Characterization of the Bull Mountains Aquifer System in Treasure and Yellowstone Counties, Middle Yellowstone River Area, Montana

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Atlas organization

The Montana Ground-Water Assessment Atlas for the Middle Yellowstone River Area (Atlas 3) consists of a descriptive overview (Part A) and seven hydrogeologic maps (Part B). This map is intended to be a stand-alone document that describes a single hydrogeologic unit, the Bull Mountains aquifer system. To obtain a more integrated understanding of the area's hydrogeology, see Part A and the other Part B maps.

Introduction

The Bull Mountains aquifer system underlies northern and western Yellowstone County and most of Treasure County. As of May 2006, there were about 1,250 wells completed in this aquifer within the map area. The wells are located in a low-density pattern throughout the aquifer area (see *Well distribution*). The wells are primarily for stockwater or domestic use (see *Well use*).

Geologic setting

The Bull Mountains aquifer system is a composite of several hydrogeologically similar formations that act as a single aquifer on a regional scale. Geologic units within the aquifer include the Fox Hills, Lance, and Fort Union Formations (hereafter described as 'the aquifer'). The Fort Union is further divided into the Tullock, Lebo, and Tongue River Members. The aquifer is underlain by the 800-ft-thick Bearpaw Shale, which separates the Bull Mountains aquifer system from the deeper Judith River aquifer. The outcrop patterns for the geologic units (Lopez, 2000; Wilde and Porter, 2000; Vuke and others, 2000, 2003) are shown on the *Ground-water altitude map*. The vertical relationships are shown on the *Geologic cross sections*.

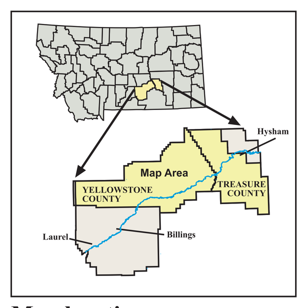
The extent, thickness, and depth of the formations in the aquifer are largely controlled by the Bull Mountains Basin, an asymmetrical east–west-trending basin centered just north of the atlas area. Formations dip toward the center of the basin at generally less than 5 degrees. The aquifer is as much as 2,400 ft thick (as determined from logs of oil and gas wells) near the center of the basin and thins outward. Erosion has removed the aquifer along the basin margins, exposing the underlying Bearpaw Shale and older Cretaceous rocks. The formations in the area are also deformed by a series of northwest–southeast-trending parallel folds along the eastern side of the area.

Most available ground water is within pore spaces and fractures in permeable rocks such as sandstone and coal. Finer-grained materials such as clay, siltstone, and shale are less permeable and typically do not produce sufficient water and impede ground-water flow. The only regionally continuous sandstone layer in the aquifer is the Fox Hills Formation. This formation consists of a 10- to 110-ft-thick layer of poorly consolidated sandstone at the base of the aquifer. The remainder of the aquifer is generally composed of discontinuous channel-shaped sandstone lenses cut into the surrounding shale. Sandstone channels or stacked channel sequences are typically larger and thicker in the Lance Formation (10–100 ft thick) and in the Tongue River Member (20–300 ft thick), and thinnest in the Lebo Member (5–50 ft thick). To the east of this map area, the Lebo Shale acts as a regional confining layer within the aquifer, hydrogeologically separating units above from those below. However, in Yellowstone and Treasure Counties, the Lebo Member is sandier than it is to the east and consequently is not a confining layer. Drilling records from 125 wells indicate that the Lance Formation and the Tullock and Lebo Members consist of about 60 percent shale and 40 percent sandstone and the Tongue River Member consists of about 50 percent sandstone and 50 percent shale.

Coal seams account for about 1–3 percent of the lithology reported in drill logs in the Lance and Fort Union Formations. The coals are typically thin (1–10 ft thick) and are laterally discontinuous. Regionally continuous coal seams in the Tongue River Member occur generally north of the map area in the Bull Mountains coalfield and southeast of the area in the Colstrip coalfield. The Big Dirty coalbed is encountered at the base of the Lebo Member in much of Treasure County (Wilde and Porter, 2000) and is 2–17 ft thick.

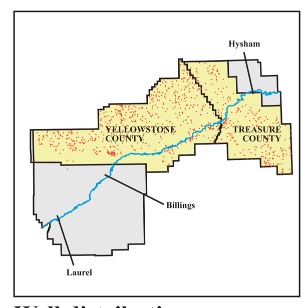
Geographic setting

Erosion has downcut the flanks of the Bull Mountains Basin leaving the Bull Mountains, Hysham hills, and Little Wolf Mountains as upland remnants. All of the area is drained by the Yellowstone River and its tributaries. The topography of the region is dominated by a system of parallel, narrow, flat-topped sandstone interfluvial ridges dissected by northwest–southeast-trending valleys. The valleys generally parallel the structural folding found on the eastern side of the area. The valley and ridge topography has a significant influence on the Bull Mountains aquifer system. Topographic position largely controls ground-water flow patterns, probable drilling depths, and water-quality patterns.



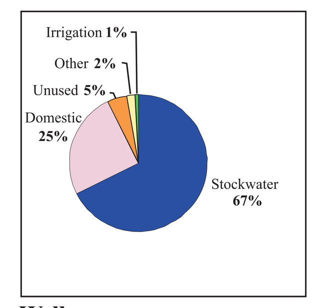
Map location

The Middle Yellowstone River Area consists of Treasure and Yellowstone Counties exclusive of the Crow Indian Reservation. Maps of the Bull Mountains aquifer system on this sheet include the portion of the Middle Yellowstone River Area shown above.



Well distribution

Wells in the Bull Mountains aquifer system are distributed throughout northern Yellowstone County and much of Treasure County.

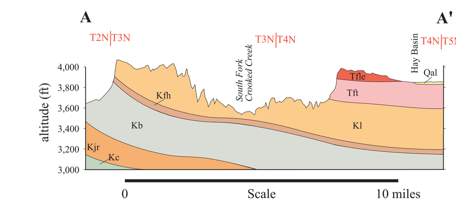


Well use

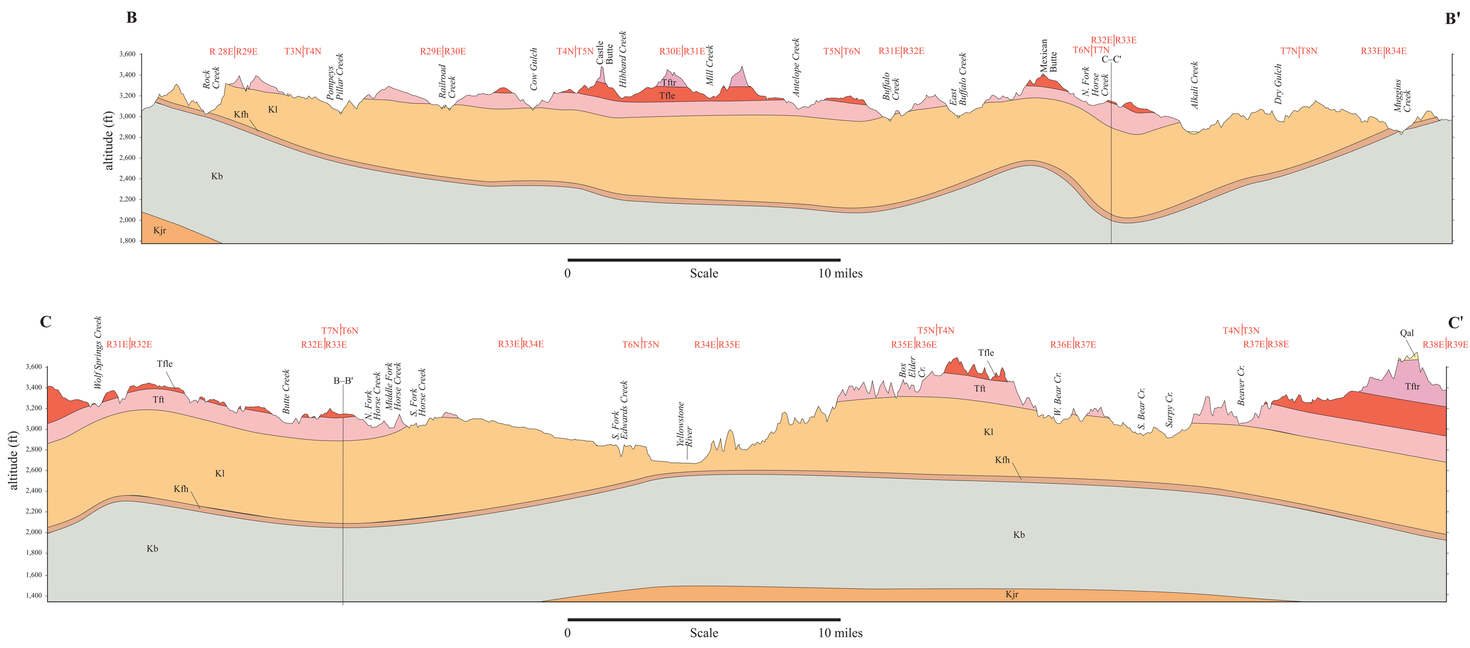
The primary use of wells in the Bull Mountains aquifer system is for stockwatering and to a lesser extent domestic purposes. Other uses are minimal.

Geologic cross sections

Three geologic cross sections were constructed through the Bull Mountains aquifer system along lines A–A', B–B', and C–C'. The locations of the cross-section lines are displayed on the *Ground-water altitude map*. The cross sections are based on interpretations of water well logs, oil well logs, and geologic mapping (Lopez, 2000; Vuke and others, 2000, 2003; Wilde and Porter, 2000). The cross sections show stratigraphic position and thicknesses of relevant formations.



Geologic cross sections



Cross section explanation

Geologic units

- Qal Alluvium
- Fort Union Formation
  - Tftr –Tongue River Member
  - Tfle –Lebo Member
  - Tft –Tullock Member
- Kl Lance Formation
- Kfh Fox Hills Formation
- Kb Bearpaw Shale
- Kjr Judith River Formation
- Kc Claggett Shale

Horizontal scale: 1:250,000
Vertical exaggeration = 20x

Ground-water altitude and flow

A ground-water altitude (potentiometric surface) map was constructed from the static ground-water levels measured in 392 inventoried wells. The map depicts a generalized potentiometric surface at the 100- to 300-ft depth interval. Reported ground-water levels in non-inventoried wells in the 100- to 300-ft depth interval were also used to qualitatively assist in contouring.

Ground-water flow in the Bull Mountains aquifer system occurs in three dimensions, with both lateral and vertical components. Flow is driven by the hydraulic gradient, the change in ground-water altitude (pressure head) per distance (horizontal or vertical). Lateral ground-water flow will follow the directions of decreasing hydraulic head.

In general, the potentiometric pattern mimics land-surface topography; ground water flows from the ridges to the valley drainages. Most recharge likely occurs on the flat-topped sandstone ridges. Superimposed over the ridge to valley flow is a regional trend toward the Yellowstone River. The lateral hydraulic gradient typically ranges from 1–10 percent, and averages about 2 percent.

Vertical hydraulic gradients are calculated from different ground-water levels in adjacent well pairs. Evaluations of 16 well pairs demonstrate vertical gradients ranging from -0.006 ft per ft (upward) to 1 ft per ft (downward). The pattern is not as defined as for the lateral dimension because of the scarcity of well pairs. However, it would be expected that vertical gradients would be greatest (closer to 1 ft per ft) on the ridges and lower, or even upward, in the drainages.

Explanation

Map features
- Streams
- Township boundaries
- Section lines

Hydrogeologic data
- Ground-water altitude contour [every 5th line (500 ft) is bold]
- 3,143 Ground-water altitude measurement
  * denotes data from wells with depths less than 100 ft or greater than 300 ft deep
- 3,300 Contour values (feet, interval = 100 ft)
- Direction of ground-water flow

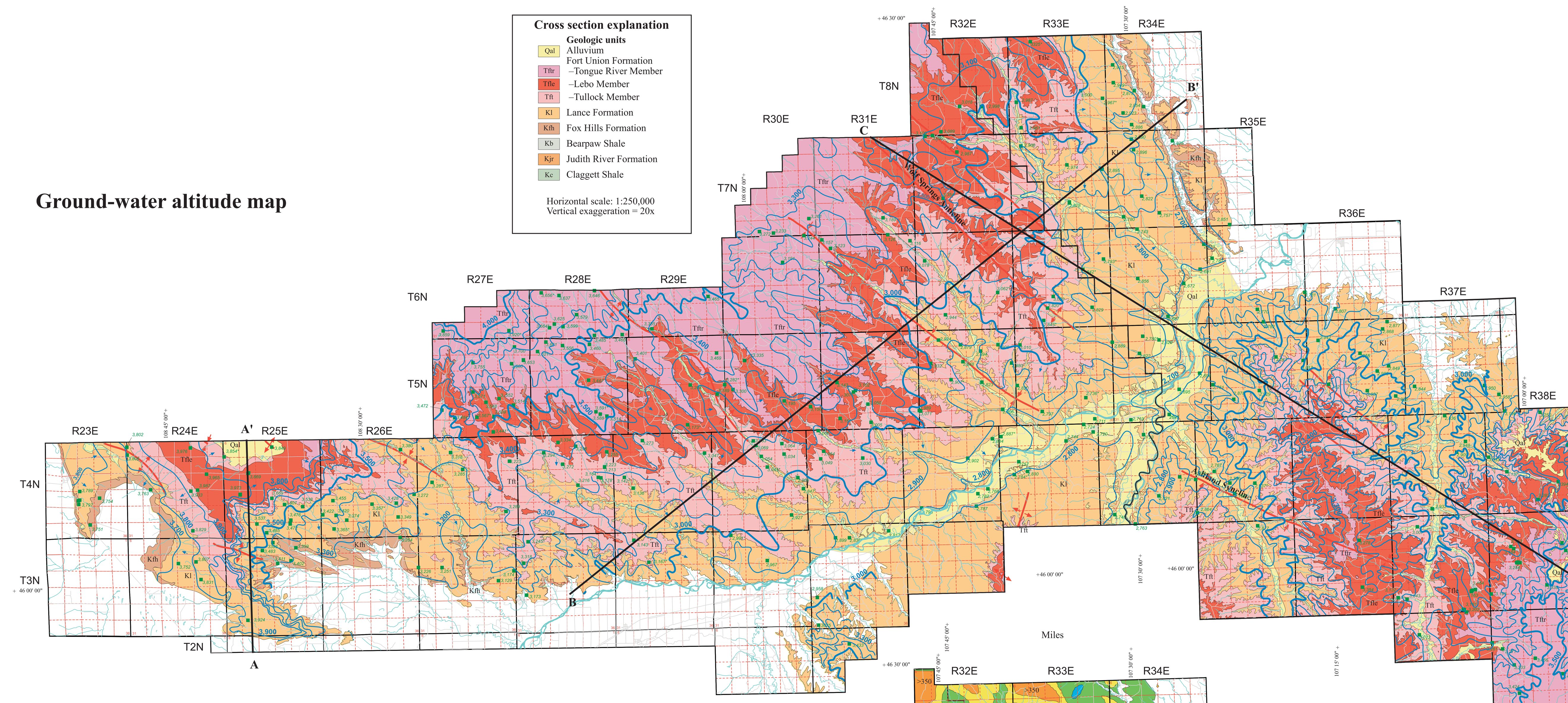
Geologic units
- Qal Alluvium
- Fort Union Formation
  - Tftr –Tongue River Member
  - Tfle –Lebo Member
  - Tft –Tullock Member
- Kl Lance Formation
- Kfh Fox Hills Formation
- Units below the Fox Hills Formation are not shown

Geologic structures (folds)
- syncline
- anticline

A —— A' Geologic cross-section line

2 1 0 2 4 6 miles
Scale: 1:250,000
Projection: Montana State Plane 1983
Datum: NAD 1983
N

Ground-water altitude map



Well statistics

Well statistics were obtained by evaluating information from driller's logs for 398 wells. The specific capacity of a well is the yield in gallons per minute (gpm) per foot of water-level drawdown and is calculated by dividing the drawdown by the pumping rate. Population percentile (*table, right*) indicates the percentage of sample data that is less than the given value. Half of the wells will have values between the 75th and 25th percentile, and 90% of the data population will have values between the 5th and 95th percentile. The 50th percentile is the population median. The 5th and 95th percentile can be considered as minimum and maximum values.

Specific capacity is a measure of productivity of a well and is influenced by well construction, pump size, and aquifer properties. The larger the specific capacity value the more productive the well. The specific capacities of most Bull Mountains aquifer system wells are low (0.05–0.29 gpm/ft) relative to other aquifers in the area (0.04–13 gpm/ft) (see the other maps in this atlas). Consequently, well depths will need to be sufficiently deep to accommodate wells with large pumping water-level drawdowns.

About 50 percent of reported yields for the aquifer were between 4 and 11 gpm, which is adequate for most domestic and stockwater use, but insufficient for irrigation, industrial, or municipal uses. Wells in the Bull Mountains aquifer system are typically 100- to 250-ft deep.

Well statistics

Population percentile	Specific capacity (gpm/ft)	Reported yield (gpm)	Total depth (ft)
95%	1.27	25	431
75%	0.29	11	250
50%	**0.11**	**7**	**162**
25%	0.05	4	100
5%	0.02	2	55

Probable drilling depths

The *estimated drilling depths map* shows the most likely completion depth for a well in a given location. Unlike other aquifers described in this atlas, there is no single stratigraphic target (geologic unit) to define well depths. The Bull Mountains aquifer system is composed of several formations, each containing numerous water-bearing strata.

Review of well depths in the region suggests that topography rather than stratigraphy is the primary influence on well depths. Shallow wells (100–200 ft deep) are generally along the valleys and deeper wells (200–400 ft deep) are on the ridges. This map was made by plotting and contouring the altitudes of the maximum drilling depths for existing wells. Contours were drawn so that the surface was deeper than the land surface. This contoured surface was then subtracted from the land-surface altitude to obtain estimated well depths.

Comparisons between predicted and actual well depths indicate a match within a standard deviation of 55 ft. The pattern of the predicted depths follows the initial qualitative observation of deeper wells on the ridges and shallower wells in the valleys.

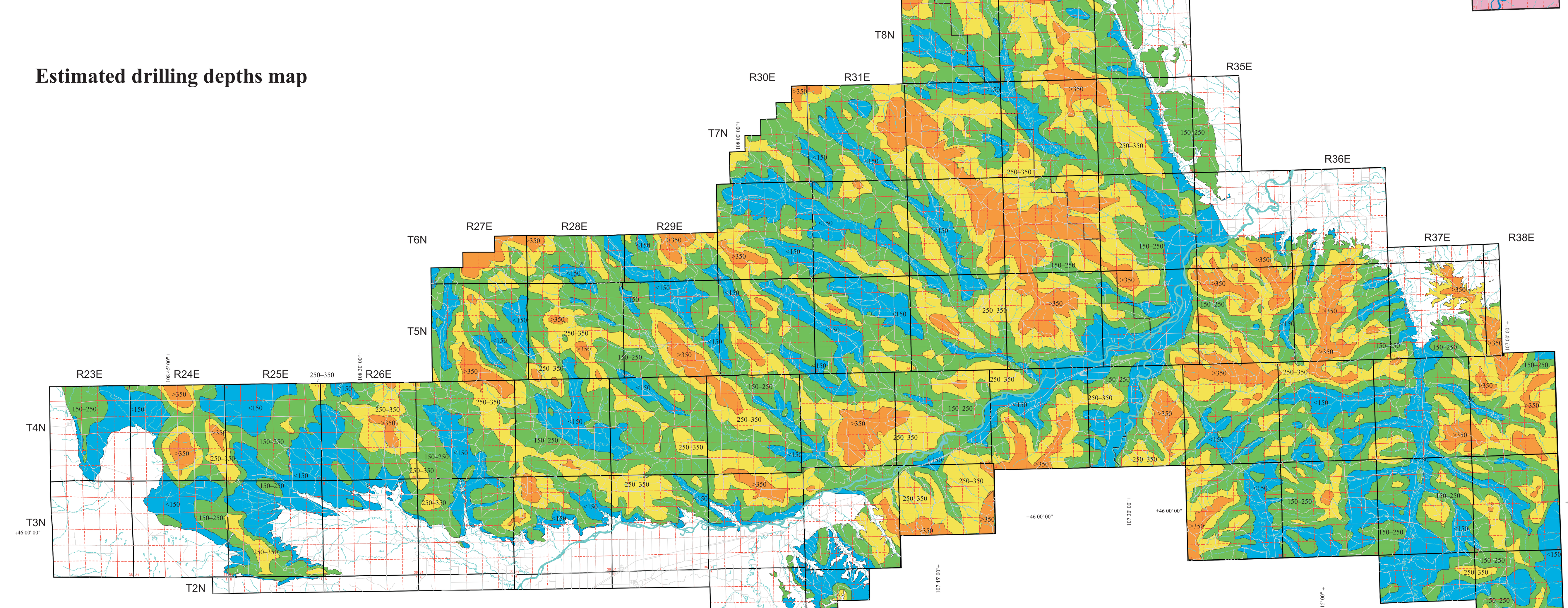
Explanation

Probable well depth (ft)
- Greater than 350
- 250–350
- 150–250
- Less than 150

Map features
- Streams
- Township boundaries
- Section lines

2 1 0 2 4 6 miles
Scale: 1:250,000
Projection: Montana State Plane 1983
Datum: NAD 1983
N

Estimated drilling depths map



Water quality

Dissolved constituents in ground water are a result of the initial chemistry of the recharge water and subsequent interaction of the water with soil and aquifer materials. Generally, as water moves from recharge to discharge areas, dissolution of minerals and cation exchange result in an increased percentage of dissolved sodium and sulfate.

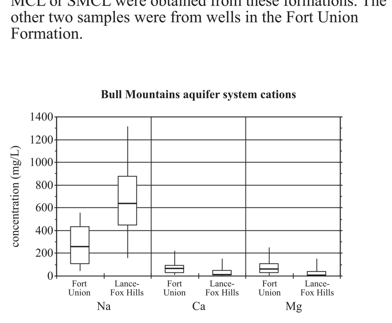
Ground-water quality in the Bull Mountains aquifer system varies considerably, primarily as a function of aquifer (geologic unit) and position within the flow system. Water from wells completed in the Fort Union Formation contains dissolved constituent concentrations that range from about 600 to 3,000 mg/L with an average of 1,650 mg/L. Sodium, sulfate, and bicarbonate are the primary constituents, with minor amounts of calcium and magnesium (see the box and piper plots). Water with smaller dissolved constituent concentrations occurs in the topographically high recharge area in the northwestern part of the map area and coincides with the mapped extent of the Tongue River Member of the Fort Union Formation (Tftr).

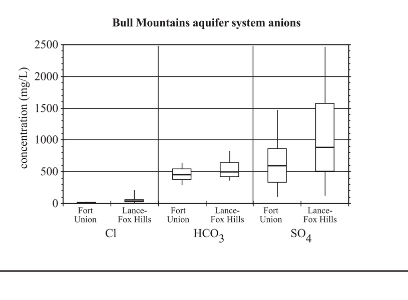
In the topographically lower area that flanks the Yellowstone River, the Lance and underlying Fox Hills Formations are near or at the land surface and contain exploitable ground water. Wells completed in these formations generally occur downgradient from wells completed in the Fort Union Formation. Water from these formations is slightly more mineralized and more uniform in composition than water from the overlying Fort Union Formation (see the box and piper plots). The dissolved constituent concentrations of water from these units range from about 900 to 4,500 mg/L with an average of 2,470 mg/L. Sodium and sulfate concentrations are noticeably larger and calcium and magnesium concentrations slightly smaller than in samples from the Fort Union Formation.

The water-quality data were compared to drinking water standards (U.S. Environmental Protection Agency, 2002) to assess the general quality of water for domestic use. Although the drinking water standards apply only to public water systems, they provide a basis for evaluating the suitability of the sampled ground water for use. There are two types of drinking water standards, primary and secondary. The primary maximum contaminant levels (MCL) are set to protect human health. The secondary maximum contaminant levels (SMCL) are set for aesthetic reasons (such as taste, odor, and color) and do not represent a health threat. Analysis of the water samples from the Bull Mountains aquifer system shows that most ground water contains constituent concentrations in excess of the secondary drinking water standards for sulfate (250 mg/L), and that total dissolved solids (500 mg/L) from all the units were commonly exceeded.

Nitrate is a necessary plant nutrient. However, excessive concentrations in drinking water can pose a human health threat. Elevated concentrations in drinking water can cause methemoglobinemia (or blue baby syndrome), a potentially fatal oxygen deficiency in infants less than six months old. Because of the human health risk, nitrate has an MCL of 10 mg/L. Four samples had nitrate in excess of 10 mg/L.

Fluoride occurs naturally in sedimentary rocks, and is also used as an additive in many municipal water supplies. Three samples exceeded the 4 mg/L MCL for fluoride, and eight samples exceed the 2.0 mg/L SMCL (see summary of water-quality parameters). Fluoride was more commonly detected in wells completed in the Lance and Fox Hills Formations; 9 of the 11 samples that exceeded either the MCL or SMCL were obtained from these formations. The other two samples were from wells in the Fort Union Formation.





Explanation

Dissolved constituent concentrations
- Less than 1,000 mg/L
- 1,000–2,000 mg/L
- 2,000–3,000 mg/L
- Greater than 3,000 mg/L

15960 Sample location and well ID number

1273 Measured sum of dissolved constituents from water sample

1273 Qualified data (italics) derived from specific conductivity value

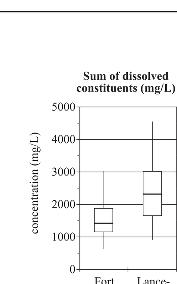
Stiff diagrams showing abundance of common ions

Sample location
Sodium, Calcium, Magnesium — Chloride, Bicarbonate, Sulfate
100 75 50 25 0 25 50 75 100
Cations (meq/L) — Anions (meq/L)

Color of diagram indicates formation:
- Fort Union Formation
- Lance or Fox Hills Formations

meq/L: milliequivalents per liter
mg/L: milligrams per liter

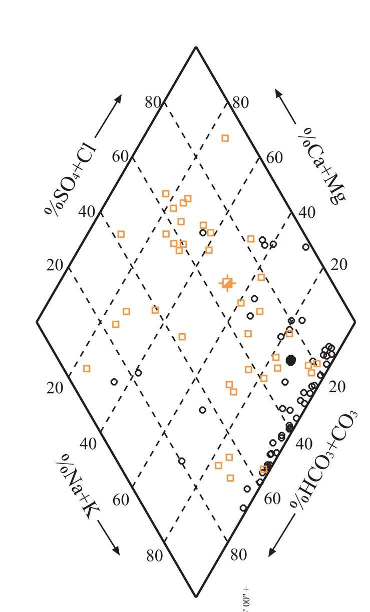
2 1 0 2 4 6 miles
Scale: 1:250,000
Projection: Montana State Plane 1983
Datum: NAD 1983
N



Proportions of common ions

The box plots summarize the distribution of common ions between the two major geologic units in the Bull Mountains aquifer system. The upper and lower edges of the boxes represent the 75th and 25th percentile, and the lines are the 95th and 5th percentile, of the ranges in concentration. The median values are shown by the heavy horizontal lines in the boxes.

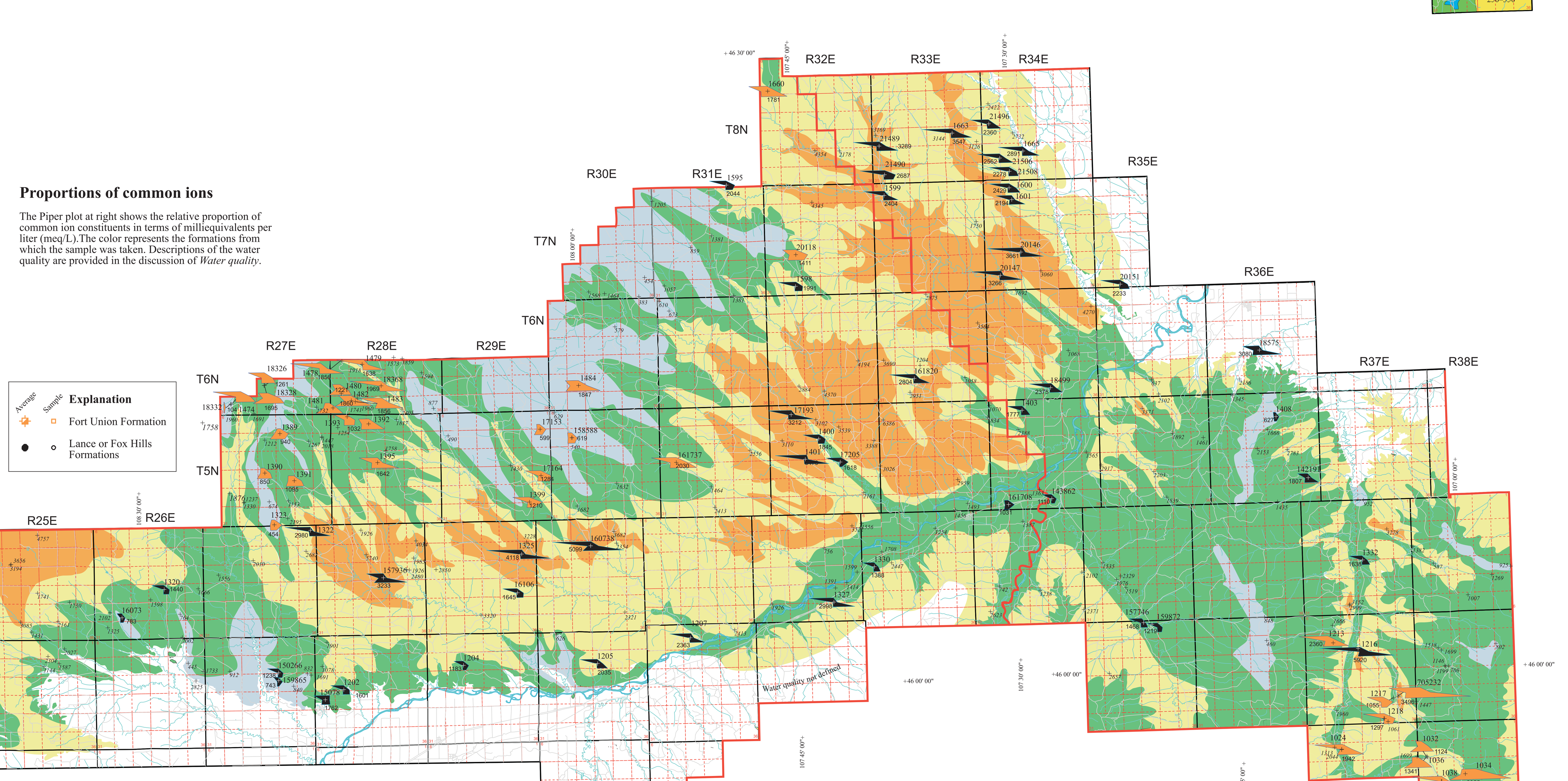
Water quality map



Proportions of common ions

The Piper plot at right shows the relative proportion of common ion constituents in terms of milliequivalents per liter (meq/L). The color represents the formations from which the sample was taken. Descriptions of the water quality are provided in the discussion of *Water quality*.

Explanation
Average / Sample
- Fort Union Formation
- Lance or Fox Hills Formations



Summary of water-quality parameters in the Bull Mountains aquifer system

Parameters	Fort Union Formation: Number of samples	Min	Median	Max	Number of exceedances	Lance and Fox Hills Formations: Number of samples	Min	Median	Max	Number of exceedances	SMCL (s) MCL (m)
pH	38	7.18	8.06	8.75	5	52	7.55	8.405	9.24	21	6.5 - 8.5 (s)
Specific conductance (SC) µS/cm	38	101	1791	6013		52	725.7	2664	9980		-
Sum of dissolved constituents (mg/L)	38	104	1415	6515		52	627	2319	8539		-
Total dissolved solids (mg/L)	38	71	1174	6285	34	52	436	2015	8477	51	500 (s)
Hardness (mg/L as $CaCO_3$)	38	18	422	3674		52	5.49	52.65	2083.73		-
Common ions (mg/L)											
Sodium (Na)	38	5.24	255.95	580		52	75	633.6	2322		-
Potassium (K)	38	1.23	4.7	21.2		52	0.4	2.31	11.6		-
Calcium (Ca)	38	4.4	63.5	361.6		52	1.65	12.15	218		-
Magnesium (Mg)	38	1.6	56.9	673.3		52	0.334	4.65	374		-
Chloride (Cl)	38	0.25	13.05	61	0	52	3.8	34.5	2630	2	250 (s)
Bicarbonate (HCO_3)	38	66.1	446.65	763.7		52	122	495.7	1006.9		-
Carbonate (CO_3)	38	0	0	40.8		52	0	7.2	72		-
Sulfate (SO_4)	38	3.73	590	4394	30	52	53.1	879.15	2841	46	250 (s)
Fluoride (F)	30	0.05	0.2	3.9	2(s)	30	0.1	1.45	5.6	6 (s) 3 (m)	2 (s) 4 (m)
Iron (Fe)	37	0.0015	0.04	1.62	7	52	0.0015	0.025	9.3	5	0.3 (s)
Nitrate (NO_3) mg/L-N	38	0.023	0.35	21.3	2	52	0.01	0.435	32.8	3	10 (m)
Manganese (Mn)	37	0.001	0.022	0.524	11	52	0	0.006	0.22	8	0.05 (s)
Silicate (SiO_4)	38	1.7	9.6	18.3		52	0.5	7.6	18.4		-
Trace elements (µg/L)											
Boron (B)	16	15	50	630.8		38	40	206.7	743		-
Barium (Ba)	13	5.6	24.2	56.8	0	36	3.8	9.35	50.4	0	2000 (m)
Beryllium (Be)	13	25	86	250		0					-
Chromium (Cr)	13	0.25	9	25	0	31	0.25	7	22.1	0	100 (m)
Copper (Cu)	13	1	4.3	21.8	0	34	1.19	10	36.9	0	1300 (m)
Lithium (Li)	16	1.62	35.5	100		46	3	60	148		-
Nickel (Ni)	13	1	4.15	13.9		0					-
Zinc (Zn)	13	1	16.9	498.5	0	34	1	10.05	330	0	5000 (s)

Acknowledgments

Well owners who allowed collection of the data necessary for this map and the people who collected the data are gratefully acknowledged. Reviews by Tom Patton, John Metesh, Ed Deal, Susan Barth, and Luke Buckley are also appreciated.

Data Sources

Geographic features:
Digital coverages of streams and public land-survey grids were obtained from the Montana Natural Resource Information System (NRIS). Geologic coverages were obtained through the Montana Bureau of Mines and Geology's State Map program.

Point Data:
Well location and water-level altitude data were obtained by Ground-Water Characterization Program staff. Measuring-point altitudes were obtained from 1:24,000-scale topographic maps. All point data presented on this map are available through the Ground-Water Information Center (GWIC) at http://mbmggwic.mtech.edu.

References

Dean, W.E., and Arthur, M.A., 1989, Iron-sulfur-carbon relationships in organic-carbon-rich sequences I: Cretaceous western interior seaway: American Journal of Science, v. 289, p. 708–743.

Lee, R.W., 1981, Geochemistry of water in the Fort Union Formation of the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Water-Supply Paper 2076, 17 p.

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

Smith, L.N., LaFave, J.I., Patton, T.W., Rose, J.C., and McKenna, D.P., 2000, Ground-water atlas of the lower Yellowstone River area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties: Montana. Montana Bureau of Mines and Geology Ground-Water Assessment Atlas 1, 44 p.

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

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

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