Montana Bureau of Mines and Geology
A Department of Montana Tech of The University of Montana

Characterization of the Eagle Aquifer in Yellowstone County, Middle Yellowstone River Area, Montana

by John L. Olson and Jon C. Reiten

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 Eagle aquifer) within the area. To obtain a more integrated understanding of the area's hydrogeology, see Part A and the other Part B maps.

Introduction

The Eagle aquifer is an important source of stock and domestic water (see *Well use*, below) in west-central Yellowstone County and provides water to about 660 wells. Most of these wells have been completed where the Eagle crops out north of the city of Billings (see *Distribution of wells*, below). The aquifer also exists east of the map area but is deeply buried and little used.

The Eagle aquifer is comprised of water-saturated sandstone layers in the Eagle Sandstone and the underlying Telegraph Creek Formation. Both of these formations are part of an approximately 4,000-ft-thick sequence of Cretaceous marine sedimentary rocks. The relative positions and thicknesses of the Cretaceous formations in the Middle Yellowstone River Area are shown below (see *Cretaceous stratigraphy*).

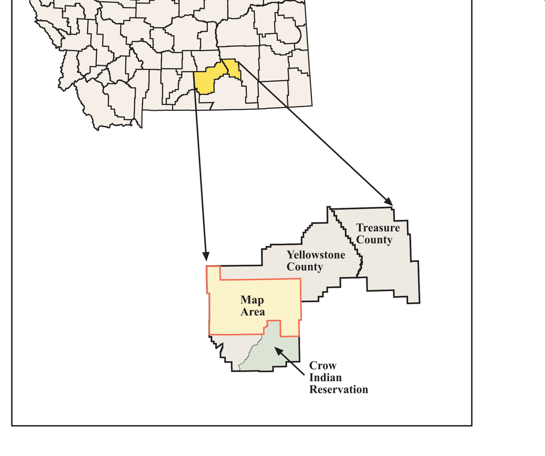
The Eagle Sandstone forms prominent cliffs (the rimrocks) north and east of the city of Billings and crops out along an east- to west-trending, one- to eight-mile-wide band in eastern Yellowstone County. South of the outcrop area, the formation has been removed by erosion. The Eagle Sandstone is 100–350-ft-thick and contains as many as four, 0–50-ft-thick sandstone intervals separated by less permeable sandy-shale layers that can be as much as 50-ft-thick (Lopez, 2000). The sandstone is typically very fin- grained to fine-grained and is light brownish gray to very pale orange. Cross bedding, bioturbation, and calcareous concretions are common.

The Telegraph Creek Formation forms the lower part of the aquifer and consists of 150 ft of thinly interbedded layers of brownish-gray to medium dark gray sandstone and sandy shale (Lopez, 2000). The sandstone layers become thin and less abundant with depth. Dusky-red concretions are common near the base of the formation. The Telegraph Creek Formation is underlain by more than 2,000 ft of low-permeability shale formations of the Colorado Group. These formations generally do not produce ground water of usable quantity or quality. The Eagle Sandstone and Telegraph Creek Formation grade laterally eastward into the Gammon Member of the Pierre Shale, which consists of silty shale (non-aquifer). The transition to the Gammon likely occurs in eastern Yellowstone County.

In the project area there are two primary structural features that influence the occurrence and depth of the Eagle aquifer: the Bull Mountains Basin and the Lake Basin fault zone. The Bull Mountains Basin is a broad regional feature centered just north of Yellowstone County (Dobbin and Erdmann, 1955). All bedrock formations generally dip gently (at 2–4 degrees) towards the basin center. As a result the Eagle aquifer is encountered at depths of greater than 1,000 ft in the northern portion of Yellowstone County (see *Drilling depths map*). A minor domal structure (the Broadview dome) causes the Eagle to be exposed in a small area along its crest southeast of the town of Broadview, Montana. The Lake Basin fault zone consists of a roughly six-mile-wide band of northeast-southwest trending, high-angle faults. Individual faults are generally oriented perpendicular to the regional fold axes. Displacements of as much as 250 ft have been reported (Hancock, 1919). The faults are a significant feature to the aquifer because they offset of sandstone beds, causing restrictions to ground-water flow. However, higher density fracturing near the faults may increase ground-water flow parallel to the faulting.

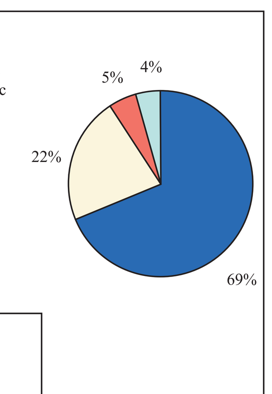
Location map

The Middle Yellowstone River Area consists of Treasure and Yellowstone Counties exclusive of the Crow Indian Reservation. Maps of the Eagle aquifer on this sheet include the portion of the Middle Yellowstone River Area shown below. The map extent was selected to include the areas where the Eagle aquifer is present and is less than 2,000 ft below the ground surface.



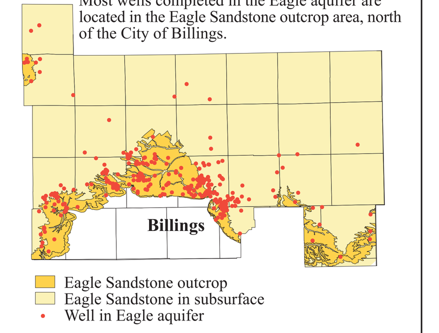
Well use

Most wells in the Eagle aquifer provide domestic water to individual residences and are used for stockwater; a few others are for irrigation and other purposes.



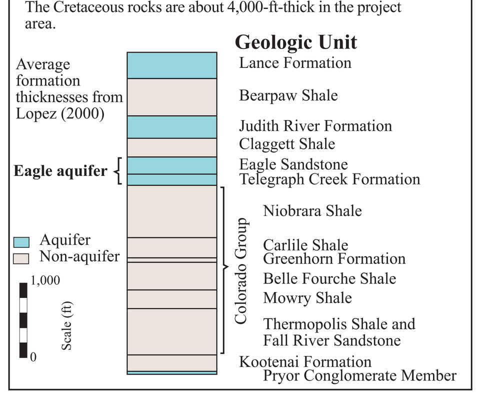
Distribution of wells

Most wells completed in the Eagle aquifer are located in the Eagle Sandstone outcrop area, north of the City of Billings.



Cretaceous stratigraphy

The Cretaceous rocks are about 4,000-ft-thick in the project area.

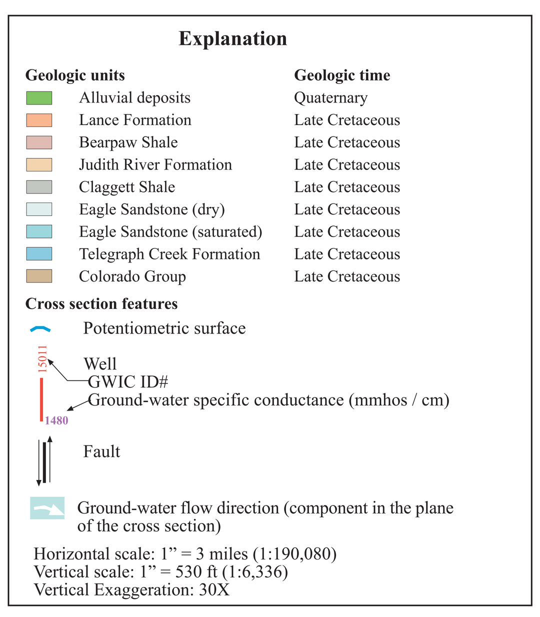


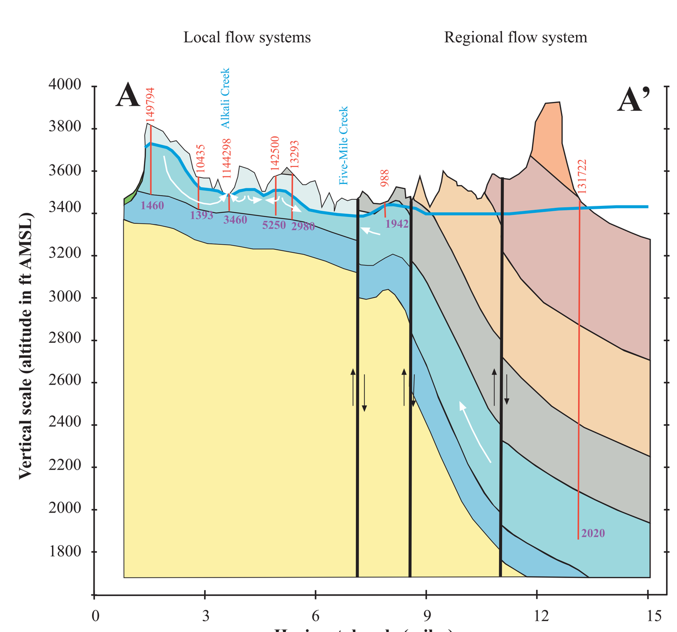
Hydrogeologic cross sections

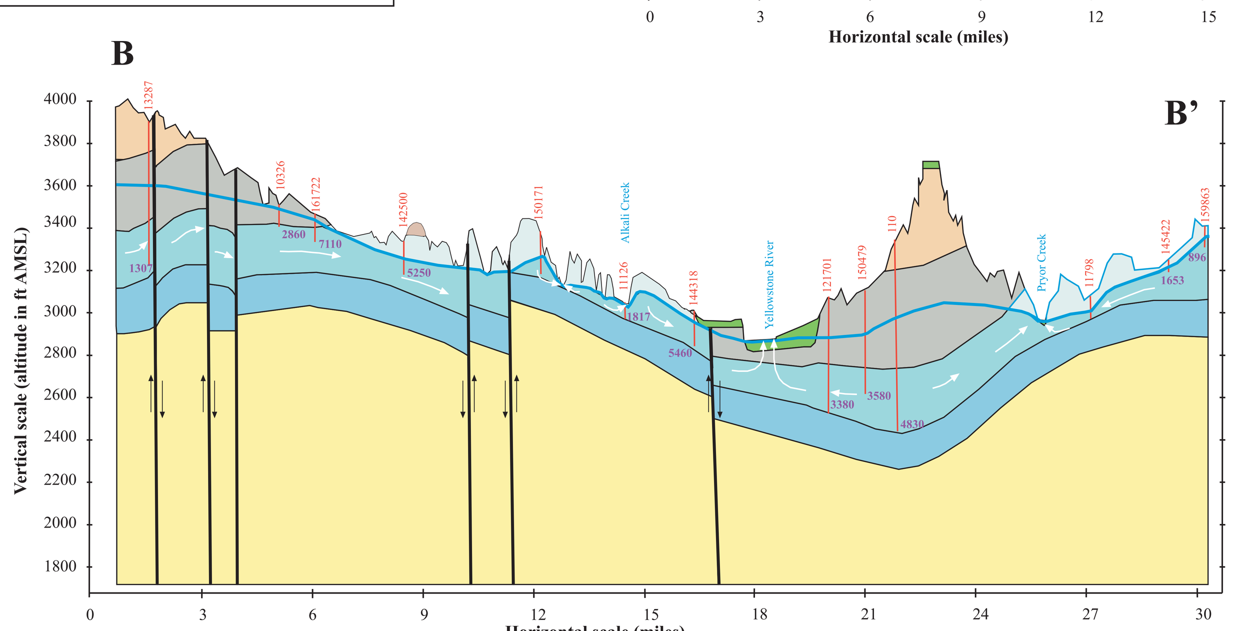
Two cross sections were constructed through the Eagle aquifer along lines A–A' and B–B' which are displayed on the *Drilling depths map*. These cross sections are based on interpretations of water well logs, hydrocarbon well logs, and geologic maps (Lopez, 2000). Locations of visited wells are shown in the cross section. The cross sections show stratigraphic position and thicknesses of relevant formations and show ground-water flow patterns normal to the cross-section plane.

Cross section A–A' is oriented perpendicular to the regional strike and shows the formations dipping northward. The steepest dips occur within the Lake Basin fault zone. North of the fault zone the Eagle aquifer plunges to depths of greater than 1,000 ft. The cross section also shows ground-water upwelling from the regional flow system into the localized flow systems (see discussion on potentiometric surface).

Cross section B–B' is oriented tangential to the regional basin and demonstrates how the faulting can disrupt the continuity of the aquifer. In some places the aquifer can be completely truncated. On a smaller scale the faults also create discontinuities by displacing individual sandstone beds.







Well performance

The well statistics presented below were obtained by evaluating information on driller logs for 147 wells. The percentile indicates the percentage of sample data that are 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 specific capacity of a well is the yield per foot of water-level drawdown and is calculated by dividing the drawdown by the pumping rate. Specific capacity is a measure of the productivity of a well; the larger the value the better the well. The specific capacity of most Eagle aquifer wells is relatively low (see below). Consequently, large drawdowns may be required to obtain a sufficient yield. About 50% of reported test yields for the aquifer were between 5–16 gpm and are typically adequate for most domestic and stockwater use, but insufficient for irrigation, industrial, or municipal uses.

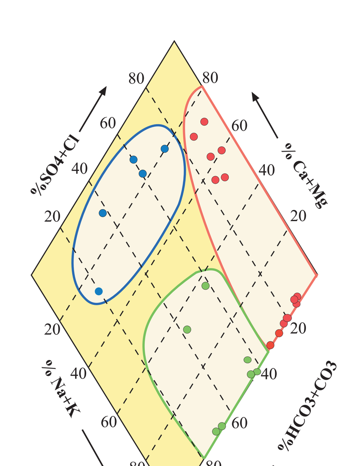
However, there appears to be the potential for high yield wells in the Lake Basin fault zone. A well located in T03N R23E Section 6 has a measured yield of 825 gpm, and a well located at T01N R25E Section 15 has a reported yield of 100 gpm. Both of these sites are within the fault zone. Data are presently too limited to understand the relationship between high yields and the fault zone. However, it may be related to increased fracturing in these areas.

Eagle aquifer well statistics

Population percentile	Specific capacity (gpm/ft)	Reported yield (gpm)	Perforated thickness (ft)	Total depth (ft)
95%	3.00	34	140	690
75%	0.48	16	60	290
50%	**0.13**	**10**	**40**	**190**
25%	0.04	5	20	130
5%	0.01	1	10	80

Piper plot of water quality

A Piper plot (right) shows the relative proportions of common ions in terms of percent milliequivalents per liter (meq/L). This plot is useful to show general grouping of water-quality compositions. Three types of water have been identified in the Eagle aquifer. The settings and the processes forming these waters are described in *Distribution of dissolved constituents*. Type 1 (blue dots) range from a Ca-Mg-HCO_3–Ca-Mg-SO_4 water with sums of dissolved constituents of between 500 mg/L and 2,000 mg/L. Type 2 (green dots) consists of a Na-HCO_3 water with sums of dissolved constituents between 1,000 mg/L and 4,000 mg/L. Type 3 (red dots) is a highly mineralized Na-SO_4 or a Na-Ca-Mg-SO_4 water with sums of dissolved constituents between 3,000 mg/L and more than 7,000 mg/L.



Concentrations of dissolved constituents

The range and average concentration of dissolved constituents in ground water from the Eagle aquifer are presented in the table below. The highest concentration of fluoride exceeded the maximum contaminant levels (MCL) for public drinking water supplies. Maximum concentrations of chloride, sodium, sulfate, iron, and manganese exceed secondary maximum contaminant levels (SMCL) for public drinking water supplies. Parameters that exceed the MCL may need treatment to prevent adverse effects on human health. Parameters that exceed the SMCL will cause aesthetic or other problems but are not generally health threats.

Summary of water-quality parameters in the Eagle aquifer

Common ion constituents (mg/L)	# of Samples	Min	Max	Average	MCL	SMCL
Bicarbonate (HCO_3)	30	54	1,622	599	-	-
Calcium (Ca)	30	1.8	570	104	-	-
Carbonate (CO_3)	30	<1	133	16	-	-
Chloride (Cl)	30	6.8	7,750	369	-	250
Fluoride (F)	10	0.2	4.8	1.93	4	-
Iron (Fe)	28	<0.003	2.5	0.48	-	0.3
Magnesium (Mg)	30	<0.01	477	72	-	-
Manganese (Mn)	23	<0.001	24	1.06	-	0.05
Nitrate +Nitrite (as N)	32	<0.25	9.8	1.97	10	-
Orthophosphate (as PO_4)	15	0.05	0.5	0.1	-	-
Potassium (K)	22	0.7	9.8	3	-	-
Sodium (Na)	24	26.7	5,226	881	-	250
Silicate (SiO_4)	28	7.4	23	12	-	-
Sulfate (SO_4)	30	1.6	4,564	1228	-	250
Other parameters						
pH	50	6.8	9.2	8.0	-	6.5–8.5
Specific conductance (mmhos/cm)	50	690	7,400	3,270	-	-
Water temperature (ºC)	40	8.6	21.9	13.3	-	-
*Sum of constituents (mg/L)	24	560	9,860	3,280	-	-
*Total dissolved solids (mg/L)	24	390	7,500	2,950	-	500

Trace elements (mg/L)	# of Samples	Min	Max	Average	MCL	SMCL
Aluminum (Al)	13	-	<30	14	-	200
Antimony (Sb)	13	<2	4.1	-	6	-
Arsenic (As)	13	<1	11.5	3	50	-
Barium (Ba)	16	5.7	330	52	2,000	-
Beryllium (Be)	13	-	<2	-	4	-
Boron (B)	17	<80	18,500	1776.3	-	-
Bromide (Br)	15	45	600	228	-	-
Cadmium (Cd)	13	-	<2	-	5	-
Chromium (Cr)	13	4.45	47.6	16	100	-
Cobalt (Co)	13	-	<2	-	-	1300
Copper (Cu)	13	2.4	28.8	8	1,300	-
Lead (Pb)	13	<2	3	1	15	-
Lithium (Li)	20	19	1,400	142	-	-
Molybdenum (Mo)	13	-	<10	-	-	-
Nickel (Ni)	13	<2	34.8	3	-	-
Selenium (Se)	19	<0.1	25	4	50	-
Silver (Ag)	13	-	<2	-	-	100
Strontium (Sr)	16	218	7,030	2680	-	-
Tin (Sn)	32	-	<10	-	-	-
Titanium (Ti)	13	-	<10	-	-	-
Vanadium (V)	13	<5	12.3	4	-	-
Zinc (Zn)	13	<2	201.3	0.3	-	5,000
Zirconium (Zr)	13	-	<20	-	-	-

Explanation:
MCL = Maximum Contaminant Level
SMCL = Secondary Maximum Contaminant Level
mmhos/cm = micromhos per centimeter
mg/L = milligrams per liter
mg/L = micrograms per liter
ºC = degree Celsius

*Total dissolved solids (TDS) is the quantity of solid residue left in a sample after evaporation. Sum of dissolved constituents is the sum of all common ion concentrations. TDS concentrations are typically less than the sum of dissolved constituents because of the off-gassing of carbonate species during evaporation.

Conclusions

The Eagle aquifer is an important source of domestic water and stockwater in an east-west trending band immediately north of the city of Billings in Yellowstone County. The aquifer is underlain by a thick sequence of non-aquifer shale (the Colorado Group), and so in many cases is the sole source of ground water. It is relatively accessible (less than 300 ft deep) in areas near the outcrop. However, the aquifer plunges to depths greater than 1,000 ft north of the Lake Basin fault zone.

Water quality in most of the aquifer is marginal for many uses and may require some treatment. In areas downgradient or overlain by the Claggett Shale the aquifer contains highly mineralized water that is not suitable for most uses. Well yields in the Eagle aquifer are generally acceptable for single-dwelling domestic use or stock wells, but insufficient for most irrigation, industrial, or municipal uses. However, there appears to be a potential for high-yield wells near the Lake Basin fault zone. Additional data will be needed to better understand the apparent relationship between the fault zone and the yields of wells.

Acknowledgements

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, Larry Smith, and Wayne Van Voast are also appreciated.

Data sources

Geographic Features:
The following digital base map coverages were downloaded from the National Resource Information System (NRIS):
Land survey lines from BLM maps, scale 1:100,000, updated 1993
TIGER redistricting 2,000 data, scale 1:1,000,000, updated 2001
County boundaries
Water polygons
Hydrography lines
Road lines
Point data:
Well-location and water-level altitude data were obtained by Ground-Water Characterization Program staff. Measuring-point altitudes were obtained from 1:24000-scale topographic quadrangle 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 : Cretaceous western interior seaway: American Journal of Science, v. 289, p. 708–743.

Dobbin, C.E., and Erdmann, C.E., 1955, Structure contour map of the Montana Plains: U.S. Geological Survey Oil and Gas Investigations Map OM-178A, scale 1:500,000.

Hancock, E.T., 1919, Geology and oil and gas prospects of the Lake Basin field, Montana: U.S. Geological Survey Bulletin 691-D, p. 101–147, scale 1:125,000.

Lopez, D.A, 2000, Geologic map of the Billings 30'x60' quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 59, scale 1:100,000.

Potentiometric surface

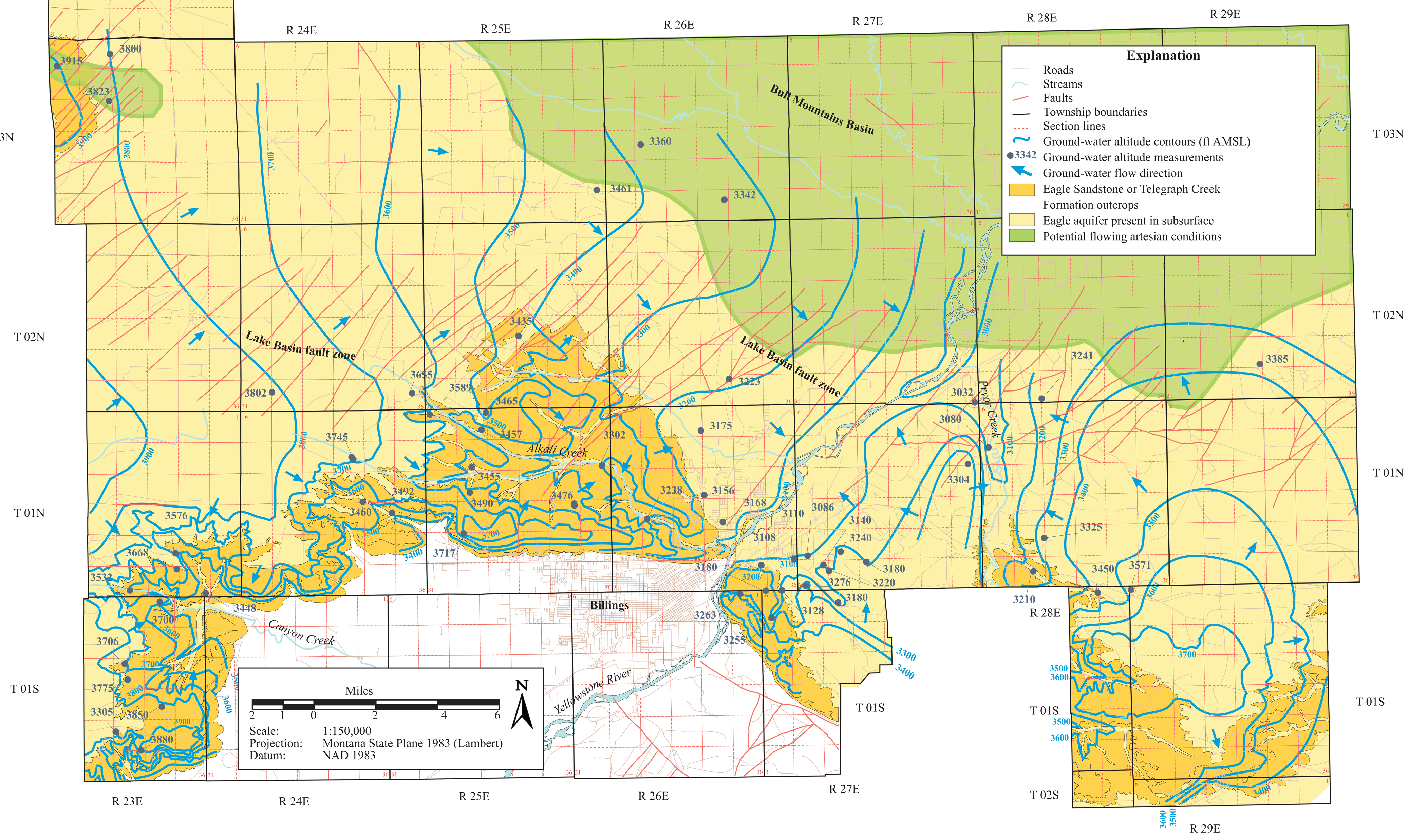
The potentiometric surface of the Eagle aquifer (below) was constructed from static water altitudes measured from 65 inventoried wells (data shown on map below). Reported water levels in non-inventoried wells were also used to qualitatively assist in contouring ground-water altitudes. This map shows the altitude to which ground water in a well will rise and indicates the direction of ground-water flow in the aquifer. Areas where the ground water may potentially rise above the surface (free-flowing) are highlighted. Ground-water flow is perpendicular to the potentiometric contours and flows from the highest to the lowest potentiometric altitude (see flow arrows on map below).

The potentiometric data demonstrates two types of ground-water flow systems in the aquifer: local systems and a regional system.

The local systems occur near outcrops of the Eagle Sandstone or Telegraph Creek Formation. In these areas, recharge is received from local precipitation infiltrating through the outcrops. Ground-water flow paths in the local systems are relatively short and roughly follow topography to the nearest streams, springs, or seeps. Perennial streams crossing the outcrop area include: the Yellowstone River, Pryor Creek, Canyon Creek, and Alkali Creek. Gradients in the local systems are generally steep, ranging from 0.02–0.1 ft/ft.

The regional flow system occurs where the aquifer is deeply buried. Recharge to this flow system is from precipitation occurring over aquifer outcrops many miles away. Ground-water flow in the regional system is generally directed from the distant outcrops toward the Yellowstone River or Pryor Creek. Discharges to these streams occur even where the Eagle aquifer is greater than 1,000 ft below the surface. Some of the regional flow upwells into the local system along down-dip contacts of the aquifer outcrop.

Displacement along the Lake Basin fault zone likely restricts ground-water flow across the faults. In the western portion of the map area the faults act to direct ground-water flow parallel to the faults. Near the Yellowstone River, regional ground-water flow is across the faults but at a steeper gradient (0.01 ft/ft) than in non-faulted areas (0.005 ft/ft).

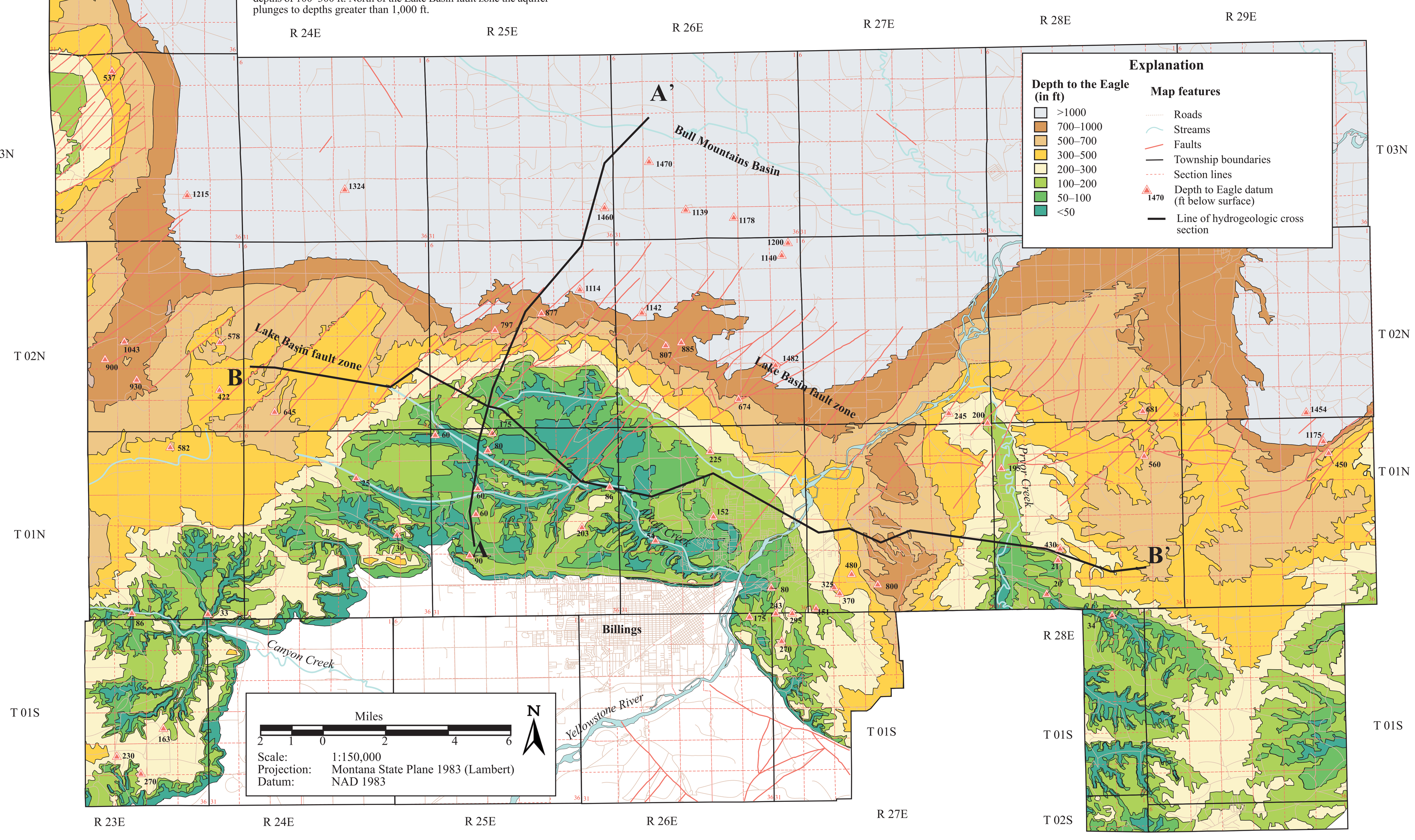


Drilling depths

The purpose of this map is to indicate the likely depth a well must be drilled to reach the top of the Eagle aquifer. A well must also be drilled to an additional depth to penetrate the aquifer. Typically wells in the area penetrate the Eagle by between 10 and 140 ft (see *Well performance*).

In general, wells located in stream valleys and draws within the outcrop area can be completed at depths of less than 100 ft. On ridges and uplands in the outcrop area wells must be completed at depths of 100–300 ft. North of the Lake Basin fault zone the aquifer plunges to depths greater than 1,000 ft.

This map was developed from water-well and hydrocarbon-well construction and lithology data. From these data, an intermediate map showing the altitude of the top of the Eagle aquifer was created. The depth to the Eagle aquifer was calculated by subtracting the intermediate map altitudes from a USGS digital elevation model (DEM) of the land surface. In the aquifer's outcrop area, the top of the aquifer is defined as the depth ground water is encountered. Otherwise, the top of the aquifer is defined as the top of the Eagle Sandstone.



Distribution of dissolved constituents

The map below shows the water quality that will likely be encountered in the Eagle aquifer at a given location. The map displays the distribution of the sum of dissolved constituents (Ca + Mg + Na + K + HCO_3, + SO_4, + Cl; numeric values) and the relative concentrations in milliequivalents per liter (meq/L) of individual constituents (Stiff diagrams). This map was developed from all available water-quality data collected from the Eagle aquifer in the project area.

Typically water does not become too salty to drink until the sum of dissolved constituents exceeds about 2,000 milligrams per liter (mg/L), and is unsuitable for most uses above concentrations of 3,000 mg/L. The ranges and averages of individual dissolved constituents and appropriate health-based concentration limits are provided in the *Summary of water-quality parameters* (to the left).

Dissolved constituents in ground water are a result of the initial chemistry of the recharge water and subsequent interactions of that water with soils and aquifer materials. Three water-quality types have been identified in the Eagle aquifer based on composition, sum of dissolved constituents, and the ground-water setting. A Piper plot (to the left) shows the composition of the waters in each group. Type 1 (shown in blue) is characterized by relatively low concentrations of dissolved constituents (500–2,000 mg/L) and a relatively low proportion of sodium. This water is relatively young (near its recharge source) and is found in local flow systems where they are isolated from the regional system. The dissolved constituents are derived from soil and rock interactions as precipitation infiltrates through outcrops of Eagle Sandstone.

Type 2 water (shown in green) has higher concentrations of dissolved constituents (from 1,000–4,000 mg/L) than does Type 1 water and the dominant ions are sodium and bicarbonate. This water is relatively old (far from its recharge source) and is found in the regional flow system. During its time in the aquifer, most of its original sulfate concentration has been removed by sulfate reduction. This is a biochemical reaction that converts sulfate to insoluble metal sulfides and oxidizes aquifer organic material to bicarbonate. Also during its long transport time, the water reacts with sodium-rich clays within the aquifer. Calcium and magnesium in the water are exchanged (via cation exchange) for sodium from the clay. Type 3 water (shown in red) is highly mineralized (dissolved constituent concentrations between 3,000 mg/L and more than 7,000 mg/L) and the dominant ions are sulfate and often sodium. This water occurs in the Eagle aquifer where the overlying Claggett Shale is exposed at the surface. Because of its relationship with Claggett Shale outcrops, it is likely that recharge through the shale accumulates sulfate and other dissolved constituents which mixes with either Type 1 or Type 2 waters. Marine shale strata such as the Claggett Shale contain abundant pyrite (iron sulfide; Dean and Arthur, 1989) that releases sulfuric acid (sulfate) when oxidized. Reaction of sulfuric acid with other minerals (primarily carbonates) enriches the water with calcium and magnesium. As in the case of Type 2 waters, sodium replaces other cations via cation exchange. There are insufficient data to evaluate vertical variation of Type 3 water in the aquifer. However, if the source of the increased dissolved constituents is from the overlying Claggett Shale (as appears likely), then water quality should improve with depth in the Eagle aquifer.