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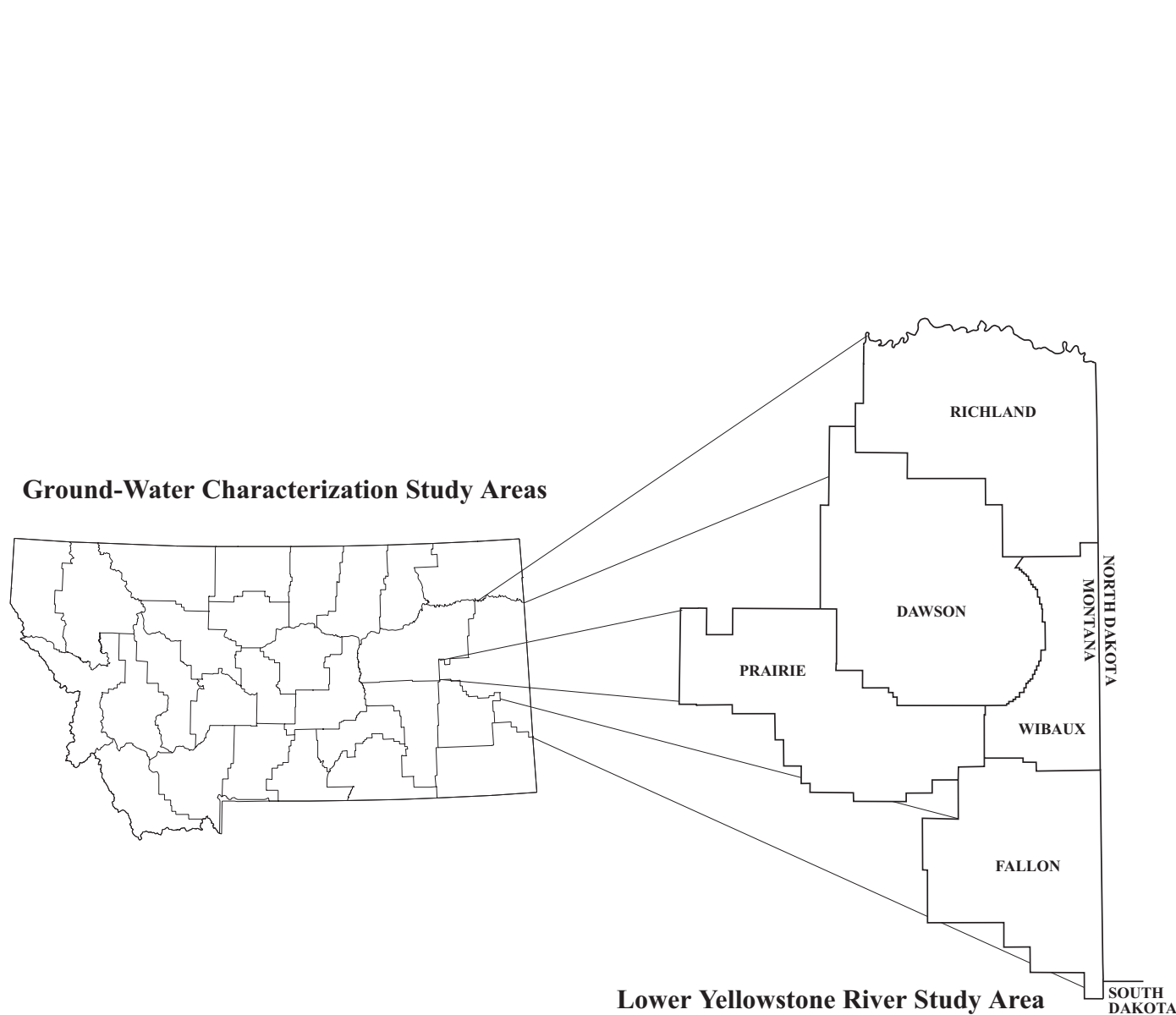 Dissolved Constituents* Map of the Fox Hills–Lower Hell Creek Aquifer, Lower Yellowstone River Area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties, Montana

by

John I. LaFave

Note - this map was originally published at a scale of 1:250,000 but the page sizes have been modified to fit the size of the paper in your printer. A full sized 36" X 45" colored print of this map can be ordered from the Office of Publications and Sales of the Montana Bureau of Mines and Geology, 1300 West Park Street, Butte, MT 59701.
Phone: 406-496-4167   E-mail: http://mbmgsun.mtech.edu

Ground-Water Characterization Study Areas

RICHLAND

NORTH DAKOTA

MONTANA

DAWSON

PRAIRIE

WIBAUX

FALLON

SOUTH DAKOTA

Lower Yellowstone River Study Area

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
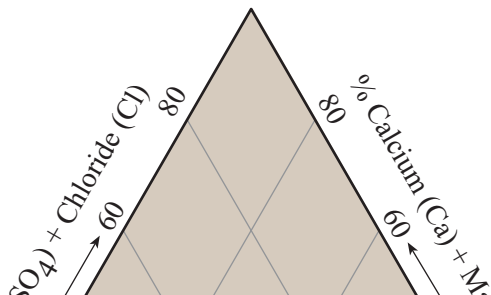
●   Dissolved constituents > 1,350 mg/L

Inventoried well used to estimate dissolved-constituents concentration from specific conductance:
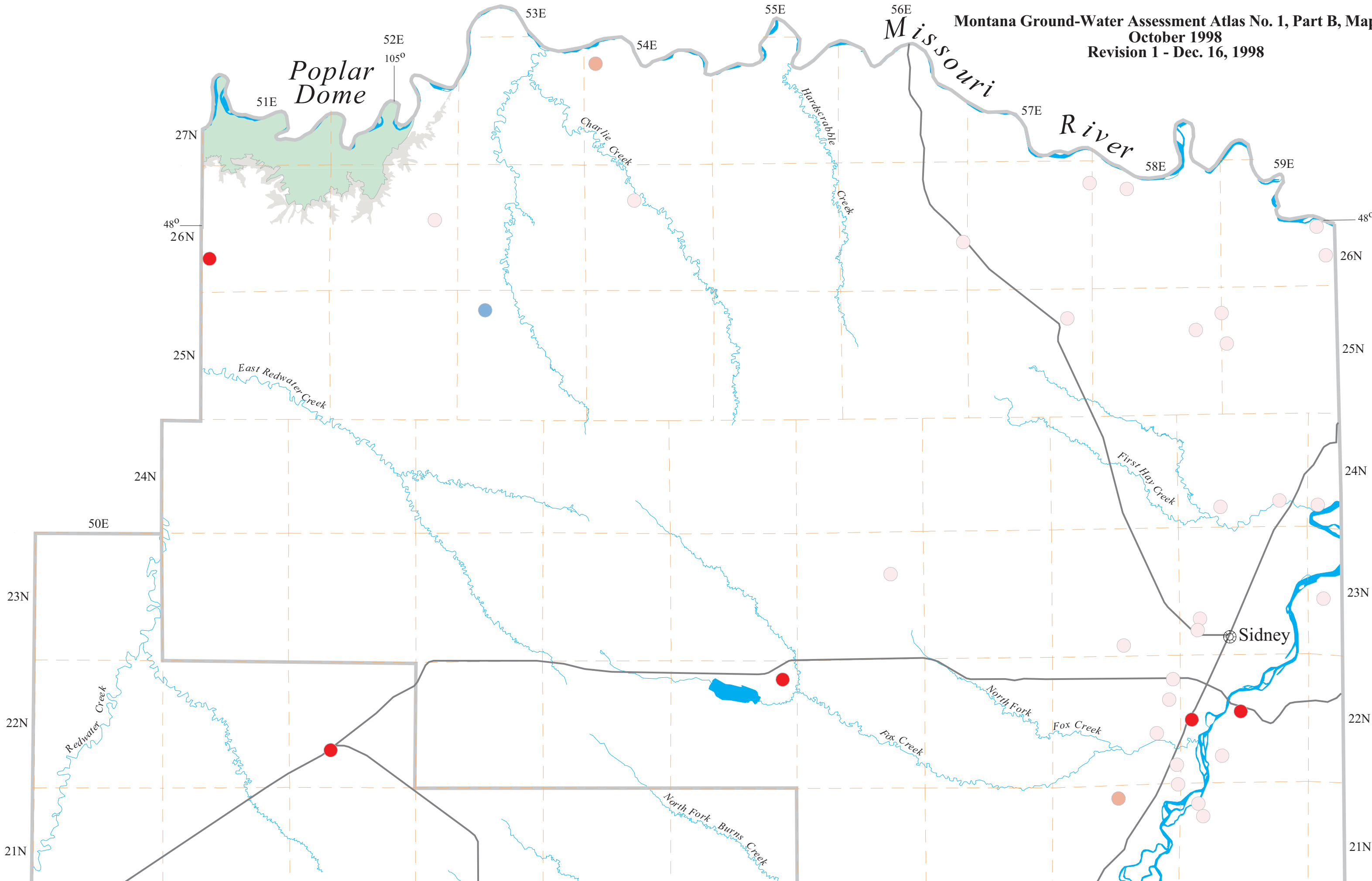
○   Estimated dissolved constituents < 1,350 mg/L

○   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.

% Chloride (Cl)

80

60

% Calcium (Ca) + M

80

60

(SO₄) + Chloride (Cl)

Poplar Dome

Missouri

River

Charlie Creek

Hardscrabble Creek

East Redwater Creek

First Hay Creek

Redwater Creek

North Fork

Fox Creek

Fox Creek

North Fork Burns Creek

⊗ Sidney

53E
54E
55E
56E
52E
105°
51E
57E
58E
59E
50E

27N
48°
26N
26N
25N
25N
24N
24N
23N
23N
22N
22N
21N
21N
48°

% Sulfate
% Magnesium (Mg)
40
40
20
20
Sodium Bicarbonate Water
% Sodium (Na) + Potassium (K)
20
40
60
80
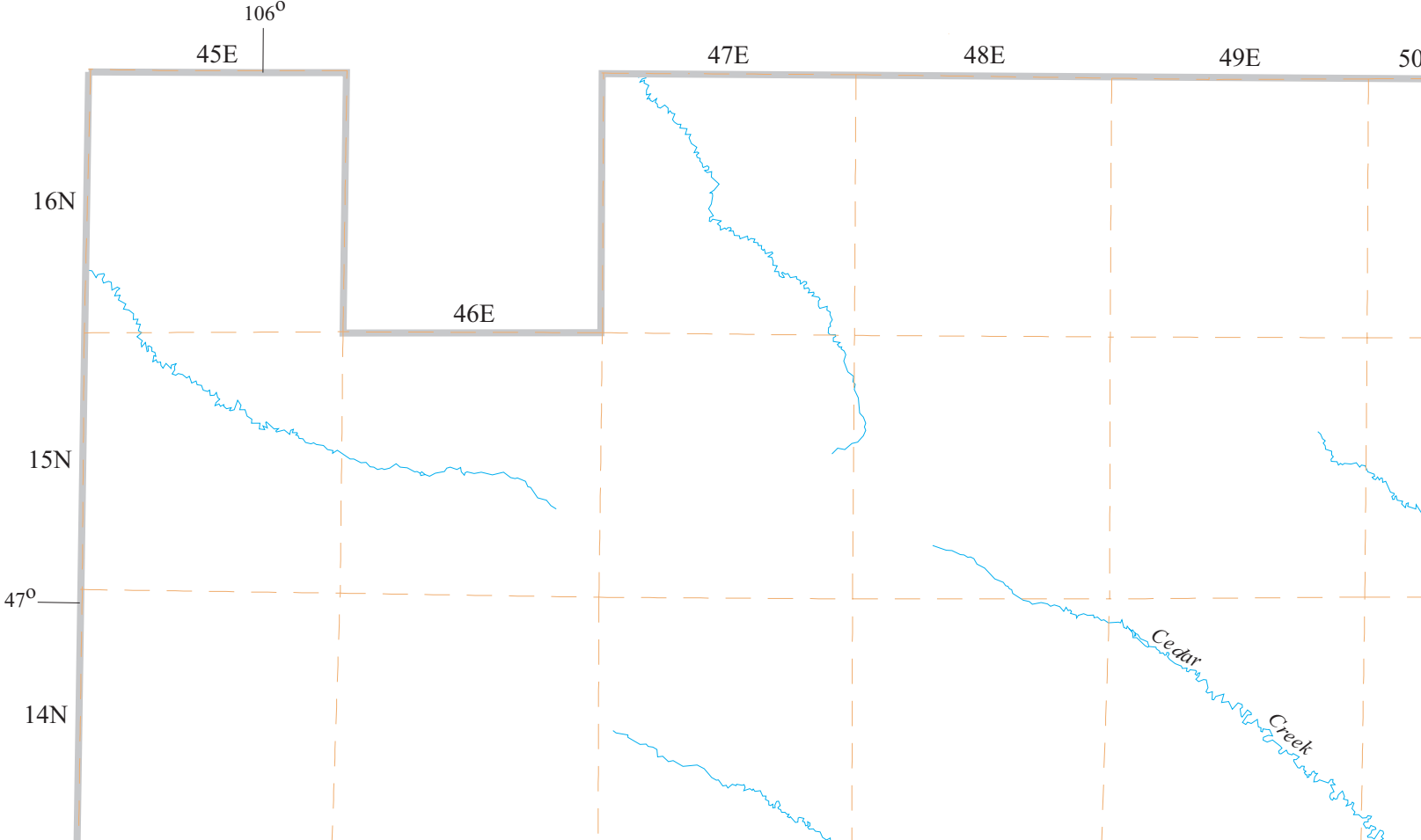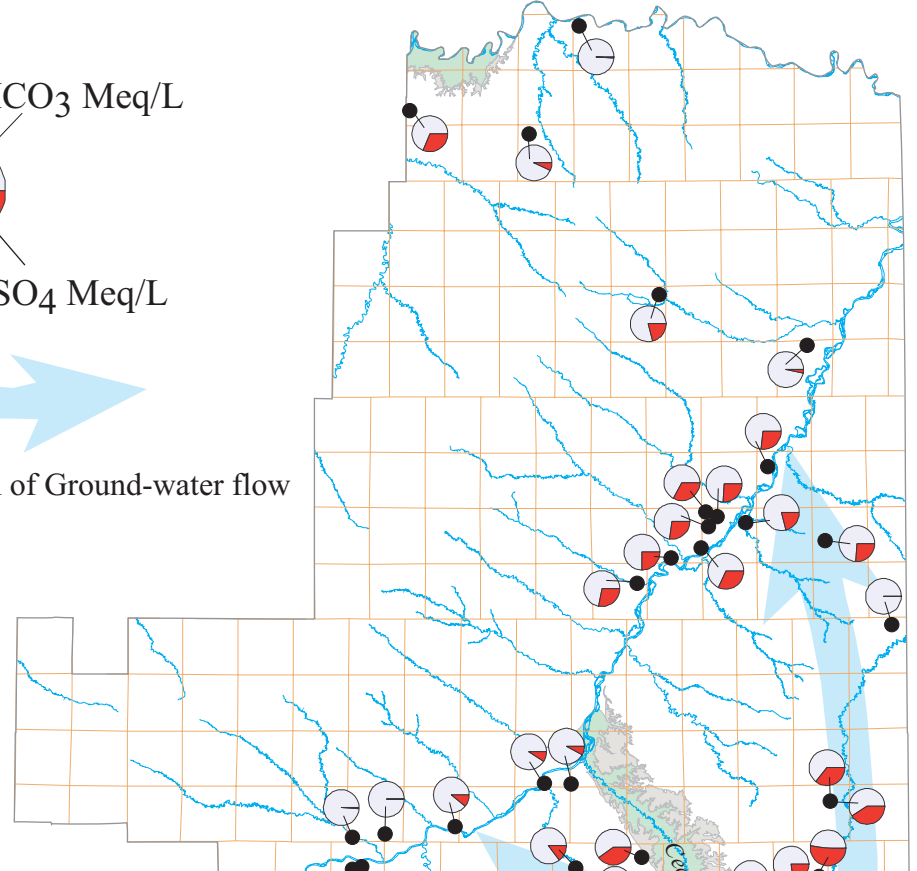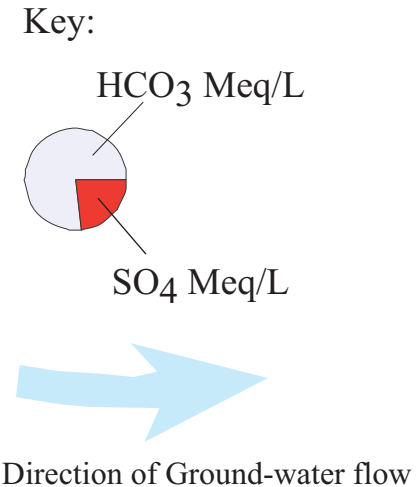% Carbonate (CO₃) + Bicarbonate (HCO₃)
20
40
60
80

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.

N

Scale 1:250,000

| 0 | 5 | 10 | 15 miles |

Transverse Mercator Projection
Central Meridian -105 Degrees
1927 Horizontal Datum

Key:

HCO₃ Meq/L

SO₄ Meq/L

Direction of Ground-water flow

106°
45E
47E
48E
49E
50

16N

46E

15N

47°

14N

Cedar

Creek

Burns Creek

Thirteenmile

Creek

Smith Creek

20N

19N

Upper Sevenmile Creek

Cottonwood Creek

18N

17N

Clear

Creek

16N

Glendive

King Creek

Glendive Creek

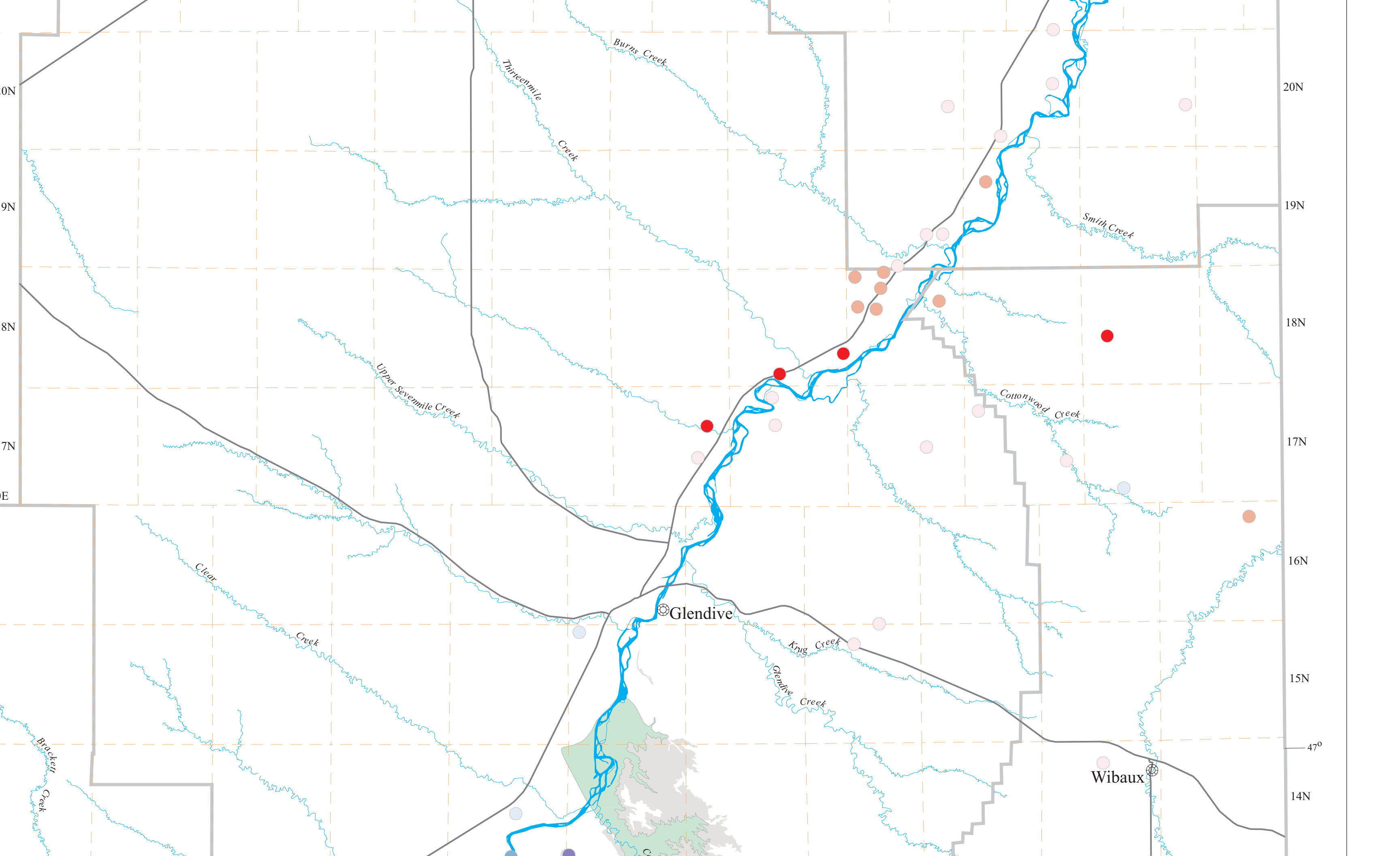15N

Bracken

Creek

47°

Wibaux

14N

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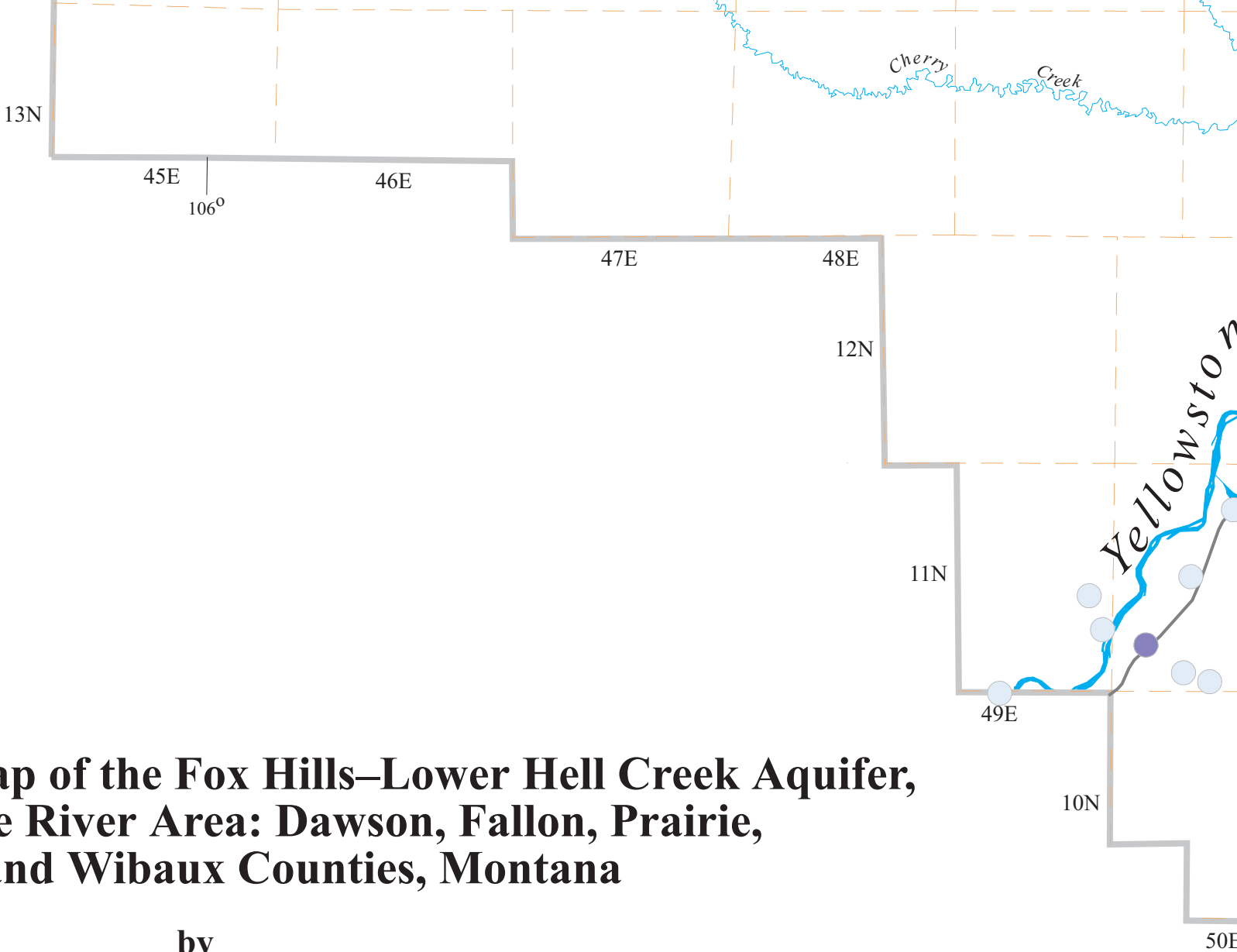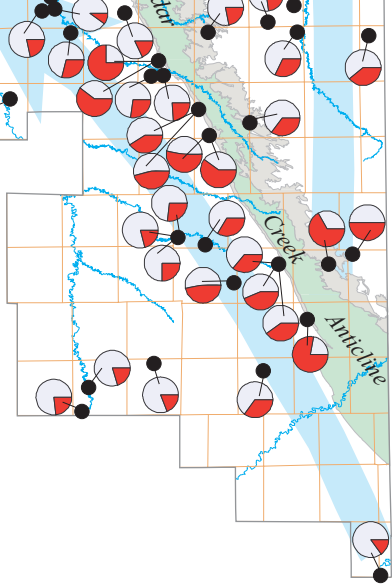
Dissolved Constituents* Map of the Fox Hills–Lower Hell Creek Aquifer, Lower Yellowstone River Area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties, Montana

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.
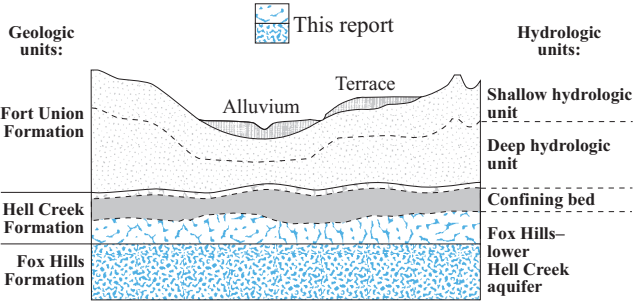
Aquifers are saturated geologic materials that yield sufficient water to supply wells and springs. Non-aquifers (confining beds) have low permeability and do not produce usable amounts of water to wells or springs. The sandstones that compose this aquifer are from 125 to 400 feet thick and are sandwiched between the Pierre Shale, which marks the
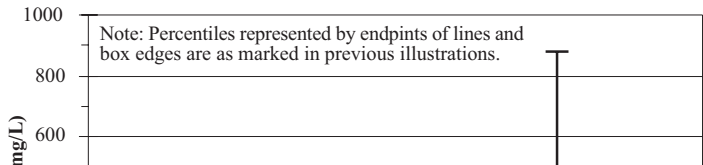
distribution of dissolved constituents in the Fox Hills–lower Hell Creek aquifer based on chemical analyses of ground-water samples and field measurements of specific conductance.

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
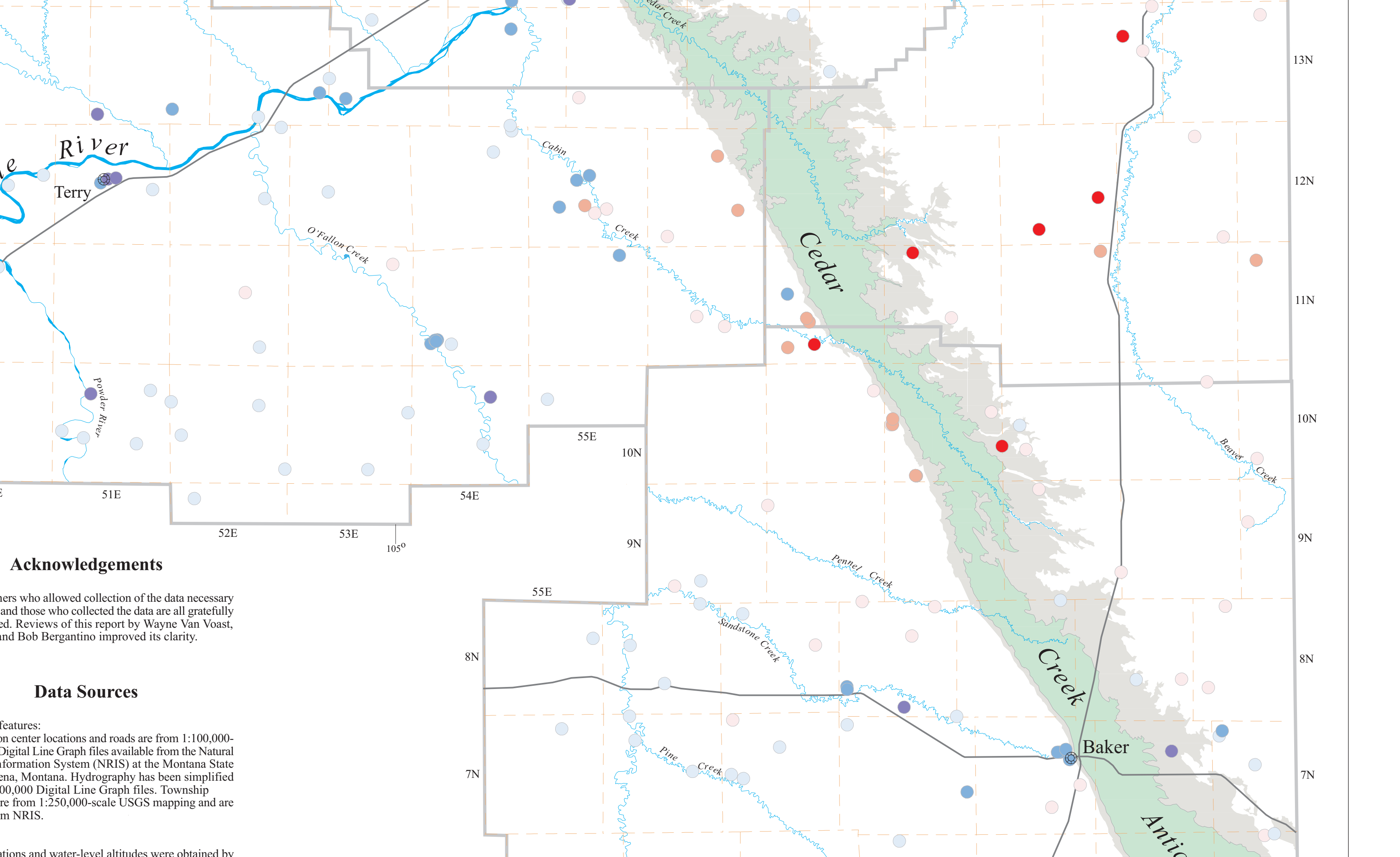
up to 850 feet/mile, resulting in surface exposures of the aquifer only about one mile wide (Smith 1997). Dips on the eastern flank are more gentle, about 70 feet/mile, resulting in exposures of the aquifer of about 6 to 10 miles wide. A map of the potentiometric surface (LaFave 1998) shows that the 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.

Note: Percentiles represented by endpoints of lines and box edges are as marked in previous illustrations.

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

River

Terry

Cabin

Creek

O'Fallon Creek

Cedar

Powder River

55E

10N

54E

51E

52E 53E

105°

Data Sources

features:
on center locations and roads are from 1:100,000-
Digital Line Graph files available from the Natural
formation System (NRIS) at the Montana State
ena, Montana. Hydrography has been simplified
00,000 Digital Line Graph files. Township
re from 1:250,000-scale USGS mapping and are
m NRIS.

ations and water-level altitudes were obtained by

55E

9N

Pennel Creek

Sandstone Creek

8N

Creek

7N

Pine   Creek

Baker

Antic

Beaver   Creek

13N

12N

11N

10N

9N

8N

7N

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.
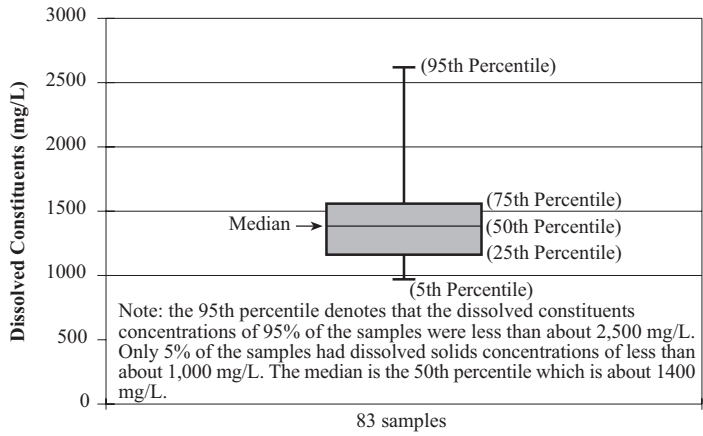
Sample Sites and Water-Quality Data

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
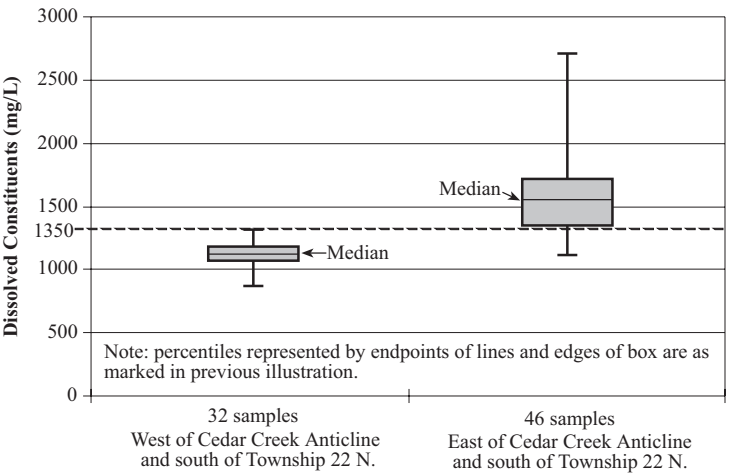
Dissolved Constituents

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_2, NO_3, F) expressed in milligrams per liter (mg/L). This map shows the general 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.

Note: the 95th percentile denotes that the dissolved constituents concentrations of 95% of the samples were less than about 2,500 mg/L. Only 5% of the samples had dissolved solids concentrations of less than about 1,000 mg/L. The median is the 50th percentile which is about 1400 mg/L.
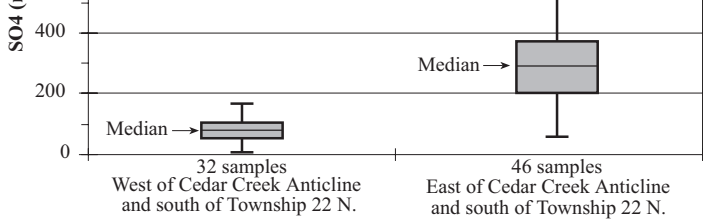
83 samples

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.

Note: percentiles represented by endpoints of lines and edges of box are as marked in previous illustration.

| 32 samples | 46 samples |
| West of Cedar Creek Anticline and south of Township 22 N. | East of Cedar Creek Anticline and south of Township 22 N. |

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,

| 32 samples | 46 samples |
| West of Cedar Creek Anticline and south of Township 22 N. | East of Cedar Creek Anticline and south of Township 22 N. |

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.

Depth Water Enters (ft)
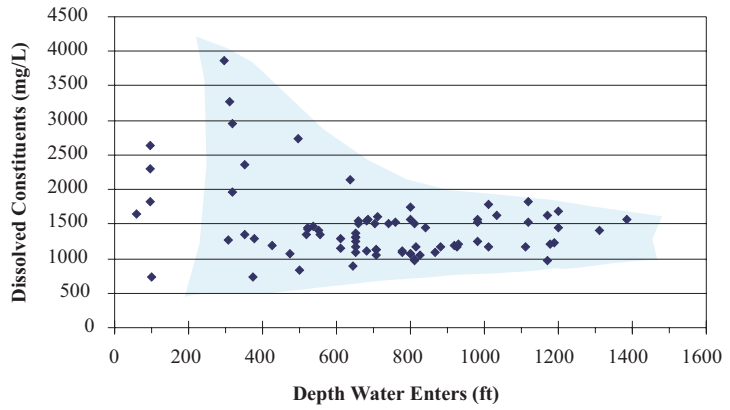
Major Ions and Suitability for Water Use

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

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.

Bergantino R. N. ...
of the Culb...
of Mines a...
Bergantino R. N. ...
of the Wolf...
of Mines a...
Colton, R. B., V...
geologic m...
Bureau of ...
Groenewold, G...
G. N., and...
the Knife R...
North Dak...
402 p.
Hem, J. D. 199...
of natural ...
263 p.
Henderson, T. ...
aquifer sys...
Wyoming. ...
84 p.
LaFave, J. I. 19...
Hell Creek...
Water Ass...
Smith, L. N., L...
P., 2000. G...
River Area...
Montana. M...
Water Ass...
Smith, L. N. 19...
Creek aqu...
Bureau of ...
1, Part B, ...
Thorstenson, D....
of the Fox ...
Dakota an...
15(6):1479...
Vuke-Foster, S. ...
J. E., and C...
30 x 60-m...
Dakota. M...
41. Scale ...
Wilde, E. M., a...
of the Gle...
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*Author's Note...
solids (TDS). ...
cations (Na, Ca...
NO_3, F) expres...
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the bicarbonate...
atmosphere dur...
(HCO_3) in solu...
the carbon diox...
dissolved-solid...
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where bicarbon...
dissolved const...
for the various ...

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...ns and water-level altitudes were obtained by
...r Characterization Program personnel, the altitude
...e points was determined from U.S. Geological
...nin. quadrangle maps. All point data used on this
...lable from the Ground-Water Information Center
...ne Montana Bureau of Mines and Geology,
...ch of The University of Montana, Butte.

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...nd Vuke-Foster, S. M. 1994. Preliminary geologic map
...ndive 1 x 2-degree quadrangle. Montana Bureau of Mines
...gy Open-File Report 295. Scale 1:250,000.

...: Dissolved constituents differ slightly from total dissolved
...The dissolved constituents value is the sum of the major
..., K, Mg, Mn, Fe) and anions (HCO_3, CO_3, SO_4, Cl, SiO_3,
...sed in milligram per liter (mg/L). TDS is traditionally
...eighing residue remaining after evaporating a known
...r, or estimated by summing the major ions after multiplying
...e (HCO_3) concentration by 0.49 to account for loss to the
...ing evaporation. For example, about half of the bicarbonate
...tion is converted to carbon dioxide during evaporation;
...xide escapes to the atmosphere and does not appear in the
...s residue. Therefore, TDS calculations generally
...he total dissolved-ion concentration in solution especially
...ate concentrations are high. A more accurate measure of
...tituents is obtained by summing the concentrations reported
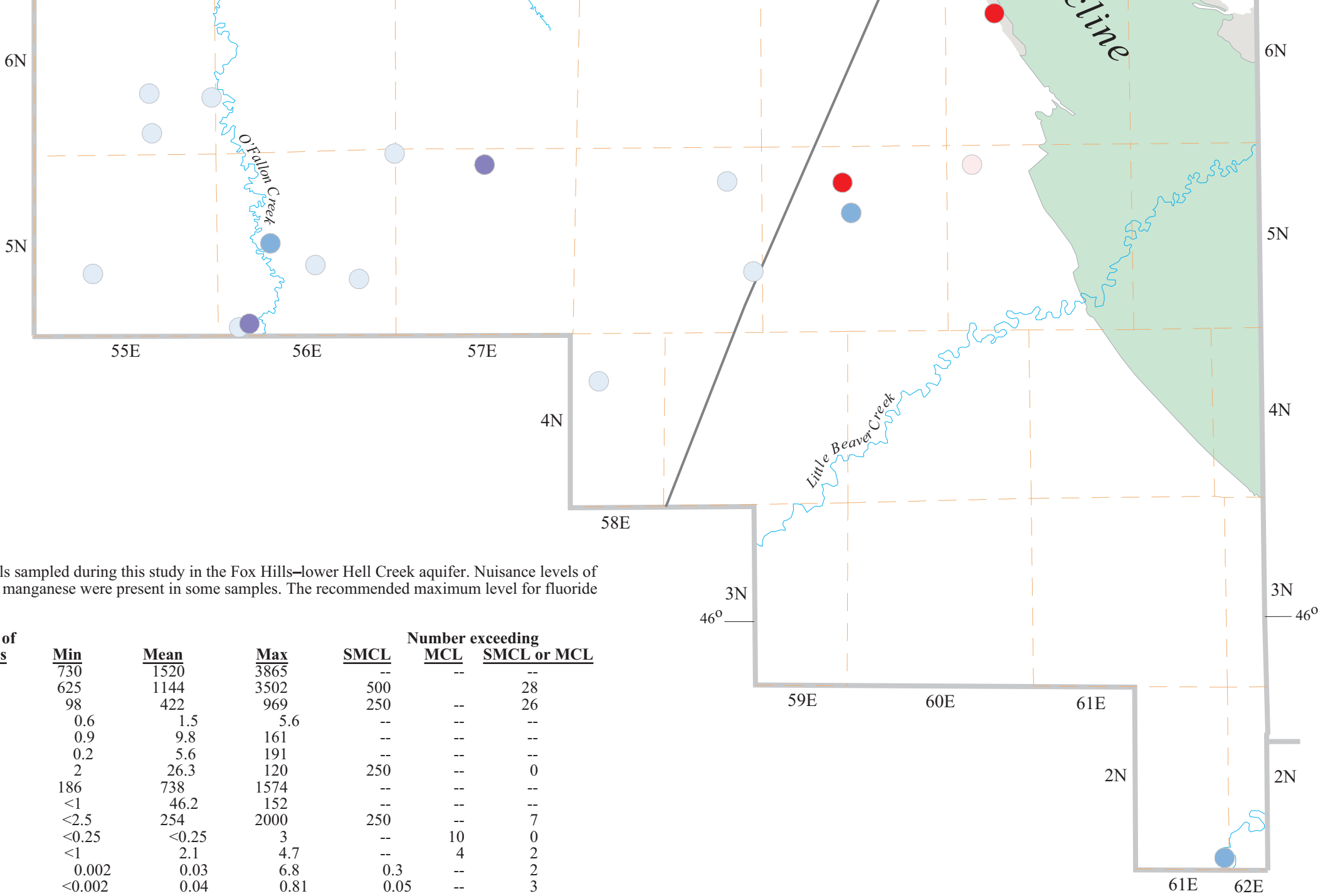...dissolved constituents.

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	SMCL	Number exceeding 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.

O'Fallon Creek

Little Beaver Creek

6N
5N
4N
3N
2N

55E 56E 57E 58E 59E 60E 61E 62E

46°