

Montana Ground-Water Assessment Atlas No. 1, Part B, Map 9
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Montana Bureau of Mines and Geology
A Department of Montana Tech of The University of Montana

**Dissolved Constituents* Map of the Deep Hydrologic Unit,
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>

Explanation



Well sampled for this study:

-  Dissolved constituents < 2,000 mg/L
-  Dissolved constituents > 2,000 mg/L

Well with historic water analysis:

-  Dissolved constituents < 2,000 mg/L
-  Dissolved constituents > 2,000 mg/L

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

-  Estimated dissolved constituents < 2,000 mg/L
-  Estimated dissolved constituents > 2,000 mg/L

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

-  Area where dissolved-constituents concentrations are generally greater than 2,000 mg/L

-  County boundary

-  Township boundary

-  County seat

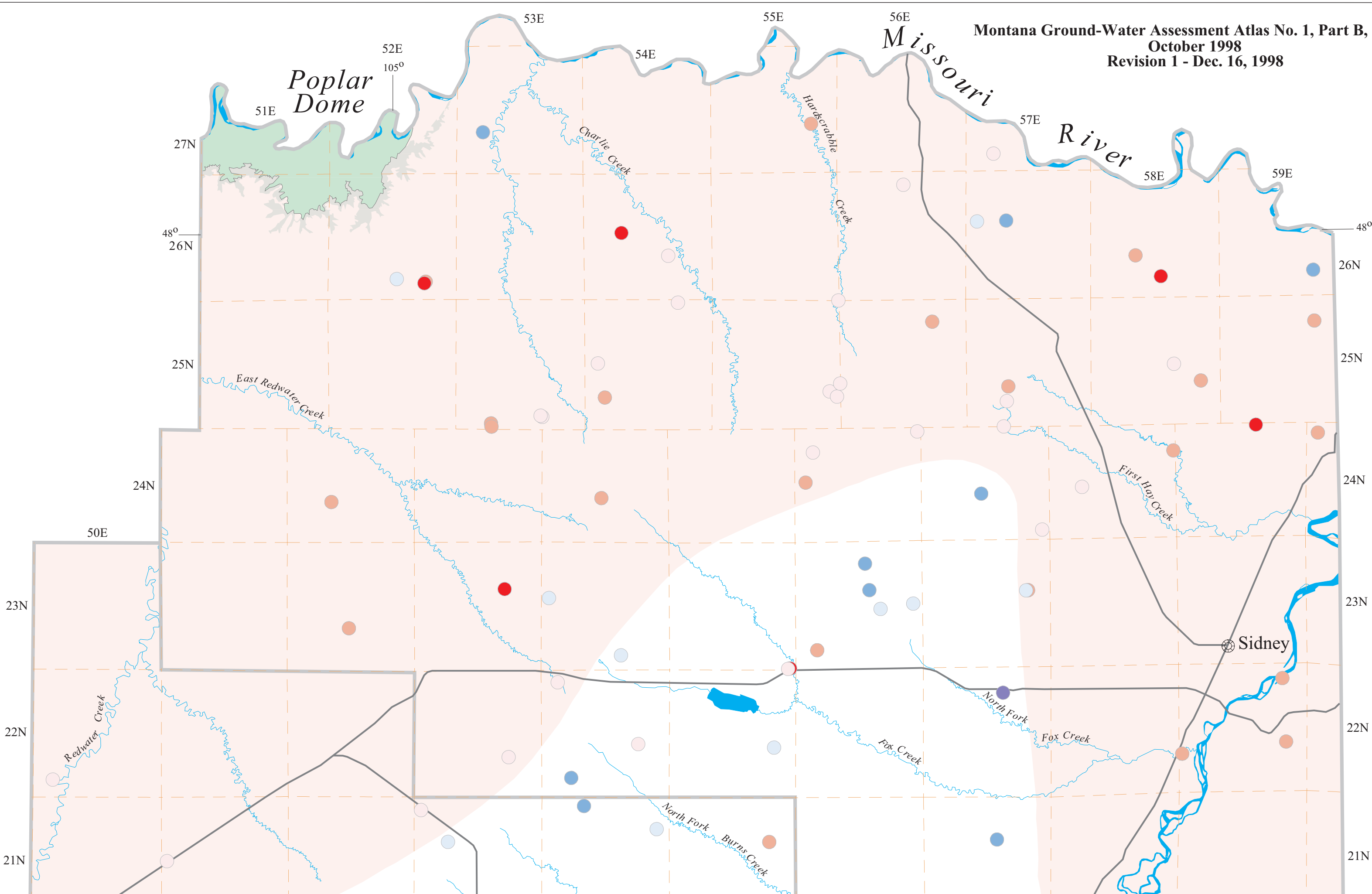
-  Major road

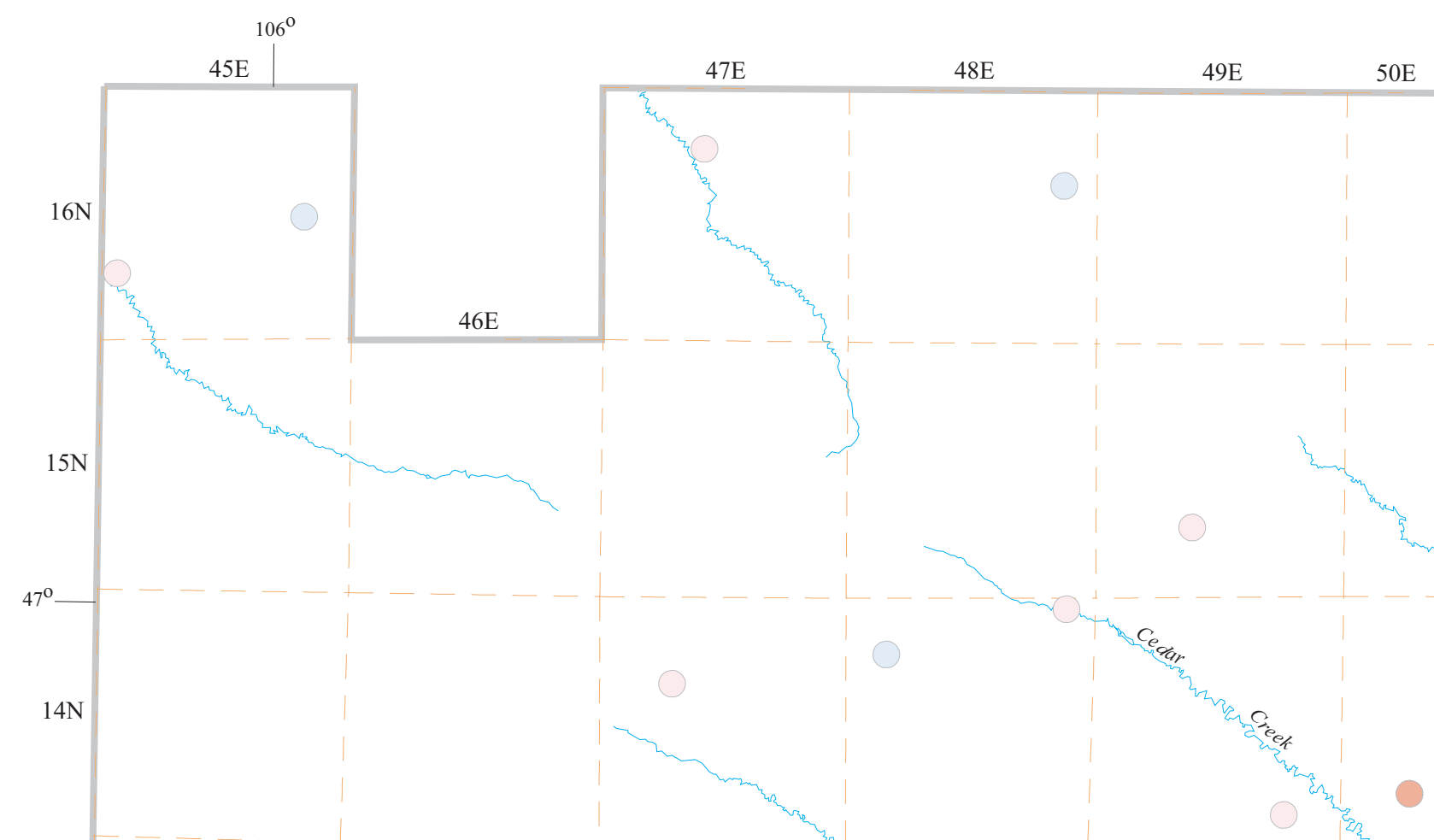
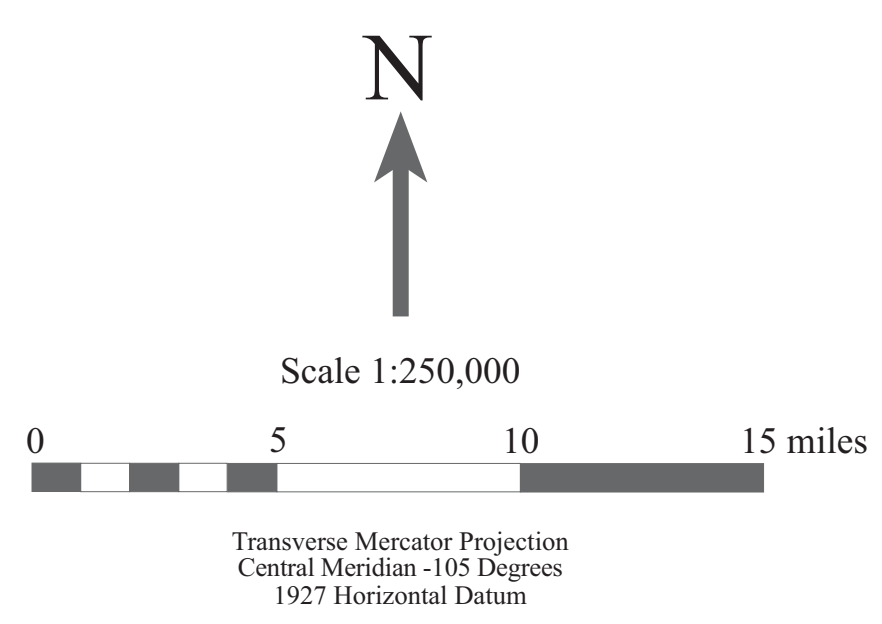
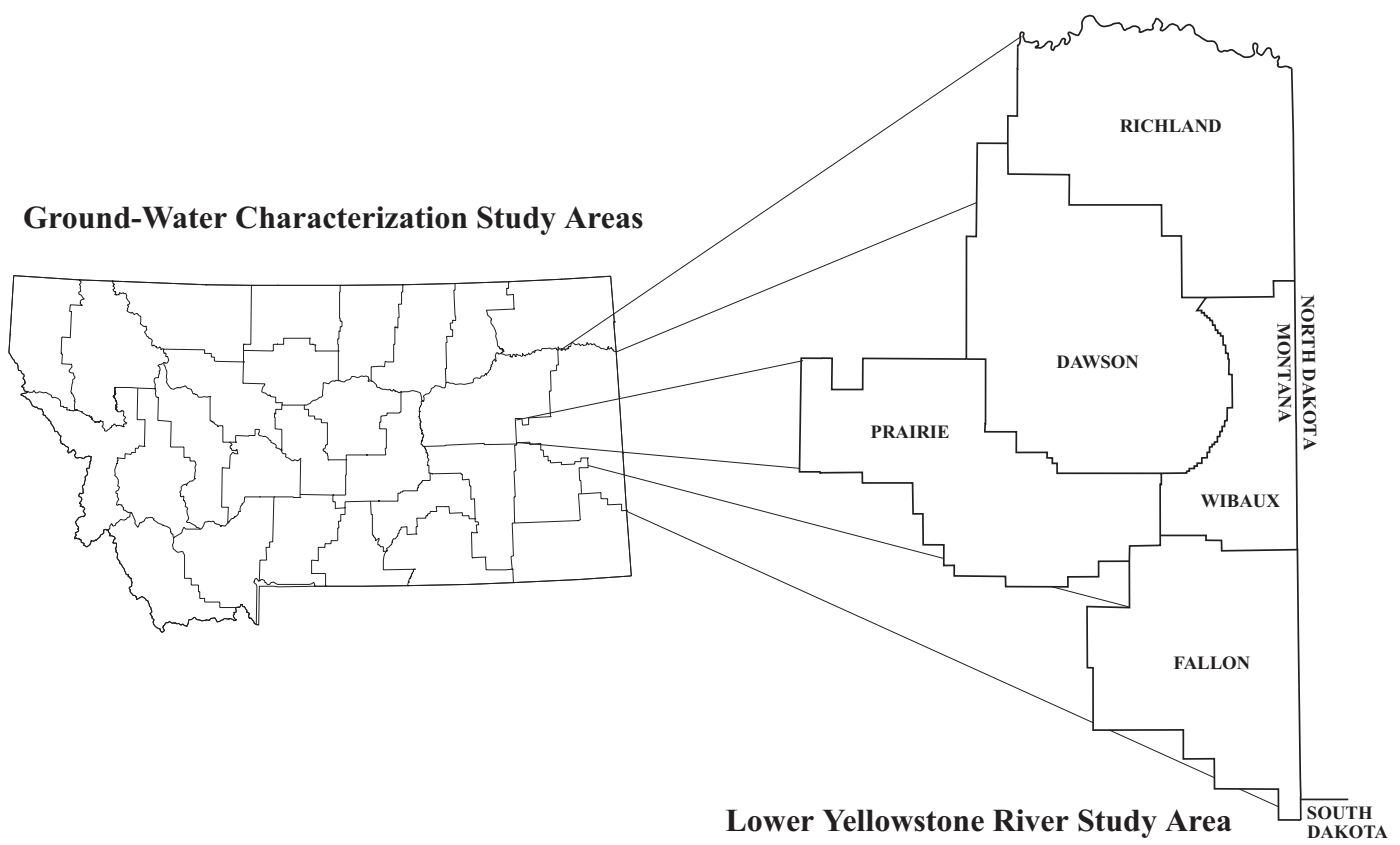
-  Principal stream

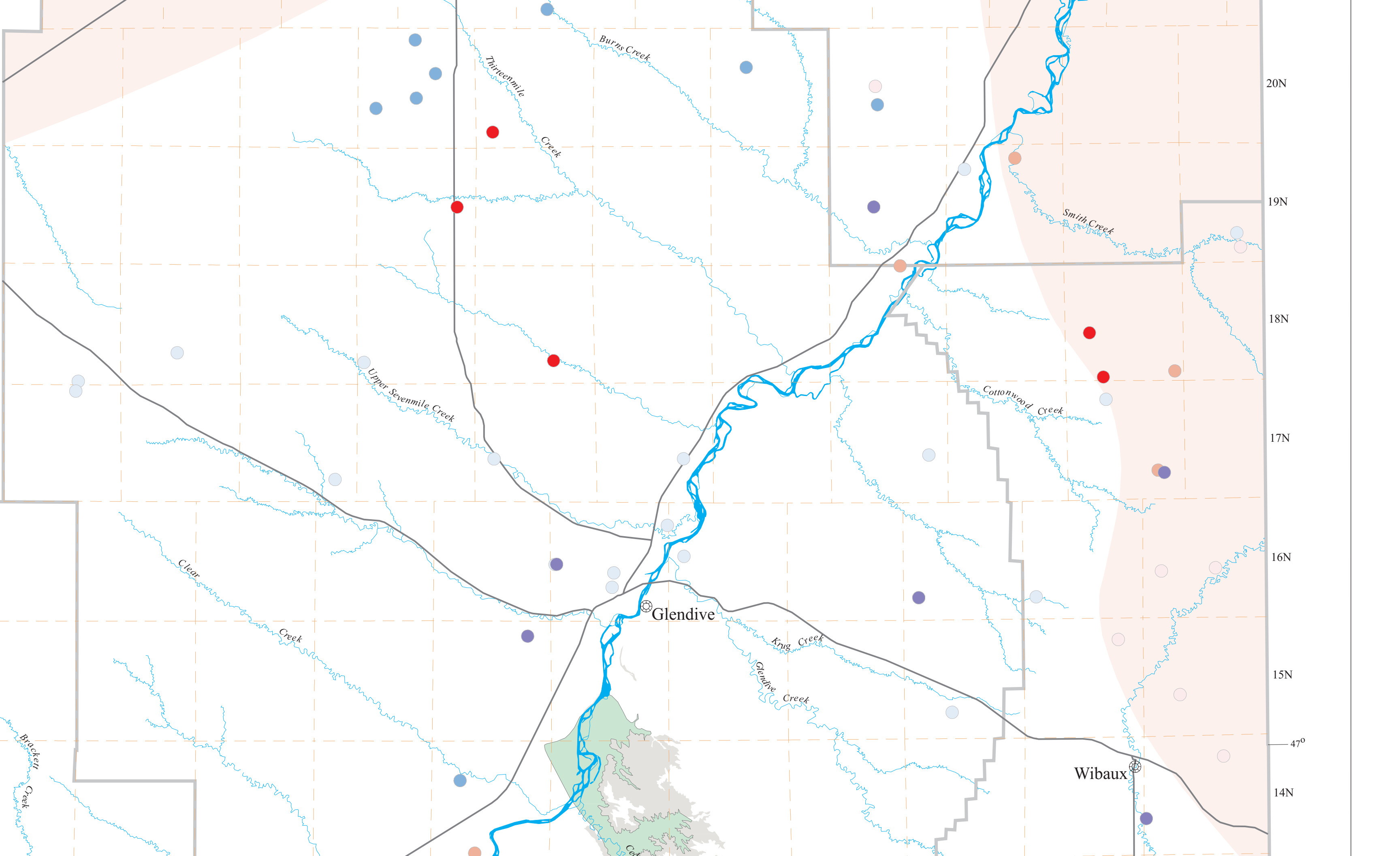
-  Outcrop and subcrop of the Pierre Shale

-  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.







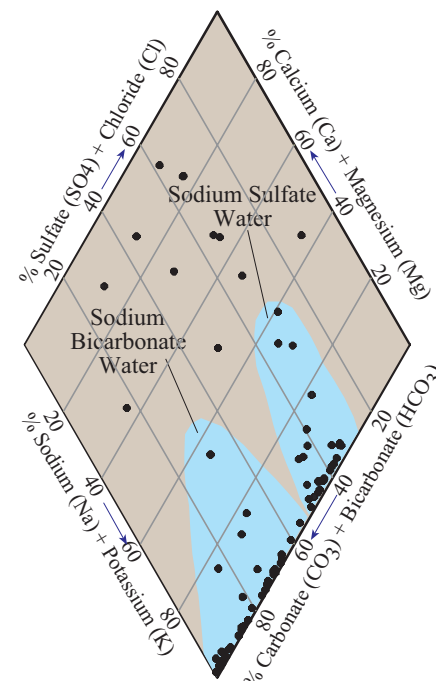


Figure 1. Ground water sampled from in the Deep Hydrologic Unit is predominately a sodium-sulfate or sodium-bicarbonate-type water; in most samples there was relatively little calcium, magnesium, or chloride.

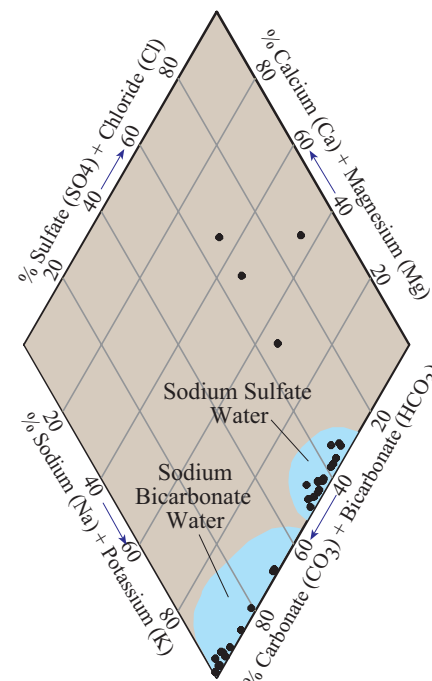


Figure 2. Ground water sampled from north and northeast part of the study area (shaded red on the map) is predominately a sodium-sulfate or sodium-bicarbonate-type water; there is very little calcium or magnesium.

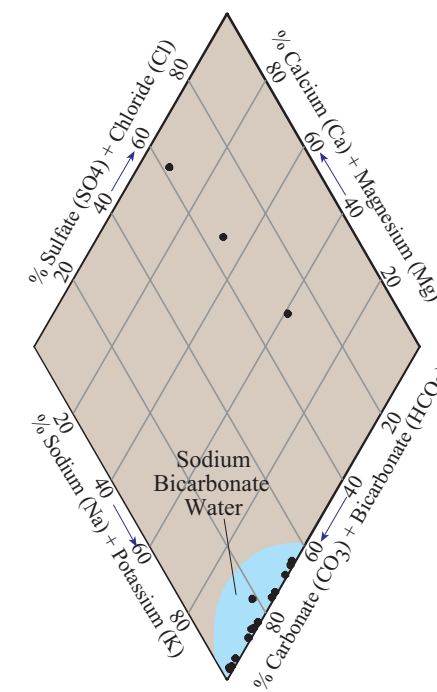
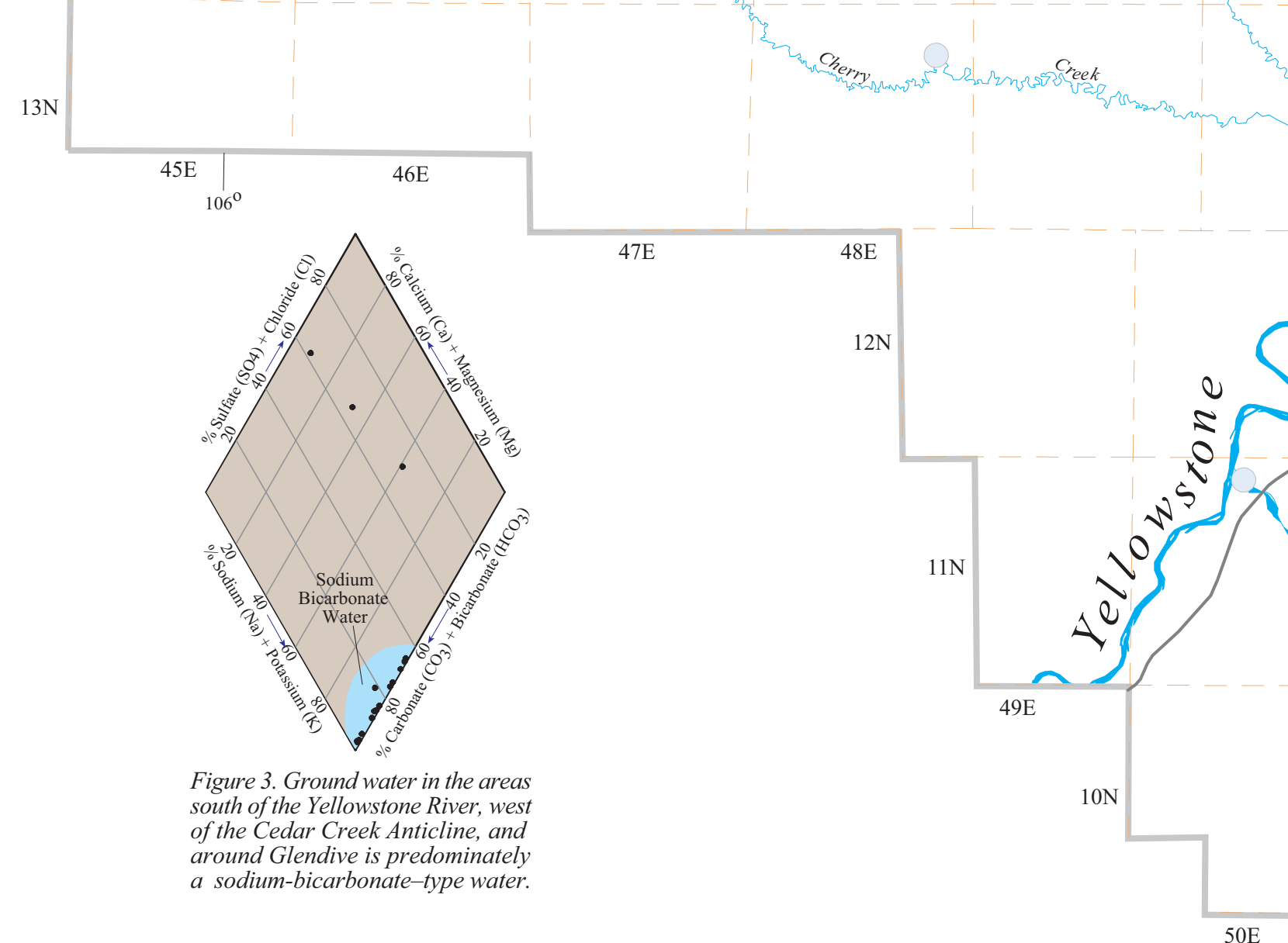


Figure 3. Ground water in the areas south of the Yellowstone River, west of the Cedar Creek Anticline, and around Glendive is predominately a sodium-bicarbonate-type water.



Dissolved Constituents* Map of the Deep Hydrologic Unit, 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 ground water of the Deep Hydrologic Unit (DHU). The unit is defined as all aquifers and non-aquifers that occur at depths greater than 200 feet below land surface and lie stratigraphically above the regionally extensive claystone and shale in the upper Hell Creek Formation. The DHU encompasses mostly the lower part of the Fort Union Formation and, in places, the upper part of the Hell Creek Formation. The Fort Union and upper Hell Creek formations are a complex sequence of aquifer and non-aquifer materials.

constituents concentrations derived from field measurements of specific conductance from an additional 112 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

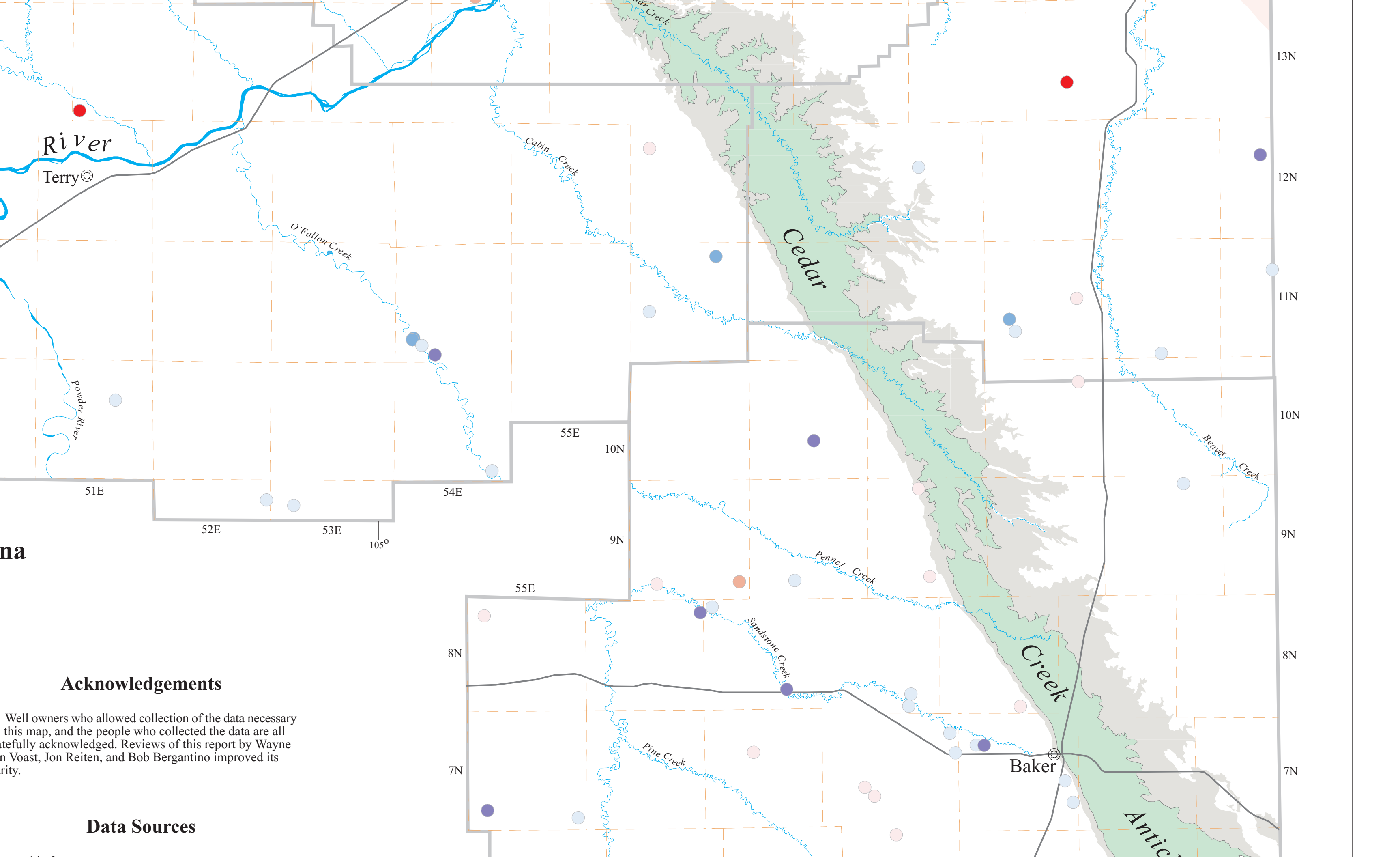
Dissolved Constituents

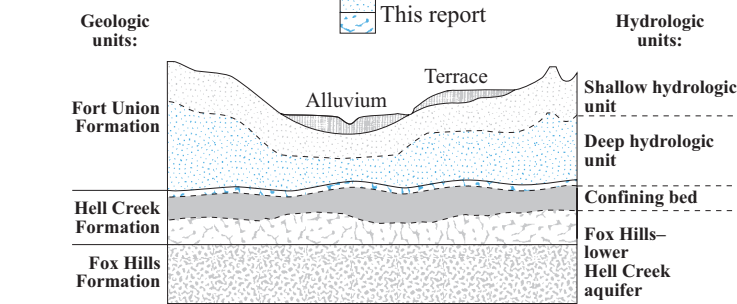
to other calcium salts—gypsum (CaSO_4) and calcite (CaCO_3)—allowing them to continue to be dissolved. Dissolution of these minerals, which are common in the Fort Union Formation, brings more sulfate and bicarbonate, respectively, into solution. Sulfate is also derived from the oxidation of sulfide minerals present in the Fort Union Formation. The area shaded red on the map coincides with low water-table altitudes in the deep ground-water flow system and represents a ground-water discharge area. Typically, water in the discharge area will have a relatively higher degree of mineralization (higher dissolved constituents) than water in the rest of the aquifer (Fetter 1994).

The areas with the lower concentrations of dissolved constituents are south of the Yellowstone River, west of the

combination with other ions, give water a bitter taste. Ground water from aquifers with high sulfate concentrations may also have a “rotten egg” odor due to hydrogen sulfide (H_2S) gas which 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.”

A high concentration 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





Aquifers are saturated geologic materials that have sufficient permeability to yield usable quantities of water to wells and springs; non-aquifers (confining beds) are composed of less-permeable geologic materials that restrict the movement of water between aquifers and do not yield water to wells. Most of the aquifers are sandstones and coals in the Fort Union Formation and sandy zones in the upper part of the Hell Creek Formation. Aquifers vary in thickness, are laterally discontinuous, and are separated by non-aquifer shale and claystone layers. Despite of the complex stratigraphy, there is sufficient hydraulic continuity on a regional scale to consider the DHU a single entity in terms of ground-water flow.

The top of the DHU is not delimited by a continuous geologic or hydrogeologic marker but is transitional beneath the Shallow Hydrologic Unit, which consists of all aquifers and non-aquifers within 200 feet of the land surface (Patton *et al.* 1997). The two units were differentiated to facilitate hydrogeologic interpretations given the scale of this investigation and the available data. Differences in water quality and ground-water flow were used to justify separating the units at 200 feet below land surface.

In the five-county Lower Yellowstone River Area, about 900 wells are completed in the DHU and compose approximately 12% of all wells in the area. Ground water from this unit is used primarily for domestic- and stock-water purposes. Most reported well yields are less than 15 gallons per minute.

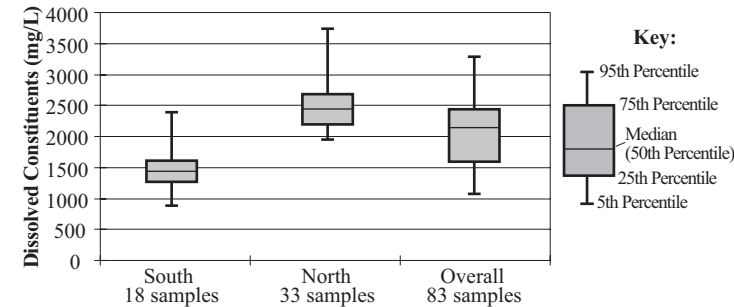
Sample Sites and Water-Quality Data

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. Water samples from 28 domestic, stock, and monitoring wells were analyzed for major ions and trace metals between April 1995 and October 1995. Field measurements of specific conductance, pH, and water temperature also were obtained from each of the sampled wells. To ensure collection 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 were also used. These laboratory data were supplemented by estimated dissolved-

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 (HCO₃, CO₃, SO₄, Cl, SiO₃, NO₃, F) expressed in milligrams per liter (mg/L). This map shows the general distribution of dissolved constituents in the deep unit 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. Therefore, for this map a dissolved-constituents concentration of 2,000 mg/L was used to differentiate between water having low-dissolved constituents (blue symbols) and that having high-dissolved constituents (red symbols). 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 2,100 mg/L.

Note: 95% of the samples in each set had concentrations less than or equal to the values indicated by the 95th percentiles. 5% of each sample set had concentrations less than or equal to the values indicated by the 5th percentiles.

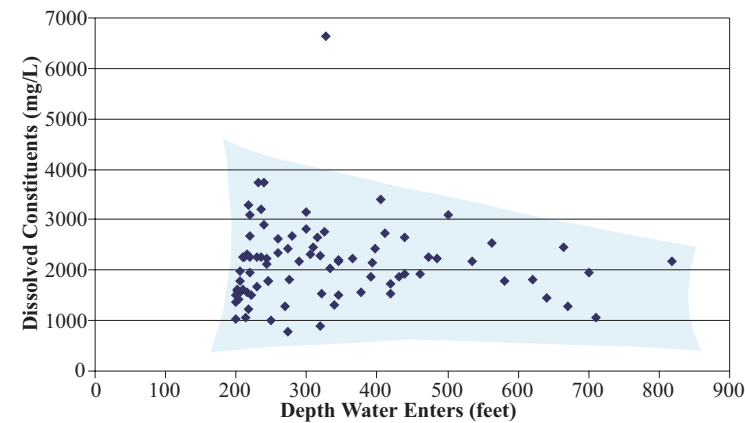


The concentration of dissolved constituents in ground water is a result of the initial chemistry of the recharge water and the subsequent interactions with soils and aquifer materials. As water moves through an aquifer from areas of recharge to areas of discharge, the concentration of dissolved constituents 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 Deep Hydrologic Unit is mineralized (high dissolved constituents), but the range in the concentration of dissolved constituents is small; in the 83 samples used for this study, most were between about 1,300 and 3,000 mg/L. In general, the water is a sodium-sulfate or sodium-bicarbonate type; a small number of samples contain significant amounts of calcium and magnesium (figure 1).

Although the water chemistry is generally uniform, there are some regional differences. Higher concentrations of dissolved constituents are found in the north and northeast part of the study area. In the area shaded red on the map, concentrations are generally greater than 2,000 mg/L. The water in this area is enriched in sodium, sulfate and bicarbonate, and depleted in calcium and magnesium (figure 2). The chemical composition is due primarily to ion-exchange reactions in which calcium and magnesium are removed from solution and exchanged for sodium. The removal of calcium from solution keeps the water under-saturated with respect

Cedar Creek Anticline, and around Glendive. Although data are sparse, they show that the dissolved constituents content in these areas is generally less than 2,400 mg/L; the average concentration from 18 samples is 1,500 mg/L (see previous illustration). Sodium and bicarbonate are the dominant ions in solution with minor amounts of sulfate (figure 3).

There are no clear trends with respect to the vertical distribution of dissolved constituents. Across the study area, most of the variability in the dissolved-constituents concentration occurs in the upper two hundred feet of the unit (200–400 feet below land surface); there is no noticeable increasing trend in the dissolved constituents concentration with depth.



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 concentration of dissolved constituents (average = 2,080 mg/L), ground water from the Deep Hydrologic Unit is generally suitable for domestic and stock consumption. Recommended maximum fluoride levels were exceeded in some samples, while exceedences of nuisance levels of total dissolved solids, sulfate, sodium, iron, and manganese were common.

Fluoride concentrations ranged from non-detectable (14 samples) to 5 mg/L; the maximum contaminant level of 4.0 mg/L was exceeded in 3 of the samples (about 10%). 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, especially in the bedrock aquifers of the Fort Union Formation. Dissolved sulfate is derived from the oxidation of pyrite in shales and coal common in the Fort Union and Hell Creek formations, and the dissolution of gypsum (CaSO₄). Excessive sulfate can produce a laxative effect and, in

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 indicate 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 most water from the Deep Hydrologic Unit is unsuited for irrigation. The SAR values ranged from less than 1 to 75 with a mean of 45; only 5 of the samples were 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. About 40% of the samples had iron concentrations above the secondary level of 0.3 mg/L, and about 25% of the 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 2,000 mg/L was used to differentiate between low and high concentrations because this is generally the upper limit of water potability. Three separate 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 April 1995 and October 1995 and represent the primary data set; 55 wells sampled between 1947 and 1985 (49 were sampled since 1975) 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 112 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 x 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.

graphic features:
Hydrography, population center locations, and roads are
m 1:100,000-scale USGS Digital Line Graph files available
m the Natural Resources Information System (NRIS) at
Montana State Library, Helena, Montana. Township
undaries digitized from 1:250,000 USGS mapping also are
ailable from NRIS.

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

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author’s Note: Dissolved constituents differ slightly from total dissolved
ids (TDS). The dissolved constituents value is the sum of the major
ons (Na, Ca, K, Mg, Mn, Fe) and anions (HCO₃, CO₃, SO₄, Cl, SiO₃,
₃, F) expressed in milligram per liter (mg/L). TDS is traditionally
asured by weighing residue remaining after evaporating a known
ume of water, or estimated by summing the major ions after multiplying
bicarbonate (HCO₃) concentration by 0.49 to account for loss to the
osphere during evaporation. For example, about half of the bicarbonate
CO₃) in solution is converted to carbon dioxide during evaporation;
carbon dioxide escapes to the atmosphere and does not appear in the
dissolved-solids residue. Therefore, TDS calculations generally
lerestimate the total dissolved-ion concentration in solution especially
ere bicarbonate concentrations are high. A more accurate measure of
solved constituents is obtained by summing the concentrations reported
the various dissolved constituents.

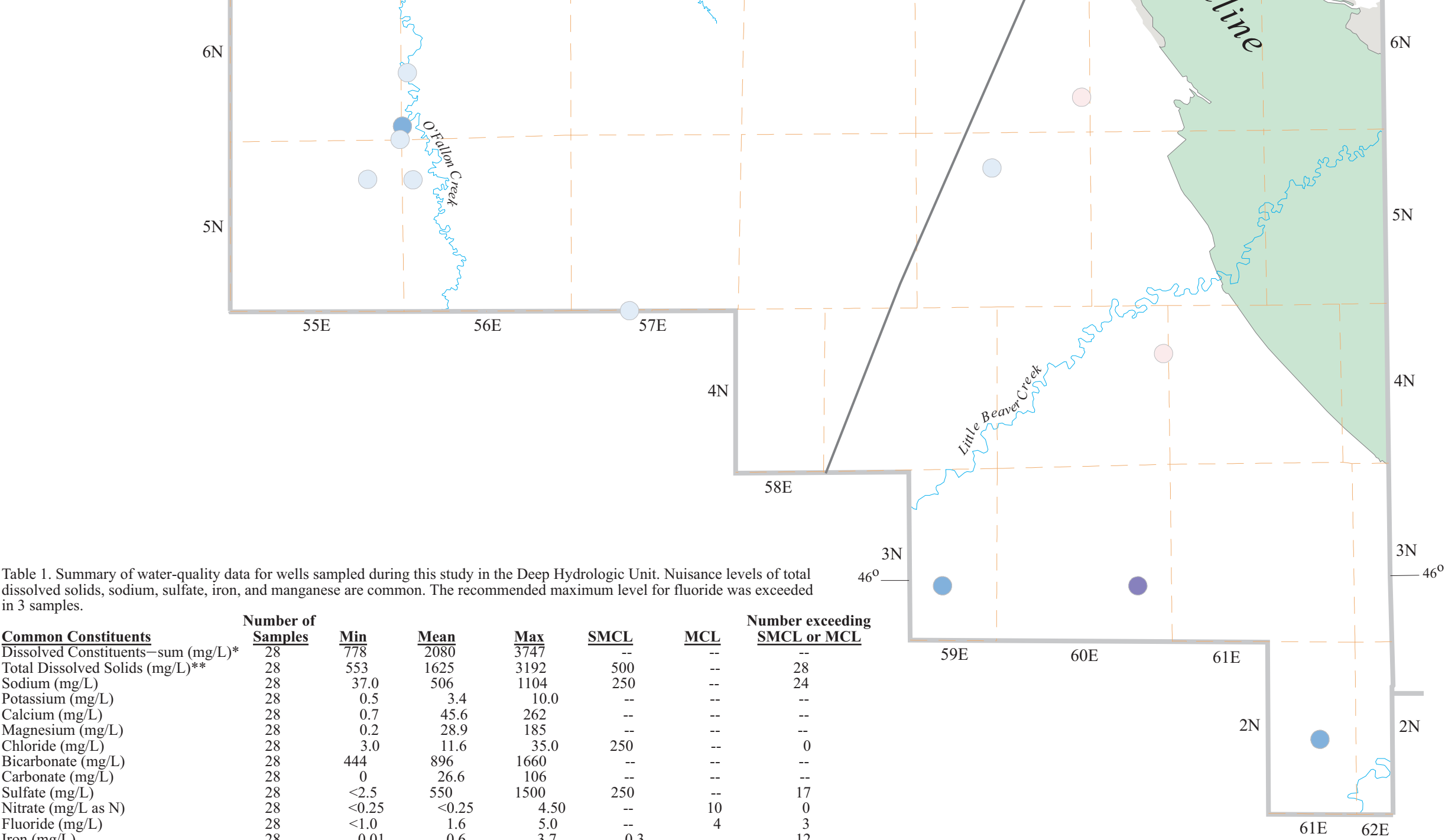


Table 1. Summary of water-quality data for wells sampled during this study in the Deep Hydrologic Unit. Nuisance levels of total dissolved solids, sodium, sulfate, iron, and manganese are common. The recommended maximum level for fluoride was exceeded in 3 samples.

Common Constituents	Number of Samples	Min	Mean	Max	SMCL	MCL	Number exceeding SMCL or MCL
Dissolved Constituents—sum (mg/L)*	28	778	2080	3747	--	--	--
Total Dissolved Solids (mg/L)**	28	553	1625	3192	500	--	28
Sodium (mg/L)	28	37.0	506	1104	250	--	24
Potassium (mg/L)	28	0.5	3.4	10.0	--	--	--
Calcium (mg/L)	28	0.7	45.6	262	--	--	--
Magnesium (mg/L)	28	0.2	28.9	185	--	--	--
Chloride (mg/L)	28	3.0	11.6	35.0	250	--	0
Bicarbonate (mg/L)	28	444	896	1660	--	--	--
Carbonate (mg/L)	28	0	26.6	106	--	--	--
Sulfate (mg/L)	28	<2.5	550	1500	250	--	17
Nitrate (mg/L as N)	28	<0.25	<0.25	4.50	--	10	0
Fluoride (mg/L)	28	<1.0	1.6	5.0	--	4	3
Iron (mg/L)	28	0.01	0.6	3.7	0.3	--	12
Manganese (mg/L)	28	<0.01	0.1	0.3	0.1	--	7
Selected Trace Elements							
Arsenic (ug/L)	28	<1.0	0.7	4.3	--	50	--
Barium (ug/L)	28	6.8	46.3	184	--	1000	--
Chromium (ug/L)	28	<2.0	5.0	22.8	--	100	--
Copper (ug/L)	28	<2.0	6.6	15.3	--	1000	--
Nickel (ug/L)	28	<2.0	3.5	45.2	--	100	--
Selenium (ug/L)	28	<1.0	1.2	5.2	--	50	--
Other Constituents							
Sodium Adsorption Ratio (SAR)	28	0.5	45	75	--	--	--
Hardness as CaCO ₃	28	2.8	230	1420	--	--	--
pH	28	6.9	8.4	9.1	6.5 - 8.5	--	12

'--', 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 (HCO₃, CO₃, SO₄, Cl, SiO₃, NO₃, F) in mg/L.
**Total dissolved solids reported as equivalent to weight of evaporation residue.