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

Montana Ground-Water Assessment Atlas No. 1, Part B, Map 10
October 1998
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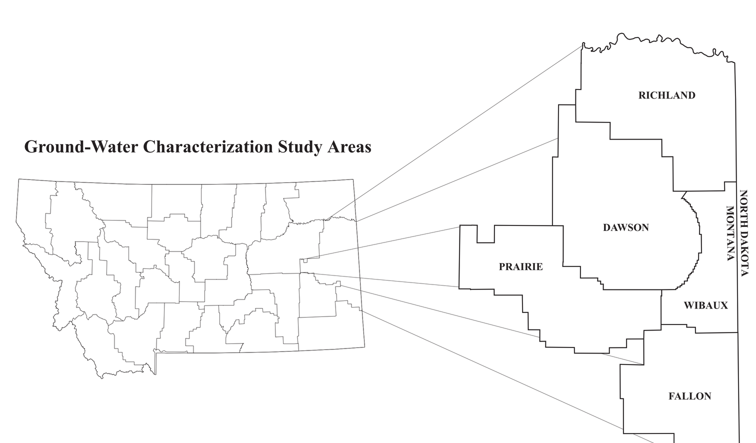


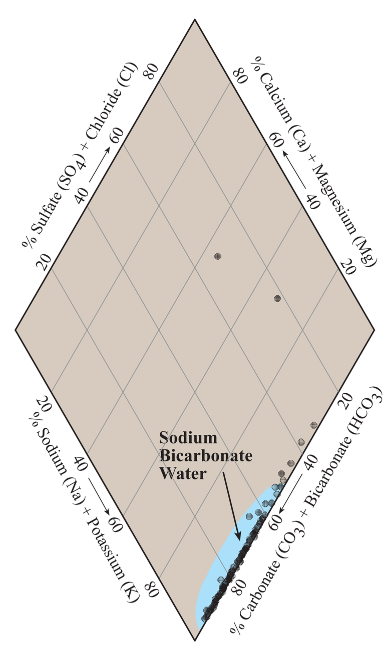


Figure 1. The water chemistry in the Fox Hills–lower Hell Creek aquifer is uniform, consisting predominantly of sodium and bicarbonate with sulfate in places; there is little calcium, magnesium, or chloride. The two outliers are from shallow wells in the outcrop area.

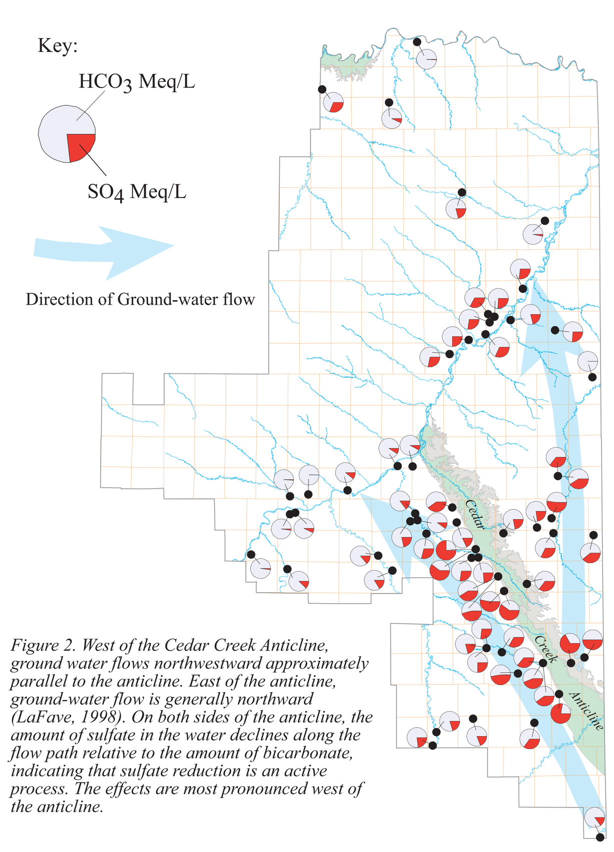
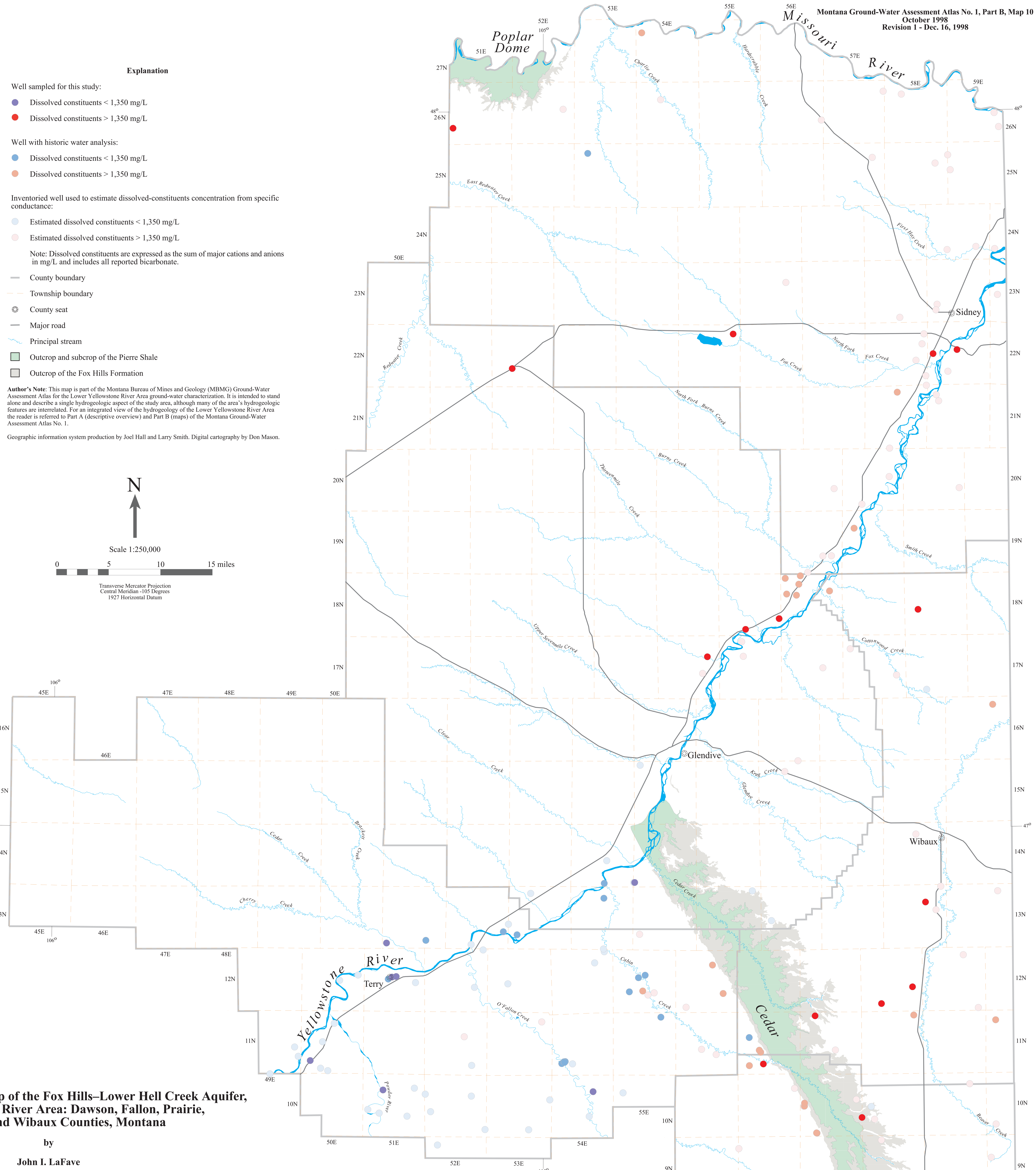


Figure 2. West of the Cedar Creek Anticline, ground water flows northwestward approximately parallel to the anticline. East of the anticline, ground-water flow is generally northward (LaFave, 1998). On both sides of the anticline, the amount of sulfate in the water declines along the flow path relative to the amount of bicarbonate, indicating that sulfate reduction is an active process. The effects are most pronounced west of the anticline.



Explanation

Well sampled for this study:

- Dissolved constituents < 1,350 mg/L
- Dissolved constituents > 1,350 mg/L

Well with historic water analysis:

- Dissolved constituents < 1,350 mg/L
- Dissolved constituents > 1,350 mg/L

Inventoried well used to estimate dissolved-constituents concentration from specific conductance:

- Estimated dissolved constituents < 1,350 mg/L
- Estimated dissolved constituents > 1,350 mg/L

Note: Dissolved constituents are expressed as the sum of major cations and anions in mg/L and includes all reported bicarbonate.

- County boundary
- Township boundary
- County seat
- Major road
- Principal stream
- Outcrop and subcrop of the Pierre Shale
- Outcrop of the Fox Hills Formation

Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground-Water Assessment Atlas for the Lower Yellowstone River Area ground-water characterization. It is intended to stand alone and describe a single hydrogeologic aspect of the study area, although many of the area's hydrogeologic features are interrelated. For an integrated view of the hydrogeology of the Lower Yellowstone River Area the reader is referred to Part A (descriptive overview) and Part B (maps) of the Montana Ground-Water Assessment Atlas No. 1.

Geographic information system production by Joel Hall and Larry Smith. Digital cartography by Don Mason.

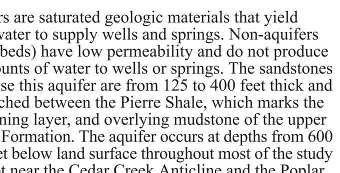
Dissolved Constituents* Map of the Fox Hills–Lower Hell Creek Aquifer, Lower Yellowstone River Area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties, Montana

by

John I. LaFave

Introduction

The purpose of this map is to show the distribution of dissolved constituents in the Fox Hills–lower Hell Creek aquifer. This aquifer consists of near-continuous sandstone deposits found in the lower part of the Hell Creek Formation and most of the Fox Hills Formation.



Aquifers are saturated geologic materials that yield sufficient water to supply wells and springs. Non-aquifers (confining beds) have low permeability and do not produce usable amounts of water to wells or springs. The sandstones that compose this aquifer are from 125 to 400 feet thick and are sandwiched between the Pierre Shale, which marks the basal confining layer, and overlying mudstone of the upper Hell Creek Formation. The aquifer occurs at depths from 600 to 1,600 feet below land surface throughout most of the study area, except near the Cedar Creek Anticline and the Poplar Dome (Smith 1997). Typically, the water level in wells completed in the aquifer will rise above the top of the aquifer because of artesian pressure, and in low-altitude areas—such as the Yellowstone River valley—flowing wells are common.

The Fox Hills–lower Hell Creek aquifer is the deepest and most dependable potable-water aquifer in the five-county Lower Yellowstone River Area. About 1,000 wells (roughly 10% of the total) are completed in the aquifer. Most of the wells are in the Yellowstone River valley and south of the river. There are few wells north of the river because the aquifer is more than 1,000 feet below land surface (Smith 1997), and water levels are lower; thus well drilling costs and pumping costs are higher. Water from the aquifer is used primarily for domestic- and stock-water purposes; however, the towns of Baker, Lambert, and Richey rely on it for municipal water supply. Reported well yields average less than 15 gallons per minute (gpm), but individual wells may yield as much as 100 gpm.

Sample Sites and Water-Quality Data

Three sets of data on dissolved constituents in ground water are presented on the map: laboratory analyses obtained as part of this study, laboratory analyses from earlier studies, and values estimated from field data. Ground water from 28 domestic, stock, municipal and monitoring wells was analyzed for major ions, and trace metals between November 1994 and October 1995. Field measurements of specific conductance, pH, and water temperature also were obtained from each of the sampled wells. To ensure acquisition of a representative sample, each well was pumped prior to sample collection until the field parameters stabilized and at least three well-casing volumes were removed. Analyses were performed by the Montana Bureau of Mines and Geology's (MBMG) Analytical Laboratory. In addition to the samples collected for this study, 55 ground-water samples collected by the MBMG or the U.S. Geological Survey prior to this study also were used. These laboratory data were supplemented by estimated dissolved-constituents concentrations derived from field measurements of specific conductance from an additional 161 inventoried wells. The laboratory analyses and field measurements presented on this map are available from the Montana Ground-Water Information Center data base.

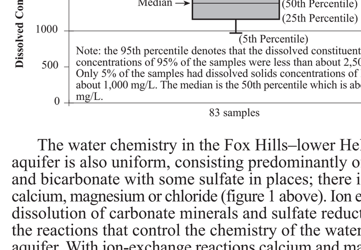
Ground-Water Quality

Dissolved Constituents

Water may be characterized by the type and concentration of its dissolved constituents. The dissolved constituents value is the sum of the major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO_3, CO_3, SO_4, Cl, SiO_3, NO_3, F) expressed in milligrams per liter (mg/L). This map shows the general distribution of dissolved constituents in the Fox Hills–lower Hell Creek aquifer based on chemical analyses of ground-water samples and field measurements of specific conductance.

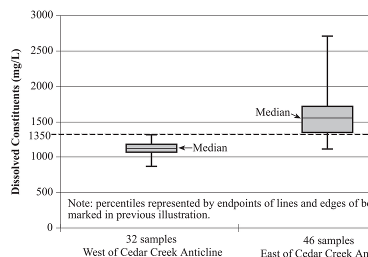
The concentration of dissolved constituents provides a general indicator of water quality. Typically, water does not become too salty to drink until the concentration of dissolved constituents reaches about 2,000 mg/L. Most ground water in the Lower Yellowstone River Area has relatively high concentrations of dissolved constituents; of the 83 ground-water analyses used in this study the average was about 1,500 mg/L.

The concentration of dissolved constituents in ground water is a result of the initial chemistry of the recharge water and the subsequent interactions with soils and aquifer materials. As water moves through an aquifer, from areas of recharge to areas of discharge, the concentration of dissolved constituents generally increases. Additionally, the type of constituents (cations and anions) dissolved in the ground water will be controlled by the length of time that the water has been in the subsurface, the composition of the aquifer materials, and the controlling geochemical reactions (primarily dissolution, precipitation, oxidation reduction, and ion exchange). Water in the Fox Hills–lower Hell Creek aquifer is mineralized (has high amounts of dissolved constituents), but the range in the concentration of dissolved constituents is small; in the 83 samples used for this study the concentration of dissolved constituents ranged from about 1,000 to 2,500 mg/L.



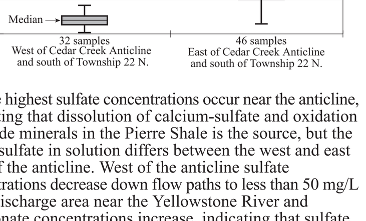
The water chemistry in the Fox Hills–lower Hell Creek aquifer is also uniform, consisting predominantly of sodium and bicarbonate with some sulfate in places; there is little calcium, magnesium or chloride (figure 1 above). Ion exchange, dissolution of carbonate minerals and sulfate reduction are the reactions that control the chemistry of the water in the aquifer. With ion-exchange reactions calcium and magnesium are removed from solution and exchanged for sodium. The removal of calcium from solution keeps the water under saturated with respect to carbonate minerals ($CaCO_3$) present in the Fox Hills Formation—allowing them to continue to be dissolved. Dissolution of these minerals brings more bicarbonate into solution. In places, bacterial reduction decreases sulfate concentrations in ground water to negligible amounts and also increases the amount of bicarbonate in solution. These reactions have been documented in other parts of the Fox Hills–lower Hell Creek aquifer (Henderson 1985; Groenewold *et al*. 1979; Thorstenson *et al*. 1979).

A dissolved-constituents concentration of 1,350 mg/L was used to differentiate between low-dissolved constituents (blue symbols) and high-dissolved constituents (red symbols) water. This value was chosen because it shows the influence of the Cedar Creek Anticline on water quality in the aquifer. In general, the anticline separates areas of high-dissolved constituents from low-dissolved constituents. High concentrations of dissolved constituents (> 1,350 mg/L) occur near and east of the anticline. West of the anticline concentrations are generally less than 1,350 mg/L.



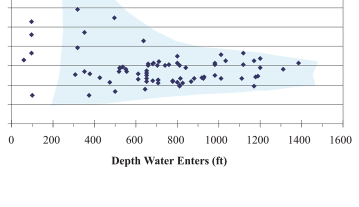
The Pierre Shale is exposed along the axis of the anticline; elsewhere it is overlain by the Fox Hills–lower Hell Creek aquifer. Dips on the western side of the anticline are steep, up to 850 feet/mile, resulting in surface exposures of the aquifer only about one mile wide (Smith 1997). Dips on the eastern flank are more gentle, about 70 feet/mile, resulting in exposures of the aquifer of about 6 to 10 miles wide. A map of the potentiometric surface (LaFave 1998) shows that the wider exposures result in more recharge to the aquifer along the east side of the anticline; there is little recharge along the west side of the anticline. There is a halo of poor-quality water around the Cedar Creek Anticline where the aquifer and Pierre Shale are exposed at the surface. The high concentrations of dissolved constituents west of the anticline, proximal to the outcrop, and east of the anticline where the aquifer dips more gently into the subsurface suggest that the Pierre Shale is the source of the poor water.

Although the overall chemistry of water in the Fox Hills–lower Hell Creek aquifer is uniform, there are noticeable differences in the sulfate concentrations on either side of the anticline.



The highest sulfate concentrations occur near the anticline, suggesting that dissolution of calcium-sulfate and oxidation of sulfide minerals in the Pierre Shale is the source, but the fate of sulfate in solution differs between the west and east sides of the anticline. West of the anticline sulfate concentrations decrease down flow paths to less than 50 mg/L at the discharge area near the Yellowstone River and bicarbonate concentrations increase, indicating that sulfate reduction is an active process (figure 2). East of the anticline the effects of sulfate reduction are not as pronounced; sulfate concentrations decrease down flow paths but generally remain greater than 200 mg/L. Therefore, the Cedar Creek Anticline not only separates the ground-water flow but also influences the quality of water in the aquifer.

Across the study area, most of the variability in the concentration of dissolved constituents occurs where the aquifer is within about 600 feet of the land surface. At greater depths dissolved constituents range from about 1,000 to 1,700 mg/L.



Major Ions and Suitability for Water Use

Table 1 summarizes the results of 28 ground-water analyses performed as part of this study. For reference, the U.S. Environmental Protection Agency's recommended maximum contaminant levels and secondary maximum contaminant levels for public water supplies are also presented. Constituents for which maximum levels have been set may pose a health threat at elevated concentrations. Secondary levels are set for aesthetic reasons—elevated concentrations of these constituents may be a nuisance (bad taste or odor, or staining) but do not normally pose a health risk.

Despite the relatively high concentrations of dissolved constituents (average = 1,500 mg/L), ground water from the Fox Hills–lower Hell Creek aquifer is generally suitable for domestic and stock consumption. Recommended maximum levels for fluoride were exceed in two samples, and nuisance levels of total dissolved solids, sulfate, sodium, iron and manganese were present in some samples.

Fluoride concentrations ranged from non-detectable (4 samples) to 4.7 mg/L; the maximum contaminant level of 4.0 mg/L was exceeded in 2 of the samples. Small amounts of fluoride (usually less than 2.5 mg/L) in drinking water are beneficial, and it is added to many water supplies in the United States. However, chronic exposure to high concentrations of fluoride may cause mottling of tooth enamel or skeletal damage (Driscoll 1986).

Sulfate is a natural constituent in eastern Montana ground water. Dissolved sulfate is derived from the oxidation of pyrite in shales and coal, and the dissolution of gypsum ($CaSO_4$). Excessive sulfate can produce a laxative effect and, in combination with other ions, give water a bitter taste. Water from aquifers with high sulfate concentrations may also have a "rotten egg" smell because of hydrogen sulfide (H_2S) gas that is formed by the bacterial reduction of sulfate in ground water. Hydrogen sulfide can corrode iron and steel and form ferrous sulfide or "black water."

High concentrations of sodium may give water a salty taste, but for most other domestic purposes has little effect on the water use. Ion exchange reactions within aquifers are an important source of sodium in eastern Montana ground water. Clays interbedded in the aquifer material act as a natural water softener, removing calcium and magnesium from solution and exchanging it for sodium. Commonly, elevated concentrations of sodium are associated with low concentrations of calcium and magnesium. Sodium salts may cause foaming in boilers and high sodium concentrations may limit use of water for irrigation by destroying soil structures and impairing plant growth. The sodium hazard for irrigation is measured by the sodium-adsorption ratio (SAR), which indicates the abundance of sodium relative to calcium and magnesium and provides an indication of the suitability of water for irrigation use. High SAR values show a greater abundance of sodium relative to calcium and magnesium and indicate that the water may present a sodium hazard to soils. SAR values below 10 are desirable for irrigation waters. The results from the 28 samples analyzed as part of this study suggest that water from the Fox Hills-lower Hell Creek aquifer is unsuited for irrigation. The average SAR value was 68; only one of the samples was less than 10.

Iron and manganese are essential to plants and animals but may cause unpleasant taste, odors, and staining of plumbing fixtures. The primary source of iron and manganese in ground water is dissolution of minerals in the bedrock. Iron concentrations in well water may also be elevated (increased) by corrosion of iron well casings and from bacterial activity in and around the well screen. Two samples had iron concentrations above the secondary level of 0.3 mg/L, and three samples had manganese concentrations above the secondary level of 0.05 mg/L.

Map Construction

This map was constructed by classifying concentrations of dissolved constituents of ground-water samples into low or high groupings. A concentration of 1,350 mg/L was used to differentiate between low- and high-dissolved constituents water to show the influence of the Cedar Creek Anticline on the water quality. Three data sets are plotted on the map. More than 80 wells are shown from which samples were collected for laboratory analysis. Of these, 28 were sampled as part of this study between November 1994 and October 1995 and represent the primary data set; 55 wells sampled between 1947 and 1985 (32 were sampled since 1976) represent the historic data set. These analytical data were supplemented by estimates of dissolved constituent concentrations derived from specific-conductance measurements made at an additional 161 wells during the current study. These estimated values represent the inventory data set. The specific conductance (SC) measurements were used to estimate dissolved constituents (DS) according to the equation: $DS = A \times SC$. A plot of dissolved constituents against specific conductance shows a well-defined relationship for ground-water samples from the Lower Yellowstone River Area. The data set closely fits a straight-line regression ($r^2 = 0.92$) when the value of A in the above equation is equal to 0.90 (Smith *et al*. in preparation). Therefore, field specific-conductance measurements were multiplied by 0.90 to estimate the dissolved-constituents concentrations in water from wells that were not sampled for laboratory analysis.

Well locations visited during the current study are accurate to the 2.5-acre level.

Acknowledgements

Well owners who allowed collection of the data necessary for this map, and those who collected the data are all gratefully acknowledged. Reviews of this report by Wayne Van Voast, Jon Reiten, and Bob Bergantino improved its clarity.

Data Sources

Geographic features:

Population center locations and roads are from 1:100,000-scale USGS Digital Line Graph files available from the Natural Resources Information System (NRIS) at the Montana State Library, Helena, Montana. Hydrography has been simplified from the 1:100,000 Digital Line Graph files. Township boundaries are from 1:250,000-scale USGS mapping and are available from NRIS.

Point data:

Well locations and water-level altitudes were obtained by Ground-Water Characterization Program personnel, the altitude of each of the points was determined from U.S. Geological Survey 7.5-min. quadrangle maps. All point data used on this map are available from the Ground-Water Information Center (GWIC) at the Montana Bureau of Mines and Geology, Montana Tech of The University of Montana, Butte.

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*Author's Note: Dissolved constituents differ slightly from total dissolved solids (TDS). The dissolved constituents value is the sum of the major cations (Na, Ca, K, Mg, Mn, Fe) and anions (HCO_3, CO_3, SO_4, Cl, SiO_3, NO_3, F) expressed in milligram per liter (mg/L). TDS is traditionally measured by weighing residue remaining after evaporating a known volume of water, or estimated by summing the major ions after multiplying the bicarbonate (HCO_3) concentration by 0.49 to account for loss to the atmosphere during evaporation. For example, about half of the bicarbonate (HCO_3) in solution is converted to carbon dioxide during evaporation; the carbon dioxide escapes to the atmosphere and does not appear in the dissolved-solids residue. Therefore, TDS calculations generally underestimate the total dissolved-ion concentration in solution especially where bicarbonate concentrations are high. A more accurate measure of dissolved constituents is obtained by summing the concentrations reported for the various dissolved constituents.

Table 1. Summary of water-quality data for wells sampled during this study in the Fox Hills–lower Hell Creek aquifer. Nuisance levels of total dissolved solids, sodium, sulfate, iron, and manganese were present in some samples. The recommended maximum level for fluoride was exceeded in 2 samples.

Common Constituents	Number of Samples	Min	Mean	Max	Number exceeding SMCL	MCL	SMCL or MCL
Dissolved Constituents–sum (mg/L)*	28	730	1520	3865	--	--	--
Total Dissolved Solids (mg/L)**	28	625	1144	3502	500		28
Sodium (mg/L)	28	98	422	969	250	--	26
Potassium (mg/L)	28	0.6	1.5	5.6	--	--	--
Calcium (mg/L)	28	0.9	9.8	161	--	--	--
Magnesium (mg/L)	28	0.2	5.6	191	--	--	--
Chloride (mg/L)	28	2	26.3	120	250	--	0
Bicarbonate (mg/L)	28	186	738	1574	--	--	--
Carbonate (mg/L)	28	<1	46.2	152	--	--	--
Sulfate (mg/L)	28	<2.5	254	2000	250	--	7
Nitrate (mg/L as N)	28	<0.25	<0.25	3	--	10	0
Fluoride (mg/L)	28	<1	2.1	4.7	--	4	2
Iron (mg/L)	28	0.002	0.03	6.8	0.3	--	2
Manganese (mg/L)	28	<0.002	0.04	0.81	0.05	--	3
Selected Trace Elements							
Arsenic (ug/L)	28	<1	<1	1.7	--	50	0
Barium (ug/L)	28	4.6	48.6	105	--	1000	0
Chromium (ug/L)	28	<2	<2	6.4	--	100	0
Copper (ug/L)	28	<2	5.5	9.7	--	1000	0
Nickel (ug/L)	28	<2	<2	7.1	--	100	0
Selenium (ug/L)	28	<1	1.8	7.2	--	50	0
Other Constituents							
Sodium Adsorption Ratio (SAR)	28	3	68	98	--	--	--
Hardness as $CaCO_3$	28	3	48	852	--	--	--
pH	28	7.1	8.8	9.1	6.5 - 8.5	--	22

'--', No standard available or not applicable
SMCL - U.S. EPA Secondary maximum contaminant level for public water supplies
MCL - U.S. EPA Maximum contaminant level for public water supplies
* Dissolved constituents is the sum of major cations (Na, Ca, K, Mg, MN, Fe) and anions (HCO_3, CO_3, SO_4, Cl, SiO_3, NO_3, F) in mg/L.
**Total dissolved solids reported as equivalent to weight of evaporation residue.