Montana Bureau of Mines and Geology

MONTANA GROUND WATER ASSESSMENT ATLAS NO. 3

GROUNDWATER RESOURCES OF THE MIDDLE YELLOWSTONE RIVER AREA: TREASURE AND YELLOWSTONE COUNTIES, MONTANA

Part A*—Descriptive Overview and Water-Quality Data

by

James P. Madison, John I. LaFave, Thomas W. Patton, Larry N. Smith, and John L. Olson

*The atlas is published in two parts: Part A contains a descriptive overview of the study area, water-quality data, and an illustrated glossary to introduce and explain many specialized terms used in the text; Part B contains the ten maps referenced in this document. The maps offer expanded discussions about many aspects of the hydrogeology of the Middle Yellowstone River area. Parts A and B are published separately and each map in Part B is also available individually.

2014

Cover photo: Yellowstone River and Eagle Sandstone, Billings, Yellowstone County. Photo by Clay Schwartz, Montana Bureau of Mines and Geology.

TABLE OF CONTENTS

FIGURES

TABLES

PREFACE

The Montana Ground-Water Assessment Act

In response to concerns about management of groundwater in Montana, the 1989 Legislature instructed the Environmental Quality Council (EQC) to evaluate the State's groundwater programs. The EQC task force identified major problems in managing groundwater that were attributable to insufficient data and lack of systematic data collection. The task force recommended implementing long-term monitoring, systematic characterization of groundwater resources, and a computerized database. Following these recommendations, the 1991 Legislature passed the Montana Ground Water Assessment Act (85-2-901 et seq., MCA) so that the quality of decisions related to groundwater management, protection, and development might be improved. The Act established three programs at the Montana Bureau of Mines and Geology to address groundwater information needs in Montana:

- the Groundwater Monitoring Program: to provide long-term records of water quality and water levels for the State's major aquifers;
- the Groundwater Characterization Program: to map the distribution of and document the water quality and water-yielding properties of individual aquifers in specific areas of the State; and
- the Groundwater Information Center (GWIC): to provide readily accessible information about groundwater to land users, well drillers, and local, State, and Federal agencies.

The Groundwater Assessment Steering Committee oversees program implementation. The Steering Committee includes representatives from water agencies in State and Federal government, and representatives from local governments and water user groups. The committee also provides a forum through which units of local, State, and Federal government can coordinate functions of groundwater research.

Montana Ground-Water Assessment Atlas Series

Groundwater characterization-area boundaries as defined by the Steering Committee and the active study areas at the time of this report are shown in figure 1; an atlas is planned for each area. Each atlas contains a series of maps and/or plates that provide detailed overviews of the area's hydrogeology and water quality. The maps are intended for interested citizens and others who may make decisions about groundwater use but who are not necessarily specialists in hydrogeology.

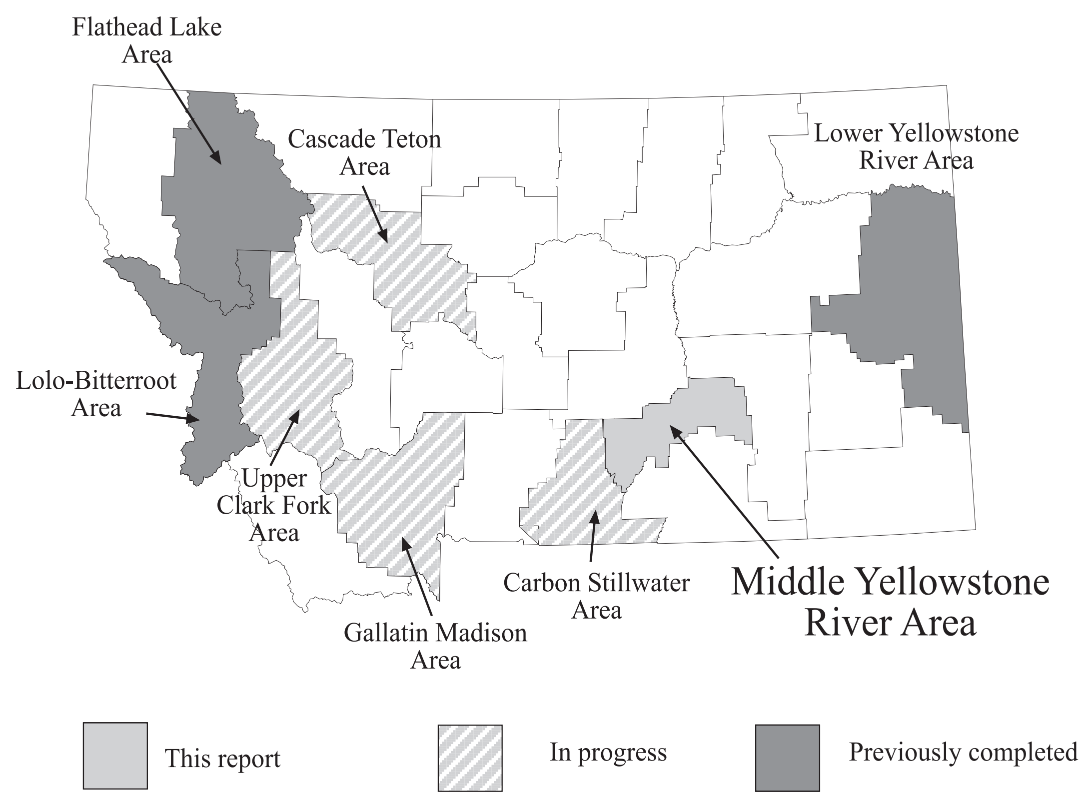


Figure 1. The Middle Yellowstone Area Groundwater Assessment Atlas is the third atlas prepared by the Groundwater Characterization Program. Other areas selected by the Groundwater Assessment Program Steering Committee where work was in progress at the time of this report are marked with stripes.

INTRODUCTION

The Montana Bureau of Mines and Geology (MBMG) conducted the Middle Yellowstone Area groundwater characterization study as part of the Montana Groundwater Assessment Program. The area includes all of Treasure County and the portion of Yellowstone County outside the Crow Indian Reservation (fig. 2). Groundwater in the Middle Yellowstone Area occurs in relatively thin unconsolidated deposits mostly along the Yellowstone River or in consolidated sedimentary rock units. The objectives of the characterization were to: (1) describe the extent, thickness, and water-bearing properties of the area's aquifers, and (2) describe the chemical characteristics of the groundwater. The basic information presented in this report should help local landowners and public officials make decisions regarding groundwater development, protection, and management.

Groundwater is an important resource within the Middle Yellowstone Area. About 22,300 people in the study area (17% of the study area population) depend on groundwater as their source of domestic water (Cannon and Johnson, 2004). Most of the people (80%) who rely on groundwater are self-served through private wells, while the remainder (20%) are supplied through public-supply wells. Besides meeting domestic needs, groundwater also is used for commercial, industrial, irrigation, and stock watering needs. The city of Billings (83% of the study area population) gets its municipal water from surface-water diversions; in some instances where neither a municipal connection nor groundwater is available due to hydrogeologic constraints, water is hauled and stored in cisterns.

The distribution and physical characteristics of the geologic units in the study area significantly affect groundwater availability, groundwater movement, and water quality.

Purpose and Scope

This atlas (Part A) and the associated maps (Part B) summarize and interpret basic geologic and regional hydrogeologic conditions for the Middle Yellowstone Area. Part A provides an overview of the most used aquifers in the area. The Part B maps show the geologic framework, potentiometric surfaces, and dissolved constituent concentrations for the major aquifer systems. The data used to compile these maps are stored in the MBMG's Ground Water Information Center (GWIC) database, which is continually updated with new information. Because the GWIC database allows for automated storage and retrieval, up-to-date information can be retrieved and used to enhance the interpretations presented here. Copies of the individual maps in Part B are available through the MBMG, in either paper or digital format.

Methods of Investigation

Program staff visited about 1,000 wells during the project's well inventory phase. Wells were located to at least the nearest 1/256th of a square mile, about 2.5 acres, using navigational-grade GPS and/or 7.5´ USGS quadrangle maps (appendix A). Field-data collection included, where possible, the measurement of static and pumping water levels, pumping rates, and basic field water-quality parameters (temperature, pH, and specific conductance). Water samples were collected from a subset of the inventoried wells. Most of the hydrologic fieldwork was conducted during the spring, summer, and fall of 1996 and 1997. MBMG studies for other groundwater projects in the area inventoried additional wells between 1999 and 2008 (Olson and Reiten, 2001).

Lithologic descriptions from about 8,100 wells were compared to geologic maps (Lopez, 2000a,b; Vuke and others, 2000; 2001a,b; 2003; Wilde and Porter, 2000; Olson and Reiten, 2002) to determine aquifers corresponding to well completion intervals. Location accuracy was checked for most wells, and about 1,000 wells were relocated based on land-ownership records and geologic units. Water-well logs were used to prepare maps and cross sections showing location, depth, and thickness of the principal hydrogeologic units.

Monthly water-level measurements were collected from a network of about 75 wells between 1996 and 2002, and water-level measurements from other studies in the area (Olson and Reiten, 2002) were used to evaluate the timing and magnitude of seasonal groundwater fluctuations. Historical water-level data from the GWIC database were also used to assess the effects of climate, development, and

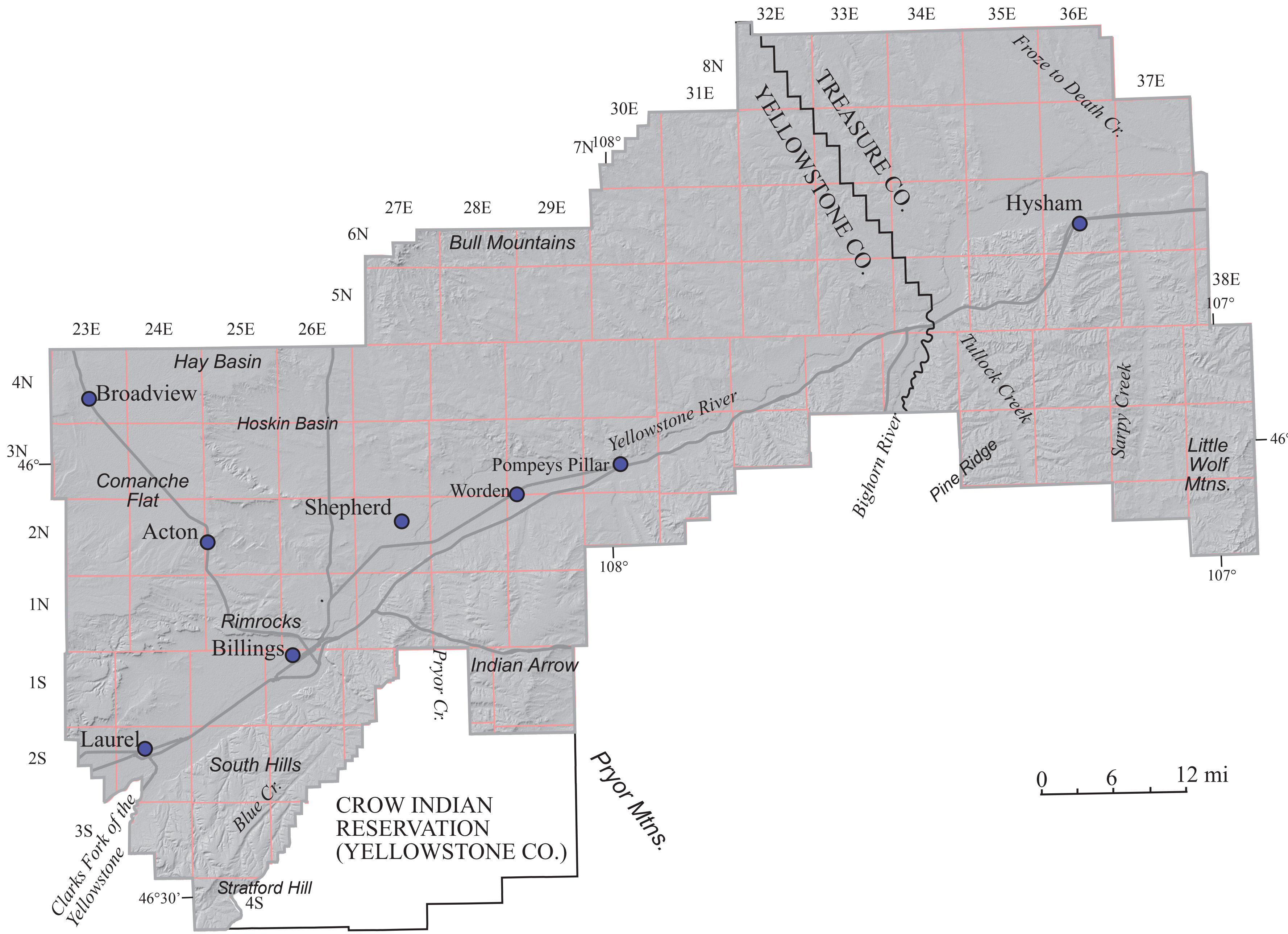


Figure 2. The Middle Yellowstone Area groundwater characterization study covers all of Treasure County and Yellowstone County outside of the Crow Indian Reservation. About 22,300 people within the study area depend on groundwater for domestic purposes.

water use on groundwater supplies.

Water levels in the Middle Yellowstone Area continue to be monitored in a network of 49 wells maintained by the Groundwater Monitoring Program; updated hydrographs and data from these wells can be viewed at the GWIC website, at http://mbmg-gwic.mtech.edu.

Water-quality sampling

To describe the groundwater quality of the major aquifers in the Middle Yellowstone Area, MBMG field staff collected 206 water-quality samples for full analysis from 182 domestic, stock, public supply, and dedicated groundwater monitoring wells during the 1997 and 1998 field seasons, and for other projects between 1998 and 2008. Sample sites were selected to obtain a uniform areal distribution of samples and to obtain data from along groundwater flow paths. The samples were analyzed by the MBMG Analytical Laboratory for major cations (calcium, magnesium, sodium, and potassium), major anions (bicarbonate, chloride, and sulfate), nitrate, and trace elements (including fluoride, iron, manganese, arsenic, and selenium). Samples from 42 additional wells were analyzed for nitrate only. The analytical results are presented in appendix B. For background on the nomenclature, meaning, and interpretation of these analyses, see the appropriate sections in the glossary.

Water samples were bottled only after field parameters (specific conductance, pH, alkalinity, redox potential, and water temperature) stabilized during pumping, or at least three well-casing volumes of water had been removed, to ensure collection of a representative sample. Water-quality data from these wells can be viewed and downloaded at the GWIC website, at http:\\mbmggwic.mtech.edu.

Data set and data analysis

Only water-quality samples collected by MBMG field staff and analyzed at the MBMG laboratory were used for interpretation in this report. These samples have complete major-ion determinations, cation/anion milliequivalent charge balances within 10 percent, and known aquifer sources. In cases where multiple analyses were available for a well, the most recent analysis was used for statistical summaries, or in the case of nitrate, the highest concentration was used. The full water-quality data set contains representative samples from all the major hydrogeologic units in the Middle Yellowstone Area; 106 analyses are from wells in alluvial aquifers and 100 are from wells completed in bedrock formations. For the additional nitrate-only samples, 28 were from alluvial aquifers and 14 were from bedrock aquifers.

The laboratory results were supplemented by estimates of total dissolved solids (TDS) concentrations derived from specific conductance (SC) measurements made during the well inventories at an additional 717 wells. SC measurements from these sites were used to estimate TDS according to the equation: TDS = A x SC (Hem, 1992). The value of ‘A’ was determined to be 0.82 based on a straight-line regression of laboratory-determined TDS vs. specific conductance (with an R^2 of 0.93).

Water-quality summaries include standard measures of statistical minimum, maximum, and median values. Where applicable, the water-quality data were compared with U.S. Environmental Protection Agency primary and secondary maximum contaminant levels (MCL and SMCL) for drinking water. These standards are the permissible levels allowable for selected constituents in public water-supply systems. Constituents for which MCLs have been set may pose a health threat at elevated concentrations. Secondary levels (SMCLs) are set for aesthetic reasons; elevated concentrations of these constituents may be a nuisance (bad taste, odor, or staining) but do not normally pose a health risk.

Previous Investigations

Hall and Howard (1929) provided a comprehensive study of the geology, groundwater, and surface-water resources of Treasure and Yellowstone Counties. This study sampled wells completed in Yellowstone River alluvium and terraces, and the Fort Union, Lance, Judith River, Eagle, and Cloverly (Kootenai) Formations. Gosling and Pashley (1973) mapped the hydrogeology of the Yellowstone River alluvium and terraces from Park City to Billings and recognized the importance of irrigation recharge to the thin alluvial aquifers. The regional hydrogeology and descriptions of aquifers in central and eastern Montana were described in Noble and others (1982) and Downey and Dinwiddie (1988). Thompson

(1982) analyzed groundwater conditions in the Bull Mountains coal area, which includes part of a township in northwestern Yellowstone County. Slagle and others (1985) mapped aquifers within 200 ft of land surface (mostly in the Fort Union and Hell Creek Formations) in the southeastern portion of Treasure County. Clark (1990) sampled a no-till cornfield near the Huntley agricultural experiment station for pesticide residues in soil and shallow groundwater.

Olson and Reiten (2002) analyzed the hydrogeology of the Yellowstone alluvial valley aquifer from Billings to southwest of Laurel. The project produced potentiometric and water-quality maps for this suburban and agricultural area and concluded that groundwater quantity in these thin alluvial aquifers is a function of irrigation leakage. A corollary conclusion was that groundwater quality is poor where recharge occurs through fine-grained surficial deposits. Results of their study likely apply to a large portion of the Yellowstone River Valley.

Reiten and Hanson (2008) evaluated the aquifers near Broadview as potential sources for municipal supply wells. Results included drilled test wells, water-quality samples, and aquifer tests in the Eagle aquifer near the Broadview Dome.

DESCRIPTION OF THE STUDY AREA

The Middle Yellowstone River Area occupies 3,200 mi^2 within a broad, terraced valley between the Bull Mountains to the north and the Pryor Mountains to the south (fig. 2). The land-surface altitude ranges from a high of 4,971 ft at Stratford Hill in southern Yellowstone County to a low of 2,575 ft where the Yellowstone River flows out of eastern Treasure County. With the exception of two internally drained areas (Comanche Flat and Hay Basin) in northwest Yellowstone County, the Yellowstone River drains the entire area. Major Yellowstone River tributaries include the Clarks Fork of the Yellowstone River, the Bighorn River, and Pryor Creek. Most other tributaries are ephemeral streams except where they drain irrigated lands within the Yellowstone River Valley.

The area's most prominent physiographic feature is the Yellowstone River Valley. The bedrock lithologies on the northwest and southeast sides of the valley affect the width of the main valley floor. The river valley crosses a series of shale- and sandstone-dominant bedrock units. The valley is as much as 5 miles wide west of Billings, in the Worden, and in the Hysham areas where the valley is eroding shale. Where the valley crosses resistant sandstone formations east of Billings and east of Pompey's Pillar, it locally narrows to less than 0.25 mi. Down-cutting by the Yellowstone River has left abandoned floodplains and terraces. Lopez (2000a,b) mapped seven Quaternary terraces and two Pliocene terraces within the study area.

Surrounding the major river valleys and large terraces are prominent cliffs of sandstone (locally termed 'rims' such as the Rimrocks north of Billings) and areas of shale that have eroded into 'badlands.' Cretaceous sandstone units are exposed in a roughly west–east direction across the area; the units dip north–northeast and are cut by the Yellowstone River Valley (see the geologic map in Part B, map 2). The shallowly dipping Eagle Sandstone forms the Rimrocks, north and south of Billings. Above each of these rims are relatively flat surfaces that have locally rugged topography due to badland erosion of mudstone-dominated rock units.

North of Billings, a series of northeast-to-southwest trending steep-angle faults in the Lake Basin Fault Zone offset large blocks of sedimentary rocks that, in turn, control drainage network development (Part B, map 2). This 3- to 7-mi-wide fault zone cuts across Yellowstone County west of Acton and trends northeast of Indian Arrow. Fault-controlled drainages are also prevalent in the south hills area (south of Billings). Blue Creek and several other small drainages have a northeast–southwest orientation that parallels the Fromberg Fault Zone (Part B, map 2).

Where the Bearpaw Shale is at land surface, the topography becomes flat or gently rolling. This is most evident in Hoskin Basin northeast of Shepherd and in the Froze to Death Creek drainage in northern Treasure County.

Two internally drained basins in northwestern Yellowstone County, Comanche Flat (52 mi^2), and Hay Basin (7 mi^2), apparently formed relatively recently, within the past 2.6 million years, due to recent up-warping and possible faulting along the Lake Basin Fault Zone (Ellis and Meinzer, 1924). This deformation has disrupted previous drainage patterns. Neither closed basin contains permanent lakes, but water accumulates in low areas during wet periods, where it eventually evaporates.

All the uplands in the area were formed though deformation and erosion of weakly to moderately consolidated sedimentary rocks. Although compared with ranges of the Rocky Mountains to the west, the mountains in or near the area are little more than hills, they do rise prominently above the general area of the surrounding country. Uplands in or near the area include the Bull Mountains (northern Yellowstone County), Pine Ridge (south of Yellowstone County), Little Wolf Mountains (southern Treasure County), and Pryor Mountains (south of Yellowstone County; fig. 2).

Cultural Features

The estimated population of Treasure and Yellowstone Counties in 2010 was about 148,000 people. The principal population centers in decreasing order of population are Billings, Laurel, Hysham, and Broadview. These population centers account for 77 percent of the area's residents (U.S. Census data, http://factfinder.census.gov/). The rest of the study area's population is primarily suburban, grouped in small towns, or spread across rural acreage. Most people work in the management, professional, service, sales, office work, construction, and transportation fields (U.S. Census data, http://factfinder.census.gov/). About 90 percent of the land is privately owned, 5 percent is State land, and 5 percent is Federal land.

Climate

Central Montana has a continental climate, distinguished by cold winters and warm summers. Temperatures range from extremes above 100°F in June and August to below -20°F in December and January [Western Regional Climate Center (WRCC) climate data for the City of Billings, 2008]. Incursions of cold arctic air masses and periods of warm “Chinook” winds can make winter weather highly variable. Annual precipitation ranges from about 12 to 20 in across the Middle Yellowstone Area (Part B, map 2); average annual precipitation across the study area during the period 1971–2000 was about 14.4 in (PRISM Group, Oregon State University, http://www.prismclimate.org). The climate is semi-arid, with more than 30 percent of the precipitation falling in May and June (fig. 3). The distribution of precipitation across the region is modified by topography, with the relatively high-altitude landscape in southern Treasure and Yellowstone Counties receiving the most precipitation (see Part B, map 2).

Water Use

In order of decreasing volume, predominant withdrawals or uses of surface water and groundwater in the area are irrigation, thermo-electric (for cooling), public water supply, industrial, livestock, and private-system domestic (fig. 4). Cannon and Johnson (2004) estimate the annual average withdrawal of water in Yellowstone and Treasure Counties amounted to 643 million gallons/day (Mgal/d), of which only 8.8 Mgal/d (1.4 percent) came from groundwater. Of groundwater used, 67 percent was for irrigation, 16 percent for self-supplied domestic, 10 percent for public supply, 6 percent for industry, and 1 percent for livestock purposes (Cannon and Johnson, 2004).

Of the 643 Mgal/d of water withdrawn, 130 Mgal/d (20 percent) is consumed and the remaining 80 percent returned to the immediate water environment; about 36 percent (3.1 Mgal/day of the 8.8 Mgal/day of groundwater) is lost to consumptive uses (fig. 4). Consumptive use refers to that part of water withdrawn that is evaporated, transpired, incorporated into other products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment.

The estimated total for surface water and groundwater withdrawn or used within the study area is about 10 percent of the average annual discharge of the Yellowstone River, measured below the study area at Forsyth, Montana between 1978 and 2008. Comparison of water-use figures with those of stream flow shows that the estimated annual amount of groundwater used (9,900 acre-ft) is a very small fraction (0.1 percent) of the surface water draining from the area (7,344,000 acre-ft).

Water Balance

A regional water balance accounts for water fluxes into and out of a designated area and provides better understanding of water distribution and

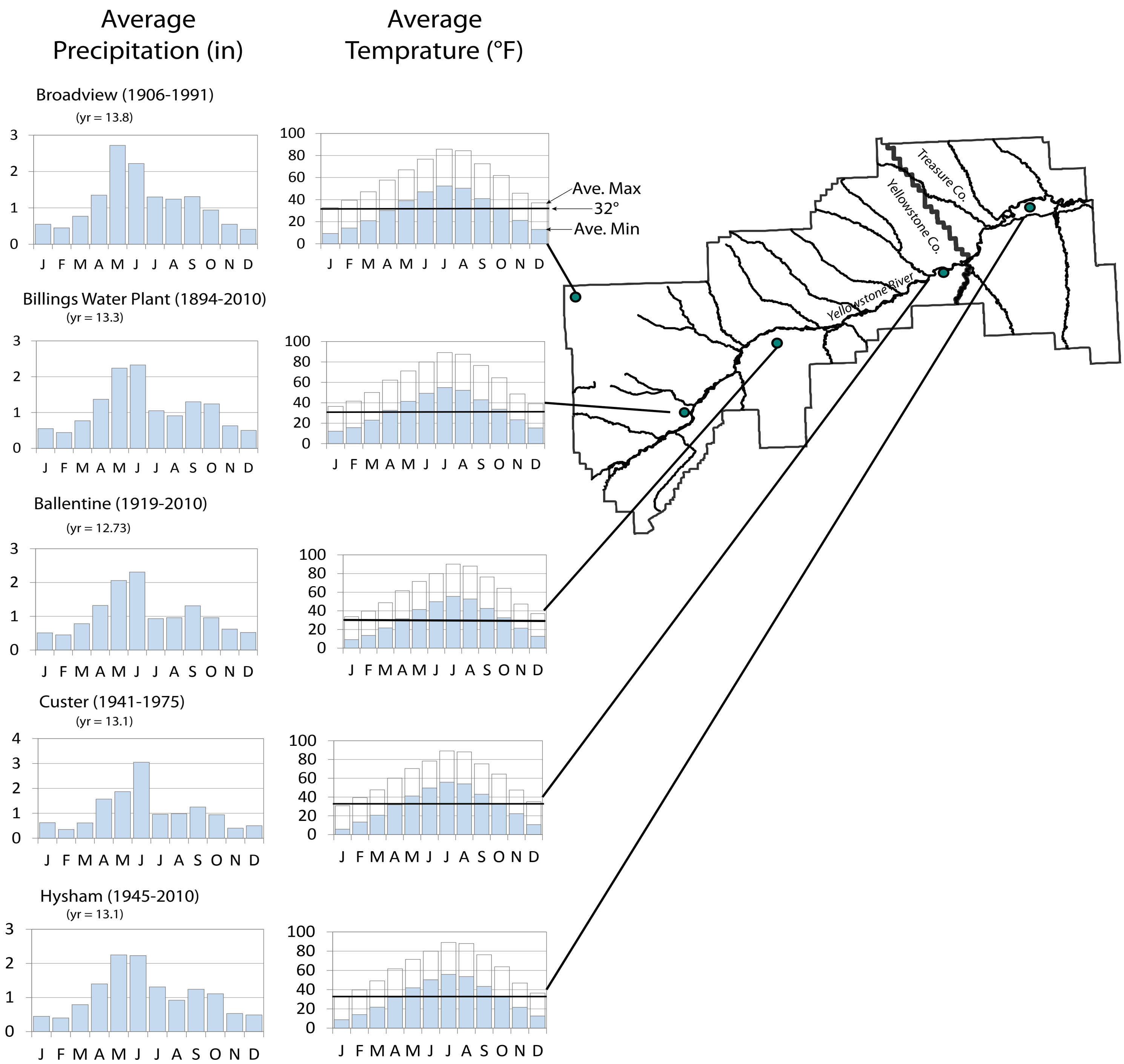


Figure 3. Precipitation and temperature are generally similar throughout much of the Middle Yellowstone Area. The wettest months are May and June. On average, the area receives more than 30% of its precipitation during these 2 months (Western Regional Climate Center 2011:Montana Climate Summaries).

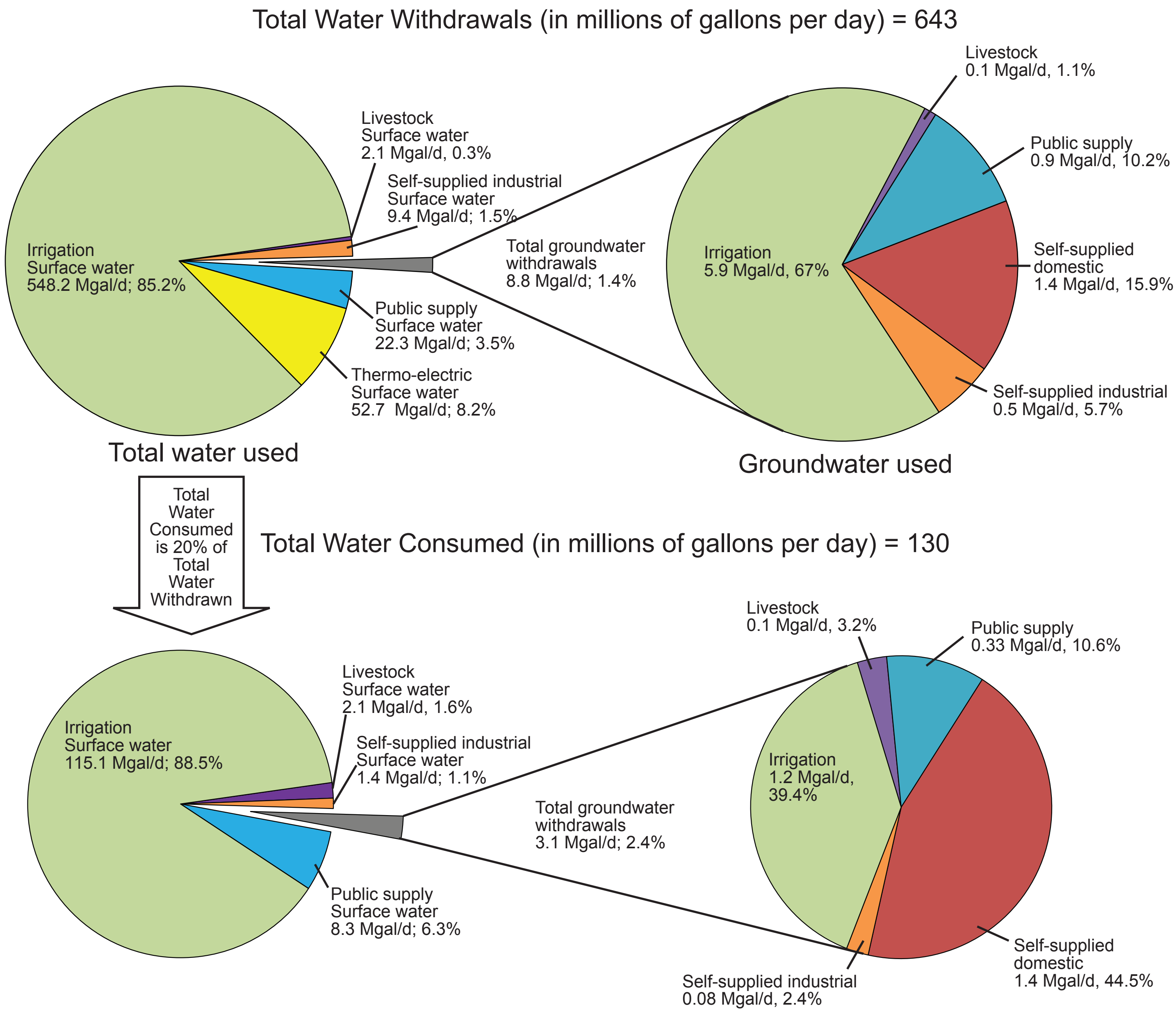


Figure 4. Estimated fresh-water usage statistics for 2000 show that groundwater accounts for about 1 percent of all water used in the area. However, groundwater is an important source of domestic water for people outside of Billings. Most groundwater is used for irrigation, industrial, public, and domestic supplies (data from Cannon and Johnson, 2004).

pathways through the hydrologic system. The water balance is based on the concept that surface water, groundwater, and atmospheric water are linked by inflows and outflows. For a given watershed where the surface water and groundwater divides coincide and for which there are no external groundwater inflows or outflows, the water balance equation for an annual period takes the form:

$$\text{Inflow} = \text{Outflow} \pm \Delta SS \pm \Delta SG,$$

where Inflow is water flowing into the hydrologic system, Outflow is water leaving the hydrologic system, ΔSS is the change in storage of the surface-water reservoir, and ΔSG is the change in groundwater storage. For the Middle Yellowstone Area, it is assumed that during long periods, natural variations in groundwater and surface-water storage are balanced, due to wet or dry climates, and that there are no long-term changes in groundwater or surface-water storage ($\Delta SS = \Delta SG = 0$). The equation then simplifies to:

$$\text{Inflow} = \text{Outflow}$$

Inflow into the Middle Yellowstone Area consists of precipitation, the Yellowstone River, Bighorn River, Pryor Creek, Armells Creek, and irrigation canals. Outflow consists of evapotranspiration (includes evaporated soil and surface water, and water transpired by plants and animals) and the Yellowstone River where it exits the study area near Forsyth. The following is the water balance equation developed for the Middle Yellowstone Area:

$$YSR_{in} + BHR_{in} + PC_{in} + AC_{in} + PPT_{in} + IRR_{in} = YSR_{out} + IRR_{out} + ET_{out},$$

where
YSR_{in}, Yellowstone River in;
BHR_{in}, Bighorn River in;
PC_{in}, Pryor Creek in;
AC_{in}, Armells Creek in;
PPT_{in}, Precipitation in;
IRR_{in}, Irrigation in;
YSR_{out}, Yellowstone River out;
IRR_{out}, Irrigation water out; and
ET_{out}, Evapotranspiration out.

The land surface area tributary to the Yellowstone River drainage between the USGS gauging stations at Billings and Forsyth—excluding the Upper Pryor Creek, Bighorn River, and Armells Creek drainages—covers an area of about 3,293,100 acres and includes almost all of the Middle Yellowstone Area (fig. 5). Because the Middle Yellowstone Area is defined by county borders and not watershed boundaries, and because the USGS gauging stations are not located at county borders, the area used to estimate the water balance does not exactly fit, but covers most of the two-county study area.

A generalized water balance for the Middle Yellowstone Area was calculated using mean annual precipitation data (period 1971–2000) developed by Oregon State University and the Oregon Climate Service (Daly and others, 1994, 1997), USGS average annual stream flow at stations upstream and downstream, and reported irrigation diversions into the area (Olson and Reiten, 2002; Cannon and Johnson, 2004). Evapotranspiration was calculated as a residual of the water balance equation.

Based on mean annual precipitation of 14.4 in, the 3,293,100-acre area receives about 3,951,700 acre-ft/yr (34 percent of total inflow) from precipitation (PPT_{in}). Average annual stream flow into the area is about 7,265,200 acre-ft/yr (63 percent of the total inflow) and includes 4,834,600 acre-ft/yr from the Yellowstone River (YSR_{in}), 2,406,800 acre-ft/yr from the Bighorn River (BHR_{in}), 19,500 acre-ft/yr from Pryor Creek (PC_{in}), and 4,300 acre-ft/yr from Armells Creek (AC_{in}). Inflow from irrigation (IRR_{in}) is about 268,200 acre-ft/yr (2 percent of total inflow). Average annual stream flows were calculated for the period 1978–2008, except for Armells Creek, which was calculated for the period 1975–1994 (table 1).

The average annual amount of water leaving the area from the Yellowstone River (YSR_{out}) at Forsyth is about 7,344,000 acre-ft/yr (64 percent of the total outflow). About 15,700 acre-ft of water diverted for irrigation from within the area flows across the eastern boundary and is used to irrigate land outside the area (IRR_{out}). Subtraction of $YSR_{out} + IRR_{out}$ from the total average inflow ($Total_{in}$) into the basin results in estimated average annual evapotranspiration (ET_{out}) of 4,125,400 acre-ft/yr (36 percent of the total outflow). Total average annual outflow ($Total_{out}$) is about 11,485,100 acre-ft/yr (table 1, fig. 5).

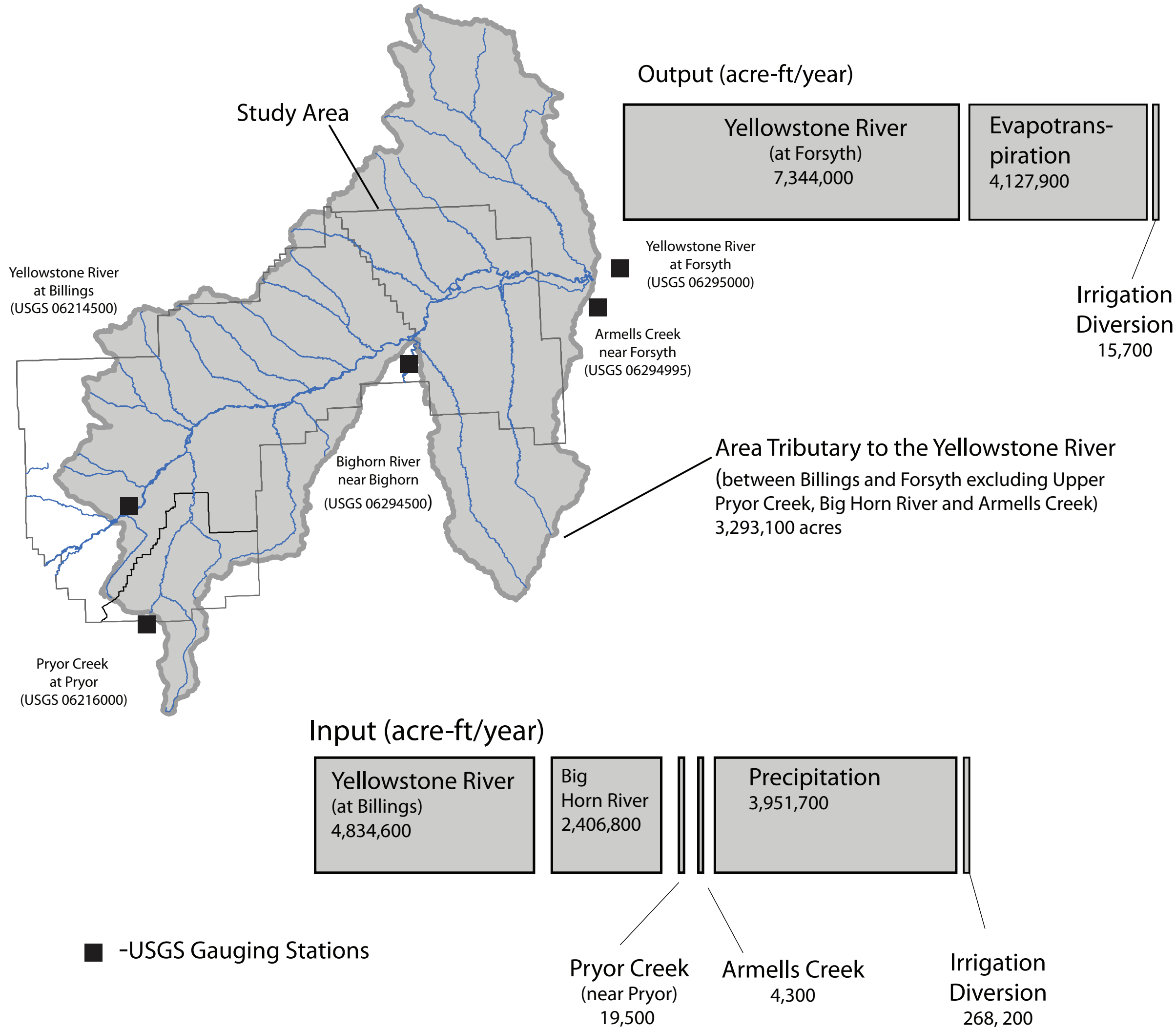


Figure 5. Schematic diagram showing average annual hydrologic budget for the watershed between Billings and Forsyth excluding upper Pryor Creek, the Bighorn River, and Armells Creek drainages. Streamflow data are from USGS gauging stations: Yellowstone River at Billings 006214500, Yellowstone River at Forsyth 06295000, Pryor Creek at Pryor 06216000, Bighorn River near Bighorn 06294500, and Armells Creek near Forsyth 06294995. Streamflow is for the period 1978 through 2008 except in Armells Creek, which is for the period 1975 through 1994. Average precipitation on 3,293,100-acre tributary area is about 14.4 in (PRISM Group, Oregon State University, http://www.prismclimate.org).

Table 1. Water balance summary for the Yellowstone River drainage between Forsyth, Montana and Billings, Montana.

Inflow (acre-ft/yr)						
YSR_{in}	BHR_{in}	PC_{in}	AC_{in}	Irr_{in}	PPT_{in}	$Total_{in}$
4,834,600	2,406,800	19,500	4,300	268,200	3,951,700	11,485,100

Outflow (acre-ft/yr)			
YSR_{out}	IRR_{out}	Et_{out}	$Total_{out}$
7,344,000	15,700	4,125,400	11,485,100

The long-term average gain in flow in the Yellowstone River between Billings and Forsyth can be accounted for entirely by input from the Bighorn River (BHR_{in}), Pryor Creek (PC_{in}), Armells Creek (AC_{in}), and irrigation (IRR_{in}). The accounting implies that groundwater contributions are negligible between these two gauging stations; however, considering the error associated with the stream flow measurements, any groundwater inflow may be masked by measurement error.

Estimated average annual evapotranspiration is actually a measure of consumed water (water removed from the immediate water environment), and includes water consumed by irrigated crops as well as water consumed by public, domestic, industrial, and livestock uses. Cannon and Johnson (2004) estimated that in 2000, irrigated crops consumed about 144,700 acre-ft of water, and public supply, domestic, industrial, and livestock sources consumed another 15,400 acre-ft in Yellowstone and Treasure Counties. These five categories (irrigation, domestic, public, industrial, and livestock) represent a small fraction (about 4 percent) of the total water consumed by evapotranspiration (ET_{out}). The other 96 percent is water transpired by riparian vegetation and other non-irrigated plants, evaporation from surface-water bodies including lakes, ponds, and rivers, and evapotranspiration of precipitation falling on non-irrigated areas.

HYDROGEOLOGY

Geologic units consist of either unconsolidated sediments or consolidated rock. A geologic unit containing interconnected pore spaces or crevices that are filled or saturated with water is termed an aquifer. The principal aquifers in the Middle Yellowstone Area are grouped into: (1) unconsolidated Quaternary alluvium and (2) consolidated Cretaceous and Tertiary rocks (figs. 6, 7, 8). Alluvial aquifers occur along the modern floodplain of the Yellowstone River Valley, its major tributaries, and terraces topographically above the modern floodplain (Part B, map 3). The major sedimentary rock aquifers consist of multiple sandstones separated by thick sequences of shale. The Fox Hills, Lance, and Fort Union Formations are hydraulically connected sandstone formations that for this report are grouped together as the Bull Mountains aquifer system (Part B, map 4). The Bearpaw Shale, a regional confining unit that is up to 800 ft thick, separates the Bull Mountain aquifer system from the underlying Judith River Formation aquifer. A few thin transitional sandstone beds in the Bearpaw Shale near the contact with overlying Fox Hills Formation and underlying Judith River Formation may yield water to wells; however, the formation is not considered to be an aquifer (Feltis and Litke, 1987). Sandstones within the Judith River Formation act as a regional aquifer that underlies the northern part of the study area (Part B, map 5). The Claggett Shale, which is between 100 and 300 ft thick, marks the base of Judith River aquifer. Like the Bearpaw Shale, transitional sandstone beds in the Claggett Shale near the contacts with the overlying Judith River Formation and underlying Eagle Formation may yield water to wells; however, the formation is not considered to be an aquifer (Feltis and Litke, 1987). The Eagle aquifer underlies the Claggett Shale and is comprised of water-saturated sandstone layers in the Eagle Sandstone and underlying Telegraph Creek Formation (Part B, map 6). The Eagle aquifer is underlain by the Colorado Group, which mostly consists of low-permeability shale units, and is not considered an aquifer except locally where thin sandstone beds near the outcrop may be a source of water. Below the Colorado Group are the Kootenai and Fall River Formations. These units are exposed at the surface only in the very southwestern part of the study area (fig. 7), and together are considered an aquifer; however, there are few wells completed in the Kootenai–Falls River aquifer because it is deeply buried almost everywhere else (fig. 8). Other geologic formations that are aquifers in other parts of the State but are deeply buried in most of the study area include the Swift, Chugwater, Tensleep, and Amsden Formations, and the Madison Group (Mission Canyon and Lodgepole Formations).

The alluvial aquifer, the Bull Mountain aquifer system, the Judith River Formation aquifer, and the Eagle aquifer are the area’s principal groundwater sources, and 95 percent of wells are completed in these four hydrogeologic units (fig. 9). Groundwater flow, water levels, and groundwater quality for these hydrogeologic units are discussed in more detail below. The Bearpaw Shale, Claggett Shale, and Colorado Group yield water to only about 5 percent of wells in the Middle Yellowstone Area.

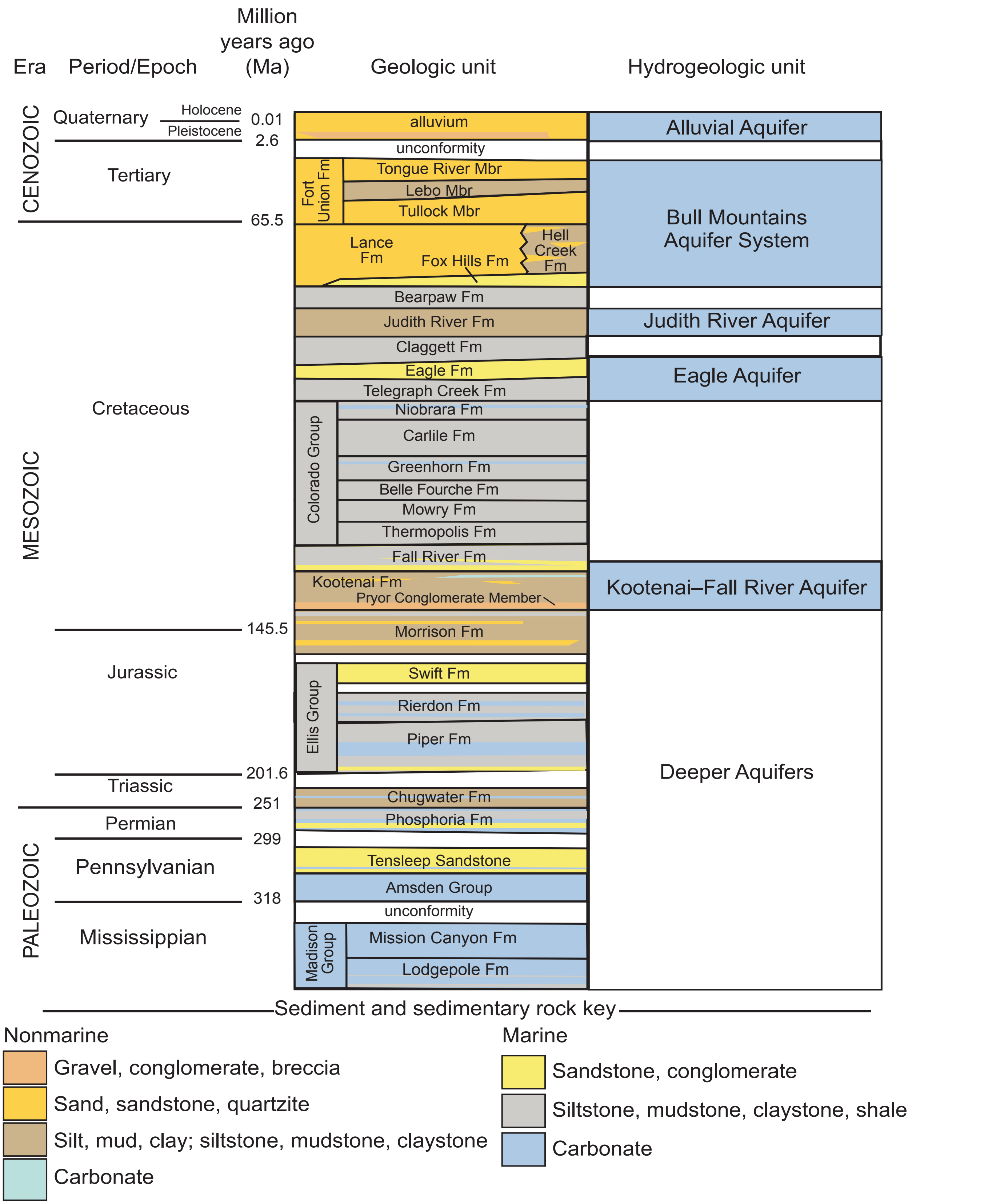


Figure 6. Stratigraphic diagram of geologic and hydrogeologic units in the Middle Yellowstone Area. Most wells are completed in the alluvial aquifer, which consists of unconsolidated sand, gravel, silt, and clay deposits within the Yellowstone River Valley and its tributaries.

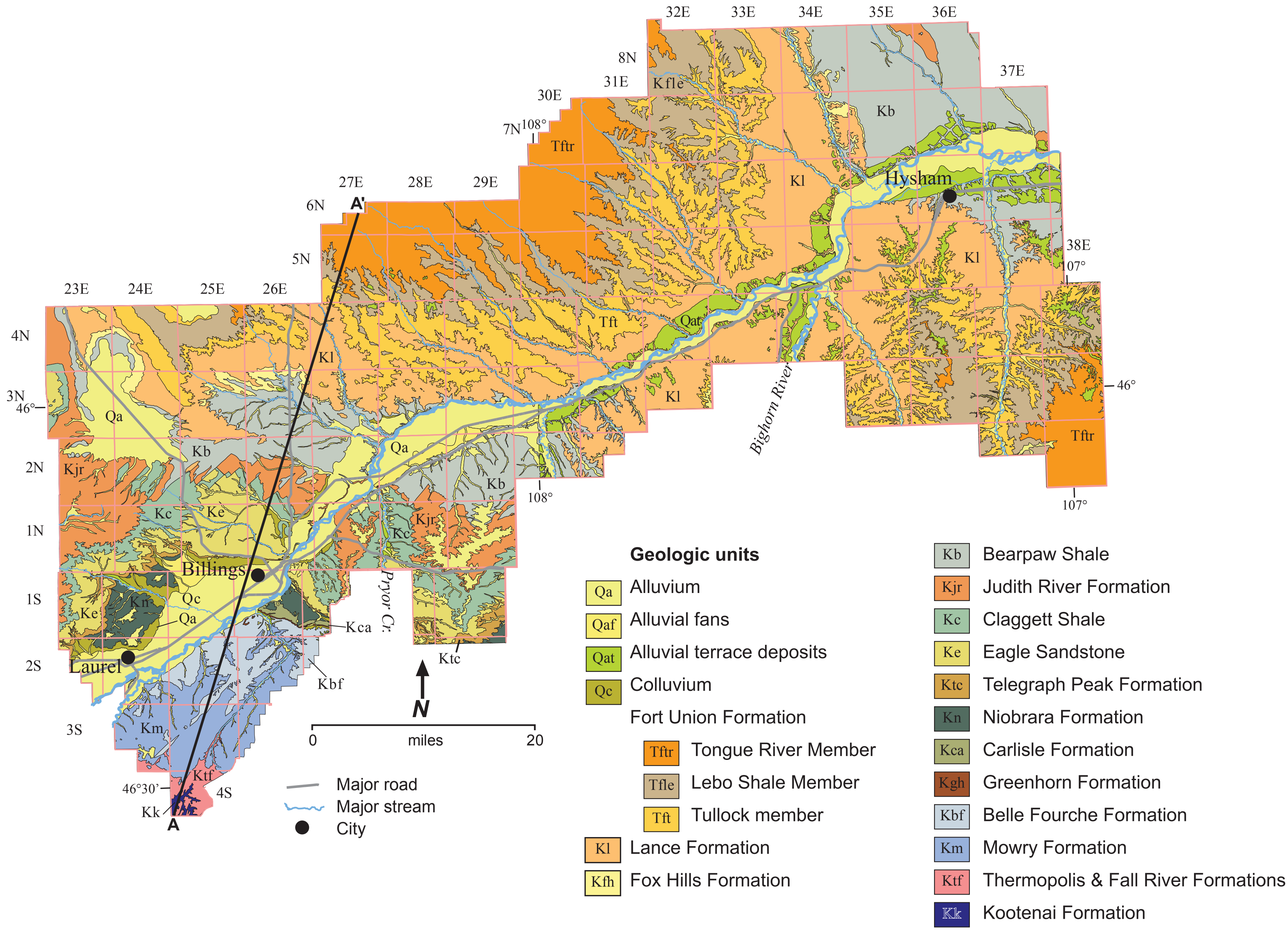


Figure 7. Generalized geologic map of the Middle Yellowstone Area. At the surface, bedrock units are oldest in the southwest and become younger towards the northeast, which reflects the gentle north–northeast dip of the bedrock units.

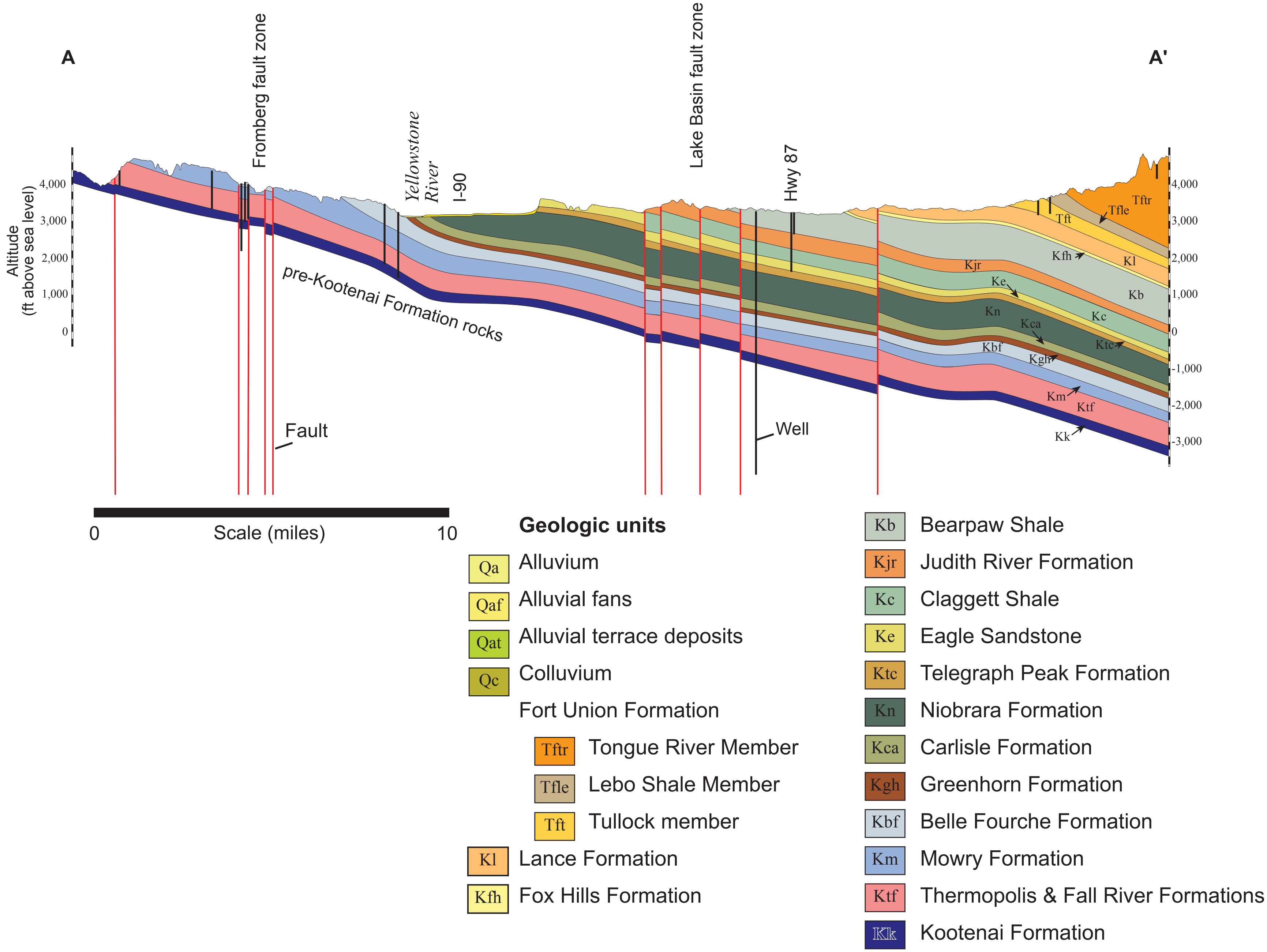


Figure 8. Generalized cross section of geologic units in the area based on interpretations of water well logs. The line of section is on fig. 7.

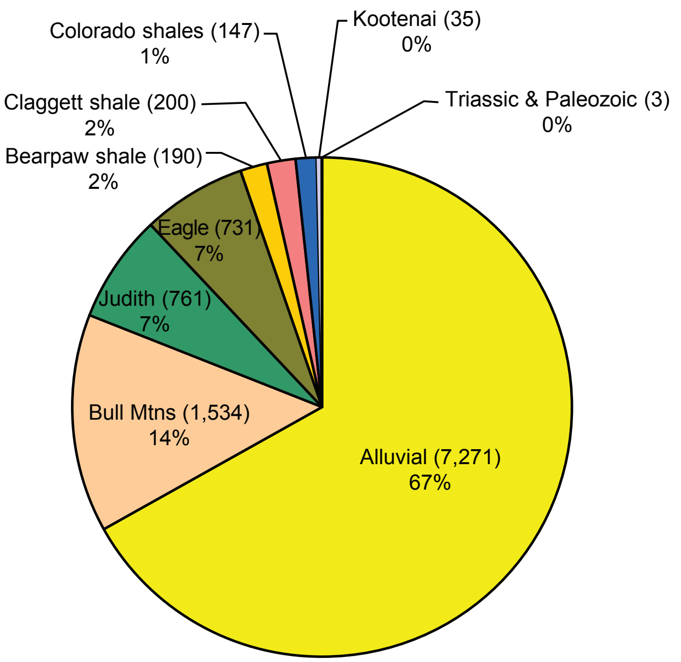


Figure 9. Most of the wells in the study area are completed in alluvium, with fewer in the Bull Mountain, Eagle, and Judith River units.

Alluvial Aquifers

The Yellowstone River and its tributaries drain the entire study area. Alluvium associated with the Yellowstone River (channels and floodplains) and on upland alluvial terraces is composed of a heterogeneous mix of interbedded sand, gravel, silt, and clay. Where saturated, these alluvial deposits form productive aquifers. Two-thirds of all the wells are completed in alluvial aquifers (fig. 9). The distribution of alluvial wells corresponds to both the distribution of deposits and the population density (fig. 10).

Olson and Reiten (2002) present a detailed characterization of alluvial aquifers in the West Billings area. They analyzed groundwater and surface-water flow, seasonal fluctuations, groundwater quality, isotopic variations in groundwater, and water-level changes in response to land-use change. Their conclusions are broadly applicable to the alluvial aquifers throughout Treasure and Yellowstone Counties, and incorporated into the discussion below.

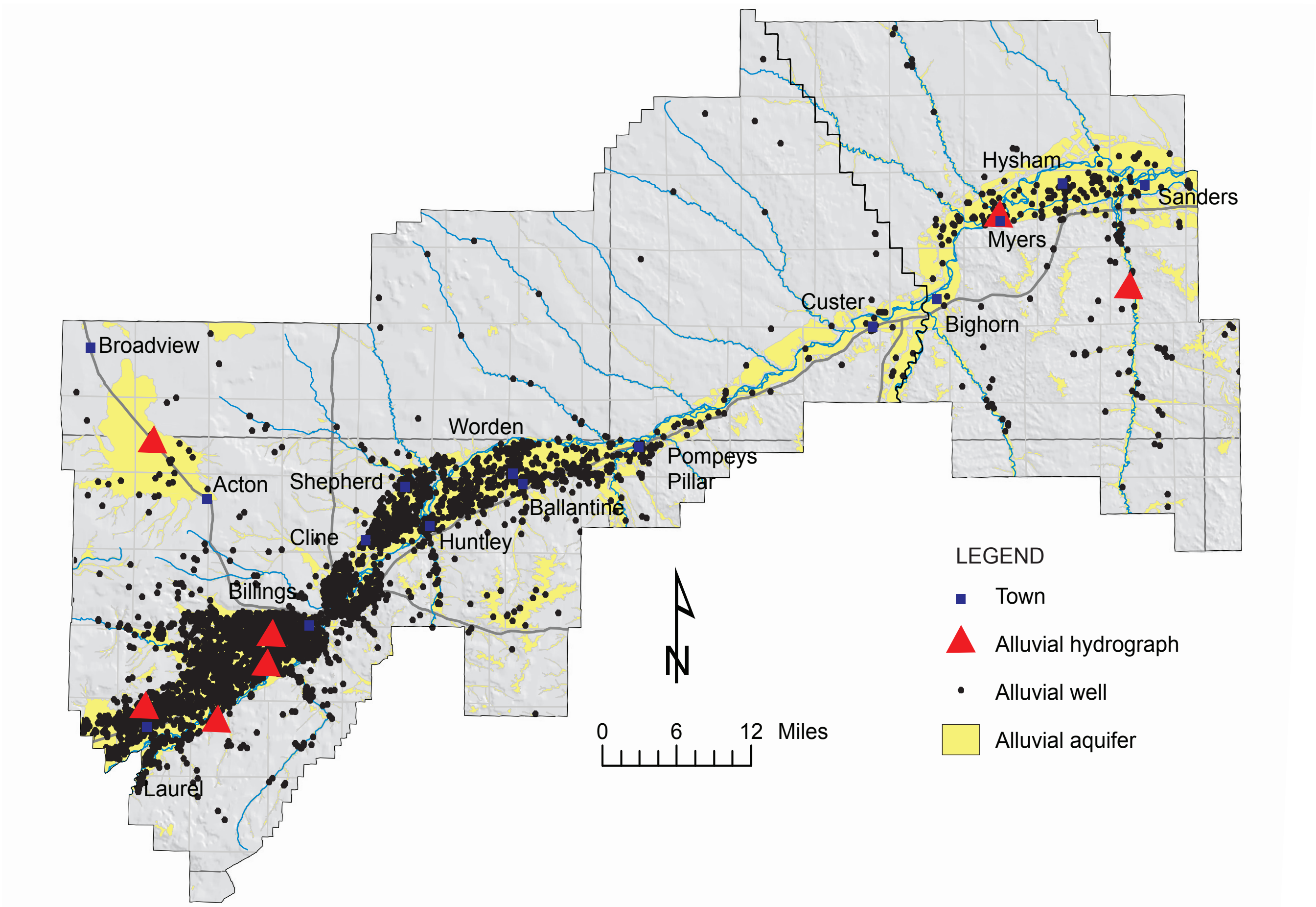


Figure 10. Water wells completed in alluvium are concentrated near the population centers of Billings and Laurel, and along stream valleys. Some valleys contain alluvial fill that is too narrow to be shown on the map.

Alluvial sediments on terraces above the modern floodplains are typically 10- to 50-ft-thick accumulations of sand, gravel, and silt; however, thicknesses may locally reach as much as 100 ft. Fining-upward sequences are common within terrace deposits. Near the valley margins, the sand and gravel aquifer materials are covered by fine-grained sand and silt derived from slope wash at the base of shale and fine-grained sandstone outcrops. Additionally, some small tributary streams carried shale-derived alluvium onto the terraces (Olson and Reiten, 2002). The fine-grained colluvium that caps the subjacent terrace sand and gravel contains salts derived from marine shale. These properties influence the water levels and water quality in the terrace alluvial aquifers.

Some of the terraces have been dissected by erosion, forming isolated areas of permeable alluvium above bedrock. Areas where a terrace's sand and gravel are too thin to provide sufficient water to wells (less than 10 ft thick), or absent due to erosion, are shown on Part B, map 3.

Groundwater from the alluvial aquifers is mostly produced from within 30 ft of land surface [depth water enters (DWE), fig. 11]. Although many wells have been drilled to depths [total depth (TD), fig. 11) greater than 30 ft, their casings were perforated in productive sand and gravel near the land surface when deep aquifers were not encountered. The distribution of drilling depths in the alluvial aquifers is shown on Part B, map 3. The aquifer is a preferred water source because it is shallow and productive; most reported well yields range between 10 and 85 gpm, with a median of 30 gpm (fig. 12).

Groundwater flow

The alluvial aquifers are unconfined and interconnected with surface water; groundwater flow and

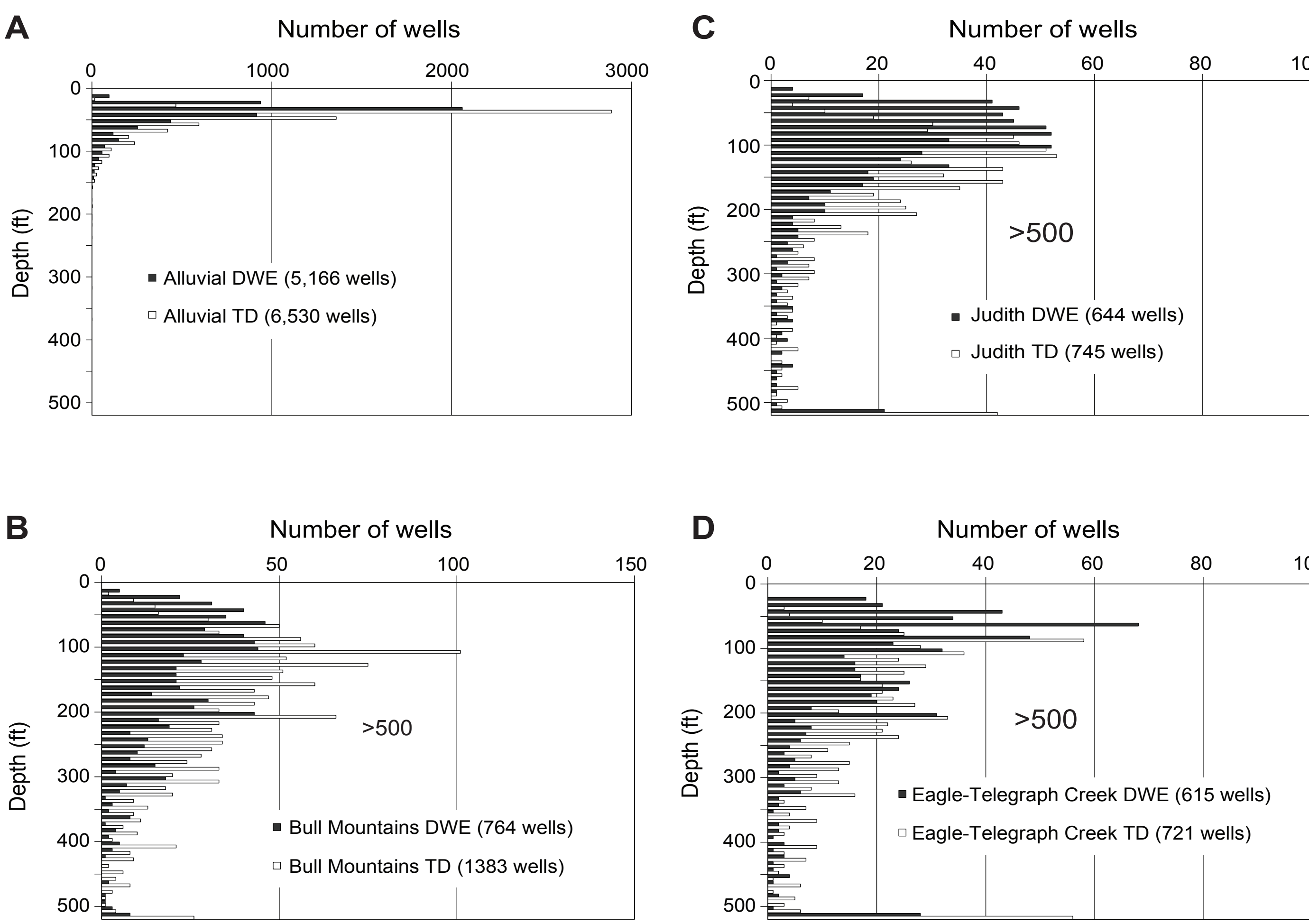


Figure 11. (A) Water enters wells in the alluvial aquifers at shallow depths, reflecting the approximate thicknesses of alluvial deposits in the area. (B) Water enters wells in the Bull Mountains aquifer system, mostly between depths of 60 and 200 ft. Most of the wells were drilled to depths of 100–250 ft. (C) Water enters wells in the Judith aquifer mostly between depths of 60 and 100 ft. Most of the wells were drilled to depths of 200 ft or less. (D) Water enters wells in the Eagle aquifer mostly between 50 and 200 ft. Most wells were drilled to depths of 80–220 ft. DWE, depth water enters well; TD, total depth.

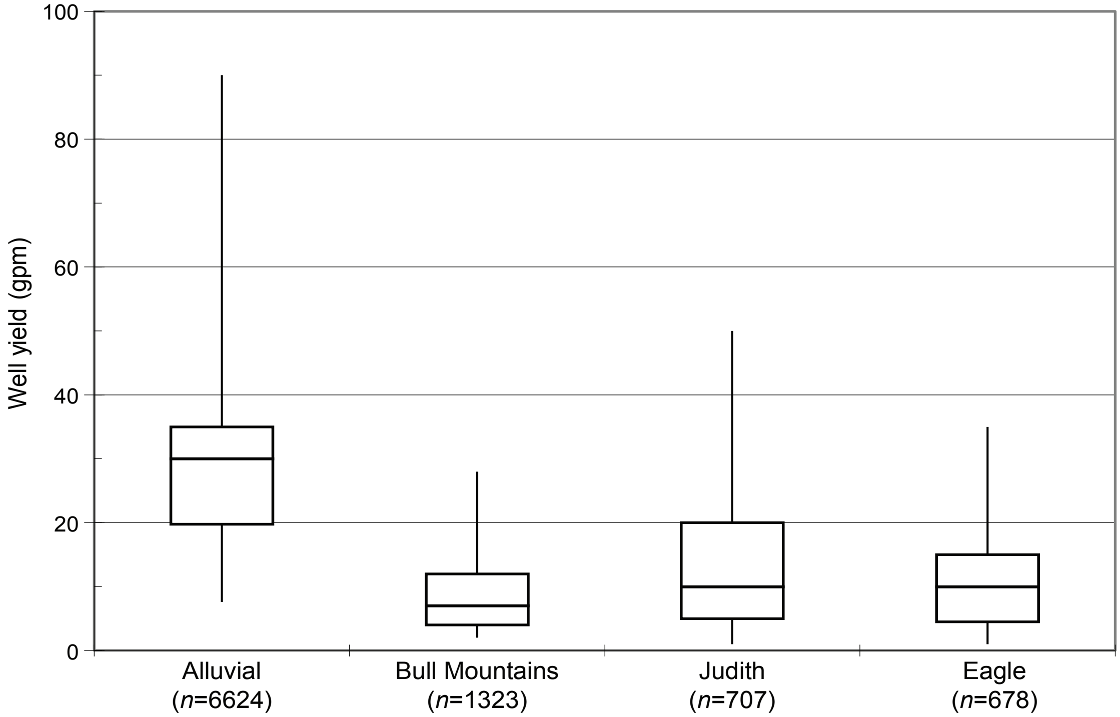


Figure 12. Reported well yields in aquifers within the Middle Yellowstone Area are summarized by these box plots that show the 95th, 75th, 50th (median), 25th, and 5th percentiles. Most of the wells in each aquifer have reported yields of less than 30 gpm, but about 86 wells in the alluvial aquifer have reported yields of more than 200 gpm. Yields are lowest in wells completed in bedrock. Short boxes and short lines show that the median reported yield in the alluvial aquifer is about three times greater than in the bedrock aquifer.

levels may exhibit seasonal variation in response to surface-water flow and recharge events. Groundwater flow directions in the alluvial aquifers are shown on Part B, map 3 and are generally from the southwest to the northeast and in the valley bottom subparallel to the Yellowstone River. Locally, groundwater-discharge areas, such as streams and drain tiles, may modify the groundwater flow direction.

Groundwater in the lowest terrace appears hydraulically connected to modern alluvium in the main channel of the Yellowstone River Valley. However, stratigraphic and potentiometric data indicate that many topographically elevated terraces may not be hydraulically connected. Where the terraces have been incised or dissected by tributary streams, direct groundwater flow between adjacent terrace remnants is either limited or absent (Part B, map 3).

Water levels

Between 1996 and 2000, water levels were measured at monthly to hourly frequencies in 53 alluvial wells (fig. 13); three of the wells have periods of record extending back to the 1980s. Annual water-level fluctuation patterns vary, but in general appear to be controlled by seasonal stream flow and recharge from irrigation practices. Long-term (yearly to decadal) water-level trends in the alluvial aquifers appear to be related to climate variations and land-use changes (figs. 14, 15).

Two general seasonal water-level patterns occur in the alluvial aquifers. The most common pattern is related to irrigation canal leakage and seepage of applied irrigation water. Water levels controlled by irrigation recharge generally rise in the spring, remain elevated throughout the summer and into autumn, and fall once the ditches are “turned off” or are no longer used; water levels then decline until the next spring when the irrigation season restarts.

The timing of irrigation-related water-level change is similar in the alluvial aquifers; however, the magnitudes vary depending on the proximity to surface-water features such as streams, drains, or lakes that control nearby aquifer water levels. Annual water-level fluctuations range from less than 1 to as much as 15 ft and average about 4 ft (fig. 16A, well 18521; and B, well 158212). In general, seasonal-irrigation-induced water-level fluctuations increase with increasing distance from the Yellowstone River. Well 18521 (fig. 16A) is located about 0.2 mi north of the Yellowstone River, and the water level fluctuates less than 5 ft per year. Conversely, water levels in well 158212 (fig. 16B), located about

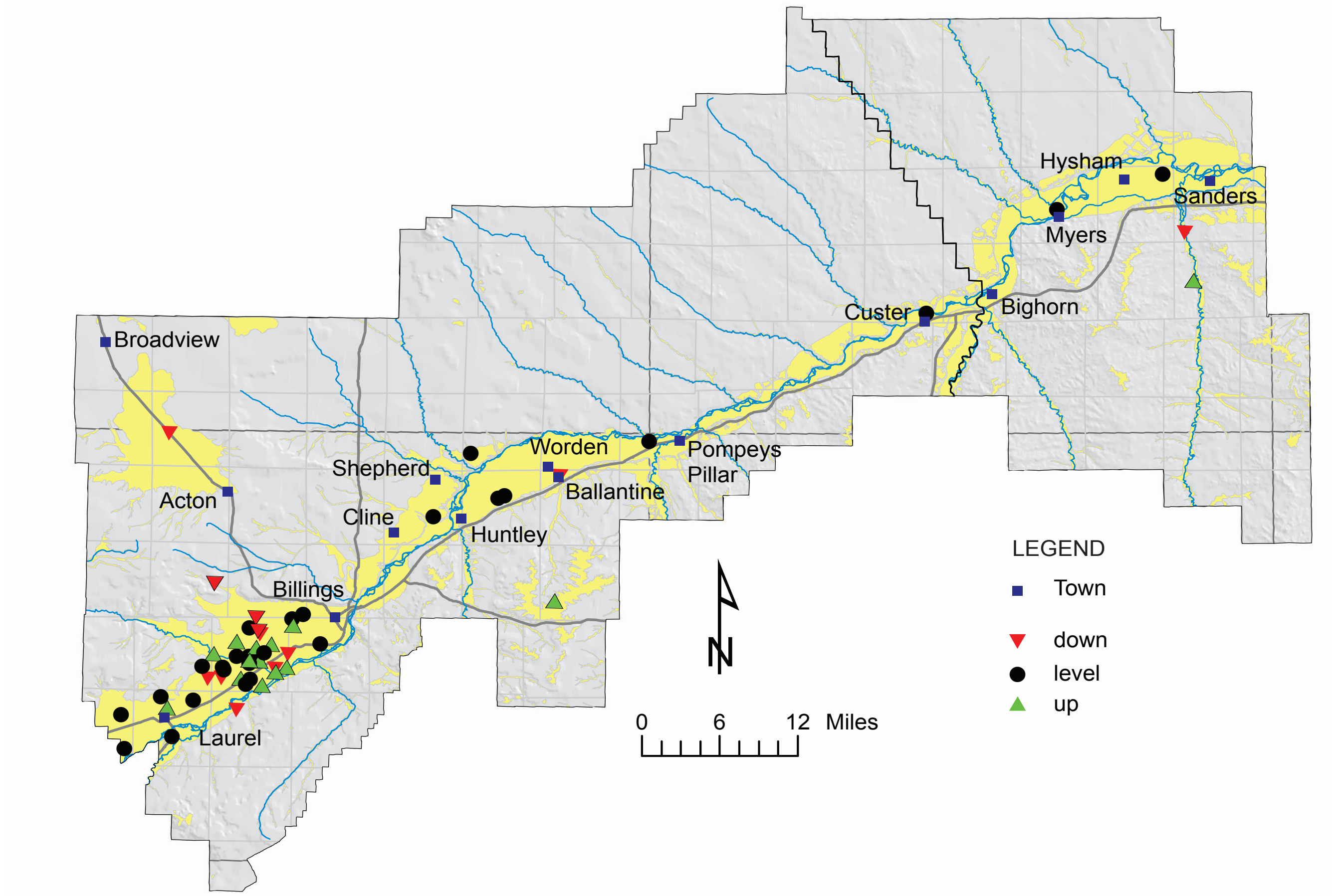


Figure 13. Location of alluvial wells with more than 3 years of regular water-level measurements mostly shows level trends. Although some agricultural land has been converted to residential use, there does not appear to be a regional correlation with declining water levels.

3 mi southeast of the Yellowstone River, fluctuate by more than 10 ft annually.

Groundwater levels in areas not impacted by irrigation recharge show a different response (fig. 15). The runoff-type response, characterized by elevated groundwater levels during spring and early summer recharge, generally occurs in alluvial aquifers not recharged by irrigation. In the Sarpy Creek area, the water-level changes in well 17277 (fig. 16c) follow a clear "runoff" pattern, rising each spring and summer to a peak in July and falling during the fall and winter to lows in March and April. Annual water-level change is generally less than 2 ft.

Most of the areas underlain by alluvial aquifers are influenced by irrigation recharge. Water-level data from these areas generally show regular seasonal fluctuations and no long-term trends. However, locally there are wells where long-term water-level trends are upward, and some wells where trends are downward (fig. 13). Olsen and Reiten (2002) suggest that conversion of irrigated land to residential lots in the Yellowstone River Valley caused decreased irrigation recharge to the shallow alluvial aquifer, which may explain downward trends in some hydrographs.

Water quality

Water quality in the alluvial aquifers is variable, reflecting the variable geology and recharge sources as well as the susceptibility of the aquifer to land-use practices. Summary statistics for water quality are presented in table 2. Part B, map 3 shows the distribution of dissolved constituents (TDS) in the alluvial aquifers. TDS concentrations range from relatively fresh (272 mg/L) to highly mineralized (6,918 mg/L). The median TDS concentration for the 90 samples was 953 mg/L, or almost twice the 500 mg/L SMCL (fig. 17); 79 percent of the samples (70 of 90) did exceed 500 mg/L, and 16 percent exceeded 2,000 mg/L. The alluvial aquifer is used as a source of drinking water; however, in many places it is not well suited for this purpose because of elevated TDS concentrations.

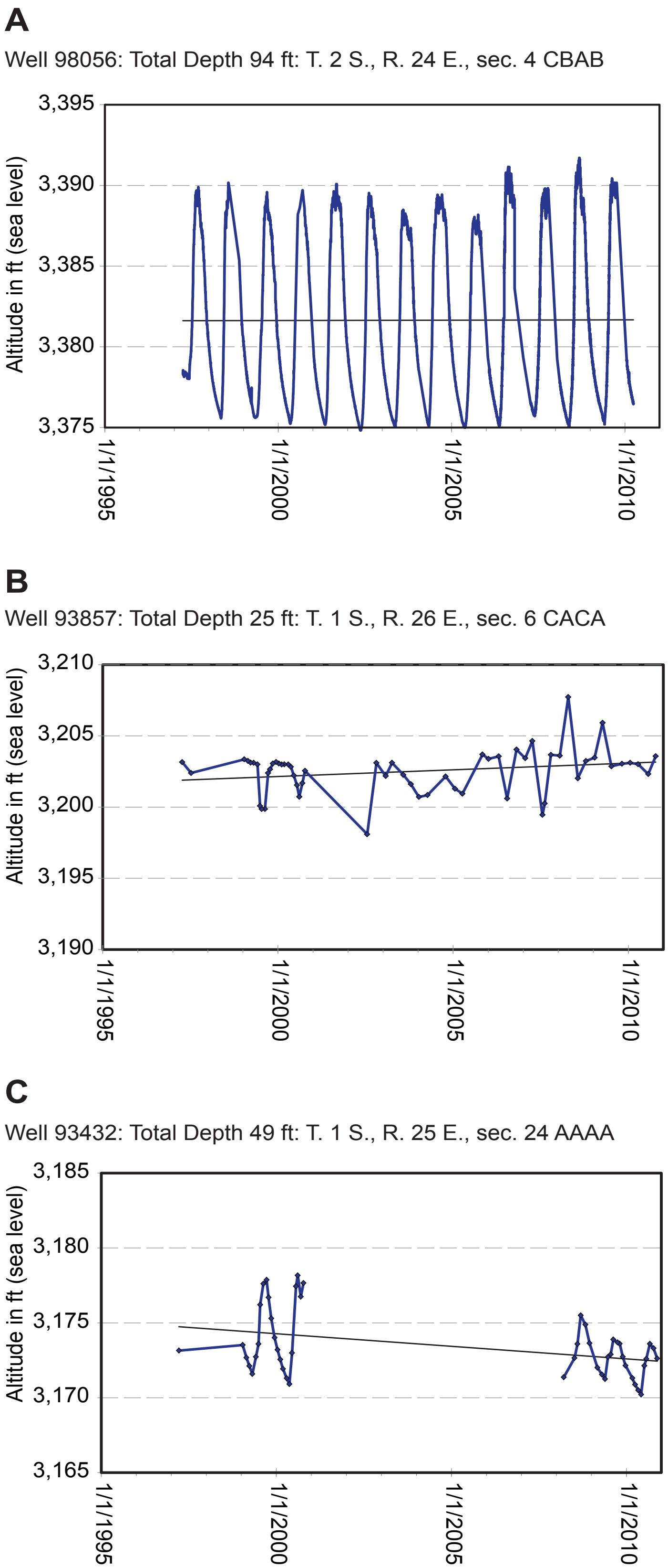


Figure 14. (A) Most (51%) long-term hydrographs in the alluvial aquifers of the Middle Yellowstone Area show seasonal response to irrigation recharge but no long-term trends. (B) Long-term hydrographs for 14 wells show a slight increasing trend in water levels. (C) Long-term hydrographs for 12 wells show a slight decreasing trend in water levels.

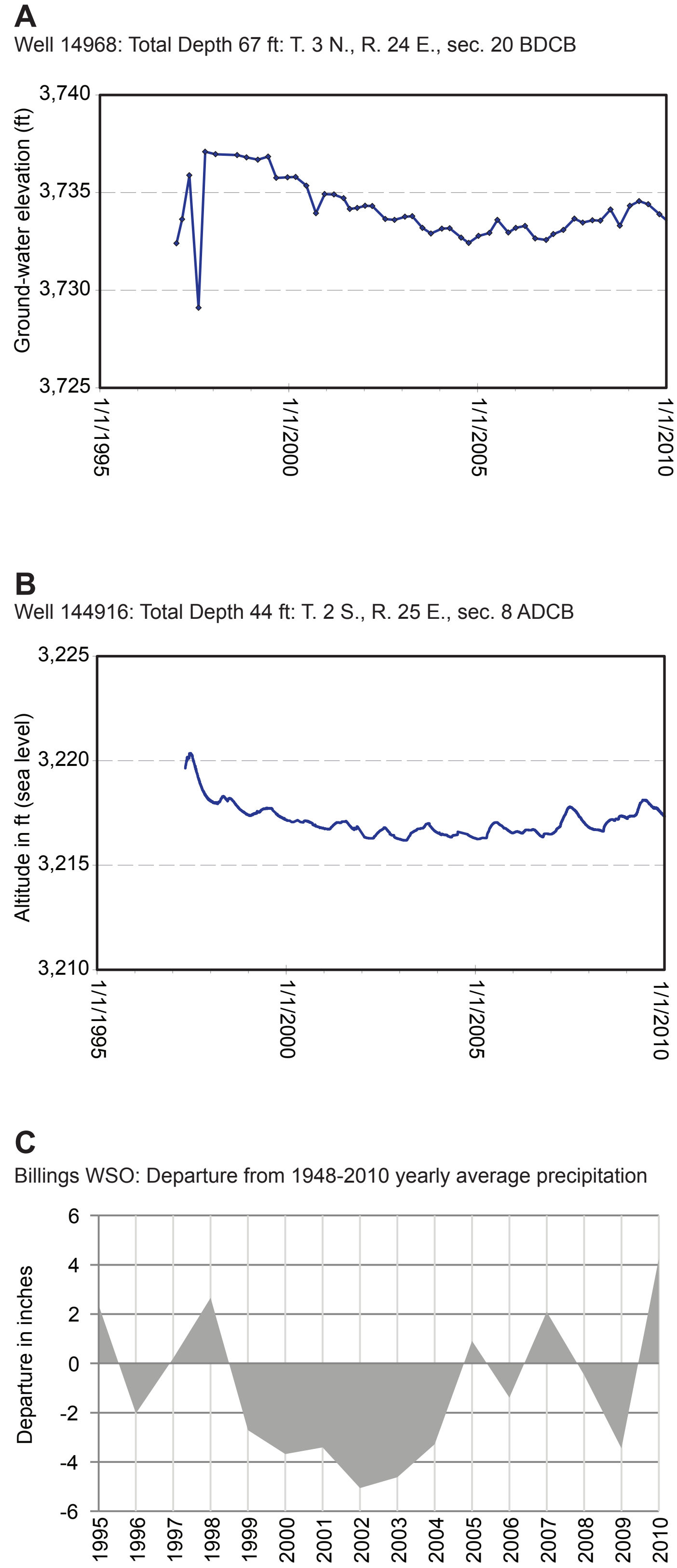


Figure 15. In the absence of irrigation effects, changes in water levels in the alluvial aquifer are subtle. Hydrographs of wells 14968 (A) and 144916 (B) exhibit declining water levels that correspond closely to the relatively dry years between 1999 and 2005, and increasing water levels that correspond to the relatively wetter years between 2005 and present. (C) Departures from 1948 to 2010 yearly average precipitation show a prolonged period of below normal precipitation between 1999 and 2005.

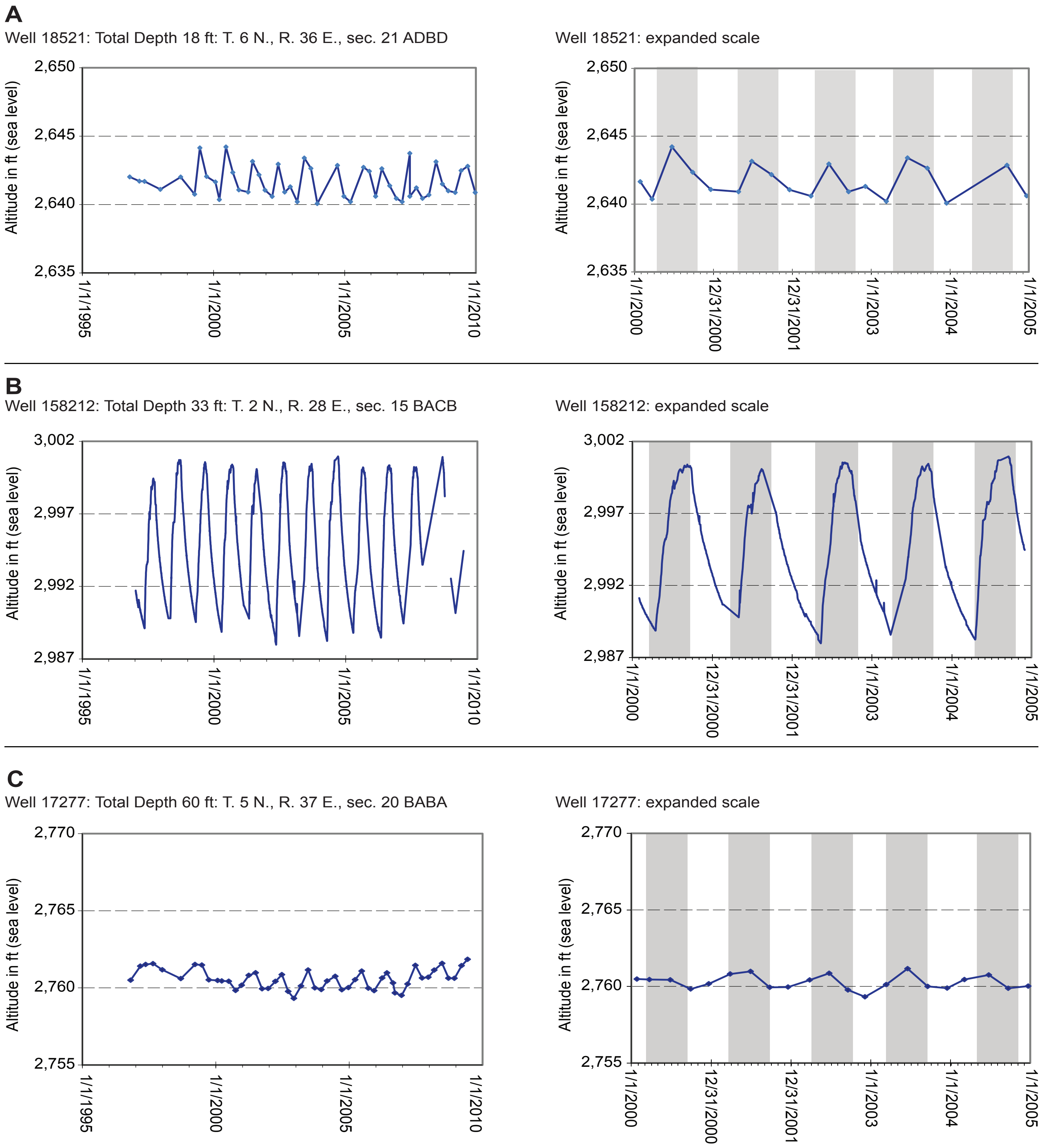


Figure 16. There are two general patterns of water-level response in the alluvial aquifers. (A–B) Irrigation response is generally synchronized with seasonal leakage of water from irrigation canals and irrigated fields. Typically water is diverted into the irrigation canals and applied to fields mid-April through mid-October (shaded periods).Water-level altitudes increase in spring, remain elevated throughout the summer, and decrease in fall when irrigation is stopped for the season. (C) “Runoff” response, which is generally synchronized with annual precipitation and runoff. Water levels increase in April, May, or June, and show a rapid decrease by July, mimicking river stages.

Table 2. Groundwater quality summary, alluvial aquifer.

Constituent or Property	Number of Detections/ Wells	Minimum	Median	Maximum	USEPA SMCL or MCL	Exceeds
Major Ions (mg/L)						
Ca	90/90	4.10	97.20	449.00	—	—
Mg	90/90	0.82	60.85	440.00	—	—
Na	90/90	15.90	138.35	1250.00	250	22
K	90/90	1.20	4.62	18.90	—	—
Mn	63/90	<0.001	0.39	3.15	0.05	43
HCO_3	90/90	97.60	409.85	716.10	—	—
SO_4	90/90	44.60	424.20	4605.50	250	58
Cl	87/90	<0.50	16.10	162.60	250	0
NO_3	93/119	<0.25	2.50	209.00	10	14
F	40/61	<0.50	0.86	3.80	4	0
Fe	46/90	<0.003	2.70	3.10	0.3	10
Other Parameters						
TDS (mg/L)	90/90	272.52	953.27	6918.18	500	72
Dissolved Constituents	90/90	365.00	1174.14	7215.92	—	—
Hardness (as mg/L $CaCO_3$)	90/90	13.59	485.35	2847.30	—	—
pH	90/90	6.90	7.60	9.26	6.5–8.5	1

Note. mg/L, milligrams per liter; USEPA, United States Environmental Protection Agency; SMCL, secondary maximum contaminant level; MCL, maximum contaminant level.

There are distinct spatial zonations in the water quality. In general the water evolves from highly mineralized Na-SO_4 type water along the northwest margin of the alluvial valley to 'relatively fresh' Ca-Mg-HCO_3 type water in the middle of the valley (Part B, map 3, fig. 17). The sodium and sulfate concentrations show the most variability and are likely derived from underlying marine shales.

Typically in a groundwater flow system water becomes more mineralized in the downgradient direction due to increased water–rock interaction. In the alluvial aquifer system there is a marked decrease in TDS from the valley margin downgradient toward the valley center, clearly showing the influence of irrigation recharge. Low TDS water (<200 mg/L) diverted from the Yellowstone River is conveyed across terraces and the valley bottom through an extensive network of mostly unlined canals and ditches. Water level-data (see above) indicate that large volumes of irrigation water recharge the alluvial aquifer system. The decrease in TDS and change in groundwater composition beneath, and downgradient from, irrigated areas highlights the significance of irrigation recharge. The irrigation recharge maintains large areas of potable groundwater within the alluvial aquifer system that would not exist in its absence (fig. 18).

Nitrate

Alluvial groundwater samples from 119 sites were analyzed for nitrate. The samples were obtained between 1997 and 2008; at sites where multiple samples were collected, the highest nitrate concentration was included in the summary statistics. Nitrate in groundwater is derived primarily from inorganic fertilizer, animal manure, human sewage, waste water, atmospheric deposition, and natural soil processes. In general, nitrate concentrations are highest in shallow groundwater beneath agricultural land-use areas with well-drained soils and oxygenated geochemical conditions (Burow and others, 2010). The USEPA MCL for nitrate in groundwater is 10 mg/L. Concentrations greater than the MCL pose a risk to pregnant women and children (see glossary for more details). Additionally, because

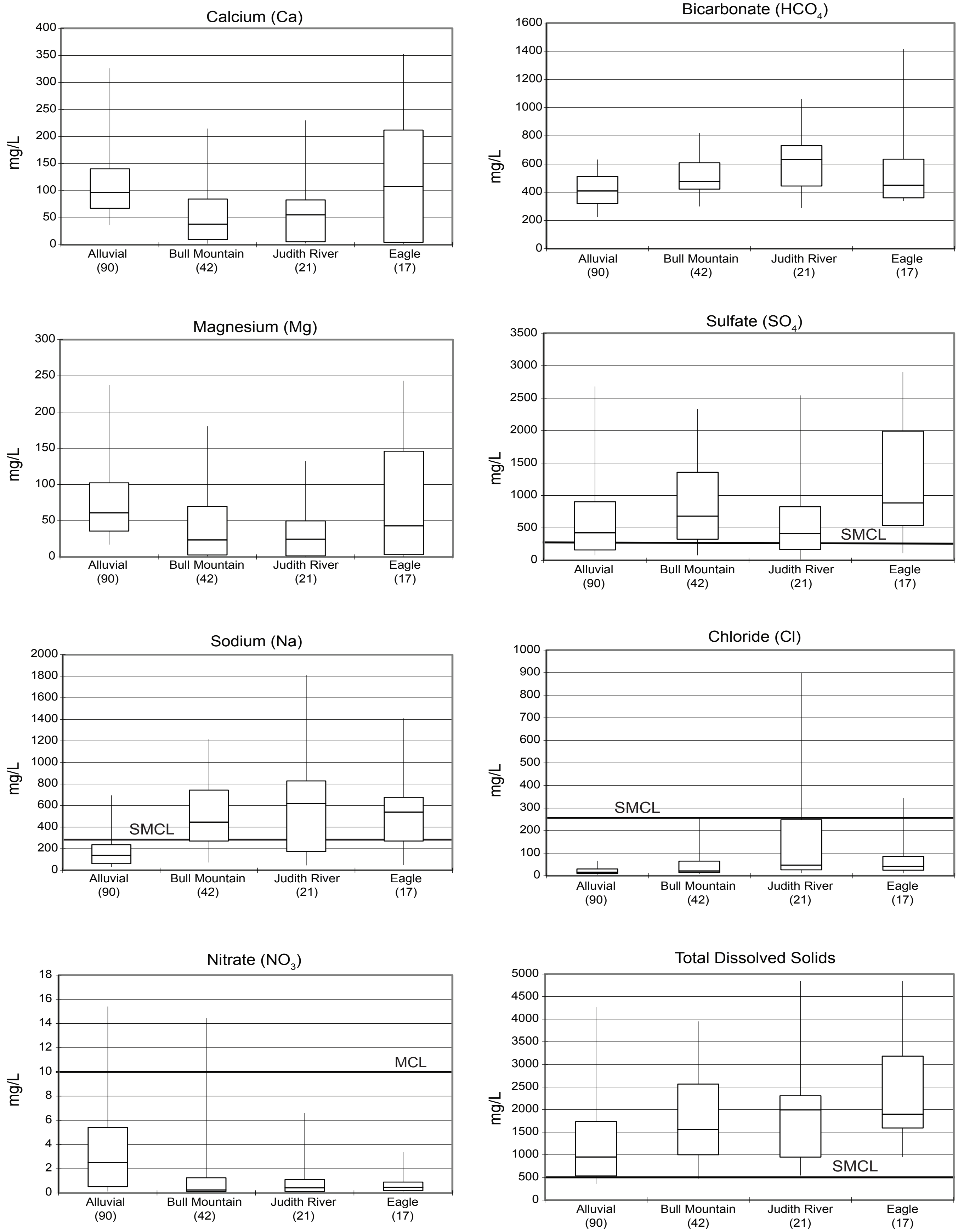


Figure 17. Box plots summarizing concentrations of dissolved constituents in the major aqifers. Groundwater in the alluvial aquifer is less mineralized than water from the bedrock aquifers. However, TDS in 75% of the samples from the alluvial aquifer exceeded the secondary drinking water standard of 500 mg/L; TDS in almost all of the samples from the bedrock aquifers exceeded the secondary standard.

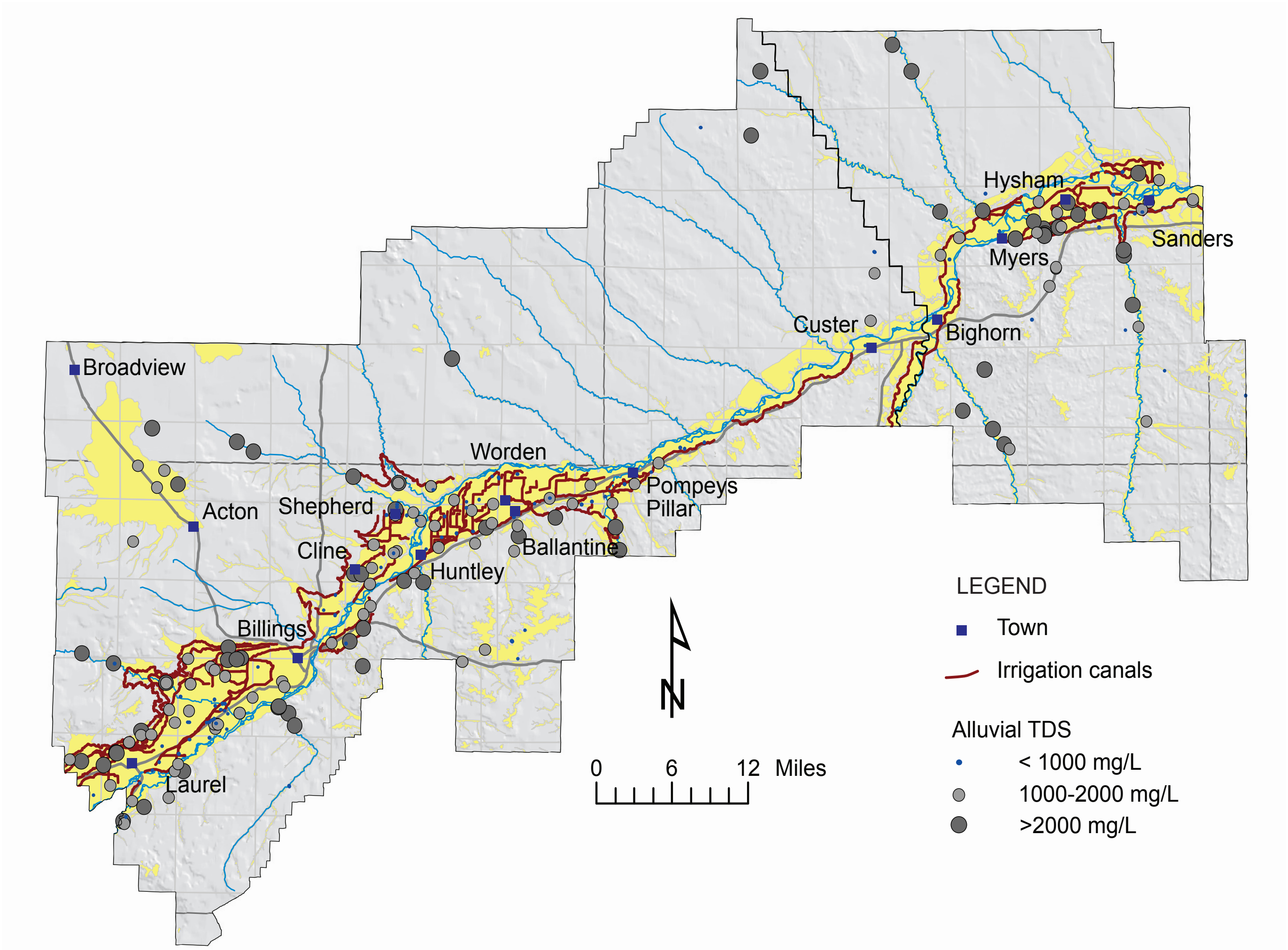


Figure 18. The greatest TDS concentration in the alluvial aquifer is in tributary valleys and along the margins of the Yellowstone River Valley. Relatively fresh water that recharges the alluvial aquifer evolves into highly mineralized, sodium and potassium-rich sulfate-dominated water as it flows through fine-grained colluvial deposits in upgradient areas overlying the aquifer in tributary valleys and near the Yellowstone River Valley margins.

groundwater discharges to surface water, excess nitrate in groundwater can lead to ecological disturbances in the surface water.

Nitrate is widespread in the alluvial aquifer; 78 percent of sampled sites had detectable nitrate, concentrations ranged up 209 mg/L, and the median was 2.8 mg/L (fig. 17). The 10 mg/L MCL was exceeded in 14 wells.

As a way to discern land-use impacts, nitrate concentrations were grouped into three reporting ranges:

(1) Low level, not detected (less than 0.5 mg/L) to less than 2 mg/L: may reflect natural occurrence or minor land-use impacts,
(2) Impacted (2 to 9.9 mg/L): elevated concentrations probably reflecting land-use impacts, and,
(3) Impacted and MCL exceedances (greater than or equal to 10 mg/L): elevated concentrations that represent land-use impact as well as a human-health risk.

In 56 of the 119 wells sampled (47 percent), nitrate concentrations were less than 2 mg/L and reflect sites with minor land-use impacts. In more than half the wells (63 of 119) nitrate concentrations exceeded 2 mg/L, suggesting land-use impacts; in 14 wells, the concentration was greater than 10 mg/L and poses a human health threat. Impacted alluvial wells are distributed throughout the alluvial aquifer (fig. 19).

Land use and underlying geology affect the nitrate concentrations in the alluvial aquifer. In Yellowstone County near Billings, elevated concentrations were detected beneath unsewered subdivisions in what was historically agricultural land. In Treasure County, elevated nitrate concentrations were de-

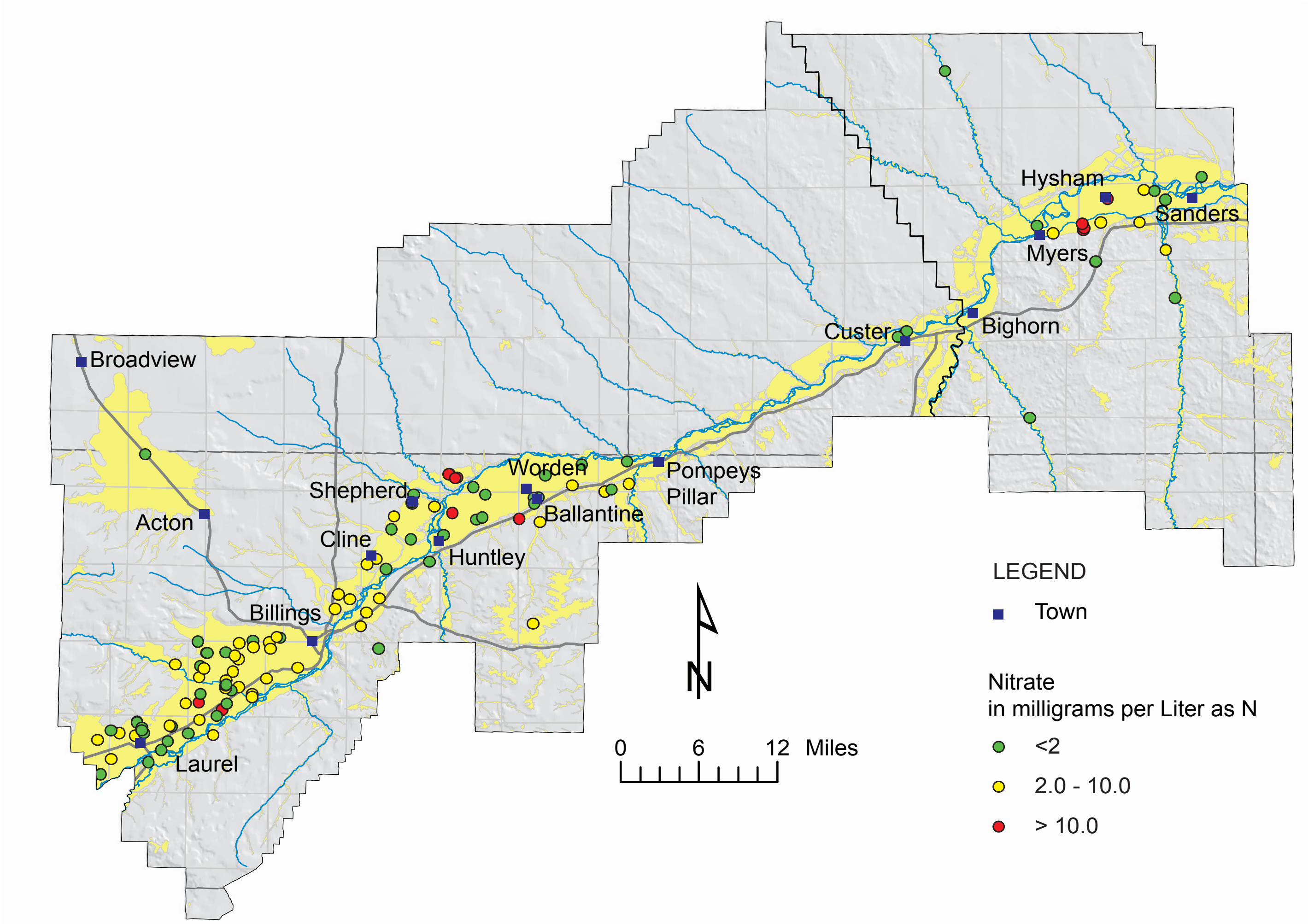


Figure 19. Distribution of nitrate in the alluvial aquifer system. The groundwater at 63 of the 119 (53 percent) alluvial wells sampled contained nitrate concentrations greater than 2 mg/L, which indicates impacts from land-use practices that may include subsurface disposal of septic system effluent and leaching of fertilizer near and upgradient from the wells impacted. At 14 wells the concentration of nitrate in the groundwater exceeds the maximum contaminant level of 10 mg/L, and may pose a threat to pregnant women, infants, and the elderly.

tected adjacent to heavily irrigated sugar beet fields, a feed lot, and where the alluvial valley has incised into Bearpaw Shale (figs. 7, 19).

Other constituents detected above SMCLs in the alluvial aquifer include sodium, sulfate, manganese, and iron. The median sodium concentration in water from 90 wells was 138 mg/L (table 1); about 25 percent of the samples exceeded the 250 mg/L SMCL. The median sulfate concentration was 424 mg/L, well above the 250 mg/L SMCL; 58 of 90 samples had sulfate concentrations in excess of 250 mg/L (fig. 17). The SMCL for manganese, 0.05 mg/L, was exceeded in 42 alluvial aquifer water samples; the median concentration was 0.03 mg/L. Iron was detected in 47 of 90 samples; the median concentration was 0.01 mg/L. The SMCL of 0.3 mg/L was exceeded in 10 samples.

Bull Mountains Aquifer System

An aquifer system is a heterogeneous body of alternating layers of permeable and poorly permeable material that functions regionally as a water-yielding unit. An aquifer system consists of at least two aquifers separated at least locally by confining units that impede groundwater movement but do not greatly affect the regional hydraulic continuity (Poland and others, 1972). The Bull Mountains aquifer system includes, in descending order, the Fort Union, Lance, and Fox Hills Formations in Treasure and Yellowstone Counties (figs. 6, 7, 8). These geologic units are referred to as an aquifer system because permeable aquifer materials (mostly sandstones and a few coals) are interconnected, groundwater flows across formation boundaries, and local flow-paths can be mapped within the unit (Part B, map 4). The Bearpaw Shale forms a basal confining unit. The Bull Mountain aquifer system, discussed in detail on Part B, map 4, contains about 14 percent of all wells in the Middle Yellowstone Area. The wells are distributed throughout the outcrop area (fig. 20).

The Fort Union Formation is the shallowest unit in the aquifer system and is exposed at the land surface across most of the area (fig. 7). The Fort Union was deposited by streams that generally flowed eastward across central and eastern Montana during uplift of the Rocky Mountains (Cherven and Jacob, 1985). Stream-channel sandstone, mud-rich floodplain deposits, and coal seams deposited in bogs characterize the unit. The Fort Union is subdivided into three members (Vuke and others, 2000, 2003). The uppermost Tongue River Member is a major coal-bearing unit that contains in sub-equal parts fine- to medium-grained sandstone, shale, and mudstone. The middle, Lebo Member, is mostly dark gray shale and mudstone with a few thin sandstones. The lowest, Tullock Member, is the most extensive of the three units and contains sub-equal proportions of sandstone and mudstone.

The Lance Formation is as much as 350 ft thick and found immediately beneath the Fort Union Formation. The Lance is fine-grained sandstone with interbeds of shale and a few thin coals (Wilde and Porter, 2000), and was deposited in stream channels and floodplains. The Lance Formation, defined in Wyoming and southern Montana, is equivalent to the Hell Creek Formation of central and eastern Montana (Fox, 1993).

The basal Fox Hills Formation is a regionally continuous, poorly consolidated, sandstone-dominated unit with interbeds of siltstone and shale; the unit ranges from about 10 to 110 ft thick. The unit was deposited in beach and near-shore environments during the time the last Cretaceous seaway was retreating eastward from central Montana (Gill and Cobban, 1973; Rigby and Rigby, 1990; Fox, 1993).

Water-bearing zones in the Bull Mountains aquifer system (as indicated by DWE records) range from depths of about 60 to about 200 ft; most wells have been drilled to depths of 100–250 ft (fig.

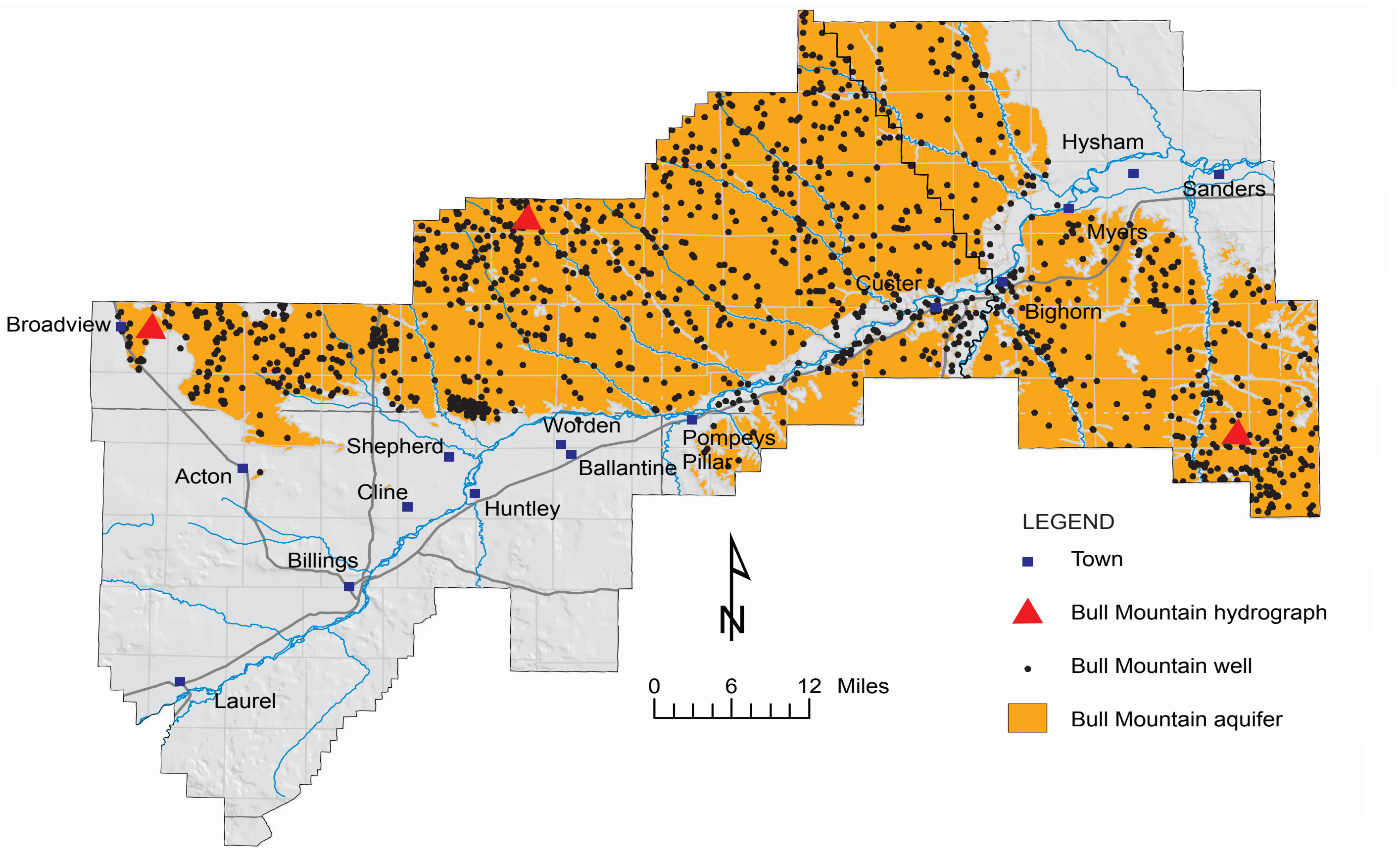


Figure 20. Water wells completed in the Bull Mountain aquifer system are concentrated in the outcrop area and the Yellowstone River Valley where alluvium is less than 70 ft thick.

11). Reported well yields range from 2 to 30 gpm with a median of 8 gpm (fig. 12). Estimated drilling depths to the aquifer range from less than 150 ft to more than 350 ft depending on topography and the potentiometric surface. Estimated drilling depths are shown on Part B, map 4.

Groundwater flow

The potentiometric surface for the Bull Mountain aquifer system is shown on Part B, map 4. Water-level altitudes range about 4,000 ft above sea level in the north–northwest part of the area to about 2,700 ft where the Yellowstone River exits the area. Similar to the alluvial aquifer, the potentiometric surface in the Bull Mountain aquifer system is a subdued expression of the topographic surface; the highest groundwater altitudes coincide with the regional topographic highs and the lowest altitudes with the regional topographic lows. In general the uppermost aquifers in outcrop areas are under water-table (unconfined) conditions, but become confined where they are buried below mudstone and shale layers. Regionally, groundwater flow is away from major drainage divides and towards the Yellowstone River. North of the Yellowstone River, the predominant direction of groundwater flow is towards the southeast; south of the Yellowstone, the predominant direction is towards the northwest.

Water levels

Long-term water-level measurements from 13 Bull Mountain aquifer system wells show that water levels respond mostly to multi-year climate variability rather than seasonal recharge events. Water levels in a shallow well completed in the outcrop area of the Lance Formation (well 15966), with an open interval between 37 and 80 ft below land surface, show little seasonal variation but suffered about a 15-ft decline related to drought between 1999 and 2006 (fig. 21). A shallow Fort Union well near Sarpy Creek, a major tributary to the Yellowstone River in southeastern Treasure County (well 705232), obtains water from the Tullock Member at about 55 ft below the surface (fig. 21). The water level dropped more than 7 ft between 1999 and 2006, but there is little seasonal water-level fluctuation. Another Fort Union Formation well completed in a recharge area in northern Yellowstone County (well 18368) is open to the formation at 60 ft below the land surface. Between 1999 and 2006 water levels were stable, fluctuating between 41 and 43 ft below the surface (fig. 21).

Water quality

Water in the Bull Mountain aquifer system is generally of marginal quality. The concentration of dissolved constituents in 42 samples ranged from 71 to about 8,477 mg/L; 93 percent of the samples exceeded 500 mg/L (fig. 17). The median TDS concentration was 1,559 mg/L, or more than three times the 500 mg/L SMCL. In about 40 percent of the samples, the concentration was greater than 2,000 mg/L, indicating the water is unsuitable for drinking water purposes. TDS estimated from specific conductance measurements also confirmed that much of the water in the Bull Mountain aquifer system is mineralized. In water from 188 wells, the median estimated TDS was 1,769 mg/L. Only 7 of the TDS estimates were less than 500 mg/L, and 73 were greater than 2,000 mg/L. Although water-quality parameters may indicate marginal water quality in the Bull Mountain aquifer system, many residents still use this water with or without treatment because it may be their only water source.

The best quality water, as measured by TDS, generally occurs in topographically high recharge areas. As water moves downgradient it becomes more mineralized. Part B, map 4 shows TDS concentrations in recharge areas near the north border of the study area that are generally less than 1,000 mg/L. Southward, down the groundwater flow path, TDS concentrations increase to more than 3,000 mg/L. However, near the Yellowstone River, concentrations again decrease to between 1,000 and 2,000 mg/L, likely due to mixing with relatively fresh alluvial groundwater.

The water varies from a sodium-bicarbonate to a sodium-sulfate type. Sodium concentrations exceeded the 250 mg/L SMCL in 34 samples (77 percent); the median concentration was 471 mg/L (fig. 17). Sulfate concentrations exceeded the 250 mg/L SMCL in 35 samples, with a median of 730 mg/L (fig. 17). Nitrate concentrations were measured in samples from 55 wells; the concentrations ranged from not detected to 39 mg/L. Most of the samples (42 of 55) had concentrations less than

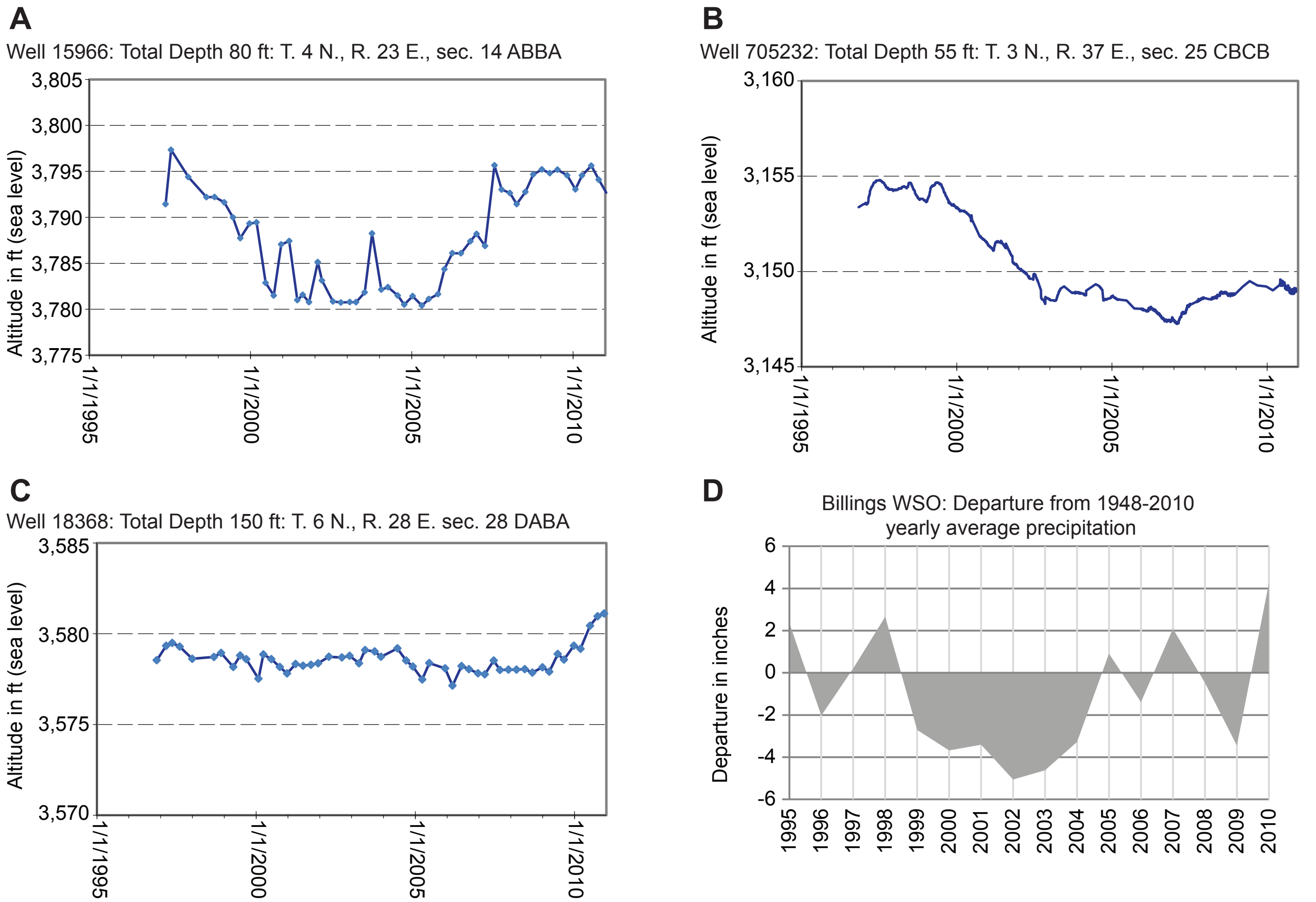


Figure 21. Hydrograph records for Bull Mountain aquifer wells and departures from 1948 to 2010 yearly average precipitation. (A) Water level in well 15966 tracks closely to departure from 1948–2010 yearly average precipitation. (B) Well 705232 shows a decline in water levels from about 1999 through 2007; water levels have recovered since 2007. (C) Water levels in well 18368 in northern Yellowstone County represents water-level fluctuations in a recharge region close to the drainage boundary between the Musselshell and Yellowstone Rivers. (D) Departures from 1948 to 2010 yearly average precipitation show a prolonged period of below normal precipitation between 1999 and 2005.

2 mg/L, 5 samples (9 percent) exceeded the 10 mg/L MCL, and 8 samples (14 percent) had concentrations between 2 and 10 mg/L, suggesting land-use impacts.

Iron and manganese were also detected at concentrations above their respective SMCLs in a few wells. Iron was detected in 28 of the 43 samples, and concentrations ranged up to 1.32 mg/L; the median concentration was 0.2 mg/L and 4 samples exceeded the 0.3 mg/L SMCL (table 3). Manganese was detected in 29 samples, with a median concentration of 0.01 mg/L; the SMCL of 0.05 mg/L was exceeded in 10 samples.

Judith River Formation Aquifer

The Judith River Formation aquifer includes fine-grained sandstone and sandy shale of the Judith River Formation. The formation thickens to the west, from about 200 ft in Treasure County to greater than 500 ft in northwestern Yellowstone County; the cumulative thickness of sandstone also increases westward, from about 50 ft to about 200 ft (Feltis, 1982b, d). Most individual sandstones are about 10 ft thick. However, a 20- to-70-ft-thick sandstone is locally present at the formation's base; it attains a thickness of 110 ft in northeastern Big Horn County (Richards and Rogers, 1951). The Judith River Formation is underlain by the Claggett Shale, which consists of 100–300 ft of sandy shale and forms the base of the Judith River Formation aquifer. Where the Judith River Formation dips into the subsurface,

Table 3. Groundwater quality summary, Bull Mountain aquifer system.

Constituent or Property	Number of Detections/ Wells	Minimum	Median	Maximum	USEPA SMCL or MCL	Exceeds
Major Ions (mg/L)						
Ca	42/42	1.65	38.25	237.80	—	—
Mg	42/42	0.33	23.51	374.00	—	—
Na	42/42	5.24	446.90	2322.00	250	19
K	42/42	0.69	2.34	21.20	—	—
Mn	29/42	<0.002	0.06	0.52	0.05	10
HCO_3	42/42	66.10	477.96	1006.90	—	—
SO_4	42/42	3.73	683.40	2841.00	250	33
Cl	36/42	1.95	21.25	2630.00	250	2
NO_3	21/55	<0.25	1.99	32.80	10	4
F	10/12	<0.5	1.97	3.68	4	0
Fe	27/42	<0.003	0.17	1.32	0.3	4
Other Parameters						
TDS (mg/L)	42/42	70.87	1558.81	8477.55	500	39
Dissolved Constituents	42/42	104.41	1783.65	8539.45	—	—
Hardness (as mg/L $CaCO_3$)	42/42	5.49	209.41	2083.73	—	—
pH	42/42	7.24	8.26	9.24	6.5–8.5	14

Note. mg/L, milligrams per liter; USEPA, United States Environmental Protection Agency; SMCL, secondary maximum contaminant level; MCL, maximum contaminant level.

it is overlain by the Bearpaw Shale. The Claggett and Judith River Formations have a gradational contact (Lopez, 2000a,b).

Although the Judith River Formation aquifer is present in the subsurface throughout most of the area, it is typically greater than 1,000 ft below land surface in areas more than 1 or 2 miles from the outcrop (Part B, map 4). It is utilized as an aquifer where it is exposed at, or near, the land surface to the north and east of Billings, and in the northeast part of Treasure County (fig. 22). About 7 percent of all water wells in the Middle Yellowstone Area are completed in the Judith River Formation aquifer (fig. 9). Most of the wells obtain water from within 100 ft of land surface, although they are mostly drilled to twice that depth (fig. 11). Many of the wells produce water from multiple sandstone beds. The median reported well yield was 10 gpm; most reported yields are between 7 and 20 gpm (fig. 12).

Groundwater flow

The potentiometric surface map for the Judith River Formation aquifer depicts a series of local flow systems superimposed on a regional flow system (Part B, map 4). Local flow systems occur in the outcrop areas where the aquifer is not confined by the Bearpaw Shale. Recharge is from infiltration of rain and snowmelt, groundwater is under unconfined conditions, and groundwater flow is towards the nearest drainage. Hydraulic gradients in local flow systems typically range from 0.01 to 0.10 ft/ft. Where the Judith River Formation aquifer becomes deeply buried distant from recharge sources, groundwater is under artesian conditions, groundwater flow becomes uniform and regional, and hydraulic gradients are about 0.001 to 0.01 ft/ft. Near Billings, the potentiometric surface ranges from 4,100 to 3,100 ft above sea level and groundwater flow is generally eastward. Near Hysham the potentiometric surface ranges from 2,800 to 2,600 ft above sea level and groundwater flow is towards the Yellowstone River Valley.

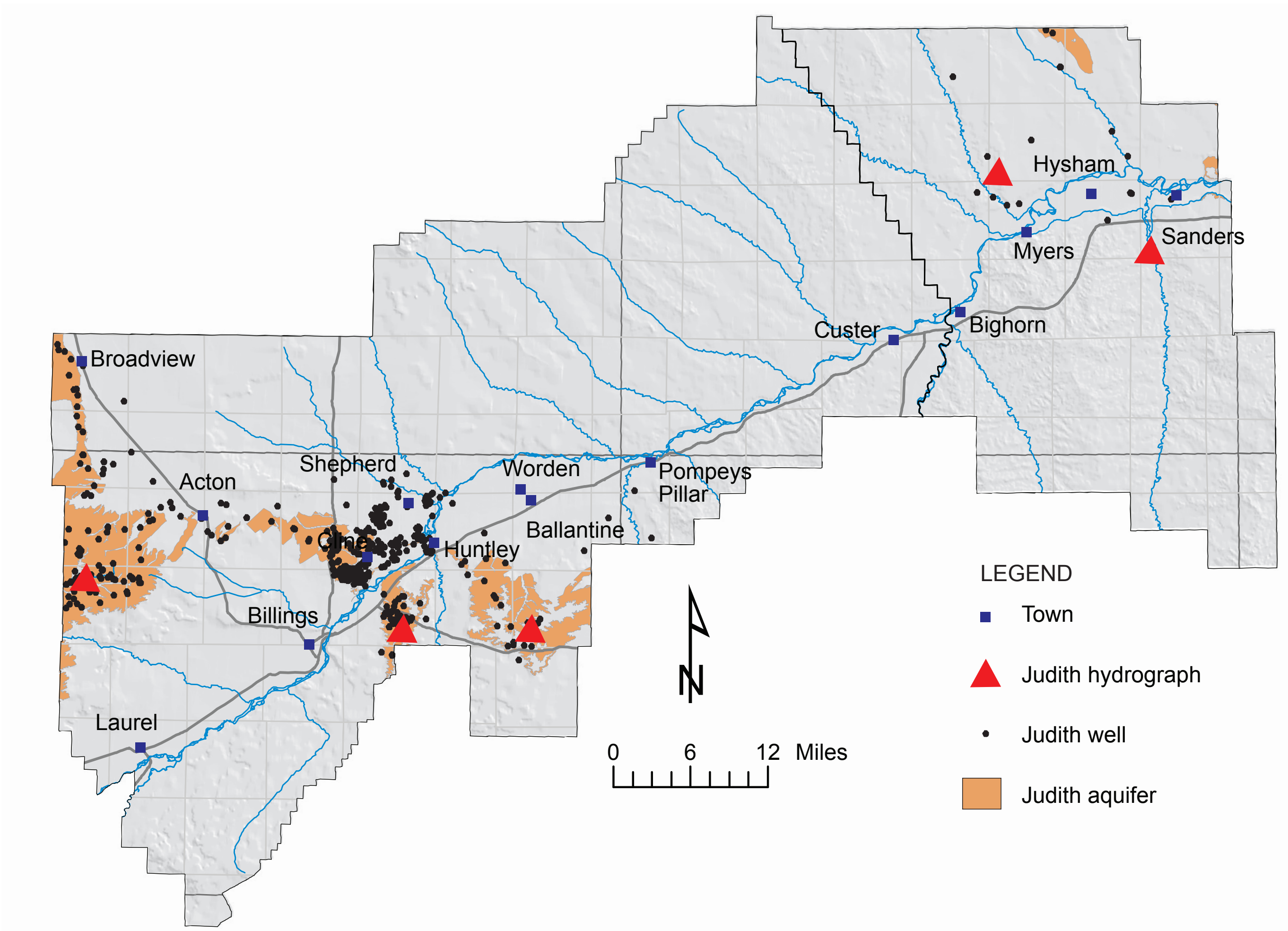


Figure 22. Water wells completed in the Judith aquifer are concentrated in the outcrop area of the formations and in areas where the Bearpaw Shale is at the surface.

Water levels

Long-term water-level measurements are available for five wells in the Judith River Formation aquifer. Three wells are in the western part of the study area near Billings and two are in the eastern part near Hysham (fig. 22). In the west, well 10289 is 75 ft deep and completed in the outcrop area of the Judith River Formation, where groundwater is under unconfined conditions (fig. 23A). Recharge is derived from precipitation and the water levels reflect long-term climate variability and show little seasonal variation. During the period of below-average annual precipitation, between 1997 and 2005, the water level dropped almost 15 ft. In the subsequent relatively wet period from 2005 to 2010, water levels recovered more than 15 ft.

Wells 144353 and 131693 (fig. 23B,C) are completed where the Judith River Formation is exposed at the surface east of Billings and on the east–southeast side of the Yellowstone River. Quarterly or semi-annual water-level measurements only extend back to 2002 for these wells. For the period of record, both wells show seasonal water-level fluctuations superimposed on an increasing trend. Based on quarterly measurements in well 144353 (DWE = 302 ft), the seasonal fluctuation is as much as 10 ft per year with seasonal high (water level closest to the land surface) occurring in December. Between 2002 and 2010, average water levels rose by about 20 ft. In well 131693 (DWE = 160 ft), the seasonal fluctuation is less than 5 ft per year, and the average water level has increased about 6 ft between 2002 and 2010.

In the east part of the study area, the Judith River Formation aquifer is deeply buried and confined by the Bearpaw Shale. Quarterly measurements in well 1502 (DWE = 886 ft) dating back to 1997 show that in this part of the aquifer the water levels are not affected by climatic variability like the Judith River Formation wells in the western part of the study area. Water levels fluctuate seasonally on

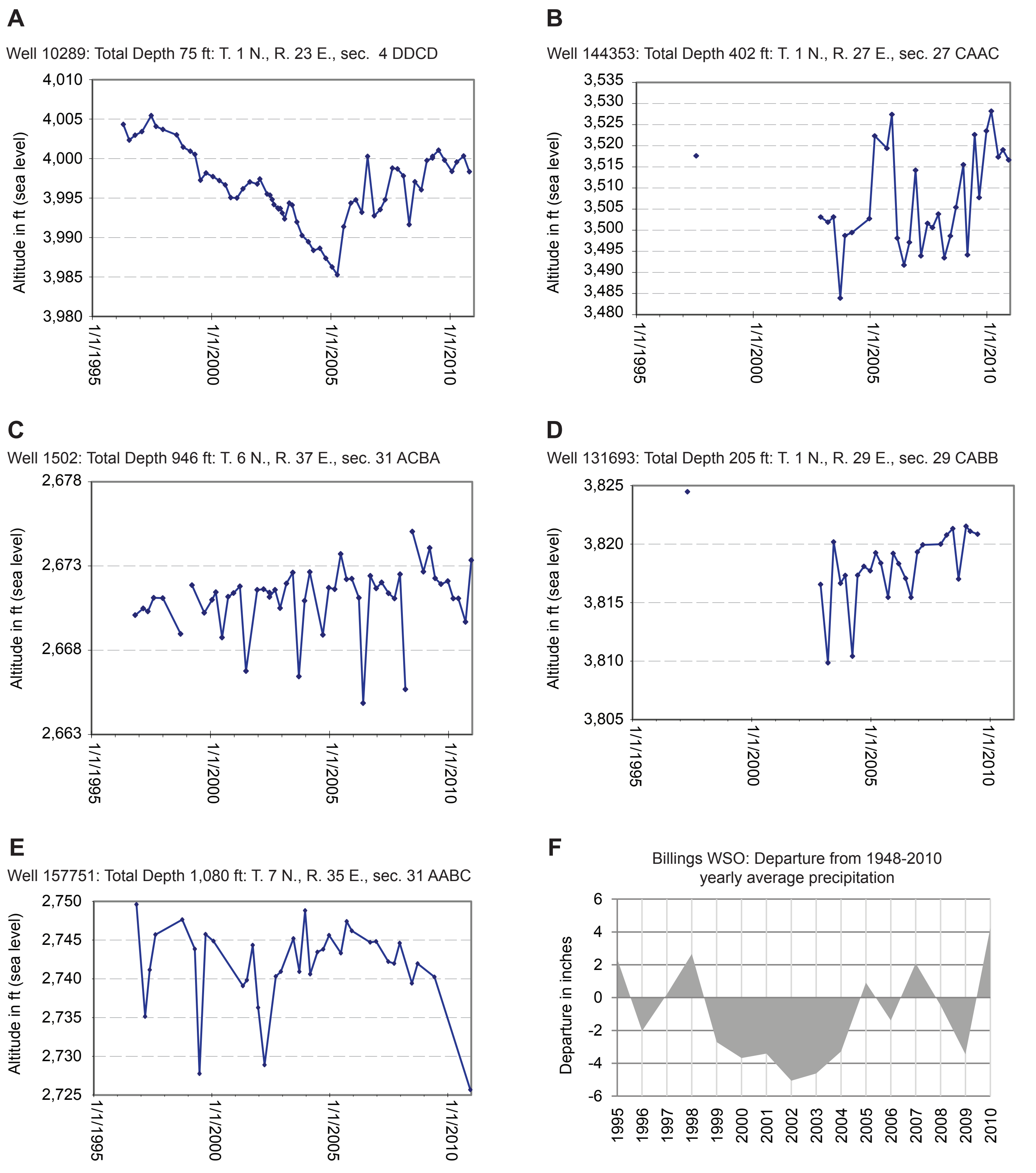


Figure 23. Hydrograph records for Judith aquifer wells and departures from 1948 to 2010 yearly average precipitation. (A) Water levels in well 10289 track closely to departure from 1948 to 2010 yearly average precipitation. This well is 75 ft deep and located in the outcrop area of the Judith Formation. (B, C) Hydrographs for wells located near outcrop that show seasonal water-level fluctuations superimposed on an increasing trend. (D, E) Hydrographs for wells located more than a mile from the closest outcrop in Treasure County do not appear to track with departure from 1948 to 2010 yearly average precipitation. (F) Departures from 1948 to 2010 yearly average precipitation show a prolonged period of below normal precipitation between 1999 and 2005.

the order of 5 ft per year, but there is a persistent long-term increasing trend even through the drought years of 1997–2005. The hydrograph shows a water-level increase of about 2.5 ft from 1996 through 2010 (fig. 23D).

Well 157751 is another deep Judith River Formation aquifer well with quarterly measurements dating back to 1996 (fig. 23E). There is a slight downward trend in water levels during the period of record, but water-level measurements show no trend through the drought cycle of 1997–2005.

Water quality

MBMG personnel collected 22 groundwater samples from 21 wells in the Judith River Formation aquifer; 21 of the samples were analyzed for major ion and trace-element concentrations, and one sample was analyzed for nitrate only. The areal distribution of water quality and dissolved constituents in the Judith River Formation aquifer are presented on Part B, map 5. Groundwater suitable for domestic use (TDS less than 2,000 mg/L) occurs mostly in outcrop areas, or where alluvial deposits overlie the aquifer. Dissolved constituents in groundwater underlying outcrop areas is derived from water–soil–mineral reactions as rain and snowmelt infiltrate and recharge the aquifer.

TDS concentrations in the Judith River aquifer are variable, ranging in 21 samples from 414 mg/L to 5,529 mg/L (fig. 17); only one sample did not exceed the 500 mg/L SMCL. The median TDS concentration was about 2,000 mg/L, or more than four times the SMCL. Eleven of the 21 samples (52 percent) had TDS concentrations greater than 2,000 mg/L, indicating water not suitable for drinking purposes. Estimated TDS from specific conductance measurements in water from 57 wells confirmed the mineralized nature of Judith River Formation aquifer water; the median estimated TDS was 2,266 mg/L; only 1 measurement did not exceed 500 mg/L, but 32 measurements were greater than 2,000 mg/L.

Where the Judith River Formation is confined by the Bearpaw Shale away from outcrop/recharge areas, the TDS concentration increases and the water evolves from a Ca-Mg-SO_4 to Na-SO_4 type water. The increase in the proportion of sodium occurs through cation exchange in which calcium and magnesium are exchanged with sodium on clay minerals. Sulfate is likely derived from weathering of pyrite, anhydrite, and/or gypsum. In the eastern part of the study area near Hysham, where the Judith River Formation aquifer is deeply buried, the water evolves to a Na-Cl type water. Sulfate is reduced to hydrogen sulfide and chloride is leached from the overlying marine shale.

In the Judith River aquifer, the median sodium concentration was 523 mg/L (fig. 17); the SMCL of 250 mg/L was exceeded in water from 12 wells (table 4). The median sulfate concentration was 411 mg/L, and the SMCL was exceeded in water from 13 wells. The manganese SMCL was exceeded in 6 samples. Iron was not detected above the SMCL.

Nitrate was detected in about half of the samples (12 of 22) from the Judith River Formation aquifer. All but four of the samples were less than 2 mg/L or non-detect. Two samples exceeded the 10 mg/L MCL and one concentration was 19.1 mg/L.

Eagle Aquifer

The Eagle aquifer is an important source of stock and domestic water in west-central Yellowstone County. The Eagle aquifer consists of water-saturated sandstone layers within the Eagle Sandstone and also the underlying Telegraph Creek Formation. About 7 percent of the wells in the study area are completed in the Eagle aquifer (fig. 9). Where the formation has not been eroded, the Eagle Sandstone contains three to four sandstones separated by shale and sandy shale in the Laurel and Billings areas. The sandstones are mostly fine- to medium-grained, and arranged in sheet-like beds as much as 50 ft in thickness (Lopez, 2000a; Wilde and Porter, 2000). The transition from the Eagle Sandstone to the underlying Telegraph Creek Formation is gradational as sandstone bed numbers and thicknesses decrease, and shale and sandy shale beds become predominant (Lopez, 2000a). The Eagle and Telegraph Creek Formations are about 600 to 800 ft thick in Treasure and Yellowstone Counties (Feltis, 1982c); however, the cumulative sandstone thickness increases from only about 25 ft in Treasure County to about 225 ft northwest of Billings, the greatest thickness of sandstone in the formations within Montana (Feltis, 1982a).

Water wells drilled into the Eagle aquifer are

Table 4. Groundwater quality summary, Judith River aquifer.

Constituent or Property	Number of Detections/Wells	Minimum	Median	Maximum	USEPA SMCL or MCL	Exceeds
Major Ions (mg/L)						
Ca	21/21	2.6	55.31	233.10	—	—
Mg	21/21	0.43	24.70	221.00	—	—
Na	21/21	29.5	619.60	1823.70	250	12
K	21/21	1.30	2.80	12.10	—	—
Mn	13/21	<0.001	0.08	0.14	0.05	5
HCO_3	21/21	282.70	633.20	118.70	—	—
SO_4	21/21	1.25	411.30	2997.00	250	13
Cl	21/21	11.30	47.00	1139.00	250	5
NO_3	11/21	<0.25	0.28	19.10	10	1
F	1/7	<0.5	4.96	4.96	4	1
Fe	16/21	<0.003	0.03	0.17	0.3	0
Other Parameters						
TDS (mg/L)	21/21	413.73	2004.36	5528.83	500	20
Dissolved Constituents	21/22	560.31	2245.37	6096.45	—	—
Hardness (as mg/L $CaCO_3$)	21/21	8.49	242.75	1483.95	—	—
pH	21/21	7.2	8.08	8.69	6.5–8.5	3

Note. mg/L, milligrams per liter; USEPA, United States Environmental Protection Agency; SMCL, secondary maximum contaminant level; MCL, maximum contaminant level.

mostly in the outcrop area that extends from northeast of Billings to northwest of Laurel (fig. 24). The Eagle aquifer is in the subsurface throughout much of the area; however, it is greater than 1,000 ft below land surface in most places (Part B, map 6). The median Eagle aquifer well depth is 180 ft, and the median DWE is 100 ft (fig. 11); however about 10 wells are 1,200 ft or deeper. The median reported yield for the aquifer is 10 gpm (fig. 12); the reported yields for most wells were between 4 and 15 gpm.

Groundwater flow

The potentiometric map depicts local and regional flow systems in the Eagle aquifer. Local flow systems occur in the outcrop areas where the Eagle Telegraph Creek aquifer is not confined by the Claggett Shale. Recharge is from infiltration of rain and snowmelt, and groundwater flow is directed towards the nearest drainage, roughly following topography. Hydraulic gradients in local flow systems typically range from 0.02 to 0.1 ft/ft.

Beyond the outcrop areas where the Eagle aquifer becomes deeply buried and far from recharge sources, the groundwater flow adopts a regional flow pattern with hydraulic gradients of about 0.005 to 0.01 ft/ft. Groundwater flow in the regional flow system is generally directed away from outcrops towards the Yellowstone River or Pryor Creek.

Water levels

Five Eagle aquifer wells have long-term quarterly or semi-annual measurements. The monitored wells range from shallow unconfined (DWE = 30 to 74 ft) to deep confined (DWE = 800 to 1,050 ft). The shallowest well (well 155351) is completed in the Telegraph Creek outcrop area, at the base of the rim rocks west–northwest of Billings, where the aquifer is unconfined. Measurements date back to 1984; however, the record is incomplete prior to 1996 (fig. 25A). The monthly to quarterly measurements from 1996 onward show that the water table fluctuates about 6 to 8 ft annually, with seasonal high water levels in the spring and lows in the fall or late

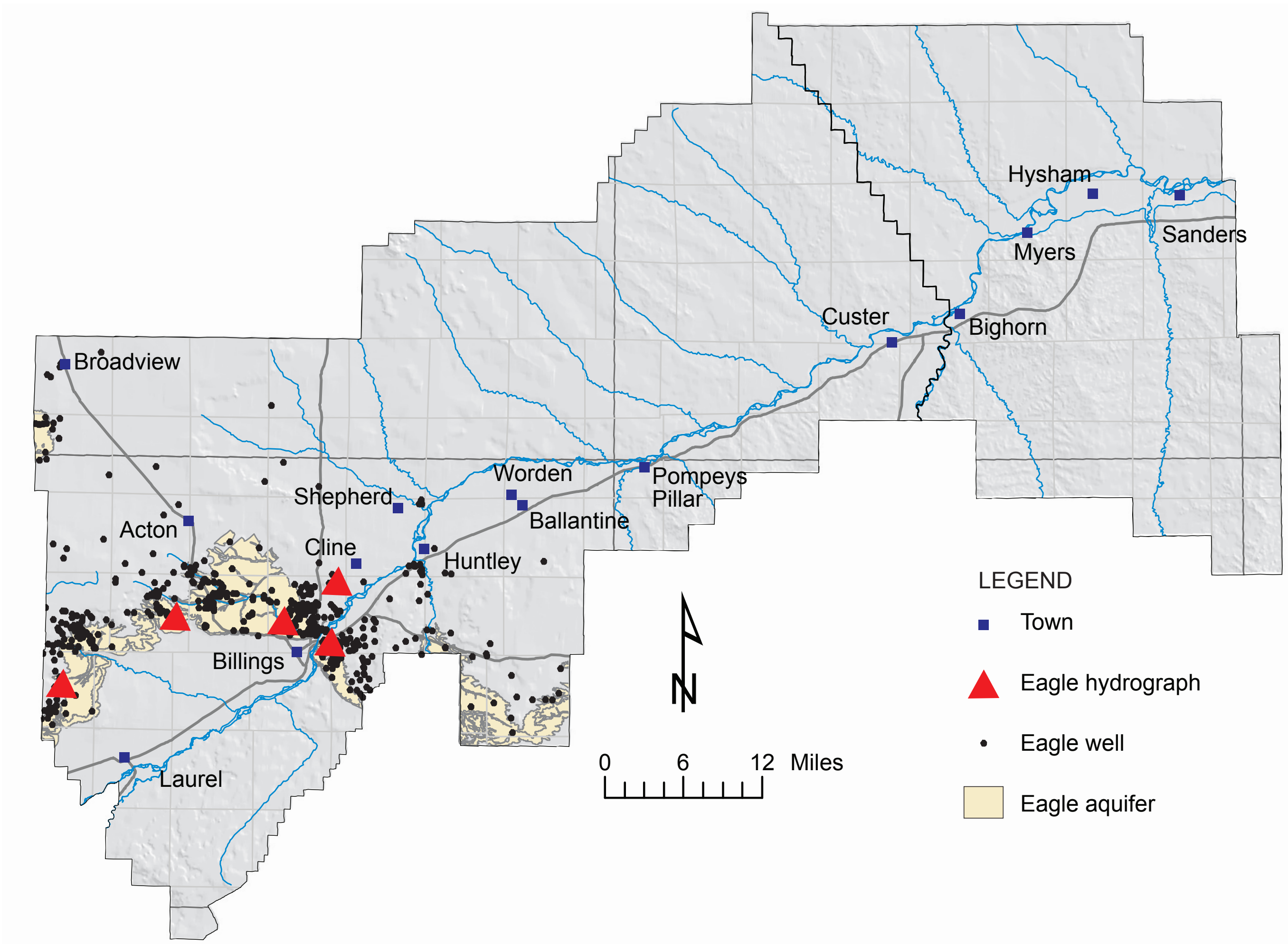


Figure 24. Water wells completed in the Eagle aquifer are concentrated in the greater Billings-to-Laurel areas, near to, and downdip from, the outcrop areas of the Eagle.

summer. The long-term record shows a water-level decrease between the 1980s and early 1990s, and a water-level recovery through the mid-1990s that reaches a maximum in 1997. Between 1997 and 2005 water levels decreased but have increased slightly since. In general, the long-term trend follows periods of above and below average annual precipitation during the same period (fig. 25F).

Two wells (11126 and 11531) with measurements since 2002 (quarterly or semi-annual) are completed in the Eagle outcrop area near Billings where the aquifer is unconfined (fig. 25). Well 11126 is located north of Billings, is perforated at 54 ft below the surface, and has a regular annual fluctuation of less than 4 ft with seasonal high water levels in the spring and seasonal lows in the late fall. Between 2002 and 2007 there was no water-level trend; however, between 2007 and 2011 water levels generally increased (fig. 25). Well 11531 is located east–northeast of Billings on the southeast side of the Yellowstone River, and is perforated 80 ft below the surface. The water levels show a regular annual fluctuation, but the seasonal highs and lows are slightly out of sync with the record from well 11126. Water-level highs occur in the fall and the lows in the spring. The water levels show a general decreasing trend during the period of record between 2003 and 2011 (fig. 25).

Well 96 is located about 5 miles northeast of Billings where the Eagle is in the subsurface and confined by the Claggett Shale. The well is perforated at 800 ft below the surface and water levels do not show a pronounced seasonal pattern. However, over the period of record between 1996 and 2011, water-level altitudes generally increased (fig. 25).

Well 92715 (fig. 25) is completed in the Eagle outcrop area about 15 miles east of Billings near its contact with the overlying Claggett Shale. The well is perforated at 69 ft below the surface and has quarterly water-level data since 1998. The

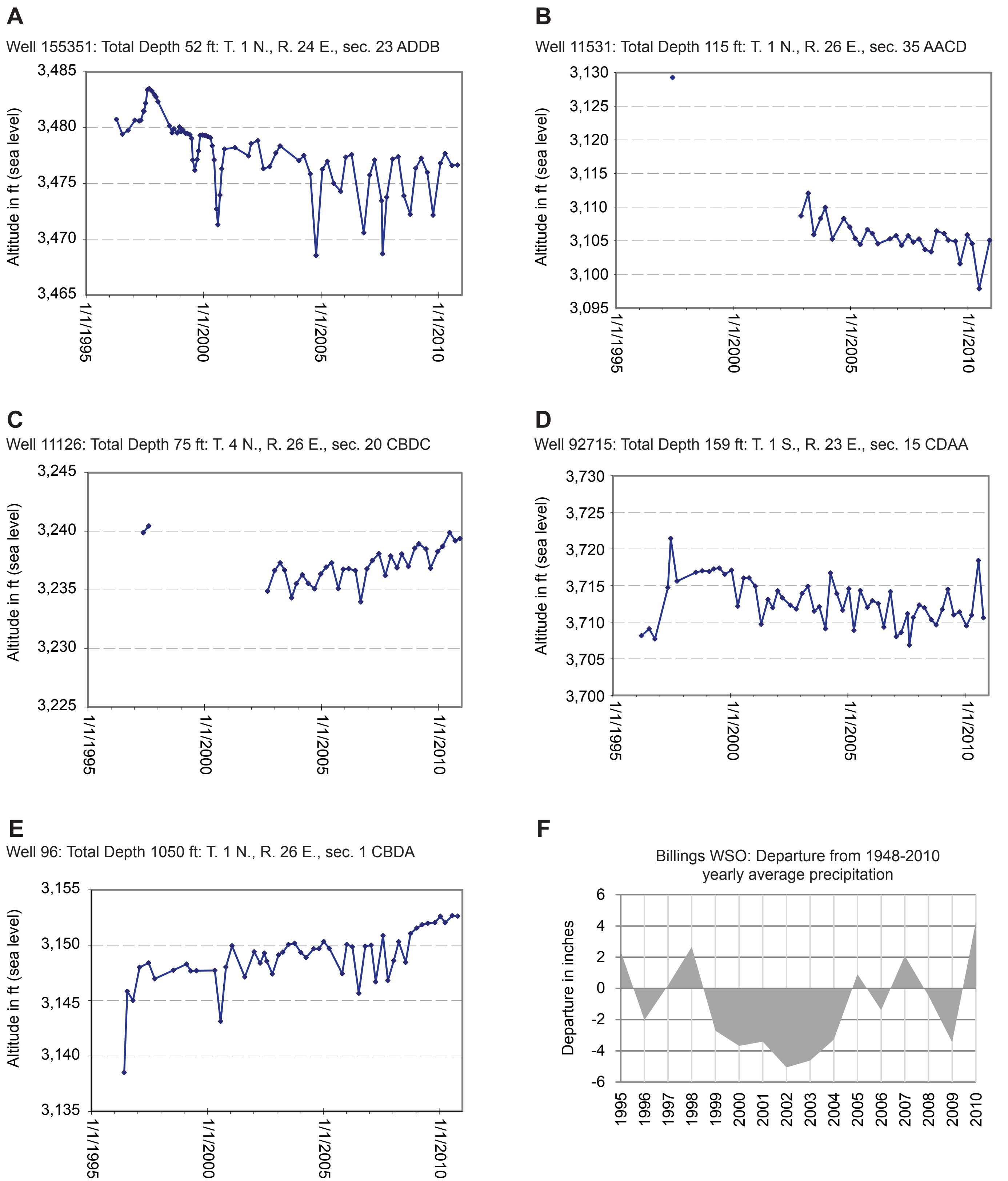


Figure 25. Hydrograph records for Eagle Aquifer wells and departures from 1948 to 2010 yearly average precipitation. (A) Water level in well 155351 (52 ft deep) declined about 5 ft from 1997 to 2005 and leveled off between 2005 and present. (B,C) Water-level records for wells 11126 and 11531 are incomplete between 1997 and 2002, but appear to decline by about 5 ft between 1997 and 2005, and increase between 2005 and present. (E) Hydrograph for well 96 does not appear to track with departure from 1948 to 2010 yearly average precipitation but rather shows an increasing trend. This well is 1050 ft deep and is located more than 3 mi northeast from the outcrop area. Hydrographs for (A) and (B) generally track with departure from 1948 to 2010 yearly average precipitation, which shows a prolonged period of below normal precipitation between 1999 and 2005.

water level fluctuates seasonally, generally on the order of 6 to 8 ft per year. However, the pattern is erratic and does not show a regular cycle. Long-term trends reflect departures from annual average precipitation, with water-level altitudes decreasing between1999 and 2005 and increasing slightly between 2005 and 2011.

Water quality

Groundwater in the Eagle aquifer is highly mineralized and poorly suited for most uses. For this study, 17 Eagle–Telegraph Creek wells were sampled, all of the wells in Yellowstone County. The areal distribution of water quality and a summary of the concentrations of dissolved minerals in the Eagle aquifer are presented on Part B, map 6. Groundwater suitable for domestic use (TDS less than 2,000 mg/L) occurs mostly in outcrop areas where the aquifer is unconfined, or where alluvial deposits overlie the aquifer. Low TDS water is generally Ca-Mg-SO_4 type water. Where the aquifer is confined by the Claggett Shale, the water becomes more mineralized and the chemistry changes to Na-SO_4-HCO_3 type water.

Most of the samples had TDS concentrations between 1,500 and 3,500 mg/L, all samples exceeded the 500 mg/L SMCL, and concentrations ranged from 538 to 7,506 mg/L with a median of 1,902 mg/L. Only 9 of the 17 samples had TDS concentrations less than 2,000 mg/L (fig. 17).

Summary statistics for the Eagle aquifer are shown in table 5. Sodium is a minor constituent in the Eagle aquifer beneath outcrop areas but becomes a major constituent due to leaching and cation exchange along groundwater flow paths. Sodium concentrations ranged from 27 to 2,457 mg/L, with a median of 540 mg/L (table 5); the 250 mg/L SMCL was exceeded in water from 13 wells. Sulfate concentrations ranged from 12.5 to 4,561 mg/L, with a median of 885 mg/L. The SMCL was exceeded in water from 13 wells. Nitrate was detected in about 60 percent of the samples, but none of the

Table 5. Groundwater quality summary, Eagle aquifer.

Constituent or Property	Number of Detections/ Wells	Minimum	Median	Maximum	USEPA SMCL or MCL	Exceeds
Major Ions (mg/L)						
Ca	17/17		107.70	370.00	—	—
Mg	17/17	0.07	43.00	276.00	—	—
Na	17/17	26.70	539.60	2457.00	250	13
K	17/17	0.67	2.92	8.46	—	—
Mn	08/17	<0.001	0.004	0.49	0.05	3
HCO_3	17/17	328.20	450.20	1520.90	—	—
SO_4	17/17	12.50	885.00	4561.00	250	13
Cl	17/17	10.90	41.60	465.00	250	2
NO_3	11/19	<0.25	0.40	4.80	10	0
F	06/07	0.29	1.68	5.62	4	1
Fe	12/17	<0.003	0.02	2.50	0.3	1
Other Parameters						
TDS (mg/L)	17/17	537.89	1901.72	7505.36	500	17
Dissolved Constituents	17/17	716.47	2573.19	7920.71	—	—
Hardness (as mg/L $CaCO_3$)	17/17	5.72	438.09	2059.91	—	—
pH	17/17	7.15	7.93	9.72	6.5–8.5	5

Note. mg/L, milligrams per liter; USEPA, United States Environmental Protection Agency; SMCL, secondary maximum contaminant level; MCL, maximum contaminant level.

concentrations exceeded the 10 mg/L MCL; the maximum concentration detected was 4.8 mg/L in a well with a DWE of 645 ft. Iron and manganese were detected in slightly more than half the samples. The iron SMCL was exceeded in 1 sample; the manganese SMCL was exceeded in 3 samples.

OTHER WATER-BEARING UNITS

Within the Middle Yellowstone Area some of the regional confining units locally yield water to wells, usually from transitional sandstone beds near contact with overlying and underlying aquifers. These units include the Bearpaw Shale, Claggett Shale, and the Colorado Group. Other rock units that are aquifers in other parts of Montana occur in the study area, but are deeply buried and therefore utilized either minimally or not at all. These units include the Fall River Formation, Kootenai Formation, Swift Formation, Chugwater Formation, Tensleep Formation, Amsden Formation, and Madison Group.

Bearpaw Shale

In most areas, the Bearpaw is dark gray to black shale containing bentonitic clay beds, is a confining unit, and is not a regional aquifer. The unit ranges in thickness from about 1,100 ft in eastern Treasure County to about 450 ft in western Yellowstone County (figs. 6, 7, 8).

About 2 percent of the wells in the Middle Yellowstone Area are reported as being completed in the Bearpaw Shale (fig. 9). Some wells are completed in thin sandstones near the upper part of the formation, but other sandstones in Yellowstone County are roughly mid-formation, about 300-400 ft below the upper contact. Sandstones in the Bearpaw are either individual 1- to 10-ft-thick beds, or found within 100-ft-thick intervals of shale with sand stringers. A few wells are completed in fractured shale. Most wells are located in or near the Bearpaw outcrop area near the top of the formation, or in areas where the Bearpaw is directly overlain by alluvium (fig. 26).

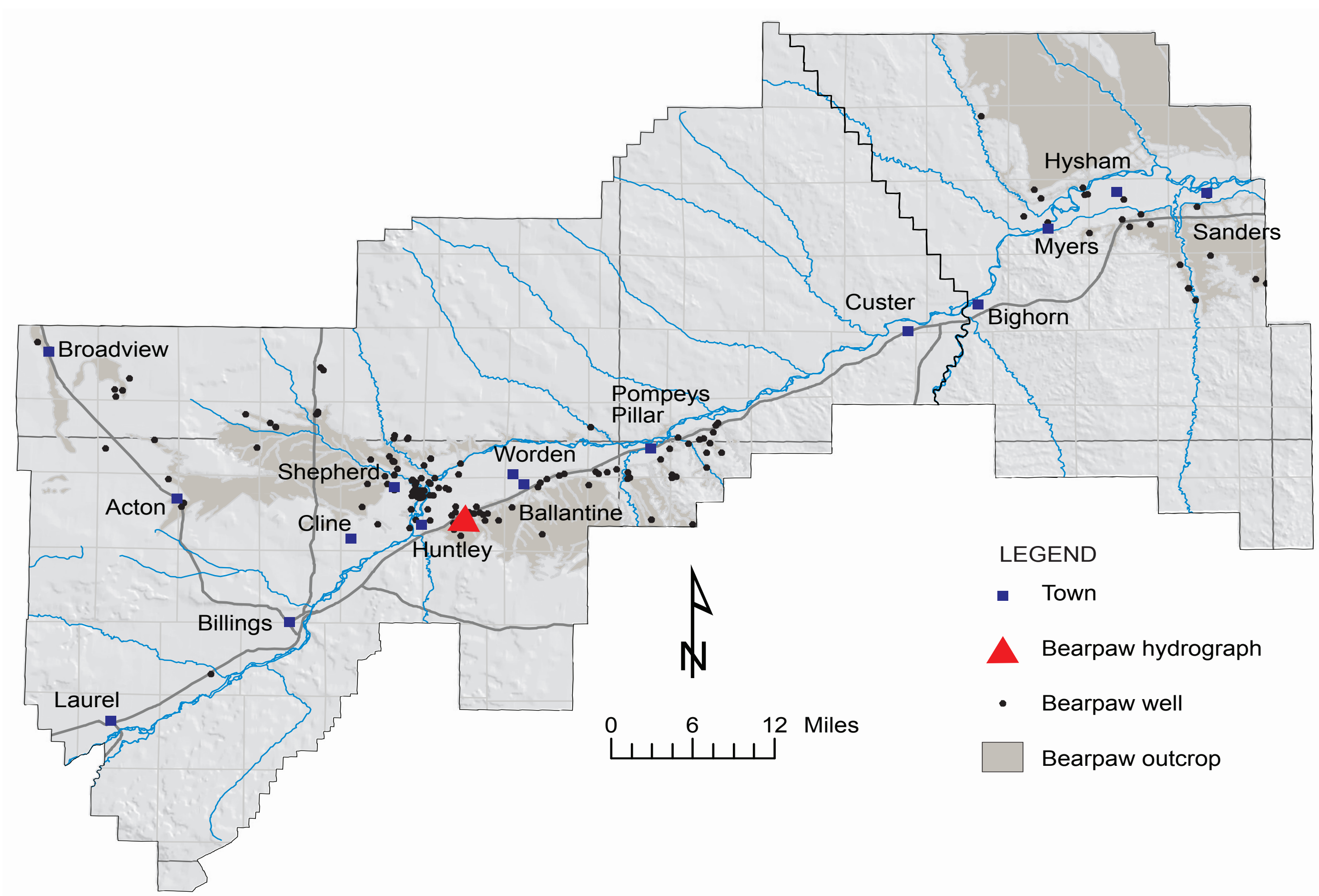


Figure 26. Wells drilled in the Bearpaw Shale are in central Yellowstone County and the northwest part of Treasure County. Sandstone beds may yield water to wells especially near the outcrop; however, the formation is not considered an aquifer.

Most wells that produce water from the Bearpaw are between 50 and 120 ft deep (fig. 27) and have reported yields of less than 10 gpm (fig. 28). Of the 190 wells completed in the formation with reported yields (*n*=175), 16 percent have reported yields less than 2 gpm.

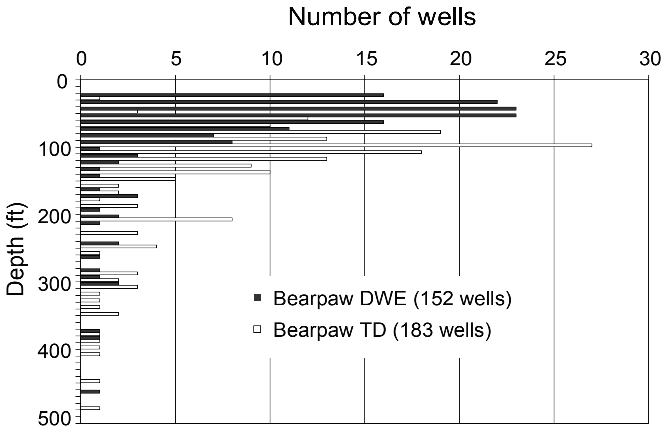


Figure 27. Water enters wells in the Bearpaw Shale mostly between 25 and 75 ft. Most wells were drilled to depths of 50–100 ft.

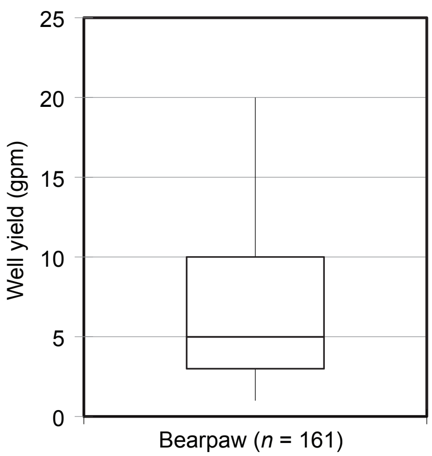


Figure 28. Reported well yields for the Bearpaw Shale average about 5 gpm and are rarely more than 15 gpm.

Long-term water-level measurements are available from one well completed in the Bearpaw Shale about 16 mi northeast of Billings. Well 157773 is 240 ft deep and completed in an area where the Bearpaw is exposed at land surface. Water levels fluctuate 3–5 ft per year, with seasonal lows during the summer months (fig. 29). The summertime decrease in water levels became more pronounced starting in 2007. There is a slight declining trend in the water levels between 1996 and 2005, corresponding to a period of below-average precipitation. Long-term water-level altitudes increased slightly between 2006 and 2011.

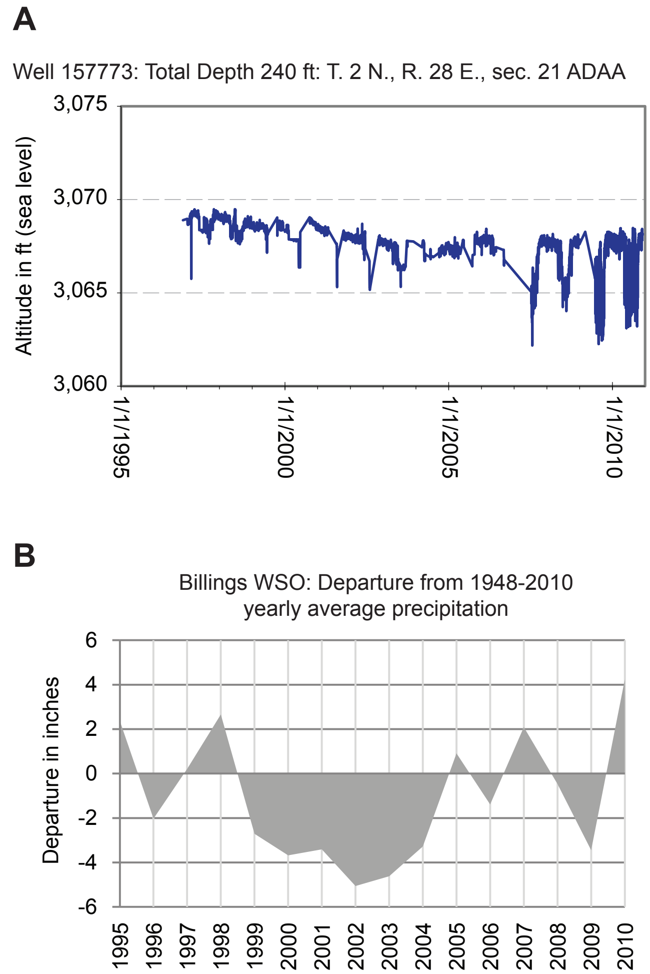


Figure 29. (A) Water-level hydrograph for well 157773, completed in the Bearpaw Shale, shows a seasonal fluctuation in water levels with a decrease of about 3–5 ft in mid-summer, representing short-term usage responses during the summer.

Based on one complete analysis and 10 field specific conductance measurements, water quality in the Bearpaw Shale is poor. TDS concentrations based on the sample and the measurements all exceeded 500 mg/L, the median was 1,351 mg/L, and 4 samples exceeded 2,000 mg/L.

Claggett Shale

The Claggett Shale, a regional confining unit, is stratigraphically below the Judith River Formation and above the Eagle Sandstone (figs. 6, 7, 8). It is dark gray, thin-bedded, mostly fissile shale with zones of calcareous nodules and bentonite beds. Near its top, there may be up to 40 ft of very fine-grained cross-bedded sandstone transitional to the overlying Judith River Formation (Vuke and others, 2003); many thick and persistent bentonite beds occur in the formation's lower strata. The Claggett

Shale is about 435 ft thick in Treasure County (Vuke and others, 2003) and thins to the west (Lopez, 2000a).

About 2 percent (200) of the wells in the Middle Yellowstone Area are completed in thin sandstones near the upper part of the Claggett Shale (fig. 9). A few wells are completed in fractured shale. Most wells are located in or near outcrop areas, or in areas where the Claggett Shale is directly overlain by alluvium (fig. 30). Well depths are generally from 70 to 140 ft deep (fig. 31), and reported yields are typically less than 10 gpm (fig. 32).

Water quality

Groundwater in the Claggett Shale is highly mineralized and of marginal quality for domestic and most other uses. Major ions and trace element concentrations were determined in samples from three wells (6983, 11653, and 92717), and a sample collected from one well (10857) was analyzed for nitrate only. The predominant ions in solution are calcium, magnesium, sodium, bicarbonate, and sulfate. The MCL for nitrate was exceeded in two wells (6983 and 11653). The SMCL for sodium was exceeded in two wells (11653 and 92717), for sulfate in all wells, and for chloride in one well (11653). All the measured and estimated values of TDS exceeded the SMCL; concentrations from 13 wells ranged from 673 to 4,768 mg/L, with a median of 1,875 mg/L.

Colorado Group

The Colorado Group consists of six regional shale-dominated units that underlie the Telegraph Creek Formation; in descending order, these are the Niobrara Shale, Carlisle Shale, Greenhorn Formation, Belle Fourche Shale, Mowry Shale, and Thermopolis Shale (fig. 6). Together, these units are about 2,300 ft thick and crop out in southwestern

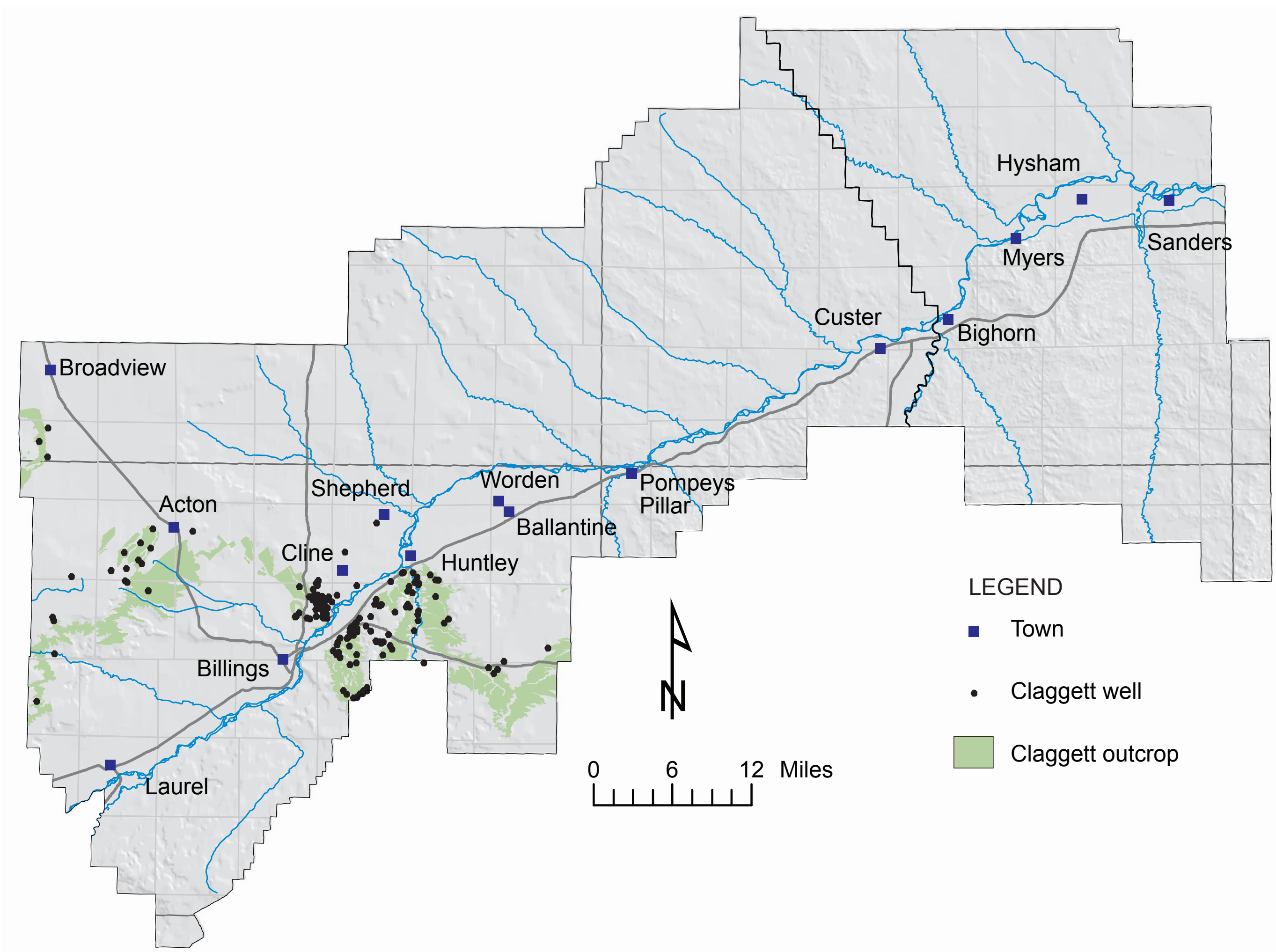


Figure 30. Wells drilled in the Claggett Shale are in central Yellowstone County. Sandstone beds may yield water to wells especially near the outcrop; however, the formation is not considered an aquifer.

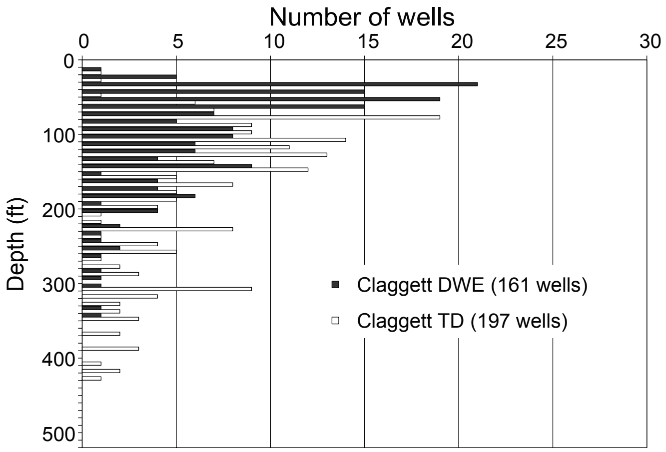


Figure 31. Water wells completed in the Claggett Shale mostly are drilled to depths between 70 and 140 ft.

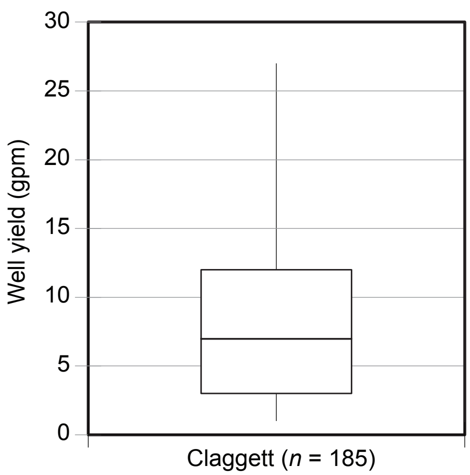


Figure 32. Reported well yields in the Claggett Shale mostly are less than 10 gpm.

Yellowstone County (Lopez, 2000a). Locally, sandstone beds near outcrop areas may produce water to wells (fig. 33).

About 150 water wells are completed in the Colorado group (fig. 33), mostly between 50 and 150 ft deep, with a few wells more than 400 ft deep; perforated intervals are mostly 25 to 75 ft below land surface (fig. 34). The wells are typically marginal producers; 36 percent (53 of 147 wells) either reported yields of less than 1 gpm or did not report a yield at all. For all the Colorado Group wells, the median reported well yield was 5 gpm; only 13 percent of the wells reported yields greater than 10 gpm (fig. 35). The largest group of wells (50 percent) is completed in the Mowry Shale, a unit of interbedded dark shale, very fine- to fine-grained sandstone, and siltstone. The highest reported yields from the Mowry Shale occur where it is fractured along faults in the Fromberg Fault Zone (Part B, map 2). The Niobrara Shale accounts for 29 percent of the wells in the Colorado Group, mostly in the area south of the Rimrocks between Billings and Laurel.

Water levels were measured monthly in two Colorado Group wells (wells 10399 and 10456) between November 1999 and October 2000. During this time water levels fluctuated about 5–6 ft. The highest water levels were attained in July through September. Levels seem to decline from the fall season highs until the following May or June, when they begin a rapid rise back to the high levels (fig. 36). The abrupt rise in water levels beginning in May or June is 1 to 2 months later than water-level changes documented in shallow alluvial aquifers; however, water levels in both aquifers begin to decrease in August or September. As both wells are located in close proximity to, and downgradient from, irrigation canals, the limited water-level data suggest that at these locations canals provide recharge to the underlying Colorado Group.

Water quality

Groundwater in the Colorado Group is highly mineralized and of marginal quality for domestic consumption, crop irrigation, and most other uses. Major ions and trace elements were analyzed in samples from two wells (124880 and 150483), and an additional sample (from well 98381) was analyzed for nitrate only. The predominant ions in solution are calcium, magnesium, sodium, and sulfate. The MCL for selenium was exceeded in the sample from well 124880. The SMCLs for sodium and sulfate were exceeded in samples from both wells (124880 and 150483). Measured and estimated TDS values from 8 wells completed in Colorado Group rocks ranged from 835 to 3,471 mg/L with a median of 1,408 mg/L. All of the TDS estimates exceeded the secondary MCL of 500 mg/L.

Kootenai–Fall River Aquifer

For this report the Kootenai Formation and the overlying Fall River Formation are combined as an aquifer unit. These formations contain more sandstone than does the overlying Colorado Group.

The Fall River Formation is an upward-coarsening sequence of dark shale and fine-grained sandstone that reaches a thickness of about 50 ft (Bolyard and McGregor, 1966; Lopez, 2000a). The

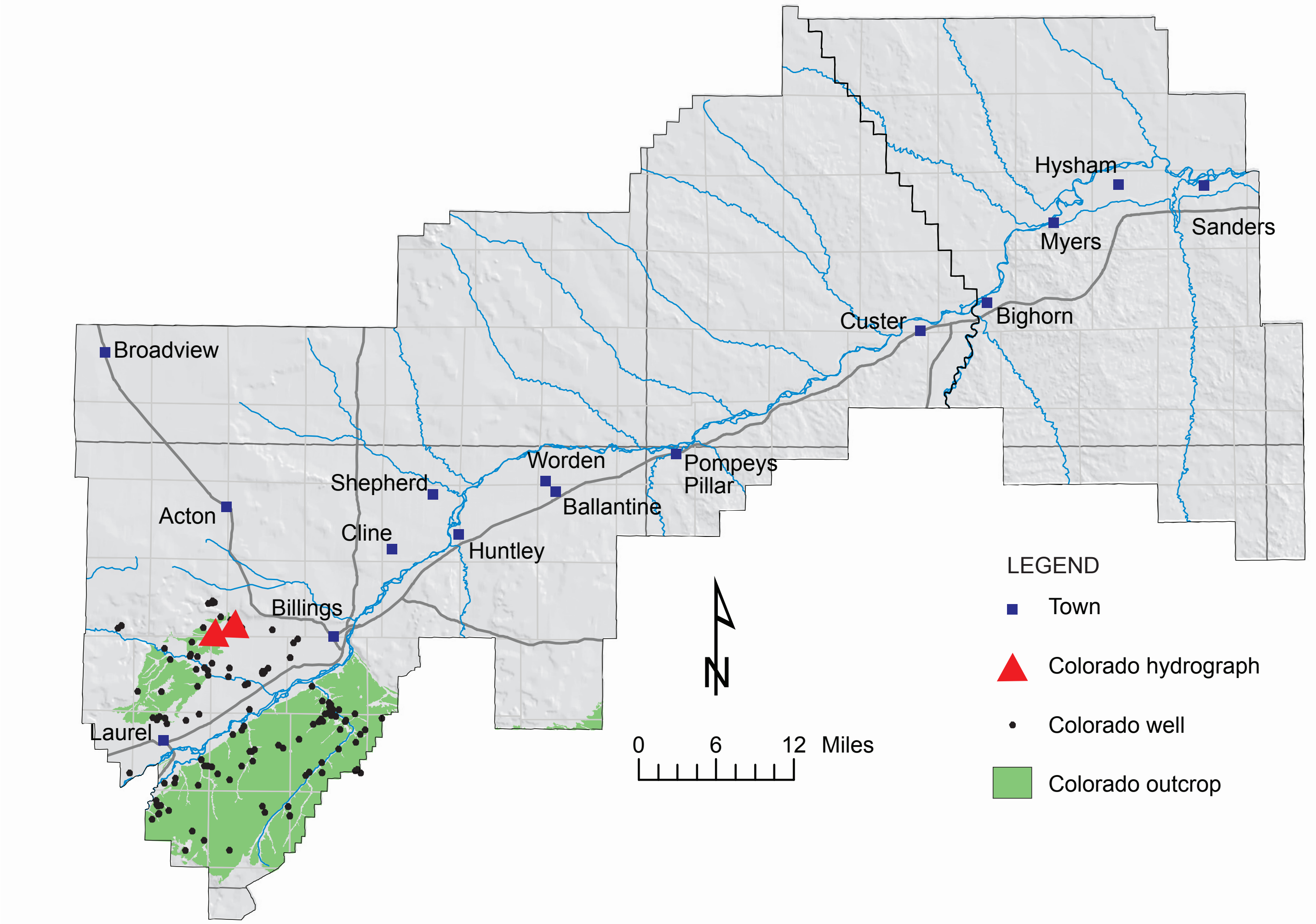


Figure 33. Wells drilled into the Colorado Shale are in Southwestern Yellowstone County. Sandstone beds and fractures associated with the Fromberg Fault Zone may yield water to wells especially near the outcrop; however, the formation is not considered an aquifer.

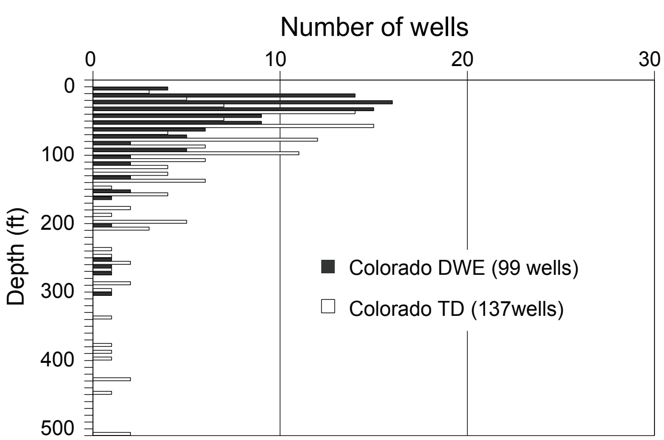


Figure 34. Water enters most wells in the Colorado Shale at depths less than 100 ft near the outcrop area.

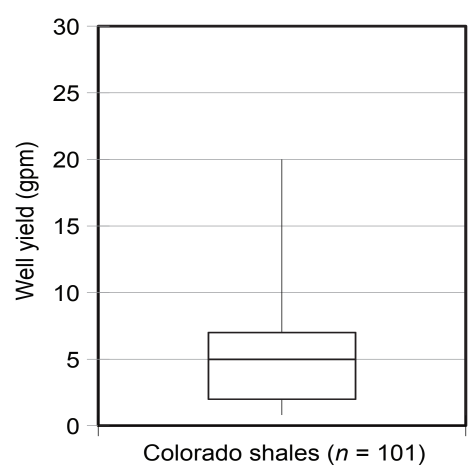


Figure 35. Reported well yields for the Colorado Shale mostly are less than 10 gpm.

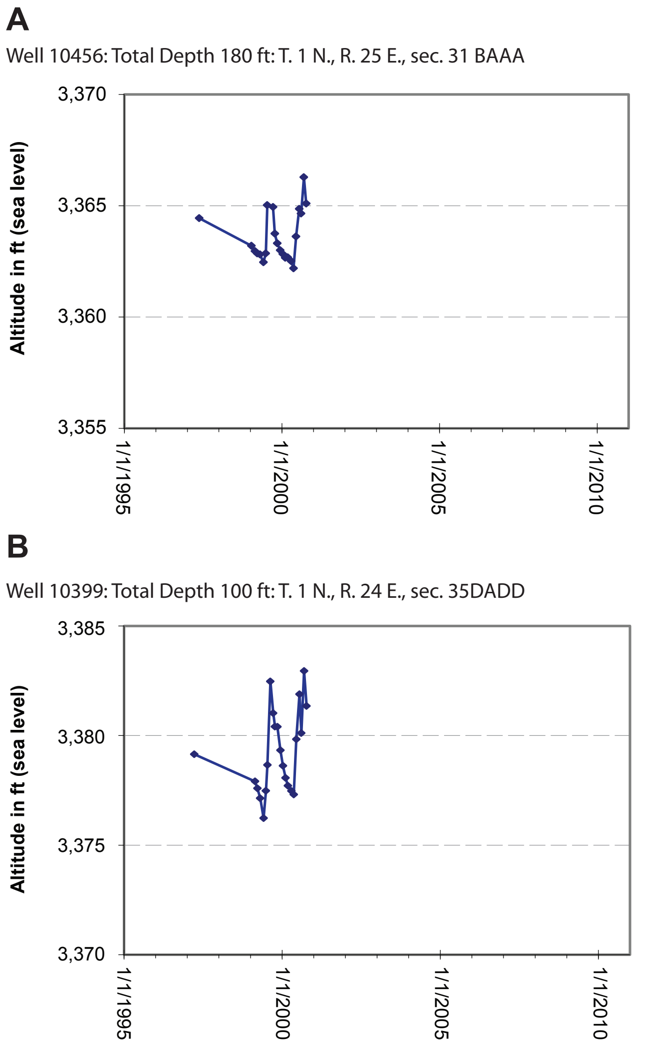


Figure 36. (A) Hydrograph for well 10456, and (B) hydrograph for well 10399. Both wells are completed in the Colorado Shale and show a late spring to early summer rise in water levels that peak in September, which is similar to the response in shallower wells in the area that show aquifer recharge by irrigation water.

Kootenai, which underlies the Fall River, is composed of about 200 ft of mudstone, which is interbedded with discontinuous, fine- to coarse-grained sandstone. The basal unit of the Kootenai is the laterally continuous, coarse-grained Pryor Conglomerate, a 20- to 60-ft-thick conglomeratic sandstone (Lopez, 2000b). Much of the Kootenai contains discontinuous sandstone beds within a sequence of mudstone beds.

Water wells in the Kootenai–Fall River aquifer are mostly south of Billings and Laurel (fig. 37). Most of these wells are greater than 1,000 ft (fig. 38) deep; a few wells in the extreme southern part of the study area are less than 200 ft deep (fig. 38). Of the 21 wells where yields were reported, the mean was 8 gpm; most wells produce between 5 and 18 gpm (fig. 39).

There is little water-level information. One well north of the Yellowstone River between Billings and Laurel (well 6964) was drilled to 2,300 ft in the Kootenai and had a reported static water level of 1,088 ft below ground. Five other wells, two in the Yellowstone River Valley and three along major tributaries south of the Yellowstone, have reported flowing artesian conditions. The potentiometric surface of the Kootenai aquifer shows that flow is to the north across the study area. Water-level altitudes range from about 4,500 ft above sea level at the outcrop area in the south to about 2,300 ft in areas west of Billings (fig. 40).

Water levels in a 1,245-ft-deep well (well 98399, DWE = 1,176 ft) completed in the Pryor Conglomerate member of the Kootenai Formation have been measured quarterly or semi-annually since 1996. The well is located about 10 mi northeast of the Kootenai Formation outcrop in southwestern Yellowstone County (fig. 41). From the initial measurements in 1996 through 2004, water levels increased by more than 5 ft, but since 2005 have declined by about 20 ft (fig. 41). The water-level response does not appear to correlate with annual precipitation departures unless, due to its position in the groundwater flow system, the water-level response lags climate by about 7 years. The hydrograph for well 98399 (fig. 41) shows a seasonal water-level change where water levels fall up to 5 ft in mid-summer. These short-term fluctuations are caused by response to increased groundwater use in the summer months.

Water quality

Groundwater in the Kootenai–Fall River aquifer is marginally suitable for domestic use (TDS less than 2,000 mg/L). Samples from 5 wells (wells 7198, 7332, 98399, 100290, and 705381) had TDS values between 1,455 and 2,556 mg/L. The sampled wells all were more than 1,000 ft deep.

Water in the Kootenai–Fall River aquifer is generally a sodium-bicarbonate type. The MCL for fluoride (4 mg/L) was exceeded in one sample, but fluoride concentrations in many samples exceeded the SMCL concentration of 2 mg/L. Sodium and TDS concentrations in all of the samples exceeded their respective SMCLs.

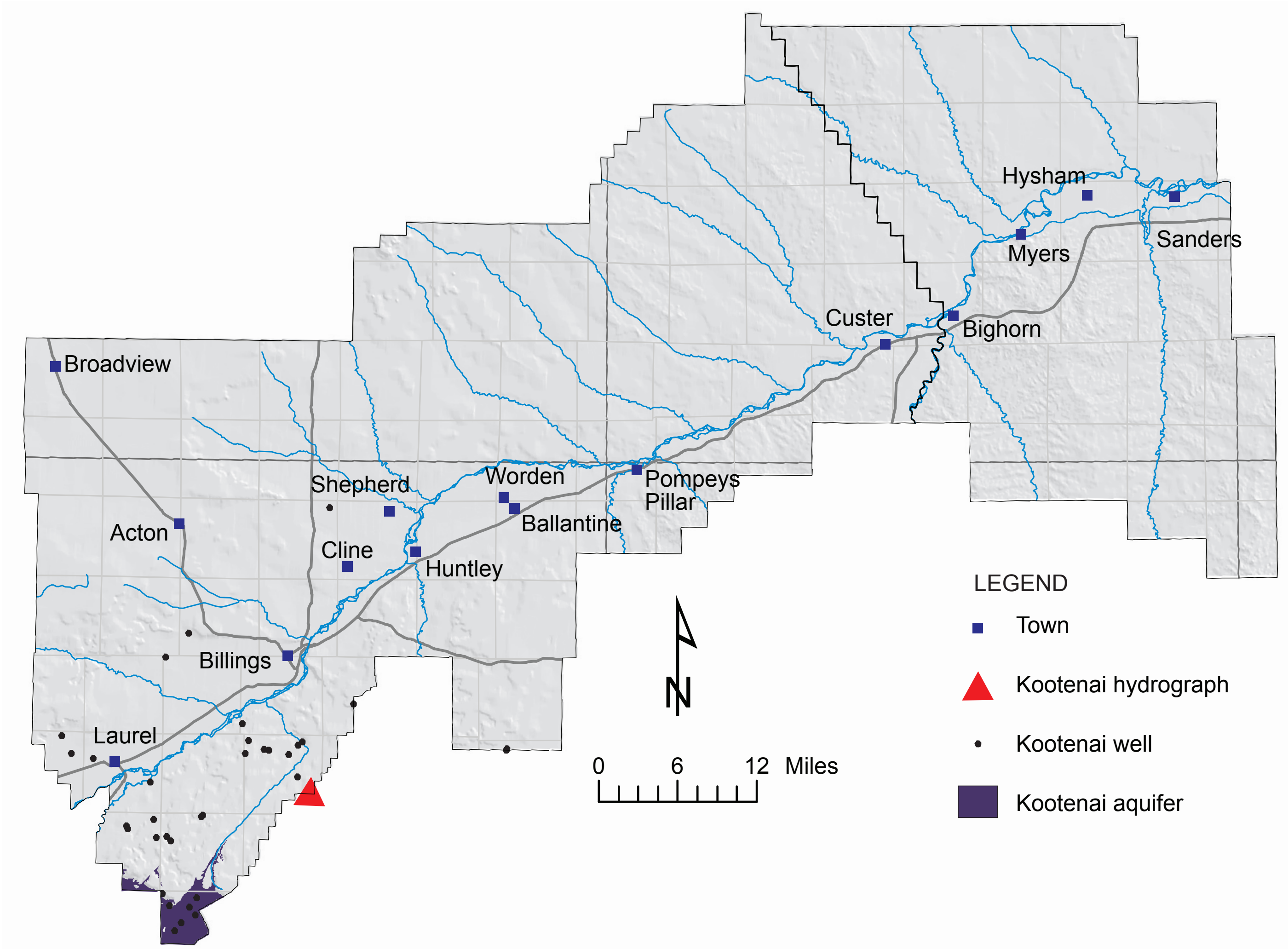


Figure 37. Most wells drilled into the Kootenai Aquifer are located in southwestern Yellowstone County.

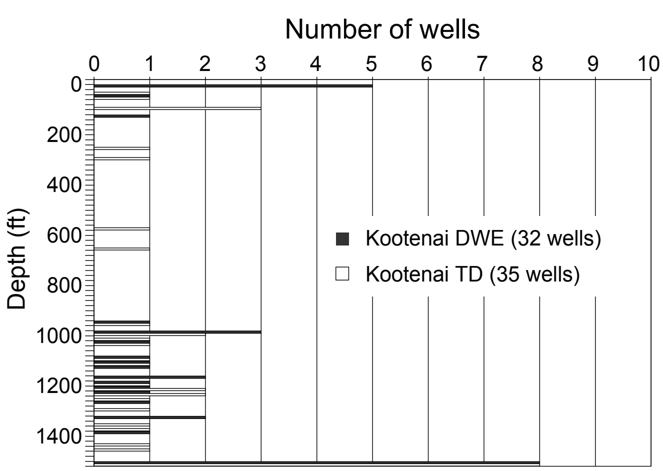


Figure 38. Water enters wells in the Kootenai aquifer at depths of less than 200 ft near the outcrop area and more commonly at depths of greater than 1,000 ft. Drilling depths range widely from 20 to greater than 1,500 ft.

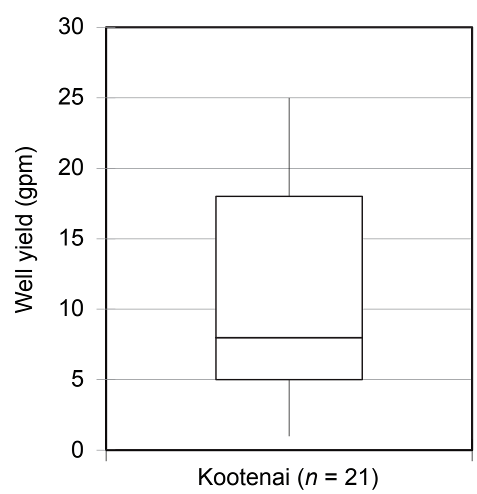


Figure 39. Reported well yields for the Kootenai aquifer average about 8 gpm.

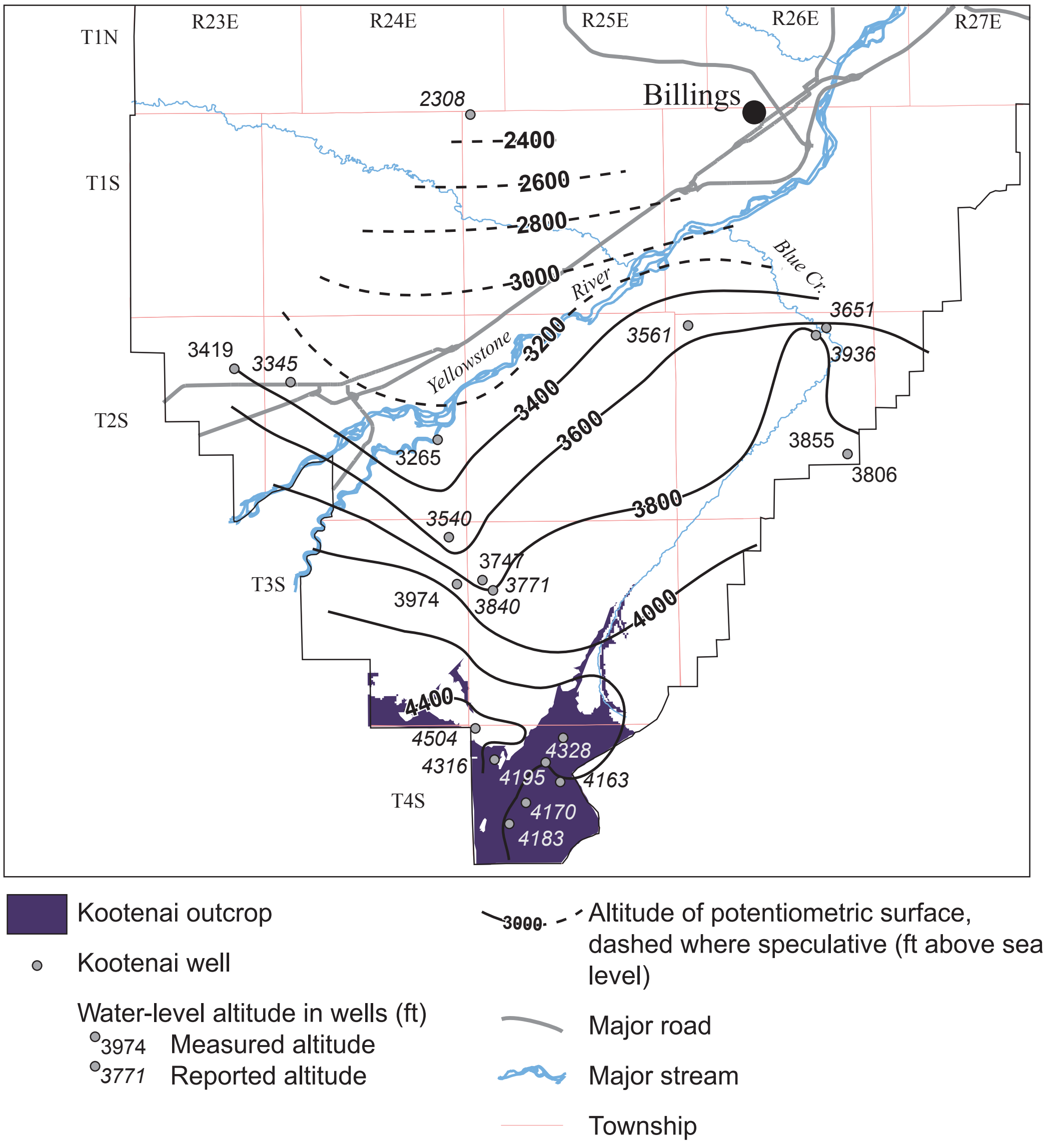


Figure 40. Potentiometric surface map on groundwater in the Kootenai aquifer.

Deep Aquifers

Bedrock units below the Kootenai were penetrated by one groundwater exploration (well 172451) drilled to 7,175 ft in the Madison Group and by many oil and gas wells, a few of which have been converted into water wells. The regional bedrock structure, and stratigraphically lowest aquifer in the area, is portrayed on maps showing the configuration of the Madison Group (Feltis, 1981, 1984a,b,c). Only three wells are known to have been completed as water wells in these deep aquifers, one in the Chugwater Formation (well 7341), one in the Amsden (well 18472), and one in the Madison Group (well 172451). Well 172451 flowed at rates up to 1,838 gpm (Blankennagel and others, 1981), but it was plugged and abandoned in the mid-1980s. All deep aquifers apparently produced highly mineralized water.

MIDDLE YELLOWSTONE RIVER AREA SUMMARY

The Middle Yellowstone Area encompasses about 3,200 mi2 in Yellowstone and Treasure Counties. The area is bisected and drained by the Yellowstone River. About 148,000 people (15 percent of the State's population) reside in the area, mostly near Billings in the Yellowstone River Valley.

The principal aquifers in the Middle Yellowstone Area include unconsolidated Quaternary alluvium and consolidated Cretaceous and Tertiary Formations (figs. 6, 7, 8). Alluvial aquifers occur along the modern floodplain of the Yellowstone River Valley and its major tributaries, and in terraces above the modern floodplain. The major sedimentary rock aquifers consist of sandstones separated by thick sequences of shale. In descending stratigraphic or-

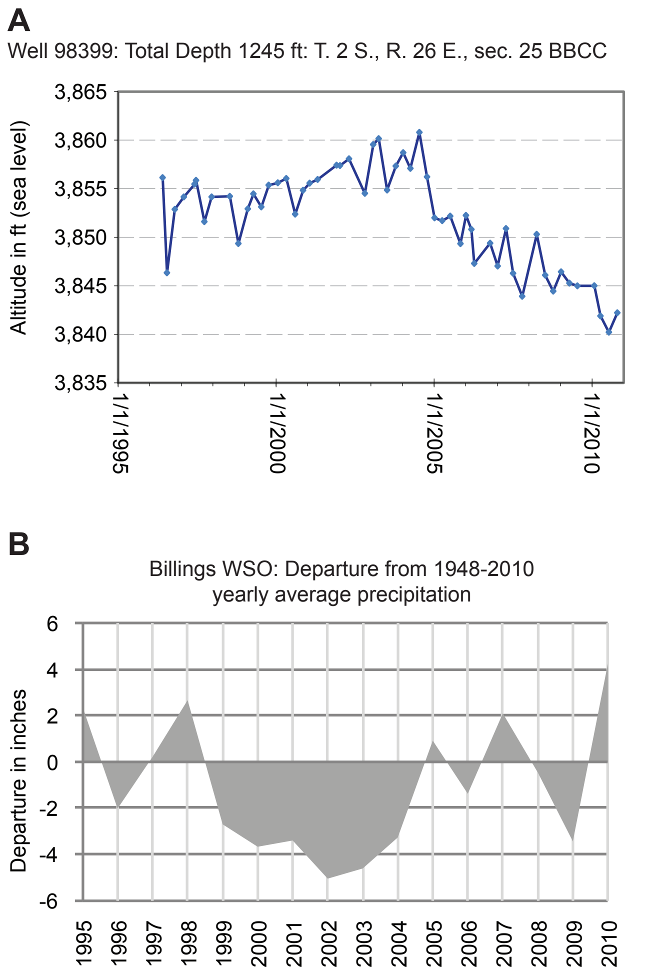


Figure 41. (A) Hydrograph for well 98399, which is completed in the Pryor Conglomerate Member of the Kootenai Formation and is more than 10 mi northeast from where the Kootenai outcrops in southwestern Yellowstone County. Water levels in this well have declined by about 20 ft since 2004. (B) Departures from 1948 to 2010 yearly average precipitation show a prolonged period of below normal precipitation between 1999 and 2005.

der, the major bedrock aquifers are: (1) Bull Mountains aquifer system, which consists of hydraulically connected sandstones within the Fort Union, Lance, and Fox Hills Formations, (2) Sandstone within the Judith River Formation, and (3) the Eagle aquifer, which is composed of water-saturated sandstone layers in the Eagle Sandstone and underlying Telegraph Creek Formation. Other geologic formations that are aquifers in other parts of Montana, but that are deeply buried in most of this study area, include the Kootenai and Fall River, Swift, Chugwater, Tensleep, and Amsden Formations as well as the Madison Group (Mission Canyon and Lodgepole Formations).

Alluvial aquifers unconfined near land surface are important water sources; 67 percent of wells are completed in the Yellowstone River alluvium, in alluvium within Hay Basin and Comanche Flat, or in other localized alluvial deposits. The median well depth is 30 ft, and the median DWE is 23 ft. Well yields reportedly range to more than 1,000 gpm; the median is 30 gpm. Alluvial aquifers are intrinsically susceptible to surface sources of contamination, can be sensitive to climatic (drought) effects, and are mostly dependent on recharge from irrigation water.

Cretaceous and Tertiary bedrock formations underlie the river valley and terrace alluvium, but are at land surface in the cliffs, badlands, and slopes along the sides of river valleys. Groundwater is mostly produced from very fine- to coarse-grained sandstone beds. A few of the shale-dominated rock units, including the Mowry, Claggett, and Bearpaw, are locally fractured in the subsurface and may yield water to wells. However, permeability is variable due to irregular fracture distribution and differing capabilities of the fractures to transmit water. In the Middle Yellowstone Area, reported well yields from bedrock aquifers range from <1 to 1,000 gpm; however, yields are generally low, with a median of 6 gpm. The median reported bedrock well depth is 140 ft, and the median DWE is 56 ft; a few wells in bedrock aquifers exceed 1,100 ft.

Based on the number of wells, the most utilized bedrock aquifers are the shallowest in the sequence: the Bull Mountains aquifer system (Fort Union, Lance, and Fox Hills Formations), the Judith River Formation, and the Eagle–Telegraph Creek Formations. These three aquifer units account for 3,026 of the 3,601 bedrock wells (84 percent). The Judith River Formation and Eagle aquifers have slightly greater reported yields (median yield of both is 10 gpm) than yields reported for the Bull Mountains aquifer system (median yield of 7 gpm). The few wells in the Kootenai–Fall River aquifer (21) have similar reported yields (median of 8 gpm); however, median well depth is 1,140 ft, 10 times that of the Judith River Formation and Eagle aquifers.

In all the aquifers, groundwater flow is generally towards and/or parallel to the Yellowstone River Valley. The potentiometric surface in the Bull Mountains aquifer system shows strong topographic control. Groundwater flows from topographic highs in northern Yellowstone County and southeastern Treasure County towards the Yellowstone River and its tributaries (Part B, map 4). Potentiometric surface maps of the Eagle and Judith River Formation aquifers show that local flow systems have developed in the outcrop areas, and regional systems have developed where these units become confined in the subsurface (Part B, maps 5, 6). Regional flow in these aquifers is down bedrock dip to the northeast and north; however, the flow is directed towards the Yellowstone River Valley.

Long-term water-level data from the major aquifers show seasonal and long-term patterns that reflect different recharge sources as well as long-term precipitation trends. In the shallow alluvial groundwater system, water-level data show either an irrigation response or a multi-year drought/wet-cycle response. The irrigation responses, in which water levels are controlled by leakage from irrigation canals or applied irrigation water, is mostly observed in shallow alluvial aquifers, but may also occur in bedrock aquifers near irrigation canals or downgradient from irrigated areas. Water levels in wells not influenced by irrigation leakage respond to multi-year wet and dry cycles. Throughout the area, precipitation was below average between 1998 and 2005, and water levels in many bedrock aquifer wells show declining trends during these years; this trend reversed when average annual precipitation returned to average or above average between 2006 and 2010. The water-level measurements in a few wells fluctuate erratically, showing little or no correlation with precipitation cycles.

Groundwater in the Middle Yellowstone Area is moderately to highly mineralized and in most instances exceeded the TDS SMCL of 500 mg/L. Water typically does not become too salty to drink until TDS exceeds 2,000 mg/L, and is unsuitable for most uses where values exceed about 3,000 mg/L. The median TDS value in groundwater at all wells sampled was 1,378 mg/L. The groundwater contains a range of different naturally occurring minerals. The general trend for mineral content in groundwater is from relatively fresh bicarbonate-dominated water to highly mineralized sulfate-dominated water as flow moves downgradient. Many water samples from each of the aquifers exceeded SMCLs for sulfate, sodium, and manganese.

Nitrate exceeded the 10 mg/L MCL in 19 of the 217 groundwater samples, mostly from alluvial aquifers (14 samples); 82 samples had concentrations equal to or greater than 2 mg/L, indicating land-use impacts; and 146 samples (68 percent) were less than 2.0 mg/L. Of the 82 groundwater samples with nitrate concentrations greater than 2 mg/L, 63 were from wells completed in the alluvial aquifer. Sources for nitrate include surface contamination from sewage disposal, fertilizers, as well as geologic sources such as the Bearpaw Shale.

ACKNOWLEDGMENTS

Many well owners graciously allowed collection of the data necessary for this report. Field data were collected by MBMG staff members including Camela Carstarphan, Donald Mason, Michael Richter, Joe Lalley, and Kurt Zeiler. Their efforts are gratefully acknowledged. Review of this report by Tom Osborne, John Lafave, and Tom Patton improved content and clarity. Graphics and cartography by Susan Smith; editing and layout by Susan Barth.

REFERENCES

Aller, L., Bennett, T., Lehr, J.H., and Petty, R.J., 1985, DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings: U.S. Environmental Protection Agency, EPA/600/2-85/018, 163 p.

Blankennagel, R.K., Howells, L.W., and Miller, W.R., 1981, Completion and testing of Madison Limestone test well 3, NW1/4 SE1/4 sec. 35, T. 2 N., R. 27 E., Yellowstone County, Montana: U.S. Geological Survey Open-File Report 81-0528, 97 p.

Bolyard, D.W., and McGregor, A.A., 1966, Stratigraphy and petroleum potential of Lower Cretaceous Inyan Kara Group in northeastern Wyoming, southeastern Montana, and western South Dakota: American Association of Petroleum Geologists Bulletin, v. 50, p. 2221–2244.

Bowman, S., 1990, Radiocarbon dating: Berkeley, University of California Press, 64 p.

Cannon, M.R., and Johnson, D.R., 2004, Estimated water use in Montana in 2000: U.S. Geological Survey Scientific Investigations Report 2004-5223, 50 p.

Cherven, V.B., and Jacob, A.F., 1985, Evolution of Paleogene depositional systems, Williston Basin, in response to global sea level changes, in Flores, R.M., and Kaplan, S.S., eds., Cenozoic paleogeography of west-central United States: Denver, Colo., Rocky Mountain Section of SEPM, v. 3, p. 127–170.

Clark, D.W., 1990, Pesticides in soils and groundwater in selected irrigated agricultural areas near Havre, Ronan, and Huntley, Montana: U.S. Geological Survey Water-Resources Investigations WRI 90-4023, 34 p.

Clark, I., and Fritz, P., 1997, Environmental isotopes in hydrogeology: New York, Lewis Publishers, 328 p.

Craig, H., 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702–1703.

Daly, C., Neilson, R.P., and Phillips, D.L., 1994, A statistical-topographic model for mapping climatological precipitation over mountainous terrain: Journal of Applied Meteorology, v. 33, p. 140–158.

Daly, C., Taylor, G.H., and Gibson, W.P., 1997, The PRISM approach to mapping precipitation and temperature, in 10th Conference on Applied Climatology: Reno, Nev., American Meteorological Society, p. 10–12.

Downey, J.S., and Dinwiddie, G.A., 1988, The regional aquifer system underlying the northern Great Plains in parts of Montana, North Dakota, South Dakota, and Wyoming—Summary: U.S. Geological Survey Professional Paper 1402-A, 64 p.

Ellis, A.J., and Meinzer, O.E., 1924, Ground water in Musselshell and Golden Valley Counties, Montana: U.S. Geological Survey Water-Supply Paper 518, 92 p.

Environmental Protection Agency, 1999, Radon in drinking water: Questions and answers: EPA Fact Sheet, EPA 815-F-99-007, 4 p.

Feltis, R.D., 1981, Forsyth 1 x 2 degree quadrangle, southeastern Montana: Structure contour (configuration) map of the top of the Madison Group: Montana Bureau of Mines and Geology Geologic Map 22, scale 1:250,000.

Feltis, R.D., 1982a, Map showing cumulative thickness of sandstone in the Eagle Sandstone and Telegraph Creek Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4032, scale 1:1,000,000.

Feltis, R.D., 1982b, Map showing cumulative thickness of sandstone in the Judith River Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4038, scale 1:1,000,000.

Feltis, R.D., 1982c, Map showing total thickness of the Eagle Sandstone and Telegraph Creek Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4033, scale 1:1,000,000.

Feltis, R.D., 1982d, Map showing total thickness of the Judith River Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4028, scale 1:1,000,000.

Feltis, R.D., 1984a, Billings 1 x 2 degree quadrangle, southeastern Montana: Structure contour (configuration) map of the top of the Madison Group: Montana Bureau of Mines and Geology Geologic Map 36, scale 1:250,000.

Feltis, R.D., 1984b, Hardin 1 x 2 degree quadrangle, southeastern Montana: Structure contour (configuration) map of the top of the Madison Group: Montana Bureau of Mines and Geology Geologic Map 37, scale 1:250,000.

Feltis, R.D., 1984c, Roundup 1 x 2 degree quadrangle, central Montana: Structure contour (configuration) map of the top of the Madison Group: Montana Bureau of Mines and Geology Geologic Map 35, scale 1:250,000.

Feltis, R.D., Litke, D.W., 1987, Appraisal of water resources of the Boulder and Stillwater River basins, including the Stillwater complex, south-central Montana, Montana Bureau of Mines and Geology: Memoir 60, 121 p., 3 sheet(s).

Fox, J.E., 1993, Stratigraphic cross sections showing electric logs of Upper Cretaceous and older rocks, Powder River basin, southeastern Montana and northeastern Wyoming: U.S. Geological Survey Oil and Gas Investigations Chart, OC-135 to OC-138, 4 sheets., Sections A-A' through F-F'; G-G' through L-L'; M-M' through R-R'; S-S' through V-V'.

Jackson, J.A., 1997, Glossary of Geology, 4th edition: Arlington, Va., American Geological Institute, 769 p.

Gill, J.R., and Cobban, W.A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: U.S. Geological Survey Professional Paper 776, 37 p.

Gosling, A.W., and Pashley, E.F., Jr., 1973, Water resources of the Yellowstone River valley, Billings to Park City, Montana: U.S. Geological Survey Hydrologic Investigation HA-454, scale 1:48,000.

Hall, G.M., and Howard, C.S., 1929, Groundwater in Yellowstone and Treasure Counties, MT: U.S. Geological Survey Water-Supply Paper 599, 118 p.

Hem, J.D., 1992, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water Supply Paper 2254, 263 p.

Hendry, M.J., 1988, Do isotopes have a place in groundwater studies?: Groundwater, v. 26, no. 4, p. 410–415.

Lopez, D.A., 2000a, Geologic map of the Billings 30' x 60' quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 59, scale 1:100,000.

Lopez, D.A., 2000b, Geologic map of the Bridger 30' x 60' quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 58, scale 1:100,000.

Madison, R.J., and Brunett, O.J., 1984, Overview of the occurrence of nitrate in groundwater of the United States, in National Water Summary 1984—Water-Quality Issues: U. S. Geological Survey Water-Supply Paper 2275, p. 93–103.

Miller, K.M., and Coffey, M.A., 1998, Radon and you: Promoting public awareness of radon in Montana's air and groundwater: Montana Bureau of Mines and Geology Information Pamphlet 3, 16 p.

National Research Council, 1993, Groundwater vulnerability assessment: Washington D.C., National Academy Press, 204 p.

Noble, R.A., Bergantino, R.N., Patton, T.W., Sholes, B.C., Daniel, F., and Scofield, J., 1982, Occurrence and characteristics of groundwater in Montana: Montana Bureau of Mines and Geology Open-File Report 99, 48 sheets, 214 p.

Olson, J.L., and Reiten, J.C., 2001, Basic hydrogeologic data for the west Billings area: Yellowstone County, Montana: Montana Bureau of Mines and Geology Open-File Report 436, 100 p.

Olson, J.L., and Reiten, J.C., 2002, Hydrogeology of the west Billings area: Impacts of land-use changes on water resources: Montana Bureau of Mines and Geology Report of Investigation 10, 32 p.

Plummer, L.N., Michel, R.L., Thurman, E.M., and Glynn, P.D., 1993, Environmental tracers for age dating young groundwater, in Alley, W.M., ed., Regional groundwater quality: New York, V.N. Reinhold, p. 255–294.

Reiten, J.C., and Hanson, J., 2008, Developing a viable water supply for the town of Broadview, south-central Montana: Montana Bureau of Mines and Geology Open-File Report 567, 89 p.

Richards, P.W., and Rogers, C.P., Jr., 1951, Geology of the Hardin area, Big Horn, and Yellowstone Counties, Montana: U.S. Geological Survey Oil and Gas Investigations Map OM-111, 2 sheets, scale 1:63,360.

Rigby, J.K., and Rigby, J.K., Jr., 1990, Geology of the Sand Arroyo and Bug Creek quadrangles, McCone County, Montana: Brigham Young University Geology Studies, v. 36, p. 69–134.

Slagle, S.E., Barney D.L., and Lee, R.W., 1985, Groundwater resources and potential hydrologic effects of surface coal mining in the northern Powder River basin, southeastern Montana: U.S. Geological Survey Water-Supply Paper W 2239, 34 p.

Thompson, K.S., 1982, Groundwater and potential coal mining in the Bull Mountains, south-central Montana: Montana Bureau of Mines and Geology Open-File Report 100, 51 p.

Vrba, A., and Zoporozec, A., 1994, Guidebook on mapping groundwater vulnerability: Hannover, V.H. Heise, International Association of Hydrogeologists, International Contributions to Hydrogeology, v. 16, 131 p.

Vuke, S.M., Wilde, E.M., and Bergantino, R.N., 2000, Geologic map of the Hardin 30' x 60' quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 57, scale 1:100,000.

Vuke, S.M., Bergantino, R.N., Colton, R.B., Wilde, E.M., and Heffern, E.L., 2001a, Geologic map of the Forsyth 30' x 60' quadrangle, eastern Montana: Montana Bureau of Mines and Geology Open-File Report 425, 11 p., scale 1:100,000.

Vuke, S.M., Heffern, E.L., Bergantino, R.N., and Colton, R.B., 2001b, Geologic map of the Lame Deer 30' x 60' quadrangle, eastern Montana: Montana Bureau of Mines and Geology Open-File Report 428, 8 p., scale 1:100,000.

Vuke, S.M., Wilde, E.M., Bergantino, R.N., 2003, Geologic map of the Hysham 30' x 60' quadrangle, eastern Montana: Montana Bureau of Mines and Geology Open-File Report 486, scale 1:100,000.

Wilde, E.M., and Porter, K.W., 2000, Geologic map of the Roundup 30' x 60' quadrangle, central Montana: Montana Bureau of Mines and Geology Open-File Report 404, scale 1:100,000.

GLOSSARY

(Modified from Gary and others, 1972)

Alluvium Sand, gravel, outwash, silt, or clay deposited during recent geological time by a stream or other form of running water.

Anion See Ion.

Aquifer Geologic materials that have sufficient permeability to yield usable quantities of water to wells and springs. Spaces between the sedimentary grains (pore spaces) or openings along fractures provide the volume (porosity) that stores and transmits water within aquifers (fig. G-1). Aquifers are either unconfined or confined. The water table forms the upper surface of an unconfined aquifer; below the water table the pore spaces of the aquifer are completely water-saturated. A layer of low-permeability material such as clay or shale marks the upper surface of a confined aquifer. This low-permeability layer is called the confining unit. Below the confining unit the aquifer is completely saturated and the water is under pressure (fig. G-2).

Artesian Aquifer An artesian or confined aquifer contains water that is under pressure. To be classified as artesian, the pressure must be adequate to cause the water level in a well to rise above the top of the aquifer (fig. G-2). Flowing wells, or flowing artesian conditions, occur in areas where the potentiometric surface is higher than the land surface (fig. G-3).

Bedrock A general term for consolidated geologic material (rock) that underlies soil or other unconsolidated material.

Carbon-14 A naturally occurring radioactive isotope of carbon, denoted as ^{14}C, with a half-life of 5,730 years. ^{14}C, with six protons and eight neutrons, is heavy compared with the most common isotope of carbon (^{12}C); see Environmental isotopes.

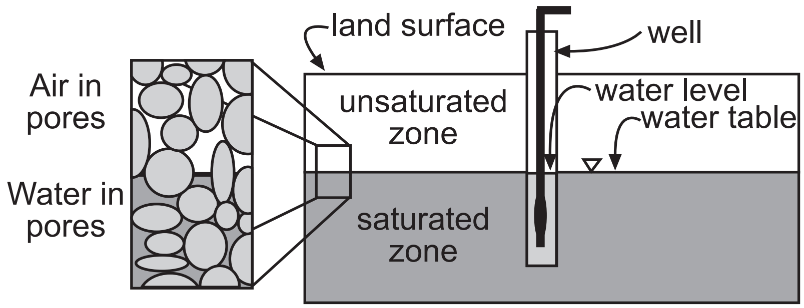


Figure G-1. In the unsaturated zone the pores (openings between grains of sand, silt, and clay and cracks within rocks) contain air and water. In the saturated zone the pores are completely filled with water. The water table is the upper surface of the saturated zone. Wells completed in unconfined aquifers are commonly referred to as water-table wells.

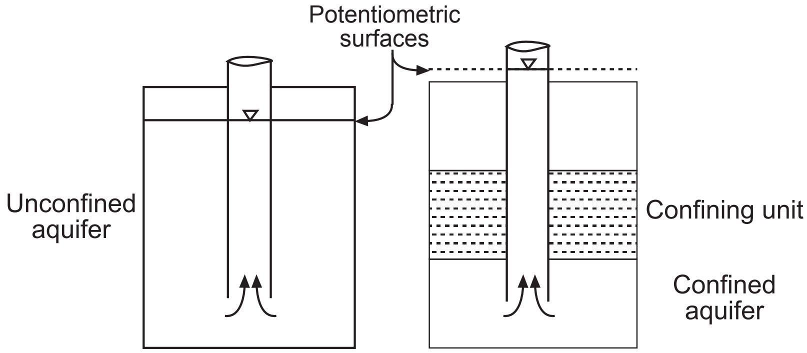


Figure G-2. In an unconfined aquifer, the water table represents a free upper surface. Therefore, water-level changes in an unconfined aquifer will increase or decrease the saturated thickness of the aquifer. In a confined aquifer, the water level in a well will rise to the potentiometric surface, above the top of the aquifer. Water-level changes in a confined aquifer do not change the saturated thickness.

Cation See Ion.

Cone of Depression See Well hydraulics.

Confined Aquifer See Aquifer.

Cumulative Departure Cumulative departure from average precipitation is calculated by determining the cumulative difference between the measured monthly precipitation for a month and the average monthly precipitation for that month for the entire period of record. Increasing (positive) cumulative departure indicates periods of greater than average monthly precipitation.

Aquifer Sensitivity

Aquifer sensitivity describes the potential for an aquifer to be contaminated based on its intrinsic geologic and hydrogeologic characteristics; it is a measure of the relative quickness with which a contaminant applied on or near the land surface could infiltrate to the aquifer of interest (usually, the aquifer of interest is the uppermost aquifer, directly below the water table). The faster water moves from the land surface to the water table, the more sensitive the aquifer is to potential contamination. The recognition of potentially sensitive groundwater areas is a critical first step in action to prevent groundwater contamination. Preventing contamination is less costly and easier than cleaning up the contamination after the fact.

The primary factors in assessing aquifer sensitivity are the depth and the permeability of geologic materials above it. Areas characterized by rapid infiltration and a shallow basin-fill aquifer at the water table are more sensitive than others. Examples of such areas are surficial alluvium and outwash with sandy soils, or sand and gravel at the surface. Areas with poorly drained soils and/or low-permeability material will restrict infiltration of water, and any associated contamination, providing a protective layer to underlying aquifers. Thus the sensitivity in these areas is lower. Also, a deep water table affords more of an opportunity for contaminants to be naturally attenuated or "filtered" before reaching the groundwater system.

The following procedure can be used to compare the relative sensitivity of broad areas given the range of conditions present in the study area. The procedure only considers the physical hydrogeologic characteristics of the study area. The steps include: (1) estimate the depth to water; (2) determine the surficial geology; (3) make a relative judgment based on range of conditions.

(1) Estimate depth to water. If shallow wells are in the area of interest, the depth to water can be measured or there may be records of measurements in the GWIC database. If site-specific data do not exist, the depth to water could be estimated by subtracting the water-table altitude from the land-surface altitude as determined from a topographic map.

(2) Determine the surficial geology. If site-specific data for near-surface geologic conditions are available, such as lithologic descriptions from well logs, assess whether the materials contain much sand and gravel (permeable) or silt and clay (less permeable). If site-specific data are not available, use a geologic map to assess the type and thickness of surficial materials. As discussed in the Geologic Framework part of this report, the materials in the surficial deposits are variable, but usually unconsolidated deposits are more permeable than consolidated deposits. Therefore, an area with unconsolidated sand and gravel at the land surface would be more sensitive than an area with clay-rich sediment at the surface.

(3) Judge the sensitivity. With the information generated in steps 1 and 2, a relative assessment of aquifer sensitivity can be made using a simple matrix that incorporates the relative permeability range of geologic material present in the unsaturated zone and the depth to water. Three classifications of sensitivity (low, medium, and high) are presented based on subdivisions of the depth to water and the surficial geology. The geologic subdivisions are based on the relative permeability of the unconsolidated deposits compared with the consolidated bedrock formations. The classifications are relative terms and not absolute indicators of aquifer sensitivity.

This method of evaluating sensitivity provides a generalized assessment that addresses the relative potential for vertical movement of contaminants to the water table. It must be recognized that the factors affecting aquifer sensitivity commonly vary considerably over short distances and the accuracy of any assessment will depend on the amount and quality of available data. Projects that require precise resolution of aquifer sensitivity will require site-specific investigation. For more detailed discussions and procedures concerning aquifer sensitivity, see Aller and others (1985), National Research Council (1993), and Vrba and Zoporozec (1994).

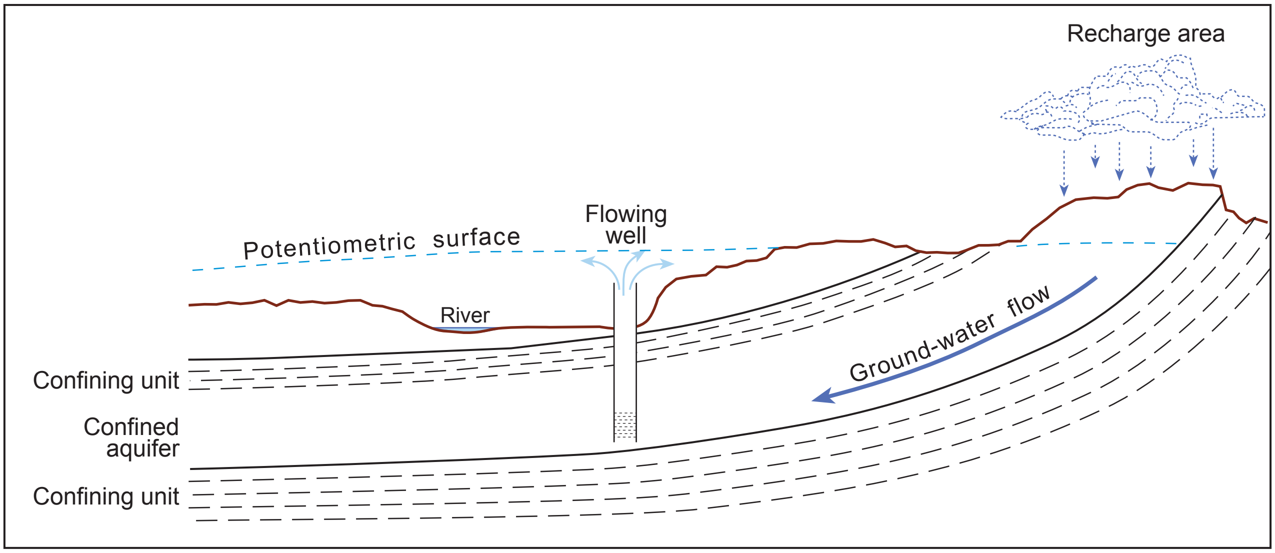


Figure G-3. Artesian conditions develop in confined aquifers when the aquifer, overlain by a low-permeability unit, dips or tilts away from its recharge area. Water percolates down to the water table in the recharge area and moves beneath the confining unit. The artesian pressure is caused by the difference in the level of the water table in the recharge area and at the top of the aquifer. Flowing wells, or flowing artesian conditions, occur in areas where the potientometric surface is higher than the land surface.

Deuterium A stable isotope of hydrogen, with one neutron and one proton, denoted as D or ^2H. Deuterium has approximately twice the mass of the most common isotope of hydrogen, protium (^1H); see Environmental isotopes.

Discharge Area An area where groundwater is released from an aquifer, generally characterized by water moving toward the land surface. Springs or gaining streams (fig. G-4) may occur in groundwater discharge areas.

Dissolved Constituents The quantity of dissolved material in a sample of water expressed as milligrams per liter. The value is calculated by summation of the measured constituents, which include major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) and anions (HCO_{3-}, CO_3^{2-}, SO_4^{2-}, Cl^-, NO_{3-}, F^-, SiO_{3-}) expressed in milligrams per liter (mg/L). See related sidebar, page 70.

Environmental Isotopes Globally distributed isotopes that occur in nature are called environmental isotopes. See related sidebar, page 71.

Flow System The aquifers and confining beds that control the flow of groundwater in an area constitute the groundwater flow system (fig. G-3). Groundwater flows through aquifers from recharge areas, which commonly coincide with areas of high topography, to discharge areas that are topographically low. The relative length and duration of the groundwater flow paths are used to classify groundwater systems. A regional system

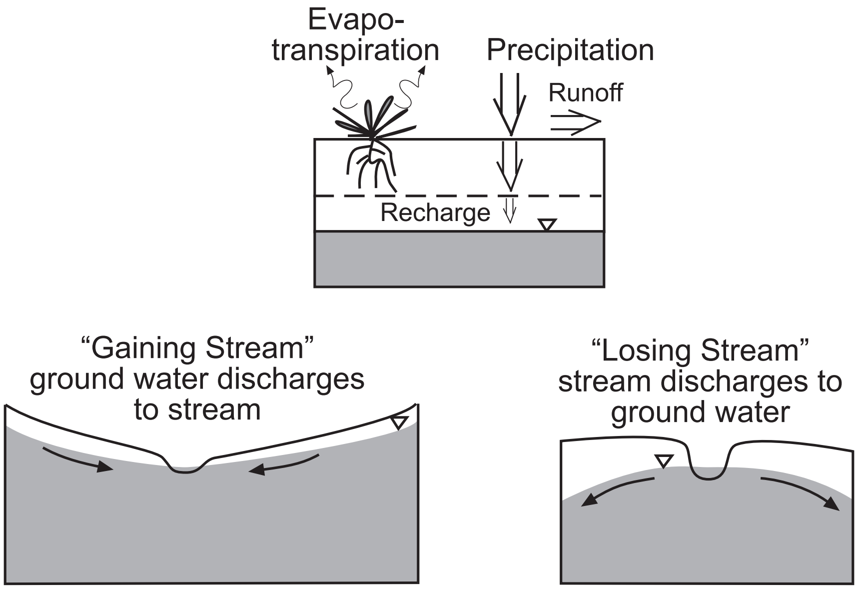


Figure G-4. Water that percolates through the unsaturated zone to the water table is said to recharge an aquifer. Recharge can also occur from the surface-water bodies (losing streams) where the water levels are higher than those in neighboring aquifers. In contrast, in a gaining stream water levels in the aquifer are above those in the stream and flow is maintained by groundwater discharge.

Dissolved Constituents

The amount of dissolved matter in water is commonly reported either as “Total Dissolved Solids” (TDS) or the “Sum of Dissolved Constituents,” or simply “dissolved constituents.” The dissolved constituents are the sum of the major cations (Na, K, Ca, Mg, Fe, Mn) and anions (HCO_3, CO_3, SO_4, Cl, SiO_3, NO_3, F) expressed in milligrams per liter (mg/L). Dissolved constituents in groundwater are a result of the initial chemistry of the recharge water and subsequent interactions of that water with soils and aquifer materials. The total concentration of dissolved matter provides a general indicator of water quality: the lower the total concentration the better the water quality.

Reported values of “dissolved constituents” differ slightly from reported values of TDS, which are also commonly reported. Total dissolved solids were traditionally measured by weighing the residue remaining after evaporating a known volume of water. However, during evaporation about half the bicarbonate (HCO_{3-}) is converted to carbon dioxide gas (CO_2), which escapes to the atmosphere and does not appear in the residue (Hem, 1992). Therefore, TDS underestimates total dissolved-ion concentration in solution, especially where bicarbonate concentrations are high. For this report the actual concentrations reported for the major constituents are summed and reported as dissolved constituents (rather than TDS), giving a more accurate measure of the total ions in solution. Typically, water does not become too salty to drink until the concentration of dissolved constituents reaches about 2,000 mg/L.

Laboratory-measured dissolved constituent concentrations can be supplemented by estimating dissolved constituent concentrations from field measurements of specific conductance made during visits to wells. Hem (1992) showed that dissolved constituents (DC) can be estimated from specific conductance (SC) according to the relationship: DC = A x SC, where A is a constant. Based on a straight-line regression between field conductances and laboratory dissolved constituents values for samples collected in the Lolo-Bitterroot Area, A = 0.92. Specific conductance data are more commonly collected than samples for analyses, and the dissolved constituents concentrations estimated from the SC data can also be used to better understand the spatial distribution of water quality.

Nitrate

Nitrate (NO_{3-}) is an essential nutrient for plant life, yet it is a potentially toxic pollutant when present in drinking water at excessive concentrations. Pregnant women and infants less than 1 year of age are most commonly at risk from nitrate poisoning if they ingest water with nitrate concentrations more than 10 mg/L. Nitrate poisoning can result in methemoglobinemia, or “blue-baby” syndrome, in which the ability of the individual’s blood supply to carry oxygen is reduced to the point that suffocation can occur.

Nitrate has natural and human-related sources. However, where nitrate contamination of groundwater has been identified, it is usually related to a known or suspected surface-nitrogen source (Madison and Brunett, 1984). It can occur naturally in groundwater through the interaction of recharging water with atmospheric nitrogen (nitrogen fixation). It also can be derived from nitrogen-rich geologic deposits (generally marine-deposited shales). Significant human sources of nitrate to groundwater include septic systems, agricultural activities (fertilizers, irrigation, dryland farming, livestock wastes), land disposal of wastes, and industrial wastes.

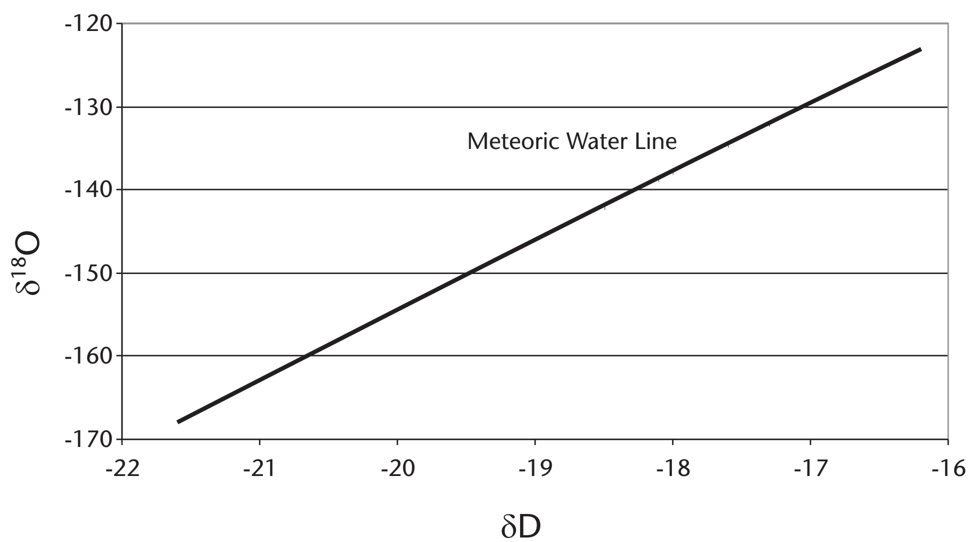


Figure G-5. Values of $\delta^{18}O$ and δD in precipitation from around the world plot linearly along a line known as the global meteoric water line (Craig, 1961). Groundwater that originates as precipitation should also plot along the global meteoric water line.

Environmental Isotopes

Isotopes of hydrogen, oxygen, and carbon in groundwater can provide insight into hydrologic process and provide independent confirmation of interpretations of groundwater flow made from other hydrologic and chemical data. Isotopic data can also help estimate the age of groundwater.

Tritium

Tritium is a naturally occurring radioactive isotope of hydrogen that has a half-life of 12.43 years. It is produced in the upper atmosphere where it is incorporated into water molecules and therefore is present in precipitation and water that recharges aquifers. Concentrations of tritium are measured in tritium units (TU), where one TU is equal to one tritium atom in 1,018 atoms of hydrogen. Before the atmospheric testing of nuclear weapons began in 1952, natural concentrations of tritium in precipitation were 2 to 8 TU (Plummer and others, 1993). Atmospheric testing of nuclear weapons between 1952 and 1963 released large amounts of tritium into the atmosphere, overwhelming the natural production of tritium; in North America tritium concentrations in precipitation peaked at several thousand TU in 1963–1964 (Hendry, 1988). Because of its short half-life, bomb-derived tritium is an ideal marker of recent (post-1952) groundwater recharge. Groundwater recharged by precipitation before 1952 will have tritium concentrations reduced because of radioactive decay to less than 1.0 TU, which is at or below the analytical detection limit. Therefore, a groundwater sample with detectable tritium (greater than 0.8 TU) includes water that must have been recharged since 1952 and would be considered “modern.” Tritium-free groundwater infers recharge before 1952 and is considered “sub-modern” or “older” (Clark and Fritz, 1997).

Oxygen and hydrogen isotopes

Ratios of the stable isotopes of oxygen ($^{18}O/^{16}O$) and hydrogen ($^{2}H/^{1}H$) in groundwater help evaluate recharge conditions and can sometimes be used to confirm age estimates for water from other methods. Concentrations of each isotope are reported as delta (δ) values in per mil (parts per thousand) relative to a standard known as Vienna Standard Mean Ocean Water (VSMOW). These values are denoted as $\delta^{18}O$ and δD for oxygen and hydrogen, respectively. A positive delta value means that the sample contains more of the isotope than the standard; a negative value means that the sample contains less of the isotope than the standard.

When water evaporates from the ocean, the water vapor will be depleted in oxygen-18 (^{18}O) and ^{2}H [or deuterium (D)] when compared with the ocean water because molecules of the lighter isotopes (^{16}O and ^{1}H) more readily evaporate than molecules containing the heavier isotopes. As air masses are transported away from the oceans, the isotopic character of the water vapor will sequentially change because of condensation, freezing, melting, and evaporation of molecules of the different isotopes. The two main factors that affect isotopic content of precipitation are the condensation temperature and how much water has already condensed from the initial water in the air mass. The isotopic composition of water that condenses at cooler temperatures (commonly associated with higher altitudes, higher latitudes, or cooler climatic conditions) is lighter than that of water that condenses at warmer temperatures (commonly associated with lower altitudes, lower latitudes, or warmer climatic conditions). Therefore, at a given locality the $\delta^{18}O$ and δD in the precipitation will depend on factors such as distance from the ocean, altitude, and temperature. Because the isotopic composition of groundwater generally reflects the average isotopic composition of precipitation in a recharge area, spatial and temporal variations in the isotopic content of precipitation can be useful in evaluating groundwater recharge sources. Craig (1961) observed another useful relationship, namely that values of $\delta^{18}O$ and δD of precipitation from around the world plot linearly along a line known as the global meteoric water line (fig. G-5). Groundwater that originates as precipitation should also plot along the global meteoric water line. The departure of $\delta^{18}O$ and δD values from the meteoric water line may suggest that the water has been subject to evaporation or geothermal processes. ^{18}O and deuterium can be used to help delineate different sources of water to a groundwater flow system.

Carbon

^{14}C is a naturally occurring radioactive isotope of carbon (C) produced in the upper atmosphere, and has a half-life of 5,730 years. Carbon atoms (99 percent are ^{12}C and the remaining atoms are ^{13}C and ^{14}C) combine with oxygen to form carbon dioxide (CO_2), which travels throughout the atmosphere and biosphere. Carbon dioxide containing ^{14}C travels throughout the atmosphere and biosphere in the same way as CO_2 that contains other carbon isotopes (Bowman, 1990). A dynamic equilibrium exists between formation and decay of ^{14}C that results in a relatively constant amount of ^{14}C in the atmosphere and biosphere.

Recharge waters dissolve atmospheric ^{12}C, ^{13}C, and ^{14}C, present in the soil-zone CO_2, and move it through the unsaturated zone. As groundwater moves below the water table and is cut off from soil-zone CO_2, no new ^{14}C can be added to the water. The radioactive carbon at this point in the system is part of the carbonate and bicarbonate anions that are in solution. Radioactive decay will cause the ^{14}C content of the carbon in these anions to decline at a known rate. The basic principle of ^{14}C dating of groundwater is to measure the ^{14}C activity in the dissolved inorganic carbon (HCO_{3-} and CO_{32-}) and relate that activity to an age. If soil-zone CO_2 were, in fact, the only source of dissolved inorganic carbon in groundwater, then the technique could be used to assign accurate numerical dates (ages) to the water. Unfortunately, other processes add old, non-radioactive carbon to groundwater, such as dissolution of carbonate minerals where the carbon has been locked up in molecules remote from the atmosphere for long periods. The added “dead carbon” dilutes the concentration of ^{14}C, increasing the apparent groundwater age. However, measured values of ^{14}C can still convey significant information about relative groundwater ages between pairs of samples along flow paths. ^{14}C is measured as percent modern carbon (PMC) relative to a 1950 A.D. standard (Bowman, 1990); water with a higher PMC value would be younger than water with lower PMC values.

generally consists of deep groundwater circulation between the highest surface drainage divides and the largest river valleys. Local and intermediate flow systems consist of shallow groundwater flow between adjacent recharge and discharge areas superimposed on or within a regional flow system.

Groundwater Strictly speaking, all water below land surface is "groundwater." The water table defines the boundary between the unsaturated (air in pores) and saturated (water in pores) zones (fig. G-1). It is the water from saturated zones that supplies water to wells (and springs) that will be called groundwater in this atlas.

GWIC The Groundwater Information Center (GWIC) is a repository for water well logs and groundwater information at the Montana Bureau of Mines and Geology, http://mbmg-gwic.mtech.edu; 1300 W. Park St, Butte, MT 59701; (406) 496-4336; GWIC@mtech.edu.

Hydraulic Conductivity Measure of the rate at which water is transmitted through a unit cross-sectional area of an aquifer under a unit gradient; commonly called permeability. The higher the hydraulic conductivity of the aquifer (the more permeable it is), the higher the well yields will be. The hydraulic conductivity of geologic material ranges over 14 orders of magnitude (fig. G-6).

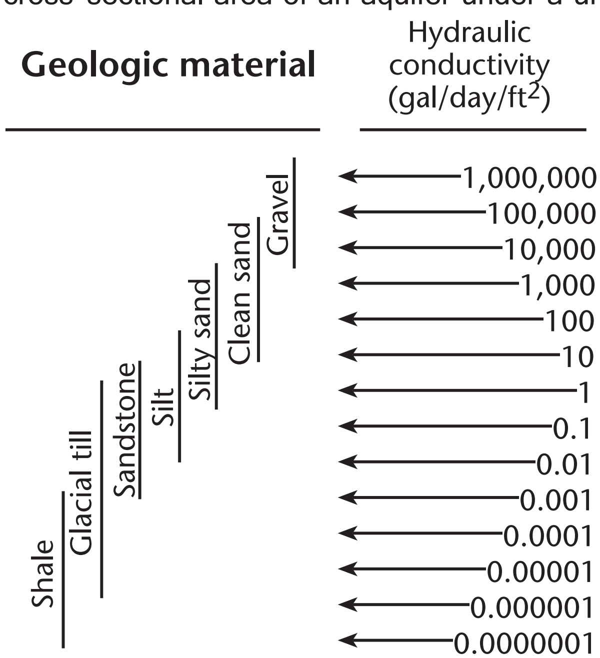


Figure G-6. The range of hydraulic conductivity values for typical geologic materials ranges over several orders of magnitude. Hydraulic conductivities not only differ in different rock types but may also be different from place to place in the same rock (modified from Freeze and Cherry, 1979).

Hydrologic Cycle The constant circulation of water among the ocean, atmosphere, and land is called the hydrologic cycle. The notion of the hydrologic cycle provides a framework for understanding the occurrence and distribution of water on the earth. The important features of the hydrologic cycle are highlighted in figure G-7. The hydrologic cycle is a natural system powered by the sun and is quantified by the hydrologic budget. Evaporation from the ocean and other surface bodies of water and shallow groundwater, and transpiration from plants, bring "clean" water (because most dissolved constituents are left behind) into the atmosphere where clouds may form. The clouds return water to the land and ocean as precipitation (rain, snow, sleet, and hail). The precipitation may subsequently follow many different pathways. Some may be intercepted by plants, may evaporate, may infiltrate the ground surface, or may run off (overland flow). The water that infiltrates the ground contributes to the groundwater part of the cycle, a small but critical item in the hydrologic budget. Groundwater flows through the earth until it discharges to a stream, spring, lake, or ocean. Runoff occurs when the rate of infiltration is exceeded. This water contributes directly to streams, lakes or other bodies of surface water. Water that reaches streams flows to the ocean where it becomes available for evaporation again, perpetuating the cycle.

Hydrologic Unit A body of geologic materials that functions regionally as a water-yielding unit.

Ion An atom or group of atoms that carries a positive (cation) or negative (anion) electric charge. Atoms in liquid solutions are typically ions; the atoms are said to have been ionized.

Isotopes Atoms of the same element that differ in mass because of differing numbers of neutrons in their nuclei. Although isotopes of the same

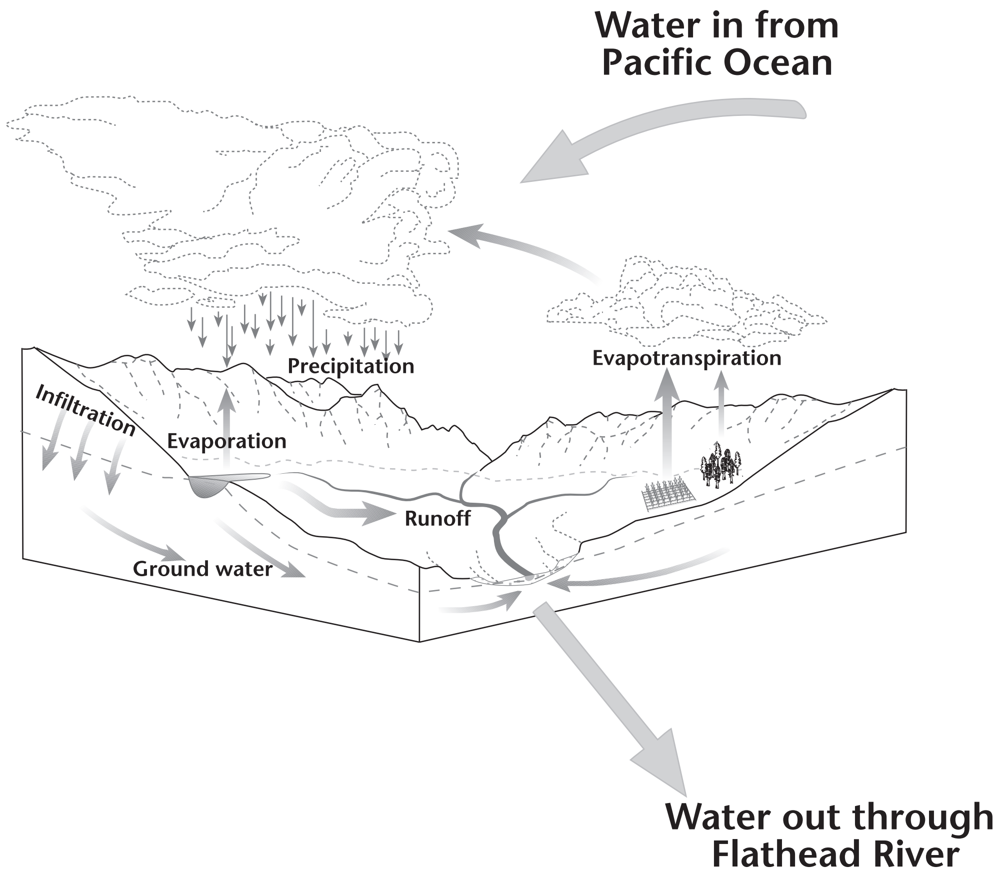


Figure G-7. The constant circulation of water among the ocean, atmosphere, and land is referred to as the hydrologic cycle. In the Flathead Lake area, most of the precipitation that enters the area is returned to the atmosphere by evaporation and evapotranspiration.

substance have most of the same chemical properties, their different atomic weights allow them to be separated. For example, ^{18}O is heavier than ^{16}O, so water molecules containing ^{16}O evaporate from a water body at a greater rate; see Environmental isotopes.

Nitrate A mineral compound described by the anionic structure of NO_{3^-} that is soluble in water and stable in oxidized environments. Common analysis of the concentration is reported as milligrams per liter (mg/L) of nitrogen (N). Common sources of nitrate are decaying organic matter, sewage, natural nitrate in soil, and fertilizers. See related sidebar, page 70.

Overdraft Long-term withdrawal of water at rates greater than long-term recharge.

^{18}O A stable isotope of oxygen, denoted as ^{18}O, with 8 protons and 10 neutrons. ^{18}O is heavy compared with the common isotope of oxygen (^{16}O); see Environmental isotopes.

Permeability The capacity of a geologic material to transmit fluid (water in this report); also called hydraulic conductivity.

Potentiometric Surface A surface defined by the level to which water will rise in tightly cased wells (figs. G-1 and G-2). The water table is a potentiometric surface for an unconfined aquifer.

Radioactive Half-Life The time over which half of a radioactive material decays to another elementary material from a parent to a daughter product.

Radon Radon is a colorless, odorless gas produced by the radioactive decay of uranium found naturally in rocks and soil, and has been linked to lung cancer in humans (EPA, 1999). Radon in indoor air poses a health risk and accumulates by seepage into a structure from the soil and rock beneath its foundation. Water that contains radon is also a source of radon in indoor air, but the U.S. Environmental Protection Agency estimates that radon released from drinking water accounts for less than 2 percent of that in indoor air. Currently no drinking water standard for radon exists. However, the U.S. Environmental Protection Agency has proposed a 300 picoCuries per liter (pCi/L) MCL for community water systems, and an alternative 4,000 pCi/L MCL for community systems that have a U.S. Environmental Protection Agency-approved Multimedia Mitigation Program (EPA, 1999). The proposed MCLs for radon will not apply to private wells.

Recharge Area An area where an aquifer receives water, characterized by movement of water downward into deeper parts of an aquifer (fig. G-3).

Sediment Solid fragments of rocks deposited in layers on the earth's surface and commonly classified by grain size (clay, silt, sand, gravel) and mineral composition (e.g., quartz, carbonate, etc.).

Storativity The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer the storativity is nearly equivalent to how much water a mass of saturated geologic material will yield by gravity drainage.

Surface Water Water at the earth's surface, including snow, ice, and water in lakes, streams, and oceans.

Transmissivity The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is equivalent to the hydraulic conductivity times the aquifer thickness.

Tritium A naturally occurring radioactive isotope of hydrogen, denoted as ^3H, with a half-life of 12.43 years. Tritium, with 1 proton and 2 neutrons, has approximately three times the mass of the most common isotope of hydrogen, protium (^1H); see Environmental isotopes.

Unconfined Aquifer See Aquifer.

Unconsolidated Sediment that is not generally cemented or otherwise bound together.

Unsaturated Zone The subsurface area above the water table where the pores are filled by air or partly by water and partly by air (see fig. G-1).

Water Quality The fitness of water for use, affected by physical and chemical factors. EPA water-quality standards: U.S. Environmental Protection Agency (EPA) primary, secondary, and proposed maximum contaminant levels (MCL, SMCL, and PMCL) for drinking water. These standards are the permissible levels allowable in a public water-supply system. Constituents for which MCLs have been set may pose a health threat at elevated concentrations. Secondary levels are set for aesthetic reasons; elevated concentrations of these constituents may be a nuisance (bad taste, odor, or staining) but do not normally pose a health risk. See related sidebar on Major Ions and Constituents.

Major Ions and Constituents

The major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}) and anions (HCO_{3-}, CO_3^{2-}, SO_4^{2-}, Cl^-, NO_{3-}, F^-, SiO_{3-}) derived from soil and rock make up most of the dissolved materials in groundwater.

Bicarbonate (HCO_{3-}) and **carbonate** (CO_3^{2-}) occur naturally; bicarbonate is the dominant anion in groundwater. Bicarbonate and carbonate are typically derived from dissolution of common carbonate minerals such as calcite and dolomite. Carbonate will only be present as a parameter in groundwater when the water's pH is greater than about 8.3.

Sulfate (SO_4^{2-}) is dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Sulfate can be present in some industrial wastes.

Chloride (Cl^-) occurs in rocks and soils and is easily dissolved from those sources. It is also present in sewage and is found in natural and industrial brines.

Nitrate (NO_{3-}) is a natural constituent in groundwater and can come from decaying organic matter and natural accumulation of nitrogen in soils. Elevated concentrations of nitrate can come from infiltration of sewage effluent and leaching of fertilizers.

Fluoride (F^-) is dissolved in low concentrations from most rocks and soils. Elevated concentrations are found in some formations and near hot and warm springs where groundwater can contain more than the recommended concentration of fluoride.

Silica (SiO_{3-}) is generally derived from the breakdown of quartz (SiO_2) and other silicate minerals, which form the bulk of the grains in most sand and gravel deposits (Hem, 1992).

Sodium (Na^+) and **potassium** (K^+) are metals present in many feldspar and clay minerals that occur in alluvial and glacial deposits. Sodium in water may also be associated with septic effluent, road salt, and industrial discharges. When combined with chloride in water, sodium may impart a salty taste.

Calcium (Ca^{2+}) and **magnesium** (Mg^{2+}) are metals that are also commonly dissolved in natural water. Calcium and magnesium are typically derived from dissolution of common carbonate minerals such as calcite and dolomite. Magnesium is chemically similar to calcium and is found in dolomite and in ferro-magnesium minerals common in metamorphic rocks. Calcium and magnesium have no health standards and elevated concentrations do not pose health risks. However, calcium, magnesium, and bicarbonate contribute to the hardness of water.

Iron (Fe^{2+}) and **manganese** (Mn^{2+}) are essential to plants and animals, but may cause unpleasant taste, odor, and staining of plumbing fixtures, clothing, or buildings sprayed by irrigation water. Primary sources of iron and manganese in groundwater are the dissolution of iron-bearing minerals in aquifers. Iron concentrations in well water may also be increased by corrosion of steel well casings and by bacterial activity in and around well screens or perforations.

Water Table The upper surface of the saturated zone, often the surface of an unconfined aquifer; occurs where the pressure of the water is equal to atmospheric pressure. Below the water table the pore spaces are completely saturated.

Well A hole drilled or dug to produce groundwater or to monitor groundwater levels or quality. A properly designed production well for domestic, stockwatering, or municipal purposes should produce good-quality, sand-free water with proper protection from contamination. The basic elements of a properly constructed well are shown below (fig. G-8).

Well Hydraulics The withdrawal of water from a well causes the water level within the well to drop below the static water level in the producing aquifer. The lowering of the water level in the well induces groundwater to move from the aquifer to the well. As pumping continues,

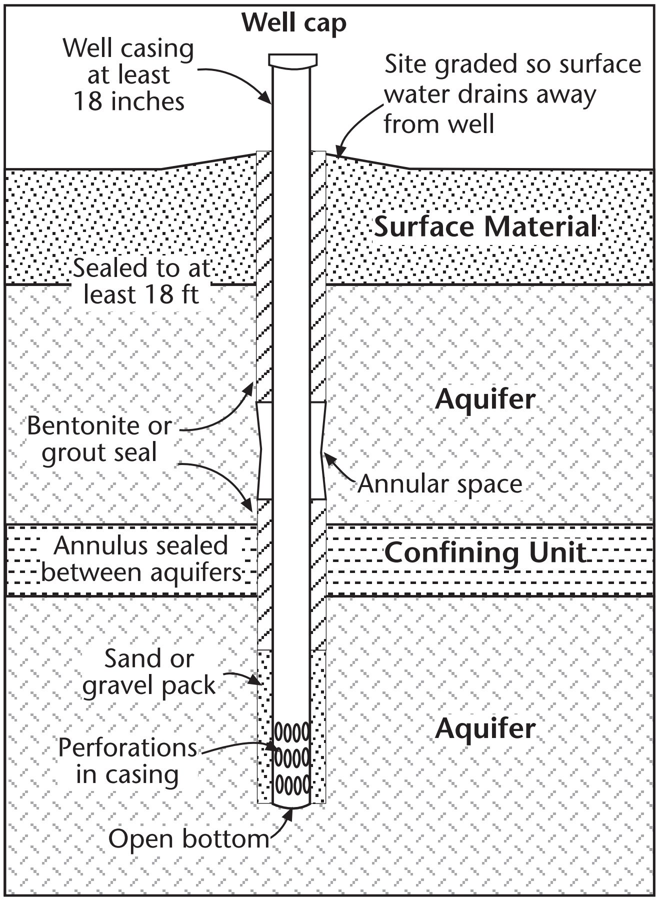


Figure G-8. Properly constructed wells are completed in single aquifers. In order to protect groundwater quality and maintain artesian pressures, wells should not serve as conduits from the surface to groundwater or connect separate aquifers.

the water levels in the well and the producing aquifer continue to decline until the rate of inflow equals the rate of withdrawal. The radial decline in the water level of a producing aquifer response to pumping is called the cone of depression. The limit of the cone of depression is called the zone of influence. The geographic area containing groundwater that flows toward the well is the zone of capture (fig. G-9).

Wellhead Protection Area Zone around a public water supply that is managed to prevent contamination of the water supply. The area typically is delineated based on geologic and hydraulic factors and includes the zone of capture within about a mile of the well (fig. G-9).

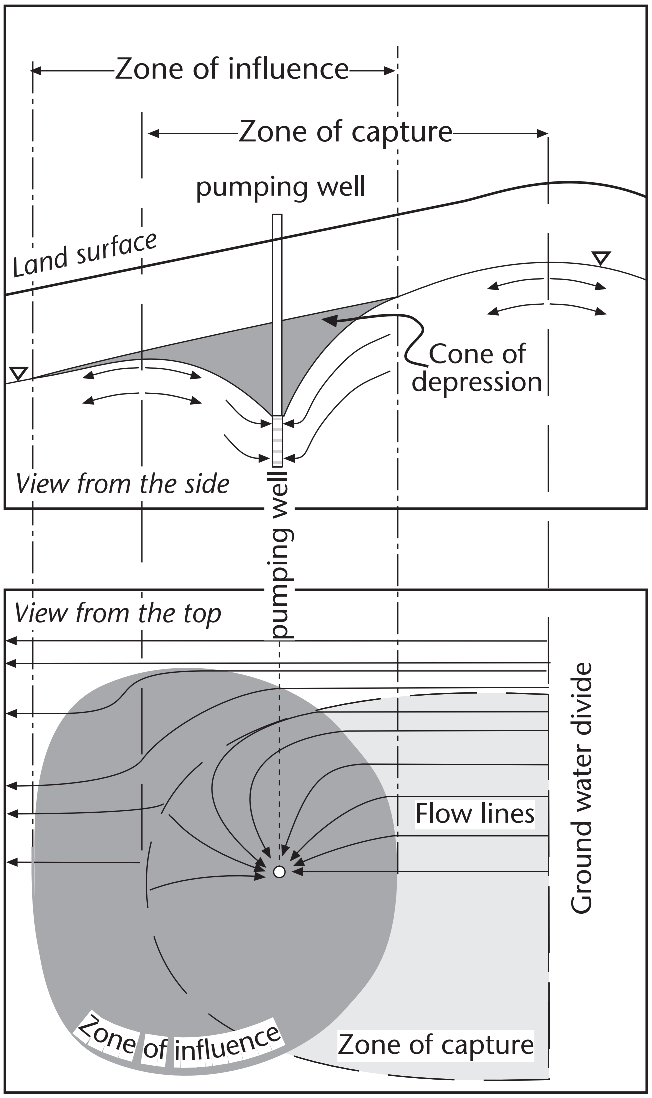


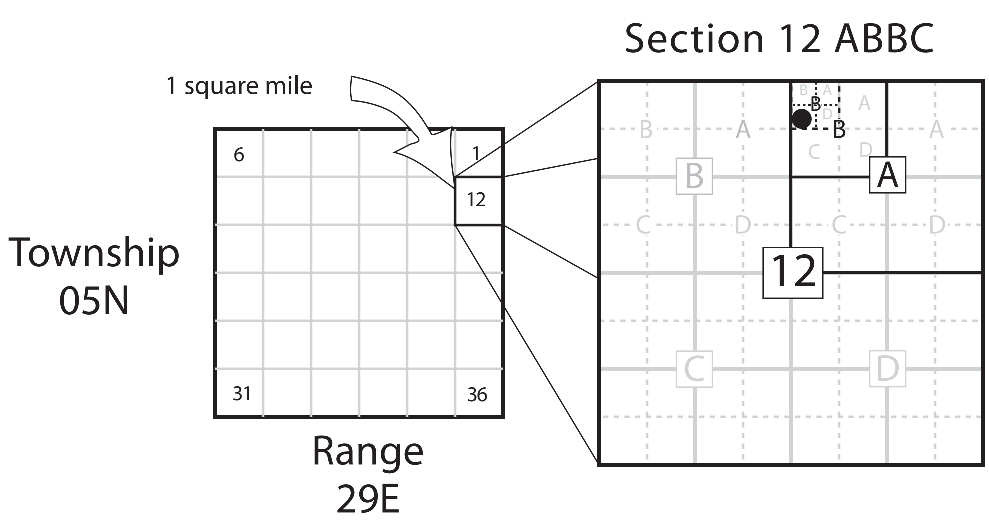
Figure G-9. Withdrawal of groundwater will temporarily depress the water level (potentiometric surface) in the region surrounding the well, creating a "cone of depression." The dimensions of the cone of depression, zone of influence, and zone of contribution depend on hydraulic characteristics of the aquifer, potentiometric surface, and discharge rate of the well.

APPENDIX A

How to Locate a Well on a Map Using GWIC Locations

For example, find well M:17153, located in 05N 29E 12 ABBC

To locate the well in the Township, Range, and Section, read the tract (ABCD) desginations from left to right, largest tract to smallest tract. Beginning in the center of the section, travel to the 'A' in the center of the northeast quarter. From there, travel to the 'B' in the center of the northwest quarter of the northeast quarter. From there, travel to the 'B' in the northwest quarter of the northwest quarter of the northeast quarter. From there, travel to the 'C' or southwest quarter of the northwest quarter of the northwest quarter of the northeast quarter of section 12.



APPENDIX B

ANALYTICAL RESULTS

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
2002Q1532	10289	01N	23E	4	DDCD	-108.8663055	45.85704888	Yellow	Judriv	75	6/7/02	353	5.14	105
2003Q1001	191512	01N	23E	10	AAAA	-108.839	45.856	Yellow	Judriv	32.5	2/26/03	130	5.19	90
2003Q1007	10297	01N	23E	10	CBCB	-108.8591	45.8465	Yellow	Judriv	76	2/25/03	169	3.39	102
2004Q0086	200607	01N	23E	31	ACBD	-108.9088	45.794	Yellow	EagleTel	640	8/18/03	568	1.48	2.12
1998Q0162	10326	01N	24E	2	AABC	-108.6983	45.8694	Yellow	EagleTel	106	8/11/97	271	4.67	348.1
1998Q0346	10336	01N	24E	7	ADAD	-108.7769	45.8516	Yellow	Judriv	125	9/8/97	185.7	4.6	146.7
1997Q0811	10336	01N	24E	7	ADAD	-108.7769	45.8516	Yellow	Judriv	125	6/2/97			
2001Q1477	155351	01N	24E	23	ADDB	-108.6956981	45.82135116	Yellow	EagleTel	52	5/2/01	485	7.96	318
2008Q0091	155351	01N	24E	23	ADDB	-108.6956981	45.82135116	Yellow	EagleTel	52	8/13/07	545	8.46	370
1997Q0866	155351	01N	24E	23	ADDB	-108.6956981	45.82135116	Yellow	EagleTel	52	6/12/97			
1998Q0158	135879	01N	25E	12	DCDD	-108.5538	45.8427	Yellow	EagleTel	96	8/10/97	539.6	4.5	250.1
1998Q0163	149794	01N	25E	29	BBAD	-108.6472	45.8116	Yellow	EagleTel	320	8/11/97	54.6	4	187.3
2002Q1533	10615	01N	25E	36	DDBB	-108.5534925	45.78725191	Yellow	Alluv	21	6/17/02	41.2	2.28	74.5
2002Q1522	96	01N	26E	1	CBDA	-108.4392889	45.86245411	Yellow	EagleTel	1050	6/17/02	827	1.96	2.41
1998Q0156	10767	01N	26E	4	DDAD	-108.4869	45.8586	Yellow	EagleTel	265	8/10/97	784.3	1.4	3.3
1997Q0729	10857	01N	26E	12	CBCC	-108.4441	45.8463	Yellow	Claggett	62	4/7/97			
1998Q0118	10917	01N	26E	13	CBCA	-108.4425	45.8327	Yellow	Alluv	22	7/27/97	45.5	3.9	79.7
1997Q0783	10979	01N	26E	14	BCAB	-108.4613	45.838	Yellow	Alluv	22	5/16/97			
1998Q0159	11126	01N	26E	20	CBDC	-108.5245915	45.81765257	Yellow	EagleTel	75	8/10/97	111.7	2.7	183.9
2005Q0211	11126	01N	26E	20	CBDC	-108.5245915	45.81765257	Yellow	EagleTel	75	9/16/04	114	2.92	188
2002Q1531	155352	01N	26E	22	ADDA	-108.4662	45.8213	Yellow	Alluv	22.9	6/7/02	15.9	2.02	54.9
1998Q0105	147379	01N	26E	25	DDAA	-108.4241	45.8013	Yellow	Alluv	90	7/25/97	23.2	5.5	100.3
2004Q0594	11531	01N	26E	35	AACD	-108.4483892	45.79495293	Yellow	EagleTel	115	6/28/04	108	3.42	141
1998Q0112	106	01N	27E	5	AADC	-108.3855	45.8677	Yellow	Alluv	20	7/25/97	209.3	5	92.4
1998Q0106	107	01N	27E	17	CABA	-108.3952	45.8338	Yellow	Alluv	54	7/27/97	228.3	5.1	82.6
1999Q0799	107	01N	27E	17	CABA	-108.3952	45.8338	Yellow	Alluv	54	6/10/99			
2002Q0840	191486	01N	27E	19	CACC	-108.4157	45.8172	Yellow	Alluv	49	2/13/02	227	5.97	203
1998Q0122	11653	01N	27E	20	DCCC	-108.3922	45.813	Yellow	Claggett	245	7/27/97	835.6	28	505.4
1998Q0009	11653	01N	27E	20	DCCC	-108.3922	45.813	Yellow	Claggett	245	6/27/97			
2006Q0870	144353	01N	27E	27	CAAC	-108.3529868	45.80385395	Yellow	Judriv	400	3/6/06	45.3	3.14	82.9
1998Q0239	110	01N	27E	33	BACB	-108.3769	45.7958	Yellow	EagleTel	846	8/22/97	1147	2.057	4.6
1998Q0248	11787	01N	28E	14	ABBA	-108.2041	45.8408	Yellow	Judriv	360	8/24/97	173.2	2	59.9
1998Q0116	158937	01N	29E	21	CCBC	-108.1294	45.8147	Yellow	Judriv	205	7/27/97	29.5	3.52	55.31
2003Q1193	131693	01N	29E	29	CABB	-108.145579	45.80465758	Yellow	Judriv	205	6/9/03	58.2	2.46	65.3
2007Q1179	11806	01N	29E	30	ADDD	-108.1514793	45.80565746	Yellow	Alluv	76	6/18/07	25.4	2.59	79.3
1998Q0121	11806	01N	29E	30	ADDD	-108.1514793	45.80565746	Yellow	Alluv	76	7/27/97	28.2	2.7	80
1998Q0352	92715	01S	23E	15	CDAA	-108.8739047	45.744647	Yellow	EagleTel	159	9/6/97	464.9	4.5	210.3
2008Q0096	92715	01S	23E	15	CDAA	-108.8739047	45.744647	Yellow	EagleTel	159	8/17/07	328	5.29	212
1998Q0354	92717	01S	23E	21	DBAA	-108.89	45.733	Yellow	Claggett	159	9/6/97	385.9	11.3	396.2
1997Q0762	92717	01S	23E	21	DBAA	-108.89	45.733	Yellow	Claggett	159	5/6/97			
1998Q0039	124880	01S	24E	9	BAAB	-108.7738	45.7694	Yellow	Colorado	46.5	7/15/97	190.1	4	115.6
1998Q0034	92738	01S	24E	12	CCCC	-108.7191	45.7555	Yellow	Alluv	50	7/11/97	230.7	5.1	182.1
1997Q0699	92738	01S	24E	12	CCCC	-108.7191	45.7555	Yellow	Alluv	50	3/24/97			
1997Q0698	92777	01S	24E	36	AABA	-108.70424	45.711192	Yellow	Alluv	38	3/25/97			
1998Q0030	92833	01S	25E	1	BBBB	-108.5958	45.7838	Yellow	Alluv	45	7/12/97	197.1	4.6	285.2

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
64	0.028	0.071	49.4	585.6	0	836	1.87 P	1.53	9.3	1711.7	2009.0	525.6		8.3	2330
62.7	0.029	0.083	26.3	548.5	0	314.9	0.6 P	<0.5	11.1	910.1	1188.7	482.8	9.8	7.56	1315
87.4	0.052	0.079	47.4	519.1	0	518.3	<0.5 P	<0.5	8.85	1191.1	1454.4	614.4	9.9	7.29	1735
0.63	0.006	0.032	361.9	872.3	12	21.6	<0.5 P	5.87	7.52	1411.3	1853.8	7.9	14.9	8.47	2480
170	0.032	0.078	19.7	347.7	0	1654	<0.25 P		8.569	2648.7	2825.3	1568.9	12.3	7.6	3000
132	0.012	0.008	248.1	633.2	0	522.1	6.0 P		12.4	1563.7	1884.9	910.4	9.9	7.46	1983
							12.5 P						9.6		
215	0.188	<0.01	216	363.6	0	2234	3.5 P	<2.5	9.08	3664.3	3849.0	1679.0		7.26	4310
276	0.076	0.016	315	341.6	0	2488	1.98 P	1.81	8.64	4181.6	4355.1	2059.9	14.1	7.25	4750
							3.7 P			0.0	0.0	0.0	11.6		
213	0.015	<0.002	25.5	499	0	1992	0.59 P		10.9	3282.8	3536.0	1500.8	10.6	7.3	3370
120	<0.003	0.004	45.8	503.3	0	537.1	0.46 P		16.8	1213.6	1468.9	959.6	12.4	7.15	1560
37.7	0.018	0.002	12.9	258.6	0	233	1.13 P	0.549	21.3	550.8	682.2	341.2	14.2	7.95	867
0.07	0.243	<0.01	465	1520.9	0	<25.0	0.775	5.62	9	2061.7	2833.5	6.3	15.1	8.23	3500
1.9	0.019	<0.002	244.6	1388.3	0.6	141.4	0.4 P		7.4	1868.0	2572.2	16.1	12.8	8.65	2930
							<0.25 P						12.8		
41.4	<0.003	0.005	19.3	357.9	0	102.7	6.7 P		25.8	495.5	677.1	369.4	11.1	7.5	821
							5.4 P						10.3		
133	<0.003	<0.002	57	417.2	0	812.9	1.5 P		11.3	1518.5	1730.1	1007.4	11.5	7.3	1810
138	0.007	<0.001	64.6	383.1	0	885	1.50 P	0.294	11.3	1592.8	1787.1	1037.4	12	7.69	1969
17.2	0.013	0.002	5.31	230.3	0	44.6	4.01 P	0.563	20.3	274.4	391.1	207.9	14.8	7.26	441
37.1	<0.003	<0.002	10.24	411.9	0	78.9	2.5 P		21.9	480.4	689.4	403.2	13.8	7.39	741
96.6	0.007	<0.001	14.6	360.5	0	653	<0.50 P	<0.50	13.7	1208.5	1391.6	749.7	13.8	8.15	1598
54.6	0.006	0.58	16	534.4	0	429.8	0.59 P		19.7	1091.1	1362.0	455.5	10.9	7.62	1453
57.9	<0.003	<0.002	22.6	465.1	0	501.7	4.5 P		22.1	1149.6	1385.5	444.6	14	7.28	1586
							5.178 P						15.3		
102	0.039	0.074	42.3	433.1	0	978	6.06	1.64	21.2	1800.3	2020.0	926.7	13.1	7.95	2390
373	<0.003	0.056	401	442.9	0	3721	48.6 P		30.5	6113.3	6338.1	2796.0	15.9	7.19	5290
							38.5 P						12.7		
49.8	0.005	<0.001	32.1	329.7	0	165	0.951 P	<0.5	9.67	550.3	717.8	412.0	7.1	7.2	846
1.4	0.023	<0.002	11.2	419.7	29	1997.6	<0.025 P		8.8	3408.9	3622.0	17.2	17.2	8.7	4240
29.8	<0.003	<0.002	71.2	435.5	0	164.9	0.28 P		17.9	733.5	954.7	272.2	13.5	8.15	1059
38.4	0.01	0.11	13.76	288.9	0	120.07	0.99 P		10.76	415.1	561.7	296.0	11.2	7.45	727
41.9	0.019	<0.001	35.1	282.7	0	180	6.59 P	<0.5	20.5	542.7	686.3	335.5	12.2	7.9	852
50.2	0.009	<0.001	33.4	246.4	0	174	6.27 P	<0.5	28.7	514.7	639.5	404.6	11.8	7.29	817
46.7	<0.003	<0.002	36.7	253.4	0	153.7	5.0 P		31.7	505.4	633.8	392.0	11.7	7.73	796
149	0.033	0.186	30.8	308.1	0	1774	<0.25 P		10.5	2796.8	2953.1	1137.2	12.1	7.58	3100
146	0.037	0.491	27	328.2	0	1547	<0.50 P	1.54	9.92	2438.6	2605.0	1130.3	11.9	7.31	2880
491	0.331	0.007	74.3	463.6	0	3222.4	1.2 P		9.6	4818.8	5054.2	3010.3	11.3	7.68	4280
							6.3 P						11.3		
90.9	<0.003	<0.002	60.7	225.5	0	709.8	4.9 P		12	1294.8	1409.5	662.8	12.7	8.4	1595
109	<0.003	<0.002	16.5	489.9	0	856.2	4.8 P		12.4	1653.4	1902.0	902.9	13.2	7.28	1859
							5.1 P						9.6		
							5.1 P						10.2		
173	0.094	0.029	21.6	404.1	0	1432	0.68 P		26.4	2339.1	2544.1	1423.8	10.4	8.31	2390

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
2000Q0337	92840	01S	25E	1	CBBB	-108.5958	45.7766	Yellow	Alluv	27	9/28/99	281	7.63	208
1997Q0696	92996	01S	25E	3	AADA	-108.6183	45.7816	Yellow	Alluv	45	3/23/97			
2000Q0343	151382	01S	25E	4	DDDC	-108.639205	45.770381	Yellow	Alluv	65	9/29/99			
1997Q0877	705285	01S	25E	6	AABB	-108.6838	45.7827	Yellow	Alluv	16	6/12/97			
2000Q0774	171247	01S	25E	8	ABBB	-108.6689	45.7694	Yellow	Alluv	24	3/20/00	1100	12.2	415
2000Q0293	171247	01S	25E	8	ABBB	-108.6689	45.7694	Yellow	Alluv	24	9/21/99	874	11.8	492
2000Q0294	93058	01S	25E	8	BAAA	-108.669873	45.769195	Yellow	Alluv	60	9/21/99	440	8.85	331
2000Q0289	171246	01S	25E	10	AABC	-108.625308	45.766816	Yellow	Alluv	35	9/21/99	90.4	3.95	120
2000Q0770	171246	01S	25E	10	AABC	-108.625308	45.766816	Yellow	Alluv	35	3/20/00	83.9	3.44	129
1998Q0036	93073	01S	25E	10	ADDC	-108.622043	45.76382	Yellow	Alluv	42	7/10/97	92.6	3.3	130.5
1997Q0691	93073	01S	25E	10	ADDC	-108.622043	45.76382	Yellow	Alluv	42	3/20/97			
1998Q0040	150483	01S	25E	14	CCB	-108.6161	45.7444	Yellow	Colorado	200	7/15/97	247.1	5.4	147
2000Q0336	171243	01S	25E	15	ACCC	-108.627651	45.748425	Yellow	Alluv	25	9/29/99	641	7.96	139
2000Q0771	171243	01S	25E	15	ACCC	-108.627651	45.748425	Yellow	Alluv	25	3/20/00	697	8.55	144
2000Q0347	172300	01S	25E	17	B	-108.67415	45.751556	Yellow	Alluv	50	10/6/99	219	5.29	159
1998Q0028	143994	01S	25E	17	BBBB	-108.67895	45.75466	Yellow	Alluv	48	7/12/97	122	3.8	197.5
1997Q0694	143994	01S	25E	17	BBBB	-108.67895	45.75466	Yellow	Alluv	48	3/20/97			
2000Q0335	93305	01S	25E	18	DDDC	-108.68109	45.72481	Yellow	Alluv	49	9/29/99	200	4.24	104
2005Q0368	93351	01S	25E	21	AADD	-108.639	45.737854	Yellow	Alluv	30	2/4/05	41.8	3.17	46.8
1998Q0029	93351	01S	25E	21	AADD	-108.639	45.737854	Yellow	Alluv	30	7/12/97	71.6	3.6	71.1
1997Q0873	93351	01S	25E	21	AADD	-108.639	45.737854	Yellow	Alluv	30	6/12/97			
1997Q0701	93351	01S	25E	21	AADD	-108.639	45.737854	Yellow	Alluv	30	3/24/97			
2000Q0288	171251	01S	25E	21	DAAA	-108.638391	45.733222	Yellow	Alluv	36.5	9/21/99	104	3.83	64.9
2000Q0295	171252	01S	25E	21	DAAA	-108.638369	45.73322	Yellow	Alluv	15	9/21/99	200	4.91	128
2000Q0290	171250	01S	25E	21	DDAD	-108.63903	45.729681	Yellow	Alluv	31	9/21/99	44.8	4.97	72
1998Q0254	162747	01S	25E	22	CDCD	-108.6294	45.7263	Yellow	Alluv	35	8/26/97			
1998Q0046	93417	01S	25E	22	DADA	-108.622115	45.73328	Yellow	Alluv	45	7/15/97	45.9	2.9	67.2
2000Q0301	171258	01S	25E	25	BCBC	-108.596797	45.720248	Yellow	Alluv	25	9/22/99	160	6.51	135
1998Q0035	154210	01S	25E	26	AADD	-108.59766	45.72329	Yellow	Alluv	38	7/12/97	165.3	5.3	197.5
2000Q0340	154210	01S	25E	26	AADD	-108.59766	45.72329	Yellow	Alluv	38	9/29/99			
1997Q0700	154210	01S	25E	26	AADD	-108.59766	45.72329	Yellow	Alluv	38	3/21/97			
2000Q0297	171248	01S	25E	29	BCCC	-108.679198	45.721783	Yellow	Alluv	18.5	9/23/99	64.2	5.3	99.2
2000Q0775	171248	01S	25E	29	BCCC	-108.679198	45.721783	Yellow	Alluv	18.5	3/20/00	143	7.52	215
1998Q0043	93528	01S	25E	30	DDDC	-108.68287	45.71225	Yellow	Alluv	20	7/13/97	62.2	5.4	110.2
2003Q0536	158589	01S	25E	33	ACDA	-108.644155	45.705102	Yellow	Alluv	25	9/27/02	62.4	4.98	98.7
1998Q0026	158946	01S	25E	34	BBBB	-108.636914	45.711544	Yellow	Alluv	23.5	7/15/97			
1997Q0761	158946	01S	25E	34	BBBB	-108.636914	45.711544	Yellow	Alluv	23.5	5/2/97			
1997Q0875	158960	01S	25E	34	BBBB	-108.6361	45.7113	Yellow	Alluv	22	6/12/97			
2004Q0592	93844	01S	26E	6	BACA	-108.5705931	45.7823517	Yellow	Alluv	26	6/25/04	174	5.43	121
1998Q0042	93857	01S	26E	6	CACA	-108.568693	45.77445161	Yellow	Alluv	25	7/10/97	74.4	3.5	75.8
2008Q0092	93857	01S	26E	6	CACA	-108.568693	45.77445161	Yellow	Alluv	25	8/13/07	76.6	3.77	94.5
2008Q0093	94118	01S	26E	16	ABCB	-108.5251912	45.75295168	Yellow	Alluv	26	8/13/07	91.4	3.87	89.6
1998Q0037	94118	01S	26E	16	ABCB	-108.5251912	45.75295168	Yellow	Alluv	26	7/10/97	130.7	4.5	127.2
2000Q0291	171256	01S	26E	18	DDCC	-108.5583	45.7887	Yellow	Alluv	19.5	9/20/99	161	8.63	101
2000Q0305	171257	01S	26E	19	BBBD	-108.5746	45.7404	Yellow	Alluv	20	9/22/99	72.6	4.69	74.2

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
132	<0.05	<0.01	36.8	594.1	0	1198	5.44 P	<0.5	26.7	2183.6	2485.0	1062.7		7.91	2540
							5.0 P						10.9		
							<0.5 P								
							0.98 P						9.2		
440	<0.1	0.555	41.46	586.8	0	4605.5	<2.5	<2.5	14.4	6918.2	7216.0	2847.3		7.36	5900
434	<0.01	0.987	31.31	549	0	3953	<0.5 P	<2.5	13.4	6080.5	6359.0	3014.9	13.6	7.45	5720
184	<0.05	0.014	26.42	388	0	2132.5	12.26 P	<1.0	21.5	3336.2	3533.0	1583.9	17.4	7.41	3660
64.7	<0.025	0.526	14.87	567.3	0	328.8	5.55 P	0.549	14.9	919.0	1206.7	565.9	13.1	7.52	1312
68.2	1.17	0.462	12.58	512.4	0	313.3	4.903	0.601	20.3	889.4	1149.2	602.8	11.4	7.34	1220
79	<0.003	<0.002	17.3	469.94	0	349	5.8 P		26.3	929.0	1167.5	651.0	10.9	8.28	1275
							5.5 P						11.1		
52.7	0.046	0.089	42.9	299.14	0	736.3	<0.25 P		10.7	1389.0	1540.7	584.0	14.2	8.31	1661
138	<0.05	0.121	22.32	512.4	0	1965	1.363 P	<2.5	18.7	3184.2	3444.0	915.1	11.8	7.87	3510
137	<0.05	0.099	19.1	511.2	0	1938.6	3.632	1.151	20	3221.7	3481.0	923.5	4.7	7.45	3610
113	<0.05	0.011	12.39	405	0	954	7.88 P	0.621	24.6	1687.5	1893.0	862.1	12.9	7.89	2210
85.3	0.011	0.009	10.2	271.3	0	818.3	0.35 P		26.9	1397.3	1534.8	844.3	11.7	8.27	1570
							<0.25 P						11.5		
71.4	<0.025	0.034	11.59	572.2	0	418.6	4.85 P	<0.5	15.2	1107.2	1397.4	553.6		8	1533
35.6	0.01	<0.001	10.2	369.7	0	81.2	3.18	0.315	22.1	425.7	613.5	263.4	13.5	7.45	782
64.7	<0.006	<0.002	14.3	420.9	0	213.5	7.2 P		22.7	670.2	883.8	443.8	10.5	8.35	1012
							4.4 P								
							4.5 P						10.6		
36.9	0.125	0.062	12.38	396.7	0	224.5	<0.5 P	0.534	11.5	655.4	856.8	313.9		7.39	1087
90.5	<0.025	0.499	25	557.5	0	628.6	<0.5 P	0.574	11.3	1364.4	1647.5	692.1	14.2	7.39	1826
28.8	<0.01	0.092	9.17	370.4	0	107.5	8.61 P	0.56	17.5	469.1	656.8	298.3	12.7	7.59	696
							1.3 P						14.8		
40.7	<0.003	0.028	6.3	260.6	12	179.3	2.6		18.9	504.5	636.9	335.3	12.2	8.44	775
63.4	<0.025	0.28	9.05	428.2	0	654.2	3.435 P	<0.5	20	1260.2	1477.4	598.0	11.6	7.42	1563
102	<0.003	<0.002	14.5	407.5	0	749	9.7 P		25.8	1460.9	1667.9	914.6	10.6	8.35	1750
							9.078 P						13.2		
							10.1 P						10.8		
52.2	0.068	1.7	8.52	343.1	0	340.2	0.521 P	0.531	17.5	759.4	933.4	462.6	14.1	7.48	1116
123	<0.05	0.605	18.34	410.4	0	842.7	1.8	0.525	21.9	1578.0	1786.0	1043.1	10.8	7.19	1962
68.9	<0.003	<0.002	23.2	344	0	359	11.1 P		28.9	826.6	1001.1	558.8	10.1	8.3	1036
57.1	0.15	0.004	35	453.8	0	145	11.0 P	0.3	28.2	654.4	884.8	481.5	14.6	7.49	1159
							0.45 P								
							1.7 P								
							1.2 P								
107	0.014	<0.001	30.1	432.5	0	754	4.89 P	<0.5	28.3	1432.3	1652.0	742.5	13.4	8.12	1761
63.5	<0.003	<0.002	21.8	455.79	0	145.8	5.3 P		26.6	636.9	868.3	450.6	11.8	8.36	929
67.2	<0.005	0.004	46.5	472.1	0	162	6.10 P	0.631	25.8	711.6	951.1	512.6	14	7.53	1220
64.5	<0.005	<0.001	26.1	468.5	0	234	9.23 P	0.689	25.5	767.2	1005.1	489.2	14.6	7.16	1180
97.6	<0.003	<0.002	30.2	519.72	0	424	20.1 P		28.2	1099.0	1362.8	719.3	11.8	8.3	1411
62.5	<0.005	1.31	32.1	379.4	0	476	3.56 P	0.822	16.9	1047.2	1239.5	509.4	16.7	7.75	1398
44	<0.01	0.474	9.74	331.8	0	170.4	6.27 P	0.589	8.86	549.7	718.2	366.4	13.4	7.49	991

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
2000Q0773	171257	01S	26E	19	BBBD	-108.5746	45.7404	Yellow	Alluv	20	3/20/00	83	5.37	102
1997Q0863	6980	01S	27E	4	ACCC	-108.3961	45.7763	Yellow	Alluv	56	6/16/97			
1998Q0242	154800	01S	27E	6	ABAA	-108.4338	45.783	Yellow	EagleTel	305	8/23/97	454.6	4.7	273.3
1997Q0876	94264	01S	27E	6	CDCA	-108.4411	45.7702	Yellow	EagleTel	415	6/15/97			
1998Q0127	6983	01S	29E	5	AAAA	-108.1522	45.7827	Yellow	Claggett	70	7/28/97	94	4	117.6
1998Q0119	159863	01S	29E	6	BBCA	-108.1997	45.7808	Yellow	EagleTel	70	7/28/97	26.7	1.9	107.7
1998Q0236	161765	02N	23E	33	BADB	-108.8744	45.8816	Yellow	Judriv	127	8/23/97	1014	2.8	16.4
1998Q0153	13287	02N	24E	32	BCCC	-108.775	45.8788	Yellow	EagleTel	696	8/12/97	296.3	2.7	57.7
1998Q0008	13287	02N	24E	32	BCCC	-108.775	45.8788	Yellow	EagleTel	696	6/28/97			
1998Q0148	161722	02N	24E	36	DBBA	-108.6808	45.8777	Yellow	EagleTel	140	8/11/97	2457	4.7	27.1
1998Q0238	13297	02N	25E	17	BC	-108.6477	45.9241	Yellow	Bullmnt	120	8/23/97	747	4.7	94.2
1998Q0347	986	02N	25E	20	CCDA	-108.6463	45.9002	Yellow	Judriv	304	9/7/97	1824	5	72.1
1998Q0349	13309	02N	26E	20	BB	-108.5272	45.9141	Yellow	Judriv	225	9/7/97	797.5	1.56	5.6
1998Q0150	13311	02N	26E	22	DC	-108.4691	45.9016	Yellow	Judriv	192	8/10/97	523.3	1.8	14.87
1998Q0398	13395	02N	27E	2	BCBC	-108.3416	45.953	Yellow	Alluv	30	9/17/97			
1998Q0128	13395	02N	27E	2	BCBC	-108.3416	45.953	Yellow	Alluv	30	7/24/97			
1997Q0785	13395	02N	27E	2	BCBC	-108.3416	45.953	Yellow	Alluv	30	5/15/97			
1998Q0038	153340	02N	27E	3	DDDC	-108.3446	45.9443	Yellow	Alluv	23	7/10/97	87.8	6.56	132
1999Q0801	153340	02N	27E	3	DDDC	-108.3446	45.9443	Yellow	Alluv	23	6/9/99			
1998Q0399	153340	02N	27E	3	DDDC	-108.3446	45.9443	Yellow	Alluv	23	9/17/97			
1997Q0782	153340	02N	27E	3	DDDC	-108.3446	45.9443	Yellow	Alluv	23	5/15/97			
1997Q0692	153340	02N	27E	3	DDDC	-108.3446	45.9443	Yellow	Alluv	23	3/22/97			
1997Q0812	13460	02N	27E	10	AAA	-108.344231	45.942829	Yellow	Alluv	33	6/4/97			
1997Q0817	13458	02N	27E	10	AADB	-108.3447	45.9426	Yellow	Alluv	20	6/4/97			
1997Q0814	144485	02N	27E	10	AADB	-108.3437	45.942	Yellow	Alluv	28	6/4/97			
1997Q0695	158559	02N	27E	12	ACBD	-108.3091	45.9388	Yellow	Alluv	23	3/21/97			
2002Q0843	191494	02N	27E	16	BBBB	-108.3731	45.9273	Yellow	Alluv	14	2/13/02	740	13.3	234
1999Q0808	13589	02N	27E	21	BA	-108.3763212	45.91282039	Yellow	Alluv	22	6/10/99			
2007Q1180	13628	02N	27E	22	DDCB	-108.3461855	45.90205601	Yellow	Alluv	28	6/18/07	42.1	3.05	31.4
1998Q0110	13628	02N	27E	22	DDCB	-108.3461855	45.90205601	Yellow	Alluv	28	7/24/97	83.1	5	70.6
1998Q0402	13628	02N	27E	22	DDCB	-108.3461855	45.90205601	Yellow	Alluv	28	9/17/97			
1997Q0786	13628	02N	27E	22	DDCB	-108.3461855	45.90205601	Yellow	Alluv	28	5/15/97			
1997Q0690	13628	02N	27E	22	DDCB	-108.3461855	45.90205601	Yellow	Alluv	28	3/22/97			
1998Q0114	161834	02N	27E	25	ABDA	-108.3063	45.8972	Yellow	Judriv	65	7/28/97	234.7	2.7	56.5
2006Q0871	191488	02N	27E	31	CDDB	-108.4164881	45.87315457	Yellow	Alluv	14.44	3/6/06	133	1.55	37.7
1998Q0111	13832	02N	27E	32	BCDD	-108.3997	45.8788	Yellow	Alluv	24	7/25/97	573.6	4.9	92.4
1999Q0810	13832	02N	27E	32	BCDD	-108.3997	45.8788	Yellow	Alluv	24	6/9/99			
1998Q0404	149788	02N	27E	33	AABA	-108.3655	45.8852	Yellow	Judriv	200	9/19/97	243.8	8.1	233.1
2002Q0834	191489	02N	27E	36	CBD	-108.3162	45.8762	Yellow	Alluv	17	2/12/02	370	5.02	110
1998Q0113	161835	02N	28E	3	BADA	-108.2267	45.9533	Yellow	Alluv	20	7/26/97	86.7	4.4	72.1
1999Q0800	161835	02N	28E	3	BADA	-108.2267	45.9533	Yellow	Alluv	20	6/10/99			
1998Q0286	162677	02N	28E	7	DADD	-108.2797	45.9325	Yellow	Alluv	30	8/26/97			
2003Q0539	158212	02N	28E	15	BACB	-108.2328806	45.92725851	Yellow	Alluv	33	9/28/02	105	3.38	33.8
2002Q1534	13934	02N	28E	16	ACAA	-108.2428813	45.92455811	Yellow	Alluv	27	6/18/02	50.3	2.14	48.6
1998Q0041	13934	02N	28E	16	ACAA	-108.2428813	45.92455811	Yellow	Alluv	27	7/10/97	54.7	2.3	54.4

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
61	<0.025	0.067	13.78	449	0	306.5	2.295	0.632	12.6	809.2	1037.0	505.8	12.3	7.49	1120
							0.30 P						12.4		
235	2.5	0.117	10.9	362.3	0	2010.4	<0.25 P		13	3183.7	3367.3	1649.3	14	7.93	3400
							1.02 P						13.7		
104	<0.003	0.003	48.8	356.24	0	482.9	10.8 P		31.9	1058.9	1239.5	721.3	11.9	7.48	1344
41.1	<0.003	<0.002	24.6	358.27	0	135.4	3.2		20.8	538.2	719.8	438.1	10.3	7.33	861
3.1	0.02	0.024	140.9	778.4	0	1244.8	0.44 P		8.4	2813.8	3208.5	53.7	17.2	8.3	3620
43	<0.003	<0.002	85.3	634.4	0	242.9	4.8 P		8.2	1048.3	1370.0	321.1	15.6	7.66	1630
							9.75 P						14.6		
11	0.097	0.014	33.4	818.6	0	4561	0.78 P		7.8	7505.6	7921.1	112.9	12.4	8.14	7410
46.1	<0.003	<0.002	33.7	597.8	0	1294.6	5.7 P		9.74	2525.9	2829.3	425.0	11.6	8.5	3150
32	0.021	0.036	<50	730.8	0	2542	19.1 P		8.3	4843.2	5214.1	311.7	12.5	8.08	6090
1.4	0.008	0.01	11.3	949.8	0	710.6	<0.25 P		8.5	2006.0	2488.0	19.7	13.6	8.22	2980
8.65	<0.003	0.018	11.7	683.2	0	684.4	<0.25 P		7.7	1589.0	1935.5	72.7	13	8.2	2680
							<0.25 P								
							2.8 P								
							2.3 P								
80.4	0.039	0.124	62.04	398.9	0	330.1	2.0 P		21.9	918.0	1120.4	660.5	11.8	8.15	1119
							0.87 P						13.1		
							0.8 P								
							0.25 P								
							0.4 P						11.4		
							12.7 P								
							8.6 P								
							6.0 P								
							5.4 P						9.7		
181	0.04	0.548	52.6	571	0	2373	3.17	3.77	23	3906.3	4196.0	1329.3		7.82	4620
							<0.5 P								
14.5	0.01	<0.001	3.61	168.8	0	85.4	<0.05 P	0.631	15.5	280.2	366.0	138.1	13.9	7.17	448
35.4	<0.003	<0.002	7.6	250.83	0	261.8	<0.25 P		19.4	606.7	734.1	322.0	17.4	7.5	869
							0.27 P								
							1.0 P								
							1.2 P						11.8		
24.7	0.166	0.082	27.7	359.9	0	411.3	<0.25 P		14.3	949.5	1132.2	242.7	10.7	7.87	1300
35.9	<0.005	<0.001	12.4	407.8	0	125	3.10 P	0.542	16.6	564.6	771.6	241.9	9	7.63	874
72.9	<0.003	<0.002	30.1	585.6	0	1142	8.4 P		22.4	2227.0	2524.3	530.8	10.8	7.58	2720
							6.95 P						10.3		
106	0.051	0.136	25.98	444.1	19	1152.3	0.43 P		12.9	2019.5	2244.8	1017.1	12.3	8.6	2350
82.4	1.56	3.13	51.8	619.8	0	903	<0.5 P	<0.5	16.4	1849.1	2163.7	613.8	2	7.27	2600
27.4	0.015	<0.002	10.5	373.32	0	134.8	1.1 P		25.7	546.2	735.5	292.8	11.7	7.45	858
							0.712 P						11		
							11.0 P								
11.2	<0.005	<0.001	3.7	250.5	0	152	0.8 P	0.93	20.6	454.6	582.0	130.5	12.6	7.89	766
23.1	0.009	0.004	5.51	236.7	0	149	<0.5 P	0.406	21.9	417.5	537.7	216.4	12.8	7.8	672
25.9	<0.003	<0.002		207.9	0				25.2	264.8	370.3	242.4	12.5	8.26	608

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
1998Q0010	13934	02N	28E	16	ACAA	-108.2428813	45.92455811	Yellow	Alluv	27	7/1/97			
2002Q0841	191443	02N	28E	19	CABA	-108.294246	45.906344	Yellow	Alluv	16.22	2/12/02	42	2.14	50.5
2003Q1179	157773	02N	28E	21	ADAA	-108.2394814	45.90995785	Yellow	Bearpaw	240	6/18/03	622	2.82	38.7
2004Q0593	14009	02N	29E	5	CABA	-108.1438751	45.94986227	Yellow	Alluv	35	6/25/04	69.9	3.3	48.6
1997Q0871	161714	02N	29E	5	CBBB	-108.1497	45.95	Yellow	Alluv	20	6/18/97			
1998Q0117	161772	02N	29E	5	CCCD	-108.1488	45.9433	Yellow	Alluv	50	7/26/97	60.87	5.62	61.58
1998Q0025	161772	02N	29E	5	CCCD	-108.1488	45.9433	Yellow	Alluv	50	7/11/97			
1997Q0763	158942	02N	29E	17	BDDD	-108.1408	45.9219	Yellow	Alluv	30	5/3/97			
2006Q0189	217039	02N	29E	18	BBC	-108.1733523	45.92603157	Yellow	Alluv	80	8/3/05	35.2	2.03	61.7
1997Q0764	14047	02N	30E	6	BAC	-108.0372	45.9575	Yellow	Alluv	11	5/6/97			
1997Q0760	14050	02N	30E	6	D	-108.0372	45.9575	Yellow	Alluv	23	5/6/97			
1998Q0250	128210	02N	30E	8	CDC	-108.0188	45.9297	Yellow	Judriv	960	8/25/97	794.4	1.4	2.7
1998Q0537	1034	02N	38E	15	CCDC	-106.9969	45.9133	Treas	EagleTel	60	10/19/97	243.4	4.6	237.8
1998Q0044	7198	02S	23E	12	CBBC	-108.8413	45.6747	Yellow	Kootenai	2285	7/13/97	834.1	1.1	2.1
2000Q0346	171264	02S	23E	13	BBAB	-108.8417022	45.66804787	Yellow	Alluv	31	10/6/99	193	5.99	238
2000Q0777	171264	02S	23E	13	BBAB	-108.8417022	45.66804787	Yellow	Alluv	31	3/20/00	140	5.84	245
2001Q1474	97745	02S	23E	25	CABD	-108.8363014	45.62944805	Yellow	Alluv	25	5/2/01	56.6	3.16	65
2004Q0589	158606	02S	24E	2	DCAA	-108.726798	45.68604991	Yellow	Alluv	33	6/29/04	34.1	2.66	100
1998Q0033	124908	02S	24E	2	DCAD	-108.7247	45.685	Yellow	Alluv	34.5	7/11/97	34.7	2.9	112.2
1998Q0032	124908	02S	24E	2	DCAD	-108.7247	45.685	Yellow	Alluv	34.5	7/11/97	34.2	2.8	113.1
2003Q0538	98056	02S	24E	4	CBAB	-108.7795001	45.68964909	Yellow	Alluv	94	9/27/02	125	3.89	95.7
1998Q0047	98059	02S	24E	4	CBBD	-108.7788	45.6891	Yellow	Alluv	70	7/15/97	143.7	4	95.1
2000Q0299	171259	02S	24E	4	CDAA	-108.7711	45.6831	Yellow	Alluv	20	9/23/99	68.9	2.73	63.4
2000Q0344	171262	02S	24E	7	BCBD	-108.8206	45.6797	Yellow	Alluv	28	10/6/99	80	5.76	320
2000Q0772	171261	02S	24E	7	DAAA	-108.8061	45.677	Yellow	Alluv	26	3/20/00	606	10	449
2000Q0334	171261	02S	24E	7	DAAA	-108.8061	45.677	Yellow	Alluv	26	9/30/99	668	11.2	449
2005Q0456	98118	02S	24E	8	DA	-108.7818	45.6741	Yellow	Alluv	45	4/29/05	1168	10.8	121
2004Q0599	98128	02S	24E	9	ACBD	-108.7689995	45.6770493	Yellow	Alluv	57	6/29/04	216	5.09	192
2000Q0304	171265	02S	24E	10	BACD	-108.7714	45.6797	Yellow	Alluv	15	9/23/99	230	4.67	186
1997Q0731	148540	02S	24E	14	ABBB	-108.7291	45.6677	Yellow	Alluv	33	4/4/97			
1997Q0730	98208	02S	24E	15	DADD	-108.74	45.6583	Yellow	Alluv	30	4/3/97			
2000Q0339	171263	02S	24E	19	BCCC	-108.8194	45.6469	Yellow	Alluv	20	9/30/99	160	6.4	126
2000Q0769	171263	02S	24E	19	BCCC	-108.8194	45.6469	Yellow	Alluv	20	3/2/00	250	7.8	168
2000Q0338	98264	02S	24E	22	CBCC	-108.7601	45.6437	Yellow	Alluv	34	10/1/99	31.7	3.38	86.2
2000Q0776	171253	02S	25E	4	BBAB	-108.6516	45.6971	Yellow	Alluv	13	3/20/00	42.7	2.66	60.3
2000Q0306	171253	02S	25E	4	BBAB	-108.6516	45.6971	Yellow	Alluv	13	9/23/99	46	3.25	60.8
1997Q0697	158551	02S	25E	6	ADAD	-108.6797	45.6927	Yellow	Alluv	21	3/25/97			
1998Q0031	705378	02S	25E	7	BCBC	-108.6977	45.6772	Yellow	Alluv	28	7/11/97	42.8	3.6	47.7
2003Q0533	144916	02S	25E	8	ADCB	-108.6585952	45.6752506	Yellow	Alluv	44.3	9/27/02	1250	9.18	346
1997Q0816	98381	02S	26E	2	CBAA	-108.4819	45.6891	Yellow	Colorado	50	6/3/97			
1998Q0235	705381	02S	26E	10	BDDC	-108.4991	45.6755	Yellow	Kootenai	1220	8/23/97	1100	1.5	4.1
1997Q0862	705381	02S	26E	10	BDDC	-108.4991	45.6755	Yellow	Kootenai	1220	6/17/97			
2006Q0868	98399	02S	26E	25	BBCC	-108.4666875	45.63555276	Yellow	Kootenai	1245	3/8/06	1088	2.01	4.04
2001Q1433	14941	03N	23E	6	CCDC	-108.921494	46.032243	Yellow	EagleTel	164	4/16/01	624	1.76	4.35
2005Q0458	14968	03N	24E	20	BDCB	-108.7716018	45.99615266	Yellow	Alluv	67	4/25/05	416	18.9	35.3

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
							<0.25 P								
18.3	0.019	0.197	7.9	248.9	0	92.1	<0.5	0.552	17.1	353.5	479.8	201.4	9.4	8.07	620
16.2	<0.025	0.038	30.3	298.9	0	1150	0.78 P	<2.5	7.56	2015.2	2166.9	163.3	18.1	8.22	2800
31.3	0.006	<0.001	7.92	315.98	0	154	1.12 P	0.255	16.5	487.6	648.0	250.2	14.4	7.75	722
							<0.25 P								
32	<0.005	<0.001	18.7	237.1	0	206.59	1.8 P		23.597	527.4	647.6	285.6	14	7.66	833
							2.9 P						13.4		
							2.9 P						10		
32.4	0.021	0.003	6.5	347.4	0	46.6	10.3 P	0.311	20.8	377.3	553.4	287.4		8.06	675
							7.6 P								
							5.4 P						8		
0.43	<0.003	<0.002	445.1	686.9	38	381.2	<0.25 P		10.8	2011.6	2360.1	8.5	18.7	8.55	2950
258	0.146	0.19	13.2	763.7	41	1378.3	7.8 P		14.7	2567.6	2955.2	1656.5	14	8.63	2820
0.49	0.266	0.004	86.5	1684.8	96	<2.5	<0.25 P		15.3	1865.9	2720.8	7.3	20.5	8.71	2710
119	1.21	2.66	46.47	488	0	1009.1	1.314 P	<0.5	18.9	1874.4	2122.0	1084.1	12.2	7.83	2220
128	0.4	1.89	25.42	425.78	0	1072.2	2.629	<0.5	20.6	1851.9	2068.0	1138.6		7.4	2200
36.1	0.031	<0.001	12.8	385.5	0	112	<0.5 P	<0.5	27.1	503.3	699.1	310.9		7.34	797
50.7	0.288	0.011	14.7	315.98	0	262	2.52 P	0.859	29.4	650.4	810.7	458.4	15.1	8.05	875
60.7	<0.003	<0.002	26.1	302.6	0	273.1	1.8 P		30.4	689.2	842.9	530.0		8.44	927
59.7	<0.003	<0.002	25.9	280.1	0	270.9	1.6 P		30.4	674.7	816.8	528.1	10.5	8.22	891
51.6	0.056	0.002	14.5	329.4	0	470	0.6 P	<1	21.9	945.4	1112.3	451.3		7.76	1344
51.6	<0.003	<0.002	14.5	296.5	0	481.5	0.469		24.1	962.0	1112.7	449.9	13.2	8.34	1263
19.8	<0.01	0.119	16.82	278.2	0	169.6	<0.5 P	0.788	18.9	499.1	640.2	239.8	17.9	7.67	725
141	<0.05	0.052	9.62	427	0	1123.9	1.558 P	<0.5	15	1906.4	2123.0	1379.4	12.2	7.63	2310
295	<0.05	0.33	77.98	341.6	0	2931.4	4.064	<2.5	21.6	4563.5	4737.0	2335.4	11.9	6.9	4480
281	<0.1	1.57	93.43	519.7	0	3061	5.267 P	<2.5	19.9	4841.2	5105.0	2277.7	11.5	7.82	4890
304	0.091	0.151	82	97.6	0	3800	<5.0 P	<1.0	<1.0	5534.3	5584.0	1553.4	10.3	8.25	5580
80.9	0.044	0.219	37.2	310.7	0	923	0.945 P	0.529	23.9	1632.2	1789.9	812.4	17.1	8.16	1950
68.5	<0.025	0.223	31.56	317.2	0	925.5	<0.5 P	0.731	25.4	1629.7	1790.5	746.4	14.5	7.51	2160
							0.6 P						10.1		
							1.1 P						10.2		
107	<0.025	1.46	18.51	461.2	0	681.3	3.945 P	0.541	28.5	1357.1	1591.0	755.0		8.37	1720
146	<0.05	1.52	22.66	469.7	0	874.2	7.172	0.583	30.2	1740.5	1979.0	1020.4	11.2	7.4	1820
28.2	0.034	0.006	4.46	329.9	0	139.7	1.855 P	<0.5	25.9	482.0	649.4	331.3	15.2	7.85	649
30	<0.015	0.116	9.75	369.9	0	54.3	0.641	0.584	23.6	408.6	596.3	274.0	7.6	7.36	599
29.4	<0.01	0.202	11.46	385.5	0	57.7	5.13 P	0.664	21	420.4	616.2	272.8		7.32	734
							2.8 P						9.8		
21.1	<0.003	<0.002	9.2	212.3	6.7	98.9	1.7 P		17.2	352.2	459.8	206.0	9.8	8.44	620
291	3.1	0.071	162.6	542.9	0	4360	3.4 P	<0.5	21	6710.5	6986.0	2061.7	10.1	7.19	6770
							3.4 P						10.1		
1.3	<0.003	<0.002	179.3	2558.3	0	4.1	<0.05 P		9.89	2560.5	3858.4	15.6	21.6	8.27	3570
							<0.25 P						20.9		
1.4	0.165	<0.005	199	2072.78	0	<50.0	<1.0 P	5.94	9.9	2331.6	3383.4	15.9	12.4	8.02	3480
3.04	0.027	0.012	90.8	836.2	12	661	<0.5 P	1.13	9.04	1819.2	2243.4	23.4	11.3	8.52	2910
73.8	0.018	0.254	50.3	441.6	0	851	<1.0	<1.0	2.02	1664.9	1889.1	391.9	10.8	8.27	2330

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
1998Q0246	159865	03N	27E	14	BCCC	-108.3413	46.0091	Yellow	Bullmnt	200	8/24/97	154.7	1.9	26
1998Q0348	1199	03N	27E	32	ADAA	-108.3847	45.9683	Yellow	Judriv	647	9/8/97	795.3	1.3	3.39
2001Q1471	15078	03N	28E	19	CADD	-108.289382	45.99325885	Yellow	Bullmnt	75	5/2/01	316	1.89	55.9
2008Q0155	15078	03N	28E	19	CADD	-108.289382	45.99325885	Yellow	Bullmnt	75	8/30/07	400	2.33	81.5
1998Q0124	15100	03N	28E	30	DBCD	-108.2855	45.9763	Yellow	Alluv	35	7/25/97	227.4	3.7	108.8
1999Q0802	15100	03N	28E	30	DBCD	-108.2855	45.9763	Yellow	Alluv	35	6/9/99			
1997Q0693	15100	03N	28E	30	DBCD	-108.2855	45.9763	Yellow	Alluv	35	3/20/97			
2002Q1519	182524	03N	28E	30	DCDB	-108.2869822	45.9761585	Yellow	Alluv	38	6/17/02	227	3.71	89
2008Q0156	182524	03N	28E	30	DCDB	-108.2869822	45.9761585	Yellow	Alluv	38	8/30/07	360	4.26	127
2002Q0839	191448	03N	28E	32	BBAB	-108.274962	45.972103	Yellow	Alluv	19.57	2/13/02	213	4.63	142
1998Q0401	158560	03N	28E	32	BBAB	-108.2718	45.9725	Yellow	Alluv	16	9/17/97			
1998Q0129	158560	03N	28E	32	BBAB	-108.2718	45.9725	Yellow	Alluv	16	7/24/97			
1997Q0784	158560	03N	28E	32	BBAB	-108.2718	45.9725	Yellow	Alluv	16	5/15/97			
2002Q0836	191492	03N	28E	33	CDAA	-108.2466	45.9617	Yellow	Alluv	10.5	2/12/02	166	2.5	58.3
2002Q0837	191442	03N	29E	26	AABB	-108.0735626	45.98772343	Yellow	Alluv	15.54	2/13/02	558	3.29	29.6
2002Q0842	191446	03N	29E	28	CCBB	-108.1321887	45.97605346	Yellow	Alluv	25.27	2/13/02	287	3.29	191
1998Q0104	135896	03N	29E	35	CBBC	-108.0894	45.9641	Yellow	Alluv	26	7/26/97	74.2	3.5	103.3
2002Q1530	158587	03N	30E	21	CCAA	-108.0008	45.9913	Yellow	Alluv	20.5	6/19/02	130	4.11	112
2002Q0838	191493	03N	30E	32	CCCC	-108.0259	45.9598	Yellow	Alluv	15	2/13/02	50.7	5.62	69
1998Q0123	15225	03N	30E	33	BDCD	-107.9977	45.9663	Yellow	Alluv	40	7/26/97	45.7	3.3	75.3
1999Q0807	15225	03N	30E	33	BDCD	-107.9977	45.9663	Yellow	Alluv	40	6/11/99			
1997Q0815	1207	03N	31E	4	CDAC	-107.8727	46.0372	Yellow	Bullmnt	315	6/1/97			
1998Q0357	159872	03N	35E	3	ACAA	-107.348	46.0391	Treas	Bullmnt	225	9/9/97	382.7	0.861	3.3
1998Q0350	157746	03N	35E	3	BACC	-107.3575	46.0405	Treas	Bullmnt	200	9/9/97	446.7	1.3	5.4
1997Q0787	144337	03N	35E	3	BBDD	-107.358	46.0408	Treas	Alluv	35	5/16/97			
2002Q1536	705232	03N	37E	25	CBCB	-107.0716056	45.97638906	Treas	EagleTel	55	6/19/02	555	11.6	217
1998Q0536	1217	03N	37E	26	DDBB	-107.0761	45.9752	Treas	EagleTel	66	10/19/97	268.5	2.9	17.01
1998Q0244	7332	03S	24E	1	CAAB	-108.7108	45.6022	Yellow	Bullmnt	1020	8/21/97	624.5	1.192	4.57
1998Q0245	100290	03S	24E	10	BABD	-108.7533	45.5947	Yellow	Kootenai	1220	8/21/97	670	0.98	2.8
1998Q0237	7339	03S	24E	12	DCCA	-108.7061	45.5822	Yellow	Kootenai	1000	8/21/97	628.8	1.044	3
1998Q0240	143992	03S	24E	14	CAAB	-108.7063	46.0088	Yellow	Bullmnt	207	8/21/97	215.6	4.4	140.6
1998Q0170	143992	03S	24E	14	CAAB	-108.7063	46.0088	Yellow	Bullmnt	207	8/12/97			
1998Q0149	15960	04N	23E	1	DDDA	-108.7997	46.1208	Yellow	Bullmnt	166	8/12/97	315.7	2.13	14.17
2004Q0569	15965	04N	23E	14	ABBA	-108.8285056	46.10335423	Yellow	Bullmnt	400	6/23/04	800	7.02	166
2005Q0040	15966	04N	23E	14	ABBA	-108.8285056	46.10345423	Yellow	Bullmnt	80	7/26/04	2322	11.6	218
1998Q0241	15965	04N	23E	14	ABBA	-108.8285056	46.10335423	Yellow	Bullmnt	400	8/22/97	705.9	8.2	254.9
1998Q0542	15974	04N	23E	16	BCCC	-108.8833	46.0957	Yellow	EagleTel	1100	10/18/97	631.7	0.665	1.8
1998Q0541	15969	04N	23E	16	BCCC	-108.8831	46.0957	Yellow	EagleTel	992	10/18/97	676.5	1.058	4.9
1998Q0243	16073	04N	26E	29	DCCB	-108.5183	46.0605	Yellow	Bullmnt	115	8/22/97	162.4	2.3	32.7
1998Q0247	150266	04N	27E	14	BBBB	-108.3413	46.0152	Yellow	Bullmnt	240	8/24/97	382.6	0.691	1.8
2003Q1194	157936	04N	28E	15	DCDD	-108.2211771	46.0891635	Yellow	Bullmnt	97	6/4/03	595	7.5	136
1998Q0161	16106	04N	29E	23	DDDA	-108.0683	46.0755	Yellow	Bullmnt	269	8/9/97	517.3	1.9	6.1
1998Q0249	160738	04N	30E	10	BCCA	-107.9841	46.1116	Yellow	Bullmnt	60	8/25/97	1373	3.6	75.6
1997Q0788	159873	04N	33E	1	BBBA	-107.5683	46.1338	Yellow	Alluv	40	5/19/97			
2002Q1523	1330	04N	33E	18	DCAB	-107.6598276	46.09068553	Yellow	Bullmnt	445	6/24/02	405	0.986	2.1

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
18.2	<0.003	<0.002	10.3	447	0	75.9	<0.25 P		9	516.4	743.2	139.8	12.8	8.18	827
0.93	0.01	<0.002	897.4	586.2	0	<100.	1.1 P		8.5	1995.0	2292.3	12.3	16	8.12	3240
34.8	0.029	<0.001	168	511.2	0	325	3.64 P	0.568	8.9	1163.4	1422.7	282.8	11.3	7.63	1845
60.1	0.035	<0.001	298	488.8	0	420	11.8 P	1.65	8.92	1513.5	1761.6	450.9		7.55	2370
85.5	<0.003	<0.002	29.4	476	0	629.1	15.1 P		27.8	1345.8	1587.3	623.6	11.7	7.36	1767
							26.28 P						12.8		
							4.0 P						10.1		
72.8	0.02	0.001	15.5	614.9	0	563	3.97 P	0.563	21.6	1297.8	1609.8	521.9	12.1	7.6	1779
97.1	0.041	<0.001	25.3	475	0	960	12.6 P	1.52	20.9	1830.1	2071.1	716.8	12.5	7.39	2450
88.7	0.039	0.147	69	523.4	0	540	34.5	0.655	22.1	1373.3	1638.7	719.7	11.1	8.08	2240
							14.2 P								
							16.9 P								
							13.5 P								
40.4	0.054	3.15	14.9	611.2	0	266	<0.5	0.529	17.3	870.7	1180.7	311.9	7.4	7.29	1242
27.4	0.022	0.425	22.9	658.8	0	1021	<0.5	0.951	20.8	2008.6	2343.0	186.7	11	7.44	2990
90.6	0.039	0.053	17.7	716.1	0	913	<0.5	1.59	23.5	1881.3	2244.6	849.8	12.5	8.02	2500
50.5	0.011	<0.002	16.2	352.6	0	277.6	3.1 P		18.9	718.7	897.8	465.8	10.5	7.43	1058
47.7	0.16	1.08	13.3	306.2	0	413	<0.5 P	<0.5	18.1	889.5	1044.7	476.0	10.4	7.59	1386
32.7	0.029	1.41	10.6	436.8	0	77.2	1.9	<0.5	19	484.0	705.7	306.9		7.7	818
41.6	<0.003	<0.002	10.7	388.4	0	107.5	1.2 P		18.6	495.0	691.9	359.2	10.7	7.4	822
							2.22 P						12.6		
							5.3 P						12.5		
0.76	<0.003	<0.002	<10.	478.9	15	328.5	<0.25 P		7.7	976.0	1219.1	11.3	12.5	8.66	1572
1.4	0.034	0.004	<50.	475.2	7.2	523.7	<0.25 P		7.3	1226.8	1467.8	19.2	11.3	8.41	1758
							<0.25 P						10.6		
141	0.08	0.524	18.2	549	0	1991	<0.5 P	2.85	8.54	3217.4	3496.0	1122.2	11.4	7.63	3760
7.1	<0.005	0.022	15.7	546.56		186	<0.25 P		9.6	777.6	1055.1	71.7	10.9	8.75	1159
2.98	0.253	0.012	40.4	1683.6	53	81.7	<0.25 P		10.617	1649.1	2503.6	23.7	17.8	8.45	2570
0.6	<0.003	<0.002	20.4	1603.1	0	<2.5	<0.25		12.5	1497.1	2310.4	9.5	21.5	8.36	2190
0.73	0.082	0.005	22.3	1599.4	0	<2.5	<0.25 P		10.8	1454.4	2265.7	10.5	17.4	8.66	2170
120	<0.003	<0.002	175	463.6	0	552.8	32.8 P		13.9	1451.1	1686.5	844.6	10.6	8.19	2090
							39.0 P								
21	0.004	<0.002	26.3	612.4	0	234.4	1.4 P		6.3	920.7	1231.2	121.9	10.8	8.3	1850
181	<0.05	<0.010	248	447.7	0	2351	2.57 P	<0.50	5.21	3978.7	4206.0	1159.5	11.1	8.08	4380
374	0.493	0.078	2630	122	18	2841	<2.50 P	2.28	<1.0	8477.1	8539.0	2083.7	11.1	8.52	9980
282	<0.003	<0.002	242.6	423.3	0	2308.4	16.2 P		5.75	4016.2	4230.8	1796.8	10.3	7.88	4290
0.3	<0.005	<0.001	45.3	450.2	65	922.5	<0.25 P	2.48	10.4	1901.8	2130.1	5.7	19.5	9.72	2770
3.04	<0.005	0.012	41.6	452.6	50	819.3	0.66		10.1	1831.1	2061.0	24.8	16.7	9.48	2410
20.8	<0.003	<0.002	14.9	388.9	0	152.8	0.88 P		8.4	585.1	782.5	167.3	14.2	8.14	944
0.57	<0.003	<0.002	16.5	477.02	24	326.2	<0.25 P		7.9	996.4	1238.4	6.8	12.8	8.73	1472
167	0.084	0.006	30.1	405.04	0	1884	<0.5 P	<2.5	8.05	3027.7	3233.2	1027.0	10.8	7.75	3350
3.76	0.052	0.003	11.2	564.9	46	488.2	0.68 P		6.4	1358.3	1644.9	30.7	12.6	8.48	2050
139	0.058	0.015	60.2	840.6	0	2598	0.37 P		7.5	4672.1	5098.8	761.7	12	8.22	5090
							0.8 P						9		
1.57	<0.005	0.006	27.4	387.1	40	513	2.12 P	3.66	7.13	1191.3	1387.7	11.7	25.4	8.95	1880

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
1997Q0869	151376	05N	27E	11	DABA	-108.3033	46.1983	Yellow	Bullmnt	122	6/17/97			
1997Q0870	17123	05N	27E	34	DBDC	-108.3283	46.1375	Yellow	Bullmnt	443	6/15/97			
1998Q0252	17153	05N	29E	12	ABBC	-108.0391	46.2047	Yellow	Bullmnt	145	8/26/97	50.6	2	40.8
1998Q0160	17164	05N	29E	24	DBCB	-108.0391	46.168	Yellow	EagleTel	120	8/7/97	279.1	2.1	35.7
1998Q0155	158588	05N	30E	8	CBAD	-108.003	46.1975	Yellow	EagleTel	103	8/9/97	68.7	2	53.9
1998Q0152	161737	05N	31E	19	AAAC	-107.8847	46.1763	Yellow	EagleTel	42	8/9/97	446.9	5.99	85.39
1998Q0151	17193	05N	32E	5	CBAD	-107.7527	46.2122	Yellow	Bullmnt	70	8/9/97	805.5	4.2	72.6
1997Q0874	17199	05N	32E	10	ADBD	-107.6988	46.2016	Yellow	Bullmnt	150	6/17/97			
1997Q0864	1401	05N	32E	20	AAAD	-107.7377	46.1766	Yellow	Bullmnt	370	6/14/97			
1998Q0355	17205	05N	32E	22	ADBA	-107.698	46.1738	Yellow	Bullmnt	260	9/5/97	495.2	1.1	3.2
1997Q0872	17220	05N	33E	19	CBBB	-107.6525	46.17	Yellow	Bullmnt	178	6/16/97			
2003Q1214	158554	05N	33E	35	DACC	-107.5555312	46.14038612	Yellow	Alluv	18.5	6/17/03	133	2.95	70.2
1998Q0351	161708	05N	34E	31	DDAD	-107.5075	46.1369	Yellow	Bullmnt	260	9/5/97	128.9	3.5	90.3
2003Q1202	143862	05N	34E	34	CBAD	-107.4587258	46.14068688	Treas	Bullmnt	100	6/18/03	321	0.834	1.65
1999Q0803	17257	05N	36E	5	BABC	-107.2513	46.2197	Treas	Alluv	65	6/11/99			
1998Q0406	17256	05N	36E	5	BACB	-107.2513	46.2186	Treas	Alluv	75	9/23/97	630.4	1.2	4.1
2003Q1205	142191	05N	36E	25	CDAB	-107.1663129	46.15158862	Treas	Bullmnt	210	6/17/03	360	2.8	78.8
2002Q1525	17277	05N	37E	20	BABA	-107.125211	46.17698881	Treas	Alluv	60	6/24/02	533	5.76	84.4
2001Q0387	18332	06N	27E	31	DBAB	-108.3908	46.2286	Yellow	Bullmnt	145	8/10/00	5.24	1.23	9.67
2008Q0157	18368	06N	28E	28	DABA	-108.2201748	46.24126805	Yellow	Bullmnt	150	8/30/07	567	3	22.3
1998Q0168	18368	06N	28E	28	DABA	-108.2201748	46.24126805	Yellow	Bullmnt	150	8/7/97	588.1	3.4	26.3
1998Q0103	18465	06N	32E	23	DDAA	-107.675	46.2536	Yellow	Bullmnt	306	7/29/97			
1997Q0813	143866	06N	33E	4	AACC	-107.5958	46.305	Yellow	Bullmnt	200	6/2/97			
1998Q0356	161820	06N	33E	28	CCBC	-107.6113	46.2386	Yellow	Bullmnt	600	9/5/97	885	1.9	9.7
1998Q0405	18499	06N	34E	34	BDDC	-107.4563	46.2286	Treas	Bullmnt	170	9/22/97	749.8	1.3	5.7
2007Q1194	18521	06N	35E	21	ADBD	-107.3450226	46.26038686	Treas	Alluv	18	6/26/07	27.5	2.32	48.6
2002Q1521	18521	06N	35E	21	ADBD	-107.3450226	46.26038686	Treas	Alluv	18	6/19/02	36.1	2.7	79.1
1998Q0167	149945	06N	35E	23	CCBD	-107.3186	46.2519	Treas	Alluv	72	8/11/97	497.8	3.8	55.7
2002Q1524	18534	06N	36E	1	CBBA	-107.1735159	46.30068823	Treas	Alluv	21	6/24/02	158	4.01	89.1
1998Q0115	18535	06N	36E	1	CCBD	-107.1719	46.2958	Treas	Judriv	692	7/25/97	934.2	2.6	2.6
1998Q0166	161829	06N	36E	1	DABD	-107.1558	46.2994	Treas	Alluv	20	8/9/97	55.6	2	47.2
1998Q0107	161828	06N	36E	9	BACB	-107.2308	46.2911	Treas	Alluv	70	7/24/97	423.4	8.8	122.5
1999Q0806	161828	06N	36E	9	BACB	-107.2308	46.2911	Treas	Alluv	70	6/11/99			
1998Q0258	162781	06N	36E	19	BACB	-107.2722	46.2625	Treas	Alluv	120	8/20/97			
1998Q0256	162714	06N	36E	19	BDDC	-107.2697	46.2575	Treas	Alluv	98	8/20/97			
1998Q0358	18571	06N	36E	19	CACA	-107.2708	46.2552	Treas	Alluv	100	9/9/97	692.6	8.4	241.6
1998Q0165	18573	06N	36E	20	ABAA	-107.2419	46.2641	Treas	Alluv	90	8/9/97	375.1	5.3	98.1
1998Q0253	18575	06N	36E	21	DDAB	-107.2169	46.2538	Treas	Bullmnt	100	8/23/97	585	5.5	174.6
1999Q0804	18575	06N	36E	21	DDAB	-107.2169	46.2538	Treas	Bullmnt	100	6/11/99			
1998Q0164	18584	06N	37E	7	ACAA	-107.138	46.2897	Treas	Alluv	40	8/11/97	178.5	5.5	90.2
1999Q0809	18584	06N	37E	7	ACAA	-107.138	46.2897	Treas	Alluv	40	6/11/99			
2002Q1526	157745	06N	37E	31	ACAA	-107.1387623	46.23186858	Treas	Alluv	32	6/24/02	574	8.5	183
2002Q1520	1502	06N	37E	31	ACBA	-107.1409525	46.23174856	Treas	Judriv	946	6/24/02	829	2.19	3.12
1998Q0255	20081	07N	30E	34	CDBB	-107.9627	46.3111	Yellow	Bullmnt	165	8/26/97			
1998Q0154	20118	07N	32E	20	DCAD	-107.7433	46.3388	Yellow	EagleTel	115	8/9/97	232	4	96.5

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
							<0.25 P						11.7		
							0.76						16.5		
52.3	0.091	0.013	1.95	327.4	0	108.4	<0.25 P		16.3	433.2	599.2	317.1	11	8.02	663
29.1	0.152	0.074	16.4	530.7	0	381.5	<0.25 P		8.6	1014.4	1283.8	208.9	13.9	7.73	1450
35.7	0.008	0.005	12.65	298.2	0	135.58	2.9 P		11	467.4	618.6	281.5	10.7	7.82	774
57.7	0.56	0.068	18.8	591.7	0	812.8	<0.25 P		9	1729.7	2030.1	450.6	10.8	7.55	2700
43.5	0.084	0.044	52.4	457.5	0	1769	<0.25 P		7.4	2979.7	3212.1	360.1	10.9	7.8	4040
							<0.25 P						12.8		
							<0.25 P						13.7		
1.7	0.004	<0.002	101.7	824.1	17	167.2	<0.25 P		7.21	1199.8	1617.9	15.0	12.8	8.63	1860
							<0.25 P						12		
58.1	0.522	0.355	36	661.24	0	160	0.543 P	1.51	19.8	808.9	1144.3	414.4	11.4	7.87	1316
72.8	<0.003	<0.002	19.1	644.8	0	53.1	22.0 P		18.4	703.9	1031.2	525.1	15.2	7.71	1372
0.33	0.008	0.006	23.4	463.6	31	258	<0.5 P	3.68	6.03	874.6	1110.0	5.5	11.3	8.73	1424
							<0.5 P						15.6		
0.82	<0.003	0.007	<20.	559.6	46	788	0.28 P		8.6	1754.8	2038.9	13.6	12.1	9.26	2390
59.1	0.193	0.127	13.9	420.7	0	860	<0.5 P	1.5	8.84	1593.3	1806.9	440.0	12.2	7.79	2170
69.5	0.81	0.458	16.2	659.1	0	1146	<0.5 P	1.91	23.2	2205.6	2539.9	496.8	12.3	7.59	2930
4.03	1.32	0.014	<0.5	66.1	0	3.73	<0.05	0.076	13	70.8	104.3	40.7		7.85	101.3
8.59	0.035	0.027	13.2	369.3	0	979	<0.50 P	1.32	6.06	1781.7	1968.9	91.0	11.4	7.72	2510
10.7	<0.003	0.032	15.2	438	0	1027	<0.25 P		7	1892.8	2115.0	109.7	12	7.91	2400
							0.91 P						11.9		
							<0.25 P						12		
3.4	<0.003	0.005	92.6	569.7	5.4	1228	<0.25 P		8.12	2515.0	2804.2	38.2	14.8	8.4	3210
1.3	0.009	0.011	79.3	518.1	43	968.5	<0.25 P		7.5	2112.2	2375.0	19.6	12.4	9.24	2820
14.6	<0.005	0.001	5.17	205	0	54.7	0.062 P	0.579	17	272.2	376.2	181.4	12.8	7.15	510
23.3	0.012	0.17	8.21	352.8	0	108	<0.5 P	0.378	18.3	449.3	628.4	293.4	12.1	7.5	729
29	0.038	0.005	4.4	506.3	0	738.4	6.8 P		22.6	1601.0	1857.7	258.4	13.2	7.79	2410
35.8	2.29	1.12	13.8	513.1	0	319	2.41 P	0.527	23.5	900.6	1160.9	369.8	9.4	7.49	1327
0.77	<0.003	<0.002	834	1060.2	0	<2.5	<0.25 P		10.3	2306.6	2844.4	9.7	15.5	8.08	3640
16.9	0.757	0.337	7.8	221.6	0	105	<0.25 P		20.8	366.5	479.1	187.4	9.4	7.59	600
104	<0.003	0.076	32.5	553.9	0	902.8	53.9 P		31.7	1899.4	2180.5	733.9	12.1	7.54	2480
							43.64 P						16		
							209 P						12.1		
							33.8 P						12.9		
117	<0.003	0.051	<50.	289.8	0	2127	67.8 P		19.7	3349.0	3496.1	1082.8	13.1	7.92	3860
71.8	<0.003	0.039	12.8	528.3	0	870	3.9 P		19.5	1713.2	1981.1	540.5	12	7.4	2120
122	<0.003	<0.002	11	384.3	0	1780	2.55 P		16.5	2885.2	3080.0	939.8	12.5	8.15	3140
							1.99 P						14.6		
103	0.004	0.221	10.7	447.1	0	586.2	1.4 P		17.2	1211.9	1438.7	647.1	11.5	7.59	1570
							1.05 P						12.7		
141	1.69	1.27	22.9	641.5	0	1894	2.81 P	2.68	26.7	3173.3	3499.0	1037.3	11.8	7.49	3740
0.81	<0.05	<0.01	761	1020.5	0	<25.0	<0.5 P	4.96	10.9	2114.9	2632.9	11.1	16	8.11	3600
							<0.25 P						13		
73.8	0.034	0.061	16.9	625.9	0	349	20.6 P		12	1092.9	1410.5	544.7	12.8	7.24	1820

Lab No.	Site No.	Township	Range	Section	Tract	Longitude	Latitude	County	Hydro Unit	Total Depth	Sample Date	Na	K	Ca
1998Q0364	1599	07N	33E	6	DBCD	-107.6408	46.3841	Treas	Bullmnt	109	9/7/97	732.6	1.6	5.8
1998Q0366	20146	07N	34E	28	BBBB	-107.4861	46.3366	Treas	Bullmnt	240	9/8/97	1226	1.415	10.7
1998Q0360	20147	07N	34E	31	ADBA	-107.5102	46.3186	Treas	Bullmnt	170	9/9/97	1029	1.9	11
2006Q0865	157751	07N	35E	31	AABC	-107.3878266	46.32128627	Treas	Judriv	1080	3/7/06	1037	2.9	4.34
1998Q0403	20151	07N	35E	32	CDDC	-107.3736	46.3091	Treas	Bullmnt	120	9/22/97	695.1	2.349	10.03
1998Q0169	128213	07N	37E	34	DBBB	-107.0791	46.3152	Treas	Alluv	24	8/10/97	352.4	6.2	107.5
1999Q0805	128213	07N	37E	34	DBBB	-107.0791	46.3152	Treas	Alluv	24	6/11/99			
1997Q0868	705253	08N	33E	19	BCDD	-107.6488	46.4319	Treas	EagleTel	135	6/15/97			
1997Q0867	21487	08N	33E	24	DCDD	-107.5336	46.425	Treas	Bullmnt	400	6/15/97			
1998Q0363	21489	08N	33E	30	BAAB	-107.6452	46.4233	Treas	Bullmnt	112	9/7/97	928.3	5.1	62.9
1998Q0365	21490	08N	33E	31	DBDB	-107.6397	46.4005	Treas	Bullmnt	130	9/7/97	874.8	2.3	8.2
1998Q0361	21496	08N	34E	18	CDDD	-107.5191	46.4388	Treas	Bullmnt	170	9/8/97	647.2	2.5	44.8
1997Q0865	21498	08N	34E	20	AABA	-107.4902	46.4383	Treas	Alluv	20	6/17/97			
2007Q1193	21506	08N	34E	30	DDDA	-107.5081352	46.4114845	Treas	Bullmnt	180	6/26/07	792	2.42	13.3
1998Q0362	21506	08N	34E	30	DDDA	-107.5081352	46.4114845	Treas	Bullmnt	180	9/8/97	779.3	1.9	13.7
1998Q0359	21508	08N	34E	32	DBBC	-107.4969	46.4008	Treas	Bullmnt	140	9/8/97	723.9	1.8	8.9
1998Q0108	141787	08N	35E	2	ABBD	-107.3075	46.4805	Treas	Judriv	140	7/26/97	619.6	1.4	6.8
1998Q0109	143882	08N	35E	13	DCDD	-107.2844	46.4386	Treas	Judriv	160	7/26/97	1810	4.8	14.1

Mg	Fe	Mn	Cl	HCO_3	CO_3	SO_4	NO_3	F	SiO_2	TDS	Dissolved Constituents	Hardness	Temp	Lab pH	Lab SC
1.5	<0.003	<0.002	52.1	433.1	29	1140	<0.25 P		8.1	2184.6	2404.3	20.7	14.1	9.18	2890
2.5	0.015	0.006	138.5	460.3	21	1793	<0.25 P		7.6	3427.9	3661.3	37.0	12.6	8.81	3910
2.1	0.019	0.016	90.5	356.2	4.8	1762	<0.25 P		7.5	3085.5	3266.1	36.1	17	8.47	3710
0.9	0.063	<0.010	1139	680.8	0	<125	<2.5 P	<2.5	11.1	2530.7	2876.2	14.5	20.3	7.9	4330
3.36	<0.05	0.03	28.1	677.5	51	756.7	<0.25 P		9.07	1889.4	2233.4	38.9	13.7	9.08	2470
32.2	0.38	0.517	30.2	573.4	0	660.1	<0.25 P		23.6	1495.0	1785.7	401.0	11	7.52	1900
							<0.5 P						12.2		
							<0.25 P						10		
							<0.25 P						12.5		
36.7	0.871	0.054	<50.	708.2	22	1517	<0.25 P		7.8	2929.5	3288.7	308.1	12.4	8.61	3540
2.6	0.032	0.003	<50.	1006.9	68	716.8	0.44 P		7.1	2175.9	2686.9	31.2	15.2	9.05	3220
15.8	0.201	0.065	<20.	628.3	7.2	1004	<0.25 P		10.1	2041.1	2359.8	176.9	15.4	8.4	2650
							<0.25 P						7.5		
4.6	0.064	0.044	22.1	644.2	0	1076	<2.5 P	<1.0	8.29	2235.1	2561.9	52.1	12.6	7.84	3190
4.5	<0.003	0.022	<50.	660.6	30	1127	<0.25 P		8.9	2290.8	2626.2	52.7	12.2	8.8	2940
2.9	<0.003	0.021	16.1	769.2	0	743.2	1.42	1.9	8.6	1887.9	2278.1	34.2	14.8	8.19	2670
1.9	0.02	0.021	21.3	556.3	30	826.6	<0.25 P		8.6	1790.6	2072.7	24.8	12.3	8.69	2500
4.8	0.139	0.009	137.7	1118.7	0	2997	<0.25 P		9.2	5529.2	6096.9	55.0	12.4	8.16	6080