HYDROGEOLOGY OF THE BURTON BENCH AQUIFER, NORTH-CENTRAL MONTANA

by James P. Madison

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ABSTRACT

The Burton Bench, north of the town of Choteau, encompasses about 100-square miles in north-central Montana. The sand and gravel aquifer underlying the Burton Bench is the sole source of domestic water supply for the residents living on the Burton bench, and is an important source of stock water.

The Tertiary-Quaternary sand and gravel bench forms an easterly sloping alluvial plain about 9 miles square. Perennial streamflow on the Burton Bench is principally from Muddy Creek, which flows easterly across the upper part of the Burton Bench and from Spring Coulee, which drains the central part of the Burton Bench. The Teton River flows south of Burton Bench, and although it is not hydraulically connected to the sand and gravel aquifer, as much as 60,000 acre feet/year may be diverted from the river for irrigation on the Burton Bench.

The Burton Bench aquifer is bounded by flat-lying Cretaceous Virgelle Sandstone, Telegraph Creek Formation, and the Mowry Shale, which are composed of mudstones and sandstones and are not important aquifers in the Burton Bench area. The Burton Bench aquifer is composed primarily of fluvially deposited sand and gravel and contains little clay and silt. The maximum thickness of the sand and gravel is about 70 feet. In the eastern part of the Burton Bench, the sand and gravel are overlain by mostly fine-grained glacial deposits. In some areas of the Burton Bench, the saturated thickness of the sand and gravel aquifer is as little as 1 foot.

Hydraulic conductivity for the Burton Bench Aquifer was determining using specific capacity results from 12 locations. At the 12 locations, the minimum hydraulic conductivity was 32 feet/day, the maximum was 495 feet/day, and the median was 116 feet/day. These results agree with other hydraulic conductivity values determined from long-term aquifer tests.

Water-level altitudes were monitored in 26 wells and used to prepare well hydrographs and a potentiometric surface map. Water levels generally were lowest in spring, rose during the irrigation season, and then fell throughout the winter and early spring; the maximum measured fluctuation was about 14 feet. The January 2003 potentiometric surface for the Burton Bench aquifer depicts flow from the west margin of the aquifer towards the east and, locally, ground water flows towards and discharges into Muddy Creek. Seasonal fluctuations in water levels do not significantly alter the shape of the potentiometric surface. The altitude of the January 2003 potentiometric surface is the same to slightly lower than the potentiometric surface in January 1988.

Recharge to the Burton Bench aquifer is through infiltration of streamflow (3,290 acre-feet/yr), irrigation water (29,120 acre-feet/yr), and precipitation (1,420 acre-feet/yr), and inflow from the alluvium in the Ralston Gap area (640 acre-feet/yr). Discharge from the Burton Bench aquifer is through evapotranspiration (20,000 acre-feet/yr), leakage to streams and drains (12,300 acre-feet/yr) discharge to wells (15 acre-feet/yr), and underflow through the eastern boundary of the study area (2,160 acre-feet/yr). Recharge from irrigation practices may account for as much 84 percent of the total recharge to the Burton Bench aquifer; future land-use decisions that remove

land from irrigation must consider the consequences of decreased ground-water recharge. Throughout most of the Burton Bench, the sand and gravel that compose the aquifer are at or near the surface, which could allow the rapid infiltration of surface contaminants to the water table. These sands and gravels become buried by fine-grained glacial deposits in the east part of the Burton Bench; these fine-grained materials inhibit the downward migration of near-surface contaminants to the sand and gravel aquifer.

Results of inorganic analyses of water samples from 21 wells completed in the Burton Bench aquifer indicate magnesium bicarbonate- and calcium bicarbonate-type water along the western margin of the Burton Bench aquifer. Along ground-water flow paths, the water becomes depleted in magnesium and enriched in sodium due to cation-exchange reactions. The median total dissolved solids concentration was 609 milligrams per liter. Water-quality results from samples collected in 2002 were compared with water-quality results from samples collected in 1985 and 1986 from 17 wells; no overall trend in major-ion constituents was decipherable. At 14 sites, a total of 43 samples were collected for pesticide analyses. At 11 of the sites, pesticides were not detected; at one site 2-4,D was detected in 1 of 4 samples; at another site Assert™ and/or Assert™ metabolite were detected in three of seven samples; and at another site, Assert™ and/or Assert™ metabolite were detected in five of seven samples. The drinking water standard for nitrate was exceeded in a sample from one well; a subsequent sample was below the standard. At six sites, water samples were collected for helium-tritium age determination; the oldest water was from the most downgradient well tested and was about 61 years old. The most upgradient well tested was in the Ralston Gap and that water had an age of about 12 years.

INTRODUCTION

The Burton Bench is located in north-central Montana and north of the town of Choteau (figure 1). The aquifer underlying the bench is the sole source of domestic supply for about 250 residents, and all of the domestic and public-supply wells used by these residents are less than 75 feet deep. Because most of the aquifer underlying the Burton Bench is shallow and unconfined, it is susceptible to contamination from increased septic-tank density, agricultural practices, accidental spills, and other effects of human activity.

The residents living on the Burton Bench and local policy makers have recently become concerned with potential adverse effects to ground-water quality from agricultural activities, especially from the application of agricultural chemicals. There is also growing concern that as subdivisions encroach on agricultural land that ground-water recharge will decline and water quality will deteriorate. To provide guidance for planning and growth, and to objectively evaluate and manage future water-quality changes, the citizens and policy makers decided that the current water resources of the Burton Bench aquifer should be assessed.

From April 2002 through July 2004, the Montana Bureau of Mines and Geology, in cooperation with Teton County, conducted a study of the aquifer beneath the Burton Bench. The study was designed to expand knowledge of the ground water through a systematic program of data collection, research, and analysis, and to document changes in water quality and ground-water flow that may have occurred since the last ground-water investigation (Patton, 1990). The results presented in this report will be useful to the development of a comprehensive management program for the use and protection of the ground-water resources of the Burton Bench.

Purpose and Scope

This report, which presents the study results, describes the hydrogeology of the Burton Bench aquifer. Specific objectives were to:

1. Describe the geometry and the hydraulic characteristics of the aquifer.

2. Define the potentiometric surface and the direction of ground-water flow.

3. Locate and quantify sources of ground-water recharge and discharge including surface- and ground-water interactions

4. Characterize the water quality in terms of concentration, distribution, and sources of major ions, trace elements, and organic compounds.

5. Compare the water-quality and static water-level information collected during this study to previous information to assess whether significant changes have occurred to the chemical and physical aspects of the aquifer.

To determine the geometry (gravel thickness, aerial extent, and saturated thickness) of the aquifer, well-completion reports on file with the Montana Bureau of Mines and Geology (MBMG) were examined for lithology; about 500 driller's logs were evaluated. To determine the hydraulic characteristics of the aquifer, short-term aquifer tests were conducted at 12 sites. Aquifer properties were also estimated using the results of constant-discharge pumping tests conducted by previous investigators. A 26-well monitoring network was established for the measurement of water levels in wells. Three of these wells were equipped with continuous water-level recorders.

Water samples were collected from 16 wells during the study for analyses of major-ion and trace-element concentrations. In addition, samples from 14 wells were analyzed for pesticides, and samples from 6 wells were analyzed for tritium-helium for age determination.

Streamflow was measured periodically at six sites in the study area. The resulting data were used to determine inflow to, and outflow from, the study area.

Data from well inventories, streamflow gaging stations, and water-level and water-quality monitoring networks were entered into the MBMG's Ground Water Information Center's (GWIC) database. These data can be used as the basis for establishing and assessing long-term water-quality and water-level trends and future changes in the physical and chemical aspects of the aquifer.

Previous Investigations

The geology of the Burton Bench was described by Alden (1932) in a report of the physiography and glacial geology of eastern Montana. Alden interpreted the gravel-capped terraces of northern Montana and southern Canada as the remnants of dissected peneplains. Alden also mapped the western edge of the continental ice sheet, which crossed the eastern part of the Burton bench. Chalmers (1968) reported on the glacial geology in the vicinity of Choteau, including the Burton Bench. Chalmers interpreted the Burton Bench as an alluvial fan composed of glacial outwash derived from the Teton River glacier. Mudge and others(1983) produced a geologic and structure map for a large area that includes the Burton Bench. The hydrogeology of the Burton Bench was first described by Fisher (1909). He was the first to note the importance that irrigation had on recharging the aquifer, and noted that within a few years of irrigating, ground- water levels were generally within 10 feet of land surface; prior to irrigation, only a few feet of the base of the sand and gravel aquifer were saturated. Norbeck (1976) and Patton (1990) described the ground-water resources of the Burton Bench including water quality, depth to water, ground-water flow, ground-water recharge and discharge, and aquifer properties; Patton's water-quality and water-level data served as a comparison for the current study. He also described the glacial geology and geomorphology in great detail. Hendrickson and Miller (2002) collected water samples from wells for inorganic and pesticide analyses, and water levels from wells for preparation of a potentiometric map.

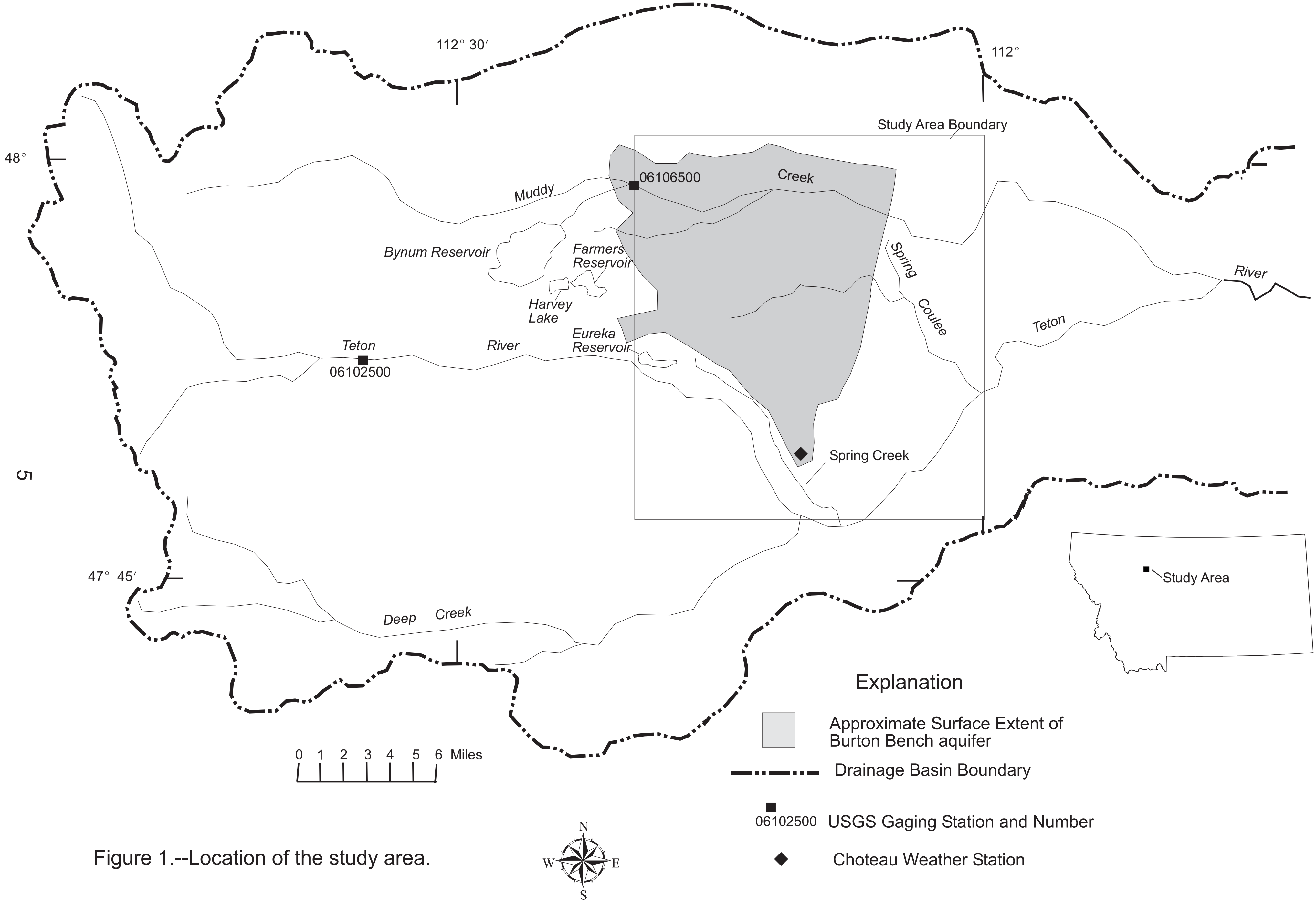

Figure 1.--Location of the study area.

Location Numbering System

The locations of wells and streamflow-measurement sites are designated by location numbers, which are based on the rectangular system for the subdivision of public lands (figure 2). Each number consists of as many as 14 characters and is assigned according to the location of the site within a given township, range, and section. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position west (W) of the Principal Meridian. The next two characters indicate the section. The next three or four characters indicate the position of the site within the section. The first letter denotes the quarter section (160-acre tract); the second, the quarter-quarter section (40-acre tract); the third, the quarter-quarter-quarter section (10-acre tract); and the fourth, the quarter-quarter-quarter-quarter section (2½-acre tract). The subdivisions of the sections are numbered A,B,C, and D in a counterclockwise direction beginning in the northeast quadrant. The last two characters form a sequence number that is assigned on the basis of order of inventory within that tract. For example in figure 2, the location number 25N04W26BCBB01 refers to the first well (01) inventoried in the NW¼ NW¼ SW¼ NW¼ sec. 26, T. 25 N., R. 4 W.

Acknowledgments

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GEOGRAPHY

The Burton Bench is an alluvial plain in the north-central part of the Northern Rocky Mountains physiographic province. The Bench marks the transition from the eastern plains to the rugged mountains to the west. The Continental Divide, which separates the Missouri and the Columbia River drainages, is located about 30 miles to the west. The town of Choteau is located just south of the Burton Bench, and Great Falls is about 60 miles to the east; Helena, Montana’s capital, is about 80 miles to the south.

Historically, land use on the Burton Bench has consisted mostly of cattle ranching and farming, with water diverted from the Teton River used to irrigate grain and hay fields. However, some of the historic ranch and farm land is beginning to be subdivided into

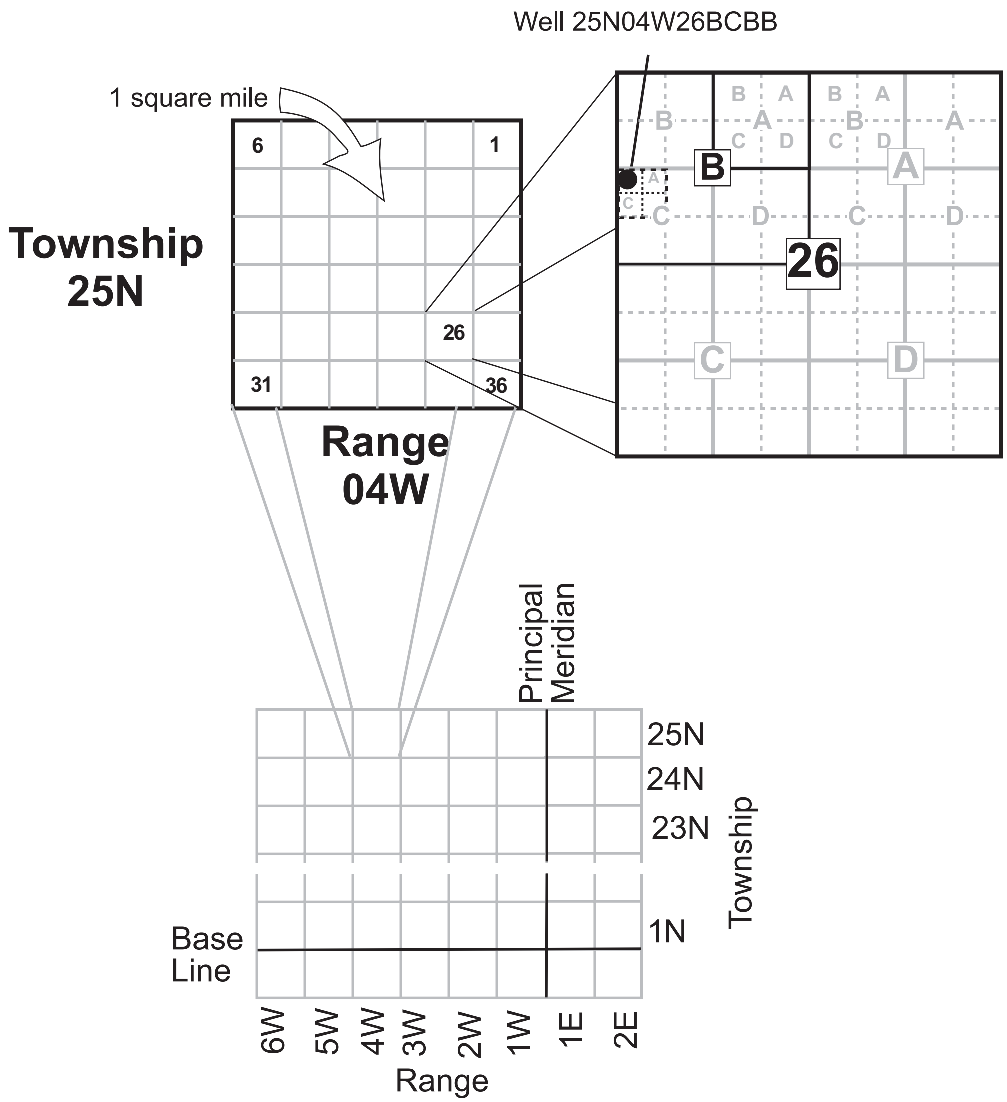


Figure 2.--Location numbering system.

small-acreage ranchettes, with other subdivisions proposed in the future (Paul Wick, Teton County Planner, per. comm., 2002).

Physiography

Quaternary alluvium forms a gentle, easterly sloping alluvial plain in the Burton Bench area and is about 100-square miles in area. The alluvial plain is bounded by the bedrock foothills of the mountains to the west. Bedrock capped by erosion-resistant material bounds the alluvial plain on the north, west, and south. To the east, the alluvial plain dips under and is bounded by rolling hills composed of fine-grained glacial deposits that extend to the east. The highest altitude of the Burton Bench is about 4,130 feet above mean sea level (amsl) along its western margin; the lowest altitude is about 3,740 feet (amsl) along its eastern margin.

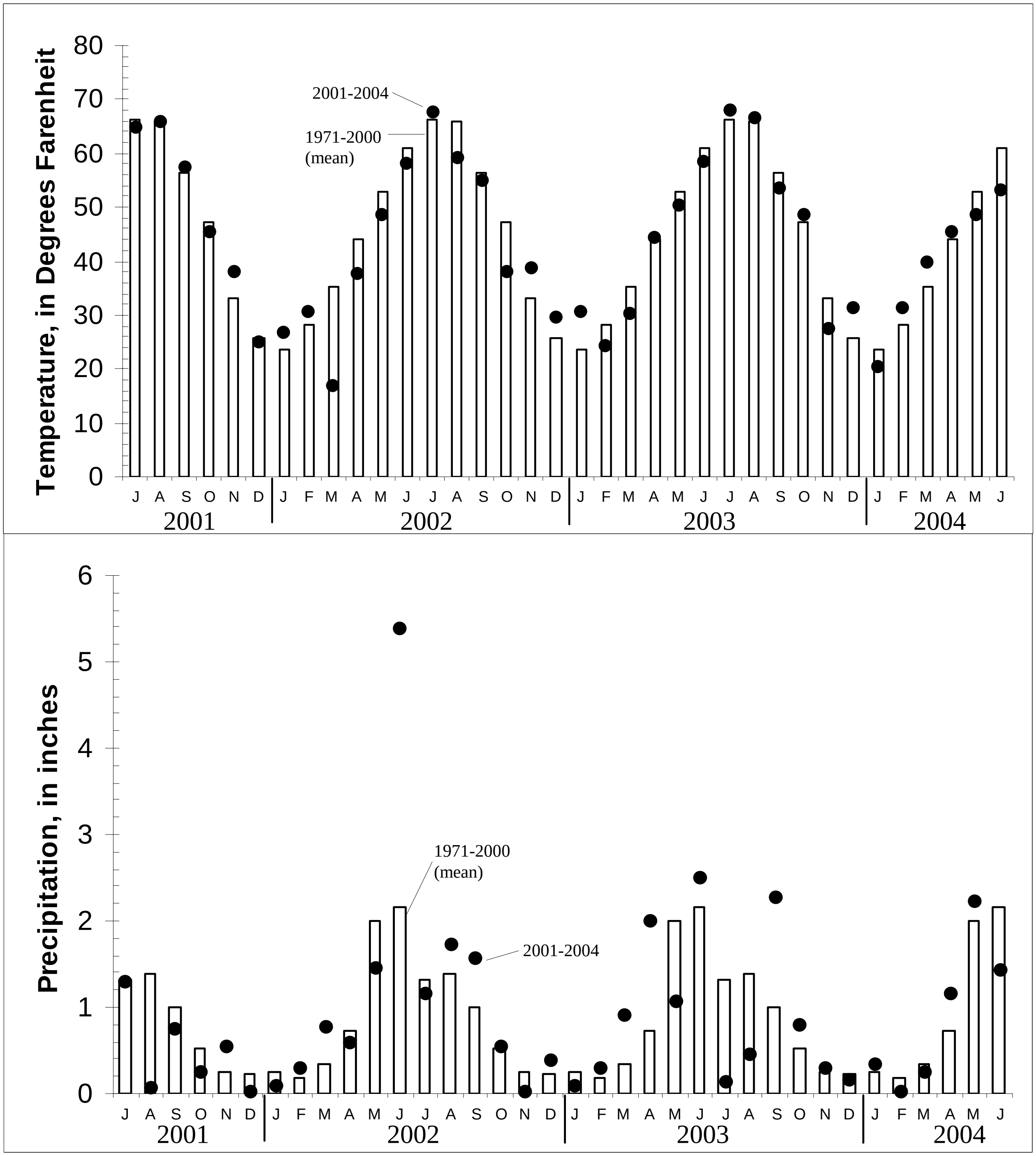
Climate

The Burton Bench area has a semiarid climate that is typical of areas in Montana east of the Continental Divide. Average annual precipitation is 10.5 inches at the Choteau Airport (Western Region Climate Center, 2004), which is just south of the Bench (figure 1). The mountains to the west of the Bench receive, on average, more than 50 inches of precipitation yearly. May and June typically have the greatest monthly precipitation, and combined they account for about one-third of the annual precipitation. Average annual free-water-surface evaporation at the Choteau weather station is about 57 inches (National Oceanic and Atmospheric Administration, 1982) which is more than five times the average annual precipitation. Daily air temperatures have an annual range from about -35 to 100 F. Mean monthly air temperature and precipitation at the Choteau weather station are shown in figure 3.

Streamflow

Three principal streams flow near or onto the Burton Bench: Muddy Creek, Teton River, and Spring Coulee. The largest of these streams is the Teton River, which, along with its tributaries drain about 105 square miles of the Rocky Mountain Front and plains to the west of Choteau and the Burton Bench. At the long-term USGS gaging station on the Teton River (06102500), the annual mean streamflow is about 100,900 acre feet (table 1). Streamflow during May, June, and July account for more than 60% of the annual mean flow.

Downstream of the USGS gaging station, water is diverted from the Teton River for irrigation. This water is mostly stored in Farmers Reservoir, Eureka Reservoir, and Bynum Reservoir before being used on the Burton Bench. The Eldorado and Farmers ditches distribute water from the Farmers Reservoir and Eureka Reservoir to users on the Burton Bench. Muddy Creek and other irrigation canals distribute water from the Bynum Reservoir to users on the north side of the Bench. The main irrigation canals and smaller laterals make up a 140-mile network of irrigation canals that distribute, on average,



EXPLANATION

Mean monthly temperature or precipitation for period of record (1971-2000)

Monthly mean temperature or precipitation for July 2001 through June 2004

Figure 3.--Monthly air temperature and precipitation for July 2001 through June 2004. Data from Western Regional Climate Center published on the internet at http://www.wrcc.dri.edu/ for station 241737 at Choteau Airport.

40,500 acre-feet of water to about 36,000 acres of irrigated land; the amount of water diverted depends on climatic conditions and runoff from the mountains. During drought conditions, as little as 20,400 acre-feet of water has been diverted onto the Burton Bench; during wetter periods, as much as 60,700 acre-feet of water has been diverted onto the Bench.

During non-irrigation periods, the irrigation canals in the Ralston Gap area have a small base flow due to shallow ground water seeping into these ditches. Shortly after flowing from the Ralston Gap onto the Burton Bench, this flow completely infiltrates into the alluvium and the ditches dry up.

Table 1.--Monthly mean and annual streamflow (http://mt.water.usgs.gov/).

	USGS station		Streamflow, in acre-feet											Annual
Stream	number	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Teton River[1]	06102500	2,964	2,587	2,796	4,890	19,530	29,580	14,136	6,820	5,070	4,917	4,116	3,528	100,900
Muddy Creek[2]	06106500	163	10	87	876	998	2,010	562	136	76	172	67	173	5,300

1, Period of record from 1947 to 1954; 1998 to 2003.

2, Period of record from 1912-1925.

On the west side of the study area, Muddy Creek drains about 71 square miles of the plains west of the Town of Bynum, and east of the Rocky Mountain front. The USGS operated a gaging station on Muddy Creek at Bynum between 1912 and 1925. Based on this period of record, the annual mean streamflow in Muddy Creek at Bynum is about 5,300 acre-feet. Streamflow in Muddy Creek is influenced by upstream irrigation diversions to and from the Bynum Reservoir.

Spring Coulee originates on the Burton Bench and drains about 35 square miles. Continuous stream monitoring has not occurred on Spring Coulee, but streamflow measurements were made during the study period (table 2). Streamflow in April 2003 was 6.7 cubic feet per second (ft^3 /sec) and in March 2004 was 7.0 ft^3 /sec. These flow measurements represent baseflow conditions and are not influenced by irrigation or stormwater runoff.

HYDROGEOLOGY

The aquifer in the unconsolidated sand and gravel deposits underlying the Burton Bench is important to the residents who utilize water from wells completed in the sand and gravel for domestic and stock water purposes. Understanding the physical framework of the aquifer will not only provide a reasonable expectation for where future development of the ground-water resource may occur, but will also provide the means for protecting the ground-water resource from contamination.

General Geology

The Burton Bench is located on the western edge of the Northern Great Plains physiographic province. Just west of the Burton Bench is the eastern edge of the Disturbed Belt of the Northern

Table 2. Results of streamflow measurements.
[ft3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Stream	Location number of streamflow measurement site	Measurement date	Discharge (ft^3/s)	Specific Conductance (µS/cm)
Muddy Creek	26N06W25ABAC01	22-Apr-03	4.7	--
		11-Mar-04	1.2	574
Muddy Creek	26N04W29BCCB01	22-Apr-04	7.6	--
		11-Mar-04	10.9	592
Spring Coulee	25N04W25ABAA01	22-Apr-03	6.8	--
		11-Mar-04	7.0	599
Farmers Ditch	25N05W21CCCD01	11-Mar-04	2.5	497
Eldorado Ditch	25N05W20AADB01	11-Mar-04	0.69	381
Eldorado Ditch	25N05W15AAAA01	11-Sep-03	29.8	--
Eldorado Ditch	25N05W15CCBB01	11-Sep-03	30.2	--
Unnamed	25N05W17DBDC01	11-Mar-04	1.29	506

Cordillera. The Disturbed Belt is characterized by numerous thrust faults and folds developed in Mesozoic, Paleozoic, and Proterozoic sedimentary rocks. The Proterozoic rocks belong to the Belt Supergroup and consist of fine-grained clastic sediments and impure limestones. The Paleozoic rocks unconformably overlie Proterozoic rocks and consist of mostly carbonates with very minor amounts of sandstone, siltstone, and shale. The Mesozoic rocks unconformably overlie the Paleozoic rocks, and consist of mudstones and sandstones deposited in alternating marine and non-marine environments. The youngest rocks underlying and surrounding the Burton Bench include the flat-lying Cretaceous Virgelle Sandstone, Telegraph Creek Formation, and the Mowry Shale.

The Burton Bench is covered by a relatively thin unconsolidated deposit (<70ft) of Pleistocene or possibly Pliocene stream-laid coarse gravel and sand that filled a broad paleovalley cut into older rocks by down-cutting of the Teton River through the Ralston Gap and by Muddy Creek (figure 4). The thickness of the sand and gravel has been determined from drillers' logs of water and stock wells. Because the transition from the sand and gravel to bedrock is easily recognized, the thickness is known with a high degree of certainty. As shown in figure 5, the thickness of the sand and gravel varies considerably due to undulations in the bedrock surface upon which it was deposited. It is thickest east of the Ralston Gap, where it may be as much as 70 ft thick. Drillers logs of water wells indicate that there is very little clay and silt in the sand and gravel, and more detailed logs indicate the gravel clasts are composed of carbonates which reflects the source area for these clasts to the west.

The Burton Bench forms a smooth plain that gently slopes to the east. About 2 miles east of Highway 220 the relatively smooth, gently sloping topography changes to hummocky topography. The change in topography roughly marks the contact where glacial drift overlies the sand and gravel of the Burton Bench. The glacial drift is composed of rock fragments in a silty clayey matrix.

Aquifer Geometry and Hydraulic Characteristics

The Burton Bench aquifer can best be described as a relatively thin layer of highly permeable sand and gravel directly overlying very low-permeability bedrock that is composed of indurated shale and siltstone. These bedrock formations provide little water to wells, and have been utilized to a limited extent in the Burton Bench area.

Near the contact with bedrock to the west, and for about 10 miles down slope to the east, the sand and gravel are exposed at or near the surface; between land surface and the water table, impermeable or protective layers do not exist and the aquifer is unconfined in this area. Farther east, the sand and gravel becomes buried or confined by fine grained glacio-lacustrine deposits associated with continental glaciation; the sand and gravel aquifer in this area is separated from the land surface by the low-permeability glacio-lacustrine silts and clays, which tend to protect the aquifer from near surface contamination.

The Burton Bench aquifer is very permeable. Zones composed of coarse gravel possibly may have hydraulic conductivity values as high as 10^4 feet/day (Heath, 1983, p. 13). Patton (1990) conducted aquifer tests at six locations on the Bench and analyzed the results with standard methods. At the sites tested, the minimum hydraulic conductivity was 3.4 feet/day, the maximum was 532 feet/day, and the median was 290 feet/day.

During this investigation, specific capacity was measured at 12 wells (table 3). The specific capacity data were converted to transmissivity values following the procedures described in Driscoll (1986). Hydraulic conductivity values for these tests were determined by dividing the transmissivity values by the saturated thickness. At the sites tested, the minimum hydraulic conductivity was 32 feet/day, the maximum was 495 feet/day, and the median was 116 feet/day. These values correspond with those of Patton's (1990) and are quite reasonable for a sand and gravel aquifer.

Potentiometric Surface and Direction of Ground-Water Flow

Water levels were measured quarterly in most of the 26 wells in the monitoring network. They generally were lowest in spring, rose during the irrigation season, and then fell throughout the winter and spring (figure 6). The altitude of all monitoring wells was determined by plotting their location on a topographic map and extrapolating the altitude between contour lines; the altitudes are estimated to be within 5 feet of the true altitude.

The potentiometric surface was determined from water levels measured in January 2003 (figure 7). Horizontal ground-water flow is perpendicular to the potentiometric contours and downgradient, so flow in the Burton Bench aquifer is generally from the west margins of the valley toward the east.

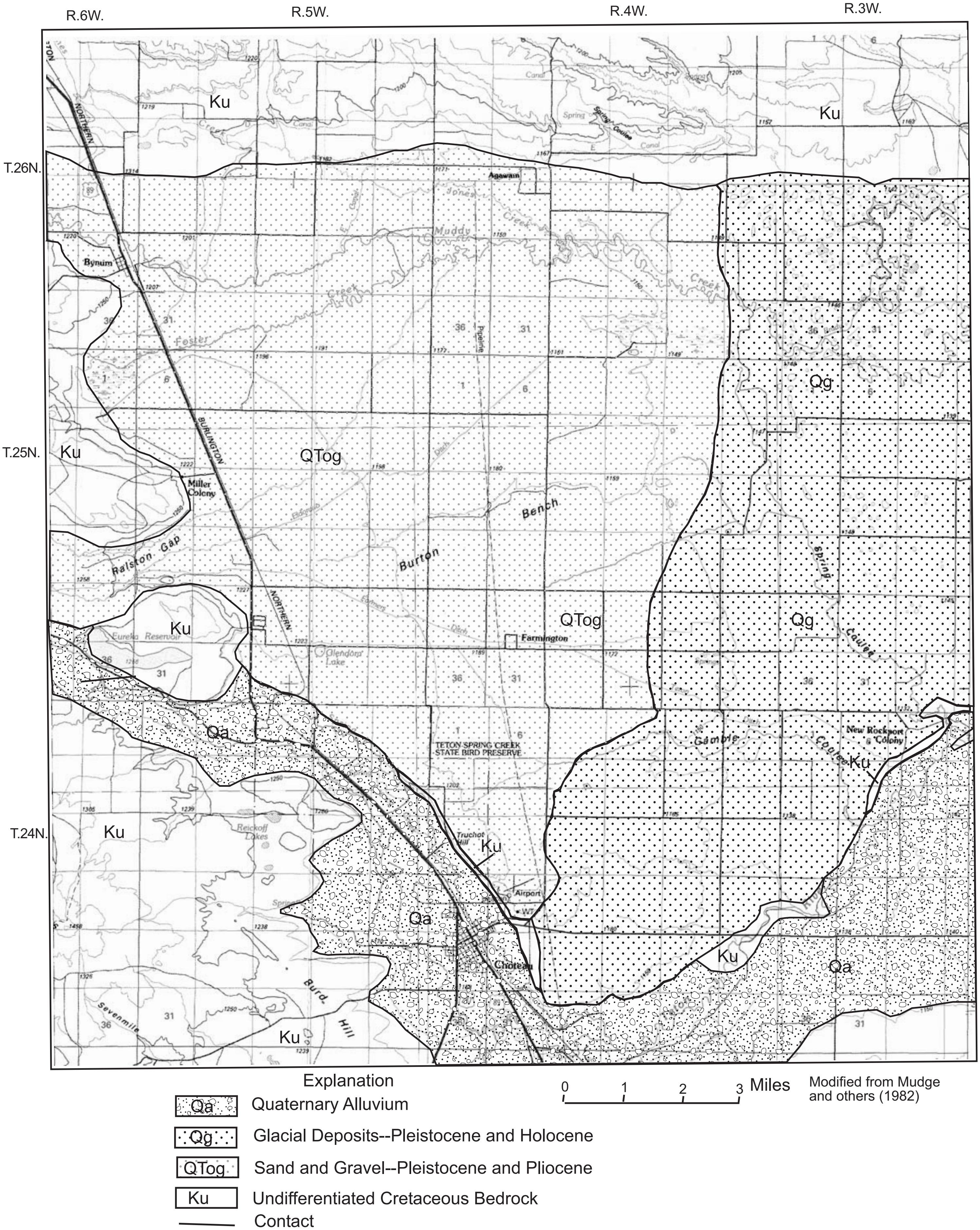
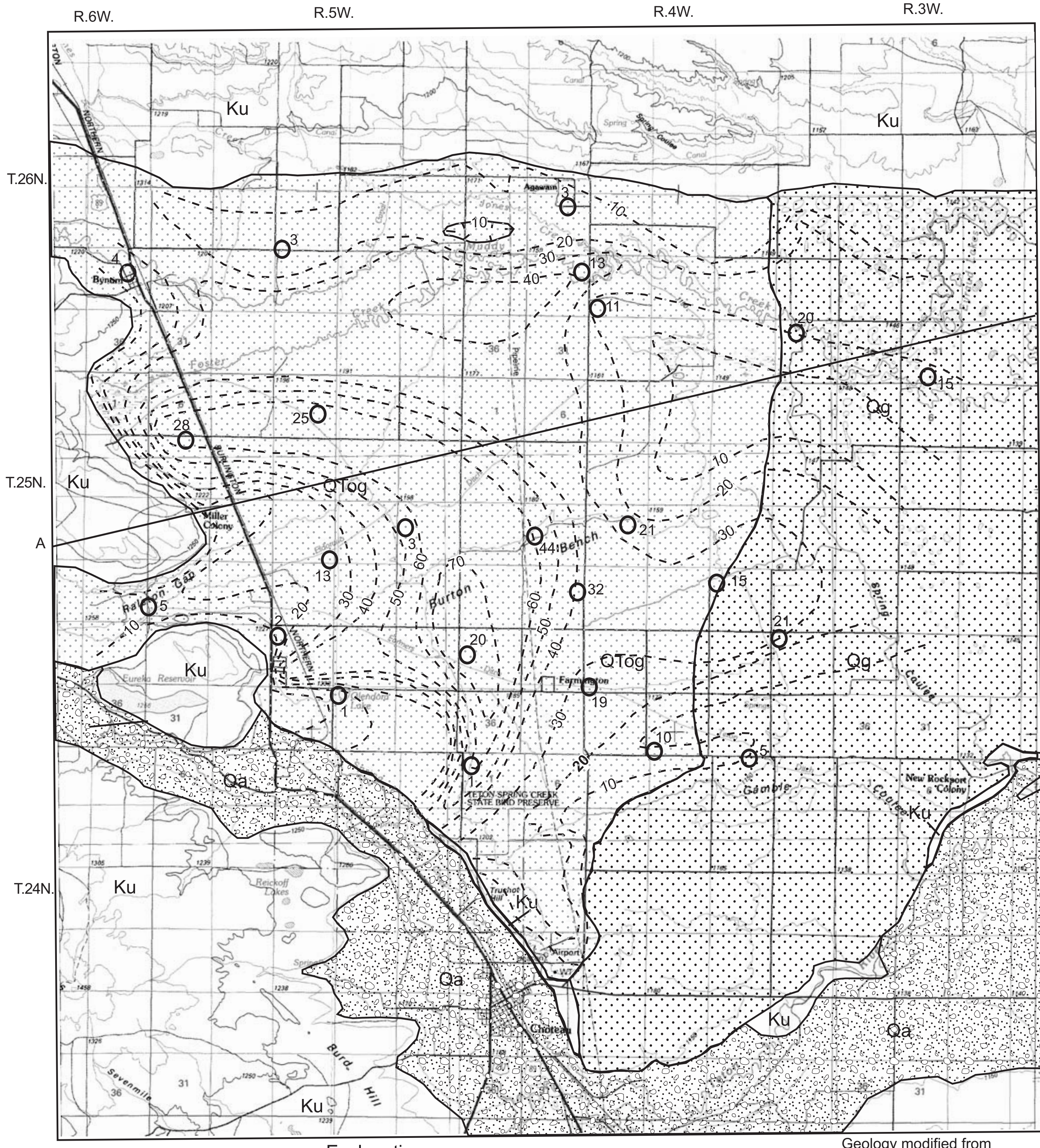


Figure 4.--Generalized surficial geology map. The surface of the sand and gravel (QTog) underlying the Burton Bench slopes to the east. East of Farmington, fine-grained glacial material (Qg) overlies the the sand and gravel (QTog).



Explanation

0 1 2 3 Miles

Geology modified from Mudge and others (1982). Gravel thickness modified from Patton (1990).

Qa	Quaternary Alluvium
Qg	Glacial Deposits--Pleistocene and Holocene
O[3]	Well and saturated thickness, in feet, of the sand and gravel aquifer based on January 2003 water level.
QTog	Sand and Gravel--Pleistocene and Pliocene
Ku	Undifferentiated Cretaceous Bedrock
(solid line)	Contact
(dashed line)	Thickness Contour, in feet

Figure 5.--The sand and gravel that compose the Burton Bench aquifer are a maximum of about 70 feet thick. In some areas, the saturated thickness of the sand and gravel is less than 5 feet.

Table 3.--Specific capacity was determined at 12 well sites and converted to hydraulic conductivity. [swl, static water level; pwl, pumping water level; gpm, gallons per minute; gpd, gallons per day; ft, feet]

Location	GWIC M#	swl (ft)	pwl (ft)	Discharge (gpm)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft^2)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)
25N04W17AADB01	78887	3.27	4.57	10.9	8.4	12,577	15	112
25N04W26BCBB01	6338	16.74	17.57	10.0	12.0	20,270	5	542
25N04W30CDBD01	6342	6.78	7.15	5.0	13.5	20,270	22	123
25N04W33CBBB01	78956	6.13	7.28	10.7	9.3	13,957	22	85
25N05W04DBDA01	78971	45.23	46.35	12.0	10.7	43,125	22	262
25N05W16DDDD01	6346	7.52	7.60	2.3	28.8	43,125	13	443
25N05W25BCCC01	6352	54.90	55.85	8.6	9.1	13,579	20	91
25N06W25AAAA01	6358	21.10	21.93	3.8	4.5	6,777	28	32
26N04W30ADDC01	195269	12.59	14.50	12.6	6.6	9,895	13	102
26N04W35BDAA01	6365	2.34	2.78	12.0	27.3	40,909	20	273
26N05W29AABA01	79420	9.12	9.63	5.0	9.8	14,706	4.5	437
26N06W25ACDD01	6369	9.29	10.76	21.7	14.8	22,143	7	423

Ground-Water Recharge and Discharge

Quantifying the recharge and discharge components of a ground-water budget is important from a water-management perspective because it allows a relative significance to be placed on the various components of a budget. For example, on the Burton Bench, quantifying the amount of recharge from leaking irrigation canals and excess irrigation water allows resource managers and planners to understand the relative significance of this component and how removing irrigated land from production may effect water levels in wells. Recharge to, and discharge from, the Burton Bench aquifer can be derived from the following equation:

$$LS\_in + LC\_in + IF\_in + PN\_in + RG\_in = SD\_out + ET\_out + UF\_out + WL\_out \qquad (1)$$

where:

LS_in = Recharge from infiltration of streamflow,
LC_in = Recharge from infiltration of irrigation canals,
IF_in = Recharge from infiltration of excess water applied to fields (applied irrigation water minus evapotranspiration),
PN_in = Recharge from infiltration of precipitation,
RG_in = Recharge from inflow from the Ralston gap,
SD_out = Discharge through leakage to streams and drains,
ET_out = Discharge through evapotranspiration
UF_out = Discharge as underflow through the eastern boundary of the study area, and
WL_out = Discharge through withdrawals from wells.

Recharge to the Burton Bench aquifer is through infiltration of streamflow, irrigation water, and precipitation, and inflow from the alluvium in the Ralston Gap area. Although no major streams flow across the Burton Bench, shallow ground water discharges to the three major irrigation canals west of the study area. Downstream these canals loose all flow within a few miles after flowing onto the Bench. Recharge from these three irrigation canals was estimated from measurements conducted on March 11, 2004. The data indicate that combined seepage from these three canals during non-irrigation periods is about 4.5 cfs (table 2). Potential streamflow losses to the aquifer were calculated as being constant throughout the year but it should be recognized that the magnitude of loss may change throughout the year. Recharge from these three canals based on the data presented is estimated to be about 3,290 acre-feet/yr.

To estimate recharge from leaky irrigation canals (LC_in), streamflow measurements were conducted on a 1.5 mile reach of the Eldorado Ditch on September 11, 2003. The 1.5 mile reach was the longest reach available without any lateral turn-outs. A longer reach of canal would have involved measuring any flow turned out to laterals and would have complicated estimating leakage due to compounding error with each additional measurement. The discharge measurements indicate that the Eldorado ditch looses about 0.27 cfs/mile in the measured reach. Assuming that this estimate of leakage is representative of canal leakage and that smaller laterals have one-third the wetted perimeter and therefore one-third the leakage of the main canals, and that the canals are on for 150 days/year, leakage from the 144-mile network of irrigation canals is estimated to be about 2,820 acre-feet/year.

Recharge to the Burton Bench aquifer from excess irrigation water applied to irrigated fields is an important source of recharge to the aquifer. Excess irrigation water is that water flowing through and past the root zone that is not consumed by the plant, thus recharging the aquifer. On the Burton Bench, about 36,000 acres of various crops are irrigated with water derived from the Teton River and wells. Recharge to the aquifer from infiltration of excess water was estimated from the following equation:

$$IF\_in = tv + p - Etag \qquad (2)$$

where:

IF_in = Infiltration of excess water from irrigated fields,
tv = Total volume of irrigation water applied to fields,
p = Precipitation on irrigated acres during irrigation season, and
ETag = Evapotranspiration by alfalfa and grain from irrigated acres during season on the Burton Bench.

Infiltration of excess irrigation water occurs when the volume of irrigation water applied to fields plus precipitation exceeds evapotranspiration.

The total volume of irrigation water applied to fields is obtained from two sources: reservoirs west of the Bench, and wells. Water pumped from wells is used to irrigate about 2,200 acres of

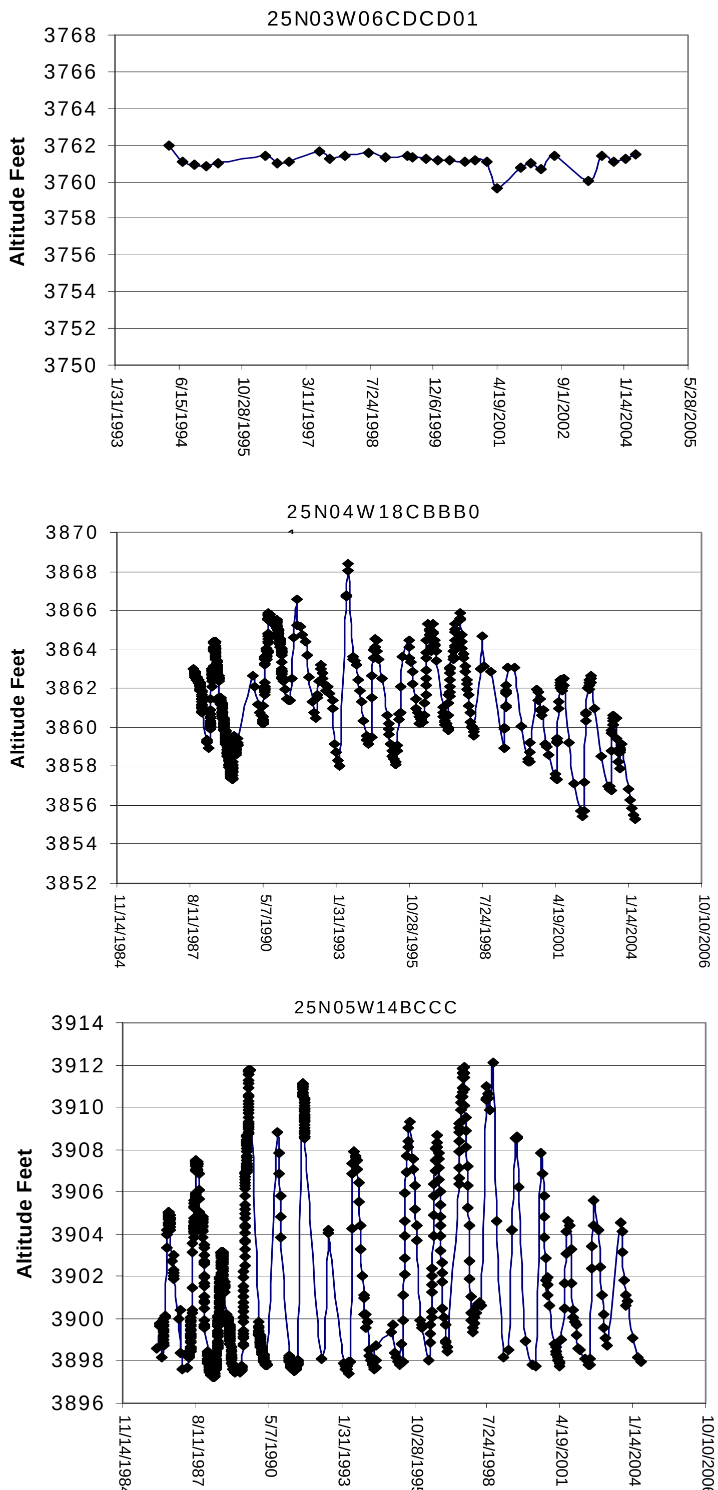


Figure 6. Near the recharge zone water level in wells may fluctuate by as much as 10 to14 feet as shown hydrographs of 25N05W14BCCC01 and 25N04W18CBBB01 (middle and bottom). In the discharge zone on the east side of the Burton Bench, water levels fluctuations are small as shown by hydrograph 25N03W06CDCD01 (top).

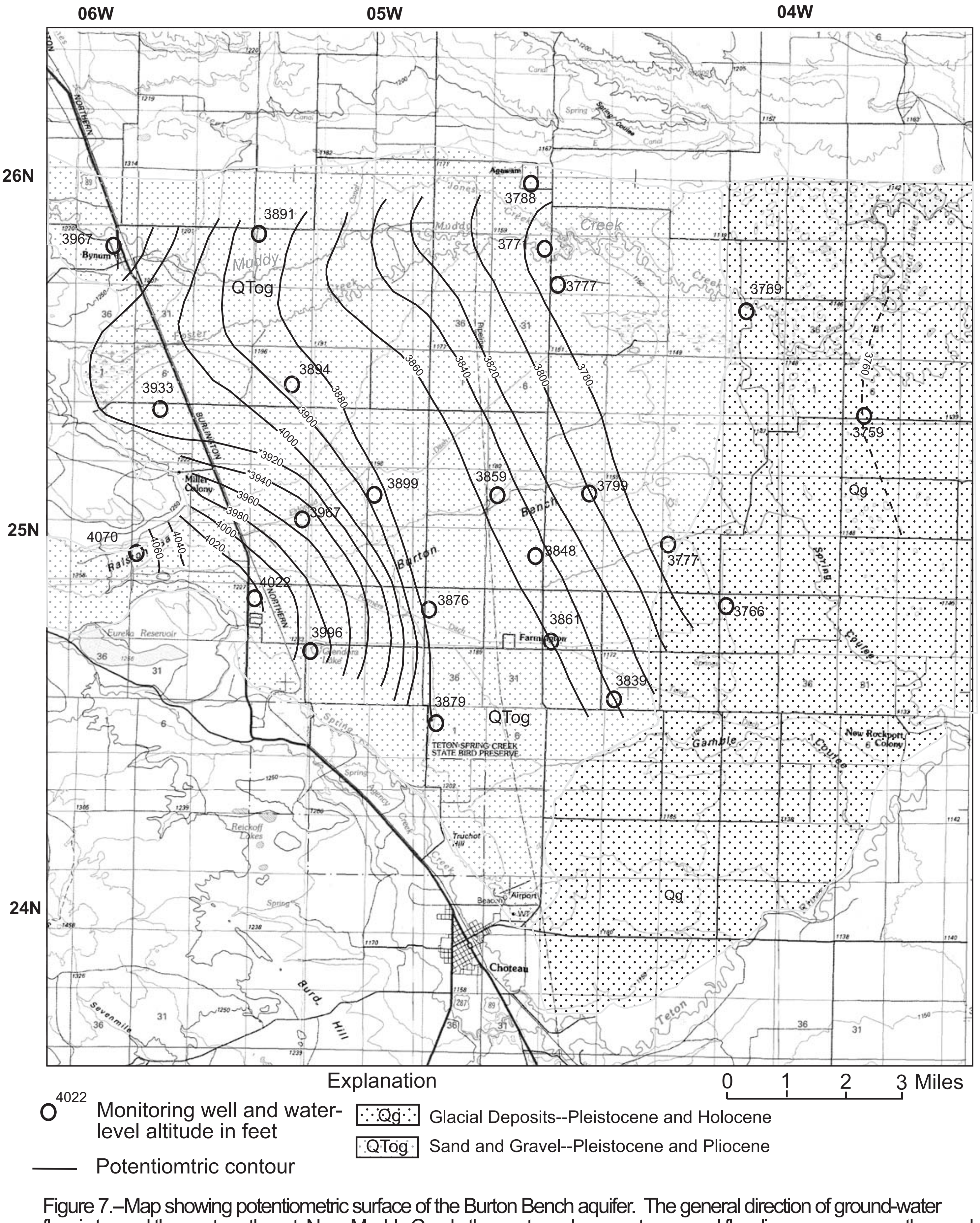


Figure 7.–Map showing potentiometric surface of the Burton Bench aquifer. The general direction of ground-water flow is toward the east-northeast. Near Muddy Creek, the contours bow upstream and flow lines converge on the creek, indicating that Muddy Creek gains ground water. The sand and gravel aquifer (QTog) becomes confined in the east third of the study area by fine-graineded glacial deposits (Qg).

land (Patton, 1990). On average, the volume of water applied to fields on the Burton Bench is estimated to be about 40,430 acre-feet/year. This value was obtained from the total volume of water released from the reservoirs (40,500 acre-feet) plus water pumped from irrigation wells (2,750 acre-feet) minus the estimated quantity of water that leaks from the canals (LC_in) (2,820 acre-feet).

Normal precipitation on irrigated acres during the irrigation season is estimated to be about 23,370 acre-ft/year using the monthly precipitation data shown in figure 3 and an estimated irrigated area of 36,000 acres This quantity represents about 71 percent of the normal precipitation for the period.

The different crops grown on the bench include alfalfa, and grain, with each requiring different amounts of water; for climatic conditions on the Bench, alfalfa and grain can consume 17 inches and 11inches of water, respectively (U.S. Soil Conservation Service, 1970). To estimate the amount of recharge from irrigated land it is assumed that grain is produced on 27,000 acres of land and that alfalfa is produced on the other 9,000 acres. On the basis of these evapotranspiration rates and an irrigated area of 36,000 acres, the total evapotranspiration by alfalfa and grain from irrigated acres is estimated to be about 37,500 acre-ft. This is a reasonable estimate of the normal evapotranspiration from irrigated areas on the Bench.

Using the quantities presented, average recharge from infiltration of excess applied irrigation water is estimated from equation 2. The total is about 26,300 acre-ft.

Most precipitation falling on non-irrigated parts of the Burton Bench is probably consumed by evapotranspiration, and therefore is not an important source of recharge. During the growing season, average precipitation falling on the Bench is about 7.79 inches (NOAA, 1982a). During the same time, potential evaporation is about 38 inches (U.S. Soil Conservation Service, 1970). Therefore, except for periods of sustained precipitation large enough to overcome the natural soil-moisture deficit, the aquifer probably receives little recharge from precipitation.

Even if infrequent periods of sustained precipitation contribute some recharge to the aquifer, the quantity is probably a relatively small part of the total recharge. If precipitation were sufficiently sustained to overcome the soil-moisture deficit and contributed 0.5 inch of recharge over the non-irrigated parts of the Burton Bench (34,000 acres), the total recharge would be about 1,420 acre feet per year.

The direction of ground-water flow indicates that inflow from the Ralston gap recharges the Burton Bench aquifer. However, the limited width and saturated thickness of the aquifer indicate that it is probably a relatively small component of the total budget. Inflow from the Ralston Gap is almost impossible to measure, and has to be estimated by less direct analysis. On the basis of Darcy’s equation and an assumed hydraulic gradient of 0.006 measured from the potentiometric map (figure 7), a hydraulic conductivity of 468 ft/day, estimated from pumping test, and a cross sectional area of flow of 27,300 square feet, estimated recharge to the Burton Bench aquifer from the Ralston gap is about 640 acre-feet/year (Patton, 1990).

Discharge from the Burton Bench aquifer is through evapotranspiration, leakage to streams and drains, discharge to wells, and underflow through the eastern downgradient boundary of the study area. The water table underlying about 15,000 acres of the Burton Bench is shallow enough that ground water may be consumed by plants (Patton, 1990). These plants may consume between 11 to 16 inches of water (U.S. Soil Conservation Service, no date). Assuming that the plants consume 16 inches of ground water, indirectly, the total discharge from the aquifer through evapotranspiration may be 20,000 acre-feet/year.

Discharge of ground water through leakage to streams is documented in table 2**.** Streamflow measurements on Muddy Creek measured on March 11, 2004 show that it gained about about 9.7 cfs between measurement site 26N06W25ABAC01 and 26N05W29AABA01. Spring Coulee originates entirely on the Burton Bench, and when the flow is not influenced by surface water runoff due to storms or irrigation return flow, all of the water in Spring Coulee is attributable to groundwater discharge. Flow was measured at 7.0 cfs in the Coulee at site 25N04W25ABAA01 on March 11, 2004. Assuming that the March measurements are representative of ground water discharge through out the year, total ground water discharge to streams from the aquifer is estimated to be about 12,300 acre-feet/year.

The direction of ground-water flow indicates that underflow to the east and outside of the study area is a source of discharge from the Burton Bench aquifer. Similar to the estimate made for the Ralston Gap, outflow through the east border of the study area is almost impossible to measure, and has to be estimated by less direct analysis. On the basis of Darcy’s equation and an assumed hydraulic gradient of 0.001 measured from the potentiometric map (figure 7), a hydraulic conductivity of 300 ft/day determined from pumping tests, and a cross-sectional area of flow of 861,250 square feet, estimated discharge from the Burton Bench aquifer along the east border of the study area is estimated to be about 2,165 acre-feet/year.

Withdrawals from domestic wells (WL_out) accounts for only a minor part of the discharge from the aquifer. Estimated average withdrawal for domestic use is 138 gal/day per person, with 87 gal/day per person or 63% returned to the aquifer through septic systems (Montana Department Natural Resources and Conservation, 1986). Assuming that 250 people live on the Burton Bench (Paul Wick, Teton County Planner, oral commun., 2004), total withdrawal for domestic purposes is about 39 acre-feet/year, with 24 acre-feet/year returned to the aquifer through septic-system discharge. Net discharge from the aquifer to domestic wells is about 15 acre-feet/year.

Table 4 summarizes the components of the water budget. Average total recharge and discharge to the Burton Bench aquifer is estimated to be about 34,470 acre-feet/year.

GROUND-WATER QUALITY

Ground-water quality on the Burton Bench is an increasing concern especially considering the amount and types of agricultural activities occurring there. Identifying those areas of the aquifer that are susceptible to contamination is important for protecting the quality of the ground water resource.

Table 4.--Estimated ground-water budget for the Burton Bench aquifer. Recharge from irrigation practices (LC_in and IF_in) accounts for about 60% of the total recharge. Ground-water discharge to wells (WL_out) accounts for only less than 1% of the total discharge from the aquifer.

Inflow	Acre-feet				
LC_in	IF_in	LS_in	PN_in	RG_in	Total
2,820	26,300	3,290	1,420	640	34,470

Outflow	Acre-feet				
	SD_out	ET_out	UF_out	WL_out	Total
	12,300	20,000	2,160	15	34,470

Water samples were collected following prescribed guidelines (Clark Fork River Superfund Site, Standard Operating Procedure, 1990; Knapton, 1985) and submitted for laboratory analysis (figure 8). Major-ion concentrations and trace-element concentrations in water samples collected during this and previous studies are presented in tables 5 and 6, respectively, in the Supplemental Data section at the back of the report. On the basis of these data, water in wells completed in the Burton Bench aquifer generally is a magnesium bicarbonate- and calcium bicarbonate-type (figure 9a). This water type probably results from the dissolution of calcium and/or magnesium carbonate clasts present in the aquifer. Downgradient, the water becomes enriched in sodium and depleted in magnesium (figure 9b-c). This is probably due to magnesium exchanging for sodium on cation exchange sites in clay minerals.

National primary drinking water regulations are legally enforceable standards that apply to public water systems. Primary standards protect human health by limiting the levels of contamination in drinking water. Although wells sampled for this study were all private non-public wells, the drinking water standards serve as a guideline for those residents consuming water from the aquifer. Of the wells sampled in 2001-2004 (see Supplemental Data), only the analyses for well 26N06W25ACDD sampled in 2002 exceeded the primary drinking water standard (10 mg/L) for nitrate; this well was re-sampled in 2004 and did not exceed the standard. Other primary standards were not exceeded in any of the wells sampled.

National secondary drinking water regulations are non-enforceable guidelines regulating the contaminants that may cause cosmetic effects (skin or tooth discoloration) or aesthetic effects(such as taste, odor, or color) in drinking water. One well— 26N04W35BDAA01— exceeded the secondary standard for manganese (0.05 mg/L). Many of the wells sampled in 2001-2004 exceeded the secondary standard for total-dissolved solids (500 mg/L).

Seventeen wells sampled in 2001-2004 have earlier water-quality analyses that date back at least 20 years. Analyses of the current water samples (2001-2004) from these 17 wells indicate no significant change during the period of record (figure 10).

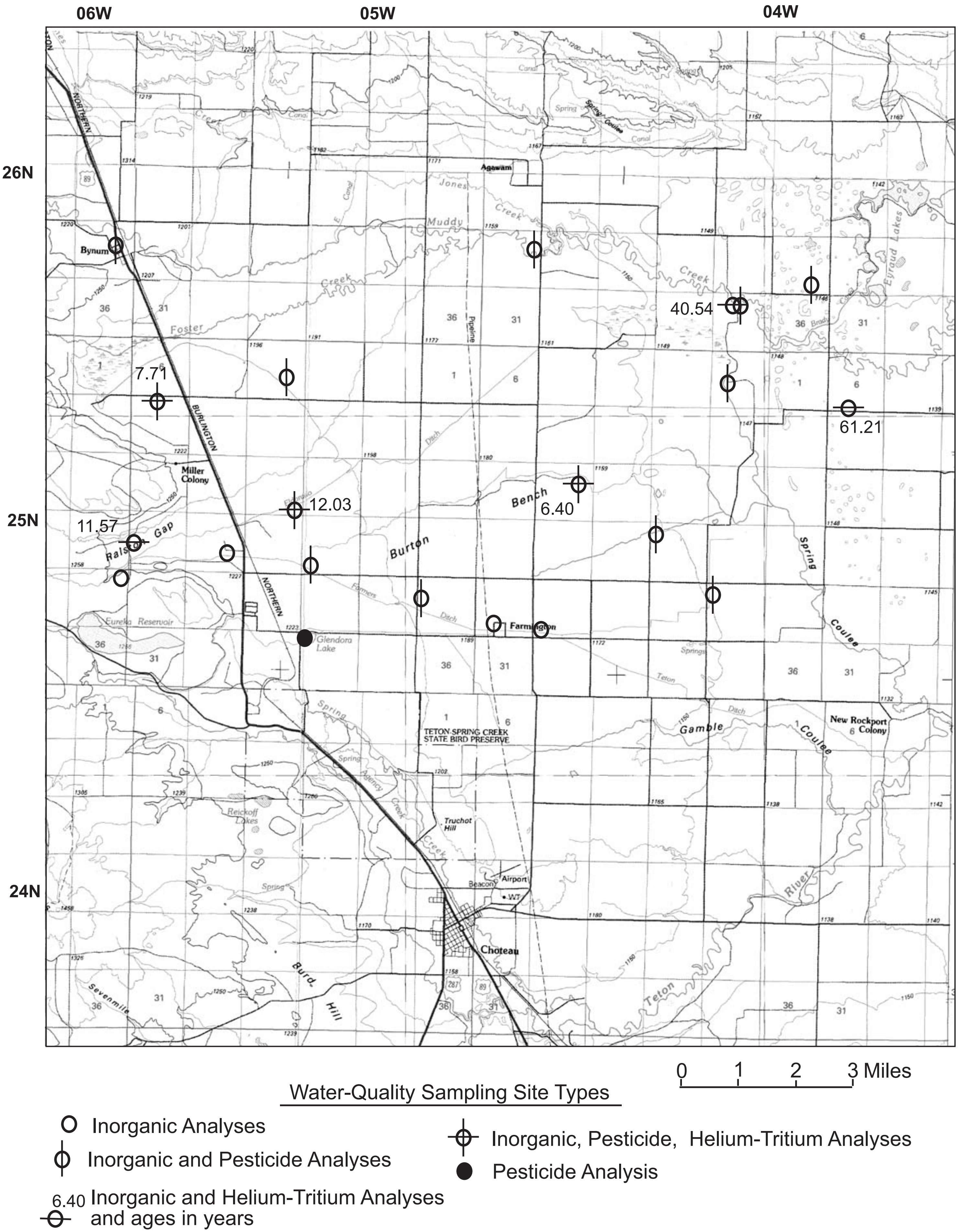


Figure 8.--Map showing water-quality monitoring sites for selected wells in the Burtron Bench aquifer.

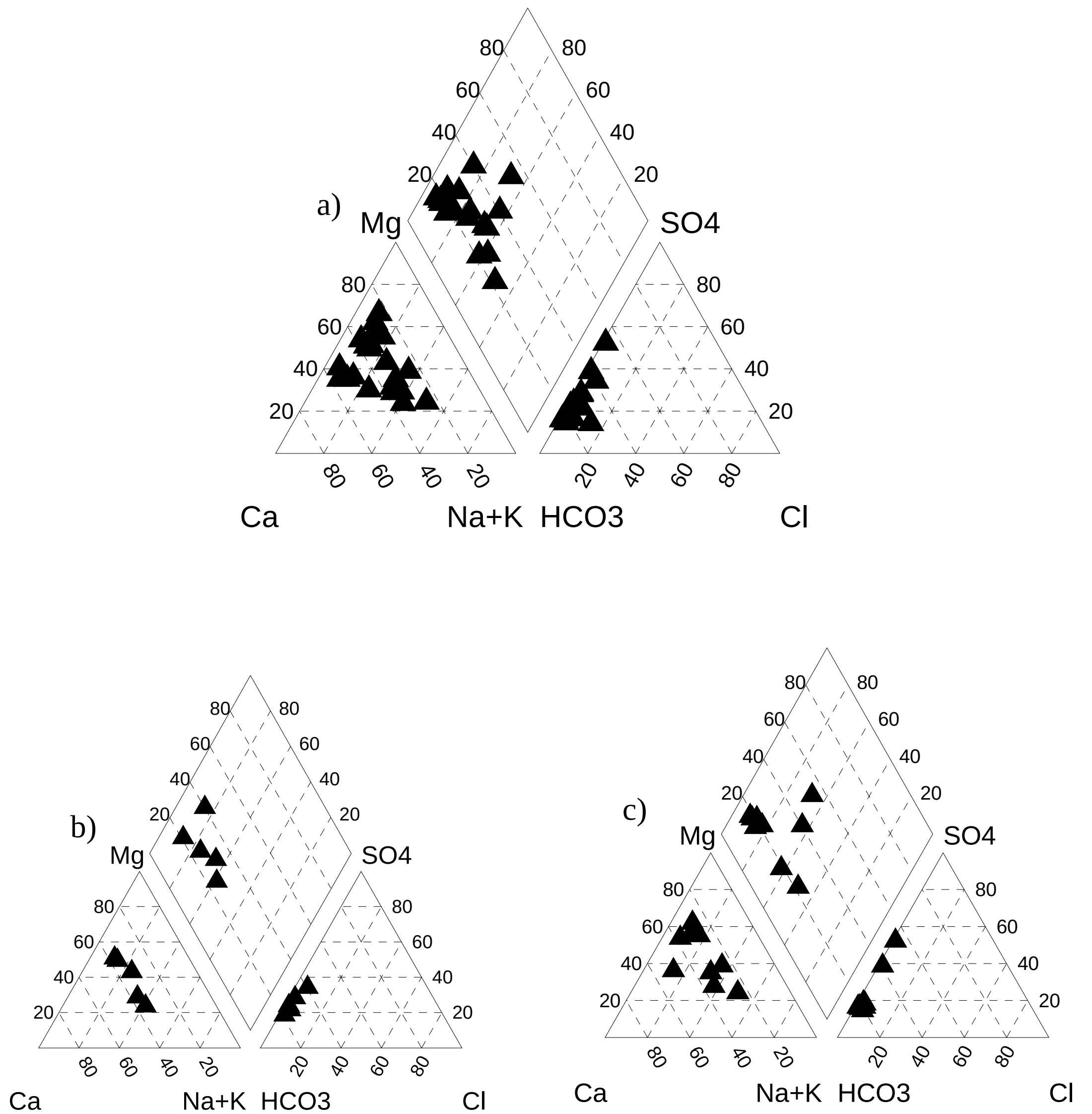


Figure 9.–Piper plots of water quality in wells completed in the Burton bench aquifer: a) data collected in 2001-2004 for wells completed in the Burton bench aquifer indicated three types of water:1)calcium bicarbonate, 2) magnesium bicarbonate, and 3) calcium-magnesium-sodium+potassium bicarbonate. b) Results along a flow path in the north part of the study area show that water becomes enriched in sodium as it flows down gradient, probably due to magnesium replacing sodium on cation exchange sites in clay minerals. c) Results along a flow path in the south part of the study area show water evolves similarly to the process in the north (b).

Pesticides

To determine if pesticides have entered the Burton Bench aquifer, 46 water samples from 14 selected wells not associated with known point sources were analyzed. The results of the analyses are given in table 7 (supplemental data section).

Only a few pesticide compounds were detected in the water samples analyzed. Assert ™ and Assert™ metabolite were detected in one well (25N 04W 26 BCBB01) and two wells (25N 04W 22 BBCD01 , 25N 04W 26 BCBB01) respectively, in concentrations slightly exceeding the minimum reporting levels and greatly below the drinking water standard. In one well (25N05W22CCCC01) 2,4-D was detected in concentration slightly above the reporting level, but subsequent samples from this site contained no detectable pesticides.

Tritium-Helium

Tritium (^{3}H or T)is produced naturally in the atmosphere by the interaction of cosmic rays with nitrogen and oxygen (Drever, 1988). Tritium has a half-life of 12.3 years and decays to helium (^{3}He). The most important source is from thermonuclear weapons testing that took place between 1952 and 1969. During the 1960's, concentrations of tritium in the atmosphere increased by two orders of magnitude compared to pre-bomb concentrations; current concentrations are 5-10 times pre-bomb levels. The most important use for tritium in ground water is distinguishing between water that entered an aquifer prior to 1953 (pre-bomb) and water that was in contact with the atmosphere after 1953. Pre-bomb water contains no tritium detectable by normal analytical procedures; therefore water with detectable tritium concentrations entered the aquifer after 1953. In addition to a relative age determined from whether or not tritium is detected in a sample, an age can be determined by measuring helium—the daughter product— concentration. Absolute age determination, however, is complicated because possible mixing of waters of two different ages to produce an intermediate-aged water.

Water samples from six wells were analyzed for tritium-helium (table 8). All of the samples contained tritium implying that the water entered the aquifer subsequent to bomb testing (1953). Considering the intense irrigation that occurs on the Burton Bench, it is very probable that young irrigation water has mixed with older ground water to yield the tritium concentrations measured. Assuming that irrigation practices are similar across the Bench, the ages reported on figure 8 are not absolute but relative to one another. Mixing models could be used to reconcile the ages (Zafer Top, University of Miami, oral commun., 2004) but an analyses of this type is beyond the scope of this project.

The relative age of the water is useful for determining ground-water flow velocity, which can be used to estimate hydraulic conductivity. The age of water from well 25N05W19CBBB01 was 11.6 years and well 26N04W35BDAA01 was 40.5 years, a difference of about 29 years. The distance between these two wells is 60,720 feet. This produces a ground-flow velocity of about 5.7 feet/day. The gradient between these two wells is 0.0048. On the basis of a modification to Darcy's equation and an assumed porosity of 0.20, the hydraulic conductivity estimated for the sand and gravel aquifer is about 240 feet/day. This estimate is in accord with those determined

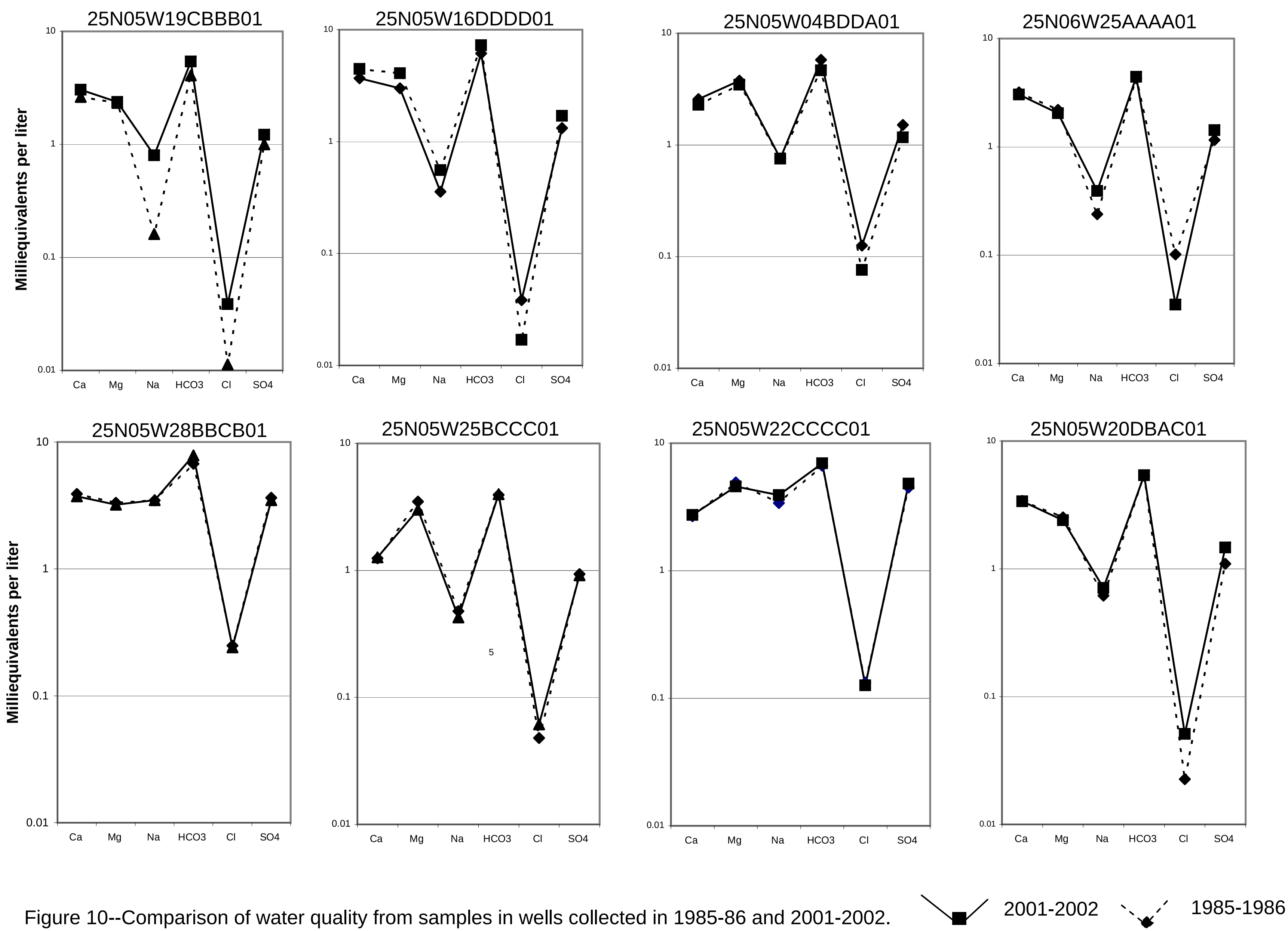


Figure 10--Comparison of water quality from samples in wells collected in 1985-86 and 2001-2002.

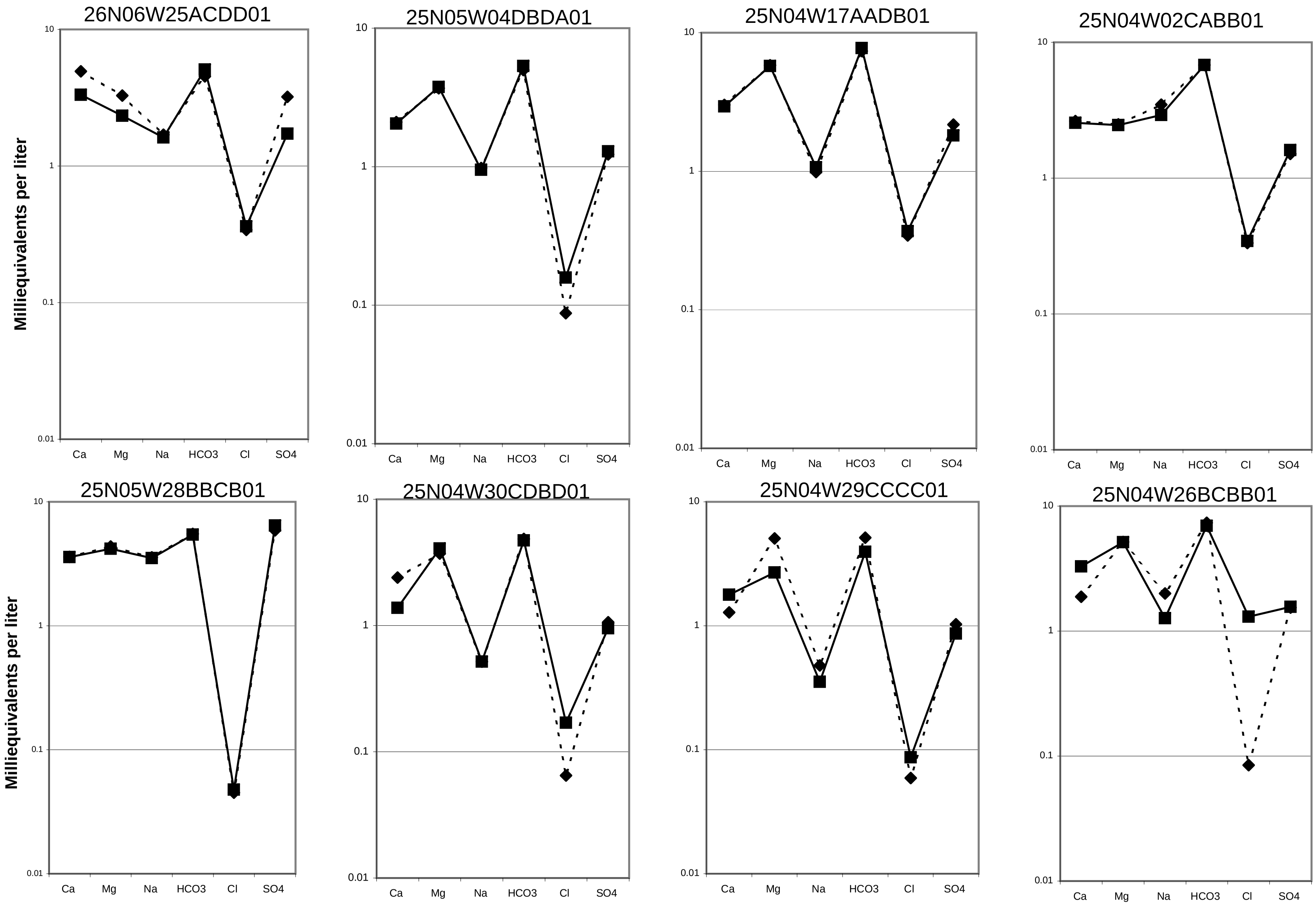
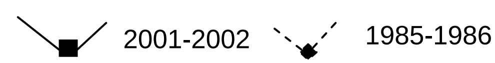
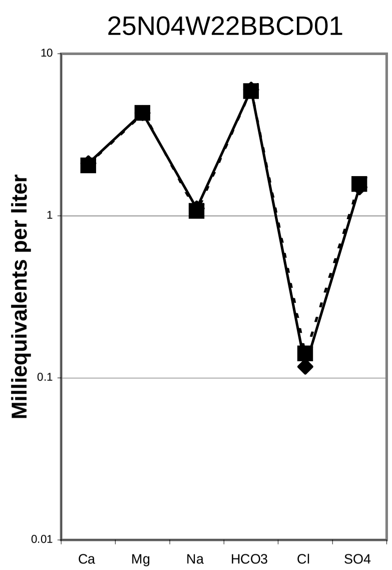


Figure 10--Comparison of water quality from samples in wells collected in 1985-86 and 2001-2002--continued





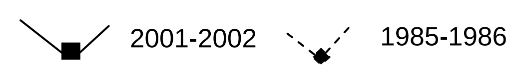


Figure10--Comparison of water quality from samples in wells collected in 1985-86 and 2001-2002--continued

from aquifer and specific capacity tests. The estimate determined here is an average value for the aquifer. Just as the aquifer tests indicate, the hydraulic conductivity can be locally higher or lower depending on the geologic character of the sand and gravel.

DISCUSSION

Significant changes or trends in ground water in the Burton Bench aquifer are not evident from data collected in this study. Since Patton's(1990) study, significant land-use changes have not occurred on the Burton Bench, and agricultural practices including both ranching and farming still remain the focus of activity. The concentrations of dissolved constituents in ground water documented by this investigation are similar to those reported by Patton (1990).

The shape of the potentiometric surface and direction of ground-water flow have also not significantly changed since Patton's (1990) study. Because ground-water recharge from irrigation practices accounts for the majority of recharge to the aquifer (table 4), changes in irrigation on the bench would influence water level in the aquifer. However, land use changes resulting in removing significant areas of land from production and eliminating irrigation have not occurred, thus recharge rates to the aquifer from irrigation practices have been similar from year to year since Patton's (1990) study and probably similar for many preceding years.

A significant change that has occurred with respect to irrigation practices that may lead to reduced recharge rates and lower water levels is the application of water by more efficient methods such as changing from flood irrigation and wheel lines to center pivots. A center pivot will apply less water compared to a wheel line, so less water will flow past the root zone and less water will recharge the aquifer (Miller and others, 2002). Widespread use of center pivots on the Burton Bench may result in lowering of the water level in the aquifer. The locally declining trend in well hydrograph 25N05W14BCCC (figure 6) for the past several years may be the result of several land owners near this well converting from flood irrigation and wheel lines to center pivots (Sherwin Smith, 2004, USDA, per. Commun.). The trend may also be influenced by the past several years of drought; separating the two effects is not possible with the available data.

Although pesticides are in widespread use across the Burton Bench, they have been detected in only a few wells. This is probably due to proper application and good land stewardship by the ranchers and farmers. It may also be due to flushing and dilution by irrigation water and the highly permeable character of the aquifer. The source of the pesticides in the one well that demonstrated chronic pesticide detection is unknown but undoubtedly is from an upgradient area to the west. Recently, the Montana Department of Agriculture and the MBMG installed a dedicated well for long-term pesticide monitoring at this site (James Rose, MBMG Hydrogeologist, per. commun., 2004). Data collected from this well can be used to determine if the pesticides persist in the future and if other upgradient wells need to be sampled.

Water contamination can include any chemical, physical, or biological constituent, compound, or characteristic that is considered to be undesirable for an intended use of the water. The contaminants considered for this study generally include only dissolved chemical constituents or compounds. The geologic character of the unconsolidated sand and gravel deposits that compose the Burton Bench aquifer preclude the existence of a low permeability layer such as clay that would prevent the downward migration of contamination originating from the surface or shallow subsurface. The Burton Bench aquifer is very susceptible to potential contamination from the surface or near surface activities because its coarse-grained character could allow contaminants, if present, to infiltrate into the subsurface and to the water table. The parts of the aquifer most susceptible to contamination are those where fine-grained glacial material is not present. This is the area defined as QTog on the geologic map (figure 4). The sand and gravel aquifer becomes buried and confined by fine-grained glacial deposits (Qg) in the east part of the study area, and is thereby less susceptible to contamination from surface or near surface activities.

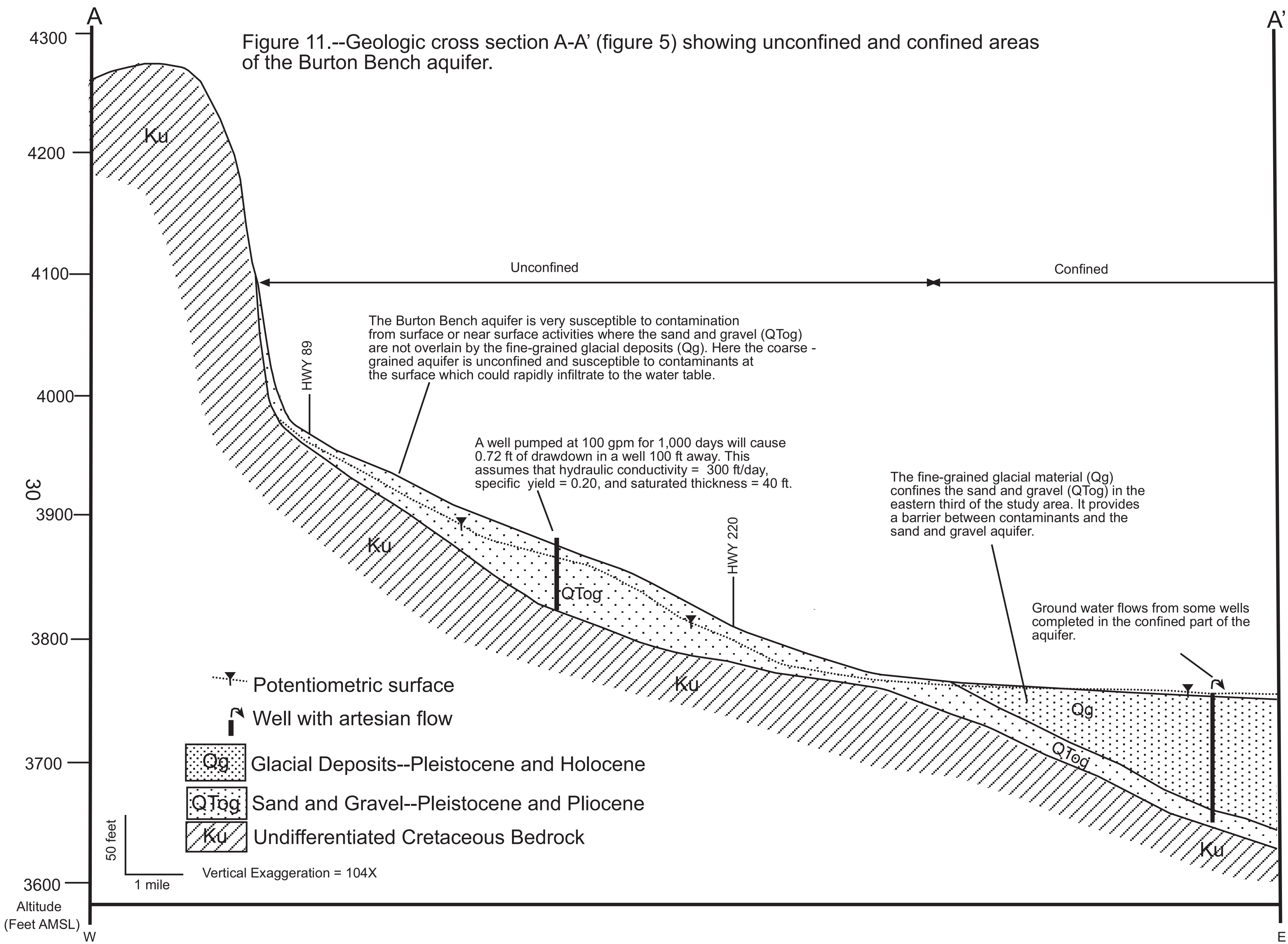
Because of its proximity to Great Falls and other nearby smaller towns, as well as the beauty of the area, some limited subdivision of the agricultural land into smaller ranchettes has occurred in recent years and will continue to occur in the future as the population looks for more rural areas to live. Current net-water consumption by wells for domestic needs accounts for less than one tenth of one percent of the total discharge from the aquifer. Even if the number of residences on the bench increased to 1,000 from the estimated 250 currently living there, net consumption for domestic purposes would still account for less than one quarter of one percent of the total discharge. In other words, withdrawal from wells to meet future demands of increased population will not significantly impact other discharge components such as stream flow, and more importantly water levels in the aquifer.

The impacts from subdivision and housing developments on the water resources may be more significant if irrigated land is taken out of production because the aquifer would receive less recharge from leaky irrigation ditches and excess irrigation water. This possibility is restricted to the area defined as QTog (figure 4) where most irrigation on the Bench occurs. In the area defined as Qg there is little irrigation. With less recharge in the areas of QTog, water levels in the aquifer could decline and adversely impact wells. In the Bynum area for example, agricultural land was not taken out of production, but there has been less water for irrigation during the past several years of drought. Because of limited quantities of water in 2001, ground-water recharge from irrigation in the Bynum area was minimal and water levels declined, causing some wells to go dry (Wayne Thompson, Bynum resident, per. commun., 2002).

From a water-supply perspective, the Burton Bench aquifer is a very prolific producer of water and in most areas will yield an adequate quantity of water for domestic purposes. A properly constructed well completed in the aquifer that serves the needs of a single residence will exhibit minimal draw down and will not interfere with nearby wells. The aquifer is also capable of supplying water to high-capacity wells installed in the aquifer to meets the needs for a housing development or light industry. For example, a well producing 200 gallons per minute completed in an area of the aquifer that has a hydraulic conductivity of 300 ft/day and is saturated with at least 30 feet of water will experience about 5 feet of drawdown (assuming a 100% efficient well).

Although the Burton Bench aquifer is a prolific producer in most areas, the seasonal decline of water level in some areas of the aquifer is such that the aquifer is saturated with less than 5 feet of water (figure 5). This includes areas near Bynum, east of Ralston Gap, and along the southern border of the aquifer. Because of physical limitations of water pumps, these areas may be

Figure 11.--Geologic cross section A-A' (figure 5) showing unconfined and confined areas of the Burton Bench aquifer.



difficult, but not impossible, to develop a well for domestic purposes. It is important that wells drilled in these areas be completed with well screens so that the wells efficiency is maximized and drawdown is minimized. Developing high-capacity wells for other uses in these areas may be almost impossible because the limit saturated thickness will not yield large quantities of water.

SUMMARY AND CONCLUSIONS

The Burton Bench is located in north-central Montana north of the town of Choteau. The aquifer underlying the bench is the sole source of water for about 250 residents, and is an important source for stock water. A 2-year study was conducted to describe the geometry, hydraulic characteristics, potentiometric surface, direction of flow, sources of ground-water recharge and discharge, susceptibility to contamination, and water quality of the aquifer. These data will be useful for residents and local policy makers to assess potential adverse effects to ground-water quality from agricultural activities, especially from the application of agricultural chemicals and to assess the effects to ground-water recharge and water quality as subdivisions encroach on agricultural land.

Tertiary and Quaternary sediments underneath the Burton Bench form an easterly sloping alluvial plain, about 9-miles square. The Burton Bench is bounded by flat lying sedimentary rocks to the north, south, and west; the eastern part of the bench transitions from smooth topography to hummocky topography. Muddy Creek and several irrigation canals flow onto the bench from the west. The Teton River flows south of the bench, and is an important source of water for irrigation on the Bench.

The sands and gravels that compose the Burton Bench aquifer were deposited by fluvial processes in a shallow basin eroded into underlying rocks. These underlying rocks include flat-lying Cretaceous Virgelle Sandstone, Telegraph Creek Formation, and the Mowry Shale, all of which are not important aquifers on the bench. The sand and gravel is no thicker than about 70 feet, and is overlain and confined by fine-grained glacial deposits on the east side of the study area.

Hydraulic conductivity was estimated using the results of specific capacity tests from 12 wells. The median hydraulic conductivity from these test was 192 feet/day. Hydraulic conductivity was also estimated using ground-water velocity determined from tritium-helium age dating of water from wells along a ground-water flow path, hydraulic gradient along the flow path, estimated porosity, and a modification of Darcy’s flow equation; this analysis resulted in a hydraulic conductivity estimate of 240 feet/day. These estimates agree well with other values determined by long-term pumping tests.

The potentiometric surface of the aquifer depicts horizontal ground-water flow from the southwest toward the northeast. Near Muddy Creek, the potentiometric contours bow upstream and flow lines converge on the stream indicating a ground-water discharge zone. The shape of the potentiometric surface in January 2003 was not significantly different that the shape in January 1986; in some areas, the most recent potentiometric surface is lower than the 1986 surface, probably reflecting the drought conditions and below average amounts of ground-water recharge resulting from infiltration of precipitation and irrigation water.

Recharge to the aquifer is through infiltration of streamflow (3,290 acre-feet/year), leakage from irrigation canals (2,820 acre-feet/year), infiltration of excess irrigation water and precipitation applied to fields (26,300 acre-feet/year), infiltration of precipitation (1,420 acre-feet/year), and inflow from the Ralston Gap (640 acre-feet/year). Ground-water recharge from irrigation accounts for about 84% of the recharge to the aquifer; recharge from the Ralston Gap accounts for less than 2% of the total budget.

Discharge from the aquifer is through leakage to streams and drains (12,300 acre-feet/year), evapotranspiration (20,000 acre-feet/year), underflow across the east border of the study area (2,160 acre-feet/year), and withdrawals by wells (15 acre-feet/year). Withdrawals by wells account for only about 0.04% of the total ground-water discharge from the aquifer.

The Burton bench aquifer is very susceptible to contamination from surface or near surface activities in the western two-thirds of the study area where the sand and gravel are not overlain by the fine-grained glacial deposits. Here, the coarse-grained aquifer is unconfined and susceptible to contaminants at the surface which could rapidly infiltrate to the water table. Fine-grained glacial material confines the sand and gravel in the eastern third of the study area. Where the glacial material is present, it provides a barrier between contaminants and the sand gravel aquifer.

Analyses of water samples collected during this study indicate that the water in the Burton Bench aquifer is a magnesium bicarbonate, and calcium bicarbonate type. Downgradient, the water becomes enriched in sodium and depleted in magnesium. This is probably due to exchange of magnesium for sodium at cation exchange sites on clay minerals. The primary drinking water standard for nitrate was exceeded in one well; a subsequent sample was below the standard. Other primary standards were not exceeded in the samples of wells collected for this study. The secondary drinking water standard for manganese was exceeded in one well; many wells exceeded the standard for total dissolved solids.

The analyses for pesticides in water from 14 wells (46 samples) showed that two wells contained the pesticide Assert™ and/or its metabolite at concentrations about 2 orders of magnitude lower than the drinking water standard for these compounds. The pesticide 2,4-D was detected in one sample from a well, but several other subsequent samples from this well did contain this compound above detection limits.

All water samples from wells completed in the Burton Bench aquifer analyzed for tritium and helium contained detectable concentrations of tritium. This indicates that the water in the Burton Bench aquifer is younger than 50 years. Absolute ages are difficult to interpret because mixing of young irrigation water with older ground water has probably occurred. Assuming that ground-water recharge rates from irrigation are equal across the bench, the relative difference in tritium concentration between wells can be used to estimate average ground water velocity. Two wells completed in the Burton Bench aquifer separated by about 11.5 miles had a relative age difference of about 29 years resulting in a ground-water velocity of about 5.7 feet/day.

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SUPPLEMENTAL DATA

Table 5.--Physical parameters and major-ion concentrations of water from wells

[Geologic unit: Qg, Quaternary glacial deposits; Qtog, Quaternary and Tertiary sand and gravel; Ku, Cretaceous bedrock undifferentiated. Abbreviation: ºC, degrees Celsius; µS/cm, microsiemens per centimeter at 25 ºC; mg/L, milligrams per liter. Symbols: <, less than; --, no data or not applicable]

Location Number	GWIC Number	Geologic Unit	Depth of well (ft)	Date	Water temperature (ºC)	Onsite Specific conductance (µS/cm)	Onsite pH (standard units)	Hardness (mg/L as CaCO3)	Alkalinity (lab, mg/l as CaCO3)	Sum of constituents (mg/L)	Calcium (mg/L)
24N03W31BA01	892077	Ku	--	5/16/1990	7.5	30144	--	18754	960	39850	406
24N04W31ACCC01	6303	QTog	29	6/18/1985	14	683	8.67	369	316	605.23	92.2
24N04W8CBB01	6302	Ku	150	1/18/1977	16	773	7.95	447	408	743.4	32.5
24N05W14BAAA01	6304	QTog	26	6/17/1985	--	529	7.85	254	218	420.35	68.1
24N05W24CBAD01	6305	QTog	25	6/3/1987	--	538	7.65	289	237	459.67	78.8
		QTog									
24N05W24CBAD01	78294	QTog	23	5/22/2002	6	440	7.62	260	233	437.74	70
24N05W25ABAC01	6306	QTog	--	6/18/1985	--	518	8.48	285	249	478.36	76
25N03W14BAAB01	6330	Qg	180	1/14/1985	25	776	--	201	330	643.91	42.9
25N03W16CCDA01	6331	QTog	149	6/3/1987	1	1030	7.8	291	374	860.08	55.4
25N03W24BBCB01	6332	Qg	175	1/14/1985	25	1764		533	269	1385.5	118
25N03W6CDCD01	78841	QTog	95	3/16/2004	--	--	--	207	309	631.59	39.9
25N03W6CDCD02	6328	QTog	72	4/2/1986	8	650.1	7.2	191	303	607.71	39
25N04W12DADD01	6335	QTog	82	10/13/1976	--	--	--	231	383	833.42	39
25N04W17AADB01	78887	QTog	31	6/5/1996	7.3	912	7.16	442	368	725.39	60.3
				4/22/2002	5.5	859	7.47	434	387	742.69	58.9
				3/15/2004	--	--	--	472	357	708.46	61.2
25N04W18CBBB01	78891	QTog	68	8/29/1986	8.9	567	--	290	249	491.78	42.1
				6/5/1996	10.5	641	7.39	290	266	506.67	41
25N04W22BBCD01	188092		30.4	6/5/2001	9.5	723	7.48	321	300	582.86	42.3
				9/10/2001	15.3	532	7.79	317	294	579.32	40.9
				3/11/2004	--	--	--	353	270	568.97	43.6
25N04W26BCBB01	6338	QTog	23	6/17/1985	14.9	848	9.06	352	367	685.6	37.8
				6/5/2001	11.1	737	7.86	341	328	621.21	56.9
				9/10/2001	17.6	715	7.71	422	347	722.49	65.9
25N04W27CC01	78863	Ku	120	2/17/1978	--	--	--	179	445	1217.2	32
25N04W27CCC01	6339	QTog	15	3/11/1986	--	--	--	399	346	654.68	72.1
25N04W29CCCC01	6341	QTog	34	6/16/1985	1	580	8.93	318	257	470.65	25.7
				5/19/2002	9.1	551	7.89	223	198	373.3	35.6
25N04W02CABB01	6333	QTog	44	6/17/1985	10.8	881	8.78	256	340	674	52.8
				6/4/2001	8.5	815	7.71	265	346	666.36	56.7
				9/10/2001	11.7	544	7.31	251	340	661.78	51.2
25N04W30CDBD01	6342	QTog	--	8/29/1986	12.2	560	--	306	243	473.24	48
				5/19/2002	9.3	433	7.44	273	236	445.71	27.7
25N04W6ADDD01	6334	QTog	35	6/16/1985	8.9	597	8.76	317	269	522.83	50
25N05W16DDDD01	6346	QTog	28	8/28/1986	12.2	715	--	427	363	688.55	89.4
				5/19/2002	7.1	617	7.68	334	307	568.39	73.9
				3/15/2004	--	--	--	382	302	586.12	82.3
25N05W19CBBBC01	6347	QTog	22	8/26/1986	25	--	--	248	204	397.87	52.8
				6/5/2001	7.9	603	8.26	286	262	497.52	66.2
				9/10/2001	8.9	534	7.38	271	271	508.8	60.9
				3/15/2004	--	--	--	294	265	522.55	61.6

Table 5.--Physical parameters and major-ion concentrations of water from wells--Continued

Magnes-ium (mg/L)	Sodium (mg/L)	Potas-ium (mg/L)	Iron (mg/L)	Mangan-ese (mg/L)	Bicar-bonate (mg/L)	Sul-fate (mg/L)	Chlor-ide (mg/L)	Fluo-ride (mg/L)	Silica (mg/L)	Nitro-gen Nitrate (mg/L)	Phos-phorous (mg/L)	Location Number
4310	5710	63.7	48.03	1.536	1170	27400	380	0.41	6	354		24N03W31BA01
33.7	11.9	1.3	0.3	0.003	386	66.9	2.9	0.4	9.2	0.2	0.2	24N04W31ACCC01
89	31.9	1	<.01	<.01	498	52	24.4	0.4	11.9	2.3		24N04W8CBB01
20.4	6.3	0.7	<.002	0.001	265.4	49.4	2.1	1	6.6	0.22	0.1	24N05W14BAAA01
22.3	6.7	0.3	<.002	<.001	288.4	53.2	1.2	0.3	8.2	0.27	<.1	24N05W24CBAD01
20.7	5.37	0.517	0.013	<.001	284.5	49.8	1.24	0.309	5.25	<.5	<.05	24N05W24CBAD01
23.1	6.6	0.7	<.002	<.001	303	59.9	1	0.3	7.4	0.22	0.1	24N05W25ABAC01
22.8	89.4	1.7	2.36	0.31	402	61.2	12.4	0.5	8.3	0.04	<.1	25N03W14BAAB01
37.1	128	2.2	0.11	0.36	456	150	19.8	0.8	9.7	0.6	<.1	25N03W16CCDA01
58	193	3.2	4.82	0.34	328	646	25.2	0.6	8.3	0.06	<.1	25N03W24BBCB01
26.1	93	2	0.213	0.198	376.2	76.6	8.38	0.723	8.28	<0.05	<0.05	25N03W6CDCD01
22.8	88.3	1.7	0.12	0.15	370	67.6	8.1	0.8	9.1	0.04	<.1	25N03W6CDCD02
32.5	144	2.2	0.68	0.21	466	84.3	56.4	0.9	7.1	<.023		25N04W12DADD01
70.8	22.7	2.3	0.059	<.007	448.5	104.2	12.2	<1.	4	0.33		25N04W17AADB01
69.7	24.6	2.75	0.061	<.001	471.9	86.9	13.1	<.5	7.72	7.06	<.5	
77.5	26	2.33	0.008	<0.001	435.6	74.3	15.3	0.468	8.41	7.34	<0.05	
44.8	22.5	0.9	<.002	<.001	304	59	3.1	0.4	8.8	6.18	<.1	25N04W18CBBB01
45.7	21.8	1.2	0.055	<.007	324.5	62	5.6	<1.	4.4	0.35		
52.3	25.5	4.98	<..05	<.001	366	71.9	4.15	0.666	7.86	7.2	<.5	25N04W22BBCD01
52.3	24.6	5.83	0.038	<.001	358.7	75.3	5.02	0.71	8.46	7.45	<.5	
59.3	23.7	6.21	0.015	<0.001	329.4	84.7	4.75	0.807	8.45	8.03	<0.05	
62.7	45.9	1.2	<.002	0.001	448	73.9	3	0.7	10	2.35	<.1	25N04W26BCBB01
48.3	28.8	1.48	<.005	<.001	399.7	69	5.88	<.5	7.58	3.55	<.5	
62.6	29.2	1.85	0.036	<.001	423.6	75	46.2	<.5	8.51	9.58	<.5	
24	280	2.2	0.04	0.04	542	286	41.5	0.8	8.6	0.027		25N04W27CC01
53.2	18.5	1.3	<.002	<.001	422	69	5	0.4	9.7	3.39		25N04W27CCC01
61.6	11	0.5	<.002	0.001	313	49.4	2.1	0.8		6.43	0.1	25N04W29CCCC01
32.7	8.11	1.07	0.021	<.001	241.6	41.6	3.08	0.519	6.52	2.46	<.05	
30.2	79.9	1.3	0.012	<.001	415	72.4	11.8	0.7	9.5	0.18	0.2	25N04W02CABB01
30	69.9	1.49	0.01	0.001	421.6	67.7	11.2	<.5	7.76	<.5	<.5	
29.9	66.9	1.53	0.065	0.002	414.3	77.2	12.2	0.475	8	<.5	<.05	
45.2	11.9	1.6	<.002	<.001	296.7	51.1	2.3	0.5	8.8	7.14	<.1	25N04W30CDBD01
49.5	11.9	0.742	0.034	<.001	287.9	45.6	6.01	0.808	7.45	8.05	<.5	
46.7	11.1	2.1	<.002	0.001	328	60	12.5	0.5	10.8	1.12	<.1	25N04W6ADDD01
49.6	12.8	1.1	<.002	<.001	442	81.7	0.6	0.3	11	0.05	<.1	25N05W16DDDD01
36.3	8.21	0.955	0.021	<.001	374.3	63.5	1.36	0.265	8.02	1.56	<.05	
42.9	9.3	1.07	0.016	<0.001	368.1	71.6	1.2	0.211	9.1	0.318	<0.05	
28.3	3.7	1.3	<.002	<.001	248.4	48.1	0.4	0.6	14.2	0.07	<.1	25N05W19CBBBC01
29.4	19	1.05	<.05	<.001	319.2	52.7	1.71	<.5	8.26	<.5	<.5	
28.8	18.4	1.16	0.02	<.001	330.4	58.4	1.37	0.531	8.82	<.5	<.05	
34	22.6	1.95	0.012	<0.001	322.7	69.7	1.4	0.517	8.07	<0.05	<0.05	

Table 5.--Physical parameters and major-ion concentrations of water from wells

[Geologic unit: Qg, Quaternary glacial deposits; Qtog, Quaternary and Tertiary sand and gravel; Ku, Cretaceous bedrock undifferentiated. Abbreviation: ºC, degrees Celsius; µS/cm, microsiemens per centimeter at 25 ºC; mg/L, milligrams per liter. Symbols: <, less than; --, no data or not applicable]

Location Number	GWIC Number	Geologic Unit	Depth of well (ft)	Date	Water tempera-ture (ºC)	Onsite Specific conduc-tance (µS/cm)	Onsite pH (stand-ard units)	Hard-ness (mg/L as CaCO3)	Alka-linity (lab, mg/l as CaCO3)	Sum of constitu-ents (mg/L)	Calcium (mg/L)
25N05W1CBBA01	78967	QTog	27	4/1/1986	9.1	392	8.4	232	187	365.15	44.6
25N05W20DBAB01	6348	QTog	20	6/17/1985	14.9	957	8.59	292	269	502.93	64.8
25N05W20DBAC01	6349	QTog	30	8/26/1986	11.1	556	--	297	267	502.71	68.2
				5/20/2002	8.2	570	7.56	289	270	523.13	67.5
25N05W21CCC01	6353	QTog	--	4/2/1986	6.5	456	7.54	246	231	438.16	52.6
25N05W22CCCC01	6350	QTog	19	4/1/1986	5.5	857.5	7.12	380	334	853.42	53.6
				4/22/2002	4.9	982	7.71	366	348	871.14	54.9
25N05W24CDDD01	6351	QTog	32	1/17/1977	13	439	8	250	220	412.47	22.5
25N05W25BCCC01	6352	QTog	80	6/18/1984	16	530	9.08	237	197	379.44	25
				6/4/2001	11.3	483.7	8.18	237	214	406.01	28.3
				9/10/2001	14.1	338	8.13	214	199	371.39	25.4
25N05W28BBCB02	6354	QTog	33	8/28/1986	12.8	920	--	375	276	806.48	67.2
25N05W28BBCB01	6355	QTog	18.5	8/28/1986	10.6	975	--	398	276	842.9	72.2
				5/18/2002	6.9	969	7.52	387	272	857.64	71.6
25N05W32DDDA01	6357	QTog	57	6/17/1985	14.8	528	9.3	261	211	422.29	69.8
25N05W4DBDA01	78971	QTog	62	10/16/1986	--	543	--	287	233	465.68	45.8
				4/22/2002	9.4	637	7.91	317	289	561.79	51.6
25N05W7BAAD01	126048	QTog	70	5/18/2002	9.5	809	7.57	404	291	710.39	66
				3/11/2004	--	--	--	430	262	688.08	67.7
25N06W25AA01	6358			8/26/1986	8.8	485	--	269	215	428.94	63.7
				5/19/2002	10.6	473	7.58	254	222	444.85	60.9
26N04W24DACA01	6364	QTog	108	4/24/1987	--	3463	--	1500	346	3065.2	271
26N04W25DCAB01	79393		80	4/22/2002	9.8	651	8.14	218	291	600.97	50.2
26N04W30ADDC01	195269		--	4/22/2002	8.6	869	7.35	405	414	841.33	66.8
26N04W35BDAA01	6365	QTog	95	4/2/1986	7.1	882	7.51	361	337	804.54	78.2
				6/5/2001	8.7	982	8.28	374	382	845.69	83
				9/10/2001	12.5	978	7.52	347	392	857.96	74.9
26N04W35BDAA02	194530		85	3/16/2004		--	--	386	382	851.14	79.1
26N04W36DCDB01	6366	QTog	102	1/17/1977	9.5	553	7.7	204	284	561.33	43.6
26N05W12CBBB01	6367	Ku	55	1/17/1977	11	1960	7.8	813	417	1776.9	70
26N05W36BACA01	79433	QTog	50	6/3/1987	--	657	7.72	331	292	548.46	58.9
26N06W25ACDD01	6369	QTog	14	4/1/1986	6.4	744	7.33	411	227	669.87	98.8
				5/18/2002	7.6	705	8.45	283	255	556.43	66.6
				3/11/2004	--	--	--	276	256	552.14	63.2

Table 5.--Physical parameters and major-ion concentrations of water from wells--Continued

Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Nitrogen Nitrate (mg/L)	Phosphorous (mg/L)	Location Number
29.3	6	1.8	<.002	<.001	228.4	39.2	3.8	0.4	9.5	2.15	<.1	25N05W1CBBA01
31.7	14	1.1	<.002	0.001	328	52.5	0.9	0.4	9.2	0.21	<.1	25N05W20DBAB01
30.7	14.2	0.9	0.01	<.001	326	52.6	0.8	0.4	8.8	0.1	<.1	25N05W20DBAC01
29.2	16.3	1.05	0.02	<.001	329.4	70.5	1.81	0.356	6.45	0.513	<.05	
27.9	21	<.1	<.002	<.001	276.3	55.8	1.5	0.3		0.36	<.1	25N05W21CCC01
59.8	78.1	23.1	<.002	<.001	407	216	4.7	0.6	8.3	2.11	0.1	25N05W22CCCC01
55.6	89.9	1.2	0.156	0.001	424	231	4.47	0.418	7.47	2	<.05	
47	13.9	0.6	<.01	<.01	268	45.2	3.45	0.6	8.3	2.8		25N05W24CDDD01
42.4	11	0.7	<.002	<.001	240.1	44.9	1.7	0.3	9.5	3.84	<.1	25N05W25BCCC01
40.5	10.8	0.841	<.005	<.001	261.1	49.6	4.16	0.312	8.08	2.31	<.05	
36.6	9.81	0.848	0.025	<.001	243	43.9	2.17	0.436	7.81	1.32	<.05	
50.3	79.2	1.7	0.021	0.003	337	257	1.6	0.6	11.6	0.26	<.1	25N05W28BBCB02
53	81.9	1.8	0.002	0.002	337	283	1.6	0.7	11.4	0.2	<.1	25N05W28BBCB01
50.7	80.9	1.94	0.091	0.011	331.84	309	1.69	0.576	8.76	0.483	<.5	
21	8.9	0.6	<.002	0.001	257.4	56.2	0.7	0.3	7	0.35	<.1	25N05W32DDDA01
42	17.3	1.6	<.002	0.001	283.8	56.2	2.7	0.5	10.7	4.98	0.1	25N05W4DBDA01
45.7	17.4	2.07	0.049	<.001	352.8	72.7	4.45	0.407	9.5	5.11	<.05	
58.1	27.7	1.93	0.028	<.001	354.3	171	18.8	<.5	9.29	3.24	<.5	25N05W7BAAD01
63.3	28.7	2.02	0.018	<0.001	319.2	173	20	0.429	9.56	4.15	<0.05	
26.7	5.5	1.9	<.002	<.001	262	55.7	3.6	0.3	8.6	0.84	0.1	25N06W25AA01
24.8	9.01	2.17	0.022	<.001	270.8	68.6	1.24	0.33	6.73	0.242	<.05	
200	342	7.3	1.42	0.87	422	1781	26.7	0.3	10.5	1.95	<.1	26N04W24DACA01
22.6	66.4	2	0.121	0.312	354.3	88.1	8.74	0.537	7.66	<.05	<.05	26N04W25DCAB01
57.8	56.5	2.17	0.121	0.014	504.6	139	4.98	0.427	8.9	<.05	<.05	26N04W30ADDC01
40.3	79.8	1.6	0.003	0.077	411	175	8.8	0.6	9	0.06	0.1	26N04W35BDAA01
40.5	73.2	2.1	<.005	0.097	465.6	165	8.31	<.5	7.88	<.5	<.5	
38.9	79.9	2.1	0.033	0.113	478.2	167	8.54	0.449	7.83	<.5	<.05	
45.7	82.5	2.13	0.025	0.054	465.4	159	8.58	0.38	8.23	<0.05	<0.05	26N04W35BDAA02
23	71.5	1.9	0.01	0.12	346	56.8	9.6	0.7	8.1	<.1		26N04W36DCDB01
155	220	1.9	0.05	0.02	508	748	59	0.9	10.7	3.3		26N05W12CBBB01
44.8	14.6	2	<.002	<.001	356	57.7	2.8	0.4	9.4	1.86	<.1	26N05W36BACA01
39.9	38.9	12.7	0.006	0.005	276.2	154	12.1	0.3	6	30.7	<.1	26N06W25ACDD01
28.4	37.2	2.29	0.03	0.001	310.4	82.7	12.8	<.5	5.15	10.8	<.5	
28.6	47.1	2.56	0.019	<0.001	312.3	71.3	12.4	0.25	5.39	8.95	<0.05	

Table 6.--Trace-element concentrations of water from wells.

[Abbreviation: µg/L, micrograms per liter.
Symbols: <, less than; --, no data or not applicable]

Location Number	GWIC Number	Date	Ag (µg/L)	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)	Br (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	Li (µg/L)	Mo (µg/L)	Ni (µg/L)
24N03W31BA01	892077	5/16/1990	<4.	150		480	--	--	<100.	<5.	--	<5.	<4.	2500	<40.	140
24N04W31ACCC01	6303	6/18/1985	<2.	<30.	0.2	60	--	--	200	<2.	--	<2.	8	4	<20.	<10.
24N04W8CBB01	6302	1/18/1977	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24N05W14BAAA01	6304	6/17/1985	<2.	<30.	0.2	100	--	--	<100.	2	--	<2.	10	2	<20.	10
24N05W24CBAD01	6305	6/3/1987	<2.	<30.		390	--	--	<100.	<2.	--	<2.	2	2	<20.	<10.
24N05W24CBAD01	78294	5/22/2002	<1	34.5	<1	<30	78.3	<2	<50	<2	<2	<2	<2	3.77	<10	3.06
24N05W25ABAC01	6306	6/18/1985	<2.	<30.	0.2	60	--	--	<100.	<2.	--	<2.	4	<2.	<20.	<10.
25N03W14BAAB01	6330	1/14/1985	--	--	--	--	--	--	200	--	--	--	--	--	--	--
25N03W16CCDA01	6331	6/3/1987	<2.	<30.	--	270	--	--	200	<2.	--	<2.	2	49	<20.	<10.
25N03W24BBCB01	6332	1/14/1985	--	--	--	--	--	--	200		--	--	--	--	--	--
25N03W6CDCD01	78841	3/16/2004	<1	<30	<1	102	49.7	<2	112	<1	<2	<2	<2	21.5	<10	<2
25N03W6CDCD02	6328	4/2/1986	<2.	<30.	--	90	--		100	<2.	--	<2.	<2.	9	<20.	<10.
25N04W12DADD01	6335	10/13/1976	--	130	--	210	--	<5.0	--	--	--	--	--	40	--	--
25N04W17AADB01	78887	6/5/1996	<2.	<30.	<1.	<80.	154.1	<2.	<100.	<2.	<2.	36.4	<2.	12	<20.	13.7
		4/22/2002	<1	<30	<1	30.1	149	<2	<500	<2	<2	<2	<2	15.7	<10	<2
		3/15/2004	<1	<30	<1	52.7	147	<2	<50	<1	<2	<2	<2	16.2	<10	<2
25N04W18CBBB01	78891	8/29/1986	<2.	<30.	--	110	--	--	<100.	5	--	<2.	<2.	8	<20.	<10.
		6/5/1996	<2.	60.8	<1.	<80.	169	<2.	<100.	<2.	<2.	22.7	<2.	9	<20.	8.6
25N04W22BBCD01	188092	6/5/2001	<1	<30	<1	65.9	100	<2	<500	<2	<2	<2	4.98	28.2	<10	<2
		9/10/2001	<1	<30	<1	66.9	107	<2	<500	<2	<2	<2	6	31.1	<10	<2
		3/11/2004	<1	<30	<1	55.8	104	<2	<50	<1	<2	<2	6.19	29.8	<10	<2
25N04W26BCBB01	6338	6/17/1985	<2.	<30.	0.8	100	--	--	<100.	<2.	--	3	14	29	<20.	<10.
		6/5/2001	<1	<30	<1	45.9	120	<2	<500	<2	<2	<2	11.5	27	<10	<2
		9/10/2001	<1	<30	<1	54	155	<2	<500	<2	<2	<2	9.06	32.5	<10	2.37
25N04W27CC01	78863	2/17/1978	--	--	--	--	--	--	--	--	--	--	--	180	--	--
25N04W27CCC01	6339	3/11/1986	<2.	<30.	--	--	--	--	--	<2.	--	<2.	16	21	<20.	<10.
25N04W29CCCC01	6341	6/16/1985	<2.	<30.	0.4	80	--	--	<100.	<2.	--	<2.	<2.	20	<20.	<10.
		5/19/2002	<1	<30	<1	<30	153	<2	<50	<2	<2	<2	<2	16	<10	<2
25N04W02CABB01	6333	6/17/1985	<2.	<30.	0.3	130	--	--	100	<2.		<2.	5	13	<20.	<10.
		6/4/2001	<1	<30	<1	75	68.2	<2	<500	<2	<2	<2	<2	16.8	<10	<2
		9/10/2001	<1	<30	<1	74.2	69.1	<2	122	<2	<2	<2	<2	16.6	<10	<2
25N04W30CDBD01	6342	8/29/1986	<2.	<30.		70	--	--	<100.	<2.	--	<2.	<2.	22	<20.	<10.
		5/19/2002	<1	<30	<1	<30	78.5	<2	<50	<2	<2	<2	<2	20.2	<10	<2
25N04W6ADDD01	6334	6/16/1985	<2.	<30.	0.2	70	--	--	<100.	<2.	--	<2.	<2.	4	<20.	<10.
25N05W16DDDD01	6346	8/28/1986	<2.	<30.		<20.	--	--	<100.	<2.	--	<2.	<2.	17	<20.	<10.
		5/19/2002	<1	<30	<1	<30	152	<2	<50	<2	<2	<2	<2	13.8	<10	3.13
		3/15/2004	<1	<30	<1	<30	130	<2	<50	1.36	<2	<2	<2	15.8	<10	2.76
25N05W19CBBBC01	6347	8/26/1986	<2.	<30.	--	<20.	--	--	<100.	<2.	--	<2.	<2.	6	<20.	<10.
		6/5/2001	<1	<30	<1	30.3	58.9	<2	<500	<2	<2	<2	<2	9.18	<10	<2
		9/10/2001	<1	<30	<1	<30	64.8	<2	<50	<2	<2	<2	<2	9.25	<10	225
		3/15/2004	<1	<30	<1	<30	56.9	<2	<50	1.76	<2	<2	<2	11	<10	<2

Table 6.--Trace-element concentrations of water from wells--Continued

Date	GWIC Number	Pb (µg/L)	Sb (µg/L)	Se (µg/L)	Sn (µg/L)	Sr (µg/L)	Ti (µg/L)	Tl (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Zr (µg/L)	Location Number
5/16/1990	892077	--	--	76	--	7120	8	--	--	<4.	<6.	<6.	24N03W31BA01
6/18/1985	6303	--	--	0.2	--	400	18	--	--	4	19	<4.	24N04W31ACCC01
1/18/1977	6302	--	--		--			--	--	--	--		24N04W8CBB01
6/17/1985	6304	--	--	<.1	--	310	15	--	--	4	23	<4.	24N05W14BAAA01
6/3/1987	6305	--	--		--	340	12	--	--	<1.	<3.	<4.	24N05W24CBAD01
5/22/2002	78294	<2	<2	<1	--	341	<1	<5	0.75	<5	3.28	<2	24N05W24CBAD01
6/18/1985	6306	--	--	0.1	--	0.1	15	--	--	<2.	38	<4.	24N05W25ABAC01
1/14/1985	6330	--	--	--	--	--	--	--	--	--	--	--	25N03W14BAAB01
6/3/1987	6331	--	--	--	--	590	4	--	--	<1.	13	<4.	25N03W16CCDA01
1/14/1985	6332	--	--	--	--	--	--	--	--	--	--	--	25N03W24BBCB01
3/16/2004	78841	<2	<2	1.05		478	<1	<5	2.54	<5	<2	<2	25N03W6CDCD01
4/2/1986	6328	--	--	--	--	380	<1.	--	--	<1.	5	<4.	25N03W6CDCD02
10/13/1976	6335	--	--	<2.0	50	--	--	--	--	--	--	--	25N04W12DADD01
6/5/1996	78887	<2.	<2.	1.4	--	770	<10.	--	--	9.3	3.2	<20.	25N04W17AADB01
4/22/2002		<2	<2	1.39	--	862	<1	<5	5.21	<5	<2	<2	
3/15/2004		<2	<2	<1	--	905	<1	<5	5.19	<5	<2	<2	
8/29/1986	78891	--	--	--	--	460	4	--	--	<1.	<3.	<4.	25N04W18CBBB01
6/5/1996		<2.	<2.	<1.	--	486	<10.	--	--	5.9	5.4	<20.	
6/5/2001	188092	<2	<2	1.69	--	785	<1	<5	--	<5	2.43	<2	25N04W22BBCD01
9/10/2001		<2	<2	1.65	--	787	<1	<5	7.27	<5	4.52	<2	
3/11/2004		<2	<2	2.36	--	799	<1	<5	7.34	<5	<2	<2	
6/17/1985	6338	--	--	0.7	--	670	10		--	2	37	<4.	25N04W26BCBB01
6/5/2001		<2	<2	1.58	--	791	<1	<5	--	<5	5.76	<2	
9/10/2001		<2	<2	1.84	--	941	<1	<5	5.02	<5	8.29	<2	
2/17/1978	78863	--	--	--	--	--	--	--	--	--	--	--	25N04W27CC01
3/11/1986	6339	--	--	1	--	700	14	--	--	4	73	--	
6/16/1985	6341	--	--	0.5	--	650	6	--	--	3	17	<4.	25N04W29CCCC01
5/19/2002		<2	<2	<1	--	432	<1	<5	3.24	<5	15.5	<2	
6/17/1985	6333	--	--	<.1	--	500	13	--	--	4	7	<4.	25N04W02CABB01
6/4/2001		<2	<2	<1	--	597	<1	<5	--	<5	2.76	<2	
9/10/2001		<2	<2	<1	--	588	<1	<5	2.03	<5	3.71	<2	
8/29/1986	6342	--	--	--	--	510	5	--	--	<1.	<3.	<4.	25N04W30CDBD01
5/19/2002		<2	<2	<1	--	680	<1	<5	6.33	<5	20.4	<2	
6/16/1985	6334	--	--	<.1	--	550	8	--	--	<1.	5	<4.	25N04W6ADDD01
8/28/1986	6346	--	--	--	--	800	5	--	--	<1.	<3.	<4.	25N05W16DDDD01
5/19/2002		<2	<2	<1	--	720	<1	<5	1.59	<5	<2	<2	25N05W16DDDD01
3/15/2004		<2	<2	<1	--	861	<1	<5	1.78	<5	<2	<2	
8/26/1986	6347	--	--	--	--	470	5	--	--	<1.	<3.	<4.	25N05W19CBBBC01
6/5/2001		<2	<2	<1	--	638	<1	<5	--	<5	<2	<2	
9/10/2001		<2	<2	<1	--	648	<1	<5	1.35	<5	<2	<2	
3/15/2004		<2	<2	1.06	--	658	<1	<5	2.55	<5	<2	<2	

Table 6.--Trace-element concentrations of water from wells.

[Abbreviation: µg/L, micrograms per liter.
Symbols: <, less than; --, no data or not applicable]

Location Number	GWIC Number	Date	Ag (µg/L)	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)	Br (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	Li (µg/L)	Mo (µg/L)	Ni (µg/L)
25N05W1CBBA01	78967	4/1/1986	<2.	<30.	--	<20.	--	--	100	<2.	--	<2.	<2.	<2.	<20.	<10.
25N05W20DBAB01	6348	6/17/1985	<2.	<30.	0.2	50	--	--	<100.	<2.	--	<2.	21	10	<20.	20
25N05W20DBAC01	6349	8/26/1986	<2.	<30.	--	70	--	--	<100.	<2.	--	<2.	4	13	<20.	<10.
		5/20/2002	<1	<30	<1	<30	72.1	<2	<50	<2	<2	<2	5	10.9	<10	3
25N05W21CCC01	6353	4/2/1986	<2.	<30.	--	<20.	--	--	<100.	<2.	--	<2.	<2.	7	<20.	10
25N05W22CCCC01	6350	4/1/1986	<2.	<30.	--	<20.	--	--	<100.	<2.	--	<2.	<2.	17	<20.	<10.
		4/22/2002	<1	<30	<1	53	38.3	<2	<50	<2	<2	<2	4.74	32.2	<10	<2
25N05W24CDDD01	6351	1/17/1977		<50.	<2.	60	--	--	--	--	--	<10.	<10.	10		10
25N05W25BCCC01	6352	6/18/1984	<2.	<30.	0.4	80	--	--	<100.	<2.	--	2	4	9	<20.	<10.
		6/4/2001	<1	<30	<1	<30	131	<2	<50	<2	<2	<2	3.34	12.6	<10	<2
		9/10/2001	<1	<30	<1	<30	124	<2	<50	<2	<2	<2	37.6	12	<10	<2
25N05W28BBCB01	6354	8/28/1986	<2.	<30.	--	110	--	--	<100.	<2.	--	<2.	<2.	36	<20.	<10.
25N05W28BBCB01	6355	8/28/1986	<2.	<30.	--	110	--	--	<100.	<2.	--	<2.	<2.	36	<20.	<10.
		5/18/2002	<1	<30	<1	117	28.2	<2	<50	<2	<2	<2	<2	37.8	<10	2.82
25N05W32DDDA01	6357	6/17/1985	<2.	<30.	0.1	90	--	--	<100.	<2.	--	2	6	3	<20.	10
25N05W4DBDA01	78971	10/16/1986	<2.	<30.	--	<20.	--	--	100	<2.	--	<2.	<2.	8	<20.	<10.
		4/22/2002	<1	<30	<1	<30	146	<2	<50	<2	<2	<2	<2	11	<10	<2
25N05W7BAAD01	126048	5/18/2002	<1	<30	<1	108	23.9	<2	<500	<2	<2	<2	<2	32.2	<10	2.78
		3/11/2004	<1	<30	<1	97.6	23.6	<2	--	<1	<2	<2	<2	32.1	<10	2.24
25N06W25AA01	6358	8/26/1986	<2.	<30.	--	<20.	--		<100.	2	--	<2.	<2.	16	<20.	<10.
		5/19/2002	<1	<30	<1	<30	35.8	<2	<50	<2	<2	<2	4.69	16	<10	2.68
26N04W24DACA01	6364	4/24/1987	<2.	100	--	300	--	--	600	<2.	--	16	11	200	<20.	10
26N04W25DCAB01	79393	4/22/2002	<1	<30	<1	63.1	44	<2	<50	<2	<2	<2	<2	14.8	<10	<2
26N04W30ADDC01	195269	4/22/2002	<1	<30	<1	49.3	50.8	<2	<50	<2	<2	<2	<2	17.6	<10	<2
26N04W35BDAA01	6365	4/2/1986	<2.	<30.	--	<20.	--	--	100	<2.	--	<2.	<2.	6	<20.	<10.
		6/5/2001	<1	<30	<1	55.8	52.2	<2	<500	<2	<2	<2	<2	17.1	<10	2.55
		9/10/2001	<5	<150	<5	59.4	52.3	<2	103	<10	<10	<10	<10	16.4	<50	<10
26N04W35BDAA02	194530	3/16/2004	<1	<30	<1	54.6	44.9	<2	91.2	<1	<2	<2	2.25	16.8	<10	2.78
26N04W36DCDB01	6366	1/17/1977														
26N05W12CBBB01	6367	1/17/1977	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26N05W36BACA01	79433	6/3/1987	<2.	<30.	--	120	--	--	<100.	<2.	--	<2.	<2.	7	<20.	<10.
26N06W25ACDD01	6369	4/1/1986	<2.	<30.	--	<20.	--	--	<100.	<2.	--	<2.	7	4	<20.	<10.
		5/18/2002	<1	<30	<1	<30	83.9	<2	<500	<2	<2	<2	3.42	12.8	<10	4.33
		3/11/2004	<1	34	1.14	35.2	79.6	<2	<500	<1	<2	<2	4.49	13.1	<10	2.76

Table 6.--Trace-element concentrations of water from wells--Continued

Date	GWIC Number	Pb (µg/L)	Sb (µg/L)	Se (µg/L)	Sn (µg/L)	Sr (µg/L)	Ti (µg/L)	Tl (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Zr (µg/L)	Location Number
4/1/1986	78967	--	--	--	--	380	1	--	--	<1.	<3.	<4.	25N05W1CBBA01
6/17/1985	6348	--	--	<.1	--	630	15	--	--	1	100	<4.	25N05W20DBAB01
8/26/1986	6349	--	--	--	--	580	6	--	--	<.1	<3.	<4.	
5/20/2002		<2	<2	<1	--	622	<1	<5	1.48	<5	24.8	<2	
4/2/1986	6353	--	--	--	--	620	<1.	--	--	<1.	<3.	<4.	25N05W21CCC01
4/1/1986	6350	--	--	--	--	690	<1.	--	--	<1.	11	<4.	25N05W22CCCC01
4/22/2002		<2	<2	1.86		823	<1	<5	5.25	<5	17.9	<2	
1/17/1977	6351	<50.	<200.	24.5	<50.	460	--	--	--	--	120		25N05W24CDDD01
6/18/1984	6352	--	--	<.1		470	10	--	--	1	<.3	<.4	25N05W25BCCC01
6/4/2001		<2	<2	<1	--	567	<1	<5	--	<5	2.37	<2	
9/10/2001		<2	<2	<1	--	524	<1	<5	5.6	<5	34.1	<2	
8/28/1986	6354	--	--	--	--	1520	6	--	--	<1.	<3.	<4.	25N05W28BBCB01
8/28/1986	6355	--	--	--	--	1640	7	--	--	<1.	94	<4.	
5/18/2002		<2	<2	1.86	--	1650	<1	<5	7.71	<5	45.3	<2	
6/17/1985	6357	--	--	<.1	--	390	14	--	--	<1.	35	<4.	25N05W32DDDA01
10/16/1986	78971	--	--	0.6	--	470	4	--	--	<1.	<3.	<4.	25N05W4DBDA01
4/22/2002		<2	<2	<1	--	636	<1	<5	1.93	<5	<2	<2	
5/18/2002	126048	<2	<2	<1	--	1340	<1	<5	5.1	<5	5.93	<2	25N05W7BAAD01
3/11/2004		<2	<2	1.14	--	1440	<5	4.75	<5	4.5	<2	--	
8/26/1986	6358	--	--	--	--	980	6	--	--	<1.	<3.	<.4	25N06W25AA01
5/19/2002		<2	<2	<1		1110	<1	<5	3.35	<5	2.26	<2	
4/24/1987	6364	--	--	--	--	4250	22	--	--	<1.	74	<4.	26N04W24DACA01
4/22/2002	79393	<2	<2	1.01		525	<1	<5	1.89	<5	<2	<2	26N04W25DCAB01
4/22/2002	195269	<2	<2	<1		880	<1	<5	2.6	<5	18.7	<2	26N04W30ADDC01
4/2/1986	6365	--	--	--	--	680	<1.	--	--	<1.	4	<4.	26N04W35BDAA01
6/5/2001		<2	<2	<1	--	859	<1	<5	--	<5	<2	<2	
9/10/2001		<10	<10	<5	--	862	<1	<25	3.39	<25	<10	<2	
3/16/2004	194530	<2	<2	<1	--	851	<1	<5	3.4	<5	36.3	<2	26N04W35BDAA02
1/17/1977	6366	--	--	--	--	--	--	--	--	--	--	--	26N04W36DCDB01
1/17/1977	6367	--	--	--	--	--	--	--	--	--	--	--	26N05W12CBBB01
6/3/1987	79433	--	--	--	--	670	8	--	--	<1.	<3.	<4.	26N05W36BACA01
4/1/1986	6369	--	--	--	--	710	1	--	--	<1.	250	<4.	26N06W25ACDD01
5/18/2002		<2	<2	<1	--	599	<1	<5	1.78	<5	57.4	<2	
3/11/2004		2.82	<2	2.52	--	590	<1	<5	1.67	<5	33	<2	

Table 7.--Results of analyses for pesticides in water samples

[Analyses by Agricultural Experiment Station, Analytical Laboratory, Montana State University, Bozeman, MT

Abbreviation: NA, not analyzed. Symbol: --, concnetration less than minimum reporting level.

			Compound							
						Achieve Metabolites (µg/L)				
Location Number	GWIC Number	Sample collection date	Assert (µg/L)	Assert Meta-bolite (µg/L)	Achieve (µg/L)	Glutaric Acid	Imine	Tralko --ydim Acid	Pheno --y (µg/L)	Nitrogen Multi-Residue Method (µg/L)
25N05W25BCCC01	6352	6/4/2001	--	--	--	--	--	--	--	--
		9/10/2001	--	--	--	--	--	--	--	--
		4/23/2002	--	--	--	--	--	--	--	--
		7/15/2002	--	--	--	--	--	--	--	--
25N04W26BCBB01	6338	6/5/2001	--	--	--	--	--	--	--	--
		9/10/2001	--	--	--	--	--	--	--	--
		4/23/2002	0.5	0.8	--	--	--	--	--	--
		7/15/2002	0.5	0.3	--	--	--	--	--	--
		4/22/2003	0.7	1.2	NA	NA	NA	NA	--	--
		5/13/2003	0.9	2.1	NA	NA	NA	NA	NA	NA
		7/15/2003	0.4	0.3	NA	NA	NA	NA	--	--
25N 04W 22 BBCD	188092	6/5/2001	0.2	0.4	--	--	--	--	--	--
		6/27/2001	--	--	NA	NA	NA	NA	NA	NA
		9/10/2001	--	--	--	--	--	--	--	--
		4/23/2002	--	0.3	--	--	--	--	--	--
		7/15/2002	--	0.3	--	--	--	--	--	--
		4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--
25N04W22BBCD01	6365	6/5/2001	--	--	--	--	--	--	--	--
		9/10/2001	--	--	--	--	--	--	--	--
		4/23/2002	--	--	--	--	--	--	--	--
		7/15/2002	--	--	--	--	--	--	--	--
25N04W02CABB01	6333	6/5/2001	--	--	--	--	--	--	--	--
		9/10/2001	--	--	--	--	--	--	--	--
		4/23/2002	--	--	--	--	--	--	--	--
		7/15/2002	--	--	--	--	--	--	--	--
26N04W25DCAB01	79393	4/22/2002	--	--	NA	NA	NA	NA	--	--
		7/16/2002	--	--	NA	NA	NA	NA	--	--
25N05W04DBDA01	78971	4/22/2002	--	--	NA	NA	NA	NA	--	--
		7/15/2002	--	--	NA	NA	NA	NA	--	--
25N05W22CCCC01	6350	4/22/2002	--	--	NA	NA	NA	NA	--	--
		7/15/2002	--	--	NA	NA	NA	NA	0.3 (2,4-D)	--
		4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--
25N04W17AADB01	78887	4/22/2002	--	--	NA	NA	NA	NA	--	--
		7/15/2002	--	--	NA	NA	NA	NA	--	--
26N04W30ADDC01	195269	4/22/2002	--	--	NA	NA	NA	NA	--	--
		7/15/2002	--	--	NA	NA	NA	NA	--	--
25N05W34BBBA01	79032	4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--
25N05W16DDDD01	6346	4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--
25N05W7BAAD01	126048	4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--
26N06W25ACDD01	6369	4/22/2003	--	--	NA	NA	NA	NA	--	--
		7/15/2003	--	--	NA	NA	NA	NA	--	--

Table 8.--Tritium-helium concentrations and age determinations for samples of water from wells.

Location Number	GWIC Number	HELIUM[1] 1E-8cc/g	NEON[2] 1E-8cc/g	He corr.[3] 1E-8cc/g	DEL He4[4] %	Del He3[5] %	R(3/4)[6] in Ra	TRITIUM[7] TU	UNCERT.[9] TU	3H-3He[8] AGE (y)	UNCERT.[9] (y)
25N05W16DDDD01	M:6346	7.48	22.47	6.88	**45.4**	**50.5**	**1.021**	13.7	0.40	12.03	0.43
25N05W19CBBBC01	M:6347	6.44	23.01	5.85	**22.0**	**54.2**	**1.244**	15.7	0.50	11.57	0.43
25N03W06CDCD01	M:78841	16.44	22.47	15.89	**234.4**	**42.8**	**0.430**	0.38*	0.09	61.21	4.51
25N04W17AADB01	M:78887	6.87	25.49	5.57	**16.2**	**31.2**	**1.111**	19.1	0.60	6.40	0.34
25N05W07BAAD01	M:126048	6.14	22.94	5.38	**13.9**	**29.9**	**1.122**	14.4	0.50	7.71	0.43
26N04W35BDAA02	M:194530	9.36	26.74	7.57	**59.5**	**597.9**	**4.304**	18.1**	0.60	40.54	0.56

1- HELIUM column denotes observed total helium

2- NEON column denotes observed total neon

3- He corr. column denotes corrected total helium.

4- DEL He4 column is the corrected helium excess in percent, above solubility equilibrium.

5-DEL He3 column is He3 excess in percent, above solubility equilibrium, i.e. tritiogenic He3.

6- R(3/4) column is the He3/He4 ratio in sample normalized to the same ratio in air.

7- TRITIUM column is the tritium concentration in Tritium Units.

8- H3-He3 AGE column is the apparent tritium-helium age of the sample in years.

9- UNCERT.column is the analytical uncertainty in tritium-He3 age, in years.

* Sample has been recounted

** Average of two counting runs