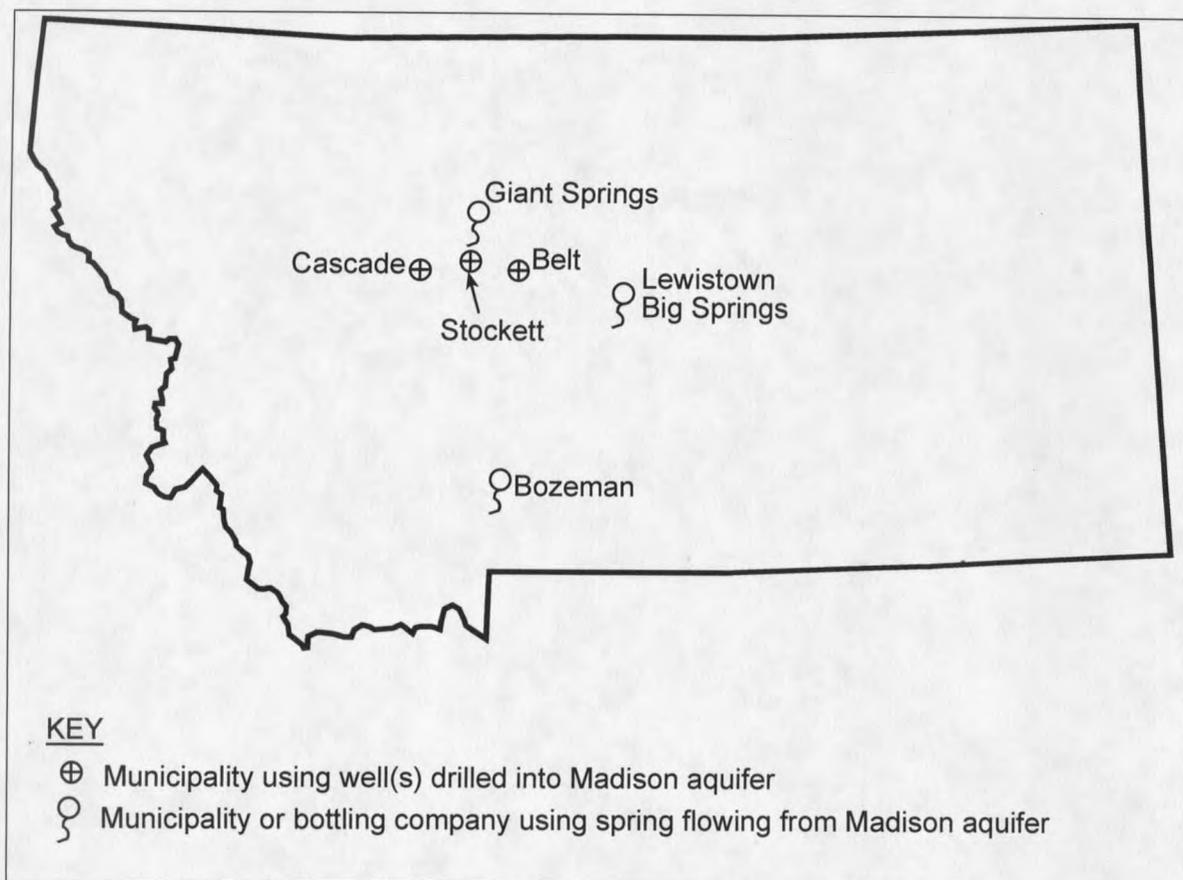


Figure 3-4. Major users of the Madison aquifer in Montana.

Officials from each of these municipalities and bottling companies were interviewed. The responses from telephone interviews with town officials in municipalities using Madison aquifer water are summarized below.

Town of Cascade

Contact: Karen Morrison, Clerk / Treasurer (406) 468-2808. The Town of Cascade has two wells drilled into the Madison aquifer, which serve a population of approximately 800 people. The wells are 730 meters and 670 meters (2400 and 2200 feet) deep. The first well was drilled in 1990 and yields 22 liters/sec (350 gpm). A second well was drilled

recently due to a bent pipe in the first well. The second well initially yielded 9.5 liters/sec (150 gpm) but was hydraulically fractured to increase yield. The well now yields over 17 liters/sec (267 gpm). The water level had been fairly constant in the wells, but began to decline during the spring of 2001. The water level had declined approximately 30 meters (100 feet) as of May 2001. The water is treated with chlorine. No water rights issues were reported.

Town of Stockett

Contact: Beverly Pepos, Water and Sewer Operator (406) 736-5351. Stockett has a population of 220 people, and a spring discharging from the Madison aquifer and a well drilled into the Madison aquifer provide the public water. The spring is the primary source of water for the town, has an average flow rate of approximately 6 liters/sec (100 gpm) and is distributed into the town by gravity flow. The discharge from the spring has declined over the last two years, leading to restrictions in water usage. The well is only used to supplement the water from the spring, and is 230 meters (750 feet) deep with a flow rate of 2 to 3 liters/sec (30 to 50 gpm). Typically the well is only used during the late spring and summer, but the well was used during this past winter due to low flows from the spring. The water from the spring is treated with chlorine and the well water is not treated. Both the well and the spring are on privately owned land and the water rights are held by the land owner. The Town of Stockett pays \$300 per month to the land owner for use of the water.

Town of Belt

Contact: Jean Fontana, Clerk / Treasurer (406) 277-3621. The Town of Belt is served by two wells drilled into the Madison aquifer. The wells are less than 60 meters (200 feet) deep and supply water to 700 to 800 people. The groundwater meets drinking water

standards and is not treated. The wells were drilled in 1978-79 and were the first use of the Madison aquifer in that area, so there were no water rights conflicts. Now there are other uses such as ranching, irrigation and residential use. The water level in the aquifer began to decline about 5 years ago and has dropped approximately 2.5 meters (8 feet) in the past year.

Giant Springs

Contact: Dave Brown, President (406) 761-6675. Giant Springs, Inc. began bottling spring water around 1992 and has a water right for 870 million liters (230 million gallons) per year. The springs flow at 720 million liters/day (190 million gallons/day), so the bottling plant uses less than 1% of the total flow. The spring water is filtered and treated with ozone prior to bottling. There were two water rights objections when the bottling company applied for a water right. The Department of Fish, Wildlife and Parks objected because of potential impacts to a trout hatchery located downstream from the springs. This objection was withdrawn when it was made clear that the bottling would consume only a small fraction of the total flow from the springs. Montana Power Company objected to the withdrawal of water from the springs, and Giant Springs Bottling Company agreed to pay Montana Power Company for lost revenue due to the water consumption.

City of Lewistown and Big Springs

Contacts: Earl Park, Clerk of Lewistown Public Works (406) 538-4430; and Nick Cerovski, Quality Control, Big Springs (406) 538-3433. Big Springs provides water to the City of Lewistown as well as to the Big Spring Water Company. Big Springs flows upward from three openings and has a total flow rate of 340 million liters/day (90 million gallons/day). A distribution line feeds water directly from the spring to the city via gravity flow. The water is typically not treated, however it is chlorinated annually when the water

storage tanks are cleaned and if coliform bacteria are detected in a water sample. The water temperature is 13.5° C (56° F) throughout the year and the flow rate remains relatively constant as well. Yearly analyses of the spring water have showed the water chemistry has remained constant. The city water supply serves a population of 6,500 people and uses between 4 and 26 million liters/day (1 and 7 million gallons/day). The bottling plant consumes 76,000 liters/day (20,000 gallons/day) from the city tap water. The City of Lewistown has owned the spring and the water rights to it since the early 1900s. The Department of Fish, Wildlife and Parks also has a water right from Big Springs in order to provide water for the operation of the Big Spring trout hatchery on Big Spring Creek, which is the outflow from the springs.

City of Bozeman (Lyman Creek)

Contact: Dean Elliott, Water Treatment Plant Supervisor, (406) 586-7158.

Lyman Creek was the original public water supply for the City of Bozeman, and was developed in the late 1800's. Lyman Creek is fed by a spring which discharges from the Madison aquifer along a fault. In 1909 a reservoir was built around the spring and the reservoir was enlarged in 1970. The City owns two water rights for Lyman Creek, dated 1864 and 1881. The combined allocation of these water rights is 170 liters/sec (5.9 cfs). Lyman Creek has not been used since 1999 and is currently undergoing upgrades. Lyman Creek is expected to be used again by 2003.

Potential Water Rights Conflicts for the City of Bozeman

Scott Compton, Regional Manager of DNRC was interviewed to determine what types of water rights conflicts might arise if Bozeman were to use water from the Madison aquifer for municipal use. The responses to this interview are summarized below.

The development of new water rights in the upper Missouri drainage is limited by a basin closure. The Montana Legislature closed the upper Missouri drainage to new consumptive uses in order to protect the existing water rights. However, municipal use, stock watering, small domestic use and groundwater use are exempt from this closure.

There could be a water rights conflict if there are any major discharges from the Madison aquifer to streams. At Two Springs, the aquifer discharges approximately 3,800,000 million liters/day (1 million gallons/day) into Sourdough Creek. If pumping the aquifer decreased the discharge of the springs and thus decreased the flow of Sourdough Creek, there may be water rights conflicts. However the City already has water rights on Sourdough Creek, so the priority dates and diversion points of the various water rights holders would have to be identified.

Based on data collected so far, streams lose water into the aquifer. Most likely this water is not appropriated to any specific users and thus belongs to the state. However, if pumping from the aquifer caused more water to be lost from the streams, then the flow of Sourdough Creek could be reduced. This would be likely to cause a water rights conflict. There are 113 claims to water rights along Sourdough Creek.

DISCUSSION

GeologyGeologic Mapping

The purposes of geologic mapping were to observe the characteristics of the Madison Group rocks that would have an impact on aquifer performance, to gather enough geologic and structural data to construct a geologic cross section through the area, and to be able to estimate the depth of drilling targets from the cross section. The geology of this area was previously mapped at 1:24,000 scale by Roberts in 1964, as part of an 8-quadrangle study of the region.

The primary area that was mapped in the Sourdough study was the Sourdough Creek anticline. This area was originally selected because it contains the largest area of Madison Group outcrops within the study area, and it includes Two Springs and each of the streams that cross the Madison Group. Also, the presence of Forest Service roads in this area provides access to potential drilling sites.

The Sourdough Creek anticline is made up of rocks ranging from Precambrian gneiss to Paleozoic and Mesozoic sedimentary rocks and Eocene volcanic deposits. The South Fork of Sourdough Creek flows near the axis of the anticline, and Madison Group rocks are well exposed on the limbs of the fold as well as at the nose of the fold (Plate 1). Most of the mapping effort was focused in the area of the nose of the fold where Madison Group exposures are found along a 2-kilometer reach of the South Fork. This provided an opportunity to look for recharge to and/or discharge from the aquifer, as well as to observe the characteristics of the Madison Group rocks.

The area southeast of the Sourdough Creek anticline is overlain by extensive deposits of Eocene extrusive rocks. These volcanic deposits form the crest of the Gallatin Range, and volcanoclastic boulders cover most of the contacts at the nose of the Sourdough Creek anticline. The extent to which the Eocene volcanic activity has affected the Paleozoic sedimentary rocks in the study area is not known. No field evidence of intrusive activity or contact metamorphism was observed.

A revised map of the Sourdough Creek anticline has been generated (Plate 1). Many of the original contacts mapped by Roberts were found to be approximately correct, but in some areas the contacts were moved several hundred meters. The thickness of the Madison Group was determined to be 430 meters (1420 feet). The most significant changes between the revised map and Roberts' map are described below.

- The upper Madison contact on the east side of the South Fork was moved approximately 250 meters (800 feet) southwest. On the west side of the Disappearing Stream, the upper Madison contact was moved approximately 350 meters (1100 feet) to the northeast. This defines a large area of Quadrant Sandstone on the divide between the South Fork and the Disappearing Stream.
- The exposure of the Madison Group in the Disappearing Stream is limited to the creek bottom, creating a very narrow band of Madison and Amsden rocks along the creek.
- On the west side of the South Fork, the upper Madison contact was moved approximately 160 meters (530 feet) northeast and the Quadrant Sandstone, not the Madison Group was mapped as the unit comprising the ridgetop.

- The axis of the Sourdough Creek anticline within the Madison Group was shifted to the southwest.
- The Precambrian/Cambrian contact is higher in elevation and the Precambrian rocks extend farther upstream along Sourdough Creek than shown by Roberts (1964).

Lithology of the Madison Group

The characteristics of the Madison Group rocks were carefully observed during field mapping. The primary purpose of this was to identify features that can affect aquifer performance, such as karst or fractures. The secondary purpose was to aid the mapping by noting the lithologic features, outcrop profiles and structural features that characterized the Madison Group. The Lodgepole Limestone and the Mission Canyon Formation were not mapped as individual units, but were mapped together as the Madison Group as was done by Roberts (1964): There were few places where the contact between the Lodgepole Limestone and the Mission Canyon Formation was observed in the field, thus an accurate contact could not be drawn on the geologic map.

The Lodgepole Limestone. Within the South Fork drainage, The Lodgepole Limestone was found to be primarily light gray, thin-bedded, fossiliferous limestone. Fossils included brachiopods, rugose corals, crinoids, and bryozoans. The texture ranged from sparry to micritic. Occasional thin units of red, brown or grey siltstone were present. The thin beds commonly associated with the Lodgepole Limestone were often characterized by discordant dip angles, suggesting parasitic folding had occurred within the Lodgepole

Limestone. Thus, structural data from the Lodgepole Limestone was not used to characterize the general dip direction.

The Mission Canyon Formation. The Mission Canyon Formation formed large, prominent outcrops in the shape of wide pinnacles. The Mission Canyon Formation was generally pale gray to tan, massive dolomite. Fossils were rarely observed within the Mission Canyon Formation. The rocks were highly fractured, particularly in the upper portion of the Mission Canyon Formation. Some of the most intensely fractured outcrops were observed along the South Fork at the nose of the anticline; fragments were as small as a few centimeters across in places. Within the upper half of the Mission Canyon Formation, breccias were observed. Typically the breccias had pale gray to tan dolomite clasts in calcite cement, with clast sizes ranging from 1 to 6 cm (0.4 to 2.5 inches).

In several locations a distinctly different breccia was observed, with clasts of gray, white or amber chert, amber quartzite and some light gray dolomite. The matrix was typically orange to red in color and was fine-grained and siliceous. This siliceous breccia was distinct in composition, texture and color from the carbonate breccias that are common in the Mission Canyon Formation. It occurred in a consistent stratigraphic position in the middle to upper Mission Canyon Formation. Figure 4-1 shows the locations where the siliceous breccia was observed. Many of the outcrops of siliceous breccia were very large, as much as 30 meters (100 feet) tall and nearly as wide. The siliceous breccia may be a result of infilling of ancient karst openings. The red color and siliceous content may have been derived from the overlying Amsden and Quadrant Formations. Sando (1988) described similar features within the Mission Canyon Formation as sinkholes and caves that developed

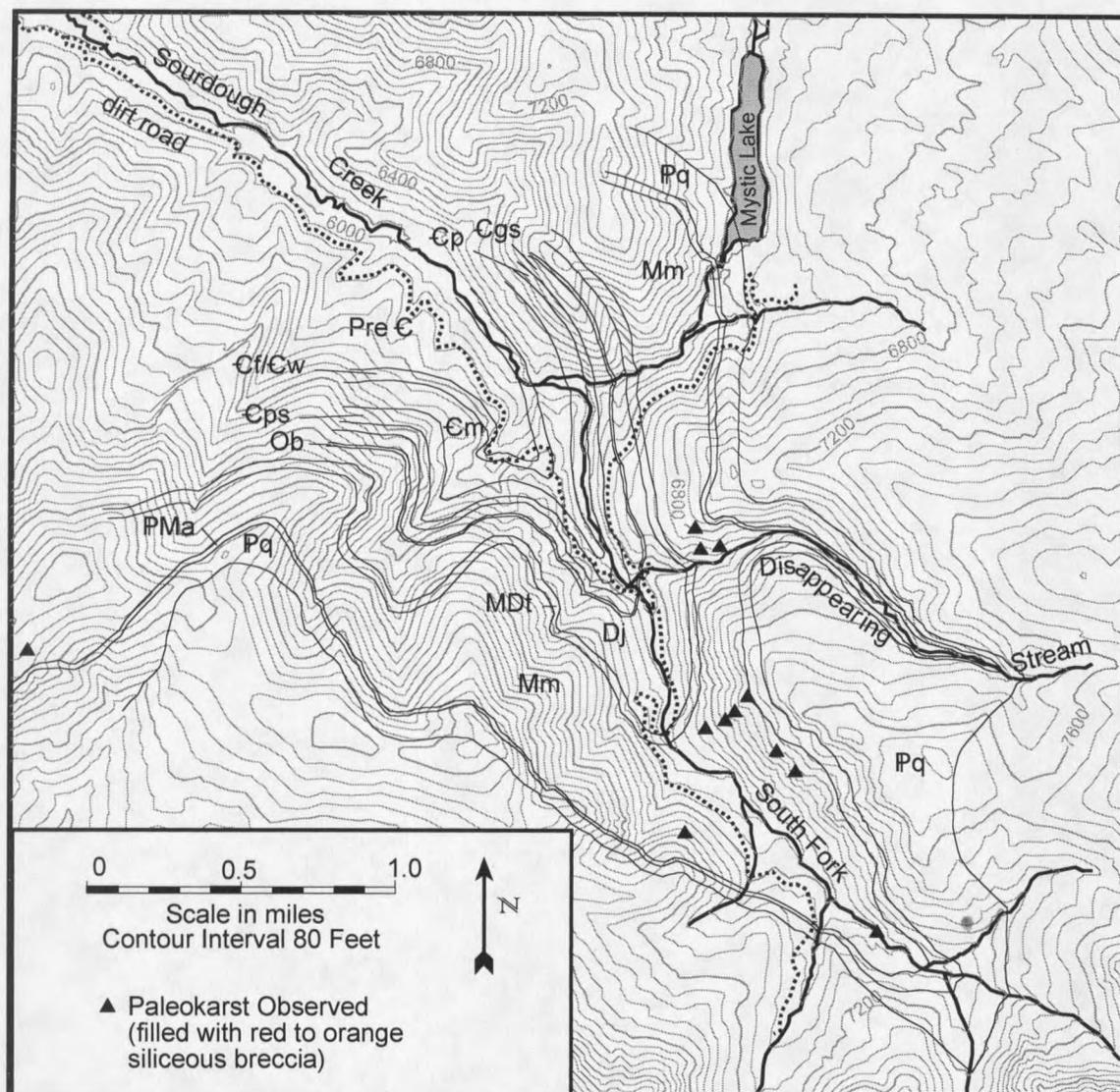


Figure 4-1. Observations of paleokarst features.

as part of the Mission Canyon Formation paleokarst prior to the deposition of the overlying formations. The fillings of sinkholes and caves are fine- to medium-grained red sandstone and red siltstone with angular clasts of carbonate and chert. The stratigraphic position of the caves and sinkholes vary slightly. Sinkholes are generally confined to the uppermost Mission Canyon Formation, while caves have been documented to depths of 60 to 105 meters (200 to 350 feet) below the top of the Mission Canyon Formation (Sando, 1988). The

stratigraphic position, lithology and form of the siliceous breccias observed in Sourdough Canyon is consistent with that of caves described by Sando. Thus, the siliceous breccias may be the remnants of infilled caves formed during an early episode of paleokarst in the Mission Canyon Formation.

While ancient karst features have typically been occluded since their formation, modern karst features remain open and thus have potential for a much greater impact on groundwater flow through the Madison aquifer. Modern (post-Laramide) karst features were observed in several locations within the Mission Canyon Formation and include caves and vugs. Small caves were present at the base of several cliff-forming outcrops. The caves were typically less than two meters across and did not appear to be extensive or connected to fracture planes. Figure 4-2 shows the largest karst feature that was observed during this study, which was located in the South Fork drainage near the nose of the Sourdough Creek anticline.

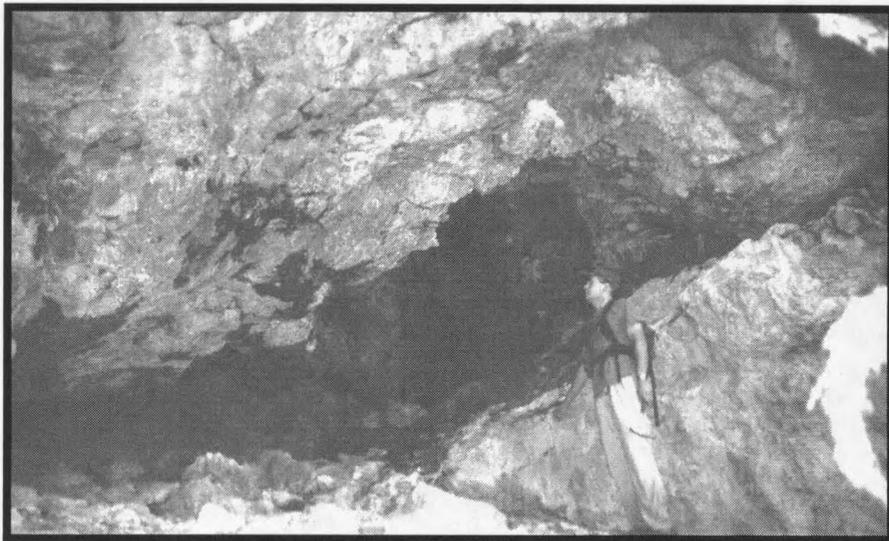


Figure 4-2. The largest karst feature observed in the Mission Canyon Formation. This photo was taken at station # 123 in the South Fork drainage. See Appendix A for station locations.

Caves were found in the upper through middle Mission Canyon Formation and were most commonly observed in the South Fork drainage and near the Disappearing Stream. Figure 4-3 shows the locations where caves and vugs were observed in Mission Canyon outcrops in the study area.

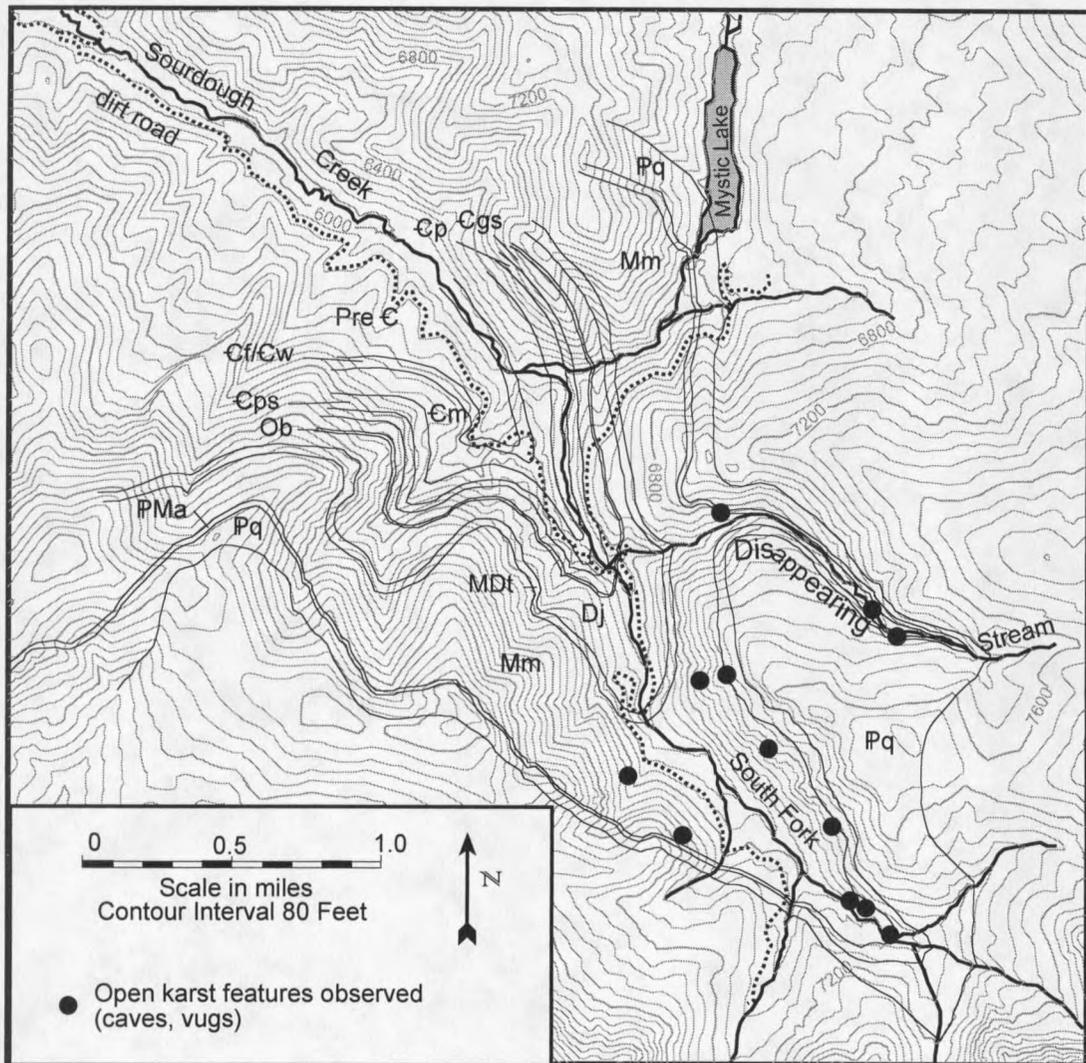


Figure 4-3. Observations of open karst features.

Fractures were also common in the Mission Canyon Formation. Open fractures may have large permeability and may allow for the rapid movement of groundwater. Many of the outcrops in the South Fork drainage were moderately to highly fractured (Figure 4-4). In some cases the fractures were filled with calcite, quartz or red silt. Slickensides were often present on fractured outcrops. In some locations, fracturing was prevalent in one bed but absent in an adjacent bed. The lithologies and textures appeared similar between the two beds. This may be a result of brittle deformation in one bed and ductile deformation in the adjacent bed due to slip along the bedding plane. The fractures may be a result of the Laramide folding that created the Sourdough Creek anticline, or the fractures may be a result of karst collapse of the Mission Canyon Formation.



Figure 4-4. An example of highly fractured rocks in the Mission Canyon Formation. This photo was taken at station #124 in the South Fork drainage. See Appendix A for station locations.

Figure 4-5 shows a map of the locations where highly fractured rocks were observed in the Madison Group. Determining the spatial orientation of fractures was not undertaken because many of the outcrops were so highly fractured and the fracture orientations were observed to be highly variable, thus measuring fracture orientations was not practical. Instead, the degree of fracturing at each outcrop was noted and highly fractured outcrops were plotted on Figure 4-5. Observations of highly fractured outcrops were most common in the Mission Canyon Formation and were less common in the Lodgepole Limestone

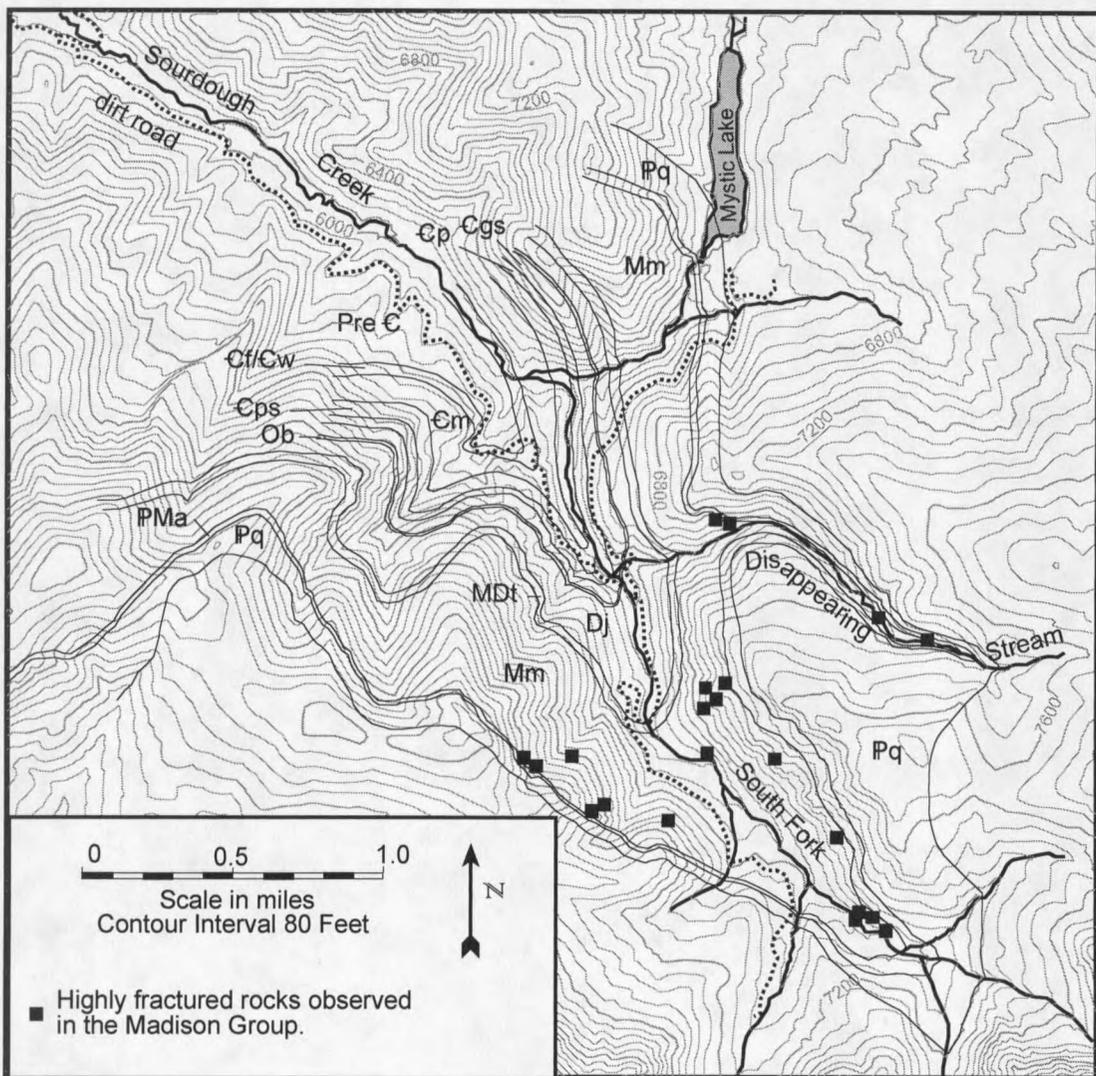


Figure 4-5. Observations of highly fractured outcrops.

Figure 4-5 illustrates that there is not clear evidence that fracturing is most prevalent along the crest of the Sourdough Creek anticline as would be expected if the fractures were tectonic in origin. Rather, the fracturing appears to be associated with the mid- to upper Mission Canyon Formation. Because karst features characterize the upper Mission Canyon Formation, karst collapse may be the cause of much of the fracturing that was observed.

Thin Sections from the Madison Group

Thin sections of rock samples from the Madison Group were examined in order to assess the lithology and matrix porosity of the Madison Group rocks (Table 3-1). The presence of a highly porous zone within the Madison Group would indicate a target for drilling. Examination of thin sections indicated that the Lodgepole Limestone had a higher percentage of calcite than the Mission Canyon Formation. The two samples from the Lodgepole Limestone contained 39 and 50 percent calcite, while the Mission Canyon Formation contained a maximum of 5 percent calcite and was primarily dolomite. No dolomite porosity or fracture porosity was observed in the thin sections of Lodgepole Limestone, but fractures were observed in outcrops of the Lodgepole Limestone. For example, a sample obtained from Two Springs did not contain visible matrix porosity in thin section. However, the springs emerge there so significant porosity must be present. The small size of a thin section does not allow for the recognition of large-scale fractures that were observed in outcrops.

Thin sections from the Mission Canyon Formation indicated the rock was composed of dolomite with only minor amounts of calcite. Dolomite porosity ranged from 0 to 7 percent (Table 3-1). Fracture porosity ranged from 0 to 15 percent in the thin sections.

Sample 95 F had 15 percent fracture porosity and was observed to be highly fractured at the outcrop. Sample 103 B contained interstitial quartz that had filled the fractures, reducing the fracture porosity to 1 percent.

The fracture porosities observed in thin section are most likely conservative estimates of the total fracture porosity. In some cases the high density of fractures precluded the collection of a sample for thin section because the outcrop was crumbling. Moreover, the scale of the fracturing was larger than could be expressed on a thin section slide.

The sample obtained from the Mission Canyon Formation at Bozeman Pass contained more calcite (15%) than the Mission Canyon samples from the Sourdough drainage. The percentages of porosity were similar to those from the Sourdough samples.

Judging by the thin sections, the Mission Canyon Formation has a higher porosity than the Lodgepole Limestone. The greatest degree of porosity occurred near the top of the Mission Canyon Formation and was due to fracture porosity.

The type of porosity has implications for the storage capacity of the aquifer. Water within the aquifer can be stored in the matrix pores, in the fractures and within karst. Water in karst and fractures is able to flow at a relatively high velocity, and provides rapid drainage from the aquifer. However, the storage capacity of the fractures and karst may be relatively low because the overall volume of these pore spaces is small and water is able to flow quickly through them. Groundwater in the matrix pores would be expected to flow slowly and provided delayed drainage from the aquifer. Thus the storage capacity of the matrix pores may be greater than that of the fractures and karst.

Lithology of Surrounding Formations

A brief discussion of the formations above and below the Madison Group is included to place the Madison Group in a stratigraphic context and to describe the lithologic characteristics of the surrounding formations. These features were used to distinguish the formations during mapping.

The Jefferson Dolomite (upper Devonian) is a thick, cliff-forming formation. The lithology consisted of grayish-brown dolomite and limestone. The texture ranged from micritic to sparry with 2mm crystals. In some locations the Jefferson contained abundant fossils such as rugose corals, bryozoans, brachiopods and gastropods. A petroliferous odor when broken often characterizes the Jefferson Dolomite, but was not always observed.

The Three Forks Shale (upper Devonian – lower Mississippian) underlies the Lodgepole Limestone. The lithology of this formation varies from shale to limestone. Most of the outcrops seen in the field area were pale brown to yellowish, silty limestones. This unit is not competent and was typically concealed.

The Amsden Formation (upper Mississippian – lower Pennsylvanian) overlies the Mission Canyon Formation. The Amsden consists predominantly of red mudstone and siltstone with some limestone. The Amsden is poorly exposed and in many cases was not observed. At several locations, a distinct red soil was observed but outcrops were not found.

The Quadrant Sandstone (Pennsylvanian) overlies the Amsden Formation. The Quadrant is comprised of mature quartz sandstone, with a very light gray dolomite at the base. The quartz sandstone was white to pale orange with cross bedding present. Typically the sandstone was very well cemented, although near Mystic Lake the lower Quadrant is poorly cemented and easily disaggregated. The Quadrant was fractured in places, and

typically had planar fractures that were perpendicular to the bedding planes. The Quadrant forms prominent, blocky cliffs along both sides of the South Fork drainage. Quadrant cliffs are linear and continuous as compared to the intermittent pinnacles of the Mission Canyon Formation. Large scree fields are commonly found below the Quadrant, obscuring the Amsden Formation and making identification of the upper Mission Canyon contact difficult.

The Phosphoria Formation (Permian) was seen only in a few locations and was not mapped separately. The formation consists of grey, yellow and tan chert. It was grouped as a part of the Quadrant Sandstone as was done by Roberts (1964).

Above the Quadrant Sandstone and the Phosphoria Formation is the Jurassic Ellis Group. The Ellis group is made up of the Piper Formation, the Reirdon Formation and the Swift Formation. The Piper Formation is a thin bedded, grey, micritic limestone that often contains pelecypod fossils. The Reirdon Formation consists of oolitic, fossiliferous limestone. The Swift Formation is a brownish-grey sandstone that contains limonite and has a conglomerate layer at the base of the formation. Ellis Group rocks were characteristically found in open meadows which were clearly visible on aerial photos. The upper contact of the Ellis Group was not mapped.

Structural Geology

The structural geology of the study area was examined for two reasons. First, in order to predict groundwater flow patterns within the aquifer it is necessary to understand the structural geometry of the formation. Second, structural information is needed to construct a geologic cross-section and to identify potential drilling sites and the depth to drilling targets.

The study area is characterized by Laramide-style deformation. Archean quartzofeldspathic gneiss forms the core of the Sourdough Creek anticline. The major fold in the study area is the Sourdough Creek anticline. The South Fork flows near the crest of the anticline except for the area downstream of the Jefferson Dolomite, where the creek flows across the non-resistant Cambrian Park Shale.

The Sourdough Creek anticline is asymmetrical (see Plate 1). In the area between the South Fork and the Disappearing Stream, the eastern limb of the fold has a shallow dip of 9 to 15 degrees, while the western limb, southwest of the South Fork, has a steeper dip and is vertical in places. There was field evidence for internal deformation of the Madison Group rocks, such as disharmonic dip angles and directions, small-scale folds, intense fracturing and slickensides. No faults were located in the area that was mapped, however it is possible that there are small faults within the Madison Group associated with the internal deformation. Because the rocks are fractured, internally deformed and massive in places, the Madison Group rocks are not a reliable source of structural data. Wherever possible, strike and dip measurements from the Quadrant Sandstone were used to characterize the structure of the area.

Cross-section A-B-C runs southwest to northeast from the Sourdough Creek anticline to the Bear Creek anticline (Plate 2). The southwestern portion of the cross section is based on the field mapping performed during this study, and is shown with solid lines on Figure 4-6. The northeastern part of the cross section is shown in dashed lines and is based on the existing geologic map by Roberts (1964). This was done in order to show both the Sourdough Creek anticline and the Bear Creek anticline, as well as the syncline between these two folds. However, problems arose when combining field data from this study and

from Roberts' map onto one cross-section. The thicknesses of the rock units based on Roberts' mapping do not match the thicknesses that resulted from the detailed mapping in the Sourdough watershed. Moreover, there is little strike and dip data on Roberts' map. To resolve these problems the thickness of each unit was maintained throughout the cross section. The thicknesses were derived from the Sourdough Creek anticline where detailed field mapping was performed, thus there is reasonable confidence that these thicknesses are correct. A digital orthophoto was used to check Roberts' contacts at the Bear Creek anticline. Roberts' contacts were adjusted slightly to bring them into agreement with the contacts observed on the digital orthophoto. Dip angles from the Bear Creek anticline were adjusted to match the thickness of each formation. Nonetheless, the contacts on the cross section do not match Roberts' contacts exactly. Thus the northeastern portion of the cross section (from B to C on Plate 2) should be considered only conceptual in nature.

Cross section A-B-C shows the syncline between the Sourdough and Bear Creek anticlines with a gentle dip on the western limb and a steep dip on the eastern limb. The Bear Creek anticline is a tight fold with steeply dipping limbs as is indicated by the steep dip angles shown on Roberts' map and by the narrow outcrop patterns shown on Roberts' map and on the digital orthophoto. Either disharmonic folding or faulting must have occurred to produce the geometry of the Bear Creek anticline, because it is not possible to maintain a constant thickness of the units and have the contacts and dip angles match those shown on Roberts' map. Detailed field mapping of the Bear Creek anticline could resolve the structural geology of this area, but this was not undertaken as a part of this study.

Groundwater that recharges the Madison aquifer near the Sourdough Creek anticline would be expected to flow northeast toward the syncline between the Sourdough Creek

anticline and the Bear Creek anticline. Groundwater within the syncline may then flow south, along the plunge of the fold. However, the actual groundwater flow direction is not known.

Stream Losses and Gains

Stream losses are a common occurrence on the Madison aquifer and have been used as a means of estimating recharge by Feltis and Shields (1982) and Greene (1997). However, Huntoon (1985) cautions that in a karst system it is possible for water to leave the stream, flow within karst openings, and then rejoin the stream or even flow underneath drainage divides and flow into adjacent streams. Thus stream loss measurements should be considered only to be an estimate of recharge.

All of the streams within the primary study area were gauged in order to determine if the streams were gaining water from the Madison aquifer or losing water to the Madison aquifer. Sourdough Creek, the South Fork of Sourdough Creek and the Disappearing Stream (Figure 3-1) were measured during the spring, summer and fall. Hyalite Creek and Bear Creek were gauged in the fall of 2001 in order to determine if the Madison aquifer was gaining or losing water at these locations. Figure 3-1 shows the gauging locations on all of the creeks, while Figures 4-7, 4-8 and 4-9 are detailed maps showing the gauging locations on each of the creeks within the Sourdough Creek watershed.

Sourdough Creek Watershed

In every case the streams in the Sourdough Creek drainage were losing water to the aquifer. The stream losses were greatest in the fall and spring, and were smallest in the summer. Table 4-1 summarizes the stream loss measurements and shows the average stream

loss for each stream. The average annual stream loss was calculated by summing the stream losses from each stream. The stream loss was not measured during winter, so the average annual stream loss only takes spring, summer and fall into account. The estimated average stream loss was $0.10 \text{ m}^3/\text{sec}$ (2,600 acre-feet/year).

Table 4-1. Summary of stream loss measurements in Sourdough Creek watershed (m^3/sec).

	July 2000	October 2000	May 2001	Average
Sourdough Creek	0.03	0.07	0.04	0.05
South Fork	0.01	0.01	0.01	0.01
Disappearing Stream	0.03	0.02*	0.06	0.04
Total	0.07	> 0.10**	0.11	0.10 (2,600 acre-feet/yr)

* This measurement was made in August 2000

** The Disappearing Stream was not measured in October.

Sourdough Creek. The stream losses in Sourdough Creek (Figure 4-6) varied by season. The greatest stream loss was measured in October 2000, with $0.07 \text{ m}^3/\text{sec}$ (2.3 cfs). The smallest loss was in July 2000, at $0.03 \text{ m}^3/\text{sec}$ (1.2 cfs) while the May 2000 measurement was between the two. The reach of Sourdough Creek that flows over the Madison Group rocks is on a bedrock channel with minor alluvial cover that directly overlies the bedrock. The stream loss is assumed to be flowing into the Madison aquifer. The pattern of large stream losses in the fall is contrary to what was found by Feltis and Shields (1982) and Greene (1997). However, the measured stream loss of 40% in the October 2000 exceeds the measurement error of $\pm 6.4\%$. Thus there is reason to be confident in these results even though they do not agree with what other researchers have found on other streams in Montana.

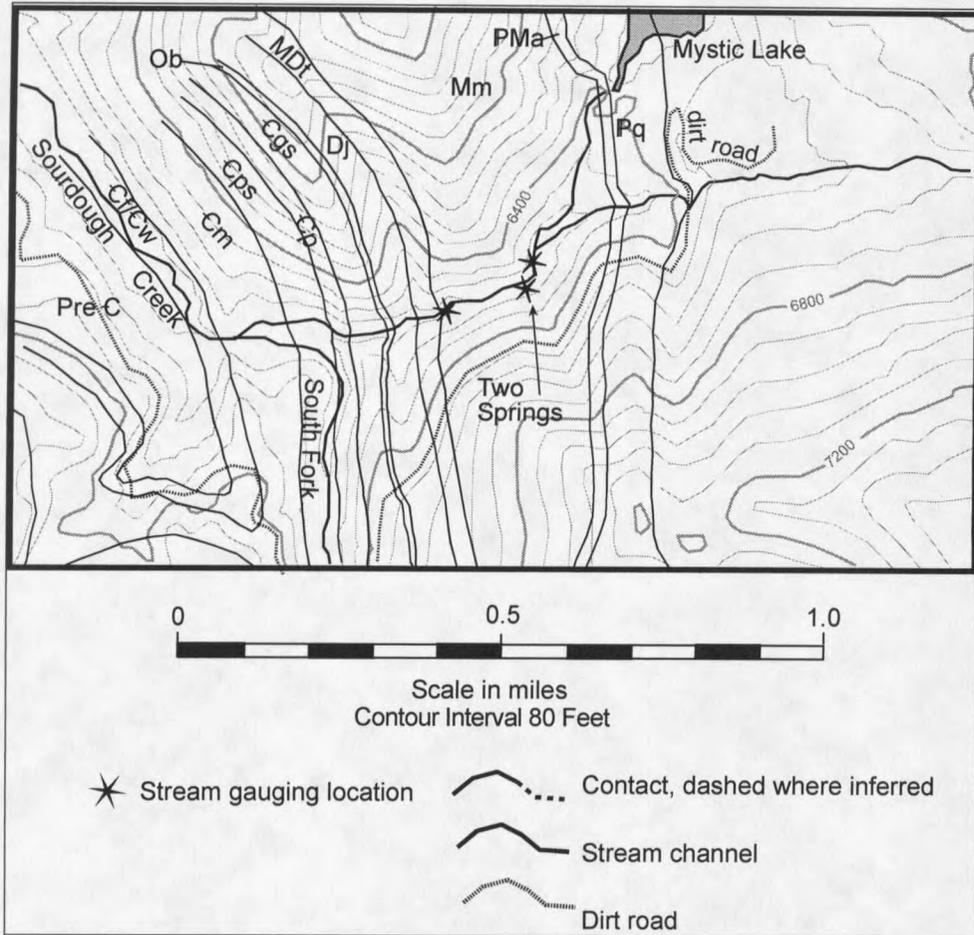


Figure 4-6. Sourdough Creek gauging locations. See Plate 1 for key to geologic units.

The South Fork. Significant aquifer recharge via stream loss was expected on the South Fork of Sourdough Creek because the stream is flowing along the crest of the Sourdough Creek anticline and highly fractured rocks were observed there. However, there are extensive surficial deposits along the stream and along the northernmost tributary. This tributary stream is entrenched approximately 1.5 meters (5 feet) into a colluvial deposit. Lobe-shaped deposits suggesting mass movements are present on the east and west sides of the South Fork, and volcanoclastic sediments are present on the west side of the South Fork. The approximate locations of colluvial deposits are shown on Figure 4-7. These surficial

deposits were not mapped in detail, but Figure 4-7 provides a general sense of the distribution of alluvial deposits in relation to the creeks. In two locations ephemeral springs were flowing out of surficial deposits. Thus, measuring stream discharge at the upstream and downstream ends of the Madison Group may not accurately quantify the stream gain or loss. Nonetheless, stream loss measurements were performed in order to get a sense of whether the stream is gaining or losing.

The South Fork was found to be losing water each of the three times it was measured. The total volume of water lost was similar during each measurement, but the percentage of water loss was similar to that of Sourdough Creek, with the largest losses in the fall and spring, and the smallest losses in the summer. However, the quantity of water lost was less than that of Sourdough Creek, with a maximum of $0.1 \text{ m}^3/\text{sec}$ (0.56 cfs) loss on the South Fork compared to $0.07 \text{ m}^3/\text{sec}$ (2.3 cfs) on Sourdough Creek (Table 4-1). The stream loss was expected to be greater on the South Fork because the creek flows for a greater distance across the Madison Group rocks, providing more opportunity for water to infiltrate the aquifer. Moreover, due to the location of the South Fork along the crest of an anticline, water would be expected to easily enter the fractured rocks observed there.

Additional water was entering the stream via the surficial deposits. In two locations, ephemeral springs were seen discharging from colluvial deposits near the banks of the South Fork (Fig. 4-7). The estimated discharge from the springs was $0.02 \text{ m}^3/\text{sec}$ (0.71 cfs). This water was not accounted for in the upstream measurement or in the tributary measurements. If the discharges from the springs were included in the stream loss measurements, the stream loss on the South Fork would have been $0.03 \text{ m}^3/\text{sec}$ (1.2 cfs) instead of $0.01 \text{ m}^3/\text{sec}$ (0.53 cfs) in May 2001.

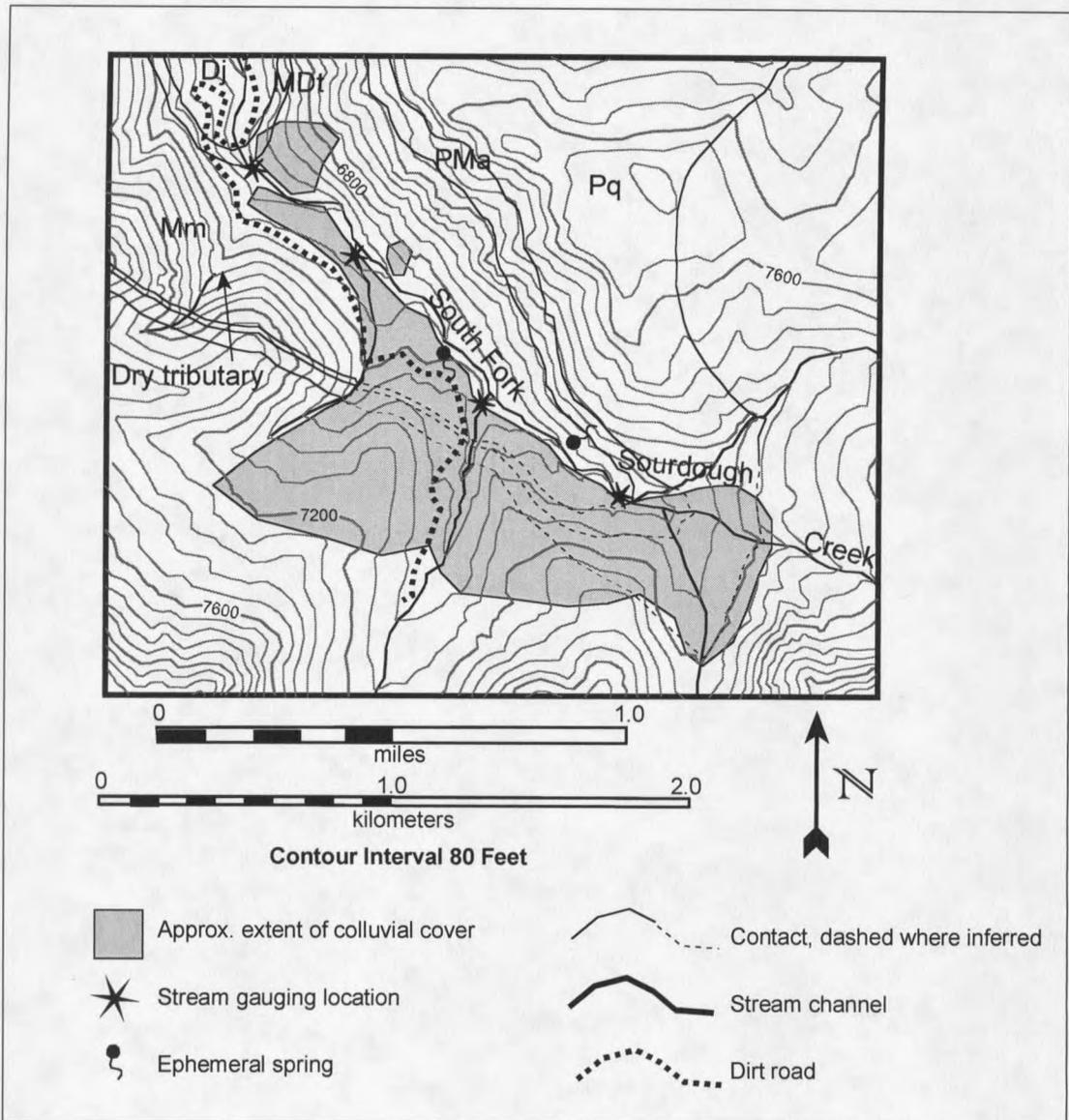


Figure 4-7. South Fork colluvial deposits and stream gauging locations.

One of the tributaries to the South Fork lost all of its water as it flowed across the Mission Canyon Formation. The stream loss of this tributary was estimated at $0.003 \text{ m}^3/\text{sec}$ (0.01 cfs). Although the quantity of water is minor compared to the measured stream losses, this stream loss provides additional evidence that stream water is entering the Madison aquifer.

The Disappearing Stream. At the Disappearing Stream, all of the creek's water drained into the aquifer (Table 4-1). Here the stream loss was equal to the stream flow at the upper Madison Group contact. The stream bed was bedrock and had a thin cover of alluvium in some places; the water lost from the stream was draining into the aquifer not into surficial deposits.

The location where the stream stopped flowing changed through the season. Figure 4-8 shows the amount of flow and the location where the stream flow ceased on each of the dates the stream was measured. The stream flow was greatest in the spring at $0.06 \text{ m}^3/\text{sec}$ (2.0 cfs) and the water flowed 1.2 kilometers (0.75 miles) down the channel before being lost into the aquifer. During the summer the stream discharge decreased to $0.03 \text{ m}^3/\text{sec}$ (1.1 cfs) and the stream flowed only 0.4 km (0.25 miles) prior to disappearing. The point at which the water ceased to flow in the stream channel was in a different location each time the stream was visited. The location of this point was dependent on the amount of water at the upstream Madison Group contact. In general, the more water flowing in the stream, the farther down the channel the stream flowed before draining into the bedrock. The total amount of stream loss is equal to the amount of flow at the gauging location, thus the stream loss was greatest in the spring and decreased through the summer.

The fact that the Disappearing Stream loses all of its water indicates the rock beneath the Disappearing Stream is sufficiently permeable to allow infiltration of the stream water before the water has a chance to flow downstream. The Disappearing Stream is flowing on the upper part of the Mission Canyon Formation, which is expected to have the greatest degree of karst permeability, and several karst features were observed in outcrops adjacent to the Disappearing Stream channel (Figure 4-3). Moreover, several of the outcrops along the

Disappearing Stream were highly fractured (Figure 4-5). The presence of a stream channel indicates that the stream periodically flows the entire length of the channel. The stream channel was covered with herbaceous vegetation where it joins the South Fork, suggesting the stream has not flowed there in the past few years. The stream would be most likely to flow the complete length of its channel during spring runoff in years of high flow.

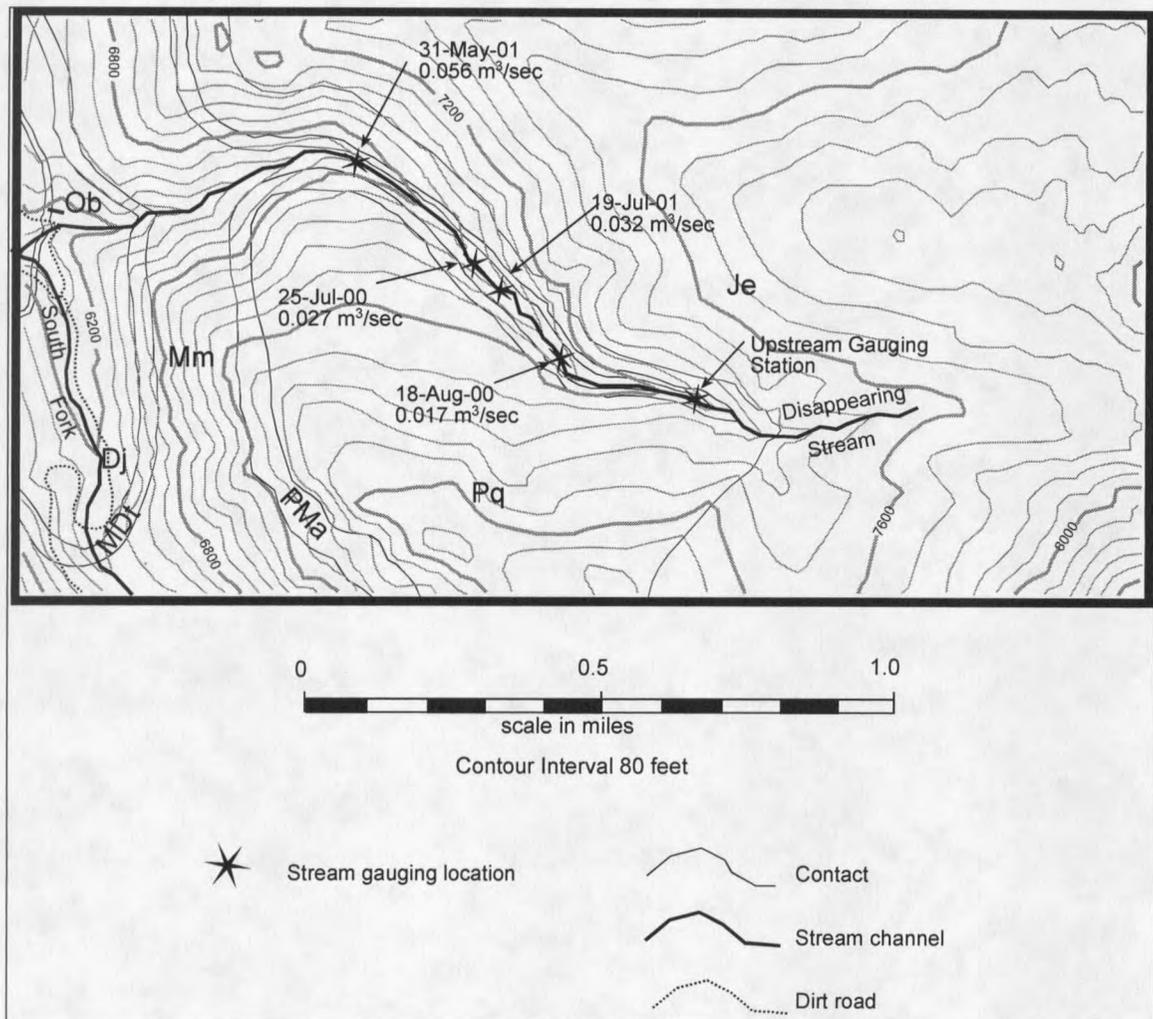


Figure 4-8. Disappearing Stream losses.

Streams Outside of the Sourdough Creek Watershed

The stream losses discussed above indicate the Madison aquifer is receiving recharge from the Sourdough Creek watershed. In order to determine where this recharge water is flowing, streams in the watersheds adjacent to the study area were gauged to determine if water was discharging there.

Hyalite Creek. Hyalite Creek flows across the Madison Group southwest of the study area at an elevation of 1920 meters (6300 feet)(Figure 3-1). This elevation is similar to the elevation of the Madison Group where Sourdough Creek flows across it. The stream was gauged in two locations as shown on Figure 3-1. The upstream gauging location was near the upper Madison contact and the stream channel was bedrock in this location. Approximately 300 meters downstream, thick alluvial deposits were present along the east side of Hyalite Creek. These deposits thickened for some distance downstream, thus it was not possible to locate the lower contact of the Madison Group. The second gauging location was selected in an area upstream from the major alluvial deposits, where Madison rocks outcropped on both sides of the stream, although some alluvial material was present on the east side of Hyalite Creek.

The stream was gaining water at a rate of $0.04 \text{ m}^3/\text{sec}$ (1.4 cfs) between the two gauging points. The stream gain was 5%, which is smaller than the measurement error of 6.4%. Therefore, the stream gain along this reach of Hyalite Creek is not significant.

Three small springs were observed on the eastern bank of the Hyalite Creek, each with an approximate flow of $0.008 \text{ m}^3/\text{sec}$ (0.28 cfs), for a combined total of $0.0024 \text{ m}^3/\text{sec}$ (0.85 cfs). The small springs provide evidence that groundwater is discharging in this

location. However, it is not known if this water is discharging from the Madison aquifer or from the alluvium or a combination of the two. Groundwater that recharges the Madison aquifer at the South Fork may flow toward the Hyalite drainage, but there are several folds and two faults between the South Fork and Hyalite Creek that may prevent the flow of water toward Hyalite Creek. The Madison aquifer may also receive recharge from other locations within the Hyalite drainage, but this was not determined during this study.

Bear Creek. Bear Creek flows across the Madison Group north of the study area and was gauged in two locations as shown in Figure 3-1. Bear Creek was losing water at the rate of $0.007 \text{ m}^3/\text{sec}$ (0.24 cfs) between the two gauging points. Because the stream has a small discharge, the measured stream loss was smaller than what can be measured confidently. However, the stream is clearly not gaining. Significant karst porosity was evident in the Mission Canyon outcrops in Bear Canyon, so presumably the rock is permeable there. The Mission Canyon Formation is at an elevation of 1750 meters (5750 feet) where Bear Creek crosses it, and this is the lowest elevation of a Madison Group exposure in the Mt. Ellis Quadrangle. Because Bear Creek was not gaining, the aquifer is not discharging at this location and elevation.

Evapotranspirative Loss

A variable in the stream loss measurements is evapotranspirative loss from the stream channel during the time of the stream discharge measurements. The process of measuring the stream in several places and hiking the length of the stream took several hours. It is possible that as the day progressed, water was being lost from the channel due to

uptake by vegetation at the margins of the stream. Losses by evapotranspiration may have been mistakenly interpreted as losses to infiltration. To assess this possibility, stage readings from a flume on the South Fork (Fig. 3-2) were used to estimate daily evapotranspirative losses. Throughout the field season, the stage was checked in the morning and again in the afternoon. During the summer the morning stage was typically 0.3 cm (0.01 feet) higher than the afternoon stage. This is equivalent to a reduction in stream discharge of 0.002 m³/sec (0.08 cfs). This is an order of magnitude smaller than the measured stream losses. Moreover, the largest stream losses were measured in October, when evapotranspiration would be expected to be less. Thus, the stream loss due to evapotranspiration was significantly less than the stream loss due to infiltration.

Stream losses were the only means of measuring recharge to the Madison aquifer in this study. The aquifer may also recharge by general infiltration of snowmelt or rainwater, but this was not accounted for. While stream losses can be measured directly, recharge by infiltration must be estimated based on factors such as precipitation, vegetative cover, evapotranspiration, slope angle, runoff and soil type (Dingman, 1994). The average annual precipitation at the Lick Creek SNOTEL site between 1975 and 2001 was 76.7 cm (30.2 inches), while the estimated annual evapotranspirative loss from a mixed conifer forest is 56 cm (22 inches) (van der Leeden, et al., 1990). The 1992 Climate Atlas of Montana states the potential evaporation for the study area is between 36 and 46 cm (14 and 18 inches) (Caprio and Nielsen, 1992). These figures imply that evapotranspiration is less than precipitation, hence excess water could be infiltrating the aquifer. It was beyond the scope of this study to determine the degree to which infiltration affects the Madison aquifer, but it appears that general infiltration could be a factor in overall recharge to the aquifer.

Spring Stage and Discharge

The only spring found in the study area that is discharging from the Madison aquifer is Two Springs (Figures 1-1 and 4-2). The springs discharge from two separate orifices yet share the same water chemistry and temperature, thus they represent the same spring system. The springs discharge out of the Lodgepole Limestone member of the Madison Group. In the area of Two Springs, the rocks dip at 72 degrees to the northeast and are somewhat fractured. Karst permeability was not observed in the vicinity of Two Springs, and dolomite porosity was not observed in a thin section collected at Two Springs.

The elevation of Two Springs is at 1890 meters (6190 feet); the lowest elevation of a Madison Group outcrop in the Sourdough Creek watershed. No evidence was observed during field work or aerial photo examination that suggested the presence of a fault, lineament or fracture zone that would cause the spring to occur in this particular location. The most likely explanation for the presence of the springs in this location is the low elevation of the outcrop.

The stage of the channel which discharges water from Two Springs was recorded by a data logger. The data logger was originally installed in July 2000, but there were problems with the unit that took several months to resolve. As a result there are gaps in the data in August and September 2000. There is a continuous record from in October 2000 until October 2001.

A stage-discharge relationship was calculated for Two Springs. Originally, the stage-discharge relationship was to be calculated using the stage readings on the ruler that was fixed to the outside of the stilling well and manual discharge measurements made at the springs. There were eight data points with the ruler stage and the manual discharge

measurement. However, the ruler stage readings did not correlate with the data logger stage readings and the ruler may have moved. During the October 1, 2001 visit to the springs, it was noted that the data logger cable had been moved and a flag affixed to the top of the stilling well had been broken off. An animal may have rubbed on or bumped into the stilling well. No offset was observed in the data logger stage readings that would have indicated that the data logger probe had moved. But the ruler stage readings no longer correlated with the data logger stage readings. Thus, a stage-discharge relationship was calculated using the data logger stage readings instead of the ruler stage readings. The drawback to this approach is that there were only four data points with data logger stage readings and manual discharge measurements. Nonetheless, a relationship was calculated in order to provide estimates of the spring discharge from October 2000 through October 2001. The data plot, trend line and equation are shown on Figure 4-9.

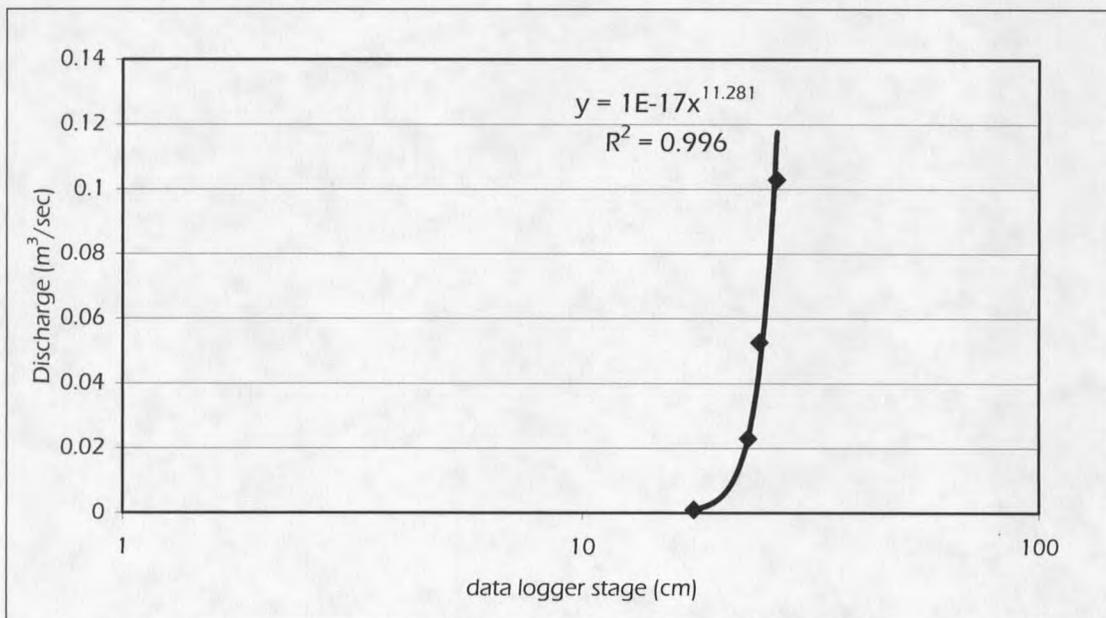


Figure 4-9. Stage-discharge relationship for Two Springs.

The stage-discharge relationship from Figure 4-9 was applied to the data logger stage readings from October 2000 through October 2001. The data logger stage readings prior to October 2000 could not be used because the data logger had been reinstalled and the probe was at a different elevation. A hydrograph of the stage and discharge of Two Springs is shown in Figure 4-10.

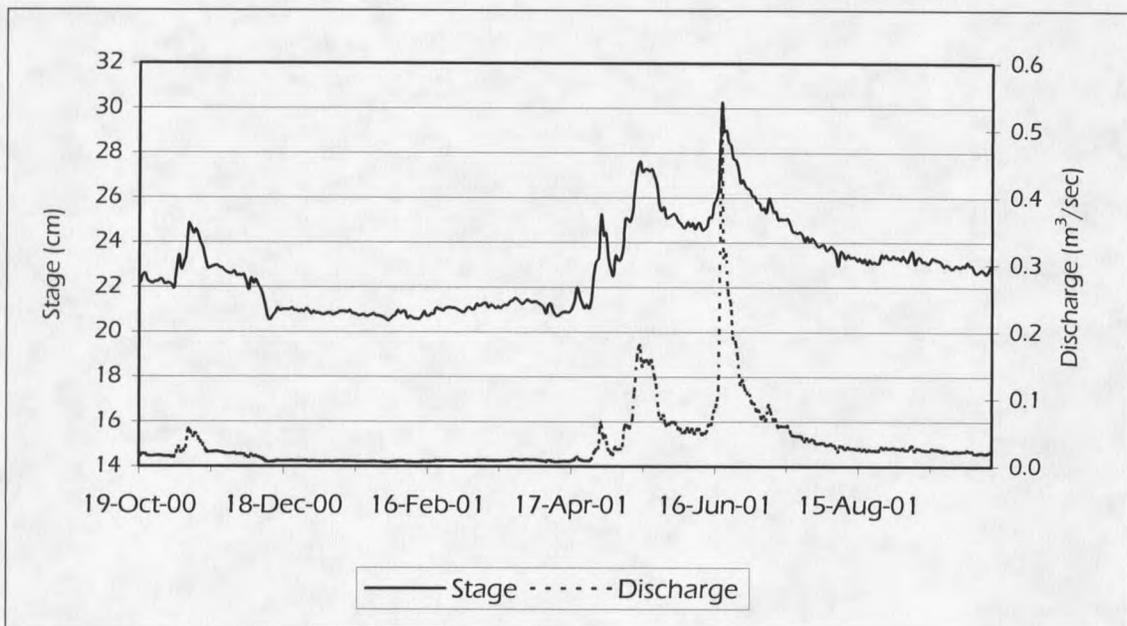


Figure 4-10. Stage and discharge of Two Springs.

In general, the stage and discharge at Two Springs show a pattern of peak discharge in May and June and declining discharge throughout the summer, fall and winter. The average discharge was $0.035 \text{ m}^3/\text{sec}$ (1.2 cfs). During the fall of 2000 there was a peak that does not appear to be correlated with either precipitation or temperature at Lick Creek

(Figure 3-4). This peak may be related to ice blocking the channel and temporarily raising the stage of the spring outlet channel.

The discharge at Two Springs was lowest in the winter, at $0.007 \text{ m}^3/\text{sec}$ (0.25 cfs). If the springs are closely connected to a shallow groundwater flow system, a low discharge would be expected during the winter because the aquifer was not receiving as much recharge from the surface as compared to other times of the year. The fact that the spring flowed throughout the winter suggests that the spring did not completely drain the aquifer during the winter, or that the spring continued to receive some recharge throughout the winter.

The discharge of Two Springs began to rise significantly in mid-April as the air temperature began to rise above freezing (Figure 3-4). During the period of spring runoff, there were three peaks in the discharge of Two Springs. The third peak was the largest and occurred on June 18, with a calculated discharge of $0.50 \text{ m}^3/\text{sec}$ (17.5 cfs). This peak is a result of a large rain and snow event that occurred from June 12 through June 14, where a combined total of 9.1 cm (3.6 inches) of water fell. This event provided an opportunity to observe the effects of an isolated precipitation event on the behavior of the spring (Figure 4-11). The storm began as rain on June 12, then changed to snow on June 13 and 14, then rain again on June 15 and 16. Based on the data from the Lick Creek SNOTEL site (http://mt.nrcs.usda.gov/swcs/snow/table_mt.html), the majority of the precipitation during the storm event fell as rain on June 12 and 13, shown as a clear peak in precipitation on Figure 4-11.

The discharge of the spring increased slightly during the period from June 12 through June 14, likely a result of rain and snow falling in the immediate area of the springs and raising the stage of the outlet channel formed by the discharge of the springs. The stage

climbed rapidly from June 15 through June 18, peaking sharply on June 18. The lag between the peak precipitation and peak discharge was 5 days. This indicates there is a rapid connection between recharge at the surface and discharge at Two Springs.

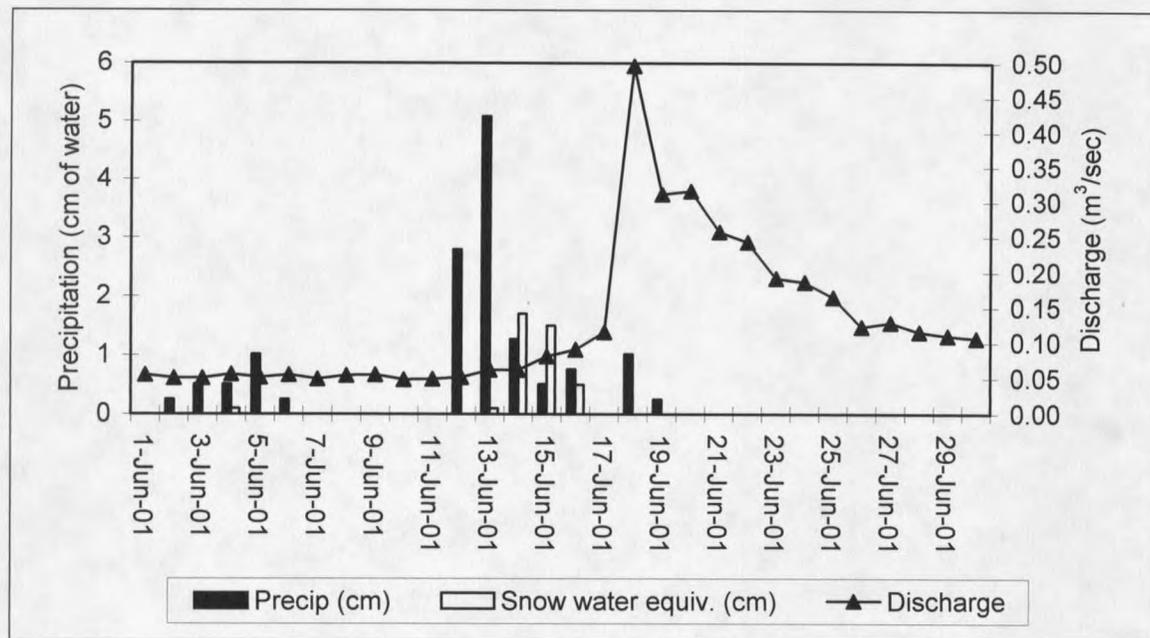


Figure 4-11. Two Springs discharge and SNOTEL precipitation for June 2001.

Spring Water Temperature

The temperature of a spring can be a reflection of the residence time of the water and the depth of circulation. Thus, the water temperature of Two Springs is an indicator of whether the water is discharging from a shallow, localized aquifer or a deep, regional aquifer. Groundwater discharging from deep regional aquifers with a long residence time is likely to have an elevated temperature due to the geothermal gradient. Shallow, localized groundwater systems with rapid circulation discharge water that is close to the mean annual air temperature (Fetter, 1994).

The water temperature of Two Springs is shown in Table 3-7 and Figure 4-12. The average water temperature of the springs was 4.2° C (40° F) while the average annual air temperature at Lick Creek SNOTEL site was 3.3° C (38° F). Thus the water discharging from Two Springs was 0.9° C (0.7° F) warmer than the average annual air temperature at the Lick Creek SNOTEL site (Figure 4-12). There was a slight seasonal change in water temperature at Two Springs. The water from Two Springs became 0.8° C (0.6° F) colder in the spring when snowmelt recharged the aquifer. During the summer Two Springs became warmer and in the fall the water temperature decreased again. Although lack of access prevented measurements of the water temperature during the winter, the trend of cooling water temperature in the fall suggests that the water temperature continued to decrease during the winter.

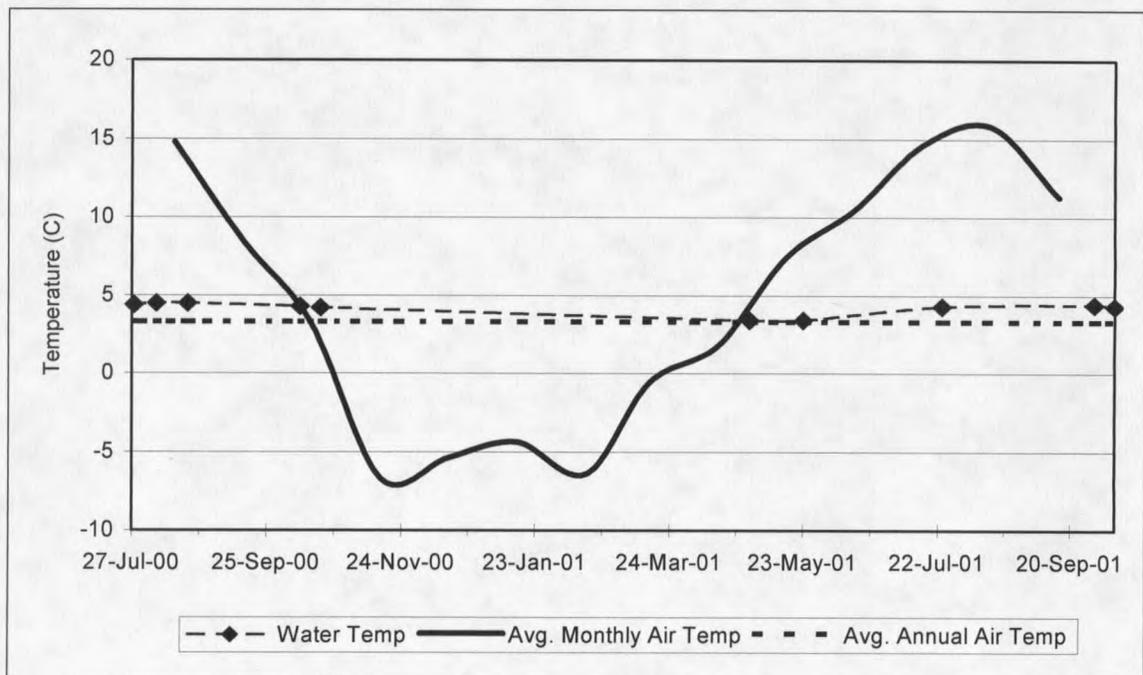


Figure 4-12. Water temperature of Two Springs and SNOTEL air temperature.

The temperature data from Two Springs indicates that the water has a relatively short residence time because the water was always fairly cold and did not rise more than 1 degree above the mean annual air temperature. Because the spring does not discharge warmer water, the flow system most likely does not circulate very deeply before discharging at Two Springs.

There are other springs in the Bozeman area that may be used for comparison to Two Springs. Lyman Springs is discharging from the Madison aquifer near the southern end of the Bridger Range. There are two separate springs discharging in at the Fish Technology Center in Bridger Canyon. One spring discharges adjacent to Bridger Creek on the south side of Bridger Canyon Road, and the other discharges from the toe of the slope on the north side of Bridger Canyon Road. The southern spring is warm while the northern spring is cool (Table 4-2). The bedrock near the springs is most likely Lodgepole Limestone but the area has not been thoroughly mapped. There are several faults in the area that may affect the groundwater flow. Thus, the aquifer the springs are discharging from may be the Madison, but the origin of the springs has not been demonstrated by existing geologic studies. However it is not unreasonable to assume that the springs are discharging from the Madison aquifer due to the proximity of the springs to Madison Group bedrock.

Lyman Springs is approximately 8 to 10 degrees warmer than Two Springs, but data regarding the seasonal temperature trend was not available. The springs at the Fish Technology Center have a different temperature trend from that of Two Springs. Both of the springs at the Fish Technology Center have warmer temperatures during the winter and cooler temperatures during the spring and summer (Table 4-2). This is because the aquifer does not receive appreciable recharge water from the surface during the winter. Without

recharge occurring, the springs discharge water that has had a longer residence time and/or deeper circulation, hence this water is warmer. Thus, the water temperature of the springs is out of phase with the air temperature. Table 4-2 also indicates that Two Springs is much colder than the other Madison springs, supporting the hypothesis that Two Springs is most likely discharging from a shallow groundwater flow system while the other springs are discharging from deeper flow systems.

Table 4-2. Comparison of water temperatures from Madison aquifer springs, in degrees C.

	Spring	Summer	Fall	Winter
Two Springs	3.4°	4.5°	4.3°	< 4.3°
Fish Technology Center – warm spring	21°	NA	NA	24° - 25°
Fish Technology Center – cold spring	5.5°	NA	NA	8.3°
Lyman Spring	Water temp. ranges from 12° to 14°			

NR – Data not reported.

Spring Water Chemistry

Drinking Water Quality

Water samples from Two Springs were collected to determine if water from the Madison aquifer meets drinking water standards. The water sample obtained from Two Springs on October 1, 2001 met EPA standards for drinking water for all parameters measured except total coliform bacteria (Tables 3-9, 4-3). Total coliform bacteria are common in nature and can be found in soil, surface water and shallow groundwater. Sources of coliform bacteria include soil erosion, or the feces of cold-blooded animals or warm-blooded animals (Hammer, 1986). Total coliform bacteria in a raw water supply is

easily treated by chlorination. Analysis for E. Coli is used as a more specific indicator for fecal contamination of water. The sample analysis indicated that E. Coli bacteria were absent. The October 10, 2001 water sample from Two Springs was analyzed for giardia and cryptosporidium, and neither of these organisms were detected in the sample. The absence of E. Coli, giardia and cryptosporidium further indicates that Two Springs was not contaminated with fecal material.

Water from Two Springs met EPA drinking water standards for all other parameters tested. The analyses did not include all of the parameters on the EPA Primary Drinking Water Regulations. For example, analysis for disinfectants, asbestos, organic chemicals and radionuclides were not performed although these parameters are on the EPA Primary Drinking Water Regulation list. These compounds are not expected to be present in the spring water, thus it was determined by the staff at the Bozeman water treatment plant that sampling for these parameters was not required in this study.

Table 4-3 provides a comparison between Two Springs water and other sources of municipal water for Bozeman. Water samples from the same time of year were used for the comparison. For most of the parameters tested, the water from Two Springs was not markedly different from the raw City water (Sourdough and Hyalite Creeks). The results for dissolved solids and turbidity were different for the two water sources. Two Springs had 159 mg/l of dissolved solids while raw City water had 84.9 mg/l. The higher concentration of dissolved solids is a result of dissolution of minerals from the Madison Group rocks as the water flows through the aquifer. The water from Two Springs was less turbid than the raw City water, with 0.33 NTU from the springs, compared to 1.22 NTU from Sourdough and

Table 4-3. Summary of water chemistry from Two Springs and City water sources.
Units are mg/l except where otherwise noted.

Parameter		Two Springs Oct. 1, 2001	Lyman Spring Oct. 1998	Raw City Water (Hyalite + Sourdough) Sept. 30, 2001	Treated City Water Average for 2000
General Water Quality	Total Hardness	95	165	76.4	88.73
	Calcium	25	38.4	20.64	23.71
	Magnesium	8	14.06	6.06	7.35
	Potassium	2	NR	NR	NR
	Sodium	2	NA	13.46	3.5
	Sulfate		24	0	0.95
	Chloride	< 1	NR	NR	NR
	Carbonate	< 1	NR	NR	NR
	Bicarbonate	117	NR	NR	NR
	Alkalinity	96	137	76	83.73
	Iron	< 0.03	0.01	0.039	0.04
	Fluoride	0.10	0.97	NR	1.01
	Nitrate + Nitrite	0.06	NR	NR	0.01
	Specific Cond.	178 μ mohs/cm	NR	NR	NR
	TDS	159	158.2	84.9	92.44
	Turbidity	0.33 NTU	NR	1.22 NTU	0.06 NTU
	pH	8.0	7.95	NR	8.45
Microbio logical	Total Coliform	Present	NR	NR	0
	E. Coli	Absent	NR	NR	
	Giardia	< 0.05/l (ND)	NR	NR	NR
	Cryptosporidia	< 0.05/l (ND)	NR	NR	NR
Trace Metals	Lead	< 0.005	NR	NR	<0.015
	Copper	<0.01	0.01	NR	< 1.3
	Antimony	ND	NR	NR	ND
	Arsenic	ND	NR	NR	ND
	Barium	ND	NR	NR	ND
	Beryllium	ND	NR	NR	ND
	Cadmium	ND	NR	NR	ND
	Chromium	ND	NR	NR	ND
	Mercury	ND	NR	NR	ND
	Nickel	ND	NR	NR	ND
	Selenium	ND	NR	NR	ND
	Thallium	ND	NR	NR	ND

ND - Not detected

NR - Data not reported

Hyalite Creeks. Surface water generally has higher turbidity than groundwater. This is because surface water erodes and transports suspended sediment and contains colloidal solids produced by biological activity and the decomposition of vegetation (Hammer, 1986).

Major Ions

An analysis of major ions in Two Springs water was performed in April and October 2001. This provided a basis for comparing seasonal changes in water chemistry and for comparing Two Springs to other springs discharging from the Madison aquifer. The concentrations of dissolved minerals from the October sampling were generally higher than in April. The overall discharge was three times higher in the spring when compared to the fall. The increased flow of the springs most likely diluted the dissolved ion concentrations during times of high flow. When plotted on a trilinear diagram (Figure 4-13) it is apparent that the proportion of dissolved ions was similar during both spring and fall.

Water chemistry reports from other springs were used to determine how the water from Two Springs compares to other springs discharging from the Madison aquifer. Table 4-4 provides a comparison of Two Springs, Lyman Creek, the warm spring at the Fish Technology Center, the cold spring at the Fish Technology Center, Giant Springs in Great Falls, and Big Springs in Lewistown.

When compared to water from other Madison aquifer springs, Two Springs water had lower concentrations of dissolved minerals than the other springs. The Two Springs water had approximately the same or slightly higher concentration of potassium than the other springs, but the concentrations of every other parameter was lower for Two Springs. The low concentrations of total dissolved solids suggest that water at Two Springs has been

in contact with the rock for a short time and is characteristic of groundwater near a recharge area.

Table 4-4. Comparison of water chemistry from Madison aquifer springs, in mg/l.

Parameter	Two Springs April 2001		Two Springs Oct. 2001	Lyman Springs	Fish Technology Center		Giant Springs	Big Springs
	Upper Spring	Lower Spring			Cold Spring	Warm Spring		
Calcium	20	20	25	38.4	50.1	54.8	86	65
Magnesium	7	7	8	14.06	20.6	22.3	30	19
Potassium	2	2	2	NR	0.77	1.4	2	<1
Sodium	2	2	2	NR	1.41	4.26	11	1
Chloride	ND	ND	ND	NR	0.23	0.19	6	<1
Sulfate	4	4	5	24	30	80	147	83
Bicarbonate	87	88	117	NR	181.3	208.8	227	201
Carbonate	ND	ND	ND	NR	ND	ND	ND	ND
SC	147	142	178	NR	385	448	NR	NR
TDS	56	65	159	158.2	192.9	263.7	425	398
pH	7.7	7.7	8.0	7.7	7.6	7.7	8.0	7.9

NR – Not reported

ND – Not detected

SC – Specific conductance at 25° C ($\mu\text{mohs/cm}$)

TDS – Total dissolved solids

Figure 4-13 is a trilinear diagram showing the proportional concentrations of ions from each of the springs. All of the springs share a similar geochemical signature, especially with regard to the cation concentrations. This is expected because the springs are derived from the same aquifer and they have acquired a similar geochemical signature as a result of flowing through similar rock materials.

However the anions show some differences between the spring waters. All of the samples contained little to no chloride, but the amount of sulfate and bicarbonate varies.

Giant Springs, Big Springs and the warm spring at the Fish Technology Center had higher

ratios of sulfate to bicarbonate as compared to the other spring waters. Sulfate may be derived from the dissolution of gypsum or anhydrite found within the Mission Canyon Formation. Increasing concentrations of sulfate may be a result of deeper circulation and/or longer residence time within the aquifer. The concentration of total dissolved solids among the spring waters increases along with the increasing sulfate to bicarbonate ratio. This also

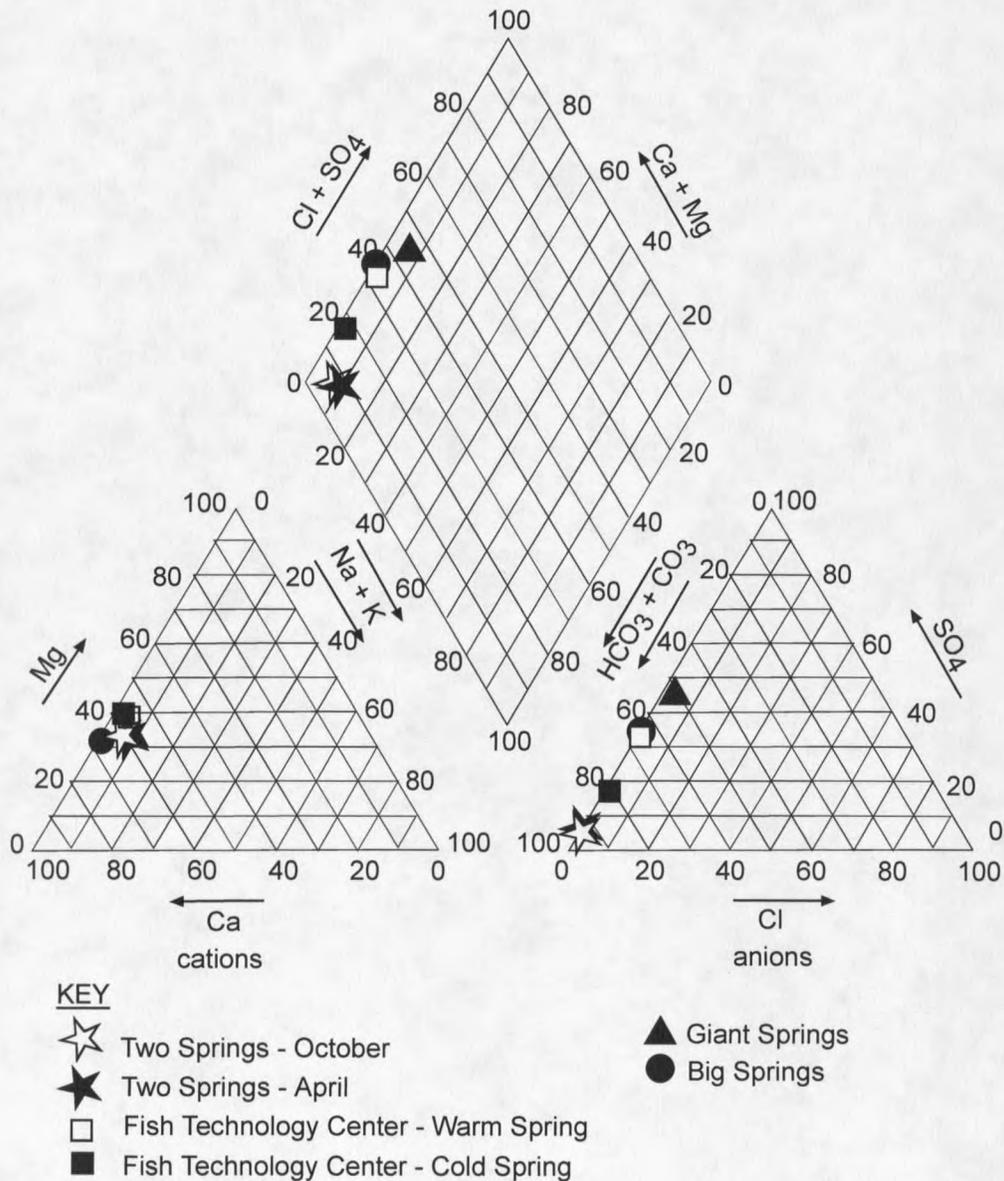


Figure 4-13. Trilinear diagram of Madison spring waters.

suggests that the water from Giant Springs, Big Springs and the warm spring at the Fish Technology Center have longer residence times, while water from Two Springs has a short residence time, indicating that Two Springs is near the recharge area.

Tritium

Samples for tritium analysis were collected from both orifices of Two Springs and from the snowpack in the vicinity of Two Springs. Groundwater with a tritium ratio of less than 2 to 4 TU is considered to have recharged prior to 1953. Water that has been in contact with the atmosphere since 1953 can have a tritium ratio significantly greater than 10 to 20 TU (Fetter, 1994). Tritium in precipitation is due to radioactive releases from nuclear testing. The amount of tritium in precipitation is dependent on tritium releases at a given time and also varies according to geography and season. Even though tritium decays with a known half life of 4500 +/- 8 days (International Atomic Energy Agency website, 2001), the residence time of groundwater cannot be calculated without knowing the amount of tritium in the recharge water as it entered the groundwater system. Because the amount of tritium in precipitation varies over time, it is difficult to obtain a precise value of residence time of groundwater based solely on the tritium ratio at the discharge point. Thus, tritium values are best used to estimate the relative ages of groundwater samples (Hendry, 1988).

The tritium value from the snowpack can be used as a baseline value for tritium that accumulated throughout the winter. The tritium ratio in the snowpack was 10.7 TU. The tritium ratios from the springs, 14.9 and 13.8 TU, are slightly larger than the snowpack tritium values. This indicates that the age of the spring water is similar to that of the snowpack.

Summary of Aquifer Potential

The objective of this research is to assess the potential of the Madison aquifer in Sourdough Canyon as a municipal water supply. This work is preliminary in nature in that the conclusions must be drawn from field observations and measurements. No wells exist in or near the study area for determination of the depth to saturation, hydraulic properties, hydraulic gradients, flow rates or subsurface geology. Nonetheless, it is possible to form a preliminary assessment of the aquifer based on the field data.

The Madison aquifer in the Sourdough Creek watershed has lithologic features that indicate it is a permeable rock unit. The predominant types of porosity are fracturing and post-Laramide karst. Fractures were observed throughout the study area, but were most abundant and obvious in the Mission Canyon Formation in the South Fork drainage. The fractures appeared to be open and interconnected. In some cases the fractures were so extensive that the rock was essentially reduced to fragments approximately 5 cm (2 inches) across. Karst openings were observed in several locations in the Mission Canyon Formation. Where the karst features are connected there is likely to be large permeability that could significantly increase groundwater flow. Dolomite porosity in thin sections of rocks from the Mission Canyon Formation was 0 to 7% (Table 3-1).

The stream losses observed in the study area, particularly in the South Fork and the Disappearing Stream, are most likely associated with infiltration along fractures and karst features. Many of the outcrops along the South Fork and the Disappearing Stream are highly fractured and karst features are present in these locations (Figures 4-3 and 4-5). The 5-day response time of Two Springs to precipitation (Figure 4-11) indicates that groundwater is able to flow quickly to the springs. Such rapid flow is characteristic of karst terrane.

Groundwater flow along fractures may focus dissolution of the carbonate rocks and open karst passageways. This is similar to the formation of karst at Lewis and Clark Caverns, where the development of karst occurred along the crest of an anticline (Aram, 1981).

Two Springs appears to be closely and quickly connected to the surface water. The 5-day response to precipitation, cold water temperature, low concentration of dissolved minerals and large tritium concentration all indicate a short residence time within the Madison aquifer. The source of Two Springs is not known but the springs may be connected to the Disappearing Stream. This could be confirmed with a tracer test. Due to possible impacts to the public water supply, a tracer test was not undertaken as part of this study. The total discharge from Two Springs is greater than that of the Disappearing Stream, so recharge to the springs must come from an additional source, such as infiltration from the surface or stream loss from the South Fork or Mystic Lake.

A plausible scenario for the groundwater system in Sourdough Canyon is illustrated in Figure 4-14. Water infiltrates the aquifer via fractures and karst near the Disappearing Stream and the South Fork drainage, flows a short distance at a shallow depth within fractures and/or karst, and is discharged at Two Springs. Two Springs is the lowest elevation where Madison Group rocks outcrop in the study area, at 1890 meters (6190 feet). Thus the groundwater may be discharging in this location because it is the lowest elevation in the drainage basin.

Because Two Springs has such a close connection with the surface water, the springs are most likely discharging from a localized saturated zone within the Madison aquifer that is at a higher elevation than, and is separate from the regional saturated zone. Thus, there are two groundwater flow systems (Figure 4-14). Two Springs may be discharging from a

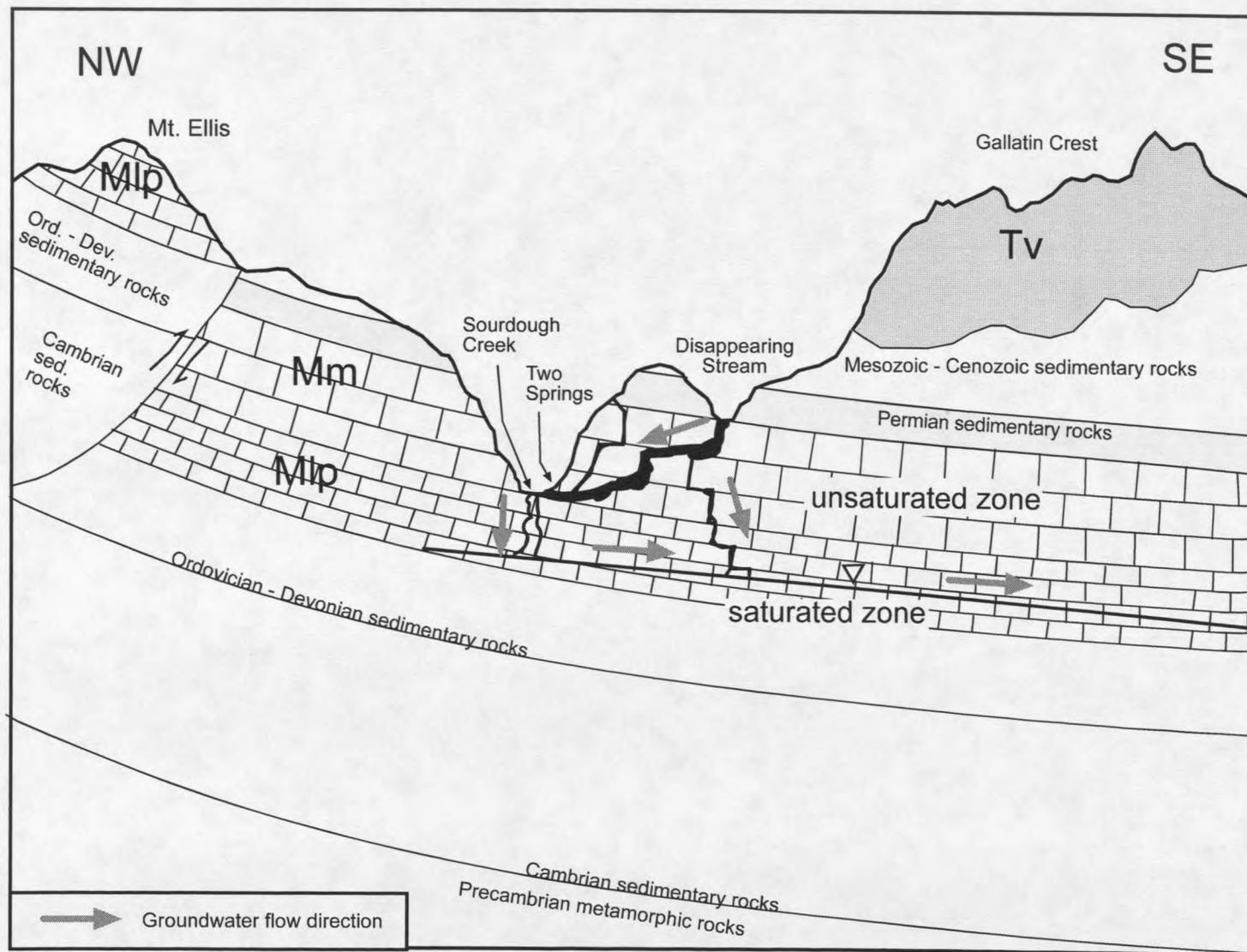


Figure 4-14. A schematic view of the Sourdough Canyon aquifer system. Not to scale.

shallow flow system that is only locally saturated and may flow through large pore spaces such as karst and fractures. Below this shallow flow system may lie a deeper, regional saturated zone.

Because no springs have been identified that discharge warm water with a higher concentration of total dissolved solids from the regional saturated zone of the Madison aquifer, the actual elevation of the regional saturated zone is not known. If present, the regional discharge point must be lower than 1890 meters (6190 feet). Without knowing the elevation of the regional saturated zone, it is not possible to predict the depth that a well would need to penetrate in order to tap the aquifer, and it is not possible to calculate the saturated thickness within the regional aquifer.

As shown on Figure 4-14, the saturated elevation lies within the Lodgepole Limestone. The Lodgepole Limestone is expected to have lower permeability than the Mission Canyon Formation. Fractures were observed in outcrops of the Lodgepole Limestone, especially along the South Fork, but karst features were neither observed nor expected within the Lodgepole Limestone. Moreover, the Lodgepole Limestone has fine-grained units such as siltstone and micrite, which have very low primary porosity. Examination of thin sections confirmed that the Lodgepole Limestone has lower porosity than the Mission Canyon Formation. However, Two Springs discharges from the Lodgepole Limestone. The springs at the Fish Technology Center may also be discharging from the Lodgepole Limestone. Thus, the secondary fracture permeability of the Lodgepole Limestone must be great enough to allow for the spring discharges. The permeability of the formation is most likely due to fractures, which have a relatively low volume and would create a low storage capacity in this part of the aquifer.

The regional groundwater flow pattern must be considered in order to estimate the elevation of the discharge point(s) and the elevation of the regional saturated zone.

Groundwater flows from recharge zones toward discharge zones. Clearly, the aquifer in the study area receives recharge from the losing streams, and thus the study area can be defined as a recharge zone.

Discharge areas are typically at low elevations and are characterized by springs, wetlands and rivers. The elevation of the water table in discharge zones remains more constant than in recharge zones. Here the groundwater flow converges at a location where the total hydraulic head is lowest. Drilling for groundwater in a discharge zone is ideal because the discharge area naturally receives groundwater flow from the surrounding area.

Two Springs represents a localized discharge point for a shallow flow system rather than a regional discharge point for the aquifer. Thus it is important to consider the locations of regional discharge points for the Madison aquifer. To this end, a limited amount of work outside the study area was done to locate a discharge zone for the Madison aquifer. Bear Creek and Hyalite Creek cross the Madison Group at elevations similar to or lower than Sourdough Creek and may represent cross-basin discharge points. To test this idea, Bear Creek and Hyalite Creek were gauged where they intersect the Madison aquifer to determine if they were gaining water from the aquifer.

Bear Creek intersects the Madison Group rocks at an elevation of 1750 meters (5750 feet). This is the lowest elevation of a Madison Group outcrop in the Mt. Ellis quadrangle, and the Mission Canyon Formation is highly karstic at this locality. It was expected that the aquifer would be discharging at this location, but no springs were observed and Bear Creek

was found to be losing water at a rate of $0.007 \text{ m}^3/\text{sec}$ (0.24 cfs). Based on this result, the saturated elevation in the Madison aquifer must be lower than 1750 meters in that area.

The elevation of the intersection of Hyalite Creek and the Madison Group rocks is 1920 meters (6300 feet). This is approximately 30 meters (100 feet) higher than the elevation at Two Springs, but it is lower than the majority of the South Fork anticline. Hyalite Creek was found to be gaining $0.039 \text{ m}^3/\text{sec}$ (1.4 cfs) and three small springs were observed on the eastern bank of the creek. The source of the springs could not be confidently determined. There is a large alluvial deposit in the area where Hyalite Creek intersects the Madison Group. The gaining stream may be a result of water draining from the alluvium, and it is also possible that the Madison aquifer is discharging at this location. The Madison aquifer may be discharging at this location after receiving recharge from the South Fork drainage and the Hyalite drainage. However, there is a series of folds and faults in the rocks between the South Fork and Hyalite Creek that may prevent groundwater from flowing directly from the South Fork to Hyalite Creek. The Madison aquifer near Hyalite Creek may also receive recharge from elsewhere within the Hyalite drainage.

Because the regional discharge area for the aquifer most likely lies neither within the study area nor the adjacent drainages, it is beyond the scope of this study to identify the specific location of the discharge area. The regional groundwater flow direction may be to the southeast along the plunge of the folds, and under the crest of the Gallatin Range below volcanic cover to an unrecognized discharge point.

Drilling Recommendations

The ideal drilling location would intersect a thick zone of regional saturation within the Madison aquifer. A drilling location near a spring that is discharging from the regional saturated zone would be ideal because that is indicative of a discharge area to which groundwater is naturally flowing. However, the elevation of the regional saturated zone within the Madison aquifer is not known. Thus, assessing the aquifer's potential for municipal use is difficult, and it is not recommended that a production well be installed without further research.

Drilling a test well is a logical next step in the process of evaluating the Sourdough Canyon area for a potential groundwater supply. Drilling a test well would be one reliable way to determine if a deep saturated flow system exists and if so, the depth to saturation in that system. Additional geologic information could be gathered by drilling a test well, to either verify or revise the geologic cross section. Hydraulic data could be gathered with a test well, such as the well yield, the aquifer hydraulic conductivity and transmissivity. Water samples could be analyzed to determine the water quality of groundwater within a deeper circulation system. Pumping tests could also be conducted to assess the effects, if any, of pumping on the discharge of Two Springs and the flow of the streams in the Sourdough Creek watershed. The water level in the well could be monitored to identify seasonal fluctuations of the saturated elevation. A test well could be of a smaller diameter than is required for a production well, which would reduce the cost of drilling. If a production well is later added, the test well could be used as an observation well in a pumping test.

There are several factors that constrain a possible test well location. The well should be located in a place where it will intersect the Madison aquifer at a low elevation, to increase

the chances of the aquifer being below the level of regional saturation. The depth to the Madison aquifer and to possible zones of saturation should be as shallow as possible in order to keep the costs of drilling reasonable. Finally, the drilling location must be in an area that is accessible by a drill rig, preferably along one of the existing Forest Service roads.

By applying these constraints, one drilling location within the primary study area becomes the clear choice. The area around Mystic Lake cabin is the most suitable location for drilling (Figure 4-15). This area has easy access from the existing road. The drilling would begin in the Quadrant Sandstone and would penetrate the entire thickness of the Madison aquifer. This would allow for the exploration of every potential water-bearing zone within the formation such as karst and fractures within the Mission Canyon Formation and fractures within the Lodgepole Limestone. According to the projections on the geologic cross section A-B, the top of the Madison formation would be expected at an elevation of approximately 1785 meters (5860 feet), or 140 meters (470 feet) below the ground surface. The formation is dipping at an angle of 31 degrees, and the bottom of the Madison formation would be expected at an elevation of 1275 meters (4190 feet), providing a total thickness of 510 meters (1675 feet). If the well were to penetrate the entire thickness of the Madison formation, the well depth would be 650 meters (2150 feet) below the ground surface. This is expected to be below the level of saturation within the aquifer. However, if the saturated elevation is deep then pumping water to the surface would require a significant amount of energy and infrastructure to provide the energy to the pump. Nonetheless, this well location presents a compromise between feasible drill rig access, penetration of the aquifer at a low elevation, and interception of the aquifer at a relatively shallow depth.

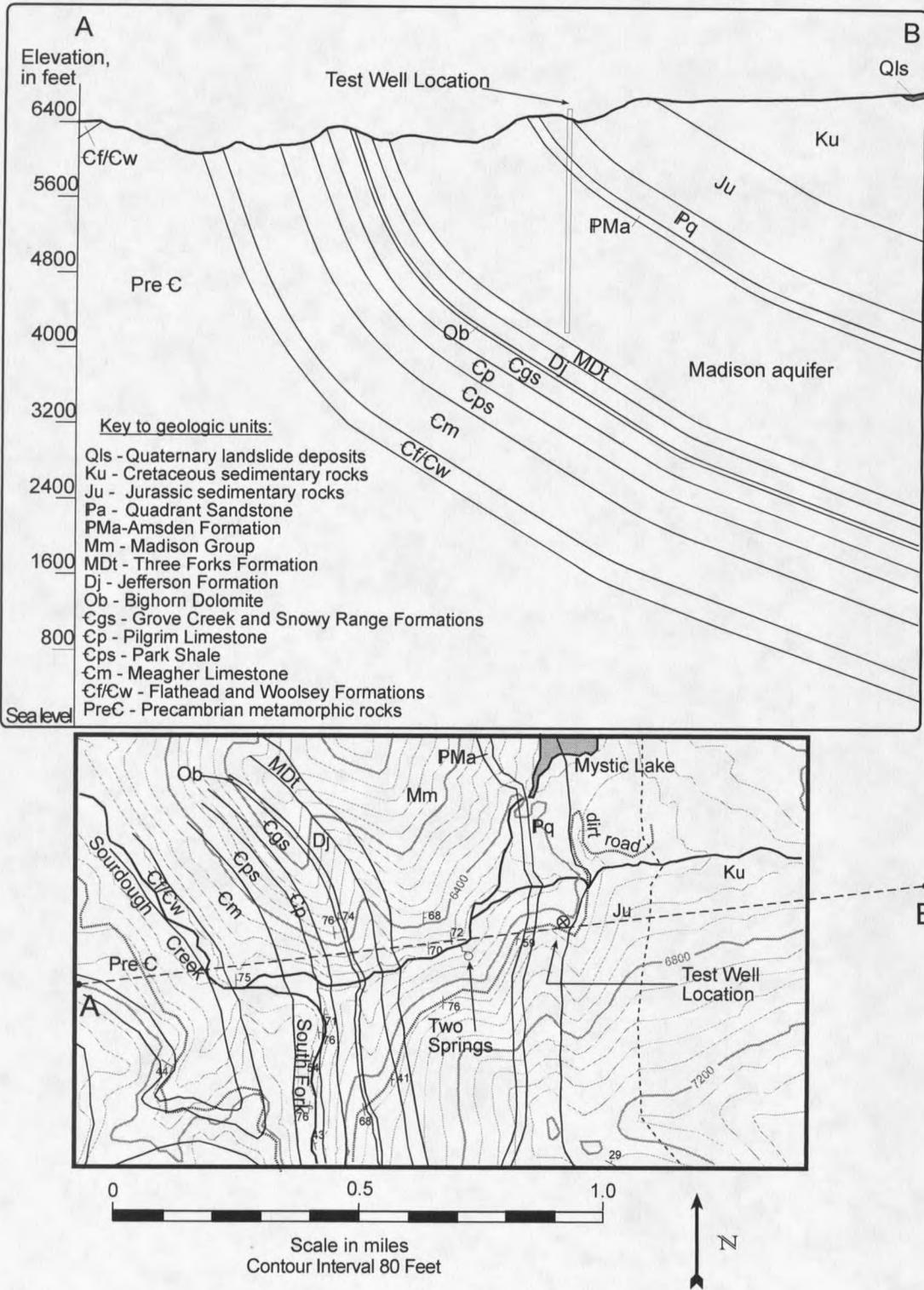


Figure 4-15. Recommended test well drilling location. Contact dashed where taken from Roberts (1964).

By contrast, the lowest elevation of the Madison aquifer within the subsurface of the study area is in the syncline that lies between the Sourdough Creek anticline and the Bear Creek anticline. Here the Madison group rocks are at an elevation of 900 meters (3000 feet) above sea level. However, the top of the Madison aquifer lies more than 365 meters (1200 feet) below the ground surface and the bottom of the Madison aquifer would be over 730 meters (2400 feet) below the surface. Moreover, there are no existing roads in this area. The large landslide deposit on the east side of Mystic Lake precludes drilling in that area because the unconsolidated debris could shift and cause the well casing to break.

Alternatives

Additional drilling locations may be found in the Hyalite Creek and Bear Creek areas (Figure 3-2). Neither of these areas were part of the study area for this project and significant research would be necessary before a drilling site could be identified.

The area around Hyalite Creek appears promising because it is possible the aquifer may be discharging there. However, this needs to be confirmed with further measurements of stream gain and/or loss along Hyalite Creek. Water chemistry may be a useful tool in identifying whether the springs observed on the bank of Hyalite Creek are discharging from alluvial material or from the Madison aquifer. Moreover, the recharge area for the aquifer in the Hyalite drainage is not known. A well drilled in the Hyalite drainage offers similar infrastructure advantages to a well in the Sourdough drainage. Water pumped from a well would not be far from the existing infrastructure which moves water from Hyalite Creek to the treatment plant.

Bear Creek holds the advantage of having the lowest elevation of a Madison aquifer outcrop on the Mt. Ellis quadrangle. Thus it is likely that the depth to saturation would be shallower there as compared to the Sourdough and Hyalite drainages. However, it is not known if there are barriers to groundwater flow between Sourdough Creek and Bear Creek. The presence of faults within the folded strata may reroute water in unexpected ways. Also, there is no existing infrastructure near Bear Canyon for the treatment or distribution of water.

Another way to gain water from the Sourdough Creek drainage basin is to prevent the loss of stream water as the streams flow across the Madison Group rocks. As has been shown in this study, the streams in the Sourdough drainage lose 3,200,000 m³/year (2,600 acre feet/year) to the Madison aquifer. If this stream loss could be prevented, the flow of the streams in the Sourdough drainage would theoretically increase by 3,200,000 m³/year (2,600 acre-feet/year) and the stream flow to the water treatment plant would increase. This could be accomplished by piping all or some of the stream water across the Madison Group rocks, thus preventing the stream water from infiltrating into the aquifer. This would be most effective along Sourdough Creek because the stream losses are greatest there, averaging 0.5 m³/sec (1.8 cfs), which is 50% of the total measured stream loss in the Sourdough watershed. The reach of the stream that flows over the Madison Group is only 300 meters (980 feet) long, so the water diversion would be relatively short. Based on the measurements made in this study, it is estimated that Sourdough Creek loses 1,600,000 m³/year (1,300 acre-feet/year). However, this estimate was made with measurements from the spring, summer and fall; winter measurements were not made. In order to provide a more accurate measurement of the stream loss on Sourdough Creek, flumes could be installed at the

upstream and downstream Madison Group contacts, and the stream loss could be measured over an entire year or more.

The Disappearing Stream may be another place to prevent stream losses because the stream ceases to flow naturally and all of the stream's flow is lost into the Madison aquifer. However, if water from the Disappearing Stream were not allowed to enter the aquifer, it is possible that the flow of Two Springs would be reduced, which may negate the benefit of capturing the water from the Disappearing Stream. The connection between the Disappearing Stream and Two Springs has not been proven during this study, but it could be confirmed or refuted with the use of a dye tracer test.

According to Scott Compton of the DNRC, stream losses are not appropriated to any existing water rights holders. However, the disadvantage to preventing stream loss is the impact to the riparian zone of the stream. If the entire stream flow were piped across the Madison Group, then the stream channel would be dry along that reach.

Water Rights

The major users of Madison aquifer water in Montana were interviewed in order to learn what types of water rights issues were encountered and how they were resolved. This may be useful in guiding the City through the process of obtaining water rights for use of the Madison aquifer in Sourdough Canyon.

Four municipalities and two bottling companies were interviewed regarding their use of Madison aquifer water. The details of water usage and water rights varied with each user, but the most relevant issues that emerged during the interviews are discussed below.

In the towns of Cascade, Stockett, and Belt the water levels in their wells have been declining in the past 1 to 5 years. This may be a reflection of increased use of the Madison aquifer in the Great Falls area. Also the recent drought has likely provided less recharge over the last two to three years, which may have contributed to water table decline in the Madison aquifer. None of these municipalities reported water rights issues regarding the Madison aquifer.

For Big Springs and Giant Springs, water rights to the springs are shared with the Department of Fish, Wildlife and Parks for the purposes of fish hatcheries located near the springs. At both Big Springs and Giant Springs, some portion of the flow must be made available for the fish hatcheries. At Giant Springs, the Montana Power Company objected to the withdrawal of water from the springs and the bottling company is compensating Montana Power Company for the lost revenue due to the water consumption.

There are two potential water rights issues confronting Bozeman that were identified by interviews with the DNRC. The first is the basin closure on the upper Missouri River drainage. This basin closure was enacted by the Montana State Legislature in order to protect the existing water rights within the basin and to protect the basin from over-allocation of the available water. However, there are exemptions to the basin closure for municipal use and groundwater use. Secondly, water rights conflicts are likely to arise if the City applies to pump water from the Madison aquifer. There are 113 claims to water rights on Sourdough Creek. The City may be asked to demonstrate that pumping from the aquifer does not impact the creek flows.

If the City intends to pump water from the Madison aquifer, an application for a water use permit must be filed with the Montana Department of Natural Resources and

Conservation (DNRC). Montana water law includes several criteria for issuance of a water use permit. Among these criteria is that the water rights of existing water rights holders must not be adversely affected. The complete list of criteria for a water use permit can be found in MCA Section 85-2-311(1). Once the permit is completed and filed, DNRC will conduct an environmental review to determine if an environmental impact statement is needed. If DNRC determines there is potential for adverse effect, a public notice of the application will be published in the newspaper and will be mailed to existing water rights holders in the areas that may be affected by the new use of water. Local water users will have the opportunity to file objections. If valid objections are received and cannot be resolved, the DNRC will conduct hearings before issuing a final order on the application for water use.

The City should begin monitoring on Sourdough Creek to establish a record of the creek's flow. A stilling well or flume with a data logger could be installed downstream from the confluence of Sourdough Creek and the South Fork. The monitoring point should be located downstream from the Paleozoic rocks. The discharge of the stream at the monitoring point will have to be manually measured several times in order to establish a stage-discharge relationship. At the present time the total flow of Sourdough Creek is not monitored. A record of the stream flow prior to groundwater exploration will be required to determine the actual long-term impacts to Sourdough Creek if and when the aquifer is pumped. This is likely to be of significant concern during the application process.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Madison Group rocks in the Sourdough Creek drainage basin consist of 430 meters (1420 feet) of limestone and dolomite. The Madison Group is comprised of the Lodgepole Limestone and the overlying Mission Canyon Formation. The permeability of the Madison Group rocks is enhanced due to fracturing, dissolution of karst features and dolomitization. The fracturing was observed primarily in the mid to upper Mission Canyon Formation in the South Fork drainage and along the Disappearing Stream. Fracturing may be due to karst collapse in the Mission Canyon Formation. Open karst features such as caves and vugs are characteristic of the upper Mission Canyon Formation and were observed in several locations in the South Fork and Disappearing Stream drainages. A maximum of 7% dolomite porosity was measured in thin sections. Paleokarst features were observed in the field, but these were filled with a well-cemented siliceous breccia and did not appear to impart any additional permeability to the formation.

The rocks in the Sourdough Creek area are folded into a series of southeast-plunging anticlines and synclines. There is evidence for internal deformation of Madison Group rocks, such as discordant dip angles, small-scale folding, slickensides and intense fracturing. There was no recognized spatial distribution of these features, but highly fractured rocks were most commonly observed in the mid to upper portions of the Mission Canyon Formation.

Each of the streams in the study area loses water as it flows across the Madison Group. The largest stream losses were measured on Sourdough Creek. On both Sourdough

Creek and the South Fork, the stream losses were greatest in the fall, and were smaller during spring and summer. The Disappearing Stream lost all of its water into the Madison aquifer. The stream loss from the Disappearing Stream was greatest in the spring when the stream flow was at its maximum; the stream flow and stream loss declined through the summer and fall. Based on stream loss estimates made on these three streams during the spring, summer and fall, the estimated annual stream loss is 3,200,000 m³ per year (2,600 acre-feet per year).

Stream discharge measurements were performed in the drainage basins adjacent to the Sourdough Creek watershed in order to determine if groundwater was discharging at these locations. At Bear Creek, stream discharge measurements showed that groundwater is not discharging from the Madison aquifer at Bear Creek. At Hyalite Creek, stream flow measurements indicated the stream is gaining water, but the stream gain was within the margin of error. Moreover, the stream gain may be from alluvial deposits that were observed on the east side of the stream. Thus, a discharge point from the Madison aquifer was not found outside the Sourdough Creek watershed.

The Madison aquifer is discharging via a spring near Sourdough Creek. Two Springs is the only spring that was found in the study area that is discharging from the Madison aquifer. Two Springs is located adjacent to Sourdough Creek and is at the lowest elevation of a Madison Group outcrop in the Sourdough drainage basin (1890 meters, 6190 feet). The springs discharge from two separate orifices in the Lodgepole Limestone. The discharge of the spring was steady through the winter, peaked sharply in the spring, and declined through the summer and fall. The average discharge between October 2000 and October 2001 was 0.035 m³/sec (1.23 cfs), and the spring flowed perennially throughout two summers with

below average precipitation. The total annual flow of Two Springs between October 2000 and October 2001 was 1,100,000 m³/yr (900 acre-feet/yr). By correlating a peak in the spring discharge with an isolated precipitation event, a response time of 5 days was evident, suggesting a rapid connection between the surface and the groundwater at Two Springs.

The water temperature and water chemistry of Two Springs also indicate a shallow circulation pattern and a short residence time for the spring water. The water temperature of Two Springs was generally cold, and was within 1 degree of the average annual air temperature. There was little seasonal fluctuation in the temperature of the spring water. The water chemistry of Two Springs indicates that the spring water has a similar proportion of cations when compared to other Madison aquifer springs, such as Big Springs, Giant Springs and Lyman Springs. Compared to these other springs, water from Two Springs has a low concentration of total dissolved solids, and lower proportions of chloride and sulfate. The water chemistry indicates that the water discharging from Two Springs has a short residence time within the aquifer, and has not migrated far from the recharge area. Tritium analyses of the spring water and snowpack yielded similar values, which also suggests a short residence time. Samples from Two Springs were analyzed for drinking water quality and met EPA drinking water standards for all parameters tested except for total coliform bacteria, which is treatable with chlorination. The water is suitable as a raw drinking water source.

The close and rapid connection between the surface water and Two Springs indicates that the springs are discharging from a shallow groundwater system that moves quickly through fractures and karst. Thus, Two Springs is most likely not connected to a deeply circulating, regional groundwater flow system. A regionally saturated system may exist at

depth below the locally saturated zone of Two Springs. However, there was no evidence during this study as to the elevation of, or the presence of, the regional saturated zone.

The only way to determine if a deep, regional saturated zone is present in the study area is to drill a test well. Much geologic and hydraulic data could be gathered by drilling a test well, such as saturated elevation, saturated thickness, well yield, hydraulic conductivity and transmissivity. Pumping tests could also be used to determine the effects of pumping, if any, on the discharges of Two Springs and Sourdough Creek. If the depth to saturation is deep, then pumping water from the well would be energy intensive and would require some infrastructure to provide the needed energy source.

The location of the test well is constrained by the geology as well as by the access from the existing Forest Service road. One drilling site was selected that intersects the full thickness of the Madison aquifer at a relatively low elevation, which increases the chances of the aquifer being saturated and decreases well depth. The test well should be drilled to the bottom of the Madison aquifer in order to penetrate all water bearing zones within the formation. Careful well logging would be required to clearly observe where the water bearing zones are with respect to the lithology of the aquifer. Based on the projections on the geologic cross section, the well would be 650 meters (2150 feet) deep.

Other drilling possibilities may exist outside the study area. There are exposures of Madison Group rocks at Hyalite Creek and stream discharge measurements showed that the aquifer may be discharging there. The City already has infrastructure in place for routing water from the Hyalite drainage to the water treatment plant. The Hyalite drainage was not included within the study area of this project, so further field research would be necessary to assess the aquifer potential in that area.

Another alternative for water development in the Sourdough drainage is to prevent stream loss in places where streams cross the Madison Group rocks. This could be done by piping the stream water across the reaches where the streams flow across the Madison Group. This would prevent water from leaving the stream and infiltrating the aquifer, and would result in a net gain in the stream flow in Sourdough Creek, one of the City's present water sources. This would be most effective on Sourdough Creek, where most of the stream losses occur and where the reach of the stream that flows across the Madison Group is relatively short.

If groundwater were pumped in large quantities from the Madison aquifer in the Sourdough Creek watershed, there would likely be water rights objections. There are 113 water rights holders on Sourdough Creek and the City may be asked to demonstrate that groundwater withdrawal does not reduce the flows on Sourdough Creek. In order to provide data to answer this question, the City should begin establishing a record of the creek's flow. This could be done by installing a flume or a stilling well and data logger along Sourdough Creek at a point downstream from the confluence of the South Fork and Sourdough Creek.

Recommendations

Based on the research presented herein, there are several options that the City should pursue in order to continue its assessment of possible water resources.

- Investigate the potential of the Madison aquifer in the Hyalite Creek drainage.

- Begin monitoring the discharge of Sourdough Creek.
- Investigate the feasibility of stream loss prevention on Sourdough Creek.
- Drill a test well near Mystic Lake.
- Use the test well to monitor the effects of pumping on the flows of Two Springs and Sourdough Creek.

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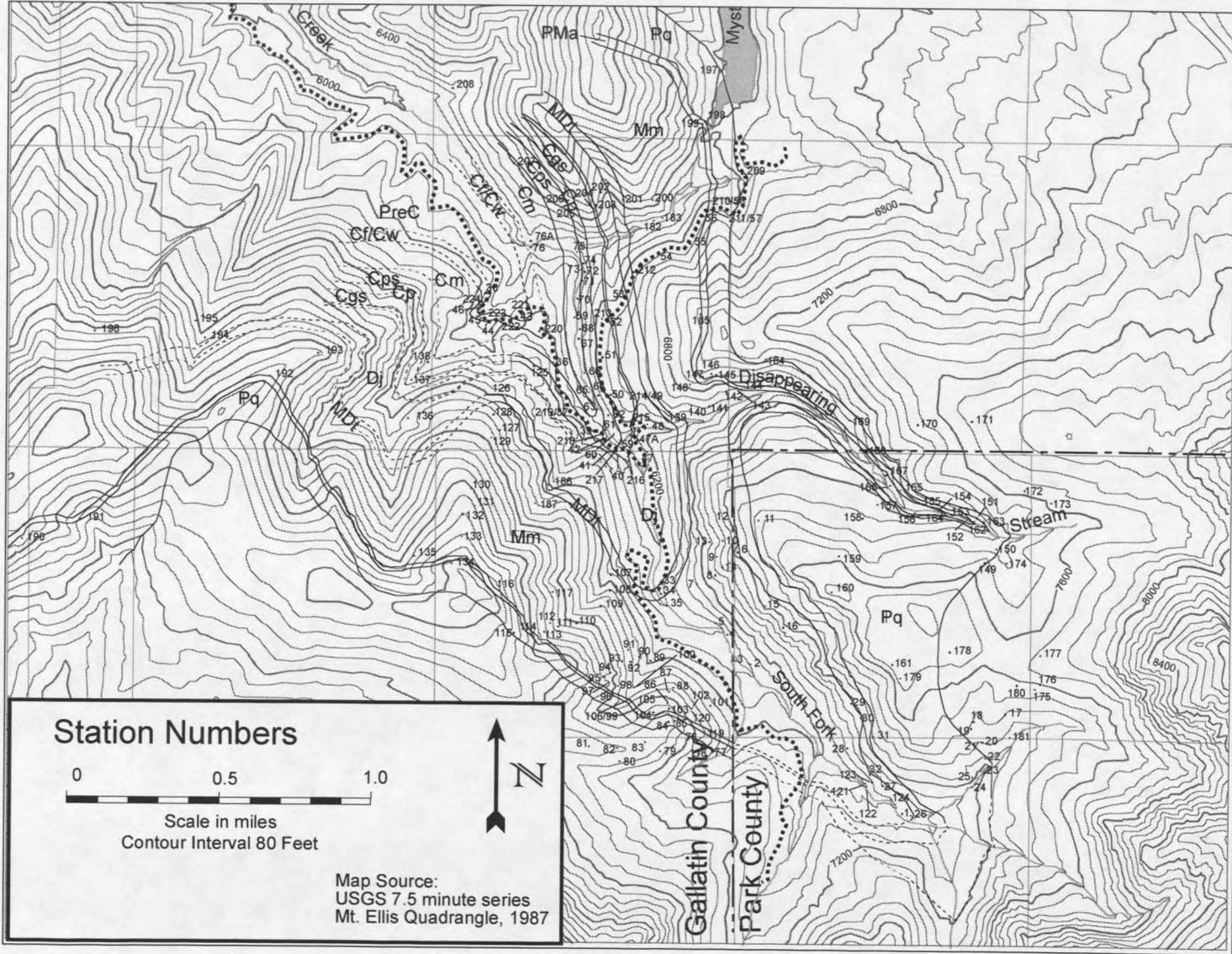
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APPENDICES

APPENDIX A

GEOLOGIC MAPPING DATA



Geologic Mapping Field Data

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
2		Tan-grey, dolomitic limestone. Fine grained, nearly micritic. Thin bedded, bedding thickness varies from 3 inches to 12 inches. Fractures/bedding planes filled with crystalline calcite.	Lodgepole	N 34 W	16 NE	Slicks trend N25W, dip 10
2A		Similar outcrop as #2. Spirifer brachiopods. Rapid fizz w/HCl.	Lodgepole	N 3 W	1 NE	
3		Brown limestone, fine grained with calcite veins. Reddish-brown-orange clay filling joints and bedding planes. Dip appears to vary across the outcrop. Slickensides present, also grooves in rock that resemble wood grain.	Lodgepole	N 10 W	14 NE	
4		Not sure if outcrop. Tan dolomite. Can't see bedding.				
5		Big outcrop. Limestone all over but texture, fossils, color change across the outcrop. Top- Massive highly fractured limestone, light grey. Middle-Limestone with some brachiopods, ooids, rugose coral. Slicks everywhere. Bottom - Grey/brown/reddish micrite, some laminated with red streaks. Some crystalline brown to grey with red.	Lodgepole	N 45 W N 30 W N 54 W N 27 W	43 NE 29 NE 38 NE 34 NE	
6		Tan/grey dolomite. Very little fizz even along a scratch. Grain size is small; approx. 1mm. Outcrop has weathered to a peachy color and is highly fractured. Rock is massive, not clear what is bedding. Orange-red chert was present. Some vugs were present. Outcrop is large and prominent.	Mission Canyon			Definite break in slope above here, with red soil. This location is the top of the Mission Canyon.
6A		Bedded dolomite		N 16 E N 24 E	48 SE 89 SE	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
6B		Clean sandstone, white, light grey, peach, very fractured.	Quadrant	N 53 E	23.5 SE	Not numbered on map.
7		Chert breccia. Bright orange, siliceous matrix with grey-tan chert clasts. Outcrop is large and not likely float. No bedding.				
8		Tan, fine grained dolomite. Very little fizz. Petrol odor, no fossils. Massive to med. Bedding. Highly fractured.	Mission Canyon			
8A		Chert breccia. Same lithology as #7.				Same location as 8.
9		Very large outcrop of Mission Canyon. Pale, grayish tan limestone. Big fizz w/ HCl. Grain size is 1mm+. No fossils. Chert stringers and 'oblate spheroids' that look like pebbles but aren't. Incredibly massive! Very fractured. Vuggy w/ small caves. Stands up in cone-shaped pinnacles.	Mission Canyon			
10		Brownish-grey, fine-grained dolomite. Similar to #8	Mission Canyon			
11		Massive, highly fractured, yellowish quartz sandstone and dolomite (or calcite cemented sandstone). Very fine grained, bedding visible.	Quadrant	N 5 W N 1 W	65 NE 50 NE	Saw float of breccia with red matrix. Phosphoria?
12		Thin-bedded, very fine grained limestone. Grey-tan-maroon. Also, dark maroon limestone.	Amsden	N 15 E	39 SE	
13		Thin to med. Bedded, grey limestone.	Mission Canyon Formation	N 33 E	26 SE	
14		Grey-tan dolomite. Massive, fractured.	Mission Canyon Formation			
14A		Breccia w/red matrix and sandstone (?) clasts. Also tan-grey dolomite.	Mission Canyon Formation	N 1 E	70 E	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
15		Upper: Quartz sandstone with orange filling along the joints. Some breccia with orange matrix and chert and sandstone clasts. Mid: red dirt Lower: Massive, pale yellow grey dolomite, cliff-former. Another 40 feet upslope, med.-dark grey limestone. Small, thin outcrop.	Quadrant Amsden Mission Canyon ??			This outcrop is next to an outcrop of Quadrant that is at the same elevation. But, more red dirt was seen above here.
16		Cliff. Top is orange chert breccia in places. Aside from that there is grey dolomite and also yellow sandstone. There are a few caves. Highly fractured. Very prominent outcrop. The bottom of this outcrop looks just like Mission Canyon seen elsewhere in this area.	Mission Canyon			
17		Pelecypod-bearing, light grey micrite. This is float within a big meadow.	Piper			Elev = 7420
18		Red, chunky limestone with some chert fragments.	Piper			
19		Red, coarsely crystalline limestone. Nice bedding.	Piper	N 44 W N 55 W N 22 W	8 NE 16 NE 6 NE	
20		Same as 19.	Piper	N 65 E	12 SE	Not sure of strike and dip.
21		Yellow to pale grey, crystalline dolomite. Finely laminated. Red filling along joints.	Piper	N 26 E	3 SE	
22		Pure white, clean quartz sandstone. Gorgeous outcrop at the edge of the meadow, along a small stream and a small waterfall. Not too fractured.	Quadrant	*N 24 E ?N 57 E N 89 E N 3 E	27 SE 15 SE 11 SE 71 SE	Joint surface
23		White, clean quartz sandstone. More fractured than 22.	Quadrant	N 7 W N 60 E	79 NE 14 SE	These dips are on joints, not bedding.
24		Quartz sandstone.	Quadrant		Horizontal	
25		Quartz sandstone.	Quadrant	N 19 E	14 SE	
26		Pale tan dolomite. Not too fractured.	Mission Canyon			

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
26A		Nearly white, soft, porous dolomite. Overall outcrop is tan colored, med. bedded, and has small vugs. This location is above 26.	Mission Canyon	N 2 W N 50 W	15 E 22 NE	Contact is just above here at a break in slope.
27		Grey-olive dolomite. Fine grained. Semi-fractured to very fractured. Outcrop is located on top of knob, next to scree slope. Caves at base of outcrop.	Mission Canyon	N 328 W	18 NE	On chert ribbon. Elev = 7040 feet
28		Peachy orange sandstone, very fractured. Float?		N 60 E	20 SE	
29		Pale tan limestone, rhombs visible. Highly fractured, massive. Caves and vugs present. Prominent outcrop. Also grey dolomite like 27.	Mission Canyon	N 5 E N 15 E N 328 W	2S E 7S E 8S E	Bedding visible above pinnacle. Trend of chert ribbon.
30		Tan-grey dolomite.	Mission Canyon			Elev = 7200, on the other side of scree slope seen from 27.
31		White qtz. sandstone. Brown-grey chert ribbon approx. 1 foot thick. Fractured.	Quadrant	N 75 E	8 SE	Strike and dip taken on top of chert bed.
32		Upper Mission Canyon contact.				
33		Silty limestone. Weathered to orange, fresh surface is grey, micritic w/ red mottling. Also, silty conglomerate, dolomitic matrix, limestone and dolomite clasts. Also chert or sandstone clasts.	Three Forks			
34		Mottled, yellow-grey dolomite, medium bedding. Some petroleum odor.	Three Forks	N 56 E S 61 W	4S E 40 NW	Not sure about 2 nd strike and dip.
35		Thin bedded, brownish grey limestone. Possibly fossiliferous. Fine to med grained < 1mm. Contains reddish limy silty layers. Dip is unusually steep.	Lodgepole	N 17 E N 4 W N 17 E	62 SE 63 SE 73 SE	
36		Dark grey micritic limestone. Looks bioturbated, and has thin bedding and some fossils. Weathers to light grey and tan.	Meagher	S 12 W	54 NW	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
37		Hard, dark grey oolitic limestone. Some fossils, also micritic in places. Bedding is thin to medium.	Meagher	S 27 E S 21 E	72 SW 87 SW	The first dip is from a small fold.
38		Grey limestone with dark green, round glauconite grains. Also fine grained, grey brown limestone or micrite. Also flat pebble conglomerate.	Pilgrim	N 19 W S 57 E	55 NE 44 SW	
39		Green shale. Dip direction is highly variable. Nearly horizontal along the roadcut, but vertical bedding along the stream on a more resistant outcrop (Pilgrim)).	Park Shale	S 41 W	7 NW	
40		Columnella Magna, with approx 30 feet of red and green shale below that.	Cgs			
41		Dense, thick bedded, dark grey, oolitic limestone. Mottled grey and brown. Moderately fractured to highly fractured in places. Also there is approx. 4 feet of red and green shale that looks just like Cgs within the upper Pilgrim. Possibly small scale folding.	Pilgrim	S 87 E S 1 E	62 SW 59 ° plunge	Strike and dip of fracture plane (contains slickensides). Trend of slickensides.
42		Pilgrim/Park Shale contact		S 33 E	67 SW	Strike and dip measured in Pilgrim.
43		Mostly white feldspar and white quartz.	Pre C			
44		Highly fractured, grey-brown, medium to coarsely crystalline limestone.	Meagher?			
45		Micaceous schist; contains chlorite, muscovite, biotite. Very fissile, weak rock. Also white feldspar as in #43.	Pre C			
46		Gneiss, amphibolite and fissile schist.	Pre C			
47		Brown, finely crystalline limestone. Slight petroleum odor.	Jefferson			
48		Brown, finely crystalline dolomite, with petroleum odor. Cuspate weathering on some surfaces. Not clear which surfaces are bedding.	Jefferson	N 00 N 8 W	73 E 66 NE	Measured on cusplate weathered surface.
49		Mottled cream and tan dolomite. Nicely bedded. Also contains yellow-green silty dolomite.	Bighorn	N 4 W	79 NE	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
50		Flat pebble conglomerate and fossils in a grey limestone; weathers to pale green. Nice bedding. Also limestone conglomerate with trilobite hash.	Cgs	N 9 E N 1 W N 6 W N 1 E	41 SE 59 NE 76 NE 39 SE	On fossil hash.
51		Columnella magna	Cgs			Location uncertain
52		Crystalline limestone with glauconite.	Cgs	N 12 W	68 NE	Location uncertain
53		Grey, fine grained limestone, micritic in spots.	Dj	N 2 W	41 NE	
54		Grey limestone, some fossils (rugose coral)	Lodgepole	N 00	76 E	
55		Light grey dolomite.	Lodgepole			
56		Light grey - tan limestone. Thin interbedded yellow-orange silty dolomite or siltstone.	Lodgepole	N 11 E	59 SE	
57		Mission Canyon/ Amsden contact. No Big Snowy.				
58		Amsden/ Quadrant contact.				
59		Grey crystalline limestone.	Pilgrim			
60		Grey brown, petroliferous limestone, some ooids, mottled grey and brown.	Pilgrim	N 87 E	76 SE	
61		Large, tall outcrop of grey and brown mottled limestone. Sparry, with rapid fizz with HCl. Petroliferous odor.	Pilgrim	N 6 W N 6 W	78 NE 84 NE	Stations 59, 60 and 61 all had very similar lithology.
62		Light grey, crystalline limestone. Petroleum odor.	Pilgrim	N 6 W	74 NE	
63		Light grey, fine grained limestone with tan weathering. Contains trilobites. Thin, wavy bedding.	Meagher			
64		Light brown to grey oolitic limestone. Ooids are very prominent. Petroleum odor; weathers to dark grey. Thin bedding. Huge outcrop, tall cliff.	Pilgrim	N 1 E	74 SE	
65		Float containing several intact columnella magna on both sides of stream. Very flat floodplain, underlain by Park shale here.	Park Shale			
66		Grey crystalline limestone with glauconite, limonite flecks and small pebbles. Also flat pebble conglomerate. Medium to thin bedding.	Upper Park Shale	N 34 W N 6 W	40 NE 52 NE	Location uncertain
67		Same as #66	Park Shale	N 16 W	43 NE	Location uncertain

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
68		Tan shale. Across the stream is limestone with glauconite.	Park Shale			Location uncertain
69		Grey brown limestone, highly oolitic. Some pebbles embedded in the rock. Blocky bedding. Large cliffs.	Pilgrim	S 7 W	76 NW	Location approximate
70		Grey, bioturbated, limestone; thin bedded. Micritic in places.	Pilgrim	N 13 E	54 SE	
71		Grey, crystalline limestone with limonite and glauconite. This is below and downstream of cliffs that are probably Pilgrim.	Pilgrim	N 6 W	76 NE	Location approximate.
72		Brown, crystalline limestone. Oolitic, but not as oolitic as #69. Undulating bedding surface.	Pilgrim	N 2 E	71 SE	Location approximate.
73		Grey, bioturbated limestone with some pebbles and some ooids. Poorly bedded and fine grained.	Pilgrim			
74		Grey oolitic limestone. Massive.	Pilgrim	N 2 W	72 NE	
75		Medium to dark grey, fine grained limestone; homogeneous. Thin bedded and ledgey.	Pilgrim			
76		Mottled grey and tan limestone. Thin, lumpy bedding.	Meagher	N 2 E	70 SE	Confluence of S. Fork and Sourdough Creeks.
76A		Same as 76	Meagher	N 00	75 E	North side of creek.
77		Dark grey micritic limestone; thin bedded; no fossils seen.	Piper	N 40 E	45 SE	Dip direction inconsistent w/ regional structure.
78		Dark grey micrite, thin bedding.	Piper	N 30 E	31 SE	
79		Red soil				
80		Grey to pinkish grey sandstone. No reaction to HCl. Small grains, < 1mm, can't see clastic texture, even with 16x hand lens.	Klk?			
81		Same lithology as 80		N 54 E	69 SE	Strike and dip unclear, many planes.

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
82		Yellow/grey/reddish silty sandstone with pebble conglomerate. Bedding obvious. No reaction to HCl.	Swift	*S 75 E	89 SW	
83		Sandstone w/ calcite cement, rapid fizz w/ HCl. Contains limonite, rounded grains that resemble ooids. Texture looks clastic.	Swift, poss Reirdon	S 51 E	23 SW	Top of knob, elev. 7440
84		White quartz sandstone with calcite cement. Rapid fizz w/ HCl; and rounded, translucent grains. 5 feet upslope is a yellow, clastic sandstone with a rapid reaction to HCl. 5 feet downslope is a clean, peachy quartz sandstone with no reaction to HCl.	Quadrant			
85		Clean white quartz sandstone. Little to no reaction to HCl.	Quadrant	* N 29 E	78 NW	
86		Elev. 7225. Quadrant last seen about 15 feet uphill.	Quadrant/ Mission Canyon contact			
87		Light brown dolomite, weak reaction to HCl.	Mission Canyon	N 19 E	88 NW	See air photo for location of Mission Canyon pillar. Elev 7240 - 7260?
88		Huge outcrop of orange-red chert breccia and quartzite. Some dolomitic parts. Highly fractured, with reaction to HCl along fractures. In one location, found cement that was white rhombus crystals, but no reaction to HCl, even along a scratch.	Mission Canyon			Dubbed the 'chert house.'
89		Light tan-grey dolomite. Finely crystalline, no fossils, thick bedded to massive. Some chert, showing dip is vertical	Mission Canyon	294	90	Elev 6790 Also saw float of white rock w/ fine laminations, similar to Big Snowy.

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
90		Large, prominent outcrop. Tan, sparry limestone, brecciated in places, with limestone clasts in a red matrix. Small caves present. Moderately fractured. Massive bedding, but dip appears to be vertical. Some joints filled with red.	Mission Canyon			Across the drainage from 89
91		Grey, finely crystalline limestone. Medium bedding. One fossil coral. Red soil and Quadrant float above here.	Mission Canyon	280 N 65 W	80 SE 90	Elev. 6960
92		Large, prominent outcrop. Light grey dolomite. Finely, crystalline, grain size < 1mm. Massive and moderately fractured.	Mission Canyon			
93		Large, prominent outcrop. White to pale tan/ grey dolomite or calcite cemented sandstone. Fairly hard, slightly scratchable w/ file. Slow reaction to HCl. Grain size approx. 1 mm.	Mission Canyon			Elev 7070
94		Huge outcrop, the biggest we've seen yet. White or very pale buff dolomite. Contains chert nodules coated w/ calcite, looks like M&Ms. Massive bedding, fractured on the small scale, fragments approx 1 cm ³ .	Mission Canyon			Elev. 7270
95		White dolomite, with limestone in places. Moderately fractured to highly fractured in certain beds. No lithologic change between moderately fractured and highly fractured beds. Samples 19 and 95 NF (not fractured) and 95 F (fractured). Chert stringers suggest vertical dip. Contains slickensides with red siliceous veneer, 90 degree dip.	Mission Canyon		90	
96		Cross bedded quartz sandstone. Has red siliceous veneer with possible slickensides.	Quadrant	290	85 S	Strike and dip measured on cross beds.
97		Pale yellow crystalline limestone, sparry. Huge outcrop.	Mission Canyon			Trending 286 degrees

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
98		White to buff, massive limestone. Moderately fractured.	Mission Canyon			Elev. 7100
99		White dolomite. The Mission Canyon/Pma/Quadrant contact has been easy to follow down this drainage. Amsden must be thin, it does not outcrop.				Elev 7000
100		Stream disappears at 6860'				
101		White quartz sandstone with weak reaction to HCl. Contains chert stringers	Mission Canyon or Quadrant?			Location approx-imate
102		White, soft dolomite. Also white dolomitic breccia. Matrix is pale grey, clasts are dolomite. Moderately fractured.	Mission Canyon			Large outcrop, seen on air photo. Amsden not seen
103		Whitish dolomitic breccia. Massive.				
103 A		10 to 20 feet uphill from #103. Pink dolomite and dolomite/chert breccia.	Mission Canyon			Just uphill from here is Quadrant, station 85.
104		Dolomitic breccia with quartz sandstone.	Mission Canyon			
105		White to pale pink dolomite	Mission Canyon			Elev 7200
106 /99		Peachy pink limestone, possibly brecciated or fractured. Noticeably orange-pink. Perhaps Amsden staining? 10 feet uphill, tall outcrop of dolomite. Mission Canyon outcrops form a straight line from 104 to 106 and across the drainage to the big pillars.	Mission Canyon			Elev 7120 This replaces #99, original location was wrong. Altimeter is often wrong and misleading.
107		Dark grey, micritic limestone. Medium bedding. Some chert, few crinoid fossils.	Lodgepole	S 48 E	29 SW	
108		Massive, pale grey limestone, little chert, some limestone breccia, but not much. One small cave.	Mission Canyon			Elev. 6900.
109		Massive, brown/grey limestone; finely crystalline and sparry.	Mission Canyon			Altimeter = 7080 seems too high
110		Pale tan limestone, thin bedded and fractured. Outcrop weathers to dark grey on outside. Crystalline, 1 mm grains, homogeneous.	Mission Canyon or Lodgepole	S 60 E	76 SW	On chert stringer Nice outcrops across the drainage to the north.
111		Whitish, massive dolomite with light colored chert.				7290'

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
111 A		Across the stream a bit more – Tan dolomite, limier on spots. Medium bedding.				
112		White quartz sandstone with carbonate cement. Weak reaction to HCl. Very homogeneous, fine-grained < 1mm. Outcrop does not look like Quadrant.				7370'
113		Pale tan to pale pink dolomite and limestone. Brecciated in places. Massive and fractured.	Mission Canyon			7460'
114		Large outcrop. Light pink to light tan dolomite and limestone. Massive, brecciated in places. Fractured. Chert stringers. Weathers in cone shaped pinnacles as does much of Mission Canyon.	Mission Canyon	S 34 E	90	On chert stringer Elev 7575
115		Clean quartz sandstone. In one location, brecciated with orange matrix.	Quadrant	* S 64 E * S 52 E	76 SW 74 SW	Top of ridge. Quadrant began at 7760 and up
116		White to pale, pale grey limestone with some breccia. This is just at the base of Quadrant scree, just below the big ridge.	Mission Canyon Upper contact			7865
117		Red soil with grey and red limestone	Mm	S 57 E	78 SW	7540 location approximate.
118		Grey micrite with pelecypod fossils. Also dirty grey brown sandstone.	Piper and Swift	190	32 W	Elev. 7050 Same general location as stations 77-78.
119		White, hard, quartz sandstone.	Quadrant			Very near Je/ Quadrant contact.

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
120		Large outcrop with three towering rocks. White to pale tan limestone and dolomite. Near the stratigraphic top of the outcrop, the rock has a very vuggy surface that almost looks like a veneer. Under that is soft limestone. Much of the outcrop is brecciated, with small clasts, approximately pea sized. Chert stringer dipping at 45 degrees. But outcrop appeared to have near vertical dip. Rock is massive and moderately fractured.	Mission Canyon	N 20 E ? N 42 E N 18 E	87 W 72 W 90	Upper Mission Canyon, near Amsden contact. Amsden does not outcrop.
121	N 45 30.542' W 110 54.565'	Large outcrop of orange-brown chert and crumbly, silty dolomite. Dolomite has red clay where it's weathered but is creamy white on a fresh surface. Highly fractured.	Mission Canyon			
122	N 45 30.540' W 110 54.555'	Tan/grey dolomite. Massive, moderately fractured.	Mission Canyon			
123	N 45 30.548' W 110 54.539'	Large outcrop of medium tan/grey brecciated dolomite and some limestone. Brecciated clasts are > 1 cm ³ . Moderately fractured to highly fractured. Large cave.	Mission Canyon			
124	N 45 30.495' W 110 54.451'	Pale grey to white, soft dolomite. Also tan dolomite, fairly hard. Highly fractured. Calcite veining.	Mission Canyon			
125	N 45 31.741' W 110 55.943'	Brown, fine grained limestone. Slightly petroliferous. Thin to medium bedding.	Dj	N 13 W N 15 W N 17 W	84-90 90 80 NE	
126		Not an outcrop, but float of yellow brown silty limestone at a break in slope.	MDt			
127	N 45 31.565' W 110 56.075'	Thin bedded, fossiliferous limestone. Medium grained (1 mm), sparry. Not sure if outcrop, but stratigraphic position seems right.	Lodgepole			

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
128	N 45 31.610' W 110 56.098'	Thin bedded, fossiliferous limestone. Dark brownish grey, micritic. A few chert stringers parallel with bedding. Strike and dip varies across the outcrop.	Lodgepole	N 84 W S 15 W S 72 W S 33 E	22 N 27 NW 4 NW 72	Bedding parallel to chert. Plunge of slickensides.
129	N 45 31.543' W 110 56.118'	Thin bedded, grey limestone. Fossiliferous in some places. Coarsely to medium sparry in some places (1-2 mm)	Lodgepole	S 28 E N 26 W S 52 W S 00	9 SW 29 NE? 19 NW 12 W	
130	N 45 31.387' W 110 56.198'	Massive limestone, tan-grey, sparry > 1mm. Moderately fractured. Poss. Mission Canyon/Lodgepole contact	Mission Canyon	S 6 W	77 W	Bedding?
131	N 45 31.337' W 110 56.181'	Same as 130.	Mission Canyon			
132	N 45 31.318' W 110 56.228'	Massive dolomite. Small scale fractures, but not highly fractured overall.	Mission Canyon			
133	N 45 31.249' W 110 56.239'	Massive, yellowish limestone. Porous, brecciated.	Mission Canyon	S 67 E	31 SW	
134	N 45 31.174' W 110. 56.273'	Quartz sandstone, cross-bedded.	Quadrant	*S 67 E	37 SW	
135	N 45 31.200' W 110 56.423'	Pale, yellow-pink limestone. Seen at the base of Quadrant scree.	Mission Canyon			
136		Light brown, finely crystalline limestone. Texture ranges from micrite to > 2mm sparry. Some petroliferous odor, fossiliferous with large rugose corals and brachiopods. Some ooids, cusped weathering. Thin to medium beds. Sheer cliffs with a blocky, planar look.	Dj	* S 10 W	20 W	
137		Massive, cliff-forming limestone. Light brown, crystalline.	Dj?			Elev. 6600'
138		Dark brown to grey limestone. Small cliffs.	Dj?			Just above break in slope, shale below here.
139	N 45 31.617 W 110 55.384	Cliff forming, brownish grey limestone. Abundant fossils: crinoids, brachiopods, rugose corals. Micritic to medium crystalline.	Dj	N 19 W 163 165	83 E 58 E 88 E	
139 A		Brown crystalline limestone with gorgeous fossils: brachiopods, gastropods, corals. Petroliferous odor.	Dj	157		Upstream ~ 75' from 139.

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
140	N 45 31.633' W 110 55.299'	Large, tall outcrop. Yellow-orange quartzite with chert fragments. Brecciated.	Mission Canyon			
141	N 45 31.634' W 110 55.216'	More chert breccia	Mission Canyon	Trend ~ 300		
142	N 45 31.677' W 110 55.149'	Massive limestone, 3 large pillars. Pale tan/grey with no bedding. Highly fractured..	Mission Canyon			
143		Middle pillar of the 3. Vuggy, massive, fractured, but possibly bedding visible. Brecciated in places (photo). Algal laminations show bedding. Finely crystalline (< 1 mm)	Mission Canyon	188 182	E	
144	N 45 31.698' W 110 55.073'	Light grey sandy dolomite or calcareous cemented sandstone.	Lower Quadrant			
145	N 45 31.723' W 110 55.180'	Very red soil with fragments of red siltstone.	Amsden			
146	N 45 31. 726' W 110 55.205'	Quartz sandstone	Quadrant			
147	N 45 31.716' W 110 55.251'	Quartz sandstone, very fractured.	Quadrant	Trend ~ 328		
148	N 45 31.698' W 110 55.299'	Chert breccia	Mission Canyon	168	70 W OT?	
149	N 45 31.183' W 110 54.073'	Quartz sandstone	Quadrant	Trend ~ 303		
150	N 45 31.309' W 110 54.144'	Quartz sandstone, very fractured, with red filling in joints.	Quadrant	285 N 16 W	4 N 79 SW	Not sure which S&D is bedding.
151	N 45 31.309' W 110 54.114'	Very red soil, likely Quadrant/Pma contact	Quadrant/ Amsden	S 78 E	28 NE	
152	N 45 31.308' W 110 54.152'	Tan dolomite with some algal laminations. Medium bedding, moderately fractured.	Mission Canyon	N 30 W	20 - 28 NE	This is the upstream gauging station of the Disappearing Stream
153	N 45 31.310' W 110 54.216'	Very red soil and break in slope. Mission Canyon is very narrow just along the stream banks.	Pma/ Mission Canyon			
154	N 45 31.339' W 110 54.258'	Very fractured breccia with limestone matrix and limestone and dolomite clasts. Outcrop was right along the stream bottom. Sample obtained.	Mission Canyon			
155	N 45 31.331' W 110 54.306'	Pale tan dolomite, some red filling in joints or fractures.	Mission Canyon	N 25 W 315	19 NE 12 NE	
156		Bedded, very pale grey dolomite. Weathers orange to white. Vuggy. The entire outcrop is overhanging the stream, forming a grotto.	Mission Canyon	N 55 W 255	11 NE 10 NE	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
157	N 45 31.351' W 110 54.520'	Quadrant float and a seep.	Quadrant			
158		Chert breccia float				Location uncertain.
159	N 45 31.199' W 110 54.689'	Quadrant on knob near top of ridge. Reddish quartz sandstone, very fractured. Strike and dip not possible.	Quadrant			
160	N 45 31.092' W 110 54.720'	Quadrant on ridgetop.	Quadrant	** N 32 W	9 NE	
161	N 45 30.891' W 110 54.452'	Grey, yellow, tan chert. Hard and vuggy.	Phosphoria	N 31 W	15 NE	On Quadrant below chert.
162	N 45 31.304' W 110 54.122'	Lower Amsden contact				
163	N 45 31.303' W 110 54.078'	Upper Amsden contact				
164	N 45 31.337' W 110 54.246'	Along Amsden				
165	N 45 31.397' W 110 54.429'	Red shale.	Amsden	N 80 W N 18 W	27 NE 24 NE	Microfold
166		Yellow dolomite, vuggy, thick bedded. Chert stringers and high to moderate fractures. Silty or fine-grained sand in places. Color ranges from yellow to pale tan to tan/grey. Bedding ranges from thick to medium. Bottom of outcrop is massive, vuggy and highly fractured with no bedding.	Mission Canyon	N 25 W 301	10 NE 12 NE	
167	N 45 31.433' W 110 54.486'	Darker tan/grey dolomite, sparry, with thick chert stringers.	Mission Canyon	285	26 NE	
168	N 45 31.504' W 110 54.574'	Quadrant scree. Stream ended just downhill from here.	Quadrant			
169	N 45 31.596' W 110 54.637'	Quadrant	Quadrant	N 50 W	30 NE	
170	N 45 31.587' W 110 54.364'	Limestone or carbonate cemented sandstone, with limonite and glauconite.	Je	264	20 NE	
171	N 45 31.589' W 110 54.135'	Thin bedded, buff, bioclastic limestone. Marine fossils.	Je	N 64 W 104	10 NE 12 NE	
172	N 45 31.394' W 110 53.914'	Grey, bioclastic limestone. Lots of pelecypods.	Je	N 16 E N 24 W N 48 E	22 E 12 NE 05 E	
173	N 45 31.354' W 110 53.806'	Porous quartz sandstone. Very round grains, not well cemented, well bedded. Also quartz pebble conglomerate.	Kk			
174	N 45 31.186' W 110 53.91'	Medium grey, fine grained sandstone, thin beds.	Kk	S 30 W	75 NW	
175	N 45 30.819' W 110 53.867'	Reddish, oolitic limestone with limonite cement. Blocky bedding.	Je	N 2 E	14 SE	

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
176	N 45 30.838' W 110 53.846'	Grey, thin bedded bioclastic limestone.	Je	100 N 12 E N 34 E	12 N 4 SE 14 SE	Wavy bedding
177	N 45 30.917' W 110 53.844'	Bioclastic limestone, as seen at station 176.	Je	8 N 40 E 18	18 SE 28 SE 20 SE	
178	N 45 30.928' W 110 54.229'	Yellow-brown, deeply weathered oolitic limestone with limonite cement.	Je			
179	N 45 30.850' W 110 54.418'	Multicolored chert (red, grey, amber), vuggy and hard. Not well exposed, possibly just a thin layer.	Phosphoria			
180	N 45 30.833' W 110 53.939'	Reddish, oolitic limestone, with limonite cement.	Je	N 40 W 310	25 NE 12 NE	
181	N 45 30.680' W 110 53.963'	Oolitic limestone with limonite cement and abundant chert.	Je			
182	N 45 32.166' W 110 55.450'		Lodgepole	N 1 W	70 NE	
183	N 45 32.172' W 110 55.417'	Lodgepole/Mission Canyon contact		N 5 W	72 NE	
184	N 45 31.770' W 110 54.990'	Quartz sandstone with cross beds, dissolution pockets. Poorly cemented at the bottom, but still cliff-forming.	Quadrant	N 63 W	29 NE	GPS coordinates are near the top of the outcrop, which is the Quadrant/Je contact.
185	N 45 31.899' W 110 55.257'	Base of Quadrant scree, break in slope. Likely upper Mission Canyon contact.				
186	N 45 31.402' W 110 55.875'	Dark brown limestone, thin bedded, slight petroleum smell.	Dj?	S 15 E	78 SW	
187	N 45 31.348' W 110 55.929'	Dark brown, brecciated dolomite. Massive. Looks like Mmc but strat. Location is wrong. Also, typical Mission Canyon is lighter colored.	Lodgepole?			
188	N 45 31.404' W 110 58.402'	Tan/brown micrite, thin beds.	Lodgepole			
189	N 45 31.313' W 110 58.169'	Row of amber chert outcrops. Massive chert.				
190	N 45 31.238' W 110 58.019'	Quadrant near Pma contact. Meadow meets sandstone cliff.	Quadrant	N 72 E	76 SE	
191	N 45 31.292' W 110 57.798'	Lower Quadrant contact.	Quadrant/ Pma			
192	N 45 31.710' W 110 57.028'	Upper Mm contact.	Mm			
193	N 45 31.781' W 110 56.821'	Mm	Mm	N 82 W	46 NE	
194	N 45 31.831' W 110 57.266'	Dj float	Dj			
195	N 45 31.888' W 110 57.337'	Fossil hash, brown, sparry limestone.	Lodgepole			

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
196		Buff, silty, shaley limestone. Top of landslide as seen on air photo.	MDt?			
197	N 45 32.600' W 110 55.172'	Je/Quadrant contact Je is reddish conglomerate (Swift)	Je/ Quadrant	N 10 W	50 NE	
198	N 45 32.450' W 110 55.274'	Quadrant/Amsden contact near dam. Lower Quadrant is pale gray dolomite	Quadrant/ Amsden			
199	N 45 32.442' W 110 55.285'	Amsden/ Mission Canyon contact Mission Canyon is tan dolomite and dolomite breccia There is red soil downsection from the upper Mission Canyon but it is volcanic, not Amsden. Grey dolomite is under the volcanic material.	Amsden/ Mission Canyon			
200	N 45 32.228' W 110 55.453'	Mission Canyon/Lodgepole contact	Mission Canyon/ Lodgepole	N 2 E	68 SE	
201	N 45 32.232' W 110 55.585'	Lodgepole/MDt contact	Lodgepole /MDt			
202	N 45 32.258' W 110 55.679'	Dj first outcrop. Brown/grey limestone with petroleum odor. Dj/MDt contact may be upstream from here.	Dj			
203	N 45 32.218' W 110 55.701'	Dj/Ob contact Strike and dip is on Ob	Dj/Ob	N 3 W	74 NE	
204	N 45 32.206' W 110 55.710'	Ob/Cgs contact Strike and dip is on Cgs	Ob/Cgs	N 8 W	76 NE	
205	N 45 32.210' W 110 55.783'	Cgs/Cp contact	Cgs/Cp			
206	N 45 32.221' W 110 55.813'	Cp/Cps contact	Cp/Cps			
207	N 45 32.339' W 110 56.029'	Cm, probably below Cps/Cm contact.	Cm			
208	N 45 32.553' W 110 56.291'	Cm	Cm			
209	N 45 32.299' W 110 55.082'	Quadrant/volcanic contact, near cabin.	Quadrant/ Tv			
210	N 45 32.207' W 110 55.211'	Quadrant/Amsden contact	Quadrant/ Amsden			
211	N 45 32.209' W 110 55.236'	Amsden/Mission Canyon contact	Amsden/ Mission Canyon			
212	N 45 32.019' W 110 55.541'	Lodgepole/MDt contact	Lodgepole /MDt			
213	N 45 31.882' W 110 55.660'	Upper Cgs	Cgs			
214	N 45 31.574' W 110 55.548'	Cgs/Ob contact	Cgs/Ob			
215	N 45 31.584' W 110 55.538'	Ob/Dj contact	Ob/Dj			
216	N 45 31.525' W 110 55.369'	Upper Cgs	Cgs			

#	GPS Location	Lithology	Formation	Strike	Dip	Comments
217	N 45 31.517' W 110 55.595'	Cgs/Cp contact	Cgs/Cp			
218	N 45 31.552' W 110 55.654'	Cp/Cps contact	Cp/Cps			
219	N 45 31.615' W 110 55.787'	Cp with small fold	Cp			
220	N 45 31.850' W 110 55.920'	Slope wash covering bedrock. This point is in Cps.	Cps			
221	N 45 31.905' W 110 56.013'	PreC	PreC			
222	N 45 31.887' W 110 56.044'	Highly weathered, orange shale particles. Cw Pale colored carbobnate (Cm) float.	Cw			
223	N 45 31.881' W 110 56.105'	Cm/Cw contact	Cm/Cw			
224	N 45 31.930' W 110 56.149'	Cm/Cw contact again.	Cm/Cw			

APPENDIX B

STREAM GAUGING SPREADSHEETS

Stream Gauging Spreadsheet
Sourdough Creek, Fall 2000

Stream Name: Sourdough Creek Date: 10-Oct-00 Weather: 60s, cloudy
Location: Upstream Time: 4:26 PM Partner: Linda Lennon

	Y	Y	U	Q	
Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
2.40	0.00	0.00	0.00	0.0079	5.82
2.52	0.40	0.12	0.33	0.0113	8.34
2.60	0.37	0.11	0.41	0.0074	5.44
2.65	0.30	0.09	0.48	0.0084	6.18
2.70	0.40	0.12	0.48	0.0093	6.84
2.75	0.40	0.12	0.45	0.0160	11.77
2.82	0.75	0.23	0.37	0.0084	6.20
2.85	0.77	0.23	0.37	0.0124	9.10
2.90	0.70	0.21	0.30	0.0101	7.41
2.95	0.69	0.21	0.28	0.0095	6.99
3.00	0.78	0.24	0.24	0.0089	6.53
3.05	0.80	0.24	0.21	0.0061	4.50
3.10	0.55	0.17	0.14	0.0037	2.70
3.15	0.70	0.21	0.10	0.0031	2.30
3.20	0.69	0.21	0.08	0.0019	1.37
3.25	0.7	0.21	0.09	0.0012	0.91
3.30	0.71	0.22	0.14	0.0019	1.38
3.35	0.7	0.21	0.21	0.0020	1.46
3.40	0.52	0.16	0.22	0.0029	2.16
3.50	0.52	0.16	0.15	0.0016	1.18
3.60	0.55	0.17	0.05	0.0004	0.31
3.70	0.44	0.13	0.00	0.0000	0.00
3.80	0.35	0.11	0.00	0.0000	0.00
3.90	0.3	0.09	0.00	0.0006	0.42
4.05	0.28	0.09	0.09	0.0006	0.42
4.15	0.17	0.05	0.07	0.0003	0.20
4.25	0.15	0.05	0.04	0.0001	0.07
4.35	0.1	0.03	0.00	0.0000	0.00
4.60	0	0	0.00		0.00
		Total Discharge (m ³ /s) =		0.1360	100%
		convert to gal/day =		3,094,574	
		convert to gal/min =		2,149	
		convert to liters/s =		136.01	
		convert to cfs =		4.80	
		convert to cfm =		288.1	

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Stream Gauging Spreadsheet
Sourdough Creek, Fall 2000

Stream Name: Sourdough Creek Date: 10-Oct-00 Weather: 60s, cloudy
 Location: Downstream Time: 3:30 PM Partner: Linda Lennon

Tape reading (m)	Y Depth (ft)	Y Depth (m)	U Velocity (m/s)	Q Discharge (m ³ /s)	% of Total Discharge
1.90	0	0.00	0.00	0.0000	0.00
2.00	0.17	0.05	0.04	0.0009	0.98
2.10	0.3	0.09	0.18	0.0013	1.40
2.20	0.3	0.09	0.11	0.0006	0.69
2.30	0.32	0.10	0.03	0.0009	0.90
2.40	0.21	0.06	0.22	0.0022	2.32
2.50	0.25	0.08	0.39	0.0029	3.12
2.60	0.32	0.10	0.30	0.0029	3.08
2.70	0.25	0.08	0.38	0.0020	2.12
2.80	0.33	0.10	0.11	0.0006	0.59
2.90	0.35	0.11	0.00	0.0008	0.81
3.00	0.28	0.09	0.18	0.0011	1.12
3.10	0.32	0.10	0.06	0.0010	1.11
3.20	0.26	0.08	0.19	0.0022	2.29
3.30	0.28	0.09	0.33	0.0025	2.63
3.40	0.22	0.07	0.32	0.0021	2.27
3.50	0.47	0.14	0.15	0.0035	3.66
3.60	0.52	0.16	0.30	0.0069	7.30
3.70	0.63	0.19	0.47	0.0079	8.36
3.80	0.6	0.18	0.37	0.0039	4.10
3.90	0.4	0.12	0.08	0.0039	4.10
4.00	0.57	0.17	0.39	0.0072	7.59
4.10	0.59	0.18	0.42	0.0080	8.43
4.20	0.67	0.20	0.41	0.0080	8.43
4.30	0.67	0.20	0.37	0.0063	6.64
4.38	0.7	0.21	0.38	0.0054	5.75
4.50	0.1	0.03	0.31	0.0018	1.89
4.60	0.27	0.08	0.32	0.0024	2.52
4.70	0.28	0.09	0.25	0.0021	2.20
4.80	0.3	0.09	0.22	0.0019	1.99
4.90	0.38	0.12	0.15	0.0012	1.26
5.00	0.3	0.09	0.07	0.0003	0.34
5.10	0.2	0.06	0.00	0.0000	0.00
6.20	0.16	0.05	0.00		0.00
		Total Discharge (m ³ /s)		0.0944	100%
		convert to gal/day =		2,148,272	
		convert to gal/min =		1,492	
		convert to liters/s =		94.42	
		convert to cfs =		3.33	
		convert to cfm =		200.0	

Stream Gauging Spreadsheet
Sourdough Creek, Fall 2000

Stream Name: Two Springs

Date: 10-Oct-00

Weather: 60s, partly cloudy

Location: Sourdough Creek

Time: 2:48 PM

Partner: Linda Lennon

	Y	Y	U	Q	
Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
0.90	0	0.00	0.00	0.0000	0.00
0.95	0.01	0.00	0.00	0.0000	0.04
1.00	0.12	0.04	0.01	0.0000	0.18
1.05	0.13	0.04	0.03	0.0001	0.39
1.10	0.15	0.05	0.05	0.0002	0.89
1.15	0.23	0.07	0.08	0.0005	2.06
1.20	0.26	0.08	0.16	0.0007	2.95
1.25	0.26	0.08	0.17	0.0003	1.52
1.30	0.25	0.08	0.00	0.0000	0.00
1.35	0.25	0.08	0.00	0.0002	0.98
1.40	0.26	0.08	0.11	0.0004	2.01
1.45	0.23	0.07	0.13	0.0005	2.35
1.50	0.24	0.07	0.16	0.0005	2.15
1.55	0.27	0.08	0.09	0.0004	1.95
1.60	0.25	0.08	0.13	0.0005	2.46
1.65	0.23	0.07	0.17	0.0007	3.15
1.70	0.25	0.08	0.21	0.0008	3.50
1.75	0.26	0.08	0.19	0.0007	3.04
1.80	0.28	0.09	0.14	0.0005	2.38
1.85	0.25	0.08	0.12	0.0005	2.47
1.90	0.3	0.09	0.14	0.0008	3.68
1.95	0.31	0.09	0.21	0.0010	4.29
2.00	0.26	0.08	0.23	0.0010	4.66
2.05	0.23	0.07	0.33	0.0010	4.39
2.10	0.2	0.06	0.26	0.0007	3.15
2.15	0.22	0.07	0.18	0.0007	2.95
2.20	0.22	0.07	0.21	0.0010	4.47
2.25	0.3	0.09	0.28	0.0012	5.57
2.30	0.23	0.07	0.34	0.0011	4.88
2.35	0.2	0.06	0.32	0.0010	4.67
2.40	0.24	0.07	0.30	0.0012	5.25
2.45	0.27	0.08	0.30	0.0008	3.43
2.50	0.1	0.03	0.19	0.0003	1.37
2.55	0.1	0.03	0.21	0.0015	6.72
2.70	0.26	0.08	0.17	0.0013	6.07
2.90	0	0.00	0.00		0.00
		Total Discharge (m ³ /s) =		0.0222	100%
		convert to gal/day =		504,923	
		convert to gal/min =		351	
		convert to liters/s =		22.19	
		convert to cfs =		0.78	
		convert to cfm =		47.0	

Stream Gauging Spreadsheet
Sourdough Creek, Spring 2001

Stream Name: Sourdough Creek Date: 23-May-01 Weather: warm, clear, dry
Location: upstream Time: 11:40 AM Partner: John Paterson

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
10.9	3.32	0	0.00	0.00	0.0000	0.00
11.4	3.47	0.2	0.06	0.18	0.0021	0.57
11.7	3.57	0.33	0.10	0.35	0.0033	0.90
12	3.66	0.23	0.07	0.53	0.0033	0.90
12.3	3.75	0.43	0.13	0.27	0.0027	0.74
12.6	3.84	0.33	0.10	0.24	0.0015	0.41
12.9	3.93	0.3	0.09	0.10	0.0006	0.16
13.2	4.02	0.15	0.05	0.08	0.0004	0.11
13.5	4.11	0.15	0.05	0.11	0.0108	2.93
14.0	4.27	0.88	0.27	0.51	0.0109	2.94
14.2	4.33	0.96	0.29	0.75	0.0067	1.81
14.3	4.36	0.97	0.30	0.74	0.0135	3.66
14.5	4.42	0.91	0.28	0.81	0.0086	2.33
14.6	4.45	0.75	0.23	1.49	0.0200	5.42
14.8	4.51	0.7	0.21	1.48	0.0191	5.16
15.0	4.57	0.7	0.21	1.45	0.0219	5.94
15.2	4.63	1.05	0.32	1.28	0.0233	6.31
15.4	4.69	1.15	0.35	1.01	0.0206	5.59
15.6	4.75	1.05	0.32	1.01	0.0209	5.66
15.8	4.82	1.1	0.34	1.08	0.0211	5.71
16.0	4.88	1.08	0.33	1.00	0.0189	5.11
16.2	4.94	1.08	0.33	0.88	0.0164	4.45
16.4	5.00	1.2	0.37	0.68	0.0132	3.58
16.6	5.06	0.98	0.30	0.62	0.0098	2.65
16.8	5.12	0.95	0.29	0.47	0.0098	2.66
17.0	5.18	1.07	0.33	0.57	0.0106	2.87
17.2	5.24	1	0.30	0.53	0.0107	2.90
17.4	5.30	0.9	0.27	0.69	0.0120	3.26
17.6	5.36	0.96	0.29	0.70	0.0118	3.19
17.8	5.43	0.99	0.30	0.60	0.0096	2.61
18.0	5.49	0.94	0.29	0.47	0.0063	1.71
18.2	5.55	0.88	0.27	0.27	0.0037	1.01
18.4	5.61	0.82	0.25	0.20	0.0028	0.76
18.6	5.67	0.8	0.24	0.17	0.0023	0.62
18.8	5.73	0.8	0.24	0.14	0.0023	0.64
19.0	5.79	0.78	0.24	0.18	0.0028	0.76
19.2	5.85	0.76	0.23	0.21	0.0031	0.84
19.4	5.91	0.64	0.20	0.27	0.0028	0.76
19.6	5.97	0.61	0.19	0.21	0.0022	0.61

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Stream Gauging Spreadsheet
Sourdough Creek, Spring 2001

Stream Name: Sourdough Creek Date: 23-May-01 Weather: warm, clear, dry
Location: downstream Time: 1:00 PM Partner: John Paterson

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
5.4	1.65	0	0.00	0.00	0.0000	0.00
5.8	1.77	0.21	0.06	0.13	0.0004	0.10
6.1	1.86	0.05	0.02	0.06	0.0002	0.04
6.4	1.95	0.06	0.02	0.18	0.0041	0.94
6.7	2.04	0.7	0.21	0.40	0.0088	2.04
7	2.13	0.66	0.20	0.53	0.0070	1.64
7.2	2.19	0.6	0.18	0.68	0.0086	2.00
7.4	2.26	0.6	0.18	0.86	0.0099	2.31
7.6	2.32	0.65	0.20	0.85	0.0103	2.41
7.8	2.38	0.7	0.21	0.80	0.0108	2.51
8	2.44	0.8	0.24	0.75	0.0124	2.88
8.2	2.50	0.78	0.24	0.94	0.0151	3.52
8.4	2.56	0.85	0.26	1.05	0.0177	4.11
8.6	2.62	0.9	0.27	1.12	0.0172	4.00
8.8	2.68	0.8	0.24	1.05	0.0136	3.17
9	2.74	0.8	0.24	0.78	0.0094	2.19
9.2	2.80	0.88	0.27	0.44	0.0059	1.38
9.4	2.86	0.87	0.27	0.29	0.0039	0.90
9.6	2.93	0.87	0.27	0.19	0.0042	0.99
9.8	2.99	0.71	0.22	0.41	0.0065	1.52
10	3.05	0.7	0.21	0.59	0.0074	1.72
10.2	3.11	0.45	0.14	0.85	0.0075	1.75
10.4	3.17	0.56	0.17	0.76	0.0052	1.22
10.6	3.23	0.92	0.28	0.15	0.0023	0.53
10.8	3.29	0.99	0.30	0.11	0.0039	0.91
11	3.35	0.97	0.30	0.32	0.0067	1.56
11.2	3.41	1	0.30	0.41	0.0106	2.48
11.4	3.47	0.8	0.24	0.92	0.0146	3.40
11.6	3.54	0.93	0.28	0.90	0.0155	3.60
11.8	3.60	0.92	0.28	0.90	0.0134	3.12
12	3.66	0.61	0.19	1.01	0.0111	2.58
12.2	3.72	0.6	0.18	0.96	0.0094	2.19
12.4	3.78	0.48	0.15	0.91	0.0079	1.85
12.6	3.84	0.46	0.14	0.91	0.0079	1.83
12.8	3.90	0.48	0.15	0.89	0.0205	4.78
13.2	4.02	1.15	0.35	0.59	0.0125	2.90
13.4	4.08	1.25	0.38	0.53	0.0115	2.68
13.6	4.15	1.13	0.34	0.51	0.0096	2.24

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Stream Gauging Spreadsheet
Sourdough Creek, Spring 2001

Stream Name: Two Springs Date: 23-May-01 Weather: warm, clear, dry
Location: Sourdough Creek Time: 10:30 AM Partner: John Paterson

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
12.3	3.75	0	0.00	0.00	0.0000	0.00
12.2	3.72	0.2	0.06	0.01	0.0001	0.06
12	3.66	0.22	0.07	0.02	0.0000	0.04
11.8	3.60	0.23	0.07	0.00	0.0000	0.00
11.6	3.54	0.24	0.07	0.00	0.0000	0.00
11.5	3.51	0.23	0.07	0.00	0.0000	0.00
11.3	3.44	0.23	0.07	0.00	0.0000	0.00
11.1	3.38	0.25	0.08	0.00	0.0003	0.25
10.9	3.32	0.4	0.12	0.07	0.0010	0.97
10.7	3.26	0.4	0.12	0.20	0.0015	1.44
10.5	3.20	0.36	0.11	0.22	0.0014	1.37
10.3	3.14	0.33	0.10	0.22	0.0015	1.43
10.1	3.08	0.33	0.10	0.26	0.0009	0.83
10.0	3.05	0.3	0.09	0.33	0.0009	0.88
9.9	3.02	0.3	0.09	0.32	0.0009	0.88
9.8	2.99	0.33	0.10	0.30	0.0012	1.20
9.7	2.96	0.42	0.13	0.40	0.0016	1.59
9.6	2.93	0.42	0.13	0.44	0.0017	1.65
9.5	2.90	0.44	0.13	0.41	0.0017	1.67
9.4	2.86	0.44	0.13	0.43	0.0018	1.70
9.3	2.83	0.4	0.12	0.47	0.0018	1.77
9.2	2.80	0.37	0.11	0.55	0.0021	2.01
9.1	2.77	0.39	0.12	0.62	0.0024	2.37
9.0	2.74	0.4	0.12	0.71	0.0030	2.88
8.9	2.71	0.5	0.15	0.71	0.0034	3.28
8.8	2.68	0.53	0.16	0.70	0.0038	3.73
8.7	2.65	0.6	0.18	0.76	0.0040	3.88
8.6	2.62	0.51	0.16	0.79	0.0037	3.61
8.5	2.59	0.51	0.16	0.78	0.0037	3.58
8.4	2.56	0.5	0.15	0.79	0.0037	3.59
8.3	2.53	0.55	0.17	0.73	0.0035	3.39
8.2	2.50	0.53	0.16	0.66	0.0032	3.13
8.1	2.47	0.5	0.15	0.69	0.0032	3.14
8.0	2.44	0.5	0.15	0.70	0.0030	2.93
7.9	2.41	0.4	0.12	0.75	0.0028	2.71
7.8	2.38	0.4	0.12	0.75	0.0033	3.24
7.7	2.35	0.41	0.12	1.02	0.0039	3.75

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Stream Gauging Spreadsheet
South Fork, Fall 2000

Stream Name: South Fork Date: 3-Oct-00 Weather: Cool, cloudy
Location: Upstream Time: 3:00 PM Partner: Linda Lennon

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
8	2.44	0.5	0.15	0.00	0.0000	0.00
8.2	2.50	0.45	0.14	0.00	0.0000	0.00
8.4	2.56	0.44	0.13	0.00	0.0000	0.00
8.6	2.62	0.45	0.14	0.00	0.0000	0.00
8.8	2.68	0.41	0.12	0.00	0.0000	0.00
9	2.74	0.43	0.13	0.00	0.0000	0.00
9.2	2.80	0.42	0.13	0.00	0.0000	0.00
9.4	2.86	0.42	0.13	0.00	0.0000	0.00
9.6	2.93	0.45	0.14	0.00	0.0001	0.24
9.8	2.99	0.44	0.13	0.02	0.0003	0.94
10.0	3.05	0.5	0.15	0.05	0.0005	1.45
10.2	3.11	0.55	0.17	0.05	0.0006	1.69
10.4	3.17	0.56	0.17	0.06	0.0009	2.62
10.6	3.23	0.61	0.19	0.10	0.0014	4.03
10.8	3.29	0.65	0.20	0.13	0.0018	5.40
11.0	3.35	0.65	0.20	0.17	0.0021	6.17
11.2	3.41	0.7	0.21	0.16	0.0022	6.49
11.4	3.47	0.72	0.22	0.17	0.0024	7.18
11.6	3.54	0.76	0.23	0.18	0.0025	7.58
11.8	3.60	0.72	0.22	0.19	0.0025	7.46
12.0	3.66	0.53	0.16	0.25	0.0023	6.99
12.2	3.72	0.52	0.16	0.23	0.0022	6.68
12.4	3.78	0.64	0.20	0.19	0.0022	6.66
12.6	3.84	0.66	0.20	0.18	0.0023	6.71
12.8	3.90	0.65	0.20	0.19	0.0021	6.12
13.0	3.96	0.65	0.20	0.15	0.0017	5.07
13.2	4.02	0.57	0.17	0.15	0.0008	2.35
13.3	4.05	0.6	0.18	0.14	0.0027	8.15
14	4.27	0	0	0.00		
			Total Discharge (m ³ /s) =		0.0335	100%
			convert to gal/day =		762,818	
			convert to gal/min =		530	
			convert to liters/s =		33.53	
			convert to cfs =		1.18	
			convert to cfm =		71.0	

Stream Gauging Spreadsheet
South Fork, Fall 2000

Stream Name: South Fork Date: 3-Oct-00 Weather: Cool, cloudy
Location: Downstream Time: 5:20 PM Partner: Linda Lennon

X	Y	Y	U	Q		
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
9	2.74	0.3	0.09	0.00	0.0000	0.00
9.4	2.86	0.35	0.11	0.00	0.0003	0.42
9.7	2.96	0.3	0.09	0.06	0.0023	3.83
10	3.05	0.74	0.23	0.20	0.0025	4.22
10.2	3.11	0.74	0.23	0.17	0.0035	5.76
10.4	3.17	0.62	0.19	0.40	0.0038	6.23
10.6	3.23	0.46	0.14	0.34	0.0032	5.32
10.8	3.29	0.54	0.16	0.35	0.0031	5.20
11.0	3.35	0.55	0.17	0.27	0.0025	4.18
11.2	3.41	0.56	0.17	0.22	0.0026	4.30
11.4	3.47	0.82	0.25	0.19	0.0025	4.17
11.6	3.54	0.82	0.25	0.14	0.0014	2.40
11.8	3.60	0.82	0.25	0.05	0.0004	0.63
12.0	3.66	0.81	0.25	0.00	0.0006	1.05
12.2	3.72	0.85	0.26	0.08	0.0018	2.94
12.4	3.78	0.82	0.25	0.15	0.0019	3.19
12.6	3.84	0.56	0.17	0.15	0.0030	5.05
12.8	3.90	0.61	0.19	0.40	0.0048	7.96
13.0	3.96	0.62	0.19	0.44	0.0056	9.25
13.2	4.02	0.63	0.19	0.52	0.0045	7.45
13.4	4.08	0.4	0.12	0.39	0.0025	4.19
13.6	4.15	0.4	0.12	0.29	0.0021	3.48
13.8	4.21	0.5	0.15	0.22	0.0018	2.97
14.0	4.27	0.46	0.14	0.18	0.0012	1.97
14.2	4.33	0.41	0.12	0.11	0.0007	1.20
14.4	4.39	0.41	0.12	0.08	0.0006	0.97
14.6	4.45	0.43	0.13	0.07	0.0005	0.86
14.9	4.54	0.35	0.11	0.02	0.0002	0.31
15.2	4.63	0.32	0.10	0.02	0.0001	0.15
15.5	4.72	0.33	0.10	0.00	0.0001	0.12
15.8	4.82	0.27	0.08	0.02	0.0002	0.25
16.4	5.00	0	0.00	0.00		
			Total Discharge (m ³ /s) =		0.0603	100%
			convert to gal/day =		1,372,367	
			convert to gal/min =		953	
			convert to liters/s =		60.32	
			convert to cfs =		2.13	
			convert to cfm =		127.8	

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Stream Gauging Spreadsheet
South Fork, Spring 2001

Stream Name: South Fork Date: 25-May-01 Weather: warm, partly cloudy,
Location: Upstream Time: 12:00 PM Partner: John Paterson

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
10.9	3.32	0	0.00	0.00	0.0000	0.00
11.1	3.38	0.15	0.05	0.05	0.0002	0.16
11.3	3.44	0.22	0.07	0.07	0.0004	0.32
11.5	3.51	0.25	0.08	0.12	0.0008	0.59
11.7	3.57	0.3	0.09	0.18	0.0014	1.05
11.9	3.63	0.37	0.11	0.26	0.0020	1.51
12.1	3.69	0.41	0.12	0.29	0.0023	1.74
12.3	3.75	0.46	0.14	0.28	0.0030	2.24
12.5	3.81	0.5	0.15	0.38	0.0042	3.18
12.7	3.87	0.55	0.17	0.48	0.0067	5.03
12.9	3.93	0.81	0.25	0.56	0.0091	6.90
13.1	3.99	0.9	0.27	0.59	0.0101	7.64
13.3	4.05	0.9	0.27	0.62	0.0110	8.30
13.5	4.11	0.92	0.28	0.68	0.0116	8.77
13.7	4.18	0.92	0.28	0.68	0.0115	8.68
13.9	4.24	0.9	0.27	0.68	0.0109	8.20
14.1	4.30	0.87	0.27	0.64	0.0102	7.67
14.3	4.36	0.88	0.27	0.61	0.0093	7.00
14.5	4.42	0.84	0.26	0.55	0.0076	5.71
14.7	4.48	0.82	0.25	0.43	0.0055	4.13
14.9	4.54	0.79	0.24	0.30	0.0039	2.94
15.1	4.60	0.76	0.23	0.24	0.0030	2.27
15.3	4.66	0.71	0.22	0.20	0.0024	1.78
15.5	4.72	0.7	0.21	0.16	0.0020	1.47
15.7	4.79	0.7	0.21	0.14	0.0013	0.99
15.9	4.85	0.71	0.22	0.06	0.0008	0.60
16.1	4.91	0.71	0.22	0.06	0.0005	0.40
16.3	4.97	0.71	0.22	0.02	0.0005	0.36
16.5	5.03	0.73	0.22	0.05	0.0004	0.31
16.7	5.09	0.75	0.23	0.01	0.0001	0.05
16.9	5.15	0.76	0.23	0.00	0.0000	0.00
17.1	5.21	0.77	0.23	0.00	0.0000	0.00
17.6	5.36	0.8	0.24	0.00	0.0000	0.00
18.4	5.61	0	0.00	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.1325	100%
			convert to gallons/day =		3,013,968	
			convert to gallons/minute		2,093	
			convert to liters/s =		132.47	
			convert to cfs =		4.68	
			convert to cfm =		280.6	

Stream Gauging Spreadsheet
South Fork, Spring 2001

Stream Name: South Fork Date: 25-May-01 Weather: warm, partly cloudy
Location: Downstream Time: 3:30 PM Partner: John Paterson

X	Y	Y	U	Q		
Tape Reading (ft)	Tape reading (m)	Depth (ft)	Depth (m)	Velocity (m/s)	Discharge (m ³ /s)	% of Total Discharge
8.5	2.59	0	0.00	0.00	0.0000	0.00
9	2.74	0.23	0.07	0.00	0.0000	0.00
9.2	2.80	0.24	0.07	0.00	0.0000	0.00
9.4	2.86	0.46	0.14	0.00	0.0000	0.00
9.6	2.93	0.47	0.14	0.00	0.0000	0.00
9.8	2.99	0.55	0.17	0.00	0.0000	0.00
10	3.05	0.61	0.19	0.00	0.0000	0.00
10.2	3.11	0.61	0.19	0.00	0.0009	0.36
10.4	3.17	0.6	0.18	0.16	0.0030	1.23
10.6	3.23	0.61	0.19	0.38	0.0056	2.26
10.8	3.29	0.7	0.21	0.53	0.0073	2.94
11	3.35	0.7	0.21	0.59	0.0089	3.60
11.2	3.41	0.72	0.22	0.76	0.0131	5.28
11.4	3.47	1	0.30	0.86	0.0153	6.17
11.6	3.54	0.9	0.27	0.87	0.0135	5.45
11.8	3.60	0.87	0.27	0.77	0.0118	4.76
12	3.66	1.05	0.32	0.57	0.0092	3.73
12.2	3.72	1.1	0.34	0.36	0.0064	2.58
12.4	3.78	1.12	0.34	0.26	0.0106	4.29
12.6	3.84	1.15	0.35	0.74	0.0156	6.29
12.8	3.90	1.16	0.35	0.71	0.0143	5.78
13	3.96	1.12	0.34	0.64	0.0168	6.79
13.2	4.02	1.08	0.33	1.01	0.0172	6.97
13.4	4.08	0.9	0.27	0.85	0.0120	4.86
13.6	4.15	0.87	0.27	0.61	0.0104	4.22
13.8	4.21	0.86	0.26	0.69	0.0116	4.68
14	4.27	0.86	0.26	0.76	0.0116	4.68
14.2	4.33	0.76	0.23	0.78	0.0099	4.01
14.4	4.39	0.71	0.22	0.67	0.0076	3.07
14.6	4.45	0.67	0.20	0.51	0.0060	2.43
14.8	4.51	0.65	0.20	0.47	0.0044	1.77
15	4.57	0.64	0.20	0.26	0.0024	0.95
15.2	4.63	0.62	0.19	0.14	0.0013	0.51
15.4	4.69	0.61	0.19	0.08	0.0007	0.30
15.7	4.79	0.5	0.15	0.01	0.0001	0.03
16.0	4.88	0.51	0.16	0.00	0.0000	0.00
16.5	5.03	0.29	0.09	0.00	0.0000	0.00
17.4	5.30	0	0.00	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.2475	100%
			convert to gal/day =		5,630,660	
			convert to gal/min =		3,910	
			convert to liters/s =		247.48	
			convert to cfs =		8.74	

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Stream Gauging Spreadsheet
Disappearing Stream, Summer 2001

Stream Name: Dissappearing Stream Date: 19-Jul-01 Weather: warm, light rain
Location: Upper Madison contact Time: 10:25 AM Partner: John Paterson

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
4.6	1.40	0	0.00	0.00	0.0000	0.00
5	1.52	0.3	0.09	0.00	0.0000	0.00
5.4	1.65	0.72	0.22	0.00	0.0000	0.00
5.6	1.71	0.74	0.23	0.00	0.0000	0.00
5.8	1.77	0.73	0.22	0.00	0.0000	0.00
6	1.83	0.72	0.22	0.00	0.0000	0.00
6.2	1.89	0.72	0.22	0.00	0.0002	0.68
6.4	1.95	0.79	0.24	0.03	0.0004	1.37
6.6	2.01	0.8	0.24	0.03	0.0004	1.38
6.8	2.07	0.8	0.24	0.03	0.0005	1.51
7.0	2.13	0.72	0.22	0.04	0.0011	3.26
7.2	2.19	0.85	0.26	0.10	0.0021	6.61
7.4	2.26	0.91	0.28	0.16	0.0018	5.66
7.5	2.29	0.96	0.29	0.26	0.0023	6.98
7.6	2.32	0.99	0.30	0.24	0.0024	7.44
7.7	2.35	0.97	0.30	0.29	0.0026	7.98
7.8	2.38	0.95	0.29	0.29	0.0025	7.73
7.9	2.41	0.88	0.27	0.30	0.0026	7.90
8.0	2.44	0.87	0.27	0.33	0.0024	7.52
8.1	2.47	0.88	0.27	0.27	0.0021	6.47
8.2	2.50	0.89	0.27	0.24	0.0017	5.31
8.3	2.53	0.87	0.27	0.18	0.0009	2.74
8.4	2.56	0.87	0.27	0.04	0.0007	2.24
8.5	2.59	0.64	0.20	0.19	0.0013	4.13
8.6	2.62	0.45	0.14	0.37	0.0016	4.93
8.7	2.65	0.37	0.11	0.48	0.0016	5.07
8.8	2.68	0.42	0.13	0.42	0.0009	2.80
8.9	2.71	0.1	0.03	0.19	0.0001	0.27
9.0	2.74	0	0.00	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.0324	100%
			convert to gal/day =		737,275	
			convert to gal/min =		512	
			convert to liters/s =		32.40	
			convert to cfs =		1.14	
			convert to cfm =		68.6	

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Stream Gauging Spreadsheet
Bear Creek, Fall 2001

Stream Name: Bear Creek Date: 30-Oct-01 Weather: 50s and cloudy
Location: Downstream Time: 12:45 PM Partner: Chris Landry

X	Y	Y	U	Q		
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
1.2	0.37	0.13	0.04	0.00	0.0000	0.00
1.5	0.46	0.22	0.07	0.00	0.0005	1.35
1.8	0.55	0.3	0.09	0.12	0.0014	3.71
2.1	0.64	0.45	0.14	0.14	0.0013	3.40
2.3	0.70	0.61	0.19	0.12	0.0012	3.32
2.5	0.76	0.6	0.18	0.10	0.0009	2.40
2.7	0.82	0.6	0.18	0.06	0.0005	1.26
2.9	0.88	0.49	0.15	0.03	0.0003	0.74
3.1	0.94	0.5	0.15	0.03	0.0002	0.53
3.3	1.01	0.62	0.19	0.01	0.0003	0.75
3.5	1.07	0.6	0.18	0.04	0.0007	1.88
3.7	1.13	0.64	0.20	0.08	0.0013	3.58
3.9	1.19	0.71	0.22	0.13	0.0025	6.84
4.1	1.25	0.7	0.21	0.26	0.0018	4.86
4.2	1.28	0.74	0.23	0.28	0.0018	4.95
4.3	1.31	0.73	0.22	0.26	0.0018	4.79
4.4	1.34	0.72	0.22	0.27	0.0017	4.52
4.5	1.37	0.7	0.21	0.24	0.0014	3.76
4.6	1.40	0.7	0.21	0.19	0.0012	3.20
4.7	1.43	0.65	0.20	0.19	0.0012	3.14
4.8	1.46	0.64	0.20	0.20	0.0012	3.09
4.9	1.49	0.6	0.18	0.20	0.0011	3.07
5.0	1.52	0.6	0.18	0.21	0.0011	2.99
5.1	1.55	0.67	0.20	0.17	0.0012	3.12
5.2	1.58	0.68	0.21	0.20	0.0013	3.41
5.3	1.62	0.55	0.17	0.25	0.0013	3.36
5.4	1.65	0.55	0.17	0.24	0.0009	2.51
5.5	1.68	0.33	0.10	0.21	0.0011	3.01
5.7	1.74	0.32	0.10	0.16	0.0009	2.35
5.9	1.80	0.33	0.10	0.13	0.0009	2.40
6.1	1.86	0.38	0.12	0.14	0.0011	2.86
6.3	1.92	0.44	0.13	0.14	0.0011	2.87
6.5	1.98	0.41	0.12	0.13	0.0012	3.27
6.8	2.07	0.34	0.10	0.10	0.0006	1.68
7.1	2.16	0.18	0.05	0.06	0.0003	0.68
7.4	2.26	0.15	0.05	0.05	0.0001	0.28
7.7	2.33	0.14	0.04	0.01	0.0000	0.08
8.1	2.47	0.1	0.03	0.00	0.0000	0.00
8.8	2.68	0	0.00	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.0372	100%
			convert to gal/day =		847,126	
			convert to gal/min =		588	
			convert to liters/s =		37.23	
			convert to cfs =		1.31	
			convert to cfm =		78.9	

Stream Gauging Spreadsheet
Hyalite Creek, Fall 2001

Stream Name: Hyalite Creek Date: 22-Sep-01 Weather: warm and sunny
Location: Upper Mm Time: 10:30 AM Field Partner: Taylor Greenup

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
23.3	7.10	0	0.00	0.00	0.0000	0.00
21.5	6.55	0	0.00	0.00	0.0000	0.00
21.4	6.52	0.02	0.01	0.06	0.0001	0.01
21	6.40	0.02	0.01	0.11	0.0000	0.01
20.6	6.28	0.03	0.01	0.00	0.0000	0.00
20.2	6.16	0.27	0.08	0.00	0.0013	0.17
19.8	6.03	0.4	0.12	0.18	0.0025	0.33
19.4	5.91	0.24	0.07	0.27	0.0044	0.57
19.0	5.79	0.4	0.12	0.43	0.0075	0.96
18.6	5.67	0.47	0.14	0.49	0.0076	0.98
18.2	5.55	0.4	0.12	0.45	0.0080	1.03
17.8	5.43	0.64	0.20	0.39	0.0088	1.13
17.4	5.30	0.66	0.20	0.34	0.0119	1.53
16.7	5.09	0.37	0.11	0.38	0.0102	1.31
16.1	4.91	0.51	0.16	0.44	0.0116	1.49
15.7	4.79	0.8	0.24	0.50	0.0138	1.78
15.3	4.66	0.9	0.27	0.38	0.0117	1.50
14.9	4.54	1.1	0.34	0.26	0.0117	1.50
14.5	4.42	0.76	0.23	0.45	0.0131	1.69
14.1	4.30	0.93	0.28	0.39	0.0142	1.83
13.7	4.18	1.22	0.37	0.33	0.0173	2.23
13.3	4.05	1.2	0.37	0.44	0.0232	2.99
12.9	3.93	1.29	0.39	0.56	0.0294	3.78
12.5	3.81	1.43	0.44	0.60	0.0233	3.00
12.1	3.69	0.66	0.20	0.60	0.0141	1.82
11.7	3.57	0.64	0.20	0.57	0.0144	1.85
11.3	3.44	0.73	0.22	0.56	0.0240	3.09
10.9	3.32	1.52	0.46	0.58	0.0177	2.28
10.7	3.26	1.6	0.49	0.64	0.0203	2.62
10.5	3.20	1.62	0.49	0.72	0.0222	2.86
10.3	3.14	1.67	0.51	0.73	0.0186	2.40
10.1	3.08	1.6	0.49	0.49	0.0123	1.59
9.9	3.02	1.6	0.49	0.34	0.0053	0.69
9.7	2.96	1.55	0.47	0.02	0.0004	0.06
9.5	2.90	1.61	0.49	0.01	0.0018	0.23
9.3	2.83	1.58	0.48	0.11	0.0089	1.15
9.1	2.77	1.51	0.46	0.52	0.0169	2.18
8.9	2.71	1.5	0.46	0.69	0.0179	2.31
8.7	2.65	1.47	0.45	0.61	0.0168	2.16
8.5	2.59	1.4	0.43	0.65	0.0164	2.11

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Stream Gauging Spreadsheet
Hyalite Creek, Fall 2001

Stream Name: Hyalite Creek Date: 22-Sep-01 Weather: warm and sunny
Location: Mid Mm, above Qal Time: 1:15 PM Field Partner: Taylor Greenup

X	Y	Y	U	Q		
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
6.7	2.04	0	0.00	0.00	0.0000	0.00
7.5	2.29	0.01	0.00	0.06	0.0031	0.38
8.5	2.59	0.33	0.10	0.20	0.0036	0.44
9	2.74	0.3	0.09	0.30	0.0026	0.32
9.5	2.90	0.3	0.09	0.08	0.0033	0.40
10	3.05	0.27	0.08	0.43	0.0027	0.33
10.5	3.20	0.26	0.08	0.00	0.0020	0.24
11.5	3.51	0.3	0.09	0.14	0.0024	0.29
12.0	3.66	0.34	0.10	0.18	0.0019	0.23
12.5	3.81	0.21	0.06	0.09	0.0013	0.17
13.0	3.96	0.3	0.09	0.13	0.0009	0.11
13.5	4.11	0	0.00	0.00	0.0007	0.09
14.0	4.27	0.2	0.06	0.15	0.0026	0.32
14.5	4.42	0.4	0.12	0.21	0.0027	0.33
15.0	4.57	0.39	0.12	0.08	0.0034	0.42
15.5	4.72	0.46	0.14	0.25	0.0032	0.39
16.0	4.88	0.45	0.14	0.05	0.0050	0.62
16.5	5.03	0.54	0.16	0.36	0.0100	1.22
17.0	5.18	0.46	0.14	0.51	0.0117	1.43
17.5	5.33	0.79	0.24	0.34	0.0134	1.64
18.0	5.49	0.81	0.25	0.38	0.0169	2.07
18.5	5.64	0.84	0.26	0.50	0.0145	1.78
19.0	5.79	0.6	0.18	0.34	0.0141	1.73
19.5	5.94	0.62	0.19	0.65	0.0168	2.06
20.0	6.10	0.63	0.19	0.51	0.0120	1.47
20.5	6.25	0.7	0.21	0.28	0.0145	1.78
21.0	6.40	0.7	0.21	0.61	0.0193	2.37
21.5	6.55	0.65	0.20	0.62	0.0150	1.84
22.0	6.71	0.53	0.16	0.46	0.0092	1.13
22.5	6.86	0.38	0.12	0.40	0.0068	0.83
23.0	7.01	0.26	0.08	0.54	0.0105	1.29
23.5	7.16	0.53	0.16	0.59	0.0107	1.31
24.0	7.31	0.39	0.12	0.38	0.0053	0.66
24.5	7.47	0.2	0.06	0.41	0.0041	0.50
25.0	7.62	0.24	0.07	0.39	0.0040	0.49
25.5	7.77	0.2	0.06	0.40	0.0025	0.30
26.0	7.92	0.1	0.03	0.27	0.0162	1.99
26.5	8.08	0.8	0.24	0.84	0.0270	3.31
27.0	8.23	0.98	0.30	0.50	0.0289	3.54
27.5	8.38	1.06	0.32	0.71	0.0345	4.23
28.0	8.53	0.86	0.26	0.85	0.0237	2.91
28.5	8.69	0.66	0.20	0.44	0.0082	1.01
29.0	8.84	0.78	0.24	0.08	0.0039	0.48
29.5	8.99	0.7	0.21	0.15	0.0052	0.63
30.0	9.14	0.65	0.20	0.18	0.0104	1.27
30.5	9.30	0.5	0.15	0.66	0.0165	2.02

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Stream Gauging Spreadsheet
Hyalite Creek, Fall 2001

(continued from previous page)

X	Y	Y	U	Q		
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
31.0	9.45	0.86	0.26	0.44	0.0179	2.19
31.5	9.60	0.93	0.28	0.42	0.0193	2.37
32.0	9.75	0.75	0.23	0.59	0.0209	2.57
32.5	9.91	0.79	0.24	0.58	0.0138	1.69
33.0	10.06	0.71	0.22	0.19	0.0127	1.56
33.5	10.21	0.69	0.21	0.60	0.0164	2.01
34.0	10.36	0.45	0.14	0.65	0.0157	1.93
34.5	10.52	0.54	0.16	0.71	0.0154	1.89
35.0	10.67	0.42	0.13	0.67	0.0107	1.32
35.5	10.82	0.41	0.12	0.44	0.0066	0.81
36.0	10.97	0.4	0.12	0.26	0.0039	0.48
36.5	11.12	0.26	0.08	0.25	0.0039	0.48
37.0	11.28	0.36	0.11	0.29	0.0043	0.53
37.5	11.43	0.31	0.09	0.26	0.0046	0.56
38.0	11.58	0.4	0.12	0.29	0.0073	0.89
38.5	11.73	0.45	0.14	0.44	0.0087	1.06
39.0	11.89	0.53	0.16	0.33	0.0100	1.22
39.5	12.04	0.67	0.20	0.38	0.0059	0.73
40.0	12.19	0.79	0.24	0.00	0.0020	0.25
40.5	12.34	0.63	0.19	0.14	0.0068	0.83
41.0	12.50	0.78	0.24	0.26	0.0095	1.17
41.5	12.65	0.8	0.24	0.26	0.0100	1.23
42.0	12.80	0.8	0.24	0.28	0.0107	1.32
42.5	12.95	0.82	0.25	0.29	0.0112	1.37
43.0	13.11	0.81	0.25	0.30	0.0119	1.46
43.5	13.26	0.9	0.27	0.30	0.0122	1.50
44.0	13.41	0.8	0.24	0.32	0.0122	1.50
44.5	13.56	0.87	0.27	0.31	0.0119	1.46
45.0	13.72	0.76	0.23	0.32	0.0129	1.58
45.5	13.87	0.89	0.27	0.35	0.0143	1.75
46.0	14.02	0.89	0.27	0.34	0.0139	1.70
46.5	14.17	0.84	0.26	0.35	0.0137	1.68
47.0	14.32	0.8	0.24	0.37	0.0127	1.56
47.5	14.48	0.74	0.23	0.34	0.0099	1.21
48.0	14.63	0.67	0.20	0.26	0.0067	0.82
48.5	14.78	0.63	0.19	0.18	0.0036	0.44
49.0	14.93	0.52	0.16	0.08	0.0012	0.15
49.5	15.09	0.31	0.09	0.03	0.0013	0.15
50.0	15.24	0.3	0.09	0.15	0.0011	0.14
50.5	15.39	0.25	0.08	0.01	0.0001	0.01
51.5	15.70	0	0.00	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.8149	100.00
			convert to gal/day =		18,540,470	
			convert to gal/min =		12,875	
			convert to liters/s =		814.89	
			convert to cfs =		28.77	
			convert to cfm =		1725.9	

Stream Gauging Spreadsheet
 Reproducibility Measurements, South Fork of Sourdough Creek

Stream: South Fork Date: 17-Oct-00 Weather: 40s, cloudy
 Location: at culvert Time: 2:10 PM Partner: Linda Lennon

X	Y	Y	U	Q		
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
7.5	2.29	0	0.00	0.00	0.0000	0.00
7.9	2.41	0.18	0.05	0.00	0.0000	0.00
8.2	2.50	0.31	0.09	0.00	0.0000	0.00
8.5	2.59	0.44	0.13	0.00	0.0008	1.17
8.8	2.68	0.39	0.12	0.14	0.0022	3.45
9.1	2.77	0.38	0.12	0.28	0.0034	5.16
9.3	2.83	0.67	0.20	0.38	0.0042	6.42
9.5	2.90	0.5	0.15	0.39	0.0034	5.21
9.7	2.96	0.5	0.15	0.34	0.0028	4.36
9.9	3.02	0.52	0.16	0.26	0.0023	3.53
10.1	3.08	0.66	0.20	0.17	0.0020	3.13
10.3	3.14	0.82	0.25	0.13	0.0021	3.26
10.5	3.20	0.81	0.25	0.15	0.0019	2.99
10.7	3.26	0.8	0.24	0.11	0.0011	1.74
10.9	3.32	0.85	0.26	0.04	0.0003	0.49
11.1	3.38	0.8	0.24	0.00	0.0000	0.00
11.3	3.44	0.83	0.25	0.00	0.0010	1.49
11.5	3.51	0.8	0.24	0.13	0.0018	2.77
11.7	3.57	0.5	0.15	0.18	0.0028	4.35
11.9	3.63	0.55	0.17	0.39	0.0044	6.84
12.1	3.69	0.6	0.18	0.44	0.0053	8.22
12.3	3.75	0.61	0.19	0.51	0.0048	7.40
12.5	3.81	0.53	0.16	0.39	0.0036	5.58
12.7	3.87	0.54	0.16	0.34	0.0066	10.22
13.1	3.99	0.58	0.18	0.30	0.0029	4.52
13.3	4.05	0.57	0.17	0.25	0.0031	4.73
13.6	4.15	0.49	0.15	0.16	0.0015	2.26
13.9	4.24	0.3	0.09	0.09	0.0005	0.72
14.2	4.33	0.33	0.100584	0.02	0.0002	0.29
14.5	4.42	0.34	0.10	0.02	0.0001	0.15
14.8	4.51	0.22	0.07	0.00	0.0000	0.00
15	4.57	0.25	0.08	0.00	0.0000	0.00
15.4	4.69	0.02	0.01	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.0650	100%
			convert to gallons/day =		1,479,486	
			convert to gallons/minute		1,027	
			convert to liters/s =		65.03	
			convert to cfs =		2.30	
			convert to cfm =		137.7	

Stream Gauging Spreadsheet
Reproducibility Measurements, South Fork of Sourdough Creek

Stream Name: South Fork Date: 10/17/00 Weather: 40s and cloudy
Location: at culvert Time: 3:00 PM Partner: Linda Lennon

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
7.5	2.29	0	0.00	0.00	0.0000	0.00
8.3	2.53	0.37	0.11	0.00	0.0000	0.00
8.6	2.62	0.45	0.14	0.00	0.0004	0.68
8.8	2.68	0.4	0.12	0.11	0.0011	1.90
9	2.74	0.39	0.12	0.20	0.0019	3.20
9.2	2.80	0.4	0.12	0.32	0.0034	5.72
9.4	2.86	0.65	0.20	0.37	0.0068	11.34
9.7	2.96	0.6	0.18	0.41	0.0037	6.25
9.9	3.02	0.52	0.16	0.30	0.0026	4.35
10.1	3.08	0.62	0.19	0.20	0.0021	3.46
10.3	3.14	0.66	0.20	0.15	0.0021	3.45
10.5	3.20	0.82	0.25	0.15	0.0017	2.87
10.7	3.26	0.77	0.23	0.08	0.0011	1.85
10.9	3.32	0.82	0.25	0.07	0.0006	1.02
11.1	3.38	0.84	0.26	0.01	0.0001	0.13
11.3	3.44	0.8	0.24	0.00	0.0000	0.00
11.5	3.51	0.8	0.24	0.00	0.0007	1.12
11.7	3.57	0.8	0.24	0.09	0.0022	3.70
11.9	3.63	0.52	0.16	0.32	0.0037	6.26
12.1	3.69	0.55	0.17	0.43	0.0052	8.63
12.3	3.75	0.56	0.17	0.57	0.0053	8.90
12.5	3.81	0.54	0.16	0.47	0.0042	7.02
12.7	3.87	0.66	0.20	0.30	0.0035	5.92
12.9	3.93	0.59	0.18	0.31	0.0031	5.18
13.1	3.99	0.58	0.18	0.26	0.0022	3.69
13.3	4.05	0.48	0.15	0.18	0.0011	1.81
13.5	4.11	0.3	0.09	0.10	0.0006	1.02
13.8	4.21	0.34	0.10	0.04	0.0003	0.53
14.1	4.30	0.31	0.09449	0.03	0.0001	0.22
14.4	4.39	0.3	0.09	0.00	0.0000	0.00
14.7	4.48	0.3	0.09	0.00	0.0000	0.00
15	4.57	0.2	0.06	0.00	0.0000	0.00
15.5	4.72	0	0.00	0.00	0.0000	0.00
			Total discharge (m ³ /s) =		0.0598	100%
			convert to gal/day =		1,360,499	
			convert to gpm =		945	
			convert to liters/s =		59.80	
			convert to cfs =		2.11	
			convert to cfm =		126.6	

Stream Gauging Spreadsheet
 Reproducibility Measurements, South Fork of Sourdough Creek

Stream Name: South Fork Date: 10/17/00 Weather: 40s and cloudy

Location: at culvert Time: 4:00 PM Partner: Linda Lennon

X		Y	Y	U	Q	
Tape Reading	Tape reading	Depth	Depth	Velocity	Discharge	% of Total
(ft)	(m)	(ft)	(m)	(m/s)	(m ³ /s)	Discharge
7.5	2.29	0	0.00	0.00	0.0000	0.00
8	2.44	0.24	0.07	0.00	0.0000	0.00
8.4	2.56	0.29	0.09	0.00	0.0000	0.00
8.6	2.62	0.43	0.13	0.00	0.0001	0.14
8.8	2.68	0.44	0.13	0.02	0.0008	1.43
9	2.74	0.38	0.12	0.21	0.0018	3.06
9.2	2.80	0.39	0.12	0.28	0.0026	4.52
9.4	2.86	0.46	0.14	0.37	0.0033	5.81
9.6	2.93	0.46	0.14	0.41	0.0034	5.96
9.8	2.99	0.46	0.14	0.39	0.0040	6.97
10.0	3.05	0.81	0.25	0.31	0.0033	5.72
10.2	3.11	0.68	0.21	0.15	0.0013	2.33
10.4	3.17	0.6	0.18	0.07	0.0012	2.05
10.6	3.23	0.77	0.23	0.11	0.0014	2.43
10.8	3.29	0.82	0.25	0.08	0.0008	1.46
11.0	3.35	0.82	0.25	0.03	0.0002	0.40
11.2	3.41	0.81	0.25	0.00	0.0000	0.00
11.4	3.47	0.8	0.24	0.00	0.0010	1.81
11.6	3.54	0.8	0.24	0.14	0.0019	3.29
11.8	3.60	0.48	0.15	0.19	0.0026	4.61
12.0	3.66	0.51	0.16	0.38	0.0046	8.02
12.2	3.72	0.58	0.18	0.52	0.0057	9.96
12.4	3.78	0.56	0.17	0.56	0.0052	9.01
12.6	3.84	0.54	0.16	0.45	0.0039	6.84
12.8	3.90	0.56	0.17	0.32	0.0031	5.48
13.0	3.96	0.59	0.18	0.27	0.0025	4.44
13.2	4.02	0.5	0.15	0.23	0.0016	2.86
13.4	4.08	0.44	0.13	0.14	0.0008	1.39
13.6	4.15	0.3	0.09144	0.08	0.0004	0.62
13.8	4.21	0.2	0.06	0.07	0.0002	0.34
14	4.27	0.34	0.10	0.02	0.0001	0.16
14.2	4.33	0.3	0.09	0.01	0.0000	0.07
14.5	4.42	0.33	0.10	0.00	0.0000	0.00
14.8	4.51	0.26	0.08	0.00	0.0000	0.00
15	4.57	0.18	0.05	0.00	0.0000	0.00
			Total Discharge (m ³ /s) =		0.0574	100%
			convert to gal/day =		1,305,503	
			convert to gal/minute =		907	
			convert to liters/s =		57.38	
			convert to cfs =		2.03	
			convert to cfm =		121.5	

APPENDIX C

TWO SPRINGS DATA LOGGER STAGE READINGS

Data recorded by data logger, Two Springs

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge (m ³ /sec)	Stage (cm)	Discharge (m ³ /sec)
7/28/00 12:00	0.977	29.778	NA	20	0.037
7/29/00 12:00	0.940	28.649	NA		
7/30/00 12:00	0.941	28.690	NA		
7/31/00 12:00	0.947	28.851	NA		
8/1/00 12:00	0.954	29.093	NA		
8/2/00 12:00	0.953	29.052	NA		
8/3/00 12:00	0.957	29.173	NA		
8/4/00 12:00	0.957	29.173	NA		
8/5/00 12:00	0.966	29.455	NA		
8/6/00 12:00	0.968	29.496	NA		
8/7/00 10:00	0.958	29.214	NA	18.75	0.041
8/8/00 12:00	0.964	29.375	NA		
Data logger out of service			NA		
8/21/00 13:20	1.134	34.558	NA	18.5	0.033
8/22/00 12:00	1.162	35.408	NA		
8/23/00 12:00	1.157	35.260	NA		
8/24/00 12:00	1.152	35.112	NA		
8/25/00 12:00	1.147	34.964	NA		
8/26/00 12:00	1.139	34.706	NA		
8/27/00 12:00	1.140	34.743	NA		
8/28/00 12:00	1.136	34.632	NA		
8/29/00 12:00	1.135	34.595	NA		
8/30/00 12:00	1.133	34.521	NA		
8/31/00 12:00	1.112	33.892	NA		
9/1/00 12:00	1.082	32.968	NA		
9/2/00 12:00	1.096	33.412	NA		
9/3/00 12:00	1.101	33.560	NA		
9/4/00 12:00	1.113	33.929	NA		
9/5/00 12:00	1.093	33.301	NA		
9/6/00 12:00	1.097	33.449	NA		
9/7/00 12:00	1.096	33.412	NA		
9/8/00 12:00	1.099	33.486	NA		
9/9/00 12:00	1.099	33.486	NA		
9/10/00 12:00	1.099	33.486	NA		
9/11/00 12:00	1.099	33.486	NA		
9/12/00 12:00	1.105	33.671	NA		
9/13/00 12:00	1.106	33.708	NA		
9/14/00 12:00	1.106	33.708	NA		
9/15/00 12:00	1.108	33.782	NA		
9/16/00 12:00	1.103	33.634	NA		
9/17/00 12:00	1.106	33.708	NA		
9/18/00 12:00	1.106	33.708	NA		
9/19/00 12:00	1.107	33.745	NA		
Data logger out of service					
10/19/00 13:00	0.729	22.213	0.016	17.75	
10/20/00 12:00	0.740	22.546	0.018		
10/21/00 12:00	0.741	22.583	0.019		
10/22/00 12:00	0.731	22.287	0.016		
10/23/00 12:00	0.729	22.213	0.016		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
10/24/00 12:00	0.728	22.176	0.015		
10/25/00 12:00	0.730	22.250	0.016		
10/26/00 12:00	0.730	22.250	0.016		
10/27/00 12:00	0.732	22.324	0.016		
10/28/00 12:00	0.732	22.324	0.016		
10/29/00 12:00	0.726	22.139	0.015		
10/30/00 12:00	0.728	22.176	0.015		
10/31/00 12:00	0.728	22.176	0.015		
11/1/00 12:00	0.725	22.102	0.015		
11/2/00 12:00	0.720	21.954	0.014		
11/3/00 12:00	0.747	22.767	0.021		
11/4/00 12:00	0.769	23.433	0.028		
11/5/00 12:00	0.748	22.804	0.021		
11/6/00 12:00	0.757	23.063	0.024		
11/7/00 12:00	0.768	23.396	0.028		
11/8/00 12:00	0.815	24.837	0.055		
11/9/00 12:00	0.810	24.689	0.051		
11/10/00 12:00	0.800	24.394	0.045		
11/11/00 12:00	0.806	24.578	0.049		
11/12/00 12:00	0.798	24.320	0.043		
11/13/00 12:00	0.787	23.987	0.037		
11/14/00 12:00	0.778	23.728	0.033		
11/15/00 12:00	0.764	23.285	0.026		
11/16/00 12:00	0.749	22.841	0.021		
11/17/00 12:00	0.751	22.878	0.022		
11/18/00 12:00	0.752	22.915	0.022		
11/19/00 12:00	0.753	22.952	0.022		
11/20/00 12:00	0.753	22.952	0.022		
11/21/00 12:00	0.751	22.878	0.022		
11/22/00 12:00	0.749	22.841	0.021		
11/23/00 12:00	0.746	22.730	0.020		
11/24/00 12:00	0.743	22.657	0.019		
11/25/00 12:00	0.742	22.620	0.019		
11/26/00 12:00	0.742	22.620	0.019		
11/27/00 12:00	0.745	22.694	0.020		
11/28/00 12:00	0.738	22.509	0.018		
11/29/00 12:00	0.740	22.546	0.018		
11/30/00 12:00	0.738	22.509	0.018		
12/1/00 12:00	0.740	22.546	0.018		
12/2/00 12:00	0.730	22.250	0.016		
12/3/00 12:00	0.718	21.880	0.013		
12/4/00 12:00	0.735	22.398	0.017		
12/5/00 12:00	0.728	22.176	0.015		
12/6/00 12:00	0.732	22.324	0.016		
12/7/00 12:00	0.724	22.065	0.014		
12/8/00 12:00	0.719	21.917	0.013		
12/9/00 12:00	0.708	21.585	0.011		
12/10/00 12:00	0.694	21.141	0.009		
12/11/00 12:00	0.677	20.624	0.007		
12/12/00 12:00	0.674	20.550	0.006		
12/13/00 12:00	0.680	20.735	0.007		
12/14/00 12:00	0.684	20.846	0.008		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
12/15/00 12:00	0.691	21.067	0.009		
12/16/00 12:00	0.688	20.956	0.008		
12/17/00 12:00	0.689	20.993	0.008		
12/18/00 12:00	0.689	20.993	0.008		
12/19/00 12:00	0.689	20.993	0.008		
12/20/00 12:00	0.689	20.993	0.008		
12/21/00 12:00	0.691	21.067	0.009		
12/22/00 12:00	0.688	20.956	0.008		
12/23/00 12:00	0.688	20.956	0.008		
12/24/00 12:00	0.686	20.919	0.008		
12/25/00 12:00	0.688	20.956	0.008		
12/26/00 12:00	0.686	20.919	0.008		
12/27/00 12:00	0.690	21.030	0.008		
12/28/00 12:00	0.688	20.956	0.008		
12/29/00 12:00	0.683	20.809	0.007		
12/30/00 12:00	0.686	20.919	0.008		
12/31/00 12:00	0.684	20.846	0.008		
1/1/01 12:00	0.684	20.846	0.008		
1/2/01 12:00	0.683	20.809	0.007		
1/3/01 12:00	0.681	20.772	0.007		
1/4/01 12:00	0.683	20.809	0.007		
1/5/01 12:00	0.684	20.846	0.008		
1/6/01 12:00	0.684	20.846	0.008		
1/7/01 12:00	0.681	20.772	0.007		
1/8/01 12:00	0.683	20.809	0.007		
1/9/01 12:00	0.684	20.846	0.008		
1/10/01 12:00	0.686	20.919	0.008		
1/11/01 12:00	0.686	20.919	0.008		
1/12/01 12:00	0.686	20.919	0.008		
1/13/01 12:00	0.685	20.882	0.008		
1/14/01 12:00	0.688	20.956	0.008		
1/15/01 12:00	0.684	20.846	0.008		
1/16/01 12:00	0.683	20.809	0.007		
1/17/01 12:00	0.681	20.772	0.007		
1/18/01 12:00	0.680	20.735	0.007		
1/19/01 12:00	0.681	20.772	0.007		
1/20/01 12:00	0.681	20.772	0.007		
1/21/01 12:00	0.679	20.698	0.007		
1/22/01 12:00	0.680	20.735	0.007		
1/23/01 12:00	0.681	20.772	0.007		
1/24/01 12:00	0.683	20.809	0.007		
1/25/01 12:00	0.680	20.735	0.007		
1/26/01 12:00	0.680	20.735	0.007		
1/27/01 12:00	0.679	20.698	0.007		
1/28/01 12:00	0.678	20.661	0.007		
1/29/01 12:00	0.675	20.587	0.007		
1/30/01 12:00	0.673	20.513	0.006		
1/31/01 12:00	0.675	20.587	0.007		
2/1/01 12:00	0.679	20.698	0.007		
2/2/01 12:00	0.681	20.772	0.007		
2/3/01 12:00	0.688	20.956	0.008		
2/4/01 12:00	0.684	20.846	0.008		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
2/5/01 12:00	0.686	20.919	0.008		
2/6/01 12:00	0.686	20.919	0.008		
2/7/01 12:00	0.677	20.624	0.007		
2/8/01 12:00	0.679	20.698	0.007		
2/9/01 12:00	0.678	20.661	0.007		
2/10/01 12:00	0.675	20.587	0.007		
2/11/01 12:00	0.675	20.587	0.007		
2/12/01 12:00	0.675	20.587	0.007		
2/13/01 12:00	0.679	20.698	0.007		
2/14/01 12:00	0.686	20.919	0.008		
2/15/01 12:00	0.680	20.735	0.007		
2/16/01 12:00	0.680	20.735	0.007		
2/17/01 12:00	0.683	20.809	0.007		
2/18/01 12:00	0.683	20.809	0.007		
2/19/01 12:00	0.691	21.067	0.009		
2/20/01 12:00	0.690	21.030	0.008		
2/21/01 12:00	0.689	20.993	0.008		
2/22/01 12:00	0.688	20.956	0.008		
2/23/01 12:00	0.691	21.067	0.009		
2/24/01 12:00	0.692	21.104	0.009		
2/25/01 12:00	0.692	21.104	0.009		
2/26/01 12:00	0.691	21.067	0.009		
2/27/01 12:00	0.691	21.067	0.009		
2/28/01 12:00	0.689	20.993	0.008		
3/1/01 12:00	0.688	20.956	0.008		
3/2/01 12:00	0.685	20.882	0.008		
3/3/01 12:00	0.686	20.919	0.008		
3/4/01 12:00	0.691	21.067	0.009		
3/5/01 12:00	0.692	21.104	0.009		
3/6/01 12:00	0.689	20.993	0.008		
3/7/01 12:00	0.690	21.030	0.008		
3/8/01 12:00	0.697	21.252	0.009		
3/9/01 12:00	0.695	21.178	0.009		
3/10/01 12:00	0.696	21.215	0.009		
3/11/01 12:00	0.698	21.289	0.010		
3/12/01 12:00	0.698	21.289	0.010		
3/13/01 12:00	0.692	21.104	0.009		
3/14/01 12:00	0.696	21.215	0.009		
3/15/01 12:00	0.695	21.178	0.009		
3/16/01 12:00	0.691	21.067	0.009		
3/17/01 12:00	0.694	21.141	0.009		
3/18/01 12:00	0.691	21.067	0.009		
3/19/01 12:00	0.695	21.178	0.009		
3/20/01 12:00	0.696	21.215	0.009		
3/21/01 12:00	0.696	21.215	0.009		
3/22/01 12:00	0.701	21.363	0.010		
3/23/01 12:00	0.702	21.400	0.010		
3/24/01 12:00	0.706	21.511	0.011		
3/25/01 12:00	0.705	21.474	0.011		
3/26/01 12:00	0.701	21.363	0.010		
3/27/01 12:00	0.697	21.252	0.009		
3/28/01 12:00	0.700	21.326	0.010		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
3/29/01 12:00	0.703	21.437	0.010		
3/30/01 12:00	0.702	21.400	0.010		
3/31/01 12:00	0.700	21.326	0.010		
4/1/01 12:00	0.701	21.363	0.010		
4/2/01 12:00	0.701	21.363	0.010		
4/3/01 12:00	0.698	21.289	0.010		
4/4/01 12:00	0.696	21.215	0.009		
4/5/01 12:00	0.692	21.104	0.009		
4/6/01 12:00	0.684	20.846	0.008		
4/7/01 12:00	0.696	21.215	0.009		
4/8/01 12:00	0.697	21.252	0.009		
4/9/01 12:00	0.688	20.956	0.008		
4/10/01 12:00	0.681	20.772	0.007		
4/11/01 12:00	0.680	20.735	0.007		
4/12/01 12:00	0.683	20.809	0.007		
4/13/01 12:00	0.685	20.882	0.008		
4/14/01 12:00	0.686	20.919	0.008		
4/15/01 12:00	0.685	20.882	0.008		
4/16/01 12:00	0.686	20.919	0.008		
4/17/01 12:00	0.691	21.067	0.009		
4/18/01 12:00	0.703	21.437	0.010		
4/19/01 12:00	0.721	21.991	0.014		
4/20/01 12:00	0.709	21.622	0.011		
4/21/01 12:00	0.700	21.326	0.010		
4/22/01 12:00	0.691	21.067	0.009		
4/23/01 12:00	0.696	21.215	0.009		
4/24/01 12:00	0.691	21.067	0.009		
4/25/01 12:00	0.703	21.437	0.010		
4/26/01 12:00	0.743	22.657	0.019		
4/27/01 12:00	0.759	23.137	0.025		
4/28/01 12:00	0.766	23.359	0.027		
4/29/01 12:00	0.828	25.244	0.066	21.75	
4/30/01 12:00	0.798	24.320	0.043		
5/1/01 12:00	0.802	24.431	0.045		
5/2/01 12:00	0.764	23.285	0.026		
5/3/01 12:00	0.749	22.841	0.021		
5/4/01 12:00	0.738	22.509	0.018		
5/5/01 12:00	0.768	23.396	0.028		
5/6/01 12:00	0.762	23.211	0.025		
5/7/01 12:00	0.763	23.248	0.026		
5/8/01 12:00	0.776	23.654	0.032		
5/9/01 12:00	0.822	25.059	0.060		
5/10/01 12:00	0.822	25.059	0.060		
5/11/01 12:00	0.819	24.948	0.058		
5/12/01 12:00	0.832	25.355	0.069		
5/13/01 12:00	0.868	26.463	0.112		
5/14/01 12:00	0.897	27.350	0.162		
5/15/01 12:00	0.906	27.609	0.181		
5/16/01 12:00	0.891	27.166	0.150		
5/17/01 12:00	0.895	27.277	0.157		
5/18/01 12:00	0.895	27.277	0.157		
5/19/01 12:00	0.892	27.203	0.153		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
5/20/01 12:00	0.895	27.277	0.157		
5/21/01 12:00	0.884	26.944	0.137		
5/22/01 12:00	0.874	26.648	0.121		
5/23/01 12:00	0.843	25.687	0.080	22.25	0.103
5/24/01 12:00	0.834	25.429	0.071		
5/25/01 12:00	0.839	25.576	0.076		
5/26/01 12:00	0.825	25.133	0.063		
5/27/01 12:00	0.825	25.133	0.063		
5/28/01 12:00	0.827	25.207	0.065		
5/29/01 12:00	0.829	25.281	0.067		
5/30/01 12:00	0.827	25.207	0.065		
5/31/01 12:00	0.819	24.948	0.058		
6/1/01 12:00	0.816	24.874	0.056		
6/2/01 12:00	0.810	24.689	0.051		
6/3/01 12:00	0.810	24.689	0.051		
6/4/01 12:00	0.817	24.911	0.057		
6/5/01 12:00	0.811	24.726	0.052		
6/6/01 12:00	0.816	24.874	0.056		
6/7/01 12:00	0.808	24.615	0.049		
6/8/01 12:00	0.815	24.837	0.055		
6/9/01 12:00	0.816	24.874	0.056		
6/10/01 12:00	0.806	24.578	0.049		
6/11/01 12:00	0.808	24.615	0.049		
6/12/01 12:00	0.811	24.726	0.052		
6/13/01 12:00	0.825	25.133	0.063		
6/14/01 12:00	0.825	25.133	0.063		
6/15/01 12:00	0.844	25.724	0.081		
6/16/01 12:00	0.852	25.983	0.091		
6/17/01 12:00	0.871	26.537	0.115		
6/18/01 12:00	0.991	30.196	0.496		
6/19/01 12:00	0.951	28.977	0.311		
6/20/01 12:00	0.952	29.014	0.316		
6/21/01 12:00	0.935	28.496	0.258		
6/22/01 12:00	0.930	28.348	0.243		
6/23/01 12:00	0.911	27.757	0.192		
6/24/01 12:00	0.908	27.683	0.186		
6/25/01 12:00	0.899	27.387	0.165		
6/26/01 12:00	0.875	26.685	0.123		
6/27/01 12:00	0.879	26.796	0.129		
6/28/01 12:00	0.871	26.537	0.115		
6/29/01 12:00	0.867	26.426	0.110		
6/30/01 12:00	0.865	26.353	0.107		
7/1/01 12:00	0.856	26.094	0.095		
7/2/01 12:00	0.855	26.057	0.094		
7/3/01 12:00	0.846	25.798	0.084		
7/4/01 12:00	0.845	25.761	0.083		
7/5/01 12:00	0.835	25.466	0.073		
7/6/01 12:00	0.838	25.539	0.075		
7/7/01 12:00	0.832	25.355	0.069		
7/8/01 12:00	0.852	25.983	0.091		
7/9/01 12:00	0.844	25.724	0.081		
7/10/01 12:00	0.833	25.392	0.070		

Date and time	Data Logger	Data Logger	Calculated Discharge	Ruler Stage	Measured Discharge
	Stage (ft)	Stage (cm)	(m ³ /sec)	(cm)	(m ³ /sec)
7/11/01 12:00	0.833	25.392	0.070		
7/12/01 12:00	0.821	25.022	0.059		
7/13/01 12:00	0.822	25.059	0.060		
7/14/01 12:00	0.821	25.022	0.059		
7/15/01 12:00	0.821	25.022	0.059		
7/16/01 12:00	0.822	25.059	0.060		
7/17/01 12:00	0.812	24.763	0.053		
7/18/01 12:00	0.804	24.505	0.047		
7/19/01 12:00	0.803	24.468	0.046		
7/20/01 12:00	0.802	24.431	0.045		
7/21/01 12:00	0.803	24.468	0.046		
7/22/01 12:00	0.799	24.357	0.044		
7/23/01 12:00	0.789	24.061	0.038		
7/24/01 12:00	0.796	24.268	0.042	21	0.0526
7/25/01 12:00	0.789	24.046	0.038		
7/26/01 12:00	0.794	24.194	0.041		
7/27/01 12:00	0.790	24.083	0.039		
7/28/01 12:00	0.784	23.898	0.035		
7/29/01 12:00	0.782	23.825	0.034		
7/30/01 12:00	0.784	23.898	0.035		
7/31/01 12:00	0.784	23.898	0.035		
8/1/01 12:00	0.777	23.677	0.032		
8/2/01 12:00	0.778	23.714	0.032		
8/3/01 12:00	0.782	23.825	0.034		
8/4/01 12:00	0.778	23.714	0.032		
8/5/01 12:00	0.772	23.529	0.030		
8/6/01 12:00	0.754	22.974	0.023		
8/7/01 12:00	0.774	23.603	0.031		
8/8/01 12:00	0.772	23.529	0.030		
8/9/01 12:00	0.765	23.307	0.027		
8/10/01 12:00	0.770	23.455	0.029		
8/11/01 12:00	0.766	23.344	0.027		
8/12/01 12:00	0.766	23.344	0.027		
8/13/01 12:00	0.766	23.344	0.027		
8/14/01 12:00	0.761	23.196	0.025		
8/15/01 12:00	0.765	23.307	0.027		
8/16/01 12:00	0.759	23.122	0.024		
8/17/01 12:00	0.763	23.270	0.026		
8/18/01 12:00	0.756	23.048	0.024		
8/19/01 12:00	0.762	23.233	0.026		
8/20/01 12:00	0.757	23.085	0.024		
8/21/01 12:00	0.759	23.122	0.024		
8/22/01 12:00	0.757	23.085	0.024		
8/23/01 12:00	0.757	23.085	0.024		
8/24/01 12:00	0.770	23.455	0.029		
8/25/01 12:00	0.766	23.344	0.027		
8/26/01 12:00	0.770	23.455	0.029		
8/27/01 12:00	0.765	23.307	0.027		
8/28/01 12:00	0.765	23.307	0.027		
8/29/01 12:00	0.768	23.418	0.028		
8/30/01 12:00	0.765	23.307	0.027		
8/31/01 12:00	0.766	23.344	0.027		

Date and time	Data Logger	Data Logger	Calculated	Ruler	Measured
	Stage (ft)	Stage (cm)	Discharge	Stage	Discharge
			(m ³ /sec)	(cm)	(m ³ /sec)
9/1/01 12:00	0.762	23.233	0.026		
9/2/01 12:00	0.768	23.418	0.028		
9/3/01 12:00	0.762	23.233	0.026		
9/4/01 12:00	0.760	23.159	0.025		
9/5/01 12:00	0.770	23.455	0.029		
9/6/01 12:00	0.774	23.603	0.031		
9/7/01 12:00	0.756	23.048	0.024		
9/8/01 12:00	0.765	23.307	0.027		
9/9/01 12:00	0.766	23.344	0.027		
9/10/01 12:00	0.760	23.159	0.025		
9/11/01 12:00	0.760	23.159	0.025		
9/12/01 12:00	0.757	23.085	0.024		
9/13/01 12:00	0.757	23.085	0.024		
9/14/01 12:00	0.765	23.307	0.027		
9/15/01 12:00	0.763	23.270	0.026		
9/16/01 12:00	0.762	23.233	0.026		
9/17/01 12:00	0.761	23.196	0.025		
9/18/01 12:00	0.759	23.122	0.024		
9/19/01 12:00	0.753	22.937	0.022		
9/20/01 12:00	0.755	23.011	0.023		
9/21/01 12:00	0.754	22.974	0.023		
9/22/01 12:00	0.750	22.864	0.022		
9/23/01 12:00	0.750	22.864	0.022		
9/24/01 12:00	0.754	22.974	0.023		
9/25/01 12:00	0.753	22.937	0.022		
9/26/01 12:00	0.751	22.901	0.022		
9/27/01 12:00	0.754	22.974	0.023		
9/28/01 12:00	0.753	22.937	0.022		
9/29/01 12:00	0.759	23.122	0.024		
9/30/01 12:00	0.754	22.974	0.023		
10/1/01 12:00	0.754	22.974	0.023	17.5	0.023
10/2/01 12:00	0.745	22.716	0.020		
10/3/01 12:00	0.743	22.642	0.019		
10/4/01 12:00	0.745	22.716	0.020		
10/5/01 12:00	0.748	22.790	0.021		
10/6/01 12:00	0.745	22.716	0.020		
10/7/01 12:00	0.742	22.605	0.019		
10/8/01 12:00	0.746	22.753	0.020		
10/9/01 12:00	0.753	22.937	0.022		
10/10/01 12:00	0.744	22.679	0.020	17.2	

APPENDIX D

LICK CREEK SNOTEL DATA

Data from Lick Creek SNOTEL Site

Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)	Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)
27-Jul-00	22.5	0.2	16	15-Sep-00	23.8	0	15
28-Jul-00	22.5	0	16	16-Sep-00	23.8	0	18
29-Jul-00	22.5	0	18	17-Sep-00	23.8	0	14
30-Jul-00	22.5	0	18	18-Sep-00	23.8	0	12
31-Jul-00	22.5	0	20	19-Sep-00	24.1	0.3	11
1-Aug-00	22.5	0	20	20-Sep-00	24.3	0.2	6
2-Aug-00	22.5	0	19	21-Sep-00	24.3	0	5
3-Aug-00	22.5	0	18	22-Sep-00	25	0.7	-1
4-Aug-00	22.5	0	16	23-Sep-00	25.1	0.1	-6
5-Aug-00	22.7	0.2	13	24-Sep-00	25.2	0.1	-5
6-Aug-00	22.7	0	14	25-Sep-00	25.2	0	0
7-Aug-00	22.7	0	15	26-Sep-00	25.2	0	7
8-Aug-00	22.7	0	16	27-Sep-00	25.3	0.1	5
9-Aug-00	22.7	0	16	28-Sep-00	25.3	0	7
10-Aug-00	22.7	0	19	29-Sep-00	25.3	0	10
11-Aug-00	22.7	0	19	30-Sep-00	25.5	0.2	10
12-Aug-00	22.7	0	15	1-Oct-00	0	0	9
13-Aug-00	22.7	0	14	2-Oct-00	0.3	0.3	7
14-Aug-00	22.7	0	16	3-Oct-00	0.4	0.1	5
15-Aug-00	22.7	0	15	4-Oct-00	0.4	0	2
16-Aug-00	22.7	0	16	5-Oct-00	0.4	0	1
17-Aug-00	22.7	0	14	6-Oct-00	0.4	0	-2
18-Aug-00	22.7	0	15	7-Oct-00	0.4	0	-3
19-Aug-00	22.9	0.2	14	8-Oct-00	0.4	0	0
20-Aug-00	22.9	0	14	9-Oct-00	0.4	0	5
21-Aug-00	22.9	0	10	10-Oct-00	0.4	0	7
22-Aug-00	22.9	0	10	11-Oct-00	0.5	0.1	9
23-Aug-00	22.9	0	14	12-Oct-00	0.7	0.2	3
24-Aug-00	22.9	0	17	13-Oct-00	0.9	0.2	1
25-Aug-00	23.1	0.2	14	14-Oct-00	1.1	0.2	1
26-Aug-00	23.1	0	14	15-Oct-00	1.3	0.2	2
27-Aug-00	23.2	0.1	14	16-Oct-00	1.3	0	2
28-Aug-00	23.2	0	14	17-Oct-00	1.3	0	3
29-Aug-00	23.2	0	10	18-Oct-00	1.3	0	6
30-Aug-00	23.2	0	14	19-Oct-00	1.3	0	7
31-Aug-00	23.3	0.1	9	20-Oct-00	1.3	0	4
1-Sep-00	23.3	0	14	21-Oct-00	1.3	0	8
2-Sep-00	23.3	0	10	22-Oct-00	1.6	0.3	1
3-Sep-00	23.4	0.1	10	23-Oct-00	1.7	0.1	-3
4-Sep-00	23.4	0	9	24-Oct-00	1.7	0	0
5-Sep-00	23.4	0	12	25-Oct-00	1.7	0	3
6-Sep-00	23.4	0	13	26-Oct-00	1.7	0	2
7-Sep-00	23.4	0	6	27-Oct-00	1.7	0	2
8-Sep-00	23.4	0	9	28-Oct-00	1.7	0	6
9-Sep-00	23.4	0	14	29-Oct-00	1.7	0	6
10-Sep-00	23.7	0.3	6	30-Oct-00	1.7	0	5
11-Sep-00	23.7	0	7	31-Oct-00	1.7	0	1
12-Sep-00	23.8	0.1	8	1-Nov-00	1.8	0.1	0
13-Sep-00	23.8	0	12	2-Nov-00	2	0.2	-2
14-Sep-00	23.8	0	13	3-Nov-00	2.1	0.1	-5

Data from Lick Creek SNOTEL Site

Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)	Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)
4-Nov-00	2.1	0	-4	24-Dec-00	5.5	0	-4
5-Nov-00	2.3	0.2	1	25-Dec-00	5.7	0.2	-4
6-Nov-00	2.6	0.3	-5	26-Dec-00	5.7	0	-6
7-Nov-00	2.7	0.1	-8	27-Dec-00	5.7	0	-1
8-Nov-00	2.7	0	-12	28-Dec-00	5.7	0	1
9-Nov-00	2.8	0.1	-7	29-Dec-00	5.7	0	-6
10-Nov-00	2.8	0	-12	30-Dec-00	5.8	0.1	-3
11-Nov-00	2.9	0.1	-17	31-Dec-00	6.2	0.4	-1
12-Nov-00	2.9	0	-13	1-Jan-01		0.1	-4
13-Nov-00	2.9	0	-13	2-Jan-01		0	-5
14-Nov-00	3	0.1	-13	3-Jan-01		0	-5
15-Nov-00	3	0	-9	4-Jan-01		0	1
16-Nov-00	3.3	0.3	-8	5-Jan-01		0	3
17-Nov-00	3.3	0	-9	6-Jan-01		0	2
18-Nov-00	3.5	0.2	-9	7-Jan-01		0	-5
19-Nov-00	3.6	0.1	-5	8-Jan-01		0	-8
20-Nov-00	3.6	0	-8	9-Jan-01		0	1
21-Nov-00	3.6	0	-6	10-Jan-01		0	1
22-Nov-00	3.6	0	-3	11-Jan-01		0	-3
23-Nov-00	3.6	0	-4	12-Jan-01		0	-2
24-Nov-00	3.6	0	-4	13-Jan-01		0.1	-1
25-Nov-00	3.6	0	-4	14-Jan-01		0	-4
26-Nov-00	3.6	0	-3	15-Jan-01		0	-8
27-Nov-00	3.7	0.1	-2	16-Jan-01		0	-8
28-Nov-00	3.9	0.2	-3	17-Jan-01		0	-12
29-Nov-00	3.9	0	-9	18-Jan-01		0.1	-8
30-Nov-00	3.9	0	-4	19-Jan-01		0.1	-3
1-Dec-00	4.6	0.7	-3	20-Jan-01		0.3	-3
2-Dec-00	4.6	0	-7	21-Jan-01		0	-7
3-Dec-00	4.6	0	-3	22-Jan-01		0.1	-3
4-Dec-00	4.6	0	-3	23-Jan-01		0	-3
5-Dec-00	4.6	0	-4	24-Jan-01		0	-7
6-Dec-00	4.6	0	-4	25-Jan-01		0.2	-2
7-Dec-00	4.6	0	-2	26-Jan-01		0	-4
8-Dec-00	4.6	0	-2	27-Jan-01		0	-9
9-Dec-00	4.6	0	-6	28-Jan-01		0	-10
10-Dec-00	4.7	0.1	-5	29-Jan-01		0	-8
11-Dec-00	4.7	0	-13	30-Jan-01		0	-6
12-Dec-00	4.8	0.1	-18	31-Jan-01		0.3	-6
13-Dec-00	4.8	0	-17	1-Feb-01		0	-4
14-Dec-00	4.9	0.1	-9	2-Feb-01		0.2	-1
15-Dec-00	4.9	0	-1	3-Feb-01		0.1	-1
16-Dec-00	5	0.1	-7	4-Feb-01		0	-6
17-Dec-00	5	0	-6	5-Feb-01		0.2	-2
18-Dec-00	5.1	0.1	-4	6-Feb-01		0	-3
19-Dec-00	5.1	0	-6	7-Feb-01		0	-10
20-Dec-00	5.3	0.2	-1	8-Feb-01		0	-19
21-Dec-00	5.3	0	-13	9-Feb-01		0.1	-19
22-Dec-00	5.4	0.1	-8	10-Feb-01		0	-10
23-Dec-00	5.5	0.1	-2	11-Feb-01		0	-6

Data from Lick Creek SNOTEL Site

Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)	Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)
12-Feb-01		0	-9	4-Apr-01		0.1	-1
13-Feb-01		0	-6	5-Apr-01		0.1	-2
14-Feb-01		0	-10	6-Apr-01		0	1
15-Feb-01		0	-10	7-Apr-01		0	1
16-Feb-01		0	-8	8-Apr-01		0.3	2
17-Feb-01		0.1	-9	9-Apr-01		0	-2
18-Feb-01		0	-2	10-Apr-01		0.1	-2
19-Feb-01		0	1	11-Apr-01		0.1	-3
20-Feb-01		0	-3	12-Apr-01		0.2	-3
21-Feb-01		0	-5	13-Apr-01		0.1	-3
22-Feb-01		0	-1	14-Apr-01		0.3	-2
23-Feb-01		0	-2	15-Apr-01		0	-4
24-Feb-01		0	-4	16-Apr-01		0	-2
25-Feb-01		0	-6	17-Apr-01		0	2
26-Feb-01		0.1	-5	18-Apr-01		0	9
27-Feb-01		0	-7	19-Apr-01		0.3	8
28-Feb-01		0	-13	20-Apr-01		0.3	2
1-Mar-01		0	-7	21-Apr-01		0.2	-1
2-Mar-01		0	-3	22-Apr-01		0	0
3-Mar-01		0.1	-1	23-Apr-01		0	1
4-Mar-01		0	-5	24-Apr-01		0	3
5-Mar-01		0	0	25-Apr-01		0	6
6-Mar-01		0	3	26-Apr-01		0	8
7-Mar-01		0	1	27-Apr-01		0	9
8-Mar-01		0	0	28-Apr-01		0.2	9
9-Mar-01		0.2	1	29-Apr-01		0.3	10
10-Mar-01		0	-1	30-Apr-01		0.4	5
11-Mar-01		0	-3	1-May-01		0.2	6
12-Mar-01		0.1	-3	2-May-01		0.1	-1
13-Mar-01		0.1	-1	3-May-01		0	-2
14-Mar-01		0.5	2	4-May-01		0	0
15-Mar-01		0.1	-5	5-May-01		0.2	5
16-Mar-01		0	-6	6-May-01		0	5
17-Mar-01		0	-5	7-May-01		0	1
18-Mar-01		0	-3	8-May-01		0	6
19-Mar-01		0	1	9-May-01		0	10
20-Mar-01		0	6	10-May-01		0	7
21-Mar-01		0	2	11-May-01		0	5
22-Mar-01		0	2	12-May-01		0	9
23-Mar-01		0	2	13-May-01		0	14
24-Mar-01		0	2	14-May-01		0	15
25-Mar-01		0	1	15-May-01		0	12
26-Mar-01		0.4	2	16-May-01		0.3	6
27-Mar-01		0.1	1	17-May-01		0	4
28-Mar-01		0.2	-2	18-May-01		0.1	7
29-Mar-01		0.2	1	19-May-01		0	8
30-Mar-01		0.5	2	20-May-01		0.2	10
31-Mar-01		0.1	-2	21-May-01		0	1
1-Apr-01		0	-1	22-May-01		0	5
2-Apr-01		0.1	2	23-May-01		0	10
3-Apr-01		0	2	24-May-01		0	12

Data from Lick Creek SNOTEL Site

Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)	Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)
25-May-01		0	14	15-Jul-01		0.5	14
26-May-01		0.1	12	16-Jul-01		0	11
27-May-01		0	12	17-Jul-01		0	12
28-May-01		0.2	9	18-Jul-01		0	12
29-May-01		0.1	10	19-Jul-01		0.1	11
30-May-01		0	8	20-Jul-01		0	14
31-May-01		0	8	21-Jul-01		0	15
1-Jun-01		0	10	22-Jul-01		0	15
2-Jun-01		0.1	15	23-Jul-01		0	12
3-Jun-01		0.2	12	24-Jul-01		0	12
4-Jun-01		0.2	3	25-Jul-01		0	15
5-Jun-01		0.4	3	26-Jul-01		0	15
6-Jun-01		0.1	6	27-Jul-01		0	15
7-Jun-01		0	7	28-Jul-01		0	16
8-Jun-01		0	9	29-Jul-01		0	17
9-Jun-01		0	12	30-Jul-01		0	14
10-Jun-01		0	12	31-Jul-01		0	12
11-Jun-01		0	13	1-Aug-01		0	10
12-Jun-01		1.1	9	2-Aug-01		0	13
13-Jun-01		2	5	3-Aug-01		0	19
14-Jun-01		0.5	1	4-Aug-01		0	20
15-Jun-01		0.2	6	5-Aug-01		0	18
16-Jun-01		0.3	7	6-Aug-01		0	17
17-Jun-01		0	10	7-Aug-01		0	19
18-Jun-01		0.4	10	8-Aug-01		0	20
19-Jun-01		0.1	6	9-Aug-01		0	17
20-Jun-01		0	8	10-Aug-01		0	12
21-Jun-01		0	14	11-Aug-01		0	15
22-Jun-01		0	15	12-Aug-01		0	15
23-Jun-01		0	17	13-Aug-01		0	17
24-Jun-01		0	14	14-Aug-01		0	16
25-Jun-01		0	17	15-Aug-01		0	15
26-Jun-01		0	13	16-Aug-01		0	14
27-Jun-01		0	15	17-Aug-01		0	15
28-Jun-01		0	16	18-Aug-01		0	17
29-Jun-01		0	16	19-Aug-01		0	18
30-Jun-01		0	15	20-Aug-01		0.1	15
1-Jul-01		0	16	21-Aug-01		0	15
2-Jul-01		0	18	22-Aug-01		0	15
3-Jul-01		0	17	23-Aug-01		0	16
4-Jul-01		0	18	24-Aug-01		0	18
5-Jul-01		0.4	16	25-Aug-01		0	14
6-Jul-01		0	16	26-Aug-01		0	14
7-Jul-01		0	16	27-Aug-01		0	16
8-Jul-01		0	17	28-Aug-01		0	16
9-Jul-01		0.1	17	29-Aug-01		0	16
10-Jul-01		0	15	30-Aug-01		0	13
11-Jul-01		0.1	14	31-Aug-01		0	16
12-Jul-01		0	14	1-Sep-01		0	16
13-Jul-01		0	14	2-Sep-01		0	17
14-Jul-01		0	14	3-Sep-01		0	15

Data from Lick Creek SNOTEL Site

Date	Accumulated Precipitation (in.)	Daily Precip. (in)	Temp (C)
4-Sep-01		0	18
5-Sep-01		0	16
6-Sep-01		0.1	14
7-Sep-01		0.7	5
8-Sep-01		0	2
9-Sep-01		0.5	4
10-Sep-01		0	9
11-Sep-01		0	12
12-Sep-01	23.7	0	12
13-Sep-01	23.7	0	11
14-Sep-01	23.7	0	12
15-Sep-01	23.7	0	8
16-Sep-01	23.7	0	8
17-Sep-01	23.7	0	9
18-Sep-01	23.7	0	7
19-Sep-01	23.7	0	10
20-Sep-01	23.7	0	9
21-Sep-01	23.7	0	8
22-Sep-01	23.7	0	12
23-Sep-01	23.7	0	9
24-Sep-01	23.7	0	12
25-Sep-01	23.5	0	15
26-Sep-01	23.5	0	16
27-Sep-01	23.4	0	15
28-Sep-01	23.3	0	14
29-Sep-01	23.4	0	15
30-Sep-01	23.2	0	9
1-Oct-01	0	0	9
2-Oct-01	0	0	12
3-Oct-01	-0.1	0	9
4-Oct-01	-0.1	0	6
5-Oct-01	-0.1	0.1	-1
6-Oct-01	0	0.2	0
7-Oct-01	0.2	0.2	6
8-Oct-01	0.4	0	8
9-Oct-01	0.2	0.2	4
10-Oct-01	0.4	0	0
11-Oct-01	0.4	0.7	
12-Oct-01	1.1	0	
13-Oct-01	1.1	0.1	
14-Oct-01	1.2	0.8	
15-Oct-01	2		

APPENDIX E

LABORATORY ANALYTICAL REPORTS



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LABORATORY ANALYSIS REPORT

Montana State University
 Karin Kirk, Earth Sciences
 329 Little Wolf Rd.
 Bozeman, MT 59715

Project ID: MSU EARTH SCIENCES
 Sample ID: UPPER SPRING
 Laboratory ID: 01-53205-1
 Sample Matrix: Water
 Sample Date: 29-Apr-01 1120
 Received at lab: 01-May-01

Reported: 07-May-01

	Results	Units	Qual	Reporting	Regulatory	Method	Analyzed
				Limit	Limit		
Calcium	20	mg/l		1		EPA 200.7	03-May-01 0209 LAB
Magnesium	7	mg/l		1		EPA 200.7	03-May-01 0209 LAB
Potassium	2	mg/l		1		EPA 200.7	03-May-01 0209 LAB
Sodium	2	mg/l		1		EPA 200.7	03-May-01 0209 LAB
Chloride	<1	mg/l		1		EPA 300.0	03-May-01 0113 LDV
Sulfate	4	mg/l		1		EPA 300.0	03-May-01 0113 LDV
Bicarbonate	87	mg/l		1		SM2320B	07-May-01 1302 LDV
Carbonate	<1	mg/l		1		SM2320B	07-May-01 1302 LDV
Specific Conductance @ 25 C	147	umhos/cm		1		SM 2510B	01-May-01 1629 QD
Solids, Total Dissolved at 180 C	56	mg/l		10		SM 2540C	01-May-01 1339 LDV
pH	7.7	s.u.		0.1		EPA 150.1	01-May-01 1629 QD



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LABORATORY ANALYSIS REPORT

Montana State University
Karin Kirk, Earth Sciences
329 Little Wolf Rd.
Bozeman, MT 59715

Project ID: MSU EARTH SCIENCES
Sample ID: LOWER SPRING
Laboratory ID: 01-53205-2
Sample Matrix: Water
Sample Date: 29-Apr-01 1120
Received at lab: 01-May-01

Reported: 07-May-01

	Results	Units	Qual	Reporting	Regulatory	Method	Analyzed	
				Limit	Limit			
Calcium	20	mg/l		1		EPA 200.7	03-May-01 0214	LAB
Magnesium	7	mg/l		1		EPA 200.7	03-May-01 0214	LAB
Potassium	2	mg/l		1		EPA 200.7	03-May-01 0214	LAB
Sodium	2	mg/l		1		EPA 200.7	03-May-01 0214	LAB
Chloride	<1	mg/l		1		EPA 300.0	03-May-01 0137	LDV
Sulfate	4	mg/l		1		EPA 300.0	03-May-01 0137	LDV
Bicarbonate	88	mg/l		1		SM2320B	07-May-01 1306	LDV
Carbonate	<1	mg/l		1		SM2320B	07-May-01 1306	LDV
Specific Conductance @ 25 C	142	umhos/cm		1		SM 2510B	01-May-01 1630	QD
Solids, Total Dissolved at 180 C	65	mg/l		10		SM 2540C	01-May-01 1341	LDV
pH	7.7	s.u.		0.1		EPA 150.1	01-May-01 1630	QD



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Lab Nos. 01-53205-1-2

QUALITY ASSURANCE DATA PACKAGE

This report is a summary of the results of the quality assurance tests performed with the sample analyses. They are performed to determine if the methodology is in control and to monitor the laboratory's ability to produce accurate and precise results. The date the quality assurance sample was analyzed is consistent with Energy Laboratories' Quality Assurance Plan.

Constituents	Duplicate Analysis		Spiked	Blank	Calibration	True Value,
	--- mg/l (ppm) ---		Analysis	Analysis	Sample	Acceptable
	Original	Duplicate	%	mg/l (ppm)	Analysis	+/- 10%
			Recovery		mg/l (ppm)	mg/l (ppm)
Calcium	20	20	90	<1	102	100
Magnesium	7	7	90	<1	105	100
Potassium	2	2	96	<1	107	100
Sodium	2	2	95	<1	106	100
Chloride	42	42	97	<1	25	25
Sulfate	1330	1340	104	<1	103	100
Specific Conductance, μ mhos/cm	454	456	NA	<1	NA	NA
Solids, Total Dissolved at 180 C	1060	1060	104	<10	NA	NA
pH, s.u.	8.1	8.1	NA	NA	NA	NA



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Lab Nos.: 001-01-53205 - 002-01-53205

Date: 01-MAY-01

Received by: Krystal McDonald

Logged In by: Krystal McDonald

SAMPLE CONDITION QA/QC REPORT

This report provides information about the condition of the sample(s) and associated sample custody information on receipt at the laboratory.

Chain of Custody Form Completed & Signed	<u>Yes</u>	Comments: _____
Chain of Custody Seal Intact	<u>No</u>	Comments: _____
Signature Match Chain of Custody vs. Seal	<u>N/A</u>	Comments: _____
Temperature Received	<u>2 C.</u>	Comments: _____
Samples Received Within Holding Time	<u>Yes</u>	Comments: _____
Samples Received in Proper Containers	<u>Yes</u>	Comments: _____
Samples Received Properly Preserved(1)	<u>N/A</u>	Comments: _____

(1) Acid preservation of samples for volatile organics is not evaluated on this form. Any preservation problems encountered for these samples are noted on the analytical parameter report pages.

Record of client contact:

Who: _____ By: _____ Date/Time: _____

Method of Shipping: UPS Ground

Additional comments: _____



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LABORATORY ANALYSIS REPORT

Kirk, Karin
329 Little Wolf Rd
Bozeman, MT 59715

Project ID: MSU BOZEMAN
Sample ID: TWO SPRINGS, SAMPLED @ 15:00 AND 15:10
Laboratory ID: 01-58595-1
Sample Matrix: Water
Sample Date: 01-Oct-01 0000
Received at lab: 02-Oct-01

Reported: 12-Oct-01

	Results	Units	Reporting		Regulatory		Method	Analyzed
			Qual	Limit	Limit			
Calcium	25	mg/l		1			EPA 200.7	04-Oct-01 1703 RLH
Magnesium	8	mg/l		1			EPA 200.7	04-Oct-01 1703 RLH
Potassium	2	mg/l		1			EPA 200.7	04-Oct-01 1703 RLH
Sodium	2	mg/l		1			EPA 200.7	04-Oct-01 1703 RLH
Hardness, Total as CaCO ₃	95	mg/l		1			Calculated	
Chloride	<1	mg/l		1			EPA 300.0	03-Oct-01 1846 LDV
Sulfate	5	mg/l		1			EPA 300.0	03-Oct-01 1846 LDV
Alkalinity as CaCO ₃	96	mg/l		1			SM2320B	04-Oct-01 1446 AK/LDV
Bicarbonate	117	mg/l		1			SM2320B	04-Oct-01 1446 AK/LDV
Carbonate	<1	mg/l		1			SM2320B	04-Oct-01 1446 AK/LDV
Specific Conductance @ 25 C	178	umhos/cm		1			SM 2510B	02-Oct-01 1350 AK
Solids, Total Dissolved - Calculated	159	mg/l		10			Calculated	
pH	8.0	s.u.		0.1			EPA 150.1	02-Oct-01 1350 AK
Nitrogen, Nitrate plus Nitrite	0.06	mg/l		0.05	10.0		EPA 353.2	11-Oct-01 1441 BS
Fluoride	0.10	mg/l		0.1	4.0		SM 4500FC mod	05-Oct-01 1512 DLR
Bacteria, Total Coliform	Present	/100 ml					SM 9223	02-Oct-01 1200 DLR
E-Coli	Absent	/100 ml					SM 9223	02-Oct-01 1200 DLR
Turbidity	0.33	N.T.U.		0.01			EPA 180.1	02-Oct-01 1130 AK
Antimony, Total	<0.003	mg/l		0.003	0.006		EPA 200.8	10-Oct-01 1143 LB/JW
Arsenic, Total	<0.005	mg/l		0.005	0.05		EPA 200.8	10-Oct-01 1143 LB/JW
Barium, Total	<0.1	mg/l		0.1	2		EPA 200.7	04-Oct-01 2113 RLH
Beryllium, Total	<0.001	mg/l		0.001	0.004		EPA 200.7	04-Oct-01 2113 RLH
Cadmium, Total	<0.001	mg/l		0.001	0.005		EPA 200.7	04-Oct-01 2113 RLH
Chromium, Total	<0.01	mg/l		0.01	0.1		EPA 200.7	04-Oct-01 2113 RLH
Copper, Total	<0.01	mg/l		0.01	1.3		EPA 200.7	04-Oct-01 2113 RLH
Iron, Total	<0.03	mg/l		0.03	0.3		EPA 200.7	04-Oct-01 2113 RLH
Lead, Total	<0.005	mg/l		0.005	0.015		EPA 200.8	10-Oct-01 1143 LB/JW
Mercury, Total	<0.0002	mg/l		0.0002	0.002		EPA 200.8	10-Oct-01 1143 LB/JW
Nickel, Total	<0.01	mg/l		0.01	0.1		EPA 200.7	04-Oct-01 2113 RLH
Selenium, Total	<0.005	mg/l		0.005	0.05		EPA 200.8	10-Oct-01 1143 LB/JW
Thallium, Total	<0.001	mg/l		0.001	0.002		EPA 200.8	10-Oct-01 1143 LB/JW

This Total Coliform bacteria analysis shows this water to be bacterially contaminated and unsuitable for drinking.



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LABORATORY ANALYSIS REPORT

Kirk, Karin
329 Little Wolf Rd
Bozeman, MT 59715

Project ID: MSU BOZEMAN
Sample ID: TWO SPRINGS #4
Laboratory ID: 01-58595-2
Sample Matrix: Water
Sample Date: 01-Oct-01 1500
Received at lab: 02-Oct-01

Reported: 12-Oct-01

	Results	Units	Qual	Reporting	Regulatory	Method	Analyzed
				Limit	Limit		
Alkalinity as CaCO ₃	101	mg/l		1		SM2320B	04-Oct-01 1450 AK/LDV
Bicarbonate	123	mg/l		1		SM2320B	04-Oct-01 1450 AK/LDV
Carbonate	<1	mg/l		1		SM2320B	04-Oct-01 1450 AK/LDV



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Lab Nos. 01-58595-1-2

QUALITY ASSURANCE DATA PACKAGE

This report is a summary of the results of the quality assurance tests performed with the sample analyses. They are performed to determine if the methodology is in control and to monitor the laboratory's ability to produce accurate and precise results. The date the quality assurance sample was analyzed is consistent with Energy Laboratories' Quality Assurance Plan.

Constituents	Duplicate Analysis		Spiked	Blank	Calibration	True Value,
	--- mg/l (ppm) ---		Analysis	Analysis	Sample	Acceptable
	Original	Duplicate	% Recovery	mg/l (ppm)	Analysis	+/- 10% mg/l (ppm)
Calcium	107	109	102	<1	51	50
Magnesium	20	21	103	<1	50	50
Potassium	2	2	105	<1	51	50
Sodium	55	56	104	<1	50	50
Chloride	23	23	99	<1	26	25
Sulfate	101	101	99	<1	104	100
Alkalinity as CaCO ₃	390	389	104	<1	111	100
Specific Conductance, µmhos/cm	178	173	NA	<1	NA	NA
pH, s.u.	8.0	8.0	NA	NA	NA	NA
Nitrogen, Nitrate plus Nitrite	6.06	6.03	102	<0.05	5.31	5.42
Fluoride	2.07	2.07	109	<0.1	3.91	3.76
Turbidity, N.T.U.	0.33	0.33	NA	0.06	0.66	0.66
Antimony, Total	0.048	0.049	99	<0.003	0.046	0.05
Arsenic, Total	0.051	0.052	102	<0.005	0.047	0.05
Barium, Total	<0.1	<0.1	98	<0.1	0.048	0.05
Beryllium, Total	0.044	0.044	88	<0.001	0.048	0.05
Cadmium, Total	0.049	0.050	100	<0.001	0.046	0.05
Chromium, Total	0.05	0.05	96	<0.01	0.046	0.05
Copper, Total	0.05	0.05	93	<0.01	0.046	0.05
Iron, Total	<0.03	<0.03	95	<0.03	4.87	5
Lead, Total	0.048	0.049	98	<0.005	0.047	0.05
Mercury, Total	0.0048	0.0047	97	<0.0002	0.0048	0.005
Nickel, Total	0.04	0.05	90	<0.01	0.045	0.05
Selenium, Total	0.054	0.055	111	<0.005	0.047	0.05
Thallium, Total	0.050	0.051	102	<0.001	0.048	0.05



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 800-735-4489 • 406-252-6325 • 406-252-6069 fax • eli@energylab.com

Lab Nos.: 001-01-58595 - 002-01-58595

Date: 02-OCT-01

Received by: Justin McMillan

Logged In by: Justin McMillan

SAMPLE CONDITION QA/QC REPORT

This report provides information about the condition of the sample(s) and associated sample custody information on receipt at the laboratory.

Chain of Custody Form Completed & Signed	<u>Yes</u>	Comments: _____
Chain of Custody Seal Intact	<u>Yes</u>	Comments: _____
Signature Match Chain of Custody vs. Seal	<u>Yes</u>	Comments: _____
Temperature Received	<u>4 C</u>	Comments: _____
Samples Received Within Holding Time	<u>Yes</u>	Comments: _____
Samples Received in Proper Containers	<u>Yes</u>	Comments: _____
Samples Received Properly Preserved(1)	<u>Yes</u>	Comments: _____

(1) Acid preservation of samples for volatile organics is not evaluated on this form. Any preservation problems encountered for these samples are noted on the analytical parameter report pages.

Record of client contact:

Who: _____ By: _____ Date/Time: _____

Method of Shipping: UPS ARS Ground

Additional comments: _____



June 27, 2001

TRITIUM LABORATORY

Data Release #01-073
Job # 1490

MONTANA STATE UNIVERSITY
TRITIUM SAMPLES

Dr. James D. Happell
Assistant Research Professor

Distribution:

Karin Kirk
329 Little Wolf Rd.
Bozeman, MT 59715

Rosenstiel School of Marine and Atmospheric Science
Tritium Laboratory
4600 Rickenbacker Causeway
Miami, FL 33149-1098
Phone: (305) 361-4100
Fax: (305) 361-4112
email: tritium@rsmas.miami.edu

GENERAL COMMENTS ON TRITIUM RESULTSTritium Scale (New)

Tritium concentrations are expressed in TU, where 1 TU indicates a T/H ratio of 10^{-18} . The values refer to the new tritium scale of U.S. National Institute of Science and Technology (formerly NBS), and based on their tritium water standard #4926 as measured on 1961/09/03 and again 1978/09/03, and age-corrected with the new half-life of 12.43 years, i.e., $\lambda = 5.576\% \text{ year}^{-1}$. In this scale, 1 TU is 7.088 dpm/kg H₂O, or 3.193 pCi/kg H₂O, or 0.1181 Bq/kg H₂O (Bq = disint/sec). TU values are calculated for date of sample collection, REFDATE in the table, as provided by the submitter. If no such date is available, date of sample arrival at our laboratory is used. The stated errors, eTU, are one standard deviation (1 sigma) including all conceivable contributions. In the table, QUANT is quantity of sample received, and ELYS is the amount of water taken for electrolytic enrichment. DIR means direct run (no enrichment).

Through 31 December 1993, we reported tritium values in the "old" scale using the half-life 12.26 years, i.e., $\lambda = 5.65\% \text{ year}^{-1}$. In that old scale, 1 TU(old) is 7.186 dpm/kg H₂O, 3.237 pCi/kg H₂O. To convert from the new scale back to the old at any given point in time, multiply the listed TU(new)-values by F, where

$$F = 0.9645 - (\text{year}-1990) \times 0.0008$$

i.e. for 1994 the factor is 0.9613. The formula is correct within 0.02% between 1962 and 1999. To convert data from the old scale to the new, divide by F.

Very low tritium values

In some cases, negative TU values are listed. Such numbers can occur because the net tritium count rate is, in principle the difference between the count rate of the sample and that of a tritium-free sample (background count or blank sample). Given a set of "unknown" samples with no tritium, the distribution of net results should become symmetrical around 0 TU. The negative values are reported as such for the benefit of allowing the user unbiased statistical treatment of sets of the data. For other applications, 0 TU should be used.

Reliability of results

Refer to Services Rendered (Tritium), Section II.8, in the "Tritium Laboratory Price Schedule; Procedures and Standards; Advice on Sampling". Tritium efficiencies and background values are different in the nine counters and values are corrected for cosmic intensity, gas pressure and other parameters. For tritium, the efficiency is typically 1.00 cpm per 100 TU (direct counting). At 50x enrichment, the efficiency is equivalent to 1.00 cpm per 2 TU. The background is about 0.3 cpm, known to about ± 0.02 cpm. Our reported results include not only the Poisson statistics, but also other experimental uncertainties such as enrichment error, etc.

References

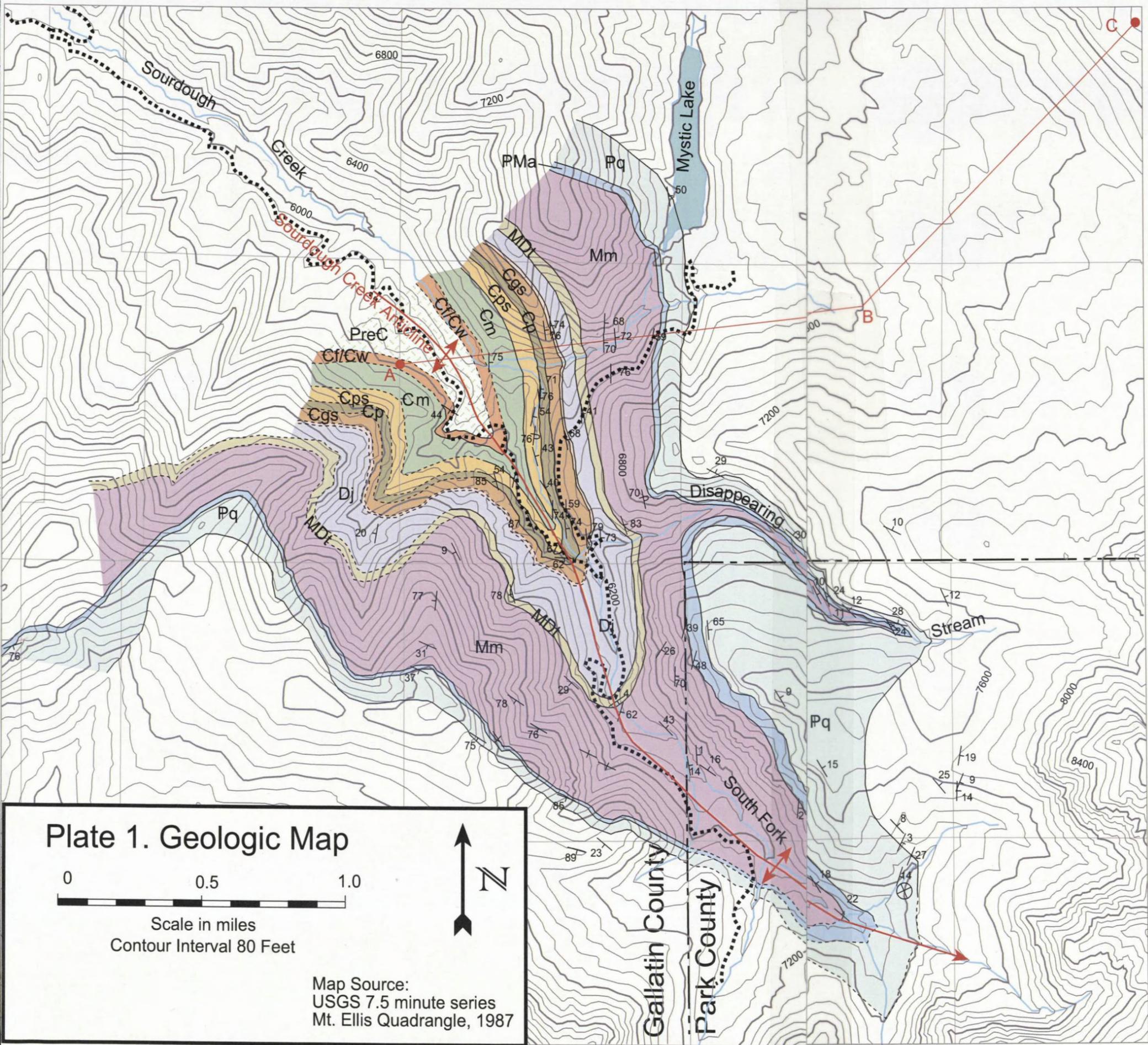
Mann, W.B., M.P. Unterweger, and B.M. Coursey, Comments on the NBS tritiated-water standards and their use, *Int. J. Appl. Radiat. Isot.*, 33, 383-386, 1982.

Taylor, C.B., and W. Roether, A uniform scale for reporting low-level tritium measurements in water, *Int. J. Appl. Radiat. Isot.*, 33, 377-382, 1982.

Client: KARIN KIRK-MONTANA STATE UNIV
 Recvd : 01/05/08 Contact:
 Job# : 1490
 Final : 01/06/26

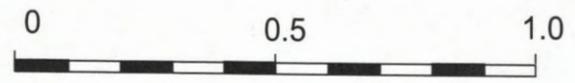
Purchase Order: NO CHARGE
 Karin Kirk, MSU
 329 Little Wolf Rd.
 Bozeman, MT 59715

Cust LABEL INFO	JOB.SX	REFDATE	QUANT	ELYS	TU	eTU
MONTANA STATE- Upper Spring	1490.01	010429	1000	254	14.9	0.5
MONTANA STATE- Lower Spring	1490.02	010429	1000	250	13.8	0.5
MONTANA STATE- Snowpack	1490.03	010429	1000	250	10.7	0.4



- Pq Quadrant sandstone
- PMa Amsden Formation
- Mm Madison Group
- MDt Three Forks Shale
- Dj Jefferson Dolomite
- Ob Bighorn Dolomite
- Cgs Grove Creek and Snowy Range Formations
- Cp Pilgrim Limestone
- Cps Park Shale
- Cm Meagher Limestone
- Cf/Cw Flathead Sandstone and Wolsey Shale
- preC Precambrian Gneiss
- Unmapped Geology
- Contact, dashed where inferred
- Stream channel
- Dirt road

Plate 1. Geologic Map

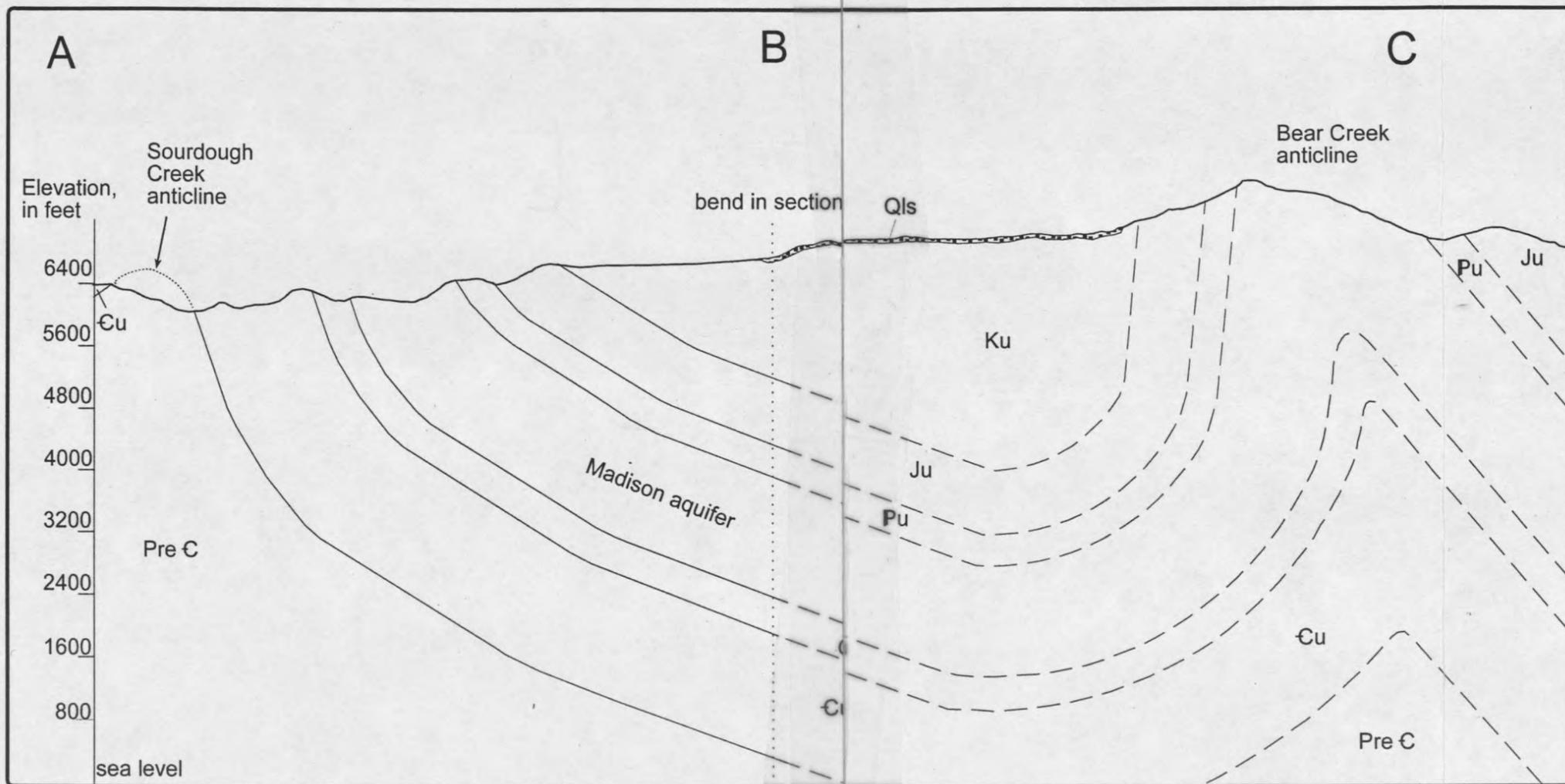


Scale in miles
Contour Interval 80 Feet



Map Source:
USGS 7.5 minute series
Mt. Ellis Quadrangle, 1987

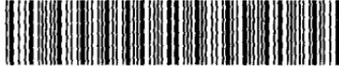
Gallatin County
Park County



- Geologic units:
- Qls - Quaternary landslide deposits
 - Ku - Cretaceous sedimentary rocks
 - Ju - Jurassic sedimentary rocks
 - Pu - Permian sedimentary rocks
 - ODu - Ordovician and Devonian sedimentary rocks
 - Cu - Cambrian sedimentary rocks
 - Pre C - Precambrian metamorphic rocks

Plate 2. Conceptual Geologic Cross Section A-B-C
No vertical exaggeration.

MONTANA STATE UNIVERSITY - BOZEMAN



3 1762 10357813 2

612 11 194