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SCIENTIFIC INVESTIGATIONS MAP 2821
(Sheet 1 of 2)

Tuck, L.K., 2004, Reconnaissance of ground-water resources of northeastern Valley County, Montana

Reconnaissance of ground-water resources of northeastern Valley County, Montana

By L.K. Tuck

INTRODUCTION

Ground water is the only source of drinking water in many small towns and rural areas of northeastern Valley County, Montana. Residents in this part of Montana rely on individual wells at homes and farms or on community wells that serve small towns. Unconsolidated deposits of Quaternary and Tertiary age are sources of water for domestic, stock, and irrigation supplies; bedrock of Tertiary and Cretaceous age also is a source of water for domestic and stock supplies, but the availability and quality of water from these hydrogeologic units can be variable (Thamke, 1991). To obtain usable quantities of ground water, many wells in the study area are deeper than 100 ft. An exception to this generalization is in the Baylor-Larslan area where irrigation wells between about 40 to 100 ft deep commonly yield between 250 and 1,500 gal/min.

Previously, little information was available about the ground-water resources in northeastern Valley County. Data about ground-water availability and quality and the occurrence of high-yielding irrigation wells in this area were needed to better define the ground-water resources of the area. Consequently, the U.S. Geological Survey (USGS), in cooperation with the Montana Bureau of Mines and Geology (MBMG), conducted a reconnaissance study to characterize the ground-water resources in northeastern Valley County.

Purpose and Scope

The purpose of this report is to describe the ground-water resources of northeastern Valley County near the towns of Larslan, Opheim, and Richland and to present data collected and compiled during the reconnaissance study. The report contains a hydrogeologic map and describes the hydrogeologic units of the area, including their water-yielding and water-quality characteristics. Physical and hydrologic data were collected during 1998-99 from 95 ground-water sites, and water samples were collected from 30 wells and analyzed for chemical quality. These data, as well as previously existing geologic and hydrologic data, were compiled for this report.

Description of the study area

The study area encompasses about 1,180 mi² in northeastern Valley County and the eastern part of Daniels County (fig. 1). The northern edge of the study area is the international boundary between the United States and Canada, whereas the southern boundary lies near the confluence of Snow Coulee and West Fork Porcupine Creek. Towns and communities within the study area include Baylor, Glentana, Larslan, Opheim, and Richland. The study area in Valley County has a population of about 480 residents (David R. Martin, Montana Department of Commerce, oral commun., 2000). Land use in the area is primarily ranching and production of small cereal grains.

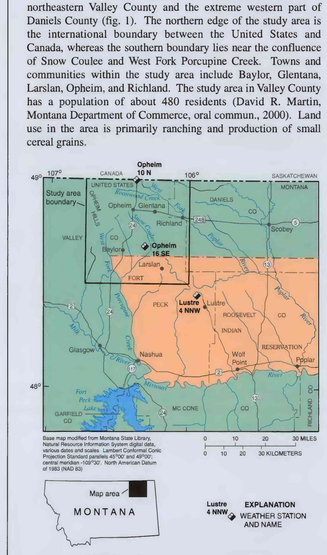

Figure 1. Location of the study area in Montana.

Topography in the study area is largely influenced by geology. Broad and relatively flat benches exist at several different altitudes and primarily are the remnants of the Tertiary Flaxville Formation. The low, rolling hills of this area were formed by continental glaciers that moved south from Canada and deposited widespread moraines. However, erosion has dissected or removed these deposits in some areas. Larger surface-water drainages (such as Snow Coulee, West Fork Poplar River, West Fork Porcupine Creek, and Roanwood Creek) as well as many smaller drainages were formed by meltwater cutting along ice margins dissecting the moraines and benches (Whitaker, 1980; Roger B. Colton, U.S. Geological Survey, retired, written commun., 1999). Land-surface altitudes range from about 3,300 ft in the Opheim Hills to about 2,600 ft near the confluence of West Fork Porcupine Creek and Snow Coulee.

The study area has a semiarid climate that is typical of most areas in eastern Montana with hot, dry summers and cold, dry winters. Average annual precipitation is about 12 in.; about one-half of this precipitation falls in May, June, and July (fig. 2). Mean-maximum monthly temperatures are as high as 91°F, whereas mean-minimum monthly temperatures are as low as 0°F. The mean annual temperature is about 40°F (Western Regional Climate Center, 2002).

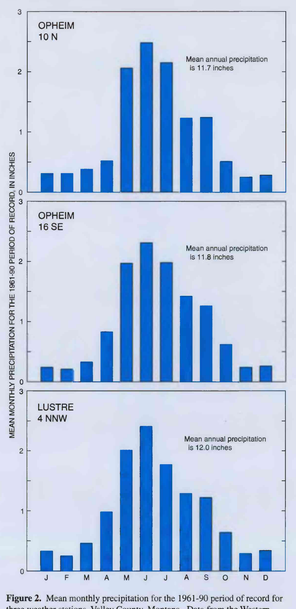

Figure 2. Mean monthly precipitation for the 1961-90 period of record for three weather stations, Valley County, Montana. Data from the Western Regional Climate Center (2002).

Previous investigations

Some of the first geologic investigations in the study area included a reconnaissance of the Tertiary Flaxville Formation in the northern part of the Great Plains (Collier and Thom, 1918). Collier (1919, 1924) described the general geology of northeastern Montana and the occurrence of lignite near Scobey. Alden (1932) conducted a reconnaissance of the physiography and glacial geology of eastern Montana and included a brief description of the Flaxville Formation in the study area. Howard (1960) described the Cenozoic history of northeastern Montana and northwestern North Dakota with an emphasis on Pleistocene history of the north-central Great Plains. Colton (1964) mapped the geology of the southern part of the study area and Colton and others (1989) mapped the geology of the Opheim 30'x 60'quadrangle. Gruber (1980a,b) investigated and described three major coal beds in parts of Daniels and Valley counties. Whitaker (1980) mapped the Flaxville Formation and described in detail the extent, lithology, and depositional environment of the Flaxville Formation in the Scobey-Opheim area. Bergantino (1987a,b) compiled geologic information about the Quaternary geology and the pre-Quaternary geology of the eastern half of the Glasgow 1° X 2° quadrangle. Bergantino (2002) also updated previous information about the geology of the area.

Methods of investigation

Hydrogeologic data were collected by an inventory of 95 existing ground-water sites in the study area. These data included location of the site, hydrogeologic unit, altitude of land surface, use of water, well depth, static water level, diameter of the well opening, well yield, and specific capacity. In addition, hydrologic information was compiled from Nimick and Thamke (1998) and MBMG. Drillers' logs were used to obtain information about well completion, pumping water levels, aquifer lithology and thickness near the well, and whether the aquifer near the well was confined or unconfined. Selected water-quality measurements were made during the well inventory and included water temperature, specific conductance, and pH (table 1).

Water-quality and quality-assurance samples were collected from selected wells to characterize existing ground-water quality in the study area (tables 2 and 3). Ground-water samples were obtained using existing pumps at a discharge point as close to the wells as possible. Water-quality properties were measured in the field and a sample was collected and processed as described by Knapton (1985). Samples collected in 1998 were analyzed for concentrations of major ions, nutrients, and trace elements by the MBMG Analytical Division, Butte, Mont., (Montana Bureau of Mines and Geology, 1998). Duplicate samples were submitted to the MBMG to document analytical precision (reproducibility). On occasion, triplicate samples were collected with one set submitted to the USGS National Water Quality Laboratory (NWQL), Denver, Colo., for an inter-laboratory comparison of analytical results. Analytical methods of the NWQL are described by Fishman and Friedman (1989) and Fishman (1993). Water-quality data from MBMG were used only when the analyses balanced electro-chemically to within 5 percent. For wells that had been sampled more than once, only the most recent analysis was used in water-quality diagrams, boxplots, or statistical summaries.

Water-quality data were compared to primary and secondary drinking-water regulations of the U.S. Environmental Protection Agency (EPA). National primary drinking-water regulations are established for chemical constituents which, if present in drinking water at concentrations exceeding specified maximum contaminant levels (MCLs), can cause adverse human health effects (U.S. Environmental Protection Agency, 2002a). MCLs are health based and enforceable for public drinking-water supplies. National secondary drinking-water regulations (SDWR) are established for constituents or properties that can adversely affect the odor and appearance of water. SDWRs are esthetically based and nonenforceable.

Transmissivity and hydraulic conductivity for unconfined conditions were estimated from pumping water level and yield data from drillers' logs (Walton, 1962) for wells completed in the Tertiary sand and gravel (table 4). Estimates of transmissivity were determined based on a specific yield of 0.2, a well diameter (opening) of 12 in., and a pumping period of either 1, 8, or 24 hours. Hydraulic conductivity was then estimated by dividing transmissivity by the saturated thickness reported from these logs. In most instances, the well diameter was not 12 in. and the pumping period was not 1, 8, or 24 hours; therefore, these estimates are believed to only approximate the aquifer hydraulic characteristics for the Tertiary sand and gravel.

Quality-assurance data for water quality

Quality-assurance data for water quality were provided by analysis of duplicate and triplicate samples (field replicates) from 11 sample sets and two blanks that were submitted from the field and analyzed concurrently with the ground-water samples. Field replicates, used to provide an assessment of precision of analytical results, were collected in such a manner that the physical and chemical characteristics of each replicate sample are considered to be essentially identical (tables 2 and 3). Precision of these results for any constituent can be determined from the relative percent difference (RPD) of the constituent concentrations in replicate analyses. For duplicate values, the RPD was calculated by dividing the absolute values of the difference between each value reported by the MBMG by the mean of the two values and then multiplying by 100 to obtain percent. For triplicate samples, the RPD was calculated by dividing the absolute value of the difference between the mean of the two values reported by the MBMG and the value reported by the NWQL by the mean of all three values. This number was then multiplied by 100 to obtain percent. RPDs were not calculated for those values that were less than the minimum reporting level (tables 2 and 3).

RPD values for major ions and nutrients typically were 20 percent or less, with many RPDs that were 15 percent or less. However, some RPDs for chloride and sulfate were higher than 20 percent, regardless of whether the RPD was calculated for values reported from the same laboratory or values reported between the two laboratories. Replicate values for fluoride almost always exceeded an RPD of 20 percent. RPD values for trace elements typically were less than 10 percent except for chromium (typically greater than 20 percent), iron (four values ranged from 0.0 to 103 percent), and selenium (one value of 22 percent).

Field blanks, used to determine the adequacy of the sample processing and equipment cleaning procedures, are aliquots of deionized water that are certified to be free of detectable concentrations of constituents and are processed through the same sampling equipment as the ground-water samples. The blanks are then subjected to the same processing, preservation, transportation, and laboratory handling as the ground-water samples. Blank samples are used to identify the presence and magnitude of cross-contamination between sites. Analytical results for field blanks (tables 2 and 3) show that most constituents were less than the minimum reporting level. Consequently, the analytical results for the ground-water samples indicate no systematic contamination that would bias the water-quality data.

Location and site numbering system

Ground-water sites are assigned location numbers according to their geographic position within the rectangular grid system used for the subdivision of lands (fig. 3, sheet 2). The location number consists of as many as 14 characters. 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 east (E) of the Montana Principal Meridian. The next two characters are the section number. The next one to four alpha characters designate the quarter section, (160-acre tract), the quarter-quarter section (40-acre tract), the quarter-quarter-quarter section (10-acre tract), and the quarter-quarter-quarter-quarter section (2.5-acre tract), respectively, in which the ground-water site is located. These four subdivisions of the section are designated A,B,C, and D in a counter-clockwise direction, beginning in the northeastern quadrant. The last two numeric characters specify a sequence number to distinguish between multiple sites at a location. For example, location number 33N40E09BCAA01 represents the first well inventoried in the NE 1/4 (A), NE 1/4 (A), SW 1/4 (C), NW 1/4 (B) sec. 9, T. 33 N., R. 40 E. For ease of reference in the text of the report, ground-water sites also are assigned a site number between W1 and W95 (fig. 4, tables 1-4).

Acknowledgments

The author acknowledges with appreciation the many land owners in the study area for allowing access to their wells. Appreciation also is extended to M.R. Cannon and Joanna N. Thamke (USGS) for discussion, review, and interpretation of ground-water data. Thanks also are extended to Robert N. Bergantino (MBMG) and Roger B. Colton (USGS, retired) who provided access to unpublished geologic maps and for discussion and review of the geology of northeastern Valley County.

GEOLOGIC SETTING

The study area is underlain by sedimentary rocks and unconsolidated deposits ranging in age from Late Cretaceous to Quaternary (fig. 4, sheet 2). Rocks of Late Cretaceous age that crop out in the study area consist of the Upper Cretaceous Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation. During the Late Cretaceous Period, a broad, shallow sea covered eastern Montana. Marine shale (Bearpaw Shale) accumulated to a thickness of more than 1,000 ft (Bergantino, 2002); volcanic ash fell and formed many thin bentonite beds. The sea progressively receded in this area near the end of Cretaceous time, owing to regional tectonic activity in western Montana, and deposition of the Bearpaw Shale ceased. As the sea receded, sand and shale were deposited in strand plain and barrier-island depositional environments that resulted in the Fox Hills Sandstone. Coastal-plain sediments of the Hell Creek Formation were deposited in delta-plain and fluvial environments resulting in a thick sequence of shale, siltstone, sandstone interbedded with bentonite, and some coal. Regional, intermittent structural deformation throughout Cenozoic time resulted in folding and erosion of pre-existing rocks. While the Hell Creek Formation was deposited, erosion locally removed much of the upper part of the Fox Hills Sandstone from the study area (Whitaker, 1980). Cretaceous rocks in the study area were folded into a broad syncline that plunges to the southeast resulting in a gentle dip to the northeast for the Cretaceous and older rocks in this area (Dobbin and Erdmann, 1955).

During the early Tertiary Period, tectonic activity and uplift in western Montana provided sediment to eastward- and northeastward-flowing rivers and streams. As a result, the area became a depositional center for sediment. Rocks of Tertiary age are the Fort Union and Flaxville Formations. The Paleocene Fort Union Formation includes interbedded shale, siltstone, sandstone, and coal that represent extensive fluvial and delta-plain systems that prograded across eastern Montana (Cherven and Jacob, 1985). By the late Miocene to early Pliocene Epochs, renewed faulting and uplift in western Montana supplied large volumes of coarse sediment to eastward- and northeastward-flowing rivers and streams in eastern Montana: some Tertiary rocks were eroded. The lower part of the Tongue River Member (uppermost member of the Fort Union Formation) might be present in the study area but exists only as erosional remnants. In the western part of the study area, the lower two members of the Fort Union Formation (the Lebo Shale and the Tullock Member) have been thinned or removed by erosion (Gruber, 1980b).

Throughout the Miocene and Pliocene Epochs, intermittent tectonic activity and climate change in Montana caused many cycles of erosion and deposition of the Flaxville Formation (Whitaker, 1980). The Flaxville Formation was deposited by the ancestral Missouri River which flowed mostly eastward or northeastward leaving several broad benches as the river flowed across this part of northeastern Montana. The ancestral Missouri River is thought to have progressively eroded older Flaxville deposits leaving terrace remnants, such that older deposits are found at higher altitudes and younger deposits are found at lower altitudes. The oldest volcanic ash deposits within the Flaxville indicate an age of late Miocene, whereas other volcanic ash beds indicate that parts of the Flaxville can be as young as about middle to late Pliocene (Whitaker, 1980). Within the study area, the highest and oldest benches are at an altitude of about 3,300 ft (generally between Opheim and Richland and just north of Richland), whereas the lowest and youngest benches are at an altitude of about 2,900 ft (just north and south of Snow Coulee). During the early to late Pliocene Epoch, renewed uplift and climate change caused the ancestral Missouri River to migrate farther south, beyond the study area. Tributary streams draining the area, however, continued to erode the Flaxville gravels so that the remnant deposits form a gentle south- or southeast-facing slope toward the present-day Missouri River (Whitaker, 1980).

The Wiota Gravel consists of gravel, sand, silt, and clay derived from the Flaxville Formation as the ancestral Missouri River and other small streams and slopewash eroded the Flaxville Formation (Whitaker, 1980). The age of the Wiota Gravel in the study area also varies as it was eroded and material was deposited across northeastern Montana. On lower terraces near the Missouri River, the Wiota Gravel may be mid-Pleistocene in age. This unit (not shown on fig. 4) typically is found on benches, pediments, and ridges that slope downward from the higher Flaxville benches (Whitaker 1980; Colton and others, 1989).

During the Pleistocene Epoch, continental ice sheets moved southward from Canada creating many depositional environments. Several episodes of glacial advance and retreat are recognized within the study area (Fullerton and Colton, 1986); some glacial deposits might be as old as early Pleistocene in age. Scattered boulders (gneiss of Precambrian age) found on bedrock that ranges in age from Cretaceous to Tertiary might indicate that the earliest glaciation took place near the end of Pliocene time (David Fullerton, U.S. Geological Survey, oral commun., 1999). Glacial till is composed of boulder- to clay-sized material. Outwash deposits are composed of gravel, sand, and silt some of which was reworked material from the Wiota Gravel and Flaxville Formation. Meltwater flows eroded pre-existing rocks and deposits (most notably the Flaxville) and the eroded coarse-grained material probably was reworked and deposited as outwash (Whitaker, 1980). Where Pleistocene meltwater streams redeposited these coarse-grained materials, the deposits can rarely be distinguished from the Flaxville Formation based on information from drillers' logs. However, extensive outwash deposits and buried outwash channels are unlikely in the study area (David Fullerton, oral commun., 1999).

Holocene streams continue to deposit sediments across channels, flood plains, and terraces along valley margins. These deposits are composed of unconsolidated gravel, sand, silt, and clay.

GROUND-WATER RESOURCES

The general hydrogeologic setting of the area consists of unconsolidated coarse-grained deposits that have moderate to high permeability or consolidated bedrock composed of sandstone and shale that has lower permeability. Unconsolidated hydrogeologic units in the study area include Quaternary sand and gravel, Quaternary glacial till, and Tertiary sand and gravel. However, coarse-grained deposits contained in the Quaternary sand and gravel (glacial outwash) and in the Tertiary sand and gravel (Wiota Gravel and Flaxville Formation) probably are complexly stratified because of multiple episodes of erosion, reworking by streams or glaciers, and deposition. Where these complexly stratified deposits exist (especially the area of high-yielding wells in the Baylor-Larslan area), many wells most likely are completed in one or more of these coarse-grained units. Thus, these units probably are hydraulically connected and probably respond as a single hydrogeologic unit. For this report, glacial outwash (that exists at depth), the Wiota Gravel, and the Flaxville Formation are herein referred to as Tertiary sand and gravel (Tsg, fig. 4) owing to their similar composition which cannot be distinguished from the lithologic information reported on drillers' logs. However, most of the Tertiary sand and gravel probably is equivalent to the Flaxville Formation (Bergantino, 2002). The Tertiary sand and gravel is discussed in detail because large water supplies can originate from this unit and because data are insufficient to describe most other hydrogeologic units in the study area.

Consolidated hydrogeologic units (bedrock) include the Tertiary Fort Union Formation and the Upper Cretaceous Fox Hills Sandstone-Hell Creek Formation. Sandstone beds of the Fox Hills Sandstone and lower part of the Hell Creek Formation (also referred to as the Fox Hills-lower Hell Creek aquifer) typically are used as a source of water in eastern Montana and generally are hydraulically connected (Feltis, 1982). The Upper Cretaceous Bearpaw Shale has very low permeability and typically does not yield water to wells; thus, the Bearpaw Shale forms a barrier to downward flow from the overlying units.

Unconsolidated hydrogeologic units

Quaternary sand and gravel

Quaternary sand and gravel (Qsg, fig. 4) generally includes alluvium of Holocene age along modern flood plains and in larger Holocene meltwater channels. Locally, this unit includes terrace, lake and pond, landslide, eolian, and colluvial deposits of Holocene and Pleistocene age. These deposits consist of gravel, sand, silt, and clay that range in thickness from about 10 to 30 ft (Colton and others, 1989). Quaternary sand and gravel is present along most streams and in most coulees in the study area. The largest deposits extend along the West Fork Poplar River, which is the only perennial stream in the study area.

Little information about the Quaternary sand and gravel is available and ground-water occurrence, recharge, discharge, and hydraulic characteristics can only be generally described. Only one well completed in this unit was inventoried in the study area. These deposits are primarily recharged by infiltration of precipitation. Along West Fork Poplar River, alluvium and adjacent terrace deposits also are probably recharged intermittently by streamflow. Along the upper reaches of Snow Coulee northwest of Larslan, possible upward hydraulic gradients in underlying hydrogeologic units might provide some recharge to these unconsolidated deposits. Owing to their small and isolated extents, ground-water flow paths within Quaternary sand and gravel most likely are relatively short. Discharge from the Quaternary sand and gravel is to wells, springs, streams, and underlying bedrock, and by evapotranspiration. Little information on water quality is available for these deposits. The specific conductance of water from the one well that was inventoried was 1,440 µS/cm.

Quaternary glacial till

Quaternary glacial till (Qt, fig. 4) primarily consists of gravel, sand, silt, and clay that is unstratified, unsorted, and unconsolidated: till covers much of the south-central part of the study area. Thickness of the till varies but averages 16 ft and can be as much as 65 ft (Whitaker, 1980; Colton and others, 1989). Although used as a source of water in parts of the study area, till generally has low permeability and yields poor quality of water. However, many springs and seeps discharge from till in the study area. Thin and laterally discontinuous outwash deposits (stringers) typically overlie till in many smaller coulees and ephemeral stream channels (not shown in fig. 4) and can grade imperceptibly into Holocene alluvium in some of the larger channels. In some of these channels, outwash gravel and Holocene alluvium are indistinguishable. This outwash gravel is most likely derived from the Wiota Gravel and the Flaxville Formation and was redeposited in meltwater channels such as Snow Coulee and its tributaries (Colton and others, 1989).

Limited information about Quaternary glacial till is available and ground-water occurrence, recharge, and discharge can only be generally described. The till is primarily recharged by infiltration of precipitation. Ground-water flow paths within this unit most likely are relatively short. Discharge from Quaternary till is to wells, springs, streams, underlying unconsolidated units, and bedrock, and by evapotranspiration.

Based on the analytical results from water samples collected from three wells sampled for this study, water in the Quaternary glacial till generally had high concentrations of some major ions (table 2). The major-ion composition was dominated by calcium, sodium, and magnesium cations and the sulfate anion. Water from wells completed in the till had dissolved-solids concentrations that ranged from 760 to 1,720 mg/L, which generally was higher than concentrations in other hydrogeologic units (fig. 5). Concentrations of trace elements typically were low (table 3). Nitrate concentrations in water from the Quaternary glacial till ranged from 8.7 to 30 mg/L (fig. 5).

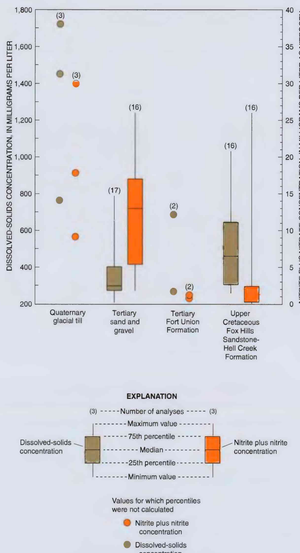

Figure 5. Distribution of dissolved-solids and nitrate concentrations in ground water of northeastern Valley County, Montana. Nitrate concentrations reported as less than the minimum reporting level are plotted as the reporting level. Nitrate concentrations in water from 86 wells completed in the Tertiary sand and gravel reported from Nimick and Thamke (1998).

The few data available indicate that some water from the Quaternary glacial till, if used for drinking water, can pose a health risk as defined by the EPA MCLs or can be esthetically unsuitable as defined by the EPA SDWRs. The health-based MCL concentration of 10 mg/L for nitrate was exceeded in water from two wells (table 2) and the MCL concentrations of 0.50 mg/L (50 µg/L) of selenium was exceeded in water from one well (table 3). The esthetically based SDWR concentration of 250 mg/L for sulfate and the SDWR concentration of 500 mg/L for dissolved solids was exceeded in water from all three wells (table 2).

Tertiary sand and gravel

The Tertiary sand and gravel (Tsg, fig. 4) is primarily composed of discontinuous beds and lenses of gravel, sand, silt, clay, and, in the upper part, occasionally volcanic ash and massive beds of caliche. The unit also locally contains interbeds of sandy gravel (Whitaker, 1980). The Tertiary sand and gravel generally exists as isolated, erosional remnants in the study area; larger deposits are found in the central and southeastern parts of the study area. The thickness of these deposits varies but typically ranges from about 40 to 120 ft (Colton and others, 1989). Basal beds of this deposit (the base of the Flaxville Formation) are commonly composed of coarse gravel or sandstone and conglomerate lenses that are fairly well cemented and can reach a thickness of 20 ft. The gravel consists of well-rounded quartzite and chert pebbles and cobbles, and, as reported in some drillers' logs, can be as much as 3-5 in. in diameter. Whitaker (1980) reported that these pebbles and cobbles average about 1 in. in diameter but can be as large as 1 ft in diameter.

Because of the limited areal extent and the dissected nature of the Flaxville Formation, Nimick and Thamke (1998) inferred that flow paths in this formation (where it exists within the nearby Fort Peck Indian Reservation) were relatively short and that water from the Flaxville Formation was recharged relatively recently. The apparent recharge dates for ground water from seven samples ranged from 1971 to 1989. The relatively young apparent age of this water (6-24 years old at the time of sampling in 1995) indicates that recharge is derived locally through direct infiltration of precipitation or leakage through the overlying glacial deposits. Hydrogeologic conditions in the Tertiary sand and gravel in northeastern Valley County are assumed to be similar to those in the nearby Fort Peck Indian Reservation; thus, ground-water flow paths in the Tertiary sand and gravel in this study area probably are relatively short. Local ground-water flow directions vary owing to variations in topography, laterally discontinuous permeable layers within the sand and gravel, amount and timing of recharge, and pumpage from the high-yielding wells in the Baylor-Larslan area. In isolated outcrops, such as those north of Opheim and Richland, flow and saturated thickness probably are limited.

Hydraulic characteristics for the Tertiary sand and gravel can be inferred from pumping water-level and yield data from drillers' logs. The specific capacity of a well provides an index of the ability of a hydrogeologic unit to transmit water. Transmissivity can be underestimated when the specific capacity is affected by well construction, partial penetration of the well in the unit, and aquifer-boundary conditions (Walton, 1962). Most of the high-yielding wells in the Baylor-Larslan area were completed with a 16-in. diameter stainless-steel screen, which probably allowed all of the screened interval to be open to the unit and the increase of drawdown (well loss) caused by water entering the well to be minimal. The few data available from the drillers' logs indicated that at some wells, pumping rates varied as wells were developed, which affects the calculations of specific capacity. However, estimates of transmissivity from specific-capacity data (table 4) for this study are considered to be representative of the transmissivity of this unit, at least in general terms. Estimates of transmissivity from specific-capacity data using methods from Walton (1962) for unconfined conditions ranged from 940 to 20,000 ft²/d with a median of about 4,400 ft²/d and an average of 6,000 ft²/d. On the basis of these values and the saturated thickness estimated from drillers' logs, the hydraulic conductivity was estimated to range from 25 to 270 ft/d with a median of about 75 ft/d and an average of about 100 ft/d (table 4).

Recharge to the Tertiary sand and gravel is by infiltration of precipitation which can vary from year to year, depending on the amount of precipitation, its seasonal distribution, land use and amount of water applied for irrigation, and soil moisture. Recharge to this unit is dependent on timing of infiltration and percolation of precipitation and, thus, recharge is intermittent. The Tertiary sand and gravel typically is coarse grained and can be readily recharged in areas where this unit crops out. About 12 in. of precipitation (fig. 2) falls in the study area and is potentially available for recharge. However, much of this precipitation evaporates and is transpired by plants. Nearby at Glasgow, as much as 40 in. of water evaporated and was transpired by plants during the April-September growing season in 1998 (Bureau of Reclamation, 2004). In addition, much of this precipitation is retained as soil moisture and runs off as streamflow; therefore, the amount of precipitation available for recharge most likely is small. Precipitation typically recharges aquifers during the late fall before the ground freezes and in early spring after the ground thaws before the growing season. Leakage from overlying Quaternary sand and gravel and glacial till and the underlying Fox Hills Sandstone-Hell Creek Formation also can recharge the Tertiary sand and gravel where these other units are saturated and permeable, and hydraulic heads in the Tertiary sand and gravel are lower than in either adjacent hydrogeologic unit.

Some excess water from irrigation also might recharge this hydrogeologic unit. Ephemeral drainages can convey irrigation return flow to stock ponds and Snow Coulee; some of this water might infiltrate and percolate into aquifers. However, ground water used for irrigation in the study area is applied by sprinklers and probably is efficiently used by plants so recharge from irrigation most likely is small.

Discharge from the Tertiary sand and gravel includes withdrawals from wells, flow to springs, loss of water into streams, ponds, or wetlands, and evapotranspiration. Available water-use information[1] for about one-half of the irrigation wells (Denise Beggar and Kim Kissner, Montana Department of Natural Resources and Conservation, written commun., 1998-2000) indicates that the average amount of water withdrawn from each of these wells is about 140 acre-ft/yr (median of about 130 acre-ft/yr). On the basis of this average withdrawal rate and 26 irrigation wells that were inventoried for this study (nearly all irrigation wells in the Baylor-Larslan area), the average amount of water withdrawn from the Tertiary sand and gravel for irrigation is estimated to be about 3,640 acre-ft/yr. This average rate will vary from year to year as timing and amount of precipitation vary for each growing season. Withdrawals from the Tertiary sand and gravel for domestic and stock use are unknown. However, on the basis of a statewide average withdrawal rate of 78 gal/d per person (Montana Department of Natural Resources and Conservation, 1986) and about 480 residents in this part of Valley County, about 42 acre-ft/yr of ground water from all aquifers in the study area is used for domestic purposes. This estimate is an upper limit to the amount of ground water withdrawn from Tertiary sand and gravel for domestic purposes because many residents use water from other hydrogeologic units. Thus, discharge from the Tertiary sand and gravel for domestic purposes is less than 42 acre-ft/yr. In the Baylor-Larslan area, the amount of water withdrawn for irrigation probably far exceeds the amount of water withdrawn for domestic and stock purposes.

Long-term records of water levels are not available for wells in the study area. However, water levels in seven irrigation wells or nearby monitoring wells (W1, W15, W33, W35, W45, W56, and W59) were periodically measured from the fall 1991 to spring 1994 (Kirk Waren, Montana Department of Natural Resources and Conservation, written commun, 1998). Although water levels varied throughout this period, a slight increasing water-level trend is indicated for most wells from fall 1991 to spring 1994 and this increase appears to have resulted from increased precipitation received in the study area (fig. 6). Most water levels measured for this study during 1998 were lower than the 1991-94 periodic water-level measurements. The lower water levels probably resulted from a decrease in precipitation from 1993 through 1998 (fig. 6).

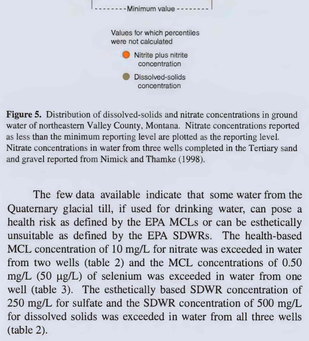

Figure 6. Comparison of periodic water-level measurements in selected wells completed in the Tertiary sand and gravel to total precipitation for selected weather stations, northeastern Valley County, Montana, 1990-98 (1990-94 water-level data modified from Kirk Waren, Montana Department of Natural Resources and Conservation, written commun., 1996).

Based on the analytical results for water samples collected for this study, water in the Tertiary sand and gravel generally had low concentrations of major ions (fig. 4, table 2). The major-ion composition was dominated by calcium, sodium, and magnesium cations and the bicarbonate anion. Water from wells completed in this unit had dissolved-solids concentrations that ranged from 206 to 787 mg/L with a median of 296 mg/L (fig. 5). Concentrations of trace elements typically were low (table 3).

Water-quality data indicate that water from the Tertiary sand and gravel can pose a health risk as defined by the EPA MCLs if used for drinking water or can be esthetically unsuitable as defined by the EPA SDWRs (U.S. Environmental Protection Agency, 2002a). The health-based MCL of 0.010 mg/L (10 µg/L) for arsenic[2] was equaled or exceeded in water from two wells, and the MCL of 0.2 mg/L (200 µg/L) for barium was exceeded in water from four wells. The esthetically based SDWR concentration of 500 mg/L for dissolved solids was exceeded in water from two wells, the SDWR of 0.3 mg/L (300 µg/L) for iron was exceeded in water from one well, and the SDWR of 0.05 mg/L (50 µg/L) for manganese was exceeded in water from one well (tables 2 and 3).

Nitrate concentrations in water from the Tertiary sand and gravel (fig. 5) ranged from 1.8 to 26 mg/L with a median concentration of about 13 mg/L (includes three values of 13.8, 15.0, and 17.5 mg/L not reported in table 2; wells were previously sampled). Nimick and Thamke (1998) investigated the extent, magnitude, and sources of nitrate in the Flaxville Formation and other hydrogeologic units of the Fort Peck Indian Reservation and nearby areas. They concluded that higher nitrate concentrations in ground water of the Reservation most likely are derived from soil organic nitrogen. Cultivation of native plants and crop-fallow farming can lead to rapid mineralization of soil organic nitrogen; nitrogen that is stored in the soil horizon can subsequently leach to the water table. Because of the similar hydrogeologic setting and similar agricultural practices in the study area compared to the Fort Peck Indian Reservation, high nitrate concentrations in ground water determined from this study also might result from soil organic nitrogen that leaches to the water table. In addition, infiltration and percolation of water from irrigation within the Baylor-Larslan area might facilitate leaching and movement of soil organic nitrogen to the water table.

Indirect evidence from water-quality data indicates that the Tertiary sand and gravel and the underlying Fox Hills Sandstone-Hell Creek Formation might be hydraulically connected. Water-quality diagrams (fig. 4) which represent the major-ion composition of water from wells completed in the Tertiary sand and gravel (for example, W1, W17, and W34) are similar to some water-quality diagrams for wells completed in the Fox Hills Sandstone-Hell Creek Formation (for example, W31, W67, W87, and W88). This similarity in water quality indicates a possible hydraulic connection between the two aquifers in some places. During the irrigation season, the large volume of water withdrawn from the Tertiary sand and gravel in the Baylor-Larslan area might induce flow from the Fox Hills Sandstone-Hell Creek Formation to the Tertiary sand and gravel and affect the quality of its water. Additionally, where the Tertiary sand and gravel overlies the Fox Hills Sandstone-Hell Creek Formation and where the hydraulic gradient is upward, water from this unit could flow upward and affect the quality of water in the Tertiary sand and gravel.

Bedrock hydrogeologic units

Tertiary Fort Union Formation

The Tertiary Fort Union Formation (Tfu, fig. 4) consists of interbedded sand and sandstone, siltstone, clay, and coal. In the study area, erosion has thinned or removed this unit; thus, thickness varies but can be as much as 600 ft (Colton, 1964). Fine-grained sandstone, shaley sandstone, and coal are the water-yielding units in the Fort Union. However, some of these units can be discontinuous or poorly connected which commonly results in variable well depths, yields, and water quality over relatively short distances. Where it exists, the Fort Union Formation is the most widely used hydrogeologic unit in eastern Montana; however, well yields can be low, generally less than about 10 gal/min (Noble and others, 1982).

Little information about the Fort Union Formation is available and ground-water occurrence, recharge, and discharge can only be generally discussed. The Fort Union Formation is primarily recharged by infiltration of precipitation and water is discharged by withdrawals from wells, flow to springs and streams, or evapotranspiration.

Coal beds within the Fort Union Formation are a source of water to some springs in the study area. Many springs are located far below the Flaxville-Fort Union Formation contact (fig. 4); some of these springs have a similar altitude and likely discharge from coal beds. Collier (1924) and Gruber (1980b) mapped several coal beds within the Fort Union in the northeastern part of the study area. Along the West Fork Poplar River northwest of Richland, many springs issue from the Fort Union Formation near the outcrop of the "D" coal bed (Collier, 1924), which is at the base of the Lebo Shale Member of the Fort Union Formation. The "D" coal bed has an average thickness of 8 ft but can be as much as 17 ft thick (Gruber, 1980b) and typically is about 55 ft above the base of the Fort Union Formation. North and northeast of Opheim, many springs also are located below the contact between the Flaxville and Fort Union Formations and have a similar altitude which suggests that water to these springs might issue from coal beds within the Fort Union Formation. Coal beds within the Fort Union can yield water of good quality (Noble and others, 1982).

Based on the analytical results for two water samples from the Fort Union Formation, water generally had low to moderately high concentrations of major ions and the major-ion composition was a mixed type with calcium, magnesium, and sodium as the dominant cations and bicarbonate as the dominant anion (fig. 4, table 2). Water from two wells completed in this unit had dissolved-solids concentrations of 265 and 794 mg/L. Concentrations of trace elements typically were low (table 3).

Nitrate concentrations in water from the Fox Hills Sandstone-Hell Creek Formation ranged from <0.05 to 26 mg/L with a median concentration of 0.26 mg/L (fig. 5). Nitrate concentrations in the Fox Hills Sandstone-Hell Creek Formation in the nearby Fort Peck Indian Reservation, Nimick and Thamke (1998) determined that nitrate concentrations in water from the Fort Union Formation ranged from <0.05 to 27 mg/L. They also concluded that nitrate concentrations in water from the Fort Union Formation decrease with well depth and in some places the clay-rich zones within this formation probably are barriers to downward movement of nitrate-rich water from the overlying Flaxville Formation (Tertiary sand and gravel, this report).

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