Controls on ground-water availability and quality, the Bridger Canyon area, Bozeman, Montana
by Bonnie K Moore

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

Abstract:
Residential expansion into the Bridger Canyon area of Bozeman, Montana has encountered localized areas of restricted ground-water availability. In some instances water wells were drilled after houses were built, but no water was found or wells did not produce sufficient water for the household. Within the canyon, water quality varies. Some domestic wells encountered hydrogen sulfide and excess fluoride. Areas where water is available and of good quality include alluvium and some springs at or near the toes of landslides. Water is not readily available or is of poor quality within thick sequences of shales of the Livingston Group. Variations in the Livingston Group deposits cause subsequent variations in ground-water availability and quality.

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APPROVAL

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Bonnie K. Moore

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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Stephen G. Custer — Chairperson, Graduate Committee

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Date August 28, 1984

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ABSTRACT

Residential expansion into the Bridger Canyon area of Bozeman, Montana has encountered localized areas of restricted ground-water availability. In some instances water wells were drilled after houses were built, but no water was found or wells did not produce sufficient water for the household. Within the canyon, water quality varies. Some domestic wells encountered hydrogen sulfide and excess fluoride. Areas where water is available and of good quality include alluvium and some springs at or near the toes of landslides. Water is not readily available or is of poor quality within thick sequences of shales of the Livingston Group. Variations in the Livingston Group deposits cause subsequent variations in ground-water availability and quality.

INTRODUCTION

Statement of Problem

The Bridger Canyon area is experiencing development associated with residential expansion near Bozeman, Montana and growth related to the Bridger Bowl Ski area to the north (Figure 1). This development has encountered localized areas of restricted groundwater availability. In some instances water wells were drilled after houses were built, but no water was found or wells did not produce sufficient domestic water supplies. Some wells once developed for use have gone dry or began to pump sand and were rendered unfit for use. It is not unusual for homeowners in the canyon to need to have two or even three wells drilled before sufficient supplies are located for domestic use.

In addition to restricted water availability in the canyon, there is also a problem with localized areas of poor water quality. Some domestic wells have encountered hydrogen sulfide gases and excessive fluoride. Also, some water supplies are iron-rich and cause severe staining of fixtures and an adverse water taste.

Knowledge of these water availability and quality problems and their most probable locations within areas under development would be useful to a landowner planning to develop property in the canyon and to government agencies overseeing such development. This study examines the possibility that geology can be used to better understand where problem areas are located. The question was assessed through

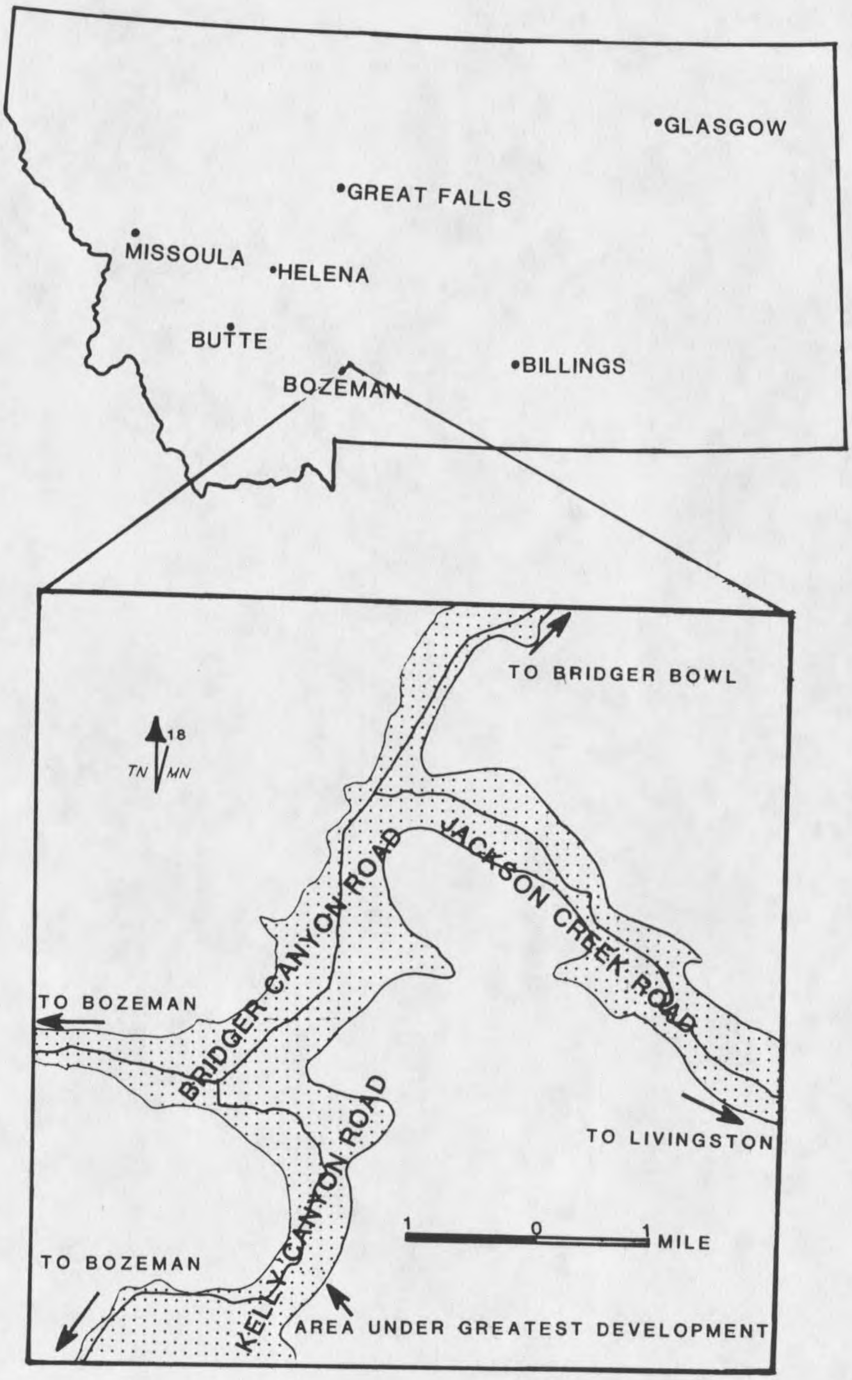

Figure 1. Location of study area indicating area of current development.

evaluation of known water supplies, evaluating the geologic framework in which water is found, and production of a composite water resource map of the area based on this data. Published water studies involving the Bridger Canyon area are scarce. Bridger Creek, which is the main stream in the valley, was included as part of a surface water study for the Gallatin Valley (Hackett and others, 1960) but no groundwater studies have been conducted. A surface water study of Bridger Creek is currently being conducted by the Montana Department of Health and Environmental Sciences Division of the Water Quality Bureau, but no data are as yet published (Montana Department of Health and Environmental Sciences).

General Setting

Geographic Setting

The setting of the study area is important because it establishes the framework in which water is found. Figure 1 shows the area in which people live and are developing homes. The study area boundary was defined on 1982 U.S.G.S. orthophotoquads by enclosing all recognized homes on the photos. At this time (1984) no development is occurring on the steepest slopes on the west side of the valley. These slopes are greater than 15 degrees as measured on topographic maps and are not readily accessible to development.

The study area is located between two National Oceanic and Atmospheric Administration (NOAA) climatological data collection sites. Climate data is collected at the base of the Bridger Bowl Ski area. This station is at an elevation of 5950 feet and records average annual precipitation of 34.81 inches. Average annual temperatures are 51.4°F maximum, 24.4°F minimum, and 37.9 overall average (National Oceanic and Atmospheric Administration, 1982). Much of the valley is at lower elevations and may experience climate more like that measured at the Montana State University data collection site at Bozeman. This station is at an elevation of 4856 feet and records an average annual precipitation of 18.63 inches. Average annual temperatures are 55.7°F maximum, 31.6°F minimum, and 43.7°F overall average. Elevations of areas within the study area currently under development range from 5040 feet to 6250 feet.

Stratigraphic Setting

Compositional variations within and between the rock units control ground water movement and storage. Table 1 lists the formations found in the study area, their age in chronological order beginning with the oldest unit, composition, and expected water bearing properties estimated from this study. The formations bounding the study area are also listed in Table 1 because development may some day occur on these units. All of these rock units are mapped on the geologic map (Plate 1). The rock descriptions are from Roberts (1964) and McMannis (1955). The oldest unit in the study area is the Cretaceous Telegraph Creek Formation (Ktc). No wells are developed in this formation so specific data are not available. However, the water-bearing characteristics should vary from poor availability and storage in the siltstones to good availability and storage in the sandstones. Above this unit is the Eagle Sandstone (Ke) which is

Table 1. Water availability and general aquifer characteristics.

UNIT NAME	AGE	COMPOSITION	SPECIFIC CAPACITY	WATER-BEARING CHARACTERISTICS
Telegraph Creek Fm.	Upper Cretaceous	siltstone, thin-bedded sandstone	unknown	variable from poor to good
Eagle Sandstone	Upper Cretaceous	sandstone, some siltstone ,some coal	unknown	generally good
LIVINGSTON GROUP				
Cokedale Formation	Upper Cretaceous	siltstone, some sandstone, some claystone, some bentonite, minor coal, minor conglomerate	unknown*	variable from poor to good
Miner Creek Formation	Upper Cretaceous	siltstone, sandstone, some bentonite, lower massive sandstone: Sulphur Flats, Sandstone Member	unknown*	good in Sulphur Flats Member, variable in upper beds
Billman Creek Formation	Upper Cretaceous	alternating olive-green, gray, red to purple shales, very minor sands, some claystone, some fresh-water mollusks	0.17 to 5.88	generally very poor

Table 1. (continued)

UNIT NAME	AGE	COMPOSITION	SPECIFIC CAPACITY	WATER-BEARING CHARACTERISTICS
Hoppers Formation	Upper Createaceous	greenish sandstone, claystone, and silt-stone, conglomerate beds throughout	unknown*	generally good where thickness is adequate
Fort Union Formation	Paleocene	conglomerate, sand-stone, siltstone	unknown	variable, but generally good
Terrace-Alluvium	Quaternary	gravel	unknown*	very poor
Stream-Alluvium	Quaternary	gravel	-6.02 to 6.76	very good
Colluvium	Quaternary	mixed clay, sand, gravel, boulders	unknown*	very poor
Landslides	Quaternary	mixed clay, sand, boulders, rock masses	2.19	variable poor to good in springs and ponds

*Indicates that no wells were completed in these units although some were begun in these. Other unknown specific capacities indicate no known wells completed in these units.

composed of interbedded sandstone and siltstone and should be a good source of water where the sandstones are thickest. There is no data for this unit. The next four formations are grouped together as the Livingston Group. This group of formations comprises the majority of the bedrock currently being developed for groundwater.

The key to understanding the geologic control of water availability in the study area is an understanding of the variations within the rock units. Roberts (1972,p. C36) describes the formations of the Livingston Group as a "thick alternating series of coarse- and fine-grained rocks that are characterized by rapid vertical and lateral variations...(that)...probably were deposited in fluvial channel systems or on associated extensive floodplains, near sea level." The Billman Creek Formation (Kbc) is the most widely developed unit for groundwater due to its location. The stratigraphic setting is illustrated diagrammatically in Figure 2 which shows rapid lateral variations in the rocks formed in such an environment. Notice that in the lower part of the figure the gravel and sand lenses are scattered and if missed by a well, thick sequences of shales will be encountered. Shale thickness can reach nearly 2,500 feet if a drill site is chosen which encounters no sand lenses. Although water can move well through a porous sandstone or conglomerate in the Billman Creek Formation, it cannot move well through a tightly compacted, fine-grained silt or clay between the lenses. Where there are few pore spaces in the fine-grained rock, there cannot be much retrievable water stored. Also, when pore spaces are not well connected water cannot move through the rock. As a result, sandstone lenses found at

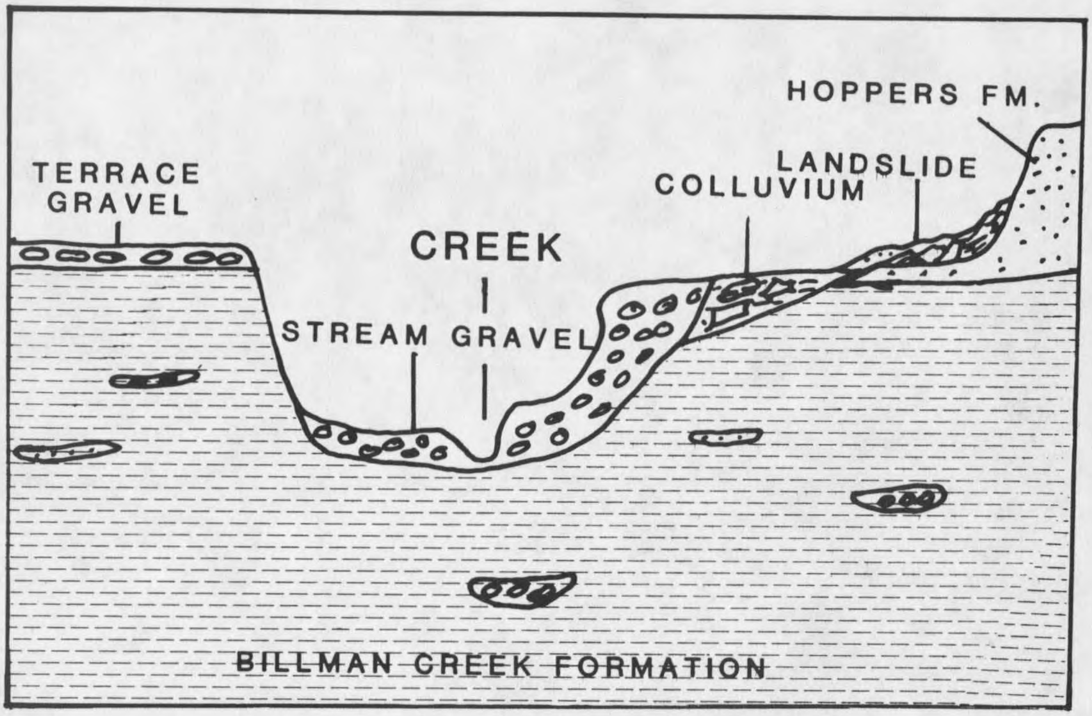

Figure 2. Schematic diagram of the study area showing thick Cretaceous-age Billman Creek Formation dominated by floodplain deposits overlain by Quaternary age sediments.

depth may not be recharged because the sands are isolated from percolating water. There are many areas of poor water availability where the less porous and less permeable zones are encountered.

Below the Billman Creek Formation are the Cokedale Formation (Kc) and the Miner Creek Formation (Km) (Table 1). The Cokedale Formation varies from siltstone and claystone, which should be poor aquifers, to sandstone which should be better. No wells are available in this area to test this hypothesis. Similarly the Miner Creek Formation is much like the Cokedale Formation except for the Sulphur Flats Member (Kms) which is a porous sandstone and should yield water. Both of these lower formations of the Livingston Group lack data for more complete descriptions.

Above the highly variable Billman Creek Formation is the Hoppers Formation (Figure 2). This rock unit should yield much water because it is made up of sandstones and conglomerates which would hold and transmit water. The intermittent claystones and siltstones not shown in Figure 2 should be the only poor water-bearing zones within the formation. The expected water-bearing nature of this rock based on rock type is poorly supported by drill data. The formation should contain much water but does not. When tested in the field, the unit absorbs water poured onto it. The contradiction between the expected and observed natures of the formation is paradoxical. Specific drill data relating to this paradox is discussed later in the text.

The next formation above the Livingston Group is the Fort Union Formation (TKF). No wells in the study area are completed in this rock unit. However, the conglomerates and sandstones of the formation should be good water-bearing units.

The Cretaceous units are not the only aquifers in the study area. Some quaternary deposits are also aquifers. Quaternary deposits in the study area are either terrace-alluvium, stream-alluvium, colluvium, or landslides (Table 1). These units are shown on the geomorphic map (Plate 2). These deposits are differentiated on the basis of morphology, clast angularity and sorting, and degree of stream development on their surfaces.

Stream-alluvium and terrace-alluvium are both composed of deposits of well-rounded gravel clasts. The stream-alluvium is found on a flat surface at and below present stream level. Terrace-alluvium is found on gently-dipping slopes above the present stream level. As described in Table 1, these gravel deposits should be good water-bearing units, but thickness controls the extent to which this is true. Notice in Figure 2 that where the stream-alluvium is thin (10-20 feet) water quantities may not be adequate for domestic supplies. The same is true for terrace-alluvium which is thin and well-drained. Where stream-alluvium is thicker (20 to 60 feet) water quantities should be sufficient for domestic supplies.

Topographically above the stream-alluvium and on slopes grading into the stream-alluvium is the colluvium. This material occurs on steep slopes and in fan-shaped deposits at the mouths of gullies. Colluvium is debris from the rock units forming the slopes and is angular material which is poorly-sorted. Stream development on colluvial deposits is poor, often consisting of tiny rills but no discrete channels. No wells are completed in colluvium to establish its water-bearing properties, but because it is usually only a few feet thick it could yield only minor water quantities if any. It is mapped only where found in thickness greater than a few feet.

Landslides are limited to the slopes of Green Mountain. The landslides are lobate features which have moved downhill as a large mass. The upper edges of the landslides are still in motion as indicated by rotated blocks with fresh scarps, scarps with water seeps, rotated fences, and interrupted drainages. Internally drained ponds of varying dimensions formed by land movement are located at the upper parts of rotated blocks within the landslides. Springs are often located at the toes of the landslides where water drains from the landslide mass along the surface of movement. These springs can be developed as sources of domestic water supplies if they are observed to flow consistently year-round.

<u>Structural Setting</u>

The structural setting of the study area is important because it controls the locations and orientations of the rocks in which water is found. The Bridger Range is at the east margin of the disturbed Belt (Woodward, 1981). This margin is a transitional zone where thrust faults and folds merge with basins and uplifts of the Rocky Mountain Foreland. The importance of this transitional zone to water availability is that it mixes the effects of two different types of faults, both thrust faults and normal faults. The older thrust faults in the valley are currently inactive and are unlikely to be reactivated. However, they may be areas in which rocks are highly broken-up and either enhance water storage and movement because they are coarse and fractured or inhibit water movement and store little water because fault movement broke up material to a fine powder which fills pores and fractures. The thrust faults are not seen at the surface and no wells are known to intersect them so no conclusions can be drawn about their water availability. Younger normal faults in the Bridger Range may be reactivated, but in general are outside the study area. Fold geometry is also important to water availability because folding will change the thickness of rock units with respect to drilling depths. The broad, open folds in the study area differ little from horizontally oriented rock units in that thicknesses are still predictable.

Figure 3 shows the overall structural setting of the Bridger Range. Deformational intensity decreases eastward. As one proceeds from west to east overturned folds become upright and more open and thrust displacement decreases from several miles to less than a mile. The study area is located at the transitional zone and includes both overturned folds and the more upright and open ones. Notice in Figure 3 that in the southeast corner of the map there are fewer faults and folds than to the north and west. Also, in this figure folds to the east of center are less commonly overturned. The more open folds will allow groundwater movement to be less obstructed by structures.

The cross-sections on Plate 1 illustrate this changing orientation of structures. East-west cross-section A-A' is located near the center of the study area. This cross-section shows steeply

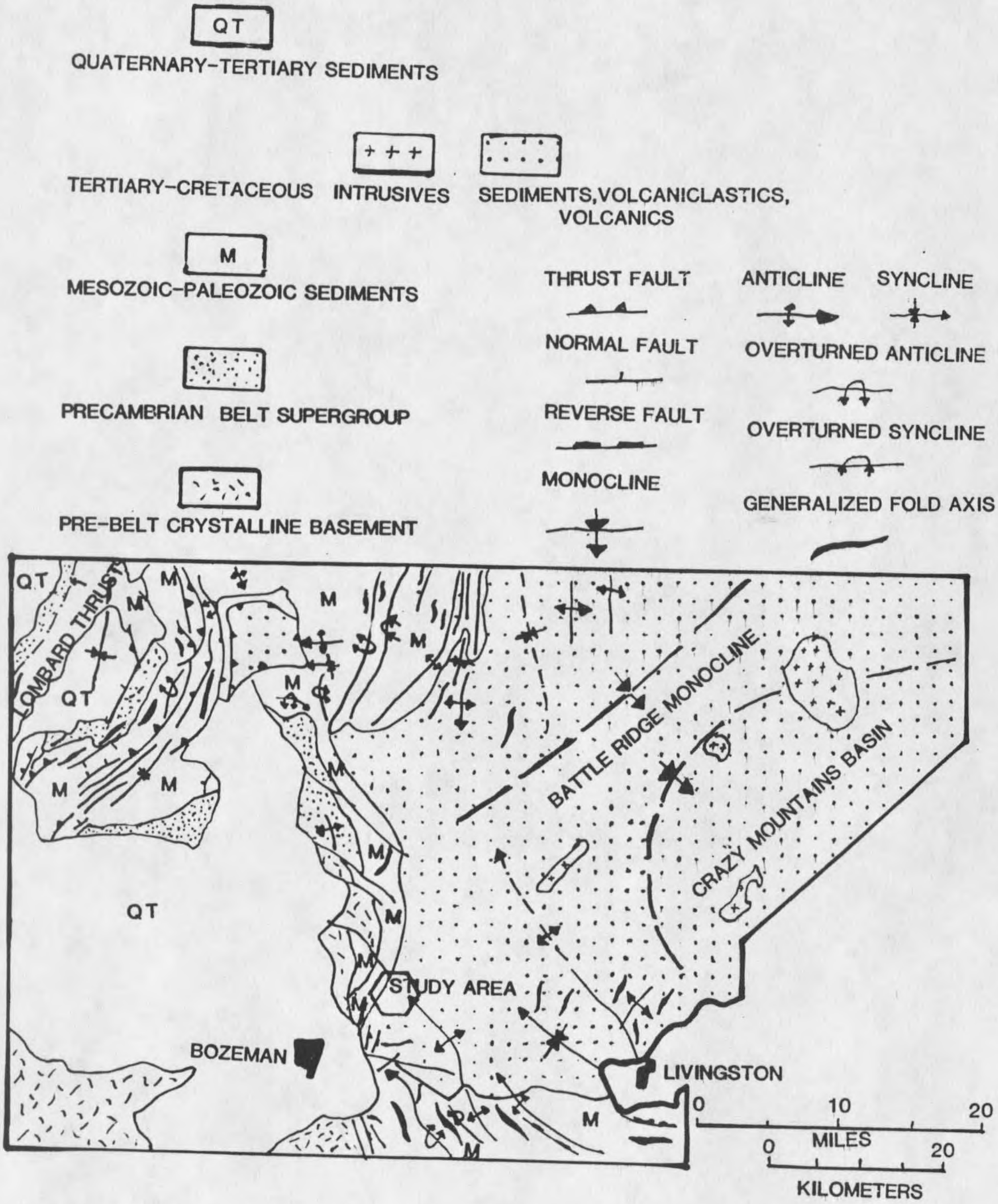

Figure 3. General structural setting of the Bridger Range. (After Woodward, 1981.)

oriented rock units in an overturned limb of an anticline becoming upright, open folds in the Livingston Group to the east with minor offset by a thrust fault. The thrust fault has raised older Cretaceous rocks above younger Cretaceous rocks. This cross-section shows the thick Billman Creek Formation (Kbc) of the Livingston Group gently folded. Resting above the Billman Creek Formation is the Hoppers Formation (Kh), which is a potential aquifer.

Cross-section B-B' crosses the study area from the southwest to the northeast. This cross-section shows the gentle folds within the Billman Creek and Hoppers Formations. Because these units are only mildly deformed, drilling depths in them are nearly the same as if they were horizontal. The absence of overturned folds prevents repetition of rock units or structural zones which might restrict water flow. The absence of faults avoids the possibility of fault-zone restrictions or conduits for flow.

The geologic map (Plate 1) differs from Roberts (1964) in a few details. The Quaternary deposits are not included because they are shown on the geomorphic map (Plate 2). More strikes and dips are added resulting in clarification of fault locations where sudden changes occur. An example of this clarification is seen on the west side of the valley in sections 24 and 25 where rapid changes in dip of the beds suggest a fault may be present. Recent unpublished seismic and gravity data further support the presence of a fault (Lageson and Kelly, 1984). In section 20 along Jackson Creek Road a fault is present in a road cut in the Billman Creek Formation.

METHODS

Field Methods

Domestic and stock wells were inventoried to determine the hydrogeologic properties of the Bridger Canyon aquifers. Plate 3 shows the location of all measured sites within the study area. Where wells are abandoned only their depths are recorded. One well was drilled to be sure water was available on the property, but has never been used, and is included in the abandoned well list. Appendix A explains field methods employed in well measurements in more detail. The most pertinent data include well-logs (Appendix E), water-levels, and specific capacity. Specific capacity is a calculated value obtained by dividing water-flow rate in gallons per minute by the number of feet water level is drawndown with pumping. The value is important because it indicates rate of flow of water into the well from the aquifer. For example, a high flow rate with little drawdown (high specific capacity) indicates fast flow into the well and a good aquifer. A good domestic well with a specific capacity of 10 would allow a homeowner to operate several water-consuming appliances at once. Values smaller than 5 indicate that fewer appliances should be operated at one time. The specific capacity measurements indirectly reflect transmissibilities (Walton, 1970).

In addition to well measurements, springs and ponds were inventoried because they are used as water supplies for both domestic and stock use and because springs represent groundwater discharge. The ponds are storage areas for water used by people or are used as direct supplies for watering stock. Springs and ponds were located, discharge was measured where possible, and specific conductance was measured. Specific conductance is a measure of electrical conductivity which reflects the amount of dissolved solids in the water. Appendix B explains field methods used in spring and pond measurements in more detail.

One other water source in the study area is streams. Streams were measured because base flow conditions represent groundwater flow and not runoff. Although no known cases of domestic water supplies coming from the main streams were found, a few water supplies come from smaller tributaries in the valley. Where possible, stream discharge and specific conductance were measured. Appendix C describes field methods employed in stream measurement in more detail.

Site Numbering System

The system for numbering wells, springs, ponds, and stream sites is shown in Figure 4. These sites are numbered according to geographic position within the rectangular grid pattern used by the U.S. Bureau of Land Management. All location numbers consist of ten or eleven characters. An example location number is 2S7E06ABCD. The first two characters indicate the township and its position relative to the Montana Base Line. In the example the 2S indicates Township 2 South. The next two characters indicate the range and its position relative to the Montana Principal Meridian. In the example, 7E