Groundwater Resources of the Livingston and Lower Shields River Valley Areas, Park County, Montana

Montana Bureau of Mines and Geology Open-File Report 680

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Montana Bureau of Mines and Geology

2016

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ABSTRACT

Groundwater resources in northern Park County near Livingston are under increasing pressure from subdivision development. Much of the new development is dependent on individual household wells for potable water, and on septic systems for wastewater disposal. With increased use, there is a potential for groundwater resources to become overutilized in some locations. The work presented here inventories the state of groundwater resources in the area (2003–2005): the quantities, the quality, and recharge sources, to facilitate science-based decisions on groundwater management.

Groundwater in the project area was delineated into alluvial aquifers of the Yellowstone and Shields Rivers, bedrock aquifers in the Fort Union Formation, and the Colorado Group.

The Yellowstone River alluvial aquifer consists of up to 75 ft of sand and gravel within the Yellowstone River valley. A large portion of the recharge to the Yellowstone River alluvial aquifer is from irrigation or leakage from irrigation ditches. The estimated velocity of groundwater in the Yellowstone River alluvium is 1 to 8 ft per day. The Shields River alluvial aquifer is much thinner and consists of up to 40 ft of fine-grained sand and clay deposits. Only a few wells exist in the Shields River alluvium, suggesting the aquifer may have low productivity or thin saturated thickness. The primary threat to groundwater availability in the alluvial aquifers is land-use change from irrigated cropland to residential.

Most of the area is underlain by the bedrock aquifers above the Colorado Group. These aquifers are typically capable of providing adequate quantity and quality of water for domestic and stock uses at depths less than 200 ft. There is the potential for higher yield (over 50 gpm) wells in this aquifer in areas where folding has increased fracturing and where sandstone layers are thicker and coarser grained. Recharge to the bedrock aquifers is primarily from local snowmelt. Groundwater flow in bedrock generally follows the surface topography at a velocity of 0.9 ft per day. The Colorado Group acts as an impermeable layer underlying most of the project area. However, within the shale, several relatively thin sandstone interbeds provide groundwater for much of the Wineglass Mountain area. The Ellis Group is used in select areas in the southern end of project area where it is deep enough to be saturated but shallow enough for economical well completion. The Madison limestone, commonly used as an aquifer throughout Montana, while present in the project area, is not used as an aquifer and may be dry. The very low aquifer storage typical of bedrock aquifers results in groundwater drawdown several hundred feet from the pumping well. Consequently, the bedrock aquifers may not support small acreage (high-density) developments with individual wells.

Good groundwater quality exists within the alluvial and bedrock aquifers, and nitrate concentrations were below drinking water standards. Isotopes were used to help determine the relative age of groundwater. Based on this assessment, the alluvial and bedrock aquifers that were less than 225 ft deep have modern water less than 50 years old, while groundwater in deeper bedrock aquifers was older than 50 years.

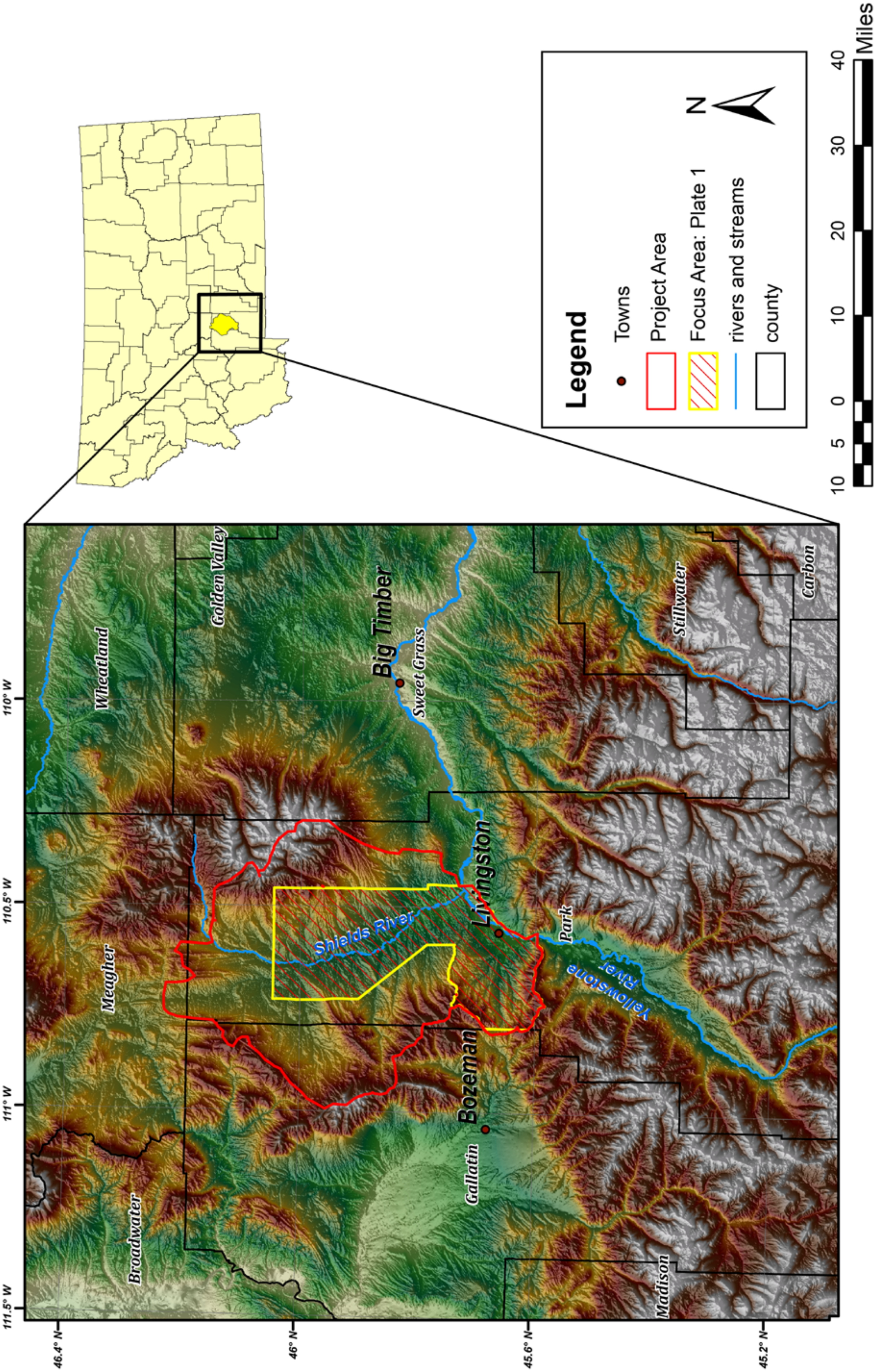

Figure 1. The project location includes the Shields River watershed and smaller watersheds around Livingston (red). A focus area was defined for the potentiometric surface map on plate 1 (yellow).

INTRODUCTION

Purpose

The purpose of this investigation was to collect and interpret baseline data and to develop a regional understanding of the hydrogeologic systems of the Livingston and lower Shields River area. Increased residential developments in rural and urban fringe areas, and concerns with potential coalbed methane (CBM) development in former coal-producing areas west of Livingston have raised concerns about the sustainability of groundwater resources. The data and hydrogeologic knowledge from this project will be useful to area residents and resource managers in making informed decisions on land use and possible CBM development.

Location

The project area (fig. 1) is in the north-central part of Park County in south-central Montana, and includes the Shields River watershed and smaller watersheds around Livingston that drain to the Yellowstone River (fig. 2). A focus area around Livingston and the Shields River valley south of Wilsall was chosen for a more detailed data evaluation. However, in the Shields River watershed, well inventory and groundwater mapping were generally confined to the areas to within 4 to 8 mi of the river due to the scarcity of wells in the upland areas (fig. 3).

METHODS

The hydrogeologic data for this project were collected between November 2003 and August 2005. Data collection included groundwater well inventories, groundwater monitoring, surface-water monitoring, and aquifer testing. Water samples were analyzed for nitrate concentrations, oxygen and hydrogen isotopes, and water chemistry (fig. 3). The data are available online at the Montana Groundwater Information Center (GWIC) website at http://mbmggwic.mtech.edu/. All wells used in this report are referred to by their GWIC ID number.

Montana Bureau of Mines and Geology (MBMG) staff inventoried 130 well sites (fig. 3, appendix A) for this project. Each well was located using a handheld GPS and USGS 1:24,000 topographic maps. Static water levels and water temperature, pH, and specific conductance were measured.

Groundwater levels were measured in 15 private domestic wells on a quarterly basis. Groundwater elevations are based on measuring point elevations estimated from USGS 1:24,000 topographic maps. The accuracy of the measuring point elevations at most sites is +/-5 ft.

Surface-water monitoring was conducted at 19 sites throughout the project area (appendix B). Monitoring consisted of measuring stream stage, flow rate, and water parameters (temperature, pH, and specific conductance). Stream flow was measured using a wading staff and a velocity meter. Samples for common ion and trace element constituent analyses, including nitrate, were collected twice from Billman Creek and the Shields River.

In the summer of 2004 and spring of 2005, water-quality samples were taken from selected inventoried wells and surface-water sites throughout the project area. Common ion and trace element constituent analyses were conducted on water samples from 30 wells and Billman Creek and Shields River surface-water sites (appendix C). To ensure good groundwater representation, samples were taken after field parameters stabilized with pumping and three well-casing volumes of water had been removed. Groundwater samples were preserved and stored in accordance with standard laboratory protocol. Field measurements of temperature, pH, and specific conductance were recorded with handheld electronic field meters. Groundwater samples for nitrate analysis were collected at nearly every inventoried well (appendix D). Common ion and trace metal

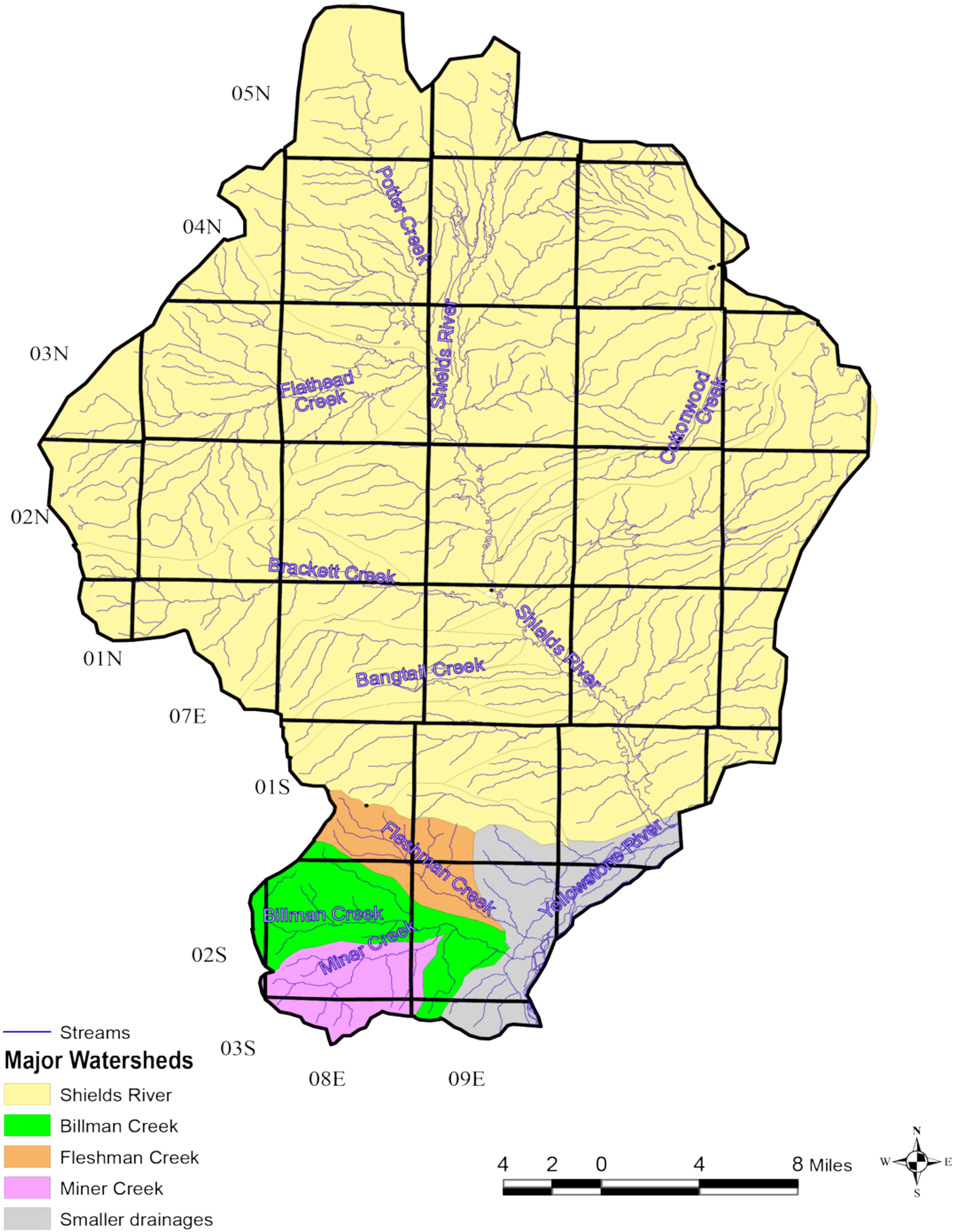

Figure 2. Locations of watersheds in the project area.

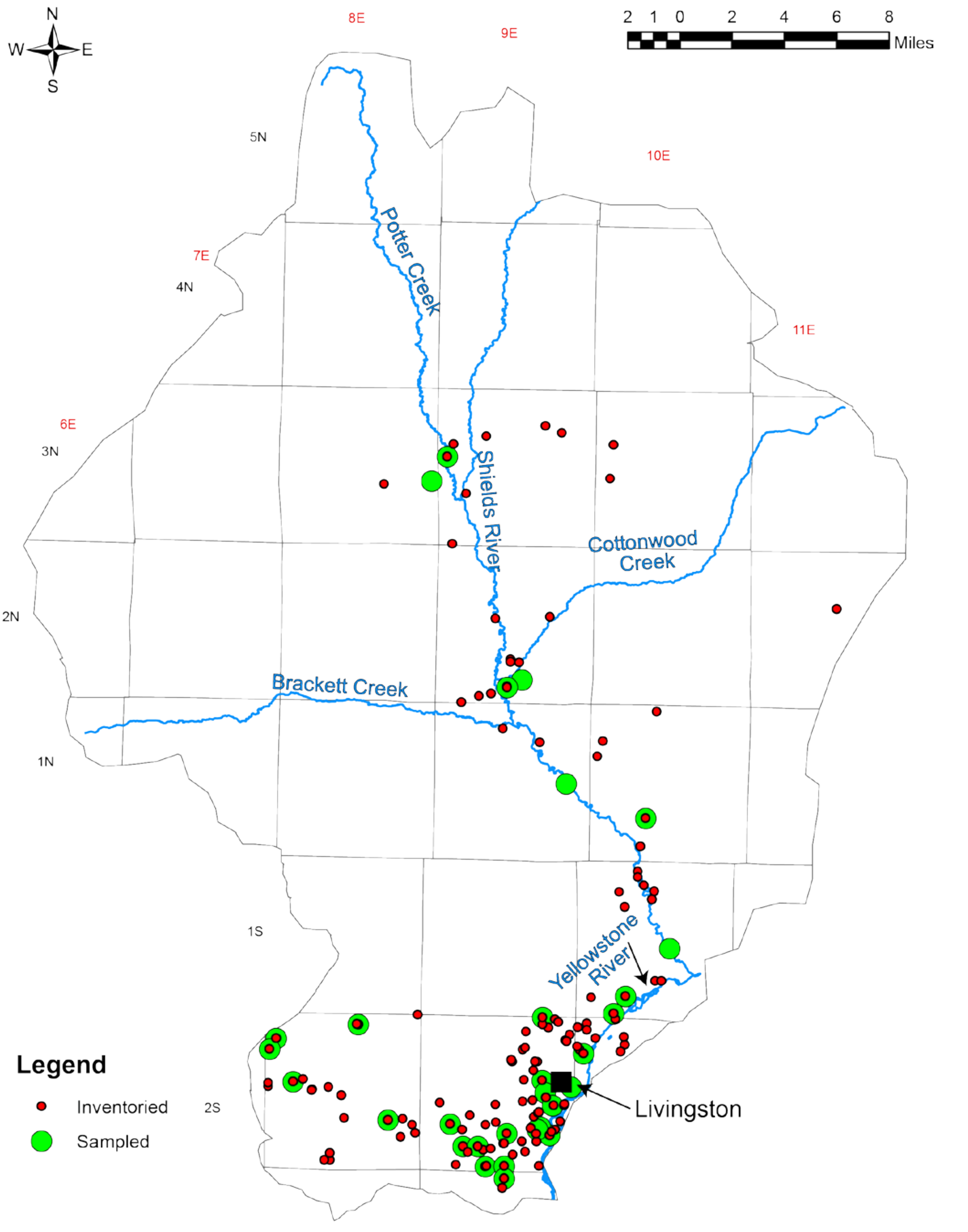

Figure 3. Groundwater field inventory and water-quality sample locations.

analyses were performed by the MBMG Analytical Laboratory in Butte. The nitrate samples were analyzed by Northern Analytical Laboratories in Billings (now Pace Analytical).

Tritium, deuterium, and oxygen-18 isotopes were collected at 28 wells (appendix E). Isotope analyses were performed to better delineate groundwater recharge. Isotope analyses were performed by the University of Waterloo Environmental Isotope Laboratory.

Aquifer pumping tests were performed at five test sites in the northern Livingston area to evaluate aquifer transmissivity, hydraulic conductivity, and storativity. The locations of the wells and descriptions of the tests are provided in appendix F. Specific capacity data was also approximated for several wells using drill logs accessed through the GWIC database.

WATERSHED ISSUES

Land and Water Use

Land use in Park County is primarily agricultural. Within the project area, 83.3 percent of the land use is agricultural, with 64 percent range land, 14.9 percent dry land farming, and 4.9 percent irrigated farming. Irrigated land is primarily in the river and stream valleys close to where surface water is diverted. Residential growth is a concern in and around Livingston, the most heavily populated area in the project. Urban areas make up 1.1 percent of the land use. The Yellowstone River, the Shields River, and numerous small lakes make up only 0.2 percent of the project area and forested lands make up the remaining 15.2 percent (fig. 4).

Population Growth and Rural Residential Development

The population of the Livingston and lower Shields River area was 11,360 in 2000 (Montana Department of Commerce, 2000), which represented 73 percent of the total Park County population. Most of the population (7,370) is concentrated in Livingston, with lesser population centers around Wilsall (240) and Clyde Park (300). Between 1990 and 2000, the population of Park County increased by 7.8 percent, with most of that growth occurring in rural or urban-fringe areas (Cossitt Consulting Team, 2004). Within the project area, only the city of Livingston has both public water and public sewer. The cities of Wilsall and Clyde Park have public water but do not have public sewer systems. In 2000, there were approximately 4,000 residents in the project area not served by municipal sewers and 3,460 residents not served by municipal water.

Septic systems have been shown to be a source of nitrate contamination in groundwater (Freeze and Cherry, 1979). In low-density population settings, well-designed drainfield systems can treat and disperse sewage effectively. At higher densities, the capacity of soils and groundwater to handle the waste load can be overwhelmed. Therefore, increasing population in rural Park County places a higher demand on the available groundwater and puts that same resource at risk for contamination.

The number of wells completed in northern Park County increased by 60 percent between 1990 and 2000 (GWIC). Most of the new wells are being completed in the following areas: Wineglass Mountain, the north Livingston area, Bozeman Pass area, the Livingston valley, and the Shields River valley (fig. 5).

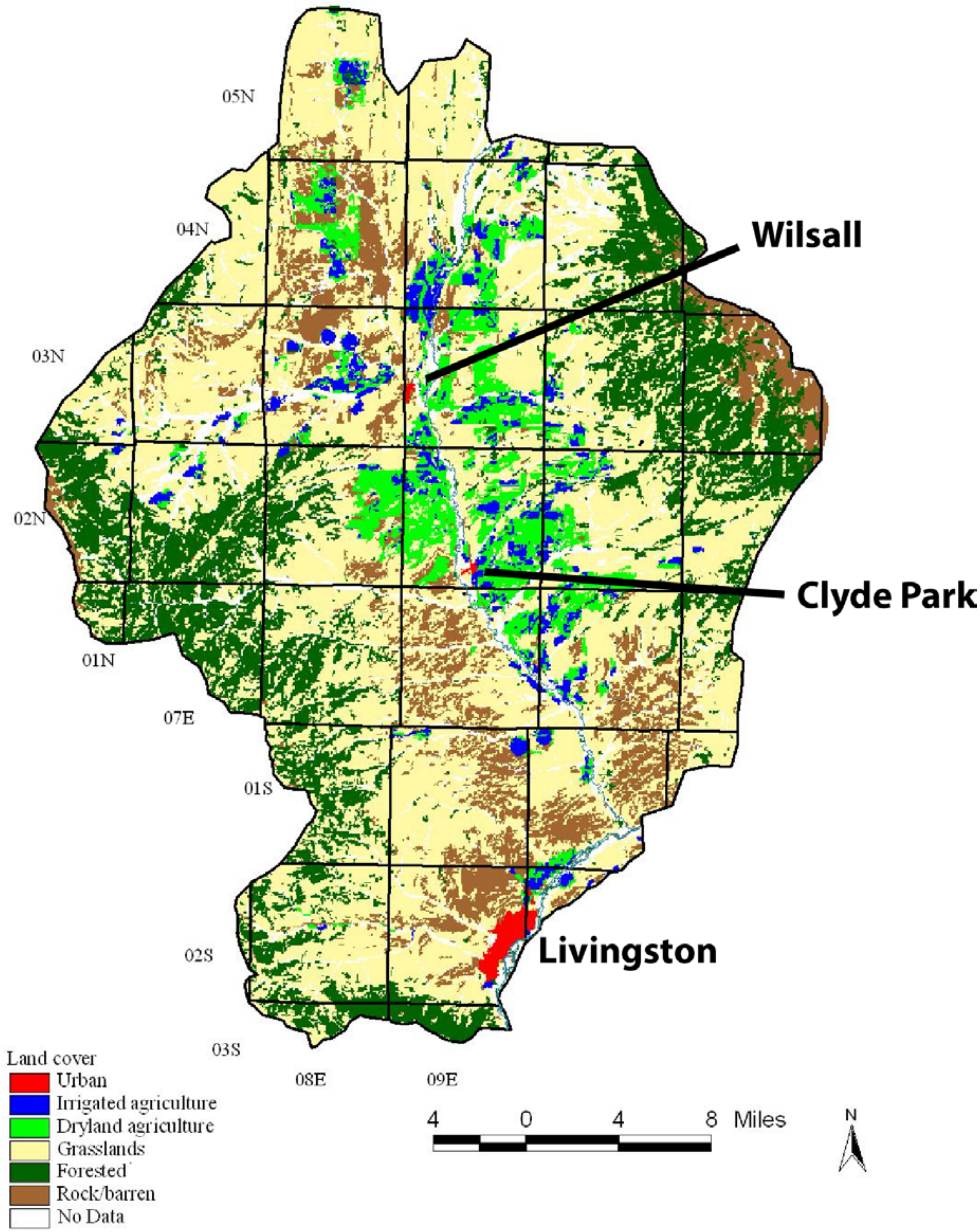

Figure 4. Land cover in the project area.

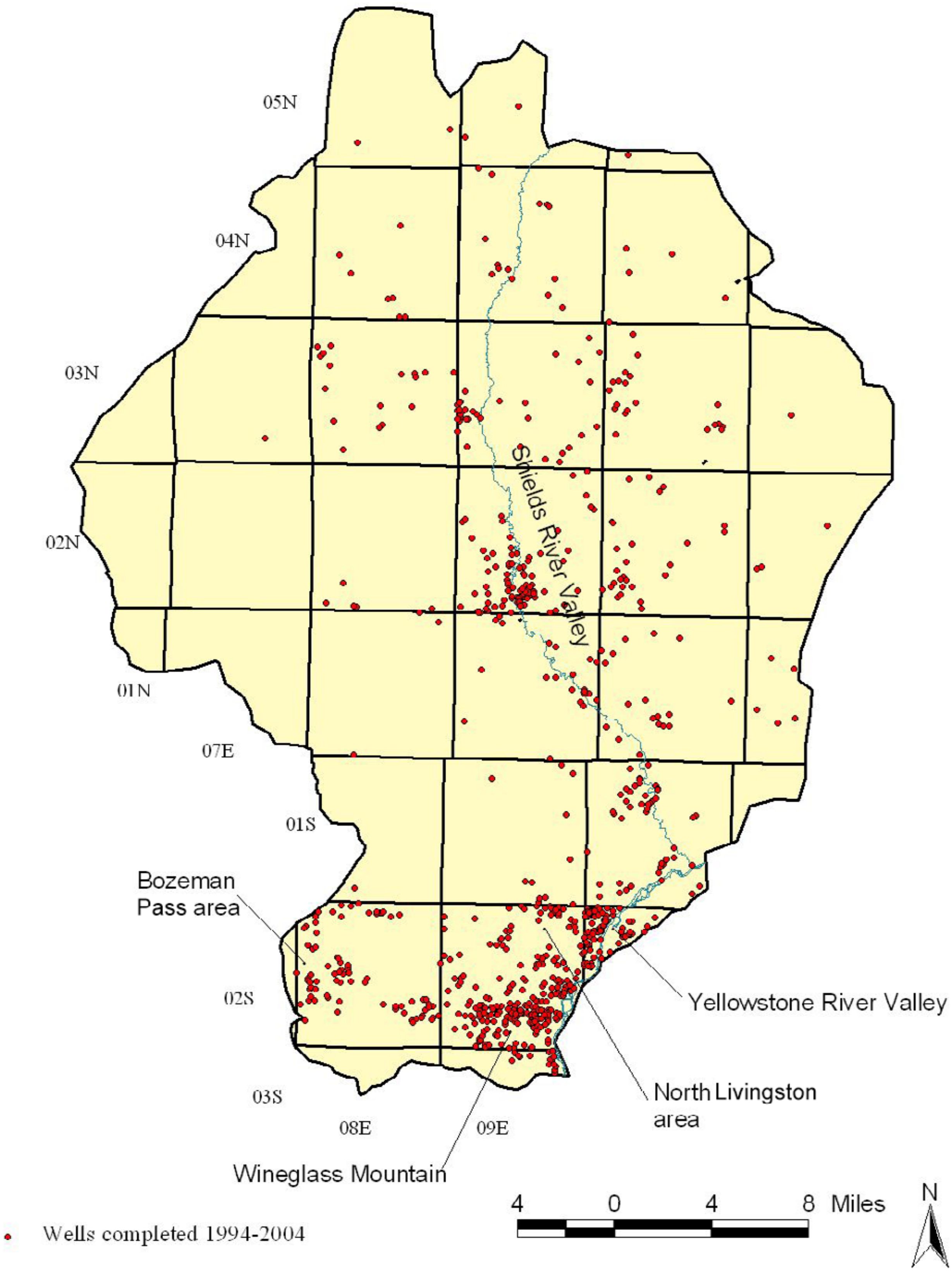

Figure 5. The distribution of wells drilled between 1994 and 2004 in the project area.

ENERGY DEVELOPMENT

The Cokedale and Timberline areas (fig. 6) west of Livingston have a history of coal mining in seams within the Eagle sandstone. The coal seams are relatively thin and generally uneconomical for commercial coal mining (Roberts, 1966). However, CBM in Eagle sandstone coal seams was encountered in Gallatin County in a test hole drilled by Sohio Petroleum in 1988. Interest in CBM development in Gallatin County by Huber Corporation sparked controversy because it requires removing large volumes of water from the coals for production. The issue also raised concern in Park County about the possibility of CBM development near Livingston.

Methane in coalbeds is held hydrostatically by groundwater pressure. To release the gas, it is necessary to pump groundwater out of the coal (Wheaton and Olson, 2001). Therefore, one of the concerns of CBM development is that the coal seam drawdown has the potential to impact water availability in nearby wells and springs. Another concern is with the disposal of the produced water. The water quality of the potentially produced water is not known, but in most CBM fields it is high in salinity and sodium (Van Voast, 2003).

The Eagle sandstone in the Cokedale and Timberline areas west of Livingston crops out along a thin band near the base of Wineglass Mountain (fig. 6). The formation dips steeply (30-50 degrees) to the north and near Interstate 90 it is over 5,000 feet deep. The formation then continues to dip into the basin and is likely greater

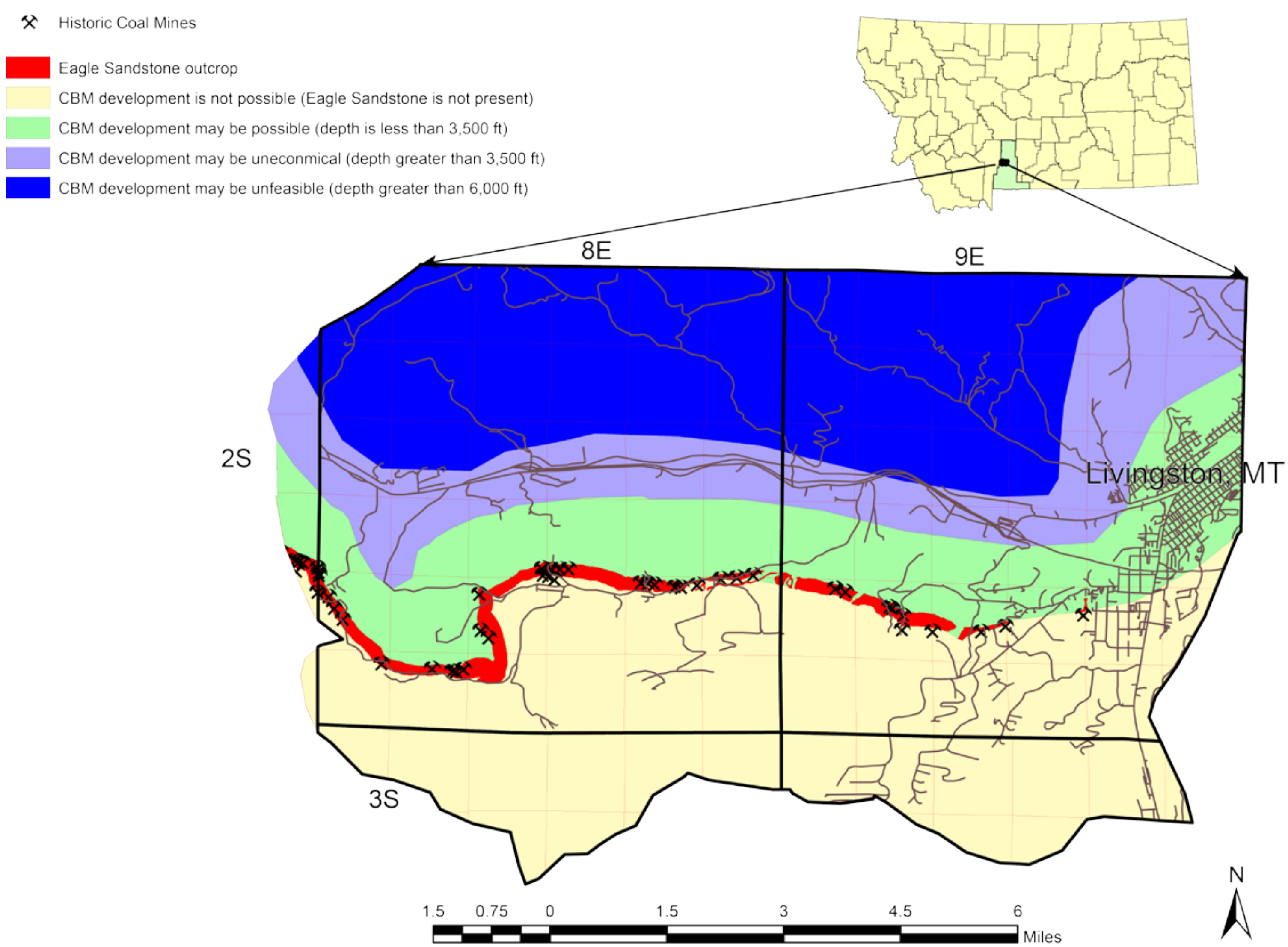

Figure 6. Potential coalbed-methane development (by depth) in the Eagle sandstone west of Livingston.

than 10,000 to 15,000 ft deep under most of the project area (Berg and others, 2000). If CBM development were to occur in the area it would most likely be limited to a narrow band from north of the outcrop to south of the interstate (Rice, 1993; Rieke and Kirr, 1984). Currently, the development of CBM is not expected in this region.

Between 2007 and 2009, seven gas and oil exploration wells were drilled to depths over 12,000 ft in the Shields River valley. Six of these wells were located in Park County. As of June 2015, all seven of the exploration wells were plugged and abandoned (Montana Board of Oil and Gas, 2016). The drilling raised concerns with the residents about potential degradation of shallow groundwater quality. In 2013, a study was conducted to describe the chemical quality of the groundwater in the entire Shields River valley (Blythe, 2015). Several wells near Wilsall and Clyde Park were sampled for this study, then again in 2014 under the MBMG Groundwater Assessment Program.

HYDROLOGIC INFLUENCES

Topography

The area around Livingston is generally typical of an intermountain setting with broad rolling uplands and river valleys surrounded by mountains. This wide distribution of elevations in the watershed is shown in figure 7. The highest elevations are found in the Crazy Mountains in the northeast (up to 11,000 ft above sea level) and the Bridger Range in the west (up to 9,000 ft above sea level). The lowest elevation in the area is along the Yellowstone River (about 4,400 ft above sea level), where it exits the project area about 6 mi northeast of Livingston.

Climate

The Livingston area has an intermountain climate with warm dry conditions in the valleys, and cool wet conditions in the surrounding mountains. Most precipitation falls in the valleys as late spring and early summer rain (1 to 3 in per month), with the remainder of the year being relatively dry (less than 1 in per month; Western Regional Climate Center, 2005). The mountain precipitation accumulates and is stored as snow; then as the higher elevation snow melts in late spring, a surge of runoff is released to mountain streams.

Precipitation is correlated with elevation in the study area (fig. 8). The average annual precipitation ranges from 14 in. in the valleys to about 60 in. in the mountain areas (NRIS, 2005). Most of the precipitation received by the watersheds in the area occurs over relatively small areas in the higher elevations.

SNOTEL precipitation records and flow records from the Shields River (United States Geological Survey, 2005) demonstrate that the area has been experiencing a drought since about 1998 (fig. 9). The most severe drought years appear to have been 2000 and 2001, during which snow accumulations were 17 to 22 percent below normal.

Drainage

The project area was defined by watersheds that flow to the Yellowstone River near Livingston (fig. 2). The Yellowstone River is located adjacent to Livingston along the southeastern edge of the project area and flows to the east. The Yellowstone River above the project area drains high-elevation areas (much of it above 8,000 ft) in southern Park County and Yellowstone Park. The flow rate of the Yellowstone River at Livingston ranges from about 1,200 cubic ft per second (cfs) in winter and early spring to 13,000 cfs in June (USGS 06192500).

The largest tributary to the Yellowstone River in the area is the Shields River, which drains most of northern Park County and parts of Meagher, Gallatin, and Sweet Grass Counties. The southern part of the watershed (south of Wilsall) drains 1.1 million acres. Average flow rates of the Shields River range from 101 cfs in Janu-

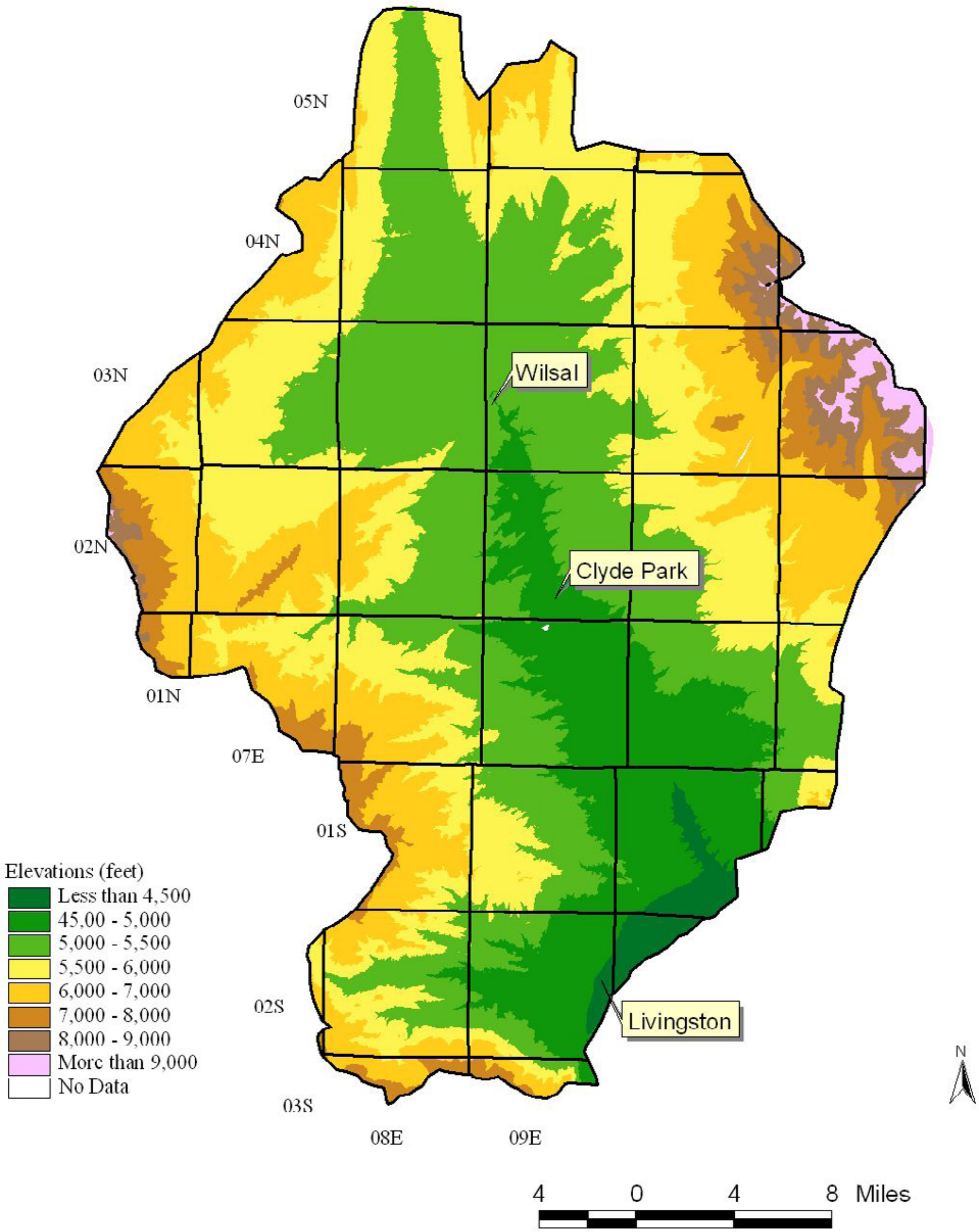

Figure 7. Ground-surface elevation in the project area.

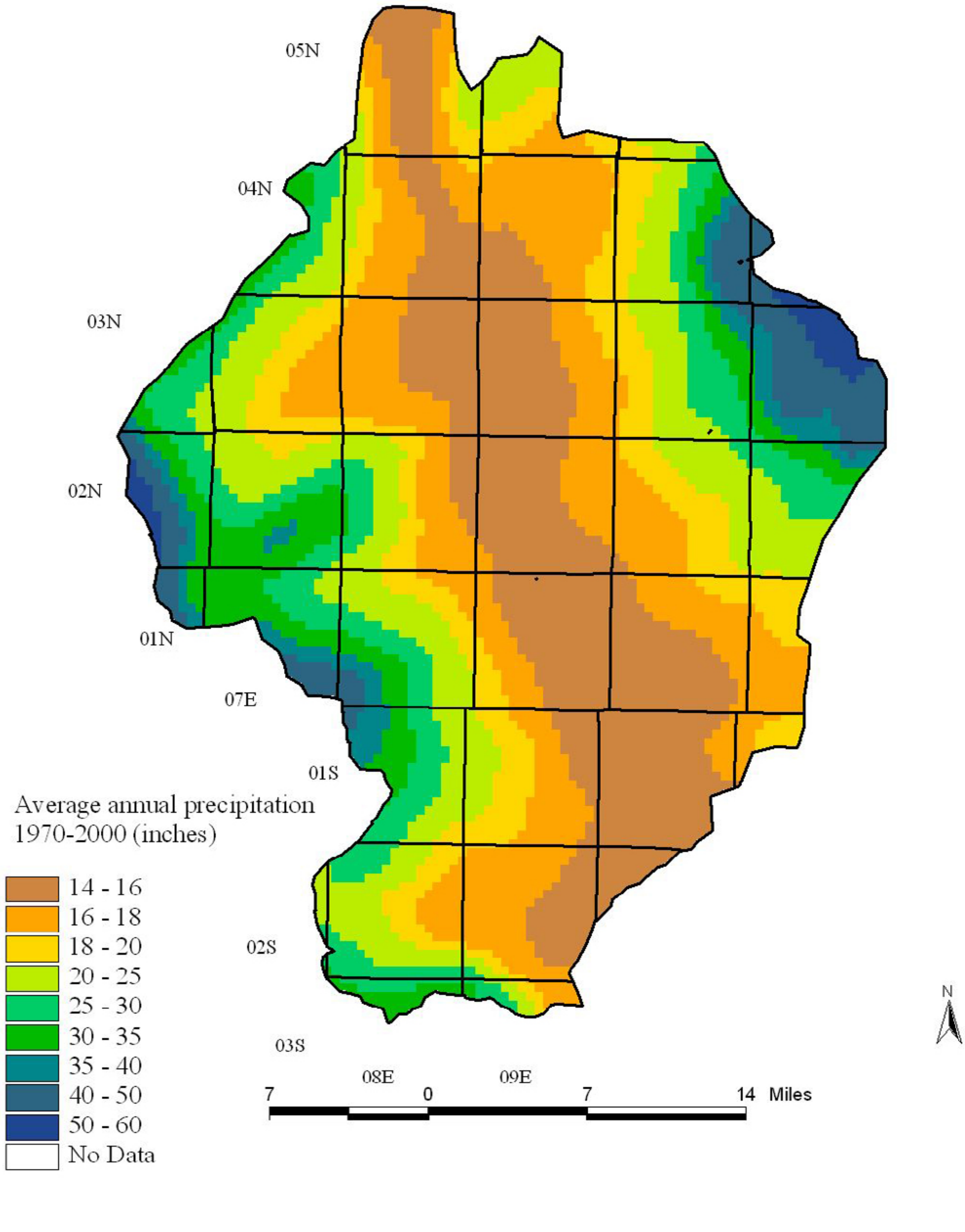

Figure 8. The distribution of average annual precipitation from rain and snow (1970–2000; NRIS, 2005).

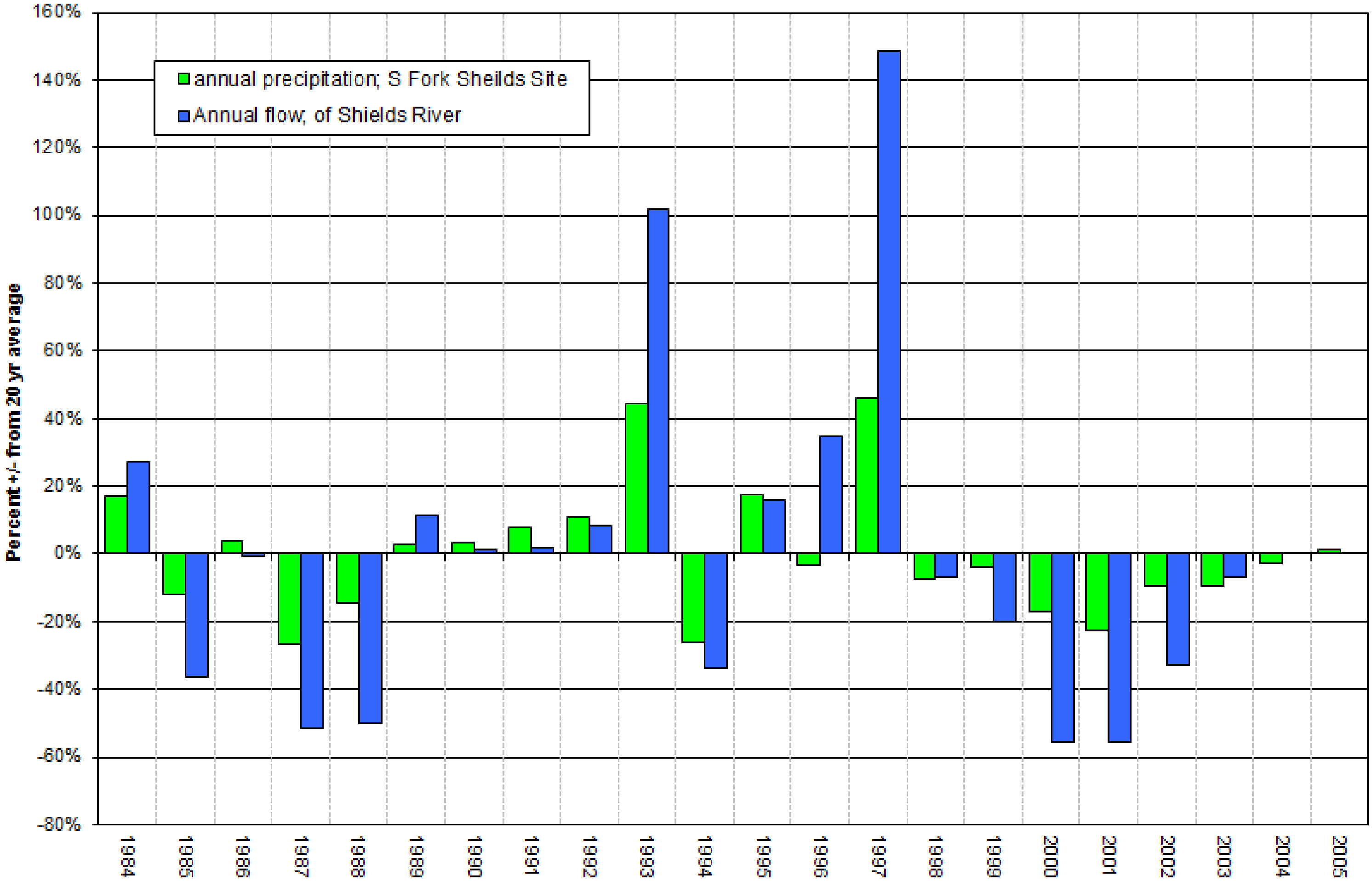

Figure 9. Mountain precipitation and average annual Shields River flow rate indicate the area experienced a drought beginning in 1998.

ary to 790 cfs in May (USGS 06195600). The river has many tributaries; most of these are small intermittent streams that flow only during snowmelt runoff. The primary perennial tributaries to the Shields River include: Flathead Creek, Brackett Creek, Canyon Creek, Cottonwood Creek, and Willow Creek.

Near Livingston, most surface water is in either Billman Creek or Fleshman Creek (see fig. 2). Measured stream flow ranged from 1 to 20 cfs in Billman Creek and 5 to 14 cfs in Fleshman Creek (appendix B). Other minor drainages in the area near Livingston include Ferry Creek, Slaughterhouse Creek, and Dry Creek.

Agriculture in the Yellowstone and Shields River valleys is supported by diverted river water via irrigation canals. According to the Montana land cover data provided by the Montana State Library Natural Resource Information System (NRIS), the Yellowstone River valley has about 750 acres of irrigated crop lands on the north side of the river and 200 acres on the south side of the river within the project boundary (NRIS, 2005). The diverted water use in the Yellowstone River valley is primarily for flood irrigation. Fields on the north side of the river are supplied by the Livingston Ditch that diverts about 50 cfs from the Yellowstone River about 4 mi south of Livingston. The ditch flows along the west side of the Yellowstone River valley near Livingston and terminates about 3 mi northeast of town. Agriculture on the south side of the river is primarily supported by the Vallis Ditch.

In the Shields River watershed there are 16,600 acres of lands that are mostly flood irrigated (DNRC, 2005; and observed). Major diversions on the Shields River include the Big Ditch, Meyers Ditch, and Horse Camp Ditch above Wilsall and the Shields Canal below Wilsall and the Shields Valley Canal, Palmer, and Balmer Ditches below Clyde Park.

GEOLOGIC SETTING

The exposed bedrock geology of the area consists of folded and faulted sedimentary rocks ranging in age from Mississippian through early Tertiary. Approximately 19,000 ft of bedrock thickness has been described and mapped in the Livingston area by Roberts (1972) and Berg and others (2000). The sequence and relative thickness of the geologic formations, groups, and their outcrop patterns are shown on the stratigraphic column on plate 1.

The project area includes the western part of the Crazy Mountains basin, which is a northwest-trending structural low that is 40 to 75 mi wide and 100 to 130 mi long (plate 1). Folds and faults that affect groundwater flow are common throughout the basin. The most significant of these include: the Fleshman Creek Syncline, the Livingston Anticline, the Wilsall Syncline, and the Battle Ridge Fault (see structure map on plate 1).

Hydrogeologic Units

Groundwater systems are described in terms of aquifers and aquitards. An aquifer is loosely defined as a geologic unit that is capable of producing sufficient water for use. Conversely, an aquitard is a geologic unit that inhibits the flow of groundwater. For the purposes of this report, the terms "aquifer" and "aquitard" will include grouped geologic units that on a regional basis have similar hydrogeologic properties. The major groundwater systems identified during this project include the Quaternary (modern) unconsolidated aquifers, which include alluvium and terrace deposits in the Yellowstone and Shields River floodplains, and the bedrock aquifers of the Fort Union, Livingston, and Eagle Formations above the Colorado Group. In the project area, there are a few wells completed in the Jurassic Ellis Group, but these older units are not widely used throughout the area.

Quaternary Unconsolidated Aquifers

Quaternary unconsolidated aquifers include groundwater within the Yellowstone River alluvium, Shields River alluvium, and pediment gravel. These deposits overlie the bedrock units.

The Yellowstone River alluvial aquifer consists of water-saturated alluvial cobbles, gravel, and sand deposits in the Yellowstone River valley. The river valley near Livingston is 0.25 to 2 mi wide and contains alluvial sand and gravel deposits to a depth of typically between 25 and 75 ft. The saturated thickness of the aquifer is about 20 ft. There are about 450 wells completed in the aquifer, and Yellowstone alluvium supplies the City of Livingston with potable water. Wells in the alluvium typically are 35 to 54 ft deep and typically yield 30 to 55 gpm (GWIC, 2005).

The Yellowstone River alluvial aquifer near Livingston has been contaminated by the Burlington Northern Railroad Shop Complex (fig. 10). The identified contaminants include volatile organic compounds (VOCs), diesel fuel, and lead (DEQ, 2001). The extent of the VOCs plume, as defined by concentrations of tetrachlorethene above a human health standard of 5 micrograms per liter (μg/L), is shown in figure 10. Much of the plume is within city limits and, according to the Montana Department of Environmental Quality (DEQ), all identified well users in the impacted area were connected to municipal water. One consequence of the contamination is that most wells completed in the area northeast of Livingston drill through the alluvium into the underlying bedrock aquifers.

Alluvial deposits from the Shields River are relatively thin (20 to 40 ft thick) and consist of fine-grained sand and clay deposits. Only 11 wells in the project area are completed in the alluvium. Of these wells, reported yields are typically 10 to 30 gpm. However, most wells are drilled through the alluvium into the underlying Fort Union Formation. This suggests that in most places, the saturated alluvium is thin, less productive, or otherwise less desirable than the underlying bedrock.

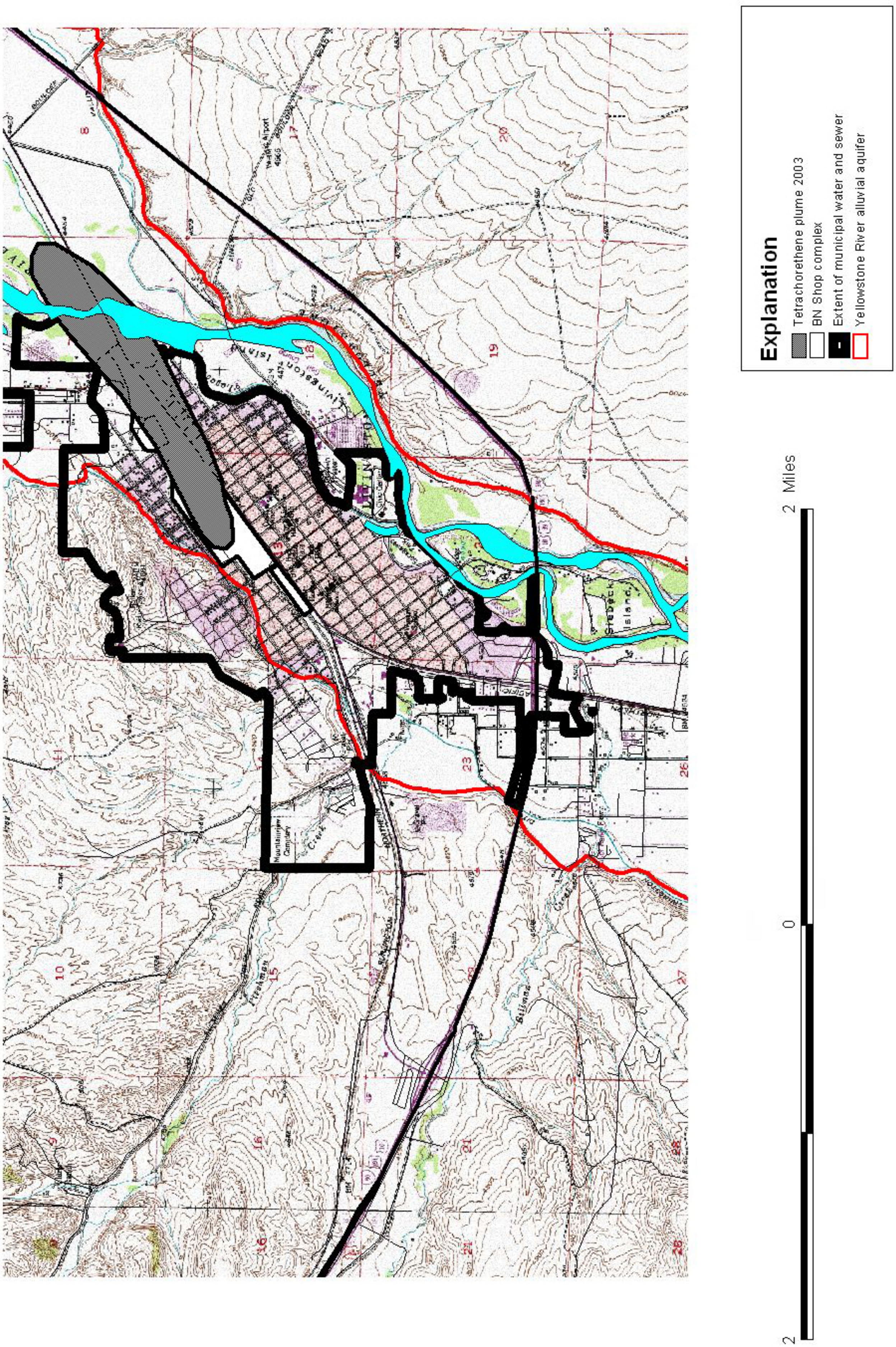

Figure 10. Location of the groundwater contamination plume from the Burlington Northern Shop Complex in Livingston (DEQ, 2001).

Gravel underlying pediment surfaces

Much of the west flank of the Crazy Mountains is mantled with pediment gravel deposits. One of these pediment surfaces is the Cottonwood Bench near Clyde Park. The pediment deposits generally range from 10 to 50 ft thick and are commonly described as clay-bound gravels. There are very few (12) wells completed in these deposits and most wells are drilled through the pediment to the underlying Fort Union Formation. Reported gravel-well yields are typically 10 to 30 gpm (GWIC, 2005). However, the groundwater in the pediment gravels appears to be the source of several springs along Cottonwood Creek.

Bedrock Aquifers above the Colorado Group

The bedrock aquifers that overlie the Colorado Group include the Telegraph Creek, Eagle, Livingston Group (Miner, Billman Creek, Hopper), and Fort Union Formations (plate 1). On a basin-wide scale, these units function as one system because there are no regional, thick aquitards to separate them and they are hydrogeologically similar. On a smaller, local scale, interbedding of sandstones and shales can create confined aquifers that do not communicate with overlying or underlying sandstone units. The formations that make up these aquifers crop out over most of the project area (plate 1). The aquifer system can be as thick as 17,000 ft (Berg and others, 2000) near the center of the Crazy Mountain structural basin; however, due to erosion, it thins to about 6,000 ft near Livingston and is absent 1 to 2 mi south of Interstate 90.

Drillers' logs typically note 5- to 20-ft-thick sandstone layers and 6- to 30-ft-thick shale layers (GWIC, 2005). The beds typically dip 20 to 30 degrees into the subsurface. The direction of the dip varies by location, but is generally northward. The Eagle sandstone contains some thin coal seams. Sandstone layers are more resistant to weathering and are visible at the surface in ridges. The shale intervals form valleys or rolling hills. Several of the sandstone outcrop ridges were mapped (plate 1) using 1:24,000 USGS topographic maps and hillshade analysis of USGS digital elevation model data (NRIS, 2005). The sandstone layers generally dip 20 to 30 degrees into the subsurface. Consequently, sandstone units encountered in wells likely crop out less than a couple hundred feet up-dip from the well.

In the northern part of the county, the Fort Union Formation has been penetrated by igneous intrusions. These intrusions occur as dikes, which cut across bedding planes, and sills, which cut along bedding planes. The igneous rocks are relatively low-permeability materials and likely act as groundwater flow barriers. Most of the dikes occur in the relatively unpopulated area near the Crazy Mountains. However, there is an igneous sill that outcrops near Clyde Park. The sill appears to block vertical infiltration and acts as a recharge barrier. Well depths become significantly deeper near the up-dip side (or east in the Clyde Park area) of the sill. Above the sill there is a potential for shallow perched groundwater.

There are about 800 wells completed in bedrock aquifers within the project area, and bedrock aquifers provide municipal water to the towns of Wilsall and Clyde Park. Typically wells are completed from 90 to 210 ft deep and yield 12 to 30 gpm.

Colorado Group

The Colorado Group is a shale-rich formation that overlies the non-marine Kootenai and Madison Formations and includes the Fall River through Cody Formations. In the Livingston area, this unit is about 3,300 ft thick. Shale is typically very poor at transmitting water; it acts more as a regional aquitard (groundwater impediment) than an aquifer. These shales lie at the base of the bedrock aquifer system used throughout the area.

The formations of the Colorado Group crop out along the flanks of Wineglass Mountain. Although these formations are younger than those of the Madison aquifer, in some locations faulting causes them to crop out at elevations lower than the Madison. The stratigraphic and topographic relationship of the hydrogeologic units is shown in the cross sections on plate 1. The strata within the Colorado Group dip steeply (30 to 45 degrees), generally to the north from Wineglass Mountain. The land surface also slopes in that direction, so 1,000 ft north of the outcrop the strata are at depths of about 400 to 700 ft.

Although as a whole the unit acts as an aquitard, it includes several, usually thin, sandstone or interlayered sandstone and shale layers that provide groundwater for much of the Wineglass Mountain area. There are approximately 100 wells in this area completed in and just below the Colorado Group. Based on the depths and locations of these wells, the target zones for well completion include the Pryor Conglomerate Member of the Kootenai Formation, and the sandstones within the Fall River Formation, the Muddy Formation, the Frontier Formation, and the Eldridge Member of the Cody Formation. Based on previous geologic mapping (Berg and others, 2000; Roberts, 1972) and observed topographic expression of the more resistant sandstone, the locations of the up-dip extent of these sandy intervals are approximated on plate 1. Immediately north of each sandstone outcrop, the target strata can be encountered at depths of less than 200 ft, but become much deeper with distance north.

The Pryor Conglomerate Member at the base of the Kootenai Formation is a 25-ft-thick layer of chert–pebble conglomerate and sandstone (Roberts, 1972) and can be found in the project area below (south) of the Kootenai Formation outcrop. The Kootenai can be identified by its characteristically dark purple to reddish color, and the Pryor Conglomerate Member outcrop usually forms a subtle ridgeline perpendicular to the slope of Wineglass Mountain. The sandstone within the Fall River Formation is also thin (40 ft), consists of yellow-gray quartz sandstone, and can be found above (north) of the Kootenai Formation outcrop. This unit also is usually more resistant to weathering than the surrounding shale and forms subtle ridges. The Muddy Member consists of greenish-gray fine-grained sandstone. It can be found above (north) of the Thermopolis Formation outcrop. There also appear to be a few wells completed in fractured shale within the Mowry Shale (GWIC, 2005). Driller logs from these wells describe a brittle or fractured shale or slate. However, it is not known how prevalent the fracture zones are or how consistently they are found through the formation. Outcrops of the Frontier Formation on Wineglass Mountain have not been mapped, but they can be found in the lower 400 ft of the grouped Lower Cody Formation through Frontier Formation presented on the map by Berg and others (2000). The middle member of the Cody Shale contains a 90- to 120-ft-thick sandy interval called the Eldridge Creek Member. This unit consists of thin-bedded, greenish-gray, fine-grained, glauconitic sandstone.

Ellis Group

The Ellis Group, interbedded limestone with sandstone and shale, is used by a few wells as an aquifer in a narrow band along the southern end of the project area. The Ellis Group crops out southwest of Livingston in the Wineglass Mountain area where the formation dips steeply, 30 to 40 degrees (Berg and others, 2000). Consequently, the formation is too deep for conventional water wells within a couple thousand feet of the outcrop.

The Madison limestone crops out south of Livingston but, while it is considered a good aquifer in much of the State, in this location there is evidence indicating that the Madison Group may be dry under much of Wineglass Mountain. A well in T. 03 S., R. 08 E., sec. 7 ADBD was drilled into the Madison Group to a depth of 1,100 ft (total depth elevation of 5,500 ft above sea level) and did not encounter water (personal commun., William Smith, Octagon Engineering). If groundwater is present, drilling would be at depths not practical for water well completions.

GROUNDWATER FLOW

Aquifer Flow Properties

Hydraulic conductivity measures the ability for a geologic material to transmit water. The best method of measuring hydraulic conductivity is by conducting multiple-well aquifer tests: pumping a well and measuring water-level drawdown in surrounding wells. This method is relatively expensive and is not performed on a regional basis. Another method allows for aquifer properties to be approximated using single-well aquifer tests that are typically conducted by drillers during well installation. From these tests a well's specific capacity (the pumping rate divided by the drawdown) can be calculated. Specific capacity is roughly proportional to hydraulic conductivity (if aquifer thickness is included). However, specific capacity is also influenced by well construction and pump factors (such as slotting type, well diameter, and pumping rate). Because specific capacity allows for a much larger data population across a wide geographic distribution, it is still a useful tool.

Aquifer testing of the Yellowstone River alluvium conducted by the DEQ at the Burlington Northern Shop Complex indicated hydraulic conductivities ranging between 170 and 380 ft/d (DEQ, 2001). This compared reasonably well to hydraulic conductivities of 60 to 560 ft/d approximated by specific capacities in 39 wells (table 1).

Multiple-well aquifer tests were conducted at six sites in the bedrock aquifers. Descriptions of these tests are provided in appendix F, and a summary of the results are provided in table 2. Hydraulic conductivity was found to range widely from 0.2 to 210 ft/d, with a median value of 10 ft/d. The hydraulic conductivities approximated from specific capacity ranged from 0.6 to 11 ft/day, with a median of 6 ft/day. The higher values from the aquifer test are from wells within a very productive area of the aquifer. Several of these wells were capable of relatively high yields (50 to 200 gpm). This high production was also reflected in the specific capacities measured in these wells, higher than anywhere else in the project area. These test wells were located near the center of the Livingston anticline just north-northwest of Livingston. It is possible that in the formation of the anticline the sandstone was fractured and therefore provides greater permeability. Some of the observed variability may

Table 1
Hydrogeologic properties estimated from specific capacity data

Hydrogeologic unit	# of wells used[1]		Specific capacity (Q/s) gpm/ft	Transmissivity (T)[4] ft^2/d	Hydraulic conductivity (K)[5] ft/d	Typical hydraulic gradient (i)[6] ft/ft	Typical effective porosity (n)[7]	Ground-water velocity (V)[8] ft/d
Colorado Group	23	Low[2]	0.02	5	0.4	0.15	0.1	0.6
		High[3]	0.14	37	1			1.5
Bedrock lower (Livingston/Eagle)	83	Low[2]	0.08	21	0.6	0.08	0.1	0.4
		High[3]	0.41	110	3.2			2.6
Bedrock upper (Fort Union Fm.)	90	Low[2]	0.07	19	0.6	0.03	0.1	0.18
		High[3]	1	270	11			3.3
Yellowstone alluvium	39	Low[2]	2.8	560	60	0.003	0.2	0.9
		High[3]	27	5,400	560			8

[1]Open bottom wells were excluded

[2]25th percentile

[3]75th percentile

[4]for confined aquifers; T = Q/s * 2,000/7.48 (Driscoll, 1995)

for unconfined (Yellowstone alluvium); T= Q/s*1,500/7.48

[5]K = T / thickness (assumed to be the perforated interval)

[6]From Plate 1

[7]Typical value (Driscoll, 1995)

[8]V= K*i/n Driscoll, 1995)

Table 2
Aquifer testing summary

Site	Location (TRSt)	Test type	Transmissivity (ft^2/day)	Hydraulic conductivity (ft/day)	Storage	Specific capacity (gpm/ft)
Donovan house well	02N-09E-2-ABAA	Recovery at pumping	6,000	210.0	-	5.00
Haug well	02S-09E-2-AACA	Recovery at pumping	180	4.5	-	0.50
Donovan SW well	02S-09E-1-DCDC	Recovery at pumping	3,700	58.0	-	3.00
Donovan SE well	02S-09E-2-CBBD	Recovery at pumping	4,800	69.0	-	4.20
		Pumping at observation	5,200	75.0	-	-
			5,000	72.0		
Meredith Ranch PW-1	02S-09E-10-DCBA	Pumping at pumping	-	-	-	0.13
		Recovery at pumping	40	0.2	-	-
		Pumping at observation	293	1.2	2.60E-05	-
		Recovery at observation	158	0.9	-	-
			164	0.8		
Meredith Ranch PW-2	02S-09E-10-DBCD	Pumping at pumping	-	-	-	0.37
		Recovery at pumping	455	3.9	-	-
		Pumping at observation	3,090	26.0	6.20E-05	-
		Recovery at observation	1,130	9.5	-	-

also be attributed to differences in grain size and permeability of the individual sandstone layers.

Due to the interlayered sandstone and shale stratigraphy, groundwater in the bedrock aquifers will likely be confined by shale in most locations. The aquifer pumping tests indicated that drawdown on the order of several feet can occur over distances of up to 500 ft away in line with the bedding strike. No drawdown was observed in wells located perpendicular to the strike in different sandstone layers. Aquifer storage was calculated from the aquifer tests to be 3×10^{-5} to 6×10^{-5}, which would be consistent with a confined aquifer 10 to 100 ft thick (Lohman, 1972). Recovery in some wells was rapid and complete, but in others it was slow and incomplete by the end of the test. These data indicate that subdivisions with small acreage lots on individual wells could run the risk of well interference, and in areas with incomplete recovery the aquifer water level could be lowered. Therefore, if feasible, it is important to conduct site-specific pump tests with an observation well to evaluate the potential for well interference.

No aquifer pumping test data for the Colorado Group were identified. Aquifer properties of the water-bearing units within the Colorado Group were approximated from specific capacity data (table 1). In general, estimated hydraulic conductivities calculated from specific capacity are relatively low (0.4 to 1 ft/d). Because of the low storage in this unit, well and pump depths will need to accommodate a fairly wide fluctuation between static and pumping water levels. For example, a 3 gpm pumping rate with the above range of hydraulic conductivity will drop the well water level between 21 and 190 ft while pumping.

Groundwater in the Colorado Group is expected to be confined by the shale unit above the producing sandstone bed. Storage in the sandstone layers is expected to be relatively low (on the order of 1×10^{-5} to 1×10^{-4}, estimated from Lohman (1972) based on sandstone thickness). In aquifers with low storage capacity (storativity), pumping drawdown can extend out for hundreds of feet. Therefore, well interference between nearby wells in the same sandstone will be a concern. Multiple well aquifer tests should be conducted for new developments in the area.

Groundwater Flow in Bedrock Units

Groundwater flow in the bedrock units is controlled by the regional hydraulic gradient (slope of the groundwater surface) and smaller, local flow pathways within the sandstone and shale layers. The bedrock units under most of the area consist of steeply dipping thin sandstone and shale layers. Groundwater will preferentially follow flow conduits provided by the sandstone layers, providing there is a decreasing hydraulic head.

Bedding strike and the hydraulic gradient are the primary controls on the local and regional flow directions, respectively. In the bedrock aquifers, complex folding creates conditions where the regional hydraulic gradient and bedding strike may be parallel, perpendicular, or some angle in between. This can make it difficult to predict flow direction on a local scale; however, on a regional scale, flow in the bedrock aquifers is toward the Shields River in the north of the study area and toward the Yellowstone River near Livingston (plate 1). Local flow systems generally discharge to small streams, which then flow to the larger rivers.

Groundwater Flow in the Alluvial Aquifers

Groundwater flow in the Yellowstone River alluvium near the edges of the valley is directed towards the river (plate 1). Towards the center of the valley, the flow direction parallels the river. The hydraulic gradient in the Yellowstone River alluvial aquifer is considerably lower (about 0.003 ft/ft) than the bedrock due to its much higher hydraulic conductivity (table 1).

GROUNDWATER QUALITY

Analyses of groundwater samples indicate that most groundwater in the area has relatively good quality. The concentration of total dissolved solids (the sum of common ions) ranged from about 200 to 800 milligrams per liter (mg/L). There were no identified concentrations of common ions, nutrients, or trace metals above EPA primary human health standards. Only one well (205605) exceeded the secondary drinking water standard as well as the primary stock standard for sulfate. The secondary standards are typically for aesthetic issues such as taste, smell, staining, or corrosion.

Common Ion Water Geochemistry

The water from the Yellowstone River alluvial aquifer is dominated by calcium and bicarbonate ions and is generally similar to that of irrigation water from the Yellowstone River (fig. 11). The common ion chemistry in the bedrock aquifers appeared to differ more by depth than by unit. Groundwater in wells less than 200 ft deep is composed of water dominated by calcium and bicarbonate ions. With increased depth the proportion of sodium increases, and in wells greater than 200 ft the water is dominated by sodium and bicarbonate (fig. 12). Only two wells, 205605 in the Madison limestone and 217213 in the bedrock aquifer, had sulfate-dominated water.

Nitrate Concentrations

Nitrate concentrations in both the Yellowstone alluvial aquifer and the bedrock aquifers were relatively low, typically 0.1 to 1 mg/L, compared to the drinking water standard of 10 mg/L. Comparison of nitrate concentrations with land use, geology, and well depth indicated no discernable pattern. Also, there was no discernable trend with nitrate and tritium concentrations.

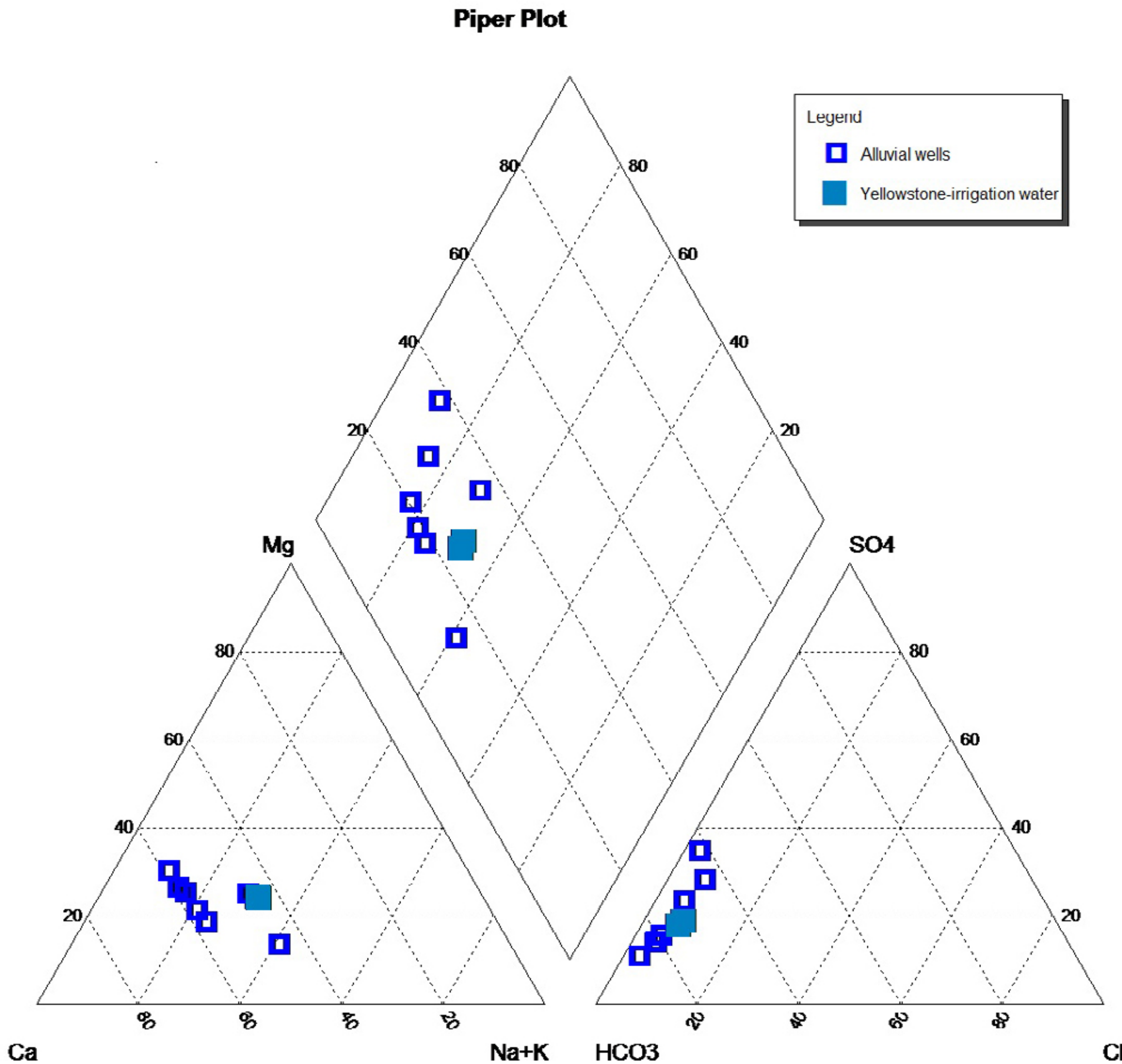

Figure 11. Piper plot showing water chemistry in the Yellowstone River alluvial aquifer and Yellowstone irrigation water.

GROUNDWATER RECHARGE

Groundwater recharge is the replenishment of water to the groundwater system. Identifying where and how much recharge occurs is an essential part of understanding the overall hydrogeologic system. The recharge rate will largely determine the groundwater flux rate through the aquifer and is important in assessing groundwater availability and vulnerability. Recharge was evaluated in this project by using physical measurements, such as groundwater level fluctuations and stream baseflows, and by chemical measurements, such as chloride concentrations, stable isotope ratios, and tritium concentrations.

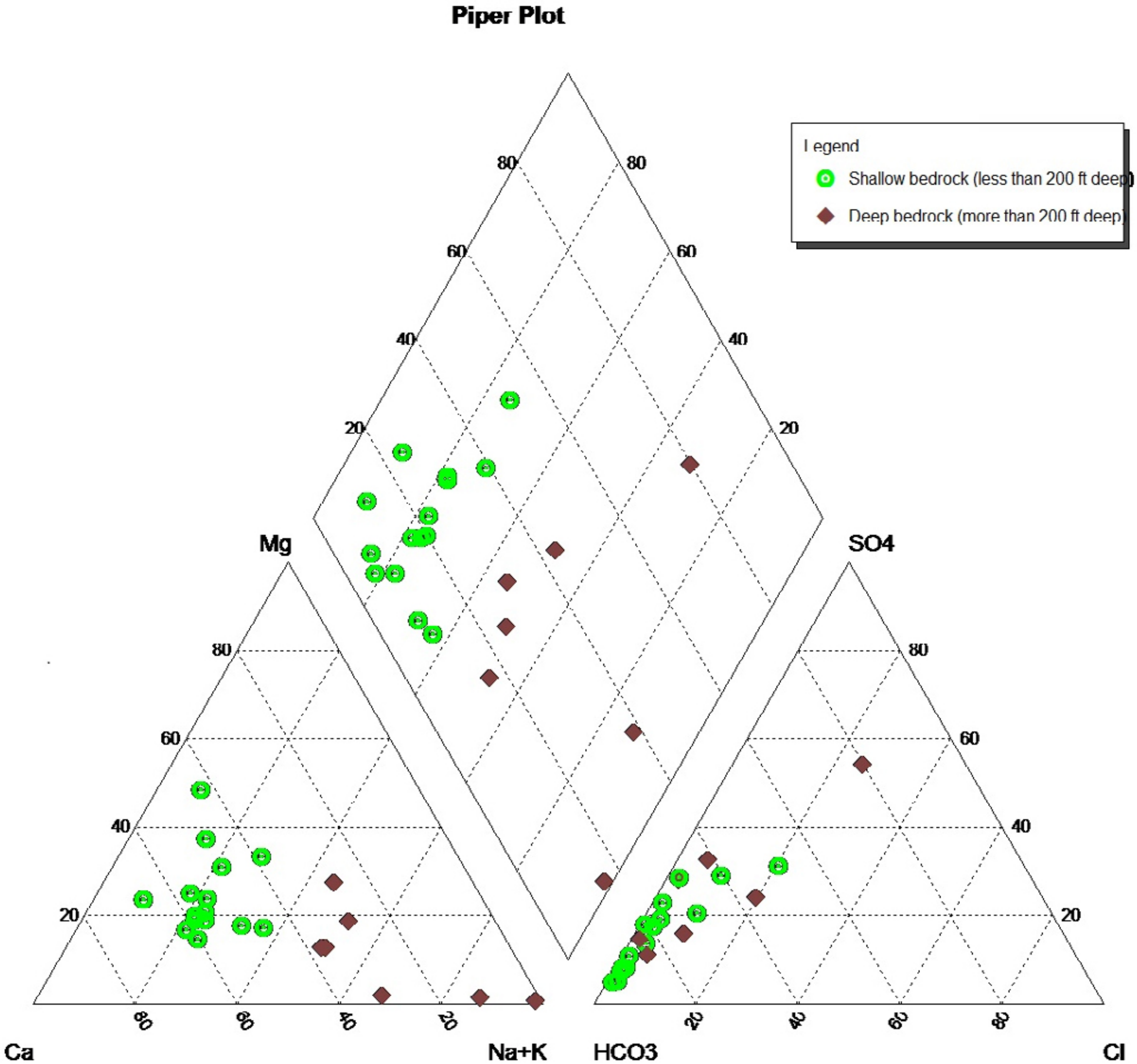

Figure 12. Piper plot showing bedrock groundwater chemistry.

Quantification of Recharge to Alluvial Aquifers

Groundwater level fluctuation method

Groundwater level fluctuations occur through changes in storage in an aquifer. When recharge occurs faster than groundwater discharge, the levels rise. Conversely, when recharge is less than the discharge, groundwater levels fall. Therefore, groundwater fluctuations can provide information on the timing and source of recharge. Significant recharge sources in the region include precipitation and irrigation (field infiltration and ditch loss). Recharge from these sources occurs over a short time span (3 or 4 months) during which the aquifers go through a short filling (rising level) season followed by a long draining (falling level) season. Most recharge from precipitation likely occurs during the mid to late spring (April–June) when there is abundant rainfall, high-elevation snow melt, and limited plant uptake. Flood application of irrigation water in the Shields River valley peaks in May and June (DNRC, 2005) and peaks in the Yellowstone River valley in August (Olson and Reiten, 2002). Following the recharge peak, groundwater levels exhibit a logarithmic decline until next year's recharge season (fig. 13). Groundwater recharge was estimated by subtracting the peak water level from the base water level, had the decline continued, and then multiplying this difference by the specific yield. Using the lowest predicted water level accounts for the fact that some water is always moving toward discharge and will not be reflected in a change in storage. The specific yield is the unit volume of water gained or lost per 1-ft water level change. This represents the volume of water that freely can move in or out of the material's pore spaces. The specific yield ranges between 15 and 25 percent for sand and gravel aquifers and between 5 and 15 percent for sandstone aquifers (Driscoll, 1995).

In the specific case of well 12953 (fig. 13), a bedrock well recharged by irrigation water, the groundwater level rise (10.28 ft) was multiplied by the specific yield (0.05 to 0.15) to arrive at a range in recharge rate of 6.2 to 18.5 in per year.

By this method, the average recharge in the Yellowstone River alluvium ranged from 19 to 34 in (table 3).

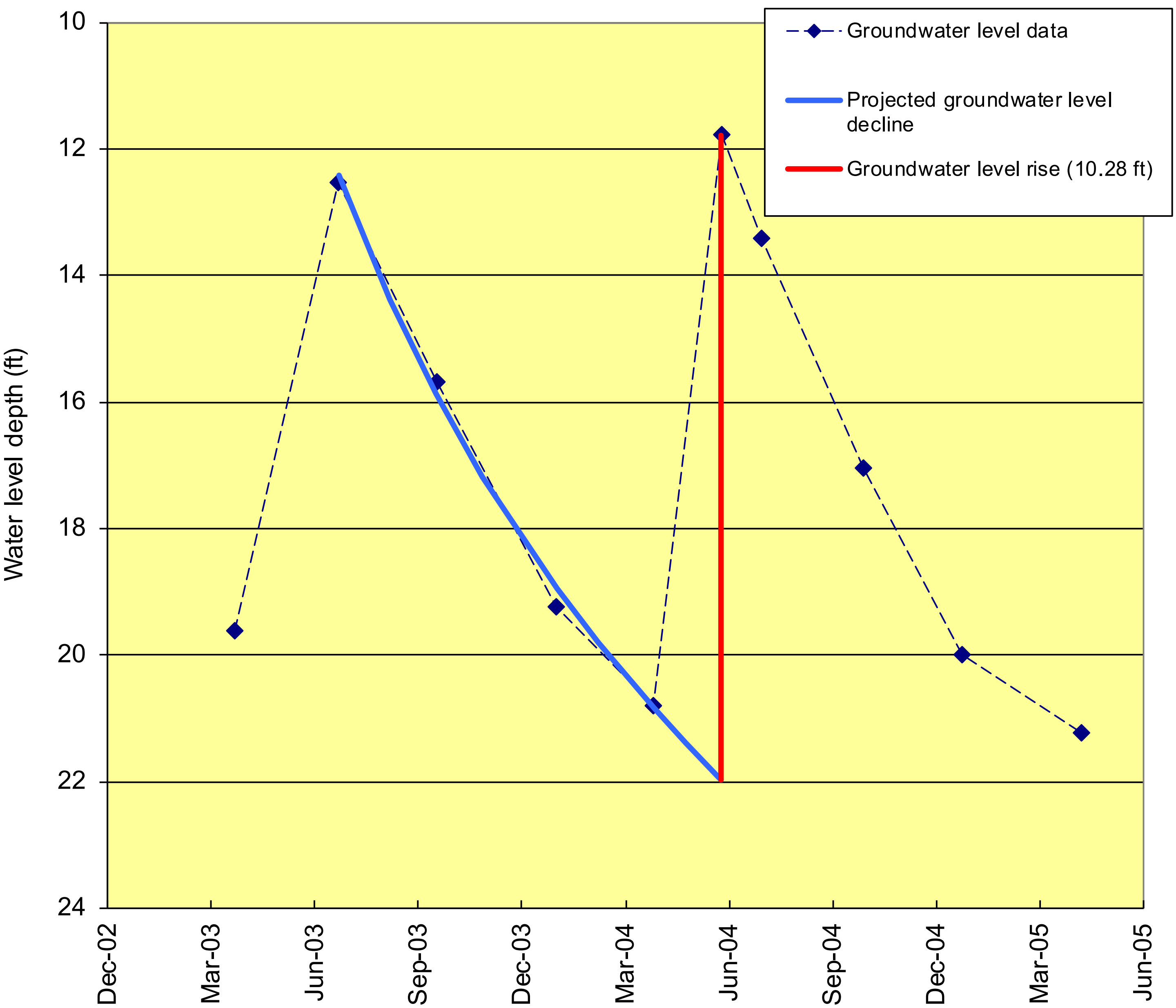

Figure 13. Recharge calculation by water level fluctuation in well 12953.

Table 3
Recharge estimates from groundwater level fluctuations

Site	Aquifer	Primary influence	Peak	Water level rise (ft)	Specific Yield Low	Specific Yield High	Estimated recharge Low (in)	Estimated recharge High (in)
96983	Yellowstone alluvium	Irrigation	July-Aug	15.47	15%	25%	27.8	46.4
129979	Yellowstone alluvium	Irrigation	July-Aug	12.92	5%	15%	7.8	23.3
211976	Yellowstone alluvium	Irrigation	July-Aug	9.28	15%	25%	16.7	27.8
212408	Yellowstone alluvium**	Irrigation	July-Aug	14.05	15%	25%	25.3	42.2
212409	Yellowstone alluvium	Irrigation	July-Aug	9.39	15%	25%	16.9	28.2
						Average	**18.9**	**33.6**
96972	Yellowstone alluvium	Near river	May-June	1.44	15%	25%	2.6	4.3
97110	Yellowstone alluvium	Near river	May-June	2.33	15%	25%	4.2	7.0
						Average	**3.4**	**5.7**
142864	Colorado shale	Precipitation	None	falling	declined 9.28 ft from 5/04 to 3/05			
153496	Colorado shale	Precipitation	May-June	<1				
199862	Colorado shale	Precipitation	May-June	falling	declined 8.39 ft from 5/04 to 8/05			
210988	Colorado shale	Precipitation	None	falling	declined 1.48 ft from 5/04 to 8/05			
92295	Bedrock aquifer	Precipitation	June-Jul	<1				
134185	Bedrock aquifer	Precipitation	None	falling	declined 16.78 ft from 5/04 to 8/05			
151249	Bedrock aquifer	Precipitation	None	<1				
200577	Bedrock aquifer	Precipitation	None	falling	declined 15.98 ft from 8/04 to 89/05			
211221	Bedrock aquifer	Precipitation	None	falling	declined 3.06 ft from 6/04 to 89/05			
211592	Bedrock aquifer	Precipitation	None	falling	declined 12.04 ft from 6/04 to 8/05			
213215	Bedrock aquifer	Precipitation	None	falling	declined 4.15 ft from 7/04 to 8/05			
9950	Bedrock aquifer	Irrigation	June-July	3.2	5.00%	15.00%	1.9	5.8
12953	Bedrock aquifer	Irrigation	June-July	10.28	5.00%	15.00%	6.2	18.5
210979	Bedrock aquifer	Irrigation	June-July	13.64	5.00%	15.00%	8.2	24.6
125664	Bedrock aquifer	Irrigation	June-July	2.33	5.00%	15.00%	1.4	4.2
						Average	**4.4**	**13.3**

Wells 96972 and 97110 were excluded from the above range because they are adjacent to the river and the levels in these wells appear to be primarily controlled by the river stage. Wells located in or near irrigated lands along the Shields River had estimated recharge rates of 5 and 16 in. This method is not easily applied to bedrock wells where precipitation is the only source of recharge because precipitation recharge rates may be lower than discharge rates, as water levels in wells 142864,199662, 210890, 134185, 151249, 200577, 211221, 211592, and 213215 demonstrated, by falling throughout the project period regardless of the season. Over a period of slightly longer than a year, bedrock water levels dropped between 3 and 17 ft. In these wells, longer term storage declines are due to the several years of drought. This method is more successful with bedrock aquifers recharged by irrigation water (9950, 12953, 210979, and 125664).

Groundwater flux method

Recharge for a groundwater drainage area can be estimated by calculating the average groundwater flux using aquifer properties and the hydraulic gradient. Aquifer flow is defined by Darcy's Equation (Todd, 1980) which is:

Flow= (Flow width) x (Aquifer thickness) x (Hydraulic conductivity) x (Hydraulic gradient).

The validity of this estimate depends on how much is known of the aquifer and groundwater flow system. All of the parameters vary throughout the watershed, especially the hydraulic conductivity, but in some simple settings, and on a regional basis, the low and high values should cancel out and a reasonable approximation may be obtained using median values.

For the Yellowstone River alluvial aquifer, the recharge estimate was calculated for the north bank and south bank areas. From the southern border of the project area to about the eastern limit of the City of Livingston, the Yellowstone River runs along the south edge of the alluvial valley, and so the river primarily receives groundwater discharge from alluvial deposits to the north. From east of Livingston to the east project border, the river switches and runs along the north edge of the valley and primarily receives groundwater discharge from alluvial deposits south of the river. Median or typical values used for the evaluation are provided in table 4. The results indicate that a recharge rate of about 21 to 24 in per year is consistent with the input values used.

Evaluation of the bedrock aquifer system in the Shields River area is more problematic than for the Yellowstone River alluvial aquifer. The aquifer system can include over 10,000 ft of evenly mixed sandstone and shale layers. Thin sandstone units make calculating the saturated thickness difficult, a combination of sandstone and shale makes the hydraulic conductivity too variable, and local hydrologic gradients are not always the same as the regional gradient. Therefore this method would not result in an accurate calculation of recharge in the Shields River watershed.

Table 4
Recharge estimates by the flux method

Area	(I) Average gradient	(K) Hydraulic conductivity (ft/d)	(B) Saturated thickness (ft)	(L) Aquifer length (ft)	Estimated aquifer discharge			(A) Area (acres)	Recharge (in/yr)
					cfd	cfs	afy		
Yellowstone River valley, north bank	0.005	275	20	38500	1,058,750	12.25	8,872	4400	24.2
Yellowstone River valley, south bank	0.005	275	20	32800	902,000	10.44	7,558	4300	21.1

Where: Q (in cfd)= K*I*B*L
Note: only 1 side of the river is calculated for each area
Recharge = Q (in AFY)/A x 12

Quantification of Recharge to Bedrock Aquifers

Stream baseflow method

An average recharge value for a watershed can be calculated if it can be assumed that all or nearly all the groundwater in the watershed drains to the major stream, that groundwater storage changes are minor, and that all groundwater has a local recharge source. This differs from the water-level fluctuation method in that it looks at an entire year, which makes it a good method for bedrock aquifers. The average recharge rate for a drainage basin is calculated by dividing the volume of annual baseflow by the area of the watershed. Annual baseflow was approximated by stream flows in February during a dry period when streams were ice-free. This evaluation included stream measurements from February 2005 of the Shields River, and of Flathead, Cottonwood, Brackett, Canyon, Bangtail, Willow, Ferry, Billman, Fleshman, and Miner Creeks. Locations of these streams are shown on figure 2. Results of the evaluation (table 5) show that average recharge rates for these watersheds range from 0.4 in to about 4 in per year, which is 4 percent to 12 percent of the total annual precipitation falling over the watershed. When the average recharge rate is plotted with the elevation-adjusted average precipitation for the drainage basin, a linear relationship is observed (fig. 14). This occurs because more precipitation occurs at higher elevations and there is less evapotranspiration at higher elevations due to the cooler temperatures.

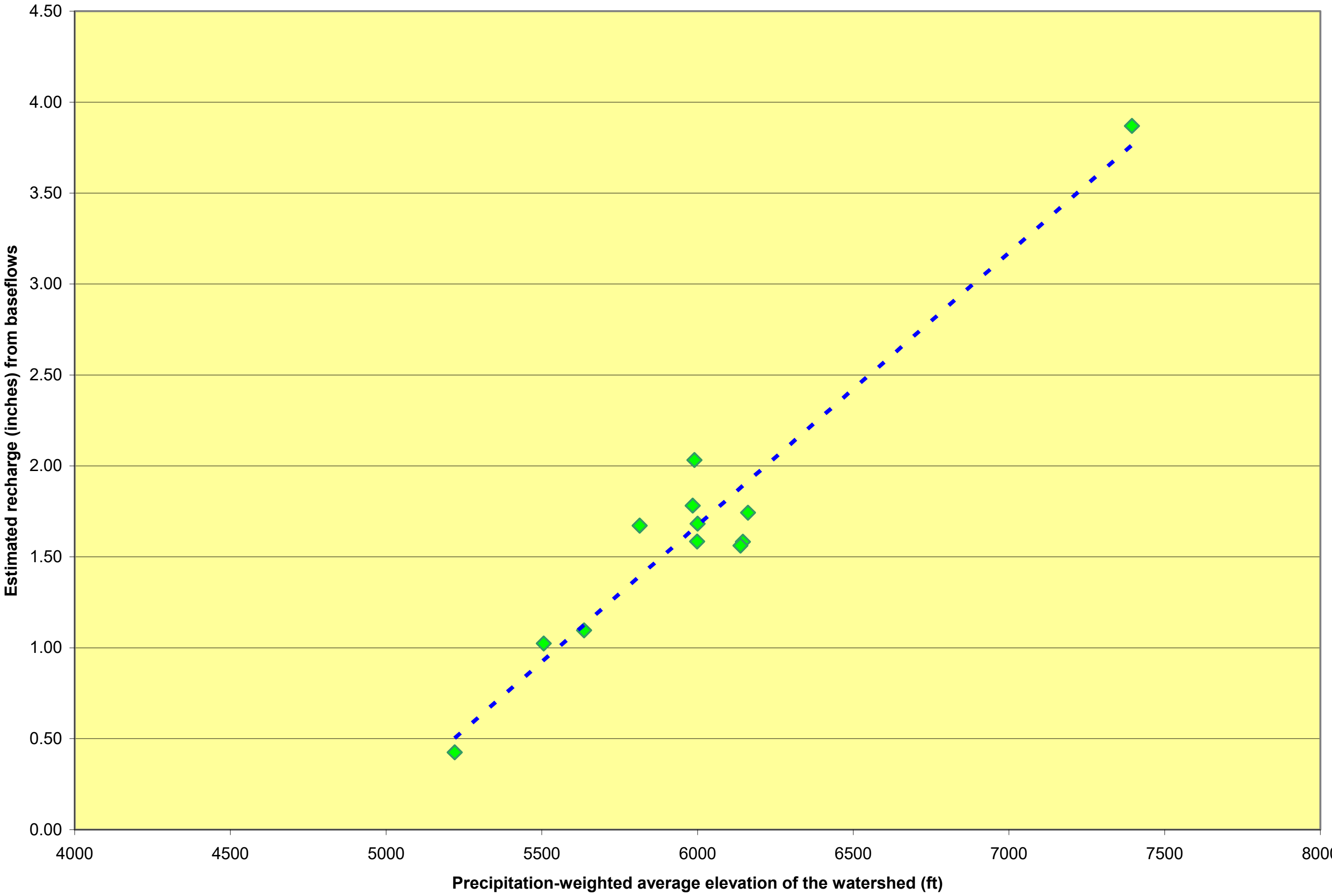

Figure 14. Recharge estimated from base flows and the precipitation-weighted average elevation of the stream watershed.

Chloride tracer method

Chloride is a highly soluble and chemically inert ion that is usually readily flushed through an aquifer. In non-marine settings, the source of chloride in groundwater is from atmospheric deposition, through both precipitation and dry deposition (dust). A water balance study can use these characteristics of chloride to estimate the amount of recharge if precipitation is the primary recharge source, there are no geologic or man-made sources of chloride introduced, and modern precipitation is the major source of chloride. Under these circumstances, the chloride concentration in groundwater is the result of evapotranspiration and the recharge rate can be approximated by:

Recharge = Annual precipitation * (Cli/Clgw),

where Cl is chloride concentration in precipitation and Clgw is chloride concentration in groundwater.

The bedrock aquifer is composed primarily of fluvial sandstone and shale deposits, which likely do not provide geologic sources of chloride. However, geologic chloride is possible within the marine shale in the Colorado Group. Potential man-made sources of chloride can include fertilizer, manures, and road salt. None of these are expected to have a significant regional impact in the Shields River watershed.

Precipitation chemistry data from the National Atmospheric Deposition Program indicate an annual average chloride concentration in south-central Montana that ranged from 0.03 to 0.08 mg/L, with an average of

Table 5
Recharge estimates by baseflows

Watershed	Area (acres)	Baseflow from watershed (cfs)	Baseflow from watershed (acre-ft/yr)	Estimated recharge (in/yr)	Precipitation weighted elevation (ft)	Average annual precipitation (in)	Percent precipitation as recharge
Flathead Creek	76934	18	13,031	2.03	5990	23.6	8.61%
Cottonwood Creek	22454	10	7,240	3.87	7395	33	11.72%
Brackett Creek	39879	8	5,792	1.74	6162	26.9	6.48%
Canyon Creek	15361	2.8	2,027	1.58	6146	27.4	5.78%
Bangtail Creek	8343	1.5	1,086	1.56	6138	26.7	5.85%
Willow Creek	19744	3.6	2,606	1.58	5999		
Ferry Creek	5938	0.7	507	1.02	5506	22.1	4.63%
U Shields	345873	67	48,506	1.68	6000	21.9	7.68%
Shields b CP	229640	50	36,198	1.89			7.70%
All shields	575,513	118	85,428	1.78	5985	22.7	7.85%
Fleshman	12992	2.5	1,810	1.67	5814	23.6	7.08%
Billman	34748	1.7	1,231	0.43	5220	23.8	1.79%
Miner	13477	1.7	1,231	1.10	5636	27.5	3.98%

about 0.07 mg/L (between 1994 and 2005). Chloride concentrations in groundwater ranged from 1.75 to 71 mg/L, which is 25 to 1,014 times that of precipitation. Groundwater chloride concentrations in wells located in non-irrigated areas demonstrated an inverse relationship with elevation (fig. 15). This may indicate that higher recharge rates at higher elevations increased chloride concentration because of evapotranspiration with distance from recharge, or dissolution of native salts. It is also interesting to note that chloride concentrations from wells in the Colorado Group had concentrations less than predicted by the elevation trend. So it does not appear that the marine shale in the Colorado Group provides a significant source of chloride to the groundwater. The lower concentrations may indicate that recharge rates are slightly higher on Wineglass Mountain.

Using the above equation, recharge rates range from 0.02 to 1.47 in per year, which is between 0.1 percent and 6 percent of the annual precipitation at the well location (table 6). Comparison with the results of the baseflow methods indicate the chloride balance produced similar rates of recharge for the higher elevation wells but had lower rates in lower elevation wells. This is likely because baseflows in the streams are dominated by higher elevation recharge.

Chloride concentrations from wells in the Yellowstone River alluvium and from irrigated areas in the Shields River valley also plot below the elevation trend line (fig. 15). For wells located in irrigated areas, the input chloride concentration would be that of the Yellowstone and Shields Rivers, rather than precipitation. Similar to non-irrigated areas, the chloride concentration of water applied to irrigated fields would increase through evapoconcentration. Chloride concentrations in the Yellowstone and Shields Rivers during the summer months are about 4 to 6 mg/L. Evapotranspiration of applied flood irrigation water in the Yellowstone River valley has been estimated to be about 80 percent (Olson and Reiten, 2002) and is listed by Montana DNRC as 15 to 60 percent efficient (Roberts, 2008). Therefore, groundwater from applied irrigation recharge should have a chloride concentration 2 to 5 times that of the river, or about 8 to 30 mg/L. However, water leaking from the ditches would have negligible losses from evapotranspiration and therefore the chloride concentration would remain the same. Chloride concentrations in the groundwater in the Yellowstone River alluvium and in the irrigated areas in the Shields River valley have chloride concentrations of 3 to 8 mg/L. Therefore, it appears that the primary source of recharge in irrigated areas is from ditch leakage.

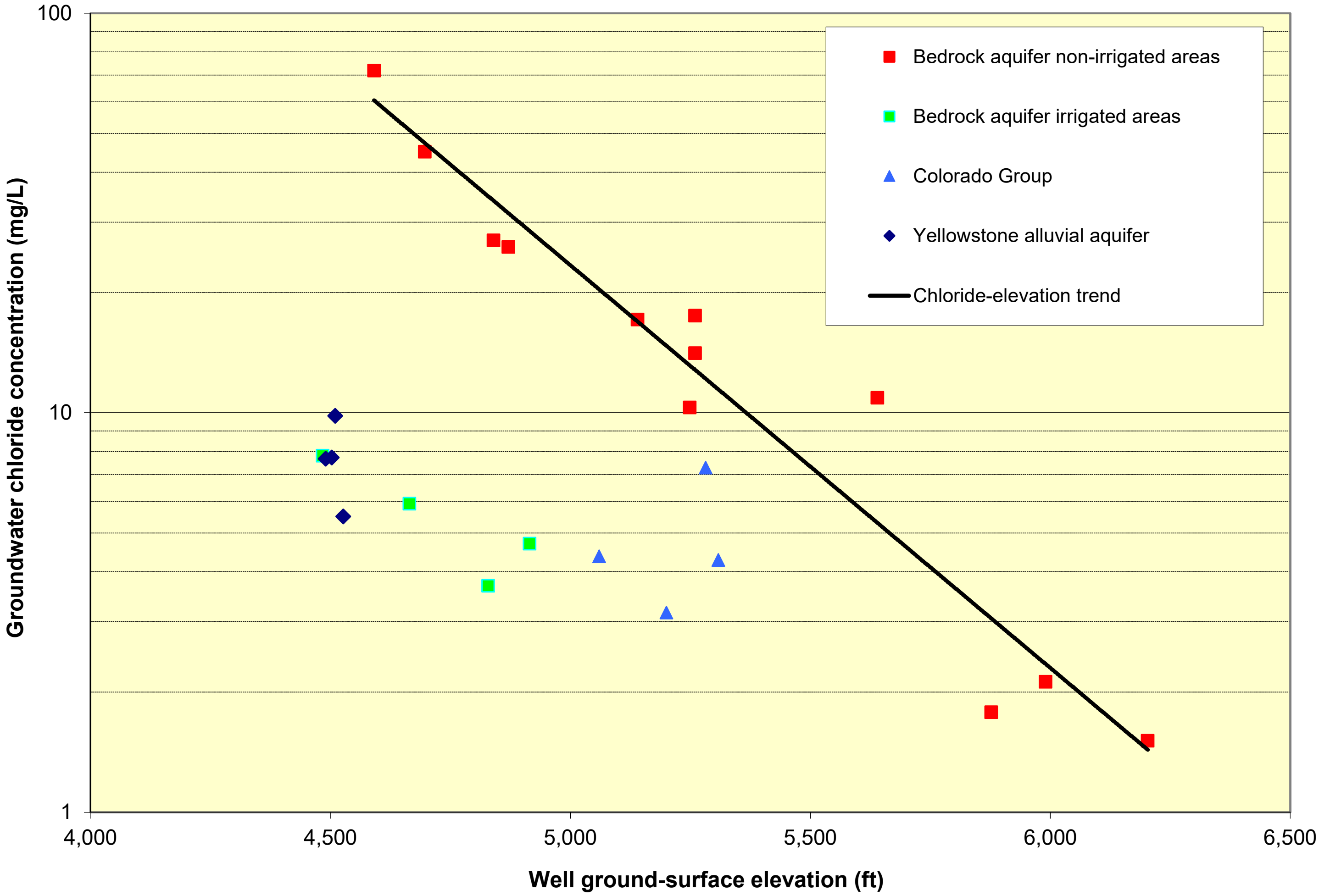

Figure 15. Chloride concentration is inversely proportional to well ground-surface elevations.

Identifying Sources and Age of Recharge

Stable isotopes

Measuring the ratio of the heavy to light stable isotopes of water, which are oxygen-18 (^{18}O) to oxygen-16 (^{16}O), and hydrogen-2 (deuterium [D]) to hydrogen-1 (H), can provide a useful tool in evaluating recharge settings. The isotope ratios are influenced by physical processes such as evaporation and precipitation. However, transpiration does not distinguish between the heavy and light isotopes. Water molecules made with the heavier isotopes tends to "rain out" of a cloud first and evaporate from surface water last. Precipitation falling over colder or higher altitude areas tends to be more depleted (have a lower heavy to light isotope ratio) than in warmer, lower altitude areas and so the isotope ratio can be an indicator of recharge elevation and temperature.

Isotopes are not measured in terms of an absolute concentration but in terms of their proportional difference (delta; δ) in parts per thousand (per mil; o/oo) from a universal reference standard. For water this is the Vienna Standard Mean Ocean Water (VSMOW). The isotope ratio and resultant δ values decrease the more depleted (or lighter) the water becomes and increase the more enriched (or heavier) the water becomes. Precipitation sample plots of $\delta^{18}O$ and δD form a straight-line trend called the local meteoric water line (LMWL) that is characteristic of the local climate. Isotope analyses of precipitation from Butte, Montana (Gammons and others, 2006) indicate a LMWL of: $\delta D = (7.318 \times \delta^{18}O) -7.5$ (fig. 16). Samples from the Yellowstone River at Livingston (Coplen and Kendall, 2000) indicate an isotopic trend that is similar to the Butte LMWL (fig. 16, white squares). Groundwater $\delta^{18}O$ and δD from the project area (appendix E) indicate that the sample values generally shifted

Table 6
Recharge estimates by chloride concentrations

Gwic ID	Aquifer	Sample date	Chloride concentration (mg/L)	Calculated Recharge (in)	Elevation (ft)
78171	217MWRY (Colorado)	8/10/2004	4.28	0.50	5308
142864	211CODY (Colorado)	8/11/2004	7.29	0.29	5282
148802	211CLRD (Colorado)	3/8/2005	4.37	0.43	5060
217197	211CODY (Colorado)	3/8/2005	3.16	0.64	5200
9950	125FRUN (Fort Union)	4/27/2000	5.92	0.25	4665
12953	125FRUN (Fort Union)	9/22/1993	4.7	0.37	4915
92295	125FRUN (Fort Union)	6/2/2004	7.8	0.17	4484
153439	125FRUN (Fort Union)	3/10/2005	1.78	1.47	5877
181733	125FRUN (Fort Union)	3/9/2005	1.51	1.90	6203
210979	125FRUN (Fort Union)	12/8/2004	3.69	0.45	4829
211592	125FRUN (Fort Union)	8/9/2004	45	0.03	4697
213215	125FRUN (Fort Union)	8/11/2004	10.9	0.22	5640
217208	125FRUN (Fort Union)	3/8/2005	2.12	1.28	5990
217213	125FRUN (Fort Union)	3/9/2005	17.1	0.11	5140
125664	211LVGS (Livingston)	4/27/2000	17.5	0.12	5260
135185	211CKDL (Livingston)	8/10/2004	71.8	0.02	4591
140147	211BMCK (Livingston)	3/8/2005	14.1	0.15	5260
200577	211HPRS (Livingston)	8/11/2004	16	0.09	4615
208390	211CKDL (Livingston)	3/8/2005	10	0.18	4980
211221	211BMCK (Livingston)	8/11/2004	27	0.06	4840
151249	211TPCK (Eagle)	8/10/2004	26	0.07	4871
184324	211TPCK (Eagle)	12/8/2004	10.3	0.20	5249
205605	221ELLS (Madison)	8/11/2004	11.8	0.18	5367

to the right of the Butte LMWL. The right shift from precipitation or snowmelt is typically an indicator of evaporation. Evaporation occurs to rain as it descends from the clouds and from the ground surface.

Groundwater in the Yellowstone River alluvial aquifer has $\delta^{18}O$ of -17.4 to -17.7 per mil (fig. 16), which is similar to that of the Yellowstone River (an average of -17.7 per mil). These data, along with the observed groundwater fluctuations, indicate that irrigation or leakage from irrigation ditches is the primary source of recharge in the Yellowstone River alluvial aquifer. Lack of an evaporation signature in the oxygen isotope values also supports the supposition that ditch leakage plays a major part in recharge to the aquifer. Most of the bedrock samples from the bedrock aquifers and Colorado Group plot to the right of the LMWL, indicating evaporation. This means that groundwater undergoes evaporation prior to infiltrating to the aquifer. This occurs when thick soils overlay the recharge areas of the bedrock aquifers.

The distribution of $\delta^{18}O$ in bedrock wells appears to be primarily a function of the sampled well elevation. The most depleted $\delta^{18}O$ values are found at the highest elevations, and the more enriched $\delta^{18}O$ are found in lower elevations (fig. 17). This indicates a wide range in the elevation of recharge to bedrock aquifers and they tend to be recharged fairly locally.

Tritium

Tritium is a naturally occurring radioactive isotope of hydrogen (^3H) and provides a useful tracer of the relative age of groundwater. Consequently, it is useful in evaluating when recharge occurred and the overall residence

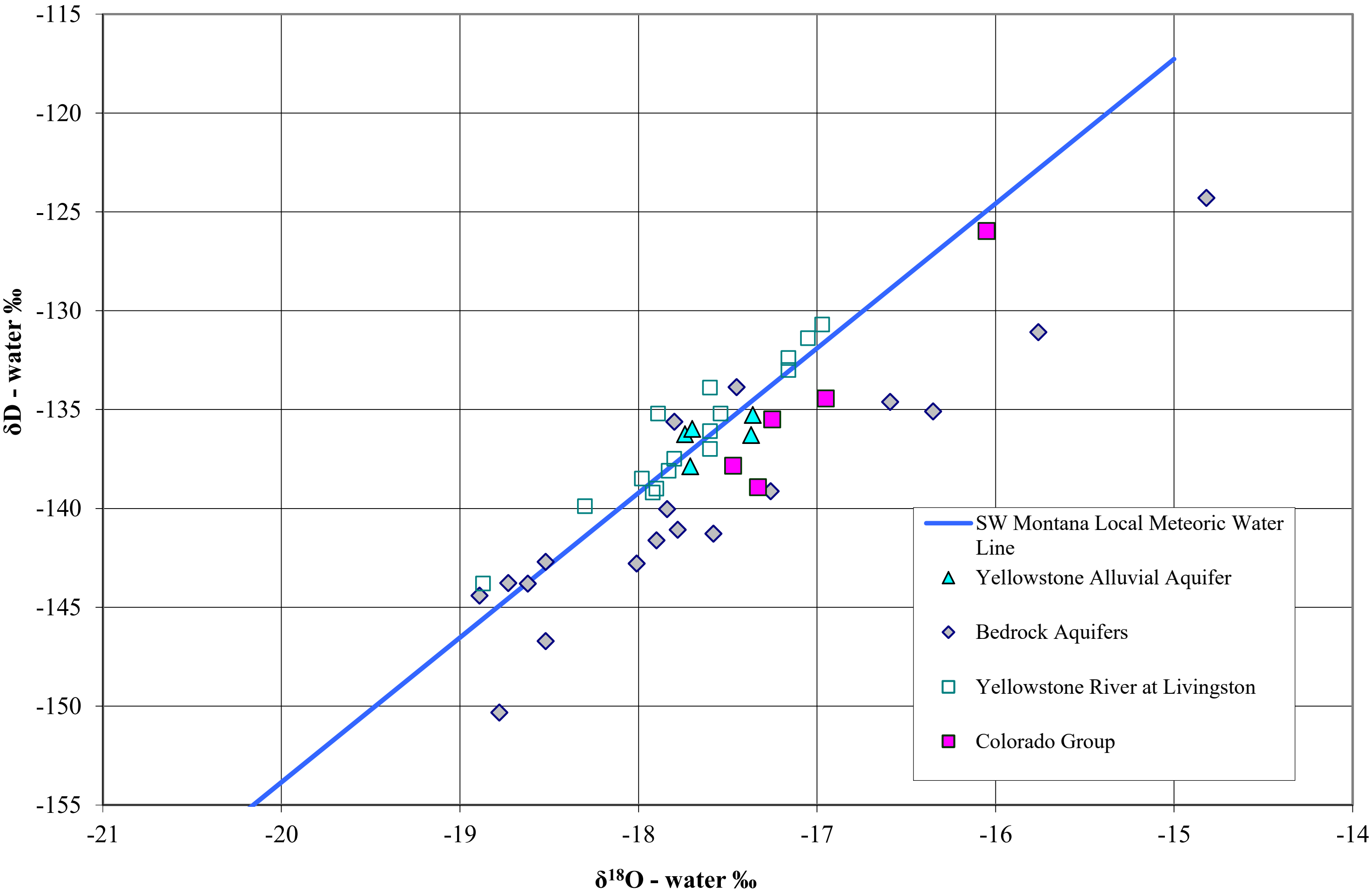

Figure 16. The δ^{18}O and δ^{2}H isotope ratios distinguish bedrock aquifers from surface water and the alluvial aquifers recharged by surface water.

time in the aquifer. Tritium occurs naturally in precipitation at levels of 3.4 to 6.6 tritium units (TU) (Clark and Fritz, 1997). However, nuclear reactors provide an additional source of tritium. Atmospheric tritium levels in 2010 were 10 to 15 TU. A sample from the Yellowstone River near Livingston had a tritium concentration of 11 TU.

Nuclear weapons testing in the 1950s and 1960s significantly increased atmospheric concentrations of tritium to several thousand TU. The high concentrations of this time are referred to as the tritium "bomb spike." Tritium has a half-life of 12.4 years, so tritium in water from the bomb spike era has decayed to considerably lower concentrations than it once was.

Recently recharged water should contain a concentration of tritium similar to current atmospheric levels. Older water further along the groundwater flow path will have a lower concentration due to the decay of tritium. In practice, water with less than 0.8 TU has a pre-1952 age; water with tritium concentrations between 5 and 15 TU is modern; intermediate tritium concentrations of 0.8 to 4 TU is most likely a mixture of modern and older water; and tritium concentrations in excess of 15 show the influence of bomb testing in the 1950s (Clark and Fritz, 1997; Drever, 1997).

Tritium samples collected from groundwater in the project area had concentrations ranging from 2 to 14 TU. The samples from Yellowstone alluvial wells and from shallow bedrock wells (less than 150 ft deep) had tritium concentrations of between 8 and 14 TU, indicating an age of less than 30 years old. However, samples from deeper wells had tritium concentrations less than 8 TU. A plot of tritium vs depth water enters in the well demonstrates a trend of decreasing tritium with increasing depth (fig. 18). This trend is interpreted to repre-

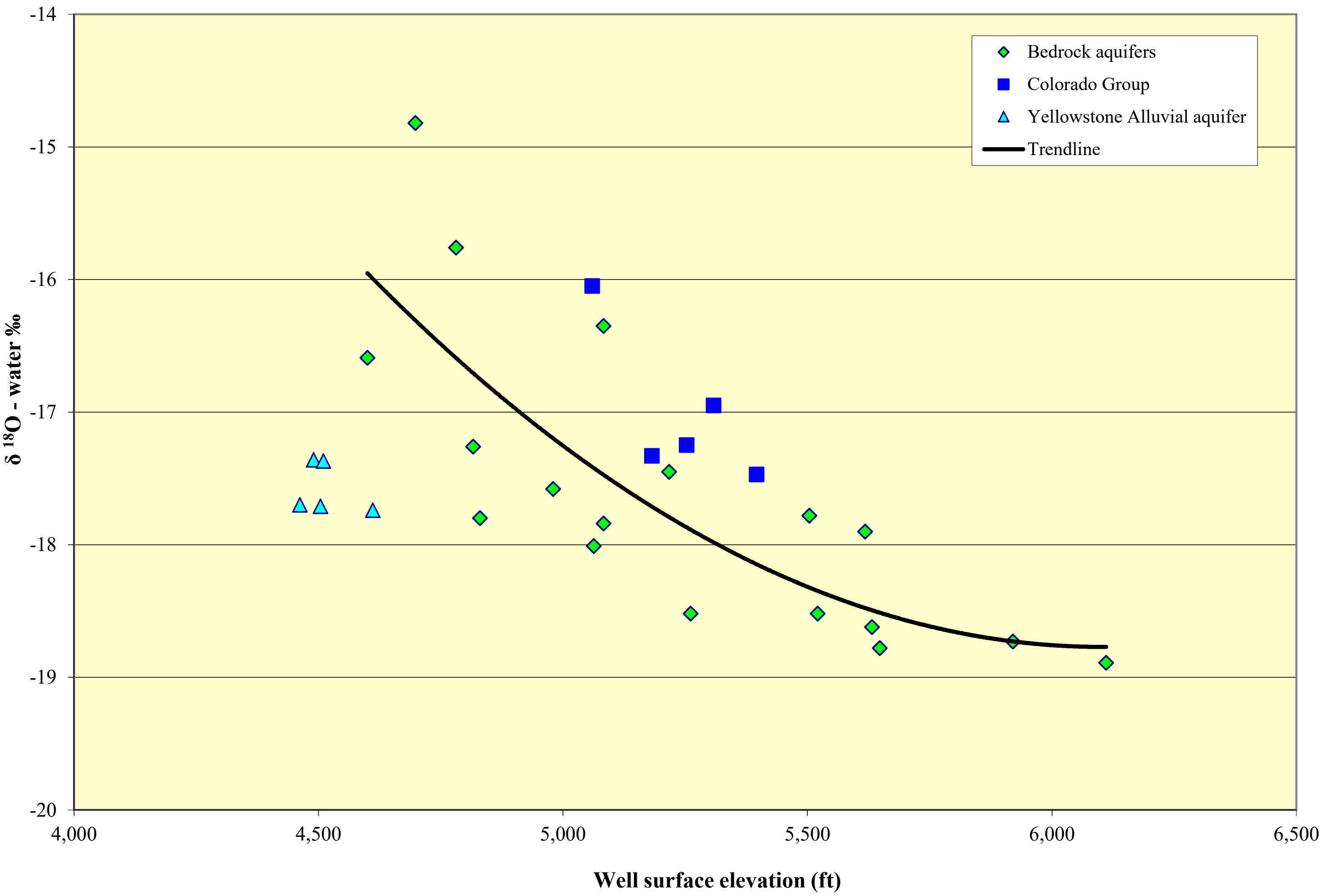

Figure 17. The $\delta^{18}O$ value of groundwater decreases with increasing well elevation indicating colder average temperature of recharge in higher elevations and local recharge.

sent mixing of young water (less than 30 years old) with old water (greater than 50 years old). Using 12 TU as a modern end-member and 2 TU as the pre-1952 end member, wells greater than about 225 ft are composed of less than 50 percent modern water.

Sodium percentages

As was discussed in the water quality section, the percentage of sodium in relation to the other cations increases with well depth in bedrock aquifers. The trend towards increasing sodium content is typical of cation exchange reactions (Freeze and Cherry, 1979). Sodium associated with clays and shales exchanges with the calcium and magnesium in groundwater. Therefore, the more contact groundwater has with shale and clay, the more enriched it becomes in sodium. A comparison of the percentage of sodium of the total cations to tritium concentration indicates that the older (low tritium) water has generally a higher percent sodium than younger (higher tritium) samples (fig. 19).

Samples from wells less than about 220 ft deep have sodium percentages of 8 to 50 percent (fig. 20). Samples from deeper wells have sodium percentages of 50 to 100 percent. Therefore, the percentage of sodium in a sample can be a relative marker for deep vs shallow groundwater. Baseflow samples from the Shields River and Billman Creek have sodium percentages of between 20 and 24 percent. These sample data indicate that stream baseflow is primarily from shallow groundwater. This may also indicate that nearly all the groundwater flow occurs in the shallow portion of the aquifer.

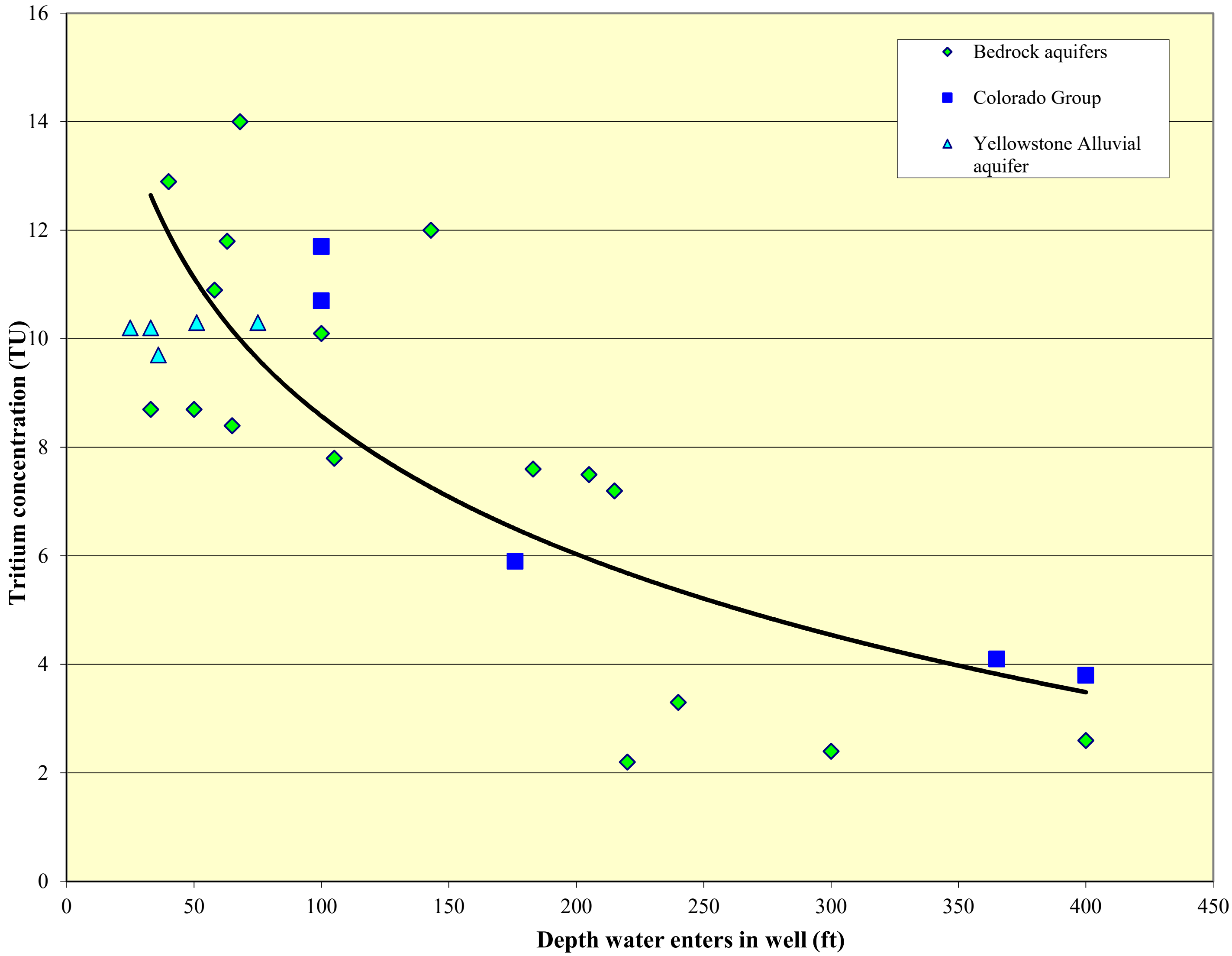

Figure 18. Tritium concentrations decrease with aquifer depth.

Aquifer Vulnerability

The tritium concentration provides a convenient measure of an aquifer's vulnerability to impacts from surface activities. Old groundwater is less likely to be immediately impacted because of the long time for surface recharge to reach the location where the tritium sample was measured. Conversely, young groundwater is more susceptible to impact because of the much shorter time for recharge to reach that location. Additionally, the quicker groundwater responds to recharge events, like irrigation or snowmelt, the more likely it is to be impacted by surface activities.

Groundwater tritium analyses have demonstrated that the Yellowstone River alluvial aquifer contains modern water and so is sensitive to surface impacts. Isotopic and groundwater fluctuation data indicate that the primary source of recharge to the alluvial aquifer is from irrigation or irrigation ditch infiltration. Changes to irrigation practices or to irrigation ditches can therefore impact groundwater levels and availability.

The tritium analyses have shown the bedrock aquifers to be a mixture of old and young water depending on well depth. Samples from wells over 225 ft deep were composed of less than half modern water. Sample ages from wells greater than about 350 ft were almost entirely pre-1950s. Therefore the bedrock aquifers less than about 225 ft are vulnerable to impacts and the deeper wells are less vulnerable. Isotopic analyses indicate that most of the recharge is likely from relatively local snowmelt. Therefore climatic changes can impact water levels and availability of the bedrock aquifers. Recharge from irrigation also occurs in the bedrock aquifer but only in the immediate proximity of the Shields River.

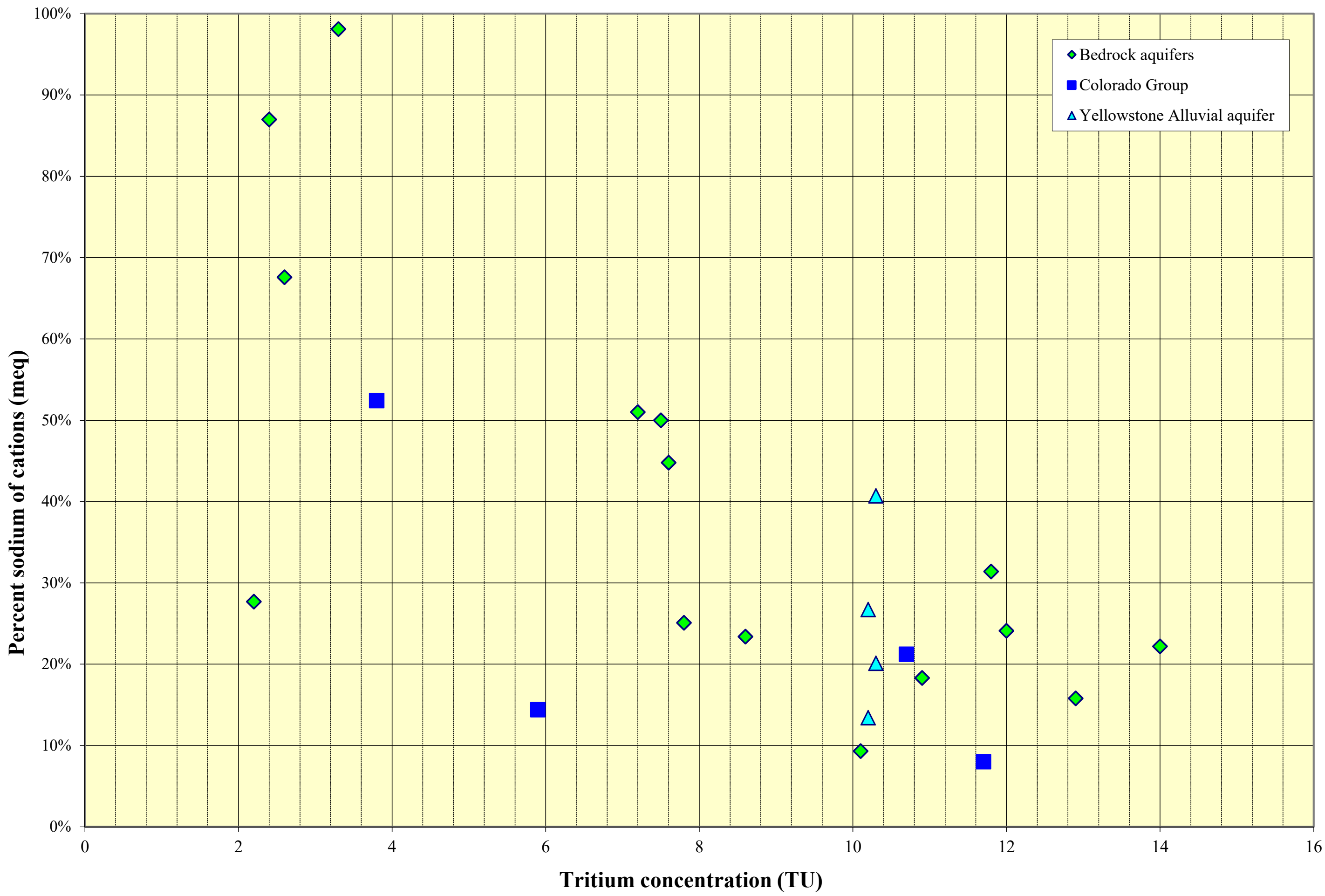

Figure 19. The percent sodium of total cations increases with the age of groundwater (low tritium concentrations indicate old water).

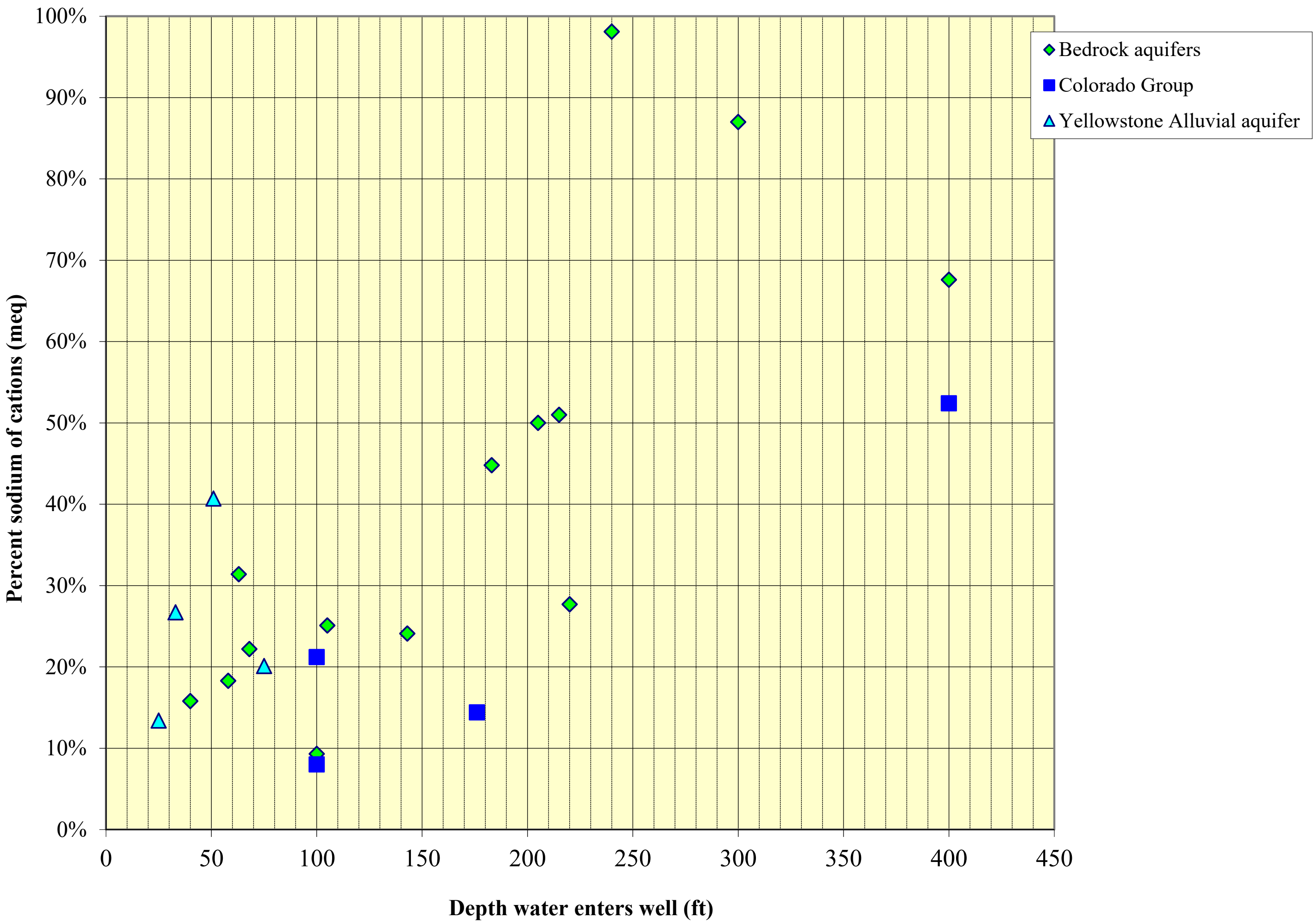

Figure 20. The percent sodium of the total cations increases with aquifer depth.

SUMMARY

The project area around Livingston includes broad, rolling uplands and river valleys that are surrounded by the Crazy Mountains to the northeast and the Bridger Range to the west. The sedimentary rocks range in age from Mississippian through early Tertiary and are extremely folded and faulted. The Quaternary alluvial deposits from the Shields River are thin (20 to 40 ft thick), fine-grained, sand and clay deposits. The Quaternary alluvial deposits from the Yellowstone River range from 25 to 75 ft thick and consist of cobbles, gravel, and sand deposits. Land use mainly consists of agricultural practices. Most of the population is concentrated in the city of Livingston, which is served by public water and sewer systems. The remainder of the population is served by public water or individual domestic wells and individual septic systems.

The hydrology of the Shields River and Yellowstone Valley alluvial aquifers is dominated by irrigation practices. Groundwater flow direction in the Yellowstone River alluvium near the edges of the valley is towards the river and, in the center of the valley, parallel to the river. The gradient of the aquifer is relatively flat, and aquifer testing indicated a hydraulic conductivity of 170 to 380 ft per day. The Yellowstone River alluvial aquifer has good water quality, with the exception of groundwater impacted by the Burlington Northern Shop Complex in Livingston, dominated by calcium and bicarbonate ions, similar to Yellowstone River water. Nitrate concentrations were relatively low within the study area.

The bedrock aquifers are recharged by precipitation during the mid to late spring when there is abundant rainfall, high-elevation snowmelt, and limited plant uptake. Groundwater flow is controlled by the regional hydraulic gradient (towards the Shields and Yellowstone River) and smaller, local flow paths within the layered sandstones and shales. Aquifer testing in the bedrock aquifers determined a median hydraulic conductivity of 10 ft per day. Drawdown from well pumping can be relatively extensive in the bedrock aquifers; this is due to the low storage within the aquifer matrix. The bedrock aquifers have good water quality but the proportion of sodium tends to increase with depth.

Stable isotope samples of $\delta^{18}O$ and δD indicate the groundwater of the Yellowstone River alluvial aquifer is very similar to the surface water in the Yellowstone River. These data indicate that irrigation or leakage from the unlined ditches is the primary recharge to the alluvial aquifer. The bedrock aquifer samples indicate the recharge is from both high- and low-altitude rain and snow that has been partially evaporated.

Tritium isotopes were also collected to determine the relative age of groundwater. The samples indicate that the Yellowstone River alluvial aquifer and shallow bedrock (less than 150 ft deep) aquifers were modern water (less than 30 years) and deeper bedrock aquifers were a mixture of modern and older water (greater than 50 years).

The alluvial and shallow bedrock aquifers within the study area are vulnerable to impacts from surface activities. The groundwater in the aquifers is modern, implying quick recharge and sensitivity to land-use changes, drought condition, and water-quality contaminates. Deeper bedrock aquifers are not as vulnerable due to the fact that surface recharge takes a long time to reach that location in the aquifer.

RECOMMENDATIONS

Most of the bedrock aquifers within the project area have groundwater that should be of sufficient quantity and quality for domestic household use. In some cases, higher yield wells are possible and could support a community well. However, the bedrock aquifers have relatively low storage and may have several feet of drawdown within a radius of about 500 ft. The bedrock aquifers are recharged locally and therefore susceptible to reduced recharge in periods of below-average precipitation. These considerations need to be accounted for when planning developments that will be based upon individual wells. Developments in the bedrock aquifers on Wineglass Mountain should have prior planning conducted on well placement to avoid deep (more than 200 ft) well constructions and interference from nearby pumping wells. Also, bedrock wells west of Clyde Park located up-dip from igneous sills may encounter deeper drilling depths (over 300 ft).

The alluvial aquifers have a close hydraulic connection with irrigation water, shallow groundwater, and surface water. Flood irrigation and ditch leakage are important sources of recharge to the alluvial aquifers. Land-use changes, such as converting irrigated land to home development or conversion from flood irrigation to center-pivot systems, could decrease recharge to alluvial aquifers and would result in less productive aquifers.

Generally, good water quality exists within the alluvial and bedrock aquifers, with the exception of the impacted groundwater in Livingston from the Burlington Northern Shop Complex. Nitrates do not seem to be a problem in the project area. However, the alluvial and shallow bedrock aquifers are susceptible to surface impacts due to the aquifers' naturally high permeability. Therefore, care should be taken to limit the possibility of contamination from surface activities.

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APPENDIX A

Well Inventory

GWIC ID	Site name	Latitude	Longitude	Township	Range	Section	Tract	Ground elevation	Measured point elevation (ft)	Total depth (ft)	Date (dd/mm/yy)	Static water level from mp (ft)	Pumping water level (ft)	Yield (gpm)	Water temperature (C°)	Field SC (umhos/cm)	Field pH	Field test nitrate (mg/L N)
9946	SHIPLET RANCH	45.8510	-110.5821	01N	09E	11	BCCD	4744	4746.2	93	7/28/2004 13:28	16.97	26.71	17.64	9.1	314	6.95	<1
12880	KAUL DAN	45.6566	-110.7580	02S	08E	17	DDCD	5260	5262.4	62	3/9/2005 14:50	32.99	-	-	9.9	444	7.43	1
14668	ZIMMERMAN CHARLES	46.0205	-110.6276	03N	09E	8	DDAA	5118	2120.0	39	5/7/2004 16:47	11.50	-	6.25	10.2	600	7.63	2
14674	TASHJIAN HANK, HENRY & KIM	46.0158	-110.6539	03N	09E	18	ABBD	5162	5102.0	237	6/8/2004 11:10	90.30	99.60	15.70	10.7	221	6.96	2
78171	BOSTON ROSEMARY	45.6154	-110.6195	02S	09E	33	DCBA	5315	5316.0	-	8/10/2004 14:55	101.12	-	-	11.9	506	7.74	-
92247	LAWELLIN JOE & C	45.7801	-110.5028	01S	10E	4	DDAB	4540	4540.0	35	5/19/2004 12:12	8.60	12.30	7.69	9.1	230	7.58	1
96950	STARWINDS (FONDREN & COCHRAN) #3	45.6177	-110.7434	02S	08E	33	DBCA	5880	5882.5	530	7/21/2004 13:00	161.00	-	-	10.1	1308	9.54	<1
96979	MATHEWS LEROY	45.6637	-110.5908	02S	09E	14	BCCB	4620	4620.7	135	1/14/2004 9:21	49.16	59.22	4.40	11.5	431	9.11	-
97006	MCCORMICK JERRY & ELIZABETH	45.6433	-110.5824	02S	09E	23	CDAC	4538	4539.5	49	5/26/2004 13:57	25.43	25.75	6.00	13.3	441	7.36	-
97034	VOYICH DAN	45.6525	-110.5838	02S	09E	23	BADC	4561	4566.0	300	5/20/2004 10:15	88.32	-	3.84	-	546	7.20	2
97110	STRONG WILLIAM H.	45.6332	-110.5698	02S	09E	25	CBBB	4503	4507.0	38	5/19/2004 17:08	8.80	8.75	2.90	-	276	7.50	1
97203	PAYNE JIM	45.6370	-110.5850	02S	09E	26	BDBA	4536	4537.0	56	5/19/2004 16:15	23.75	25.75	25.00	-	477	7.50	1
124020	BROCKWAY JOHN	45.6222	-110.5988	02S	09E	34	ACBD	4760	4761.9	130	5/11/2004 11:37	16.31	29.30	6.38	10.2	205	6.97	<1
135185	PRINTZ JOHN	45.6632	-110.5754	02S	09E	14	ADCC	4575	4577.0	106	5/26/2004 16:50	71.10	-	12.00	12.2	912	6.75	-
140147	PALMER MIKE	45.6608	-110.7732	02S	08E	17	CBDB	5620	5622.3	205	3/8/2005 11:15	102.86	-	-	8.0	397	8.09	<1
142864	SHIVER MARVIN L.	45.6263	-110.6381	02S	09E	32	ABAA	5270	5272.6	100	5/11/2004 14:00	8.03	-	-	8.4	239	6.96	<1
143008	ORENDORFF JOANN	45.8691	-110.4894	01N	10E	28	BDAB	4745	4746.1	149	6/24/2004 11:50	52.74	58.55	13.60	10.2	353	6.96	2
148802	DOUGLAS JIM AND LINDA	45.6157	-110.6055	02S	09E	34	CDBB	5060	5060.6	100	3/8/2005 14:26	16.79	-	-	9.2	655	7.05	<1
149531	SWANSON ARTHUR R & KARLIN	45.6739	-110.5806	02S	09E	11	DBCC	4690	4692.5	-	11/13/2003 12:30	81.96	117.90	15.80	11.6	1010	7.81	2
150529	CIERI CARLO	45.6811	-110.5469	02S	10E	7	BBDC	4499	4500.1	122	7/19/2004 15:55	46.05	53.40	-	13.3	678	9.33	<3
151249	BUFFALO SPRINGS	45.6338	-110.6039	02S	09E	27	CABB	4780	4782.5	-	8/10/2004 10:45	43.90	-	-	10.3	-	-	-
151387	CARUSO R A & DONNA	45.6826	-110.5489	02S	10E	7	BBBC	4510	-	210	8/25/2004 13:10	-	-	-	12.2	278	-	<1
151713	GROVE JAMES B & MARILYN J	45.6538	-110.7349	02S	08E	21	AACA	5560	5561.5	221	8/12/2004 11:56	97.20	-	-	7.7	222	6.97	<1
153439	O'CONNOR FRANK & NASHAN JEFF	45.6933	-110.7225	02S	08E	3	ACCA	5620	5621.5	45	3/10/2005 11:40	38.30	-	-	8.7	362	7.70	<1
153496	PENNY MIKE	45.6088	-110.6052	03S	09E	3	BCAA	5400	5401.7	190	5/11/2004 10:50	79.76	-	-	-	-	-	-
157308	MOORE TED	45.6384	-110.6204	02S	09E	28	ABCA	4820	4821.9	235	8/16/2005 11:45	169.88	-	-	10.7	459	7.03	-
157634	CARR RON	45.8951	-110.5991	02N	09E	27	BCDC	4920	4921.3	260	8/26/2004 11:30	47.72	153.22	-	8.3	332	8.31	<1
162122	MILKOVICH TOM OR ANNE	45.8437	-110.5360	01N	10E	18	BABC	4858	4859.7	29	6/23/2004 10:22	2.80	5.50	20.00	8.1	362	7.70	2
165434	BUCKLEY RICHARD	45.6356	-110.6390	02S	09E	29	ACDB	5060	5062.0		8/16/2005 14:00	104.40	-	-	10.1	476	7.03	-
170482	NASHAN JEFF	45.6933	-110.7233	02S	08E	3	ACCA	5640	5642.2	60	3/10/2005 11:30	39.89	-	-		-	-	-
170497	FRIENDS FOR LIFE - HUMANE SOCIETY PARK COUNTY	45.6839	-110.5115	02S	10E	5	DDCD	4450	4452.1	40	8/25/2004 14:10	13.70	-	6.25	11.1	242	-	<1
176192	MARTIN JEFF	45.6378	-110.6784	02S	08E	25	ACAA	5215	5216.4	400	7/20/2004 14:12	62.40	-	8.57	10.6	670	6.96	<1
176978	CROSS DUANE	45.6233	-110.6343	02S	09E	32	ADBA	5420	5422.4	-	3/8/2005 11:00	136.36	-	-	7.6	636	7.06	<1
177063	NAZARI ROD	45.7694	-110.4897	01N	10E	9	AADC	4518	4518.0	60	5/19/2004 10:20	9.49	9.58	8.30	11.6	166	7.64	<1
181325	NAZARI ROD	45.7694	-110.4897	01S	10E	9	AADC	4518	4518.0	-	5/19/2004 10:36	8.19	-	-	11.3	165	7.75	<1
181733	MIKAELSEN BEN	45.6846	-110.7873	02S	08E	7	BAAA	6160	6161.2	60	3/9/2005 13:20	24.78	-	-	7.7	254	7.04	<1
183676	GEORGE JAMES	45.9885	-110.6430	03N	09E	19	DDDD	5000	5002.5	152	3/9/2005 11:30	13.00	-	-	17.9	438	7.90	1
184147	CROSTON EDWARD	45.8969	-110.6063	02N	09E	28	ABCA	4820	-	103	8/16/2005 12:30	-	-	-	12.6	348	7.51	-
184324	REECE PARKS	45.6404	-110.6961	02S	08E	26	AABD	5150	5151.4	160	7/22/2004 10:34	47.95	-	-	10.4	858	7.55	<1
186852	CROSTON JOHN	45.8957	-110.6060	02N	09E	28	ACAB	4820	-	158	8/16/2005 12:45	-	-	-	14.7	521	7.71	-
188869	ALVERSON DENNIS	45.6400	-110.6125	02S	09E	28	AAAD	4750	4751.5	318	8/17/2005 15:00	84.49	-	-	11.9	572	7.03	-
188885	SHULTZ CHARLES OR MARY	45.6933	-110.5488	02S	10E	6	BCCA	4590	4591.3	180	11/12/2003 14:35	86.84	-	-	12.2	637	7.86	0
193442	HOWARD PATRICIA OR DANIEL	45.6435	-110.6329	02S	09E	20	DDDA	4980	4982.0	212	8/16/2005 10:57	96.42	-	-	9.8	403	7.04	-
195441	KELLN STEVE AND GRETCHEN	45.6244	-110.6222	02S	09E	33	ABCB	5115	5116.5	400	5/27/2004 9:10	262.65	-	-	10.2	725	9.83	1
196469	GEE DARREL*WELL 2	45.9978	-110.5289	03N	10E	19	ACBC	5462	5463.6	110	5/8/2004 14:50	18.20	32.20	7.14	8.7	679	6.77	1
196495	HART PETE AND SALLY	45.6873	-110.5347	02S	10E	6	DCAA	4470	4472.1	140	1/14/2004 11:46	32.62	33.64	1.80	12.1	417	7.98	<1
197035	LANGAAS MARLO	45.6311	-110.6876	02S	08E	25	CDBB	5490	5491.4	160	7/20/2004 13:35	113.85	125.22	14.28	9.7	673	7.44	<1
197811	YOUDAN KEITH	45.6541	-110.5733	02S	09E	23	BADC	4534	4535.3	-	5/20/2004 14:30	-	-	6.00	12.2	503	7.02	-
199404	AQUATIC DESIGN CONSTRUCTION	45.6499	-110.5588	02S	09E	24	ACCB	4486	4486.0	20	5/20/2004 11:45	7.00	7.40	2.00	13.3	346	7.20	<1
199862	BOSTON ROSEMARY	45.6157	-110.6194	02S	09E	33	DCBA	5286	5302.0	140	5/27/2004 13:00	37.71	-	-	-	-	-	-

GWIC ID	Site name	Latitude	Longitude	Township	Range	Section	Tract	Ground elevation	Measured point elevation (ft)	Total depth (ft)	Date (dd/mm/yy)	Static water level from mp (ft)	Pumping water level (ft)	Yield (gpm)	Water temperature (C°)	Field SC (umhos/cm)	Field pH	Field test nitrate (mg/L N)
200577	SEMENIC RICHARD	45.7109	-110.5115	01S	10E	32	AADB	4615	4616.8	350	7/27/2004 10:00	141.70	171.42	13.00	12.2	277	8.83	<1
203490	KAUL DAN	45.6497	-110.6129	02S	09E	22	BCCB	4610	4611.9	36	3/9/2005 15:46	7.37	-	-	9.7	714	7.49	<1
205517	NAVE BRETT	45.6505	-110.6570	02S	09E	19	ADCB	4890	4891.5	200	8/17/2005 11:30	82.71	-	-	12.8	574	7.89	-
205531	FOX JAMES AND MAXINE	45.6296	-110.5803	02S	09E	26	DCBA	4528	4528.4	16	5/19/2004 11:00	10.04	-	8.10	-	518	7.45	<1
205605	PENNY MIKE	45.6088	-110.6052	03S	09E	3	BCAA	5400	5401.3	340	5/11/2004 10:35	243.00	-	-	9.3	975	7.41	<1
206135	DENTON KRIS	45.8764	-110.6306	02N	09E	32	DCAD	5038	2.4	158	8/17/2005 14:45	71.87	-	-	12.5	350	8.32	-
207271	YOAKAM CHAD	45.6338	-110.5806	02S	09E	26	ACCC	4528	4529.6	61	5/19/2004 14:15	18.10	18.10	4.60	-	517	7.50	0
207272	MULER VIRGINIA	45.6980	-110.5190	02S	10E	5	BAAA	4445	4446.2	50	11/12/2003 13:55	12.21	-	-	12.7	431	7.59	<1
207274	SUVISON STACY	45.6741	-110.5821	02S	09E	11	CADD	4680	4681.6	325	11/13/2003 11:40	65.99	-	-	12.0	1751	7.79	5
208028	BATES GEORGE	45.7195	-110.4880	01S	10E	29	BCCC	4614	4616.5	150	7/27/2004 10:57	107.80	108.40	-	13.8	253	8.48	<2
208390	HOLMQUIST JOHN	45.6386	-110.6486	02S	09E	29	BBDD	4980	4981.5	125	3/8/2005 9:30	55.77	-	-	11.4	712	7.35	<1
208538	STANTON WILLIAM *WELL 3	45.6294	-110.5916	02S	09E	27	DDAA	4548	4549.9	54	6/10/2004 11:30	27.94	-	-	10.6	305	7.61	2
208539	STANTON WILLIAM	45.6284	-110.6063	08S	09E	22	BADA	4733	4735.5	-	6/10/2004 10:00	4.45	-	-	10.0	691	6.96	<1
210355	CHAPEL VIRGINIA AND LARRY	45.6954	-110.5418	02S	10E	6	BDBD	4559	4561.0	138	5/10/2004 11:00	85.70	128.70	10.00	12.0	458	8.48	7
210360	HARMS, DENNIS	45.7099	-110.5385	01S	10E	31	ACBB	4556	4656.0	62	5/11/2004 13:00	24.85	24.90	10.00	13.0	479	7.55	2
210363	HAUG DAVID AND MARY	45.6919	-110.5418	02N	10E	6	BDDD	4503	4504.0	140	5/10/2004 13:00	35.90	-	-	14.2	200	7.59	1
210760	LARSON DE ANNA	45.9272	-110.3476	02N	11E	15	BACA	6645	42.6	43	5/9/2004 15:05	7.75	8.15	7.80	6.8	180	7.72	1
210838	AQUATIC WETLAND COMPANY	45.6506	-110.5586	02N	09E	24	ACBD	4483	4483.0	10	5/20/2004 12:20	6.12	6.08	5.20	12.2	406	6.62	1
210845	KAPSNER, BRIAN	45.6363	-110.5656	02S	09E	23	BDBC	4502	4503.7	20	5/20/2004 16:00	7.62	7.65	3.15	13.3	272	6.85	-
210847	KAPSNER, BRIAN	45.6408	-110.5617	02S	09E	25	BAAA	4502	4502.0	13	5/20/2004 0:00	3.18	-	30.00	13.3	329	7.05	-
210974	FELLOWS WILL	45.8819	-110.6086	02N	09E	33	DBAA	4800	4801.3	50	5/25/2004 15:09	16.72	21.20	2.36	10.7	468	7.61	2
210979	KITTELMANN, LOLA	45.8814	-110.6086	02N	09E	33	DBAA	4829	4801.0	63	5/25/2004 15:55	29.83	29.85	3.44	10.3	418	7.64	1
211012	HARPER D JOE	45.7771	-110.5029	01S	10E	4	DADC	4517	4520.9	40	5/25/2004 16:50	22.24	-	-	11.6	369	7.44	1
211094	LATSCH, J. DAVID	45.6161	-110.5781	02S	09E	35	BADC	4535	4749.1	39	5/26/2004 14:45	16.80	20.10	8.00	17.8	492	7.45	-
211214	DONOVAN, CHUCK	45.6904	-110.5895	02S	09E	2	CBBD	4833	4834.5	-	8/11/2004 0:00	103.53	-	-	-	-	-	-
211216	DONOVAN, CHUCK	45.6928	-110.5722	02S	09E	2	ADDC	4686	4687.6	224	6/17/2004 13:40	49.60	-	-	-	-	-	-
211217	DONOVAN, CHUCK	45.6947	-110.5768	02S	09E	2	ACAA	4738	4739.0	254	6/17/2004 13:59	38.25	-	-	-	-	-	-
211219	DONOVAN, CHUCK	45.6976	-110.5670	02S	09E	1	BBAC	4691	4692.2	77	6/17/2004 14:20	22.70	22.90	1.10	9.9	529	6.96	<1
211221	DONOVAN, CHUCK	45.6986	-110.5766	02S	09E	2	ABAA	4840	4841.7	143	6/17/2004 15:03	61.88	68.90	75.00	9.4	212	6.96	<1
211227	HAUG, DAVID	45.6160	-110.6435	02S	09E	32	CDAB	5884	5884.0	162	6/17/2004 8:31	20.03	40.00	-	6.1	506	7.46	<1
211228	HAUG, DAVID	45.6859	-110.5584	02S	09E	1	DCCA	4561	4562.6	-	8/11/2004 13:55	92.80	-	-	-	-	-	-
211229	HAUG, DAVID	45.6892	-110.5551	02S	09E	1	DACB	4565	4566.6	276	6/17/2004 10:58	43.64	43.80	-	10.6	485	7.75	<1
211230	HAUG, DAVID	45.6854	-110.5574	02S	09E	1	DCDC	4562	4563.2	260	6/18/2004 11:55	82.10	-	-	-	-	-	-
211231	HAUG, DAVID	45.6960	-110.5642	02S	09E	1	BACC	4663	4664.1	245	6/18/2004 12:40	16.89	18.07	1.50	9.0	818	7.55	<1
211233	HURLEY JIM	45.6352	-110.5683	02S	09E	25	BCBD	4503	4502.7	28	6/16/2004 16:11	5.77	6.37	7.00	10.0	213	7.43	<1
211234	WINTER, RANDY	45.6239	-110.5888	02S	09E	35	BABA	4557	4558.8	62	6/16/2004 13:45	21.10	-	-	-	-	-	-
211305	ROSE, JIM	45.8522	-110.5319	01N	10E	7	BDDD	4955	4957.4	40	6/23/2004 11:12	9.30	11.30	7.89	9.7	308	7.93	<5
211531	SAGER SHARON	46.0228	-110.5678	03N	09E	11	DBDB	5345	5345.9	43	6/7/2004 15:03	18.35	19.50	1.57	8.9	504	6.96	3
211592	BOURQUE LA	45.8097	-110.4973	01N	10E	28	BCBD	4697	4699.4	216	6/24/2004 12:27	49.32	159.00	15.00	10.1	495	10.10	1
211595	GRAHM ELLEN	45.7724	-110.4977	01S	10E	9	ABBB	4504	4504.8	28	6/24/2004 10:15	4.35	5.25	15.00	8.1	427	6.96	1
211667	STEFAN TIM	45.8779	-110.6211	02N	09E	33	CCBA	4951	4953.5	275	6/8/2004 13:05	181.00	-	-	-	-	-	-
211806	PETERSON LIZ	45.8729	-110.6448	02N	09E	32	DDDD	5000	5001.8	173	5/10/2004 17:00	79.49	-	4.60	9.8	290	8.11	<1
211807	BRUCH CARRIE	45.6252	-110.6164	02S	09E	33	AABC	5015	5015.0	250	5/17/2004 14:00	92.10	-	-	10.0	620	6.88	<1
211817	THRIRY ANNE	45.7941	-110.5012	01N	10E	32	ADDA	4580	4581.3	77	5/19/2004 11:12	31.76	32.30	7.30	10.1	390	6.90	2
211828	DENHAM CLIFF	45.6036	-110.6069	03S	09E	3	CBDB	5660	-	266	5/11/2004 10:00	-	-	-	-	-	-	-
211972	BRAINERD SALLEY	45.7196	-110.4831	01S	10E	27	CBAA	4500	-	190	1/14/2004 0:00	-	-	-	13.1	528	8.17	<1
211976	FURSTENZER ROBERT	45.7013	-110.5198	01S	10E	32	CDAD	4470	4464.3	52	1/14/2003 12:00	26.39	-	-	12.3	380	8.18	-
211977	BROELL BOYD	45.9931	-110.7086	03N	08E	22	DADC	5126	5125.0	36	6/8/2004 12:14	18.05	-	4.20	8.1	458	7.74	3
212405	ADAMS MIKE	45.6518	-110.5914	02S	09E	23	BBBB	4605	4607.2	163	7/21/2004 16:00	67.50	93.50	7.50	11.1	505	-	<1
212406	HENDY BOB AND LINDA	45.7647	-110.4916	01S	10E	9	DABA	4497	4498.5	68	7/20/2004 10:05	8.70	23.00	7.50	10.0	443	-	<2
212408	QUESENBERRY BOB	45.6788	-110.5439	02S	10E	7	BDBD	4490	4490.6	75	7/21/2004 13:07	25.60	29.30	12.00	14.4	443	-	<2

Appendix A: Well Inventory

GWIC ID	Site name	Latitude	Longitude	Township	Range	Section	Tract	Ground elevation	Measured point elevation (ft)	Total depth (ft)	Date (dd/mm/yy)	Static water level from mp (ft)	Pumping water level (ft)	Yield (gpm)	Water temperature (C°)	Field SC (umhos/cm)	Field pH	Field test nitrate (mg/L N)
212409	POTENBERG, STEVE AND JAMIE	45.6498	-110.5671	02S	09E	24	BCAA	4510	4510.0	25	7/21/2004 11:30	19.15	20.15	4.00	14.4	482	-	<1
212413	OLSON, GERALD	46.0267	-110.5810	03N	09E	11	BCAC	5332	5332.1	172	6/7/2004 15:36	10.20	48.62	10.70	10.0	697	6.96	0
212414	LEE, MARY	45.8586	-110.6114	01N	09E	4	DCDA	4815	4817.0	71	6/9/2004 12:10	32.35	56.56	6.60	9.2	605	7.52	5
212952	DICK PETERSON	45.6455	-110.5794	02S	09E	23	DBCD	4535	4529.9	41	7/28/2004 0:00	18.00	14.00	6.00	13.5	348	7.70	<1
212953	PETERSON DICK	45.6459	-110.5787	02S	09E	23	DBDB	4535	4535.2	22	7/28/2004 11:00	15.00	15.15	1.50	12.6	437	6.95	<2
212956	LORD CORKY	45.7604	-110.5128	01S	10E	9	DDAC	4576	4576.9	90	7/28/2004 11:20	22.00	50.00	8.50	10.8	547	7.88	<1
212957	DARBY SHAWN	45.7686	-110.5173	01S	10E	8	ACAA	4680	4680.2	146	7/28/2004 12:12	62.52	64.80	14.28	11.1	336	8.20	<1
213215	PARKS ROGER	46.0166	-110.5267	03N	10E	18	ABAA	5640	5641.9	240	8/11/2004 12:50	63.88	73.84	-	11.5	691	8.21	2
213218	STARWIND RANCH #1	45.6217	-110.7433	02S	08E	33	ACBD	5668	5670.0	320	7/21/2004 11:45	34.30	-	6.15	9.1	989	-	<1
213219	HANSON, CARL	45.6334	-110.6763	02S	08E	25	DABD	5225	5226.8	39	7/20/2004 14:56	7.42	-	-	8.9	319	7.12	<1
213220	STARWIND RANCH #2	45.6177	-110.7474	02S	08E	33	CADB	5900	5901.3	450	7/21/2004 12:30	7.52	-	-	8.1	830	7.45	<1
213221	PFAHL, JASON	45.6413	-110.6861	02S	08E	25	BABA	5025	50526.3	62	7/22/2004 12:15	15.38	35.30	13.63	9.6	550	8.16	<1
213273	SOWELL DAVE	45.6690	-110.5834	02S	09E	14	BAAB	4650	4652.7	169	8/12/2004 11:55	72.10	150.60	-	12.0	446	7.63	<2
213478	GRAY KRIS	45.6411	-110.7323	02S	08E	27	BBBA	5410	5412.4	66	8/26/2004 14:13	33.50	34.40	6.38	8.9	342	-	<1
213482	MERGEN MARGRET	45.6989	-110.6757	02S	08E	1	AABA	5234	5234.9	80	8/26/2004 12:31	20.80	20.80	17.64	10.0	162	-	<1
213485	KAISER JOHN	45.6801	-110.5147	02S	10E	8	ABDC	4456	4458.5	56	8/25/2004 11:17	15.70	20.80	6.66	-	150	-	<1
213489	RG LUMBER CO	45.6881	-110.5122	02S	10E	5	DACD	4441	4443.2	16	8/26/2004 11:25	12.35	12.40	16.60	13.3	153	-	<1
213638	LARSON RUSSEL	45.9209	-110.5753	02N	09E	14	CACA	5220	5221.5	250	8/27/2004 11:22	102.29	134.60	15.00	10.6	370	6.98	2
217197	SCHARTZENBERGER SCOTT	45.6266	-110.6265	02S	09E	33	BBAA	5200	5200.8	400	3/8/2005 11:40	130.50	-	-	10.0	472	7.05	<1
217198	ALPINE SPRINGS RANCH (ROBERT CURRIE)	45.6581	-110.7928	02S	08E	18	CCAC	5520	5520.0	65	3/9/2005 10:41	34.80	-	-	8.4	339	7.04	<1
217199	ALPINE SPRINGS RANCH (ROBERT CURRIE)	45.6600	-110.7929	02S	08E	18	CCAB	5475	5474.1	125	3/9/2005 11:28	5.70	-	-	-	-	-	-
217208	HICKEY DALE	45.6786	-110.7921	02S	08E	7	BCDA	5920	5921.1	68	3/8/2005 13:20	53.00	-	-	7.1	348	7.90	<1
217213	SOPER ROY AND JOY	46.0089	-110.6586	03N	09E	18	DACD	5140	5141.5	268	3/9/2005 10:30	55.53	-	-	6.1	560	7.80	0
217214	MICKEN LORI	45.6622	-110.7653	02S	08E	17	DBBD	5510	5511.0	33	3/8/2005 9:55	15.03	-	-	9.4	314	7.77	<1
217509	SARGIS TOM	45.6563	-110.7585	02S	08E	17	DDBD	5270	5271.2	100	8/12/2004 12:30	31.96	-	-	10.1	461	7.36	<1
217514	KRONE HEROLD	45.6582	-110.7452	02S	08E	16	DCAD	5200	5201.0	85	8/12/2004 11:18	37.68	-	-	8.5	230	6.95	<1
221103	LOVELY WENDELL	45.9605	-110.6536	03N	09E	31	DCCC	5015	5017.0	100	8/16/2005 11:30	11.01	-	-	13.2	872	7.54	-
221108	WILSON DON	45.9195	-110.6184	02N	09E	16	CBDD	4859	4860.3	360	8/16/2005 11:55	36.00	-	-	-	446	8.35	-
221159	STANTON BILL	45.6284	-110.6058	02S	09E	27	CDBC	4731	4733.5	-	6/10/2004 0:00	0.00	-	-	10.5	316	6.96	2
221160	STANTON BILL(DAUGHTERS WELL)	45.6295	-110.5916	02S	09E	26	CCBC	4548	4549.4	66	6/10/2004 11:32	26.60	-	-	-	-	-	-
221232	NORTH FLESHMAN CREEK LLC	45.6737	-110.6003	02S	09E	10	DBCD	4780	4780.5	360	5/24/2005 12:25	99.40	-	-	12.0	317	9.26	-
221234	NORTH FLESHMAN CREEK LLC	45.6747	-110.6009	02S	09E	10	DBCB	4785	4786.0	420	5/24/2005 12:25	104.31	-	-	-	-	-	-
221243	NORTH FLESHMAN CREEK LLC	45.6807	-110.5919	02S	09E	10	ADAA	4741	4742.8	230	5/24/2005 13:00	47.10	-	-	-	-	-	-
221244	NORTH FLESHMAN CREEK LLC	45.6816	-110.5902	02S	09E	11	BBCB	4738	4739.5	340	5/24/2005 13:00	43.89	-	-	-	-	-	-

APPENDIX B

Stream Inventory

Appendix B: Stream inventory

Stream	GWIC ID	Station	Location (TRSq)	Latitude	Longitude	Date	Depth to Water (feet)	Flow (cfs)	Temp (C°)	pH	Conductivity (umhos/cm)	NO3 (mg/l)
Billman creek												
	222296	West of I-90 underpass	02S-09E-22-CBAB	45.6482	-110.6084	6/30/2004	3.63	2.5	16.7	8.25	366	<1
	222295	Cokedale road	02S-09E-17-CCAD	45.6583	-110.6511	6/29/2004	14.85	5.5	17	8.37	406	<1
						5/25/2005	--	10.3	9.1	--	370	<1
	214962	Miller road	02S-09E-26-ABCB	45.6394	-110.5798	5/11/2004	4.37	1.2	8.9	7.23	468	<1
						6/29/2004	3.85	10.4	16.7	6.95	433	<2
						10/13/2004	4.24	1.9	10.6	8.43	534	<1
						2/3/2005	--	1.7	--	--	--	--
						3/10/2005	--	2.2	6.6	8.49	476	--
						5/25/2005	--	19.6	10.1	--	359	<1
Miner Creek	236440	Mouth	02S-09E 17-CCAC	45.6580	-110.6505	2/3/2005	--	1.7	--	--	--	--
Fleshman creek												
	222293	9th street	02S-09E-24-BDAC	45.6509	-110.5629	5/11/2004	3.3	4.6	10.1	7.9	123	<1
						6/29/2004	3.2	14.2	17.5	8.36	112	<1
	222292	Highway	02S-09E-23-AADC	45.6528	-110.5713	5/25/2005	--	4.1	10.4	--	365	<1
						2/3/2005	--	2.5	--	--	--	--
	222291	Fleshman Creek Road on Dunn Property	02S-09E-16-ABAB	45.6698	-110.6198	6/30/2004	--	3.0	19.4	8.41	376	<1
	222290	Dunn House	02S-09E-6-DCBC	45.6867	-110.6624	6/30/2004	2	4.5	14.4	8.3	353	<1
						5/25/2005	--	10.4	7.2	--	225	<1
Livingston ditch												
	222289	Wineglass road	02S-09E-35-BBBA	45.6257	-110.5890	5/11/2004	1.77	47.8	9.7	7.91	124	<1
						6/29/2004	1.55	46.0	16.4	8.69	117	<1
		Ferry Creek crossing	01S-10E-31-DACA	45.7033	-110.5315	6/29/2004	--	9.2	--	--	--	--
Vallis Ditch												
	236439	Boulder Rd	02S-10E-8-ACCC	45.6767	-110.5195	6/29/2004	--	5.0	--	--	--	--
Fairy creek												
	222288	Willow creek road	01S-10E-31-ACCC	45.7081	-110.5386	5/11/2004	5.06	0.5	13.2	7.79	516	<1
						2/3/2005	--	0.7	--	--	--	--
Willow Creek												
	246437	Hwy	01N-10E-32-BBBD	45.7990	-110.5192	2/3/2005	--	3.6	--	--	--	--
Bangtail Creek												
	246436	Clyde Park Road	01N-09E 24-CACC	45.8177	-110.5530	2/3/2005	--	1.5	--	--	--	--
Canyon Creek												
	236435	Clyde Park Road	01N-09E-14-BBCA	45.8389	-110.5840	2/3/2005	--	2.8	--	--	--	--
Brackett creek												
	222287	Canyon creek road	01N-09E-5-BCCA	45.8648	-110.6456	7/1/2004	7.63	6.9	17.8	8.48	349	<1
	222277	Brackett Creek Road By South Side Of Road	01N-08E-2-AACB	45.8700	-110.6892	7/1/2004	--	2.7	15.5	8.47	343	<1
Shields river											--	--
	214961	Brackett creek road	02N-09E-33-BBAD	45.8855	-110.6181	10/13/2004	--	67.6	10.6	7.48	415	<1
						3/7/2005	--	47.1	3.9	8.63	453	--
Flathead Creek												
	236434	Horsefly Creek road	03N-09E-30-ABBC	45.9881	-110.6536	2/3/2005	--	18.0	--	--	--	--
Cottonwood Creek												
	236433	Hwy	02N-09E-28-DDDC	45.8878	-110.6043	2/3/2005	--	10.0	--	--	--	--

APPENDIX C

Stream Inventory

GWIC ID	Site Name	Location (TRSq)	Aquifer	Sample date	Lab pH	Lab SC (uS/cm)
Groundwater						
9950	MONTANA STATE HIGHWAY DEPT	01N-09E-24-BBBA	125FRUN (Fort Union)	04/27/00	7.25	433
12953	BOB SARRZIN	02N-09E-34-BABD	125FRUN (Fort Union)	09/22/93	7.54	519
78171	BOSTON ROSEMARY	02S-09E-33-DCBA	217MWRY (Colorado)	08/10/04	7.51	515
92295	AMES CRAIG	01S-10E-22-BDAD	125FRUN (Fort Union)	06/02/04	7.92	570
125664	WILSALL WATER DISTRICT *WELL #1	03N-08E-24-DBCA	211LVGS (Livingston)	04/27/00	7.55	446
135185	PRINTZ, JOHN	02S-09E-14-ADCC	211CKDL (Livingston)	08/10/04	7.43	921
140147	PALMER MIKE	02S-08E-17-CBDB	211BMCK (Livingston)	03/08/05	7.79	397
142864	SHIVER MARVIN L.	02S-09E-32-ABAA	211CODY (Colorado)	08/11/04	7.59	692
148802	DOUGLAS JIM AND LINDA	02S-09E-34-CDBB	211CLRD (Colorado)	03/08/05	7.49	698
151249	BUFFALO SPRINGS	02S-09E-27-CABB	211TPCK (Eagle)	08/10/04	7.63	736
153439	O'CONNOR FRANK & NASHAN JEFF	02S-08E-3-ACCA	125FRUN (Fort Union)	03/10/05	7.66	360
181733	MIKAELSEN BEN	02S-08E-7-BAAA	125FRUN (Fort Union)	03/09/05	7.35	282
184324	REECE PARKS	02S-08E-26-AABD	211TPCK (Eagle)	12/08/04	7.94	971
200577	SEMENIC RICHARD	01S-10E-32-AADB	211HPRS (Livingston)	08/11/04	8.51	324
205605	PENNY MIKE	03S-09E-3-BCAA	221ELLS (Madison)	08/11/04	7.52	2380
208390	HOLMQUIST JOHN	02S-09E-29-BBDD	211CKDL (Livingston)	03/08/05	7.41	687
210979	KITTELMANN, LOLA	02N-09E-33-DBAA	125FRUN (Fort Union)	12/08/04	8.06	557
211221	DONOVAN, CHUCK	02S-09E-2-ABAA	211BMCK (Livingston)	08/11/04	7.56	617
211592	BOURQUE LA	01N-10E-28-BCBD	125FRUN (Fort Union)	08/09/04	7.66	613
213215	PARKS ROGER	03N-10E-18-ABAA	125FRUN (Fort Union)	08/11/04	8.96	684
217197	SCHARTZENBERGER SCOTT	02S-09E-33-BBAA	211CODY (Colorado)	03/08/05	7.98	505
217208	HICKEY DALE	02S-08E-7-BCDA	125FRUN (Fort Union)	03/08/05	7.58	350
217213	SOPER ROY AND JOY	03N-09E-18-DACD	125FRUN (Fort Union)	03/09/05	7.94	544
212408	QUESENBERRY BOB	02S-10E-7-BDBD	211MRCK (Livingston)	08/10/04	7.52	455
92383	ROST JIM	01S-12E-22-ADBA	110ALVM	09/22/93	7.20	422
96972	CITY OF LIVINGSTON	02S-09E-13-DACA	110ALVM	05/16/02	7.73	431
96983	MT DEPT OF HWYS * LIVINGSTON SECT.	02S-09E-14-DDDB	110ALVM	05/15/02	7.32	533
97110	STRONG WILLIAM H.	02S-09E-25-CBBB	111ALVM	08/09/04	7.39	298
97144	E'DANNES MOBILE HOME PARK	02S-09E-26-ABDC	111ALVM	12/20/00	7.71	505
129979	PAYNE RICHARD	02S-09E-26-ACBD	110ALVM	09/22/93	7.62	438
211976	FURSTENZER ROBERT	01S-10E-32-CDAD	110ALVM	08/11/04	7.84	386
212409	POTENBERG, STEVE AND JAMIE	02S-09E-24-BCAA	110ALVM	08/10/04	7.41	440
Surface water						
207268	DUNN JOHN (JACK)	02S-09E-4ADBA		08/09/04	7.73	321
214961	SHIELDS RIVER @ BRACKET CREEK RD	02N-09E-33BBAD		10/13/04	8.20	445
214961	SHIELDS RIVER @ BRACKET CREEK RD	02N-09E-33BBAD		03/07/05	8.24	375
214962	BILLMAN CREEK @ MILLER	02S-09E-26ABCB		03/10/03	8.20	471
214962	BILLMAN CREEK @ MILLER	02S-09E-26ABCB		10/13/04	8.18	548

	Common ions (mg/L)												
GWIC ID	**(Ca)**	**(Cl)**	**(CO3)**	**(F)**	**(Fe)**	**(HCO3)**	**(K)**	**(Mg)**	**(Mn)**	**(Na)**	**(OPO4)**	**(SiO2)**	**(SO4)**
Groundwater													
9950	60.3	5.92	0.0	<.05	.041	241.6	1.36	9.87	<.005	23.6	<.05	10.7	31.0
12953	58.9	4.7	0.0	.40	<.003	341	1.0	13.1	<.002	52.8	-	13.9	24.6
78171	58.0	4.28	0.0	0.569	0.014	338.6	2.74	27.7	0.014	20.0	<0.05	13.1	14.6
92295	78.4	7.80	0.0	0.064	0.008	286.7	.901	15.1	<0.001	33.6	<0.05	12.4	55.5
125664	55.5	17.5	0.0	.124	<.025	209.8	.206	11.5	<.005	24.0	<.05	10.0	48.2
135185	125	71.8	0.0	0.497	0.015	289.4	0.625	18.1	<0.001	59.4	<0.05	16.3	147
140147	30.0	14.1	0.0	0.189	0.018	188.6	0.089	6.14	<0.001	46.1	0.236	11.1	31.3
142864	74.2	7.29	0.0	0.068	0.083	340.7	1.56	29.1	0.031	37.6	<0.05	10.3	110
148802	73.4	4.37	0.0	0.121	0.777	432.5	2.84	50.2	0.100	15.5	<0.05	13.2	41.9
151249	52.8	26.0	0.0	0.213	0.007	256.81	1.84	27.7	0.006	43.3	<0.05	10.5	96.0
153439	51.9	0.775	0.0	<0.05	0.016	214.2	0.263	9.81	<0.001	14.7	<0.05	6.93	16.8
181733	33.3	1.15	0.0	0.051	0.027	168.8	0.246	8.84	0.001	12.3	0.090	11.4	6.85
184324	60.7	10.3	0.0	0.165	0.125	476.6	2.85	36.7	0.032	113	<0.10	11.5	151
200577	6.66	6.00	6.24	0.477	<0.005	108.3	0.097	0.408	<0.001	56.1	<0.05	8.61	45.1
205605	420	11.8	0.0	0.593	<0.025	221.2	9.61	156	<0.005	20.5	<0.50	8.11	1555
208390	108	6.00	0.0	0.087	0.109	356.9	2.49	23.0	0.098	17.2	<0.05	11.4	84.7
210979	60.7	3.69	0.0	0.219	0.018	352.1	2.19	12.8	<0.001	43.0	<0.05	13.0	21.9
211221	77.3	7.00	0.0	0.065	0.048	328.5	0.48	15.5	<0.001	37.5	<0.05	9.93	56.0
211592	47.5	45.0	0.0	0.169	0.024	220.5	0.262	10.0	0.002	76.4	<0.05	7.82	73.7
213215	1.75	10.9	24.0	1.03	0.146	324.5	0.726	0.496	0.001	156	<0.05	6.33	33.0
217197	31.4	3.16	0.0	0.106	0.027	276.9	0.955	12.1	0.016	64.8	<0.05	9.44	38.0
217208	39.7	2.12	0.0	<0.05	0.019	209.1	0.139	10.6	<0.001	18.7	<0.05	9.02	14.7
217213	30.6	47.1	0.0	0.673	0.018	64.4	0.156	0.969	<0.001	77.0	<0.10	8.91	135
212408	55.3	7.67	0.0	0.473	<0.005	225.9	1.69	12.1	<0.001	21.7	<0.05	18.9	30.6
92383	52.9	10.3	0.0	.46	.005	213	3.1	12.5	<.002	20.4	<.15	23.4	38.3
96972	54.6	8.60	0.0	.488	.017	234.2	2.53	14.3	<.001	16.2	<.05	20.3	35.8
96983	66.6	10.2	0.0	.248	.017	302.6	1.35	13.0	<.001	31.2	<.05	15.2	40.4
97110	25.9	7.73	0.0	0.684	0.007	114.9	3.51	8.43	<0.001	16.6	<0.05	21.4	39.1
97144	59.1	5.78	0.0	.544	.014	192.8	3.04	18.7	<.001	10.8	<.05	22.1	84.5
129979	60.9	5.5	0.0	.64	<.003	193	3.0	18.8	<.002	10.9	<.15	22.7	83.8
211976	39.2	4.49	0.0	0.244	<0.005	212.1	0.958	6.93	<0.001	39.8	<0.05	15.1	20.6
212409	56.6	9.82	0.0	0.381	0.006	210.8	2.55	15.2	<0.001	14.5	<0.05	22.6	54.4
Surface water													
207268	36.3	1.19	0.0	0.106	0.014	161.04	0.125	8.11	0.018	17.4	<0.05	11.4	27.7
214961	58.1	4.45	0.0	0.128	0.014	245.0	1.36	13.0	0.011	26.8	<0.05	9.92	29.3
214961	48.7	4.59	0.0	0.108	0.019	205.7	1.69	10.1	0.013	18.9	<0.05	6.50	22.9
214962	60.7	19.1	0.0	0.170	0.021	246.4	1.48	14.4	0.009	25.3	<0.05	2.70	39.2
214962	71.4	16.3	0.0	0.153	0.292	270.8	2.80	17.5	0.020	29.5	<0.05	11.0	37.4

		Trace elements (µg/L)															
GWIC ID	**P Total Dissolved**	**(Ag)**	**(Al)**	**(As)**	**(B)**	**(Ba)**	**(Be)**	**(Br)**	**(Cd)**	**(Co)**	**(Cr)**	**(Cu)**	**(Li)**	**(Mo)**	**(Ni)**	**(Pb)**	**(Sb)**
Groundwater																	
9950	<.5	<1	<30	<1	31.5	52.0	<2	<50	<2	<2	2.17	<2	<25	<10	8.81	<2	<2
12953	-	<1	<30	<1	71	19.7	<2	<50	<2	<2	<2	<2	<6	<10	<2	<2	<2
78171	<0.05	-	75	<10	59.1	127	<2	69	<1	<2	<10	<5	40.9	<10	<2	<10	<10
92295	<0.05	<1	<30	<1	46.4	47.4	<2	<50	<1	<2	2.12	<2	5.47	<10	2.88	<2	<2
125664	<.5	<1	<30	<1	36.6	<2	<2	92	<2	<2	<2	<2	<25	<10	8.29	<2	<2
135185	<0.05	-	44.5	<10	111	6.09	<2	87	<1	<2	<10	11.0	23.9	<10	<2	<10	<10
140147	<0.05	<1	<10	<1	46.2	11.4	<2	<50	<1	<2	<2	48.6	12.6	<10	<2	<2	<2
142864	<0.05	-	54.6	<10	200	20.6	<2	<50	<1	<2	<10	<5	40.8	<10	<2	<10	<10
148802	<0.05	<1	<10	<1	58.0	65.9	<2	77	<1	<2	<2	<2	30.0	<10	<2	<2	<2
151249	<0.05	<1	<10	1.79	75.1	18.9	<2	310	<1	4.28	<2	<2	18.0	<10	4.68	3.17	<2
153439	<0.05	<1	<10	<1	<30	<2	<2	<50	<1	<2	<2	4.48	4.05	<10	<2	<2	<2
181733	<0.05	<1	<10	<1	<30	<2	<2	<50	<1	<2	<2	3.32	4.31	<10	<2	<2	<2
184324	<0.05	<1	<10	<1	122	48.6	<2	<100	<1	<2	2.83	<2	64.1	<10	<2	<2	<2
200577	<0.05	-	<30	<10	91.5	<2	<2	<50	<1	<2	<10	<5	17.8	<10	<2	<10	<10
205605	<0.25	-	291	<50	200	<10	<10	<500	<5	<10	<50	<25	116	<50	<10	<50	<50
208390	<0.05	<1	<10	<1	65.0	36.7	<2	<50	<1	<2	<2	<2	15.8	<10	<2	<2	<2
210979	<0.05	<1	<10	<1	82.2	25.9	<2	<50	<1	<2	2.31	3.88	2.59	<10	<2	<2	<2
211221	<0.05	-	52.9	<10	39.5	40.4	<2	<50	<1	<2	<10	5.85	12.9	<10	<2	<10	<10
211592	<0.05	-	51.7	<10	111	8.66	<2	59	<1	<2	<10	<5	28.2	<10	<2	<10	<10
213215	<0.05	-	<30	<10	87.2	112	<2	<50	<1	<2	<10	<5	43.2	<10	<2	<10	<10
217197	<0.05	<1	<10	<1	536	64.4	<2	<50	<1	<2	<2	<2	56.0	<10	<2	<2	<2
217208	<0.05	<1	<10	<1	<30	<2	<2	<50	<1	<2	<2	11.8	5.77	<10	<2	<2	<2
217213	<0.05	<1	<10	1.96	223	<2	<2	178	<1	<2	<2	<2	26.2	<10	<2	<2	<2
212408	<0.05	-	51.0	<10	177	32.3	<2	<50	<1	<2	<10	<5	29.6	<10	<2	<10	<10
92383	-	<1	<30	10.1	200	67.2	<2	<100	<2	<2	<2	<2	47	<10	<2	<2	<2
96972	<.05	<1	<30	10.1	197	59.7	<2	<50	<2	<2	<2	<2	30.8	<10	2.55	<2	<2
96983	<.05	<1	89.3	<1	69.6	69.7	<2	<50	<2	<2	<2	2.8	11.2	<10	2.64	<2	<2
97110	<0.05	-	50.3	20.3	316	39.6	<2	<50	<1	<2	<10	76.6	71.5	<10	<2	<10	<10
97144	<.05	<1	<30	5.45	125	43.2	<2	<50	<2	<2	5.58	3.75	35.6	<10	<2	<2	<2
129979	-	<1	<30	4.5	121	42.6	<2	<100	<2	<2	<2	10.2	28	<10	<2	<2	<2
211976	<0.05	-	45.0	<10	118	30.0	<2	<50	<1	<2	<10	<5	21.2	<10	<2	<10	<10
212409	<0.05	-	46.3	<10	133	60.2	<2	<50	<1	<2	<10	<5	26.7	<10	<2	<10	<10
Surface water																	
207268	<0.05		46.0	<10	<30	2.32	<2	<50	<1	4.17	<10	<5	7.31	<10	<2	<10	<10
214961	<0.05	<1	<10	<1	33.2	57.6	<2	71	<1	<2	<2	<2	4.69	<10	<2	<2	<2
214961	<0.05	<1	<10	<1	<30	49.2	<2	<50	<1	<2	<2	<2	3.89	<10	<2	<2	<2
214962	<0.05	<1	<10	<1	37.0	40.1	<2	<50	<1	<2	<2	<2	9.61	<10	<2	<2	<2
214962	0.051	<1	192	1.04	47.8	57.7	<2	<50	<1	<2	<2	<2	11.7	<10	<2	<2	<2

GWIC ID	(Se)	(Sr)	(Ti)	(V)	(Zn)	(Zr)	(Tl)	(U)
Groundwater								
9950	<1	450	<50	<5	4.37	<25	<5	-
12953	2.3	<6	<10	<5	<2	<20	-	-
78171	<15	262	<1	<10	120	<2	<20	-
92295	<1	681	<1	<5	12.5	<2	<5	1.39
125664	1.79	69.5	<50	<5	2.67	<25	<5	-
135185	<15	317	1.32	<10	48.0	<2	<20	-
140147	1.53	161	<1	<5	16.9	<2	<5	5.66
142864	<15	1746	<1	<10	14.3	<2	<20	-
148802	1.55	406	1.14	<5	32.4	<2	<5	0.572
151249	7.29	547	<1	<5	2.20	<2	<5	1.89
153439	<1	73.8	<1	<5	37.8	<2	<5	1.46
181733	<1	39.4	1.03	<5	52.2	<2	<5	0.729
184324	3.37	2763	<1	<5	2.26	<2	<5	<1
200577	<15	73.6	<1	<10	<2	<2	<20	-
205605	<75	9966	<5	<50	166	<10	<100	-
208390	<1	1105	1.64	<5	67.2	<2	<5	0.846
210979	<1	734	<1	<5	37.3	<2	<5	2.16
211221	<15	693	1.05	<10	22.0	<2	<20	-
211592	<15	733	<1	<10	47.6	<2	<20	-
213215	<15	418.7	<1	<10	<2	<2	<20	-
217197	<1	759	<1	<5	32.3	<2	<5	<1
217208	<1	22.9	<1	<5	6.34	<2	<5	1.87
217213	8.22	77.5	<1	<5	4.43	<2	<5	<1
212408	<15	321	<1	<10	17.1	<2	<20	-
92383	<1	272	<10	<5	<2	<20	-	-
96972	<1	306	<1	<5	2.10	<2	<5	1.15
96983	<1	227	<1	<5	8.26	<2	<5	3.36
97110	<15	195	<1	<10	23.6	<2	<20	-
97144	<1	393	<1	<5	11.3	<2	<5	-
129979	<1	368	<10	<5	<2	<20	-	-
211976	<15	444	<1	<10	6.83	<2	<20	-
212409	<15	359	<1	<10	34.8	<2	<20	-
Surface water								
207268	<15	119	1.06	<10	<2	<2	<20	
214961	<1	714	1.05	<5	<2	<2	<5	1.76
214961	<1	578	<1	<5	<2	<2	<5	1.44
214962	<1	347	1.03	<5	<2	<2	<5	2.27
214962	<1	396	6.64	<5	4.66	<2	<5	2.26

APPENDIX D

Nitrate Concentrations

GWIC ID	Site name	Location (TRSq)	Sample date	Nitrate+nitrite concentration (mg/L)
Wells				
9946	SHIPLET RANCH	01N-09E-11-BCCD	07/28/04	0.38
9950	MONTANA STATE HIGHWAY DEPT	01N-09E-24-BBBA	04/27/00	1.28
12880	KAUL DAN	02S-08E-17-DDCD	03/09/05	2.28
12953	BOB SARRZIN	02N-09E-34-BABD	09/22/93	1.23
14668	ZIMMERMAN CHARLES	03N-09E-8-DDAA	06/07/04	0.53
14674	TASHJIAN HANK, HENRY & KIM	03N-09E-18-ABBD	06/08/04	0.46
78171	BOSTON ROSEMARY	02S-09E-33-DCBA	08/10/04	<0.05
92295	AMES CRAIG	01S-10E-22-BDAD	06/02/04	<0.5
92383	ROST JIM	01S-12E-22-ADBA	09/22/93	1.09
96950	STARWINDS (FONDREN & COCHRAN) #3	02S-08E-33-DBCA	07/21/04	<0.05
96972	CITY OF LIVINGSTON	02S-09E-13-DACA	05/16/02	0.518
96983	MT DEPT OF HWYS * LIVINGSTON SECT.	02S-09E-14-DDDB	05/15/02	0.502
97006	MCCORMICK JERRY & ELIZABETH	02S-09E-23-CDAC	05/26/05	0.91
97034	VOYICH DAN	02S-09E-23-BADC	05/20/04	3.13
97110	STRONG WILLIAM H.	02S-09E-25-CBBB	08/09/04	0.143
97110	STRONG WILLIAM H.	02S-09E-25-CBBB	05/19/04	0.3
97144	E'DANNES MOBILE HOME PARK	02S-09E-26-ABDC	12/20/00	0.649
97203	PAYNE JIM	02S-09E-26-BDBA	05/19/04	0.68
125664	WILSALL WATER DISTRICT *WELL #1	03N-08E-24-DBCA	04/27/00	<.5
129979	PAYNE RICHARD	02S-09E-26-ACBD	09/22/93	0.6
135185	PRINTZ, JOHN	02S-09E-14-ADCC	08/10/04	5.39
135185	PRINTZ, JOHN	02S-09E-14-ADCC	05/26/05	5.69
140147	PALMER MIKE	02S-08E-17-CBDB	03/08/05	1.4
142864	SHIVER MARVIN L.	02S-09E-32-ABAA	08/11/04	<0.05
143008	ORENDORFF JOANN	01N-10E-28-BDAB	06/24/04	1.29
148802	DOUGLAS JIM AND LINDA	02S-09E-34-CDBB	03/08/05	<0.05
150529	CIERI CARLO	02S-10E-7-BBDC	07/19/04	6.99
151249	BUFFALO SPRINGS	02S-09E-27-CABB	08/10/04	1.48
151387	CARUSO R A & DONNA	02S-10E-7-BBBC	08/25/04	0.3
151713	GROVE JAMES B & MARILYN J	02S-08E-21-AACA	08/12/04	0.15
153439	O'CONNOR FRANK & NASHAN JEFF	02S-08E-3-ACCA	03/10/05	0.463
157308	MOORE TED	02S-09E-28-ABCA	08/17/05	4.06
157634	CARR RON	02N-09E-27-BCDC	08/25/04	0.38
162122	MILKOVICH TOM OR ANNE	01N-10E-18-BABC	06/23/04	1.04
165434	BUCKLEY RICHARD	02S-09E-29-ACDB	08/16/05	0.89
170497	FRIENDS FOR LIFE - HUMANE SOCIETY PARK COUNTY	02S-10E-5-DDCD	08/25/04	0.74
176192	MARTIN JEFF	02S-08E-25-ACAA	07/20/04	0.32
176978	CROSS DUANE	02S-09E-32-ADBA	03/08/05	1.07
181733	MIKAELSEN BEN	02S-08E-7-BAAA	03/09/05	0.75
184147	CROSTON EDWARD	02N-09E-28-ABCA	08/16/05	0.91
184324	REECE PARKS	02S-08E-26-AABD	12/08/04	<0.25
186852	CROSTON JOHN	02N-09E-28-ACAB	08/16/05	1.45
188869	ALVERSON DENNIS	02S-09E-28-AAAD	08/17/05	5.73
193442	HOWARD PATRICIA OR DANIEL	02S-09E-20-DDDA	08/16/05	1.15
195441	KELLN STEVE AND GRETCHEN	02S-09E-33-ABCB	05/26/05	<0.05
196469	GEE DARREL*WELL 2	03N-10E-19-ACBC	06/08/04	1
196495	HART PETE AND SALLY	02S-10E-6-DCAA	01/14/03	0.17
197035	LANGAAS MARLO	02S-08E-25-CDBB	07/20/04	0.11

GWIC ID	Site name	Location (TRSq)	Sample date	Nitrate+nitrite concentration (mg/L)
197811	YOUDAN KEITH	02S-09E-23-BADC	05/20/04	0.51
199404	AQUATIC DESIGN CONSTRUCTION	02S-09E-24-ACCB	05/20/04	0.53
200577	SEMENIC RICHARD	01S-10E-32-AADB	08/11/04	0.352
200577	SEMENIC RICHARD	01S-10E-32-AADB	07/27/04	0.32
203490	KAUL DAN	02S-09E-22-BCCB	03/09/05	0.09
205531	FOX JAMES AND MAXINE	02S-09E-26-DCBA	05/19/04	0.43
205605	PENNY MIKE	03S-09E-3-BCAA	08/11/04	<1.25
206135	DENTON KRIS	02N-09E-32-DCAD	08/17/05	0.23
207271	YOAKAM CHAD	02S-09E-26-ACCC	05/19/04	0.43
207274	SUVISON STACY	02S-09E-11-CADD	11/13/03	2.53
208028	BATES GEORGE	01S-10E-29-BCCC	07/27/04	0.58
208390	HOLMQUIST JOHN	02S-09E-29-BBDD	03/08/05	<0.10
208538	STANTON BILL #3	02S-09E-27-DDAA	06/10/04	1.11
208539	STANTON BILL #2	08S-09E-22-BADA	06/10/04	<0.05
210355	CHAPEL VIRGINIA AND LARRY	02S-10E-6-BDBD	05/19/04	0.08
210760	LARSON DEANNA	02N-11E-15-BACA	05/09/04	0.69
210838	AQUATIC WETLAND COMPANY	02N-09E-24-ACBD	05/20/04	3.92
210847	KAPSNER, BRIAN	02S-09E-25-BAAA	05/20/04	0.17
210974	FELLOWS WILL	02N-09E-33-DBAA	05/25/04	1.66
210979	KITTELMANN, LOLA	02N-09E-33-DBAA	12/08/04	1.8
210979	KITTELMANN, LOLA	02N-09E-33-DBAA	05/25/04	1.62
211012	HARPER D JOE	01S-10E-4-DADC	05/25/04	0.48
211094	LATSCH, J. DAVID	02S-09E-35-BADC	05/26/05	0.31
211217	DONOVAN CHUCK	02S-09E-2-ACAA	08/11/04	0.23
211221	DONOVAN, CHUCK	02S-09E-2-ABAA	08/11/04	0.117
211221	DONOVAN, CHUCK	02S-09E-2-ABAA	06/17/04	0.19
211229	HAUG, DAVID	02S-09E-1-DACB	06/17/04	0.21
211231	HAUG, DAVID	02S-09E-1-BACC	06/18/04	0.09
211233	HURLEY JIM	02S-09E-25-BCBD	06/16/04	0.24
211305	ROSE, JIM	01N-10E-7-BDDD	06/23/04	1.65
211531	SAGER SHARON	03N-09E-11-DBDB	06/08/04	2.6
211582	SARRAZIN JOE	01N-10E-18-DBDC	06/23/04	0.29
211587	SARRAZIN LEON	01N-10E-19-BADA	06/23/04	1.93
211592	BOURQUE LA	01N-10E-28-BCBD	08/09/04	2.68
211592	BOURQUE LA	01N-10E-28-BCBD	06/24/04	0.7
211595	GRAHM ELLEN	01S-10E-9-ABBB	06/24/04	0.2
211976	FURSTENZER ROBERT	01S-10E-32-CDAD	08/11/04	<0.05
211976	FURSTENZER ROBERT	01S-10E-32-CDAD	01/14/03	0.13
211977	BROELL BOYD	03N-08E-22-DADC	06/08/04	1.59
212405	ADAMS MIKE	02S-09E-23-BBBB	07/21/04	0.61
212406	HENDY BOB AND LINDA	01S-10E-9-DABA	07/20/04	<0.05
212408	QUESENBERRY BOB	02S-10E-7-BDBD	07/21/04	1.29
212409	POTENBERG, STEVE AND JAMIE	02S-09E-24-BCAA	08/10/04	0.874
212409	POTENBERG, STEVE AND JAMIE	02S-09E-24-BCAA	07/21/04	0.99
212413	OLSON, GERALD	03N-9E-11-BCAC	06/07/04	0.37
212414	LEE, MARY	01N-09E-4-DCDA	06/09/04	6.76
212953	PETERSON DICK	02S-09E-23-DBDB	07/29/04	1.62
212956	LORD CORKY	01S-10E-9-DDAC	07/28/04	<0.05
212957	DARBY SHAWN	01S-10E-8-ACAA	07/28/04	<0.05

GWIC ID	Site name	Location (TRSq)	Sample date	Nitrate+nitrite concentration (mg/L)
213215	PARKS ROGER	03N-10E-18-ABAA	08/11/04	0.325
213218	STARWIND RANCH #1	02S-08E-33-ACBD	07/21/04	0.08
213219	HANSON, CARL	02S-08E-25-DABD	07/20/04	<0.05
213220	STARWIND RANCH #2	02S-08E-33-CADB	07/21/04	<0.05
213221	PFAHL, JASON	02S-08E-25-BABA	07/22/04	<0.05
213273	SOWELL DAVE	02S-09E-14-BAAB	08/12/04	2.09
213478	GRAY KRIS	02S-08E-27-BBBA	08/26/04	0.19
213482	MERGEN MARGRET	02S-08E-1-AABA	08/26/04	0.29
213485	KAISER JOHN	02S-10E-8-ABDC	08/25/04	0.06
213489	RG LUMBER CO	02S-10E-5-DACD	08/26/04	0.54
213638	LARSON RUSSEL	02N-09E-14-CACA	08/27/04	1.21
217197	SCHARTZENBERGER SCOTT	02S-09E-33-BBAA	03/08/05	0.109
217198	ALPINE SPRINGS RANCH (ROBERT CURRIE)	02S-08E-18-CCAC	03/09/05	<0.05
217208	HICKEY DALE	02S-08E-7-BCDA	03/08/05	1.05
217213	SOPER ROY AND JOY	03N-09E-18-DACD	03/09/05	0.492
217214	MICKEN LORI	02S-08E-17-DBBD	03/08/05	0.207
217509	SARGIS TOM	02S-08E-17-DDBD	08/12/04	1.93
217514	KRONE HEROLD	02S-08E-16-DCAD	08/12/04	0.12
221103	LOVELY WENDELL	03N-09E-31-DCCC	08/17/05	1.06
221108	WILSON DON	02N-09E-16-CBDD	08/16/05	0.42
221159	STANTON BILL #1	02S-09E-27-CDBC	06/10/04	0.06
Streams				
214961	SHIELDS RIVER @ BRACKET CREEK RD	02N-09E-33-BBAD	10/13/04	0.194
214961	SHIELDS RIVER @ BRACKET CREEK RD	02N-09E-33-BBAD	03/07/05	0.159
214962	BILLMAN CREEK @ MILLER	02S-09E-26-ABBC	03/10/03	<0.05
214962	BILLMAN CREEK @ MILLER	02S-09E-26-ABBC	10/13/04	0.075
Springs				
207268	DUNN JOHN (JACK)	02S-09E-4-ADBA	08/09/04	0.197
211222	MEIGS RANCH SPRING #1	01S-09E-35-BABC	06/17/04	0.79

APPENDIX E

Isotope Results

GWIC ID	Site	Location	Date	$\delta\ ^{18}O$ (permil)	δ D (permil)	Tritium (TU)
Madison aquifer						
205605	PENNY MIKE	03S-09E-3-BCAA	8/11/2004	-18.24	-142.9	0.4
Colorado Group						
176978	CROSS DUANE	02S-09E-32-ADBA	3/8/2005	-17.47	-137.85	10.4
217197	SCHARTZENBERGER SCOTT	02S-09E-33-BBAA	8/10/2004	-17.33	-138.93	3.8
142864	SHIVER MARVIN L.	02S-09E-32-ABAA	8/11/2004	-17.25	-135.51	10.7
78171	BOSTON ROSEMARY	02S-09E-33-DCBA	8/10/2004	-16.95	-134.44	5.9
148802	DOUGLAS JIM AND LINDA	02S-09E-34-CDBB	3/8/2005	-15.05	-122.97	11.7
Livingston and Eagle Fm.						
12880	KAUL DAN	02S-08E-17-DDCD	3/9/2005	-18.52	-146.71	8.7
140147	PALMER MIKE	02S-08E-17-CBDB	3/8/2005	-17.9	-141.62	7.5
211221	DONOVAN, CHUCK	02S-08E-2-ABAA	8/11/2004	-17.26	-139.13	12
217214	MICKEN LORI	02S-08E-17-DBBD	3/8/2005	-	-142.7	8.7
217198	ALPINE SPRINGS RANCH (ROBERT CURRIE)	02S-08E-18-CCAC	3/9/2005	-	-125.08	8.4
208390	HOLMQUIST JOHN	02S-09E-29-BBDD	3/8/2005	-17.58	-141.28	4.1
184324	REECE PARKS	02S-08E-26-AABD	12/8/2004	-17.84	-140.03	7.6
207268	DUNN JOHN (JACK)	02S-09E-4-ADBA	8/9/2004	-17.47	-137.86	8.6
200577	SEMENIK MOLLIE	01S-10E-32-AADB	8/11/2004	-16.59	-134.62	2.4
217208	HICKEY DALE	02S-08E-7-BCDA	3/8/2005	-18.73	-143.77	14
153439	O'CONNOR FRANK & NASHAN JEFF	02S-08E-3-ACCA	3/10/2005	-18.62	-143.8	12.9
135185	PRINTZ, JOHN	02S-09E-14-ADCC	8/10/2005	-16.35	-135.09	7.8
151249	BUFFALO SPRINGS	02S-09E-27-CABB	8/10/2004	-15.76	-131.08	2.2
Fort Union Fm.						
181733	MIKAELSEN BEN	02S-08E-7-BAAA	3/9/2005	-18.89	-144.41	10.9
213215	PARKS ROGER	03N-10E-18-ABAA	8/11/2004	-18.78	-150.32	3.3
217213	SOPER ROY AND JOY	03N-09E-18-DACD	3/9/2005	-18.01	-142.78	2.6
210979	KITTELMANN, LOLA	02N-09E-33-DBAA	12/8/2004	-17.8	-135.61	11.8
211592	BOURQUE LA	01N-10E-28-BCBD	8/9/2004	-14.82	-124.29	14.2
Yellowstone alluvium						
203490	HANSON BRAD	02S-09E-22-BCCB	3/9/2005	-17.74	-142.78	9.7
97110	STRONG WILLIAM H.	02S-09E-25-CBBB	8/9/2005	-17.71	-128.26	10.2
211976	FURSTENZER ROBERT	01S-10E-32-CDAD	8/11/2004	-17.7	-139.34	10.3
212409	POTENBERG, STEVE AND JAMIE	02S-09E-24-BCAA	8/10/2004	-17.37	-136.3	10.2
212408	QUESENBERRY BOB	02S-10E-7-BDBD	8/10/2004	-17.36	-135.42	10.3

APPENDIX F

Aquifer Tests

The following are the results of the aquifer pumping test the MBMG conducted on three wells in October 2004 (Donovan Site). Also included is an analysis for an aquifer test conducted and measured by Rock Creek Drilling in June 2004.

Site Locations

The aquifer test sites are located roughly 1 to 2 mi north of Livingston in Park County, Montana. Locations of the specific wells are as follows (shown in figure 1; 'obs' refers to a well used to monitor drawdown in the aquifer):

- House Well (GWIC 176198) Township 02S, Range 09E, Section 2, tract ABAA
- Smith (OBS) Township 02S, Range 09E, Section 2, tract AACA
- Haug Well Township 02S, Range 09E, Section 1, tract BACC
- SE Well Township 02S, Range 09E, Section 1, tract DCDC
- Obs Well Township 02S, Range 09E, Section 1, tract DCCA
- SW Well Township 02S, Range 09E, Section 2, tract CBBD

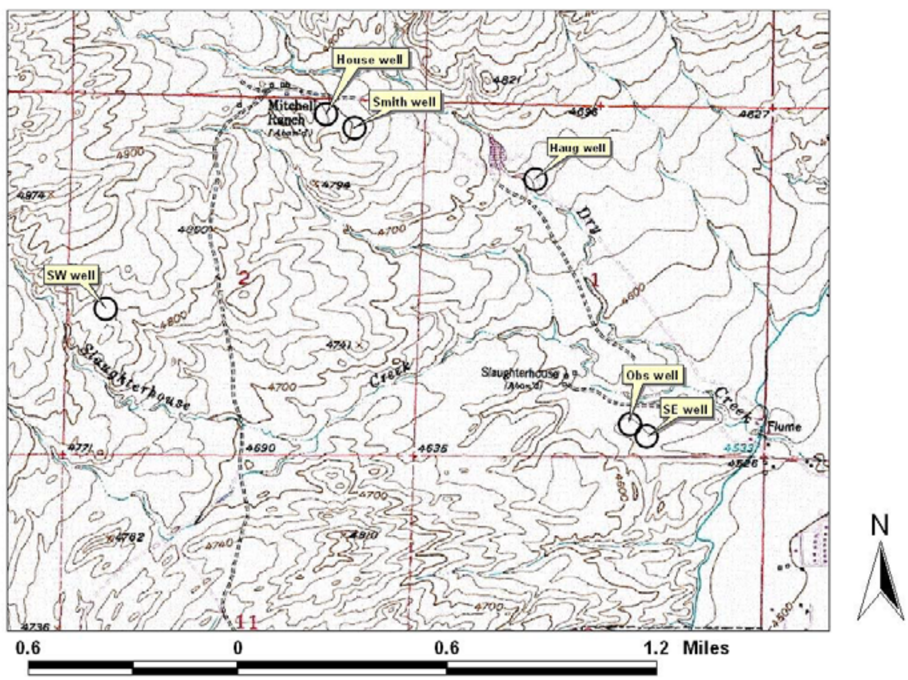


Figure 1: The test wells are located in sections 1 and 2 of Township 02S Range 09E.

Geologic Setting

All of Sections 1 and 2 are underlain by the Billman Creek Formation, which consists of shale and claystone interlayered with some sandstone (Roberts, 1972). Review of available well logs in and near this area indicates that shale or claystone accounts for 85 percent of the encountered lithology, with the remainder consisting of sandstone. The shale and claystone layers typically are a bluish color and are usually 20 to 40 ft thick, but can be up to 200 ft thick. Sandstone layers are typically a dusty-yellow-green, fine- to coarse-grained, and are typically 15 to 20 ft thick (Roberts, 1972). The outcrop patterns in the area have been identified through analyses of topography and aerial photographs. Sandstone outcrops form ridges in the area and the softer and more erodible shale and mudstones form valleys and hills (fig. 2). These rock layers generally dip 200 to 300 ft down per every 1,000 ft towards the north (Berg and others, 2000). They are further deformed by a series of north–south-trending folds (fig. 2).

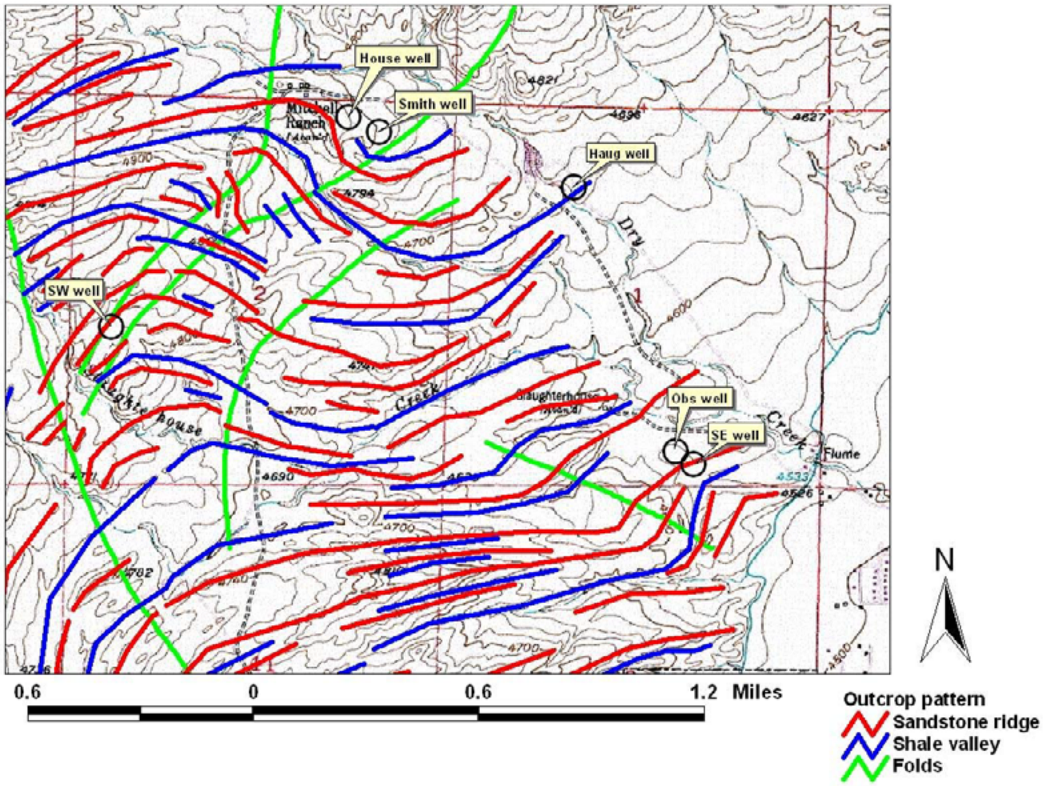


Figure 2: Topographic analyses and aerial photo interpretation show the outcrop pattern of sandstone (ridge forming) and shale (valley forming) units.

Hydrologic Setting

Groundwater yields from the Billman Creek Formation will be dependent on the location of the well completion screen within the targeted bedrock aquifer. The best yielding wells are perforated in coarse-grained sandstone whereas wells completed in fine-grained sandstones, claystone, or shale are lower yielding. Because the rock units encountered during drilling will usually crop out a few hundred feet south of the well location, it could be possible to identify target sandstone units prior to drilling. In general, yields will be higher slightly north of the ridges and lower north of valleys or hills. Another consideration is fracturing. Rocks near folds tend to be more fractured and can provide greater water production. The SW Well is located along a fold.

Recharge to the Billman Creek Formation likely occurs where the formation crops out near the Bridger Mountains (about 15 to 20 mi to the west or northwest). Groundwater flow patterns in the Billman Creek area will generally flow parallel to the outcrop pattern, which is to the southeast or east (fig. 2). Groundwater flow takes the path of least resistance and water flows easier through the sandstone layers than through shale layers. The groundwater in the pump test study area likely discharges to the east into Dry Creek, Ferry Creek, or the Yellowstone River.

Test Descriptions

Aquifer pumping tests were completed by the MBMG at the House Well, Haug Well, and SW Well. Groundwater from the House Well was withdrawn using an existing 3-horsepower pump. The other two sites used a temporary 3-horsepower pump that was supplied by the MBMG. Drawdown was monitored using a Campbell CST 3/8 recorder and a 20 PSI vented transducer. During the tests, manual measurements were made to confirm the data logger accuracy using an electronic water level tape. Data from an aquifer pumping test of the SE Well was collected by Rock Creek Drilling during a test in June 2004. Data from this test correlates well with aquifer tests performed by the MBMG.

The House Well

The House Well is competed with 4.5-in PVC pipe to a depth of 143 ft. The bottom 40 ft is perforated with 0.25-in slots; however, only 29 ft of the perforations are within sandstone. The remaining perforated interval is within shale layers and is not included in the penetrated aquifer thickness (table 1). The well was pumped at a rate of 49 gallons per minute (gpm) from 6:00 pm October 11, 2004 until 8:45 am October 12, 2004. The rate was limited by the capacity of the pump at that depth. Maximum drawdown for the pumping well was 9.74 ft out of a total water column of 77 ft. Drawdown was also monitored at the Smith domestic well located 600 ft to the southeast. No measurable drawdown was observed in this well. Review of the well log indicates that this well was not completed in sandstone and therefore not in the same unit as the House Well. A recovery test was conducted at the House Well for 350 min after the aquifer pumping test was terminated.

The Haug Well

The Haug Well is completed with 4.5-in PVC pipe to a depth of 235 ft. The perforated interval is not specified on the well log but, according to the land owner, it likely has 40 ft of perforations. This well did not penetrate sandstone layers and represents a shale unit. The well was pumped at a rate of 23 gpm from 5:25 pm October 12, 2004 to 9:37 am October 13, 2004. The pumping rate was limited by the PSI range of the transducer (drawdown of 40 ft). At this pumping rate, maximum drawdown was 39 ft out of a total water column of 217 ft. A recovery test was conducted at this well for 64 min after the pumping test was terminated.

The SW Well

The SW well is completed with 4.5-in PVC pipe to a depth of 265 ft with the lower 140 ft perforated with 1/8-in by 6-in slots. The perforated interval penetrates three sandstone layers with a combined thickness of 63 ft. The static water level before the test was 103.52 ft below the top of the surface casing. The well was pumped from 1:09 pm to 6:07 pm on October 13, 2004 at a rate of 57 gpm. This rate was the maximum capacity of the pump. Maximum drawdown at this rate was 19.2 ft out of a total water column of 162 ft. A recovery test was conducted at this well for 254 min after the pumping test was terminated.

Data Analyses

The specific capacities of the wells were calculated from the pumping and drawdown data. This value is the well yield per unit foot of drawdown (gpm/ft). Specific capacities in the tested wells (table 1) ranges from 3 to 5 gpm/ft in wells penetrating sandstone and 0.5 gpm/ft in the Haug Well, which was perforated in shale. Specific capacity is influenced by formation properties, well construction, and pump turbulence. The 4.5-inPVC casing was slightly bigger than the pump. Consequently, the restriction and added turbulence caused significant well head loss and the reduced intake area from saw slotted perforations also limited the well performance.

Because drawdown in the pumping well is influenced by well and pump factors, it is generally not useful in evaluating aquifer properties. Therefore, the focus was on the recovery data, which provides more representative data on the aquifer. The plotted recovery water levels demonstrate two distinct curves, a rapid water-level rise in the first 1 to 2 min; as the well equilibrates with the surrounding formation and a slower long-term rise, which is the formation recovery.

The Cooper-Jacob method (Cooper and Jacob, 1946) was used for analyses of recovery data. This method calculates the transmissivity using the slope of the recovery data versus the log plot of pumping time divided by recovery time. The results are presented in table 1. All three wells that were completed in sandstone appear to be capable of high water yields (possibly 100 gpm). The well completed in shale should also have sufficient production for domestic purposes.

Table 1
Test Results

Test	Specific capacity (gpm/ft)	Transmissivity (ft^2/day)	Hydraulic conductivity (ft/day)	Aquifer penetrated thickness (ft)
House well	5.0	6,000	210	29
Haug well	0.5	180	4.5	40
SW well	3.0	3,700	58	63
SE well	4.2	4,800 5,200 (obs)	69 75 (obs)	70

The following are the results of two aquifer tests conducted by the Rocky Mountain Engineers with assistance from the Montana Bureau of Mines and Geology (MBMG). The aquifer test date was May 24th–27th 2005 located at Meredith Ranch area north of Livingston, Montana.

Well Location and Construction
The aquifer test sites are located roughly 1 to 2 minorth of Livingston in Park County, Montana. Locations of the specific wells are as follows (shown in figure 1):

- PW-1 Lat: 45.67352, Long: 110.60116, T2S, R9E, Sec 10 DCBA
- MW-1 Lat: 45.67463, Long: 110.60170, T2S, R9E, Sec 10 DBCD
- PW-2 Lat: 45.68060, Long: 110.59273, T2S, R9E, Sec 10 AADA
- MW-2 Lat: 45.68146, Long: 110.59105, T2S, R9E, Sec 11 BBCB

All 4 wells were drilled by Rock Creek Drilling and were constructed with 6 1/8-inch surface casing with the remainder of the well completed with 4 ½-in PVC pipe. The bottom 200 to 300 ft of each well was perforated with 1/8-in by 4-insaw cut slots. The number of slots was not specified by the driller.

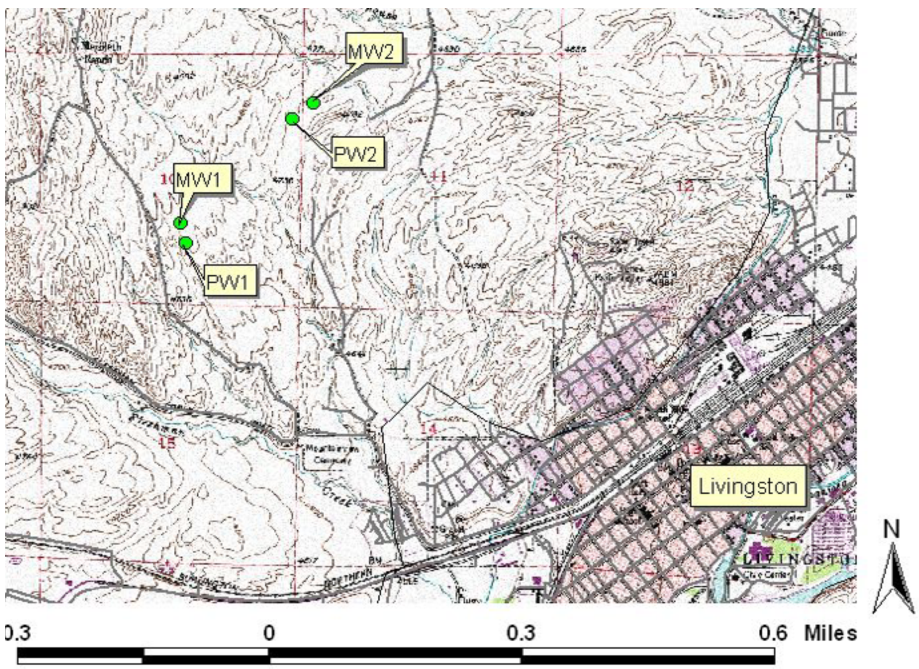


Figure 1: The test wells are located in sections 10 and 11 of Township 02S Range 09E.

Hydrogeologic Setting
All four wells are completed in the Billman Creek Formation which consists of shale and claystone interlayered with some sandstone (Roberts, 1972). Review of available well logs in and near this area indicates shale or claystone accounts for 85 percent of the encountered litholgy with the remainder consisting of sandstone. The shale and claystone layers typically are a bluish color and are usually 20 to 40 ft thick, but can be up to 200 ft thick. Sandstone layers are typically a dusky-yellow-green (Roberts, 1972) fine- to course-grained, and are typically 15 to 20 ft thick. Sandstone is much more permeable than shale and so the sandstone layers form the aquifer. The sandstone intervals were considered part of the aquifer thickness while the shale layers typically impede water movement and are poor yielding.

Review of the driller's well logs indicates the following perforated zones:

- PW-1, perforations 120 to 360 ft, encountered 3 sandstone layers with a combined thickness of 129 ft.
- MW-1, perforations 120 to 420 ft, encountered 3 sandstone layers with a combined thickness of 215 ft.
- PW-2, perforations 100 to 280 ft, encountered 2 sandstone layers with a combined thickness of 105 ft.
- MW-2, perforations 100 t0 340 ft, encountered 1 sandstone layer with a combined thickness of 130 ft.

The rocks in the area dip about 400 to 600 ft per 1,000-ft distance (26-37 degrees) to the west or northwest (Berg, 2000). Consequently, lithologic units encountered in each well crop out and become discontinuous within less than 1,000 ft east to southeast of the well.

Test Descriptions

Aquifer tests were completed at PW-1 on May 24th 2005 and at PW-2 on May 25th. A 10-HP pump for the tests was set and operated by Red Tiger Inc. Drawdown was monitored in MW-1 (for the test at PW-1) and at MW-2 (for the test at PW-2) using a Campbell CST 3/8 recorder and a 20 PSI un-vented transducer. During the tests manual measurements (using an electronic water-level tape) confirmed the data logger data. Manual water-level measurements were also collected in the pumping well during recovery. During the test at PW-1 background groundwater levels were collected using an un-vented *in situ mini-troll* probe. Barometric data were collected during both tests with an *in situ barotrol*.

<u>Test at PW-1</u>

Well PW-1 was pumped at an average rate of 29 gallons per minute (gpm) from 1:30 PM May 24th to 1:50 PM May 25th during which, 42,300 gallons of water were extracted. At this rate, the maximum drawdown in the pumping well was about 223 ft (estimated from the air-bubble pressure). The specific capacity of the pumping well (pumping rate divided by drawdown) was 0.13 gpm/ft. Maximum drawdown in MW-1, located 435 ft away was about 9 ft. The water level in well PW-1 recovered to within 90 percent of the static level within about 5 hours and within 99 percent of static level in about 2 days. Well MW-1 required 2 days for 90 percent recovery and about 3 days for 99 percent recovery.

<u>Test at PW-2</u>

Well PW-2 was pumped at an average rate of 33 gpm from 5:54 PM May 25th to 6:26 PM May 26th extracting 48,080 gallons of water. At this rate, the maximum drawdown in PW-2 was 97 ft. The specific capacity of well PW-2 was 0.37 gpm/ft. Maximum drawdown in MW-2, located 542 ft away, was about 4 ft. After 41 hours of recovery, both well MW-2 and PW-2 were about 3 ft below the original groundwater level (25 percent and 97 percent recovery, respectively).

<u>Barometric monitoring</u>

The barometric pressure was automatically measured and recorded every hour from about 1:00 PM May 25th 2005 to 11:00 AM May 28th 2005. The pressure measurements were converted to the equivalent units used by the pressure transducers (feet of water). During this time, the barometric pressure varied by 0.45 ft of water. The barometric pressure changes were used to make minor corrections to the un-vented water-level probe data.

<u>Background groundwater level monitoring</u>

During the pumping and recovery tests at PW-1, groundwater levels were also monitored at well MW-2 (about ½ mi away from the pumping well). The groundwater level dropped a negligible 0.04 ft between 12:42 PM May 24th, 2005 and 2:54 PM May 26th 2005. Background groundwater levels were not measured during the PW-2 test but they are assumed to be similarly static.

Definitions of Aquifer Property Terms

Aquifer pumping tests are conducted to evaluate the transmissivity, hydraulic conductivity, and storage of an aquifer. Transmissivity represents the ability of a formation to move water through it. It is expressed in terms of flow per foot across an aquifer (cubic feet per day per foot or ft^2/d) under a unit gradient. The hydraulic conductivity is the transmissivity divided by the aquifer's saturated thickness. The hydraulic conductivity is used to estimate groundwater flow velocity. Storage is the change of water volume per cubic foot of aquifer. In unconfined (un-pressurized) aquifers, storage is the volume of water that is drained from the pore spaces of the aquifer. In a confined (pressurized) aquifer, the storage is the change in water volume through compression and decompression. Storage in a confined aquifer is much lower than in an unconfined aquifer.

Data Analyses

The data from the pumping phase of the test were evaluated by the Cooper–Jacob time-drawdown method. By this method, drawdown is plotted on a linear Y-axis and time is plotted on a logarithmic X-axis. The straight-line slope through the data points is related to the aquifer transmissivity and the 0-drawdown intercept is related to aquifer storage. A plot of this data (Attachment A) shows that after about 500 min in MW-1 and after 100 min in MW-2, the drawdown departs from the straight-line trend and becomes greater than predicted by the transmissivity. This is likely caused by an aquifer discontinuity (aquifer boundary). The straight line was therefore fitted to the early data.

Recovery data were evaluated by the Theis recovery method. This is similar to the Cooper–Jacob method only residual drawdown is plotted on the Y-axis and the ratio of total time (since the start of pumping, t) and recovery time (t') is plotted on the X-axis. The ratio of t/t' becomes 1 at infinity. The data from PW-1 and MW-1 demonstrate a straight line trend with complete recovery before a t/t'of 1 (infinity). However, the data from PW-2 and MW-2 demonstrate incomplete recovery before t/t'= 1 (complete recovery will not occur without recharge). These data indicate that the penetrated sandstone units in this area are of limited extent and are only partially connected to the regional aquifer.

Table 1
Test Results

Test	Well	Transmissivity (ft^2/day)	Hydraulic conductivity (ft/day)	Storage	Average aquifer thickness (ft)
PW-1 pumping	PW-1 MW-1	-- 293	-- 1.2	-- 0.000026	172
PW-1 recovery	PW-1 MW-1	40 158	0.2 0.9	Complete Recovery	172
PW-2 pumping	PW-2 MW-2	-- 3,090	-- 26	-- 0.000062	118
PW-2 recovery	4.2	455 1,130	3.9 9.5	Incomplete Recovery	118

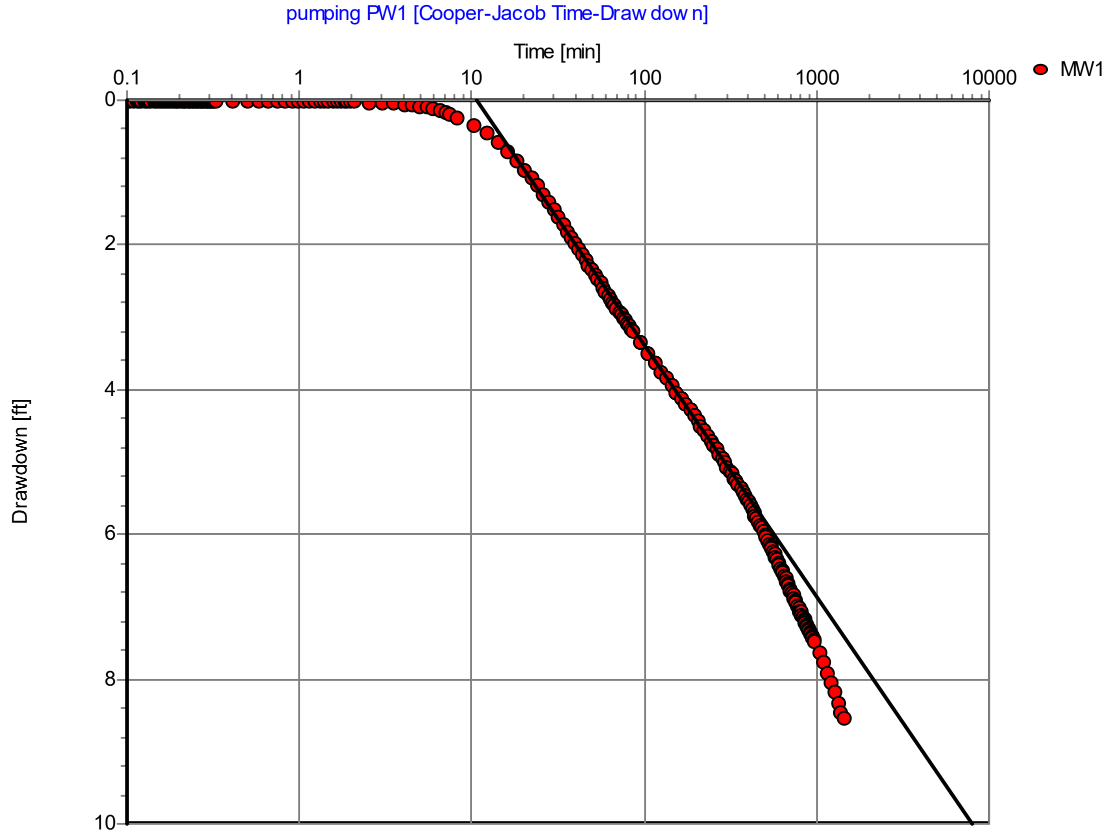
Conclusions

The data in table 1 indicate a range of hydraulic conductivity of 0.2 to 26 ft per day. The expected range for sandstone is 1 to 6 ft per day (Todd, 1980). The low storage numbers are typical of a confined aquifer. Drawdown versus time plots for both sites demonstrates the likely presence of aquifer boundaries and discontinuities. This most likely occurs to the east or northeast where the sandstone layers observed in the well intersect the land surface. It may also indicate that the sandstone layers are lenticular and pinch out laterally.

Aquifer tests previously completed by the MBMG in the same formation about ¼ mi to 2 mi away demonstrated considerably higher transmissivities and complete recoveries were observed in all cases. This would suggest that the aquifer properties in the formation are highly variable and are dependent on the continuity and properties of the individual encountered sandstone layers.

The pump tests at PW-1 and PW-2 indicate that the wells are capable of about 30 gpm which should be sufficient for most household uses. The water-level response data demonstrate that pumping drawdown can occur in surrounding wells. Therefore, ideal distances between wells would be greater than 500 ft apart and ideal lot sizes would be 10 acres or more to avoid well interference. Because of the variability of the aquifer material, some wells will be much more productive than others and some wells may have to penetrate deeper to find more productive sandstone layers.

MBMG	Pumping Test Analysis Report
1300 N 27th St	Project: Merideth2
Billings MT	Number:
406-373-5251	Client:



Pumping Test: **pumping PW1**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	2.93E+2 [ft²/d]	Conductivity:	1.70E+0 [ft/d]
	Storativity:	2.61E-5		

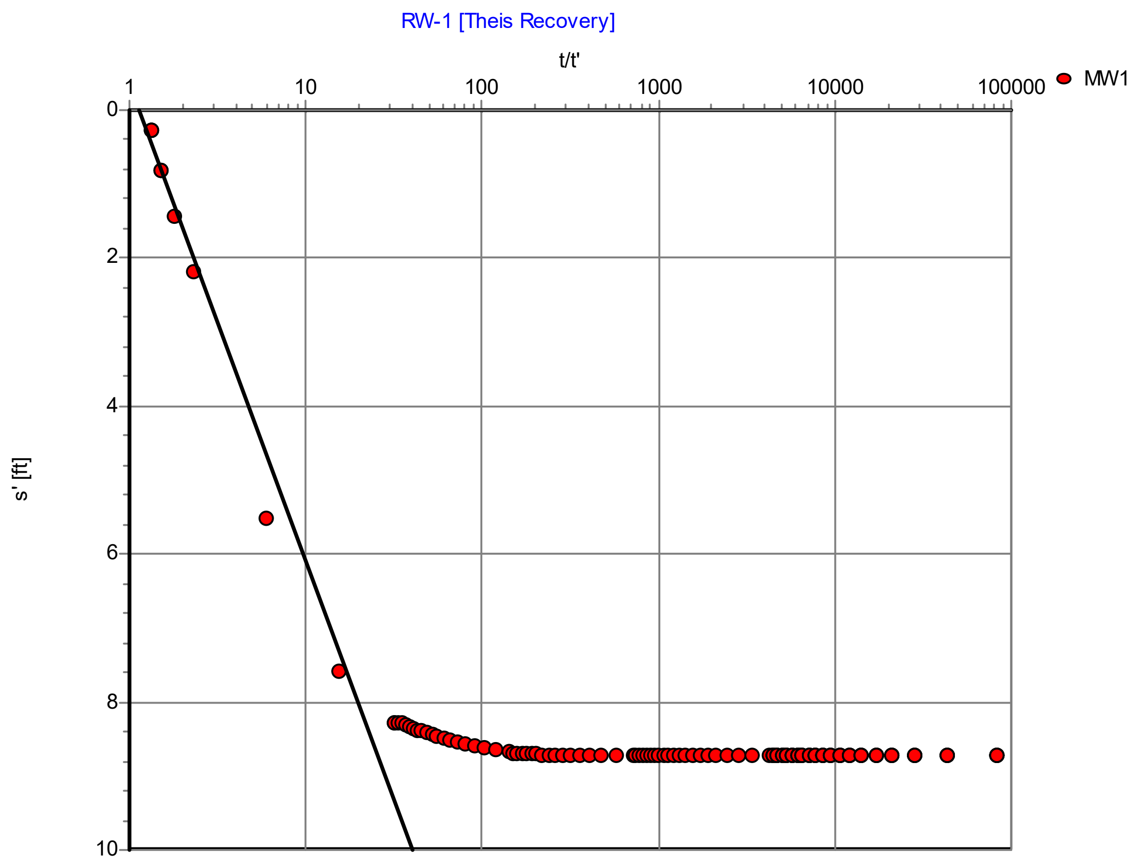
Test parameters:	Pumping Well:	PW1	Aquifer Thickness:	172 [ft]
	Casing radius:	0.38 [ft]	Confined Aquifer	
	Screen length:	215 [ft]		
	Boring radius:	0.38 [ft]		
	Discharge Rate:	29 [U.S. gal/min]		

Comments:

Evaluated by:

Evaluation Date: 6/13/2005

MBMG 1300 N 27th St Billings MT 406-373-5251	**Pumping Test Analysis Report**
	Project: Merideth2
	Number:
	Client:



Pumping Test: **RW-1**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	1.58E+2 [ft²/d]	Conductivity:	9.20E-1 [ft/d]

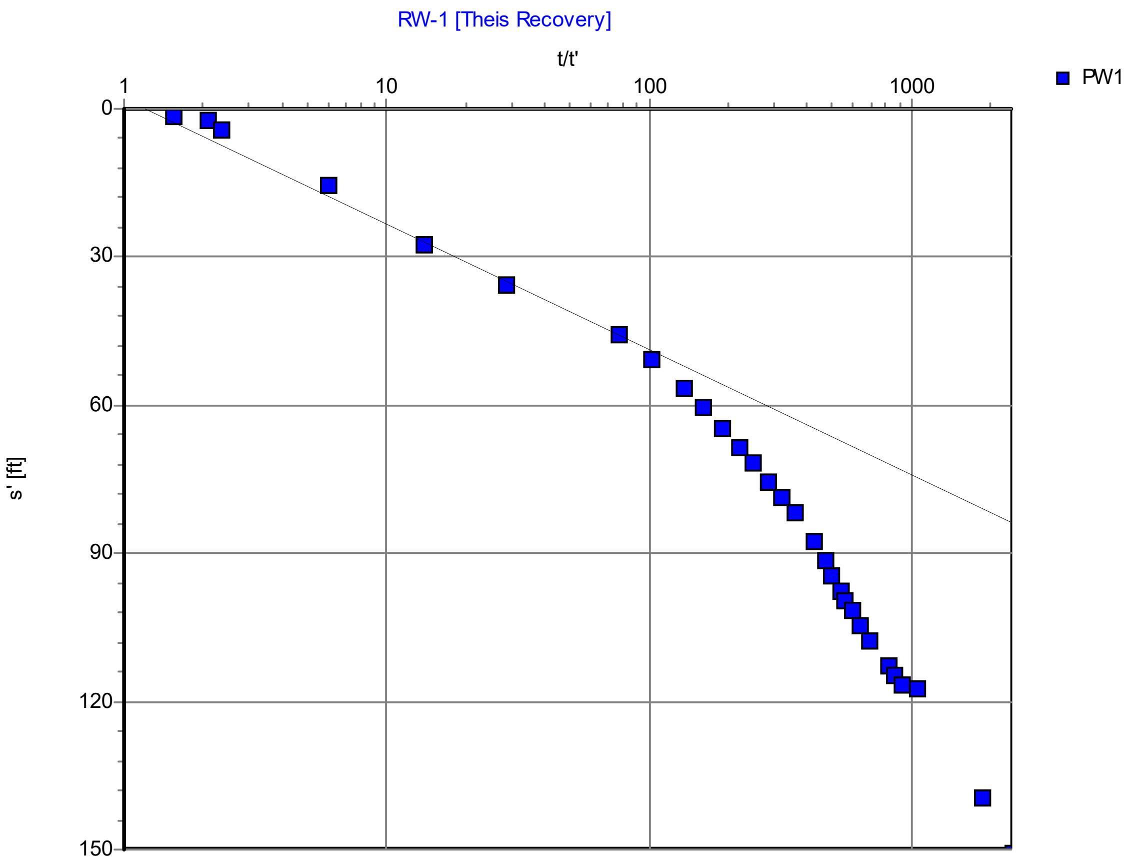
Test parameters:	Pumping Well:	PW1	Aquifer Thickness:	172 [ft]
	Casing radius:	0.38 [ft]	Confined Aquifer	
	Screen length:	215 [ft]		
	Boring radius:	0.38 [ft]		
	Discharge Rate:	29 [U.S. gal/min]		
	Pumping Time	1440 [min]		

Comments:

Evaluated by:

Evaluation Date: 6/13/2005

MBMG	**Pumping Test Analysis Report**
1300 N 27th St	Project: Merideth2
Billings MT	Number:
406-373-5251	Client:



Pumping Test: **RW-1**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	4.03E+1 [ft²/d]	Conductivity:	2.34E-1 [ft/d]

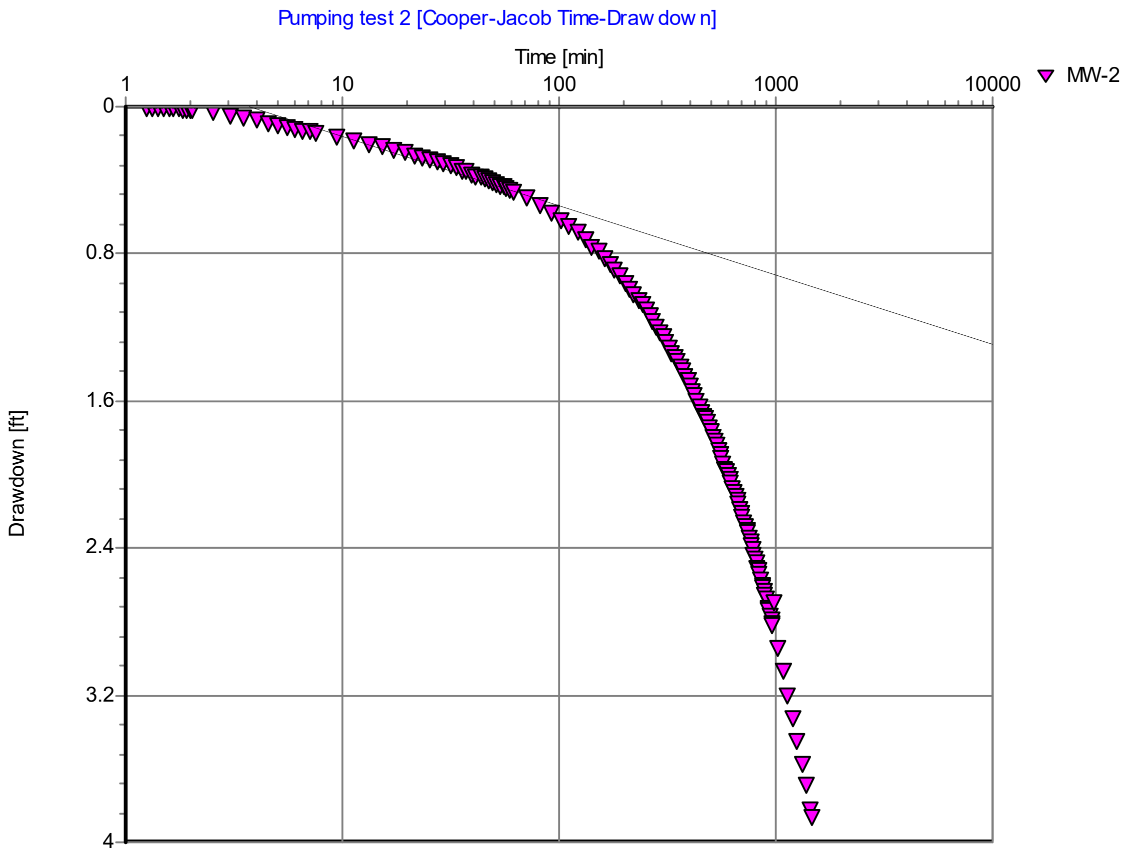
Test parameters:	Pumping Well:	PW1	Aquifer Thickness:	172 [ft]
	Casing radius:	0.38 [ft]	Confined Aquifer	
	Screen length:	215 [ft]		
	Boring radius:	0.38 [ft]		
	Discharge Rate:	29 [U.S. gal/min]		
	Pumping Time	1459 [min]		

Comments:

Evaluated by:

Evaluation Date: 6/13/2005

MBMG 1300 N 27th St Billings MT 406-373-5251	**Pumping Test Analysis Report** Project: Merideth2 Number: Client:



Pumping Test: **Pumping test 2**

Analysis Method: **Cooper-Jacob Time-Drawdown**

Analysis Results:	Transmissivity:	3.09E+3 [ft²/d]	Conductivity:	2.62E+1 [ft/d]
	Storativity:	6.15E-5		

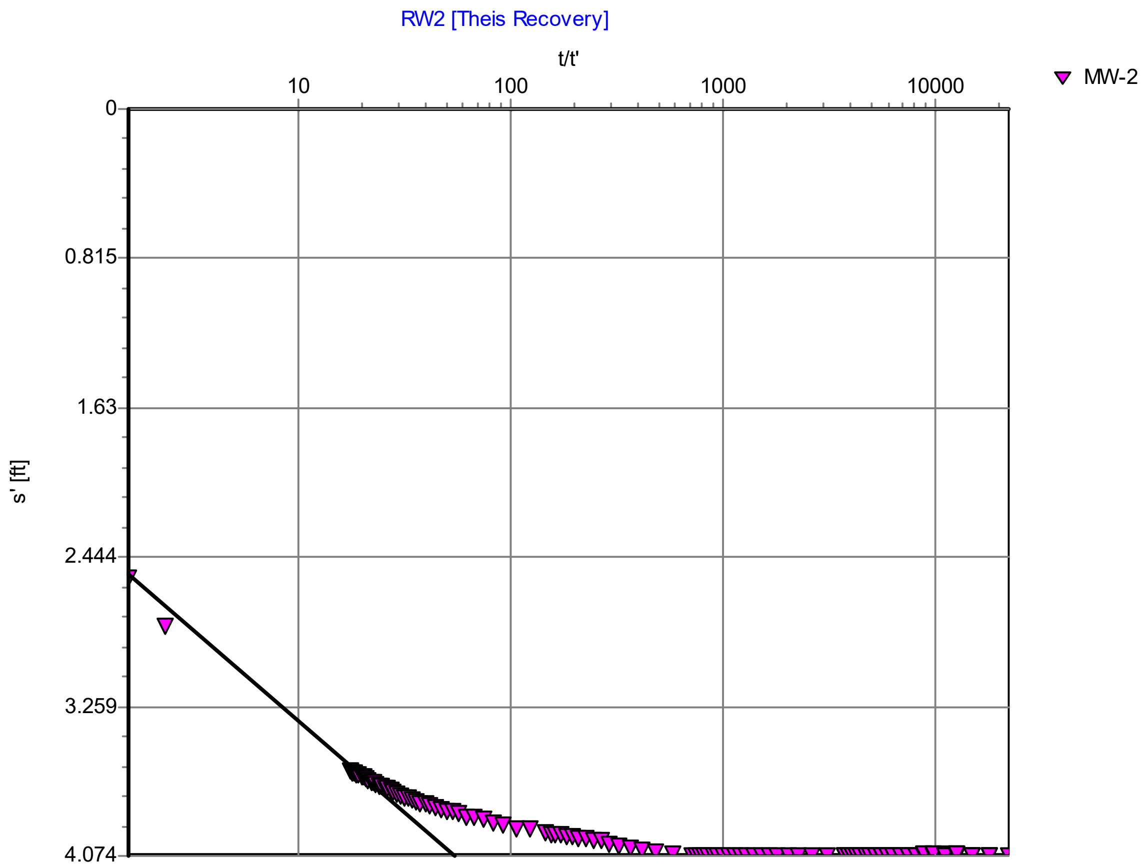
Test parameters:	Pumping Well:	PW2	Aquifer Thickness:	118 [ft]
	Casing radius:	0.35 [ft]	Confined Aquifer	
	Screen length:	165 [ft]		
	Boring radius:	0.35 [ft]		
	Discharge Rate:	33 [U.S. gal/min]		

Comments:

Evaluated by:

Evaluation Date: 6/14/2005

MBMG	**Pumping Test Analysis Report**
1300 N 27th St	Project: Merideth2
Billings MT	Number:
406-373-5251	Client:



Pumping Test: **RW2**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	1.13E+3 [ft²/d]	Conductivity:	9.55E+0 [ft/d]

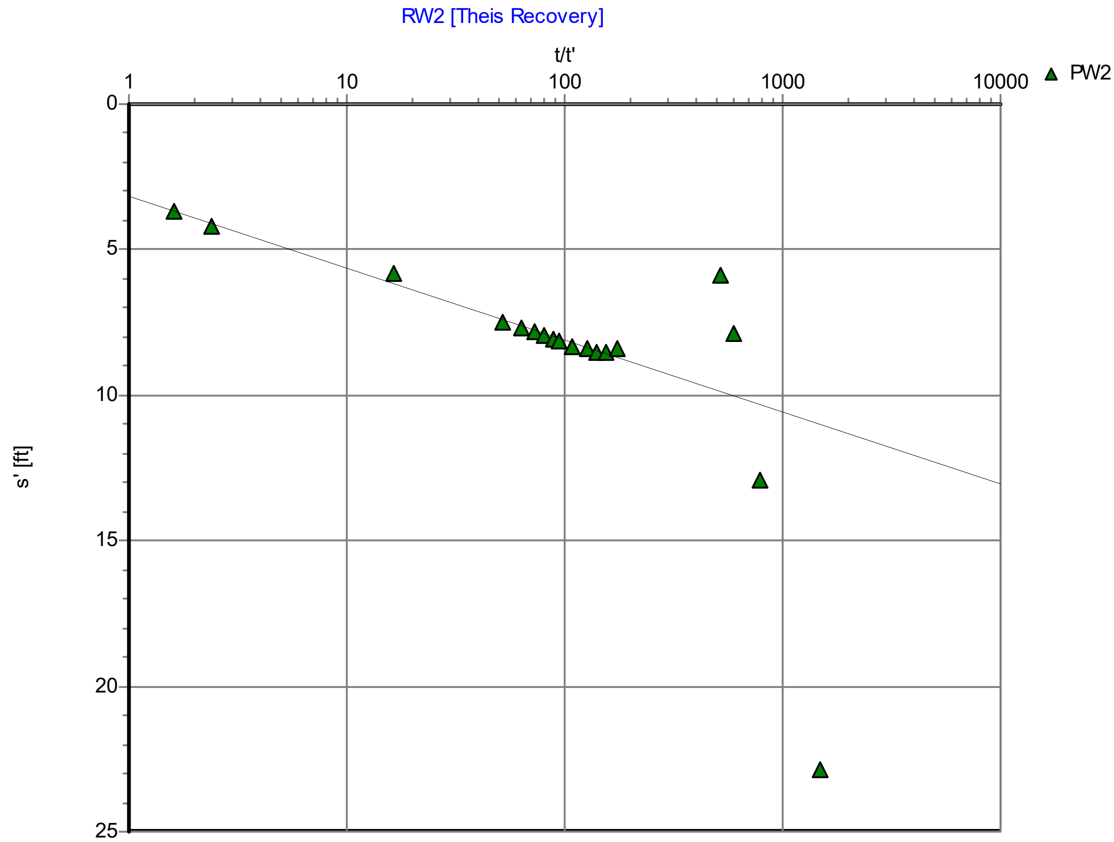
Test parameters:	Pumping Well:	PW2	Aquifer Thickness:	118 [ft]
	Casing radius:	0.35 [ft]	Confined Aquifer	
	Screen length:	165 [ft]		
	Boring radius:	0.35 [ft]		
	Discharge Rate:	32 [U.S. gal/min]		
	Pumping Time	1480 [min]		

Comments:

Evaluated by:

Evaluation Date: 6/21/2005

MBMG 1300 N 27th St Billings MT 406-373-5251	**Pumping Test Analysis Report** Project: Merideth2 Number: Client:



Pumping Test: **RW2**

Analysis Method: **Theis Recovery**

Analysis Results:	Transmissivity:	4.55E+2 [ft²/d]	Conductivity:	3.86E+0 [ft/d]

Test parameters:	Pumping Well:	PW2	Aquifer Thickness:	118 [ft]
	Casing radius:	0.35 [ft]	Confined Aquifer	
	Screen length:	165 [ft]		
	Boring radius:	0.35 [ft]		
	Discharge Rate:	32 [U.S. gal/min]		
	Pumping Time	1480 [min]		

Comments:

Evaluated by:

Evaluation Date: 6/21/2005