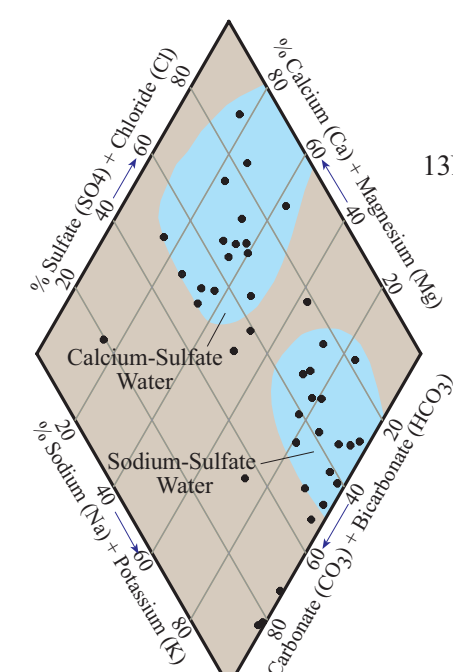
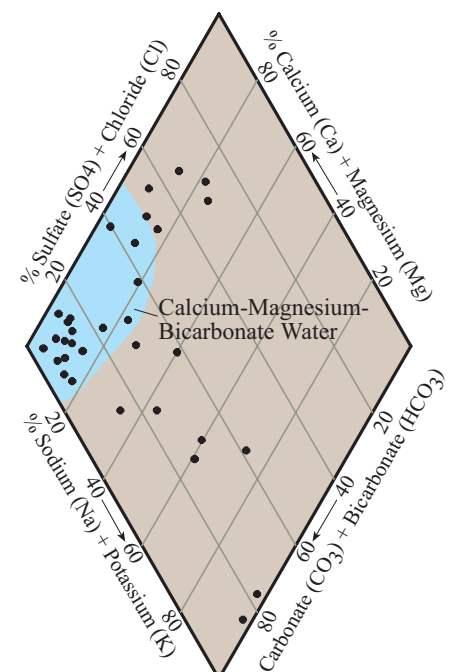
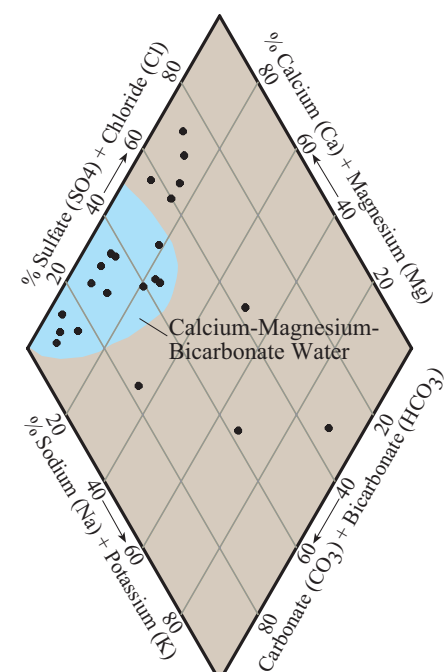
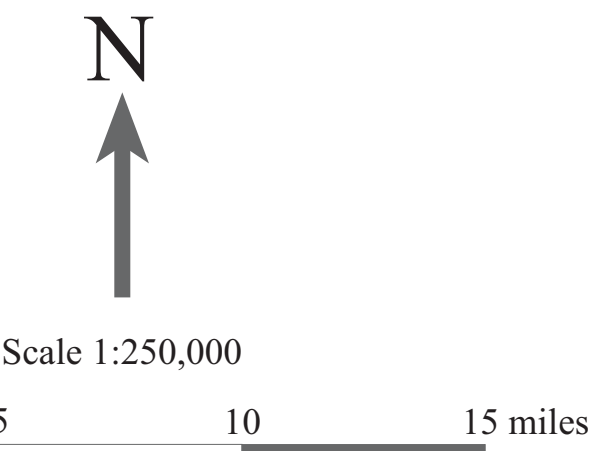
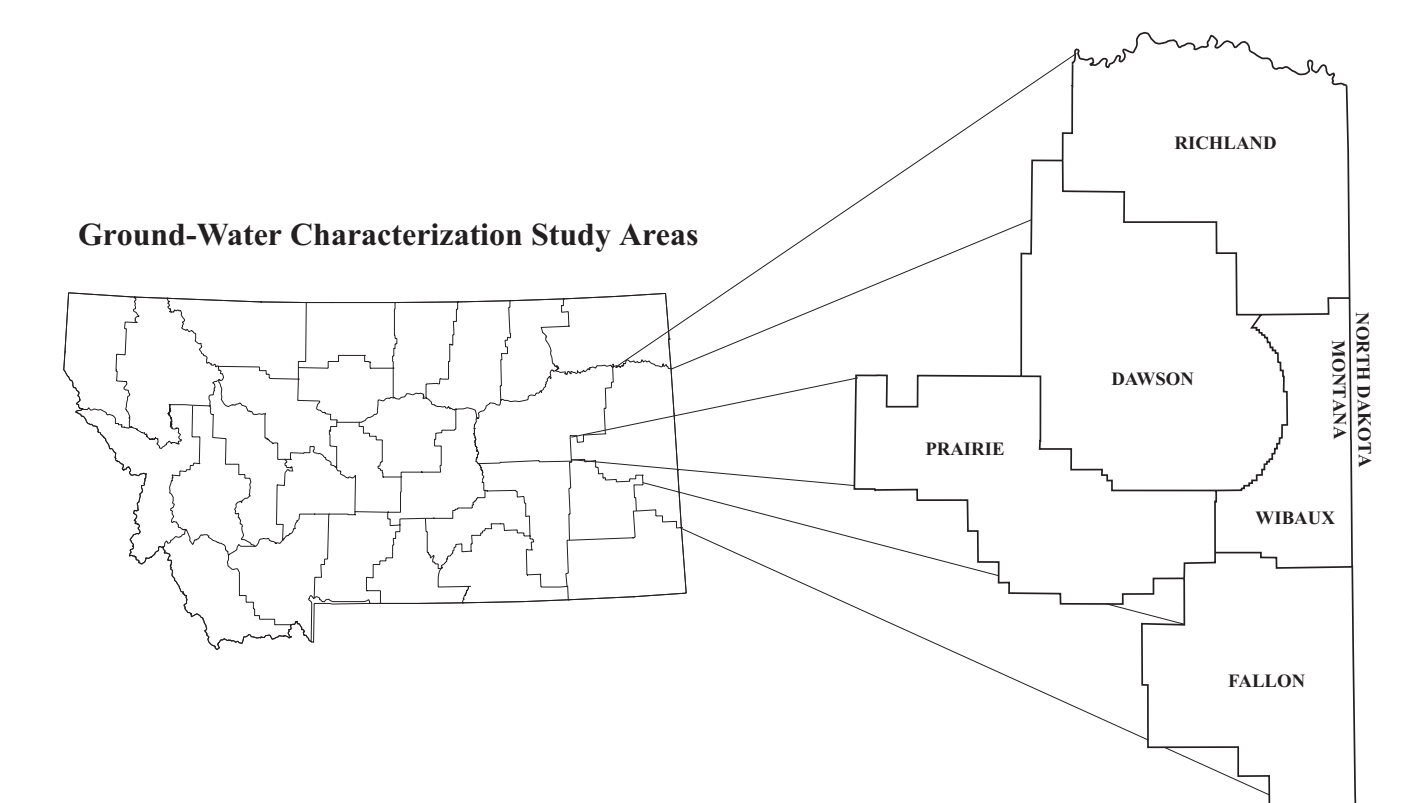


Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground-Water Assessment Atlas for the Lower Yellowstone River Area. It is intended to stand alone and describe a single hydrogeologic aspect of the study area, although many of the area's hydrogeologic features are interrelated. 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 (map) of the Montana Ground-Water Assessment Atlas No. 1.

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

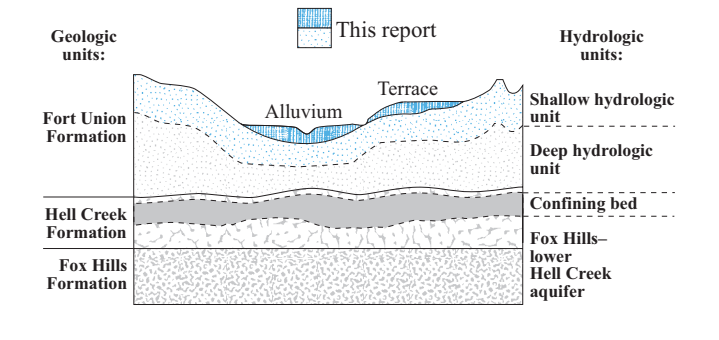


Dissolved Constituents* Map for the Shallow Hydrologic Unit, Lower Yellowstone River Area: Dawson, Fallon, Prairie, Richland, and Wibaux Counties, Montana

by
John I. LaFave and Thomas W. Patton

Introduction

The purpose of this map is to show the distribution of dissolved constituents in the ground water of the Shallow Hydrologic Unit (SHU) in the Lower Yellowstone River study area. The unit consists of all aquifers and non-aquifers within 200 feet of the land surface, exclusive of the Fox Hills-Lower Hell Creek aquifer.



Aquifers are saturated geologic materials that yield sufficient water to supply wells and springs. Non-aquifer materials also may be saturated but have low permeability and do not produce usable amounts of water to wells or springs. The aquifers vary in thickness and are laterally and vertically discontinuous over distances of 10s to 100s of feet where they are separated by non-aquifer materials or by topography. The bottom of the SHU is not defined by a continuous geologic or hydrologic marker but is transitional with the underlying Deep Hydrologic Unit (DHU) (LaFave, 1998). Differentiating the two units simplifies 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 about 200 feet below the land surface.

Geologic deposits that generally are aquifers when saturated with water include the following:

- Sand and gravel deposits in the flood plain, low-lying benches, and terraces adjacent to and along the Yellowstone and Missouri rivers and their tributaries;
- Sandstone, siltstone, and coal of the Fort Union Formation; and
- Sandstone in the upper Hell Creek Formation.

Non-aquifer materials are as follows:

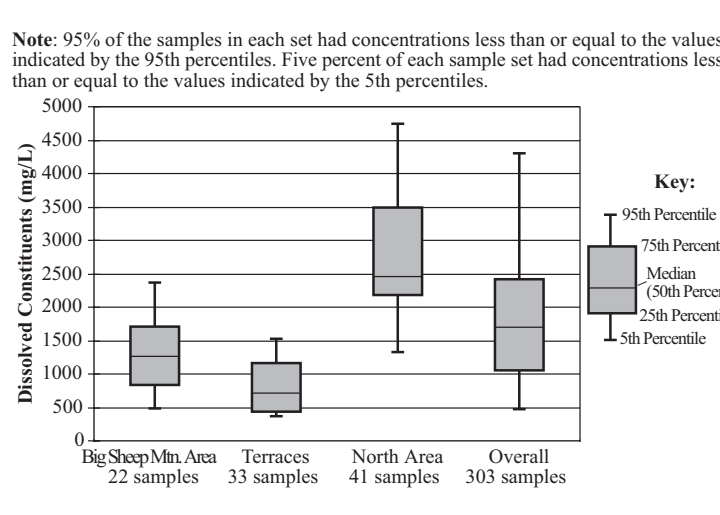
- Glacial till and glacial lake-bed deposits in the northern part of the area;
- Silt and clay deposits within the flood plain and low-lying benches of the Yellowstone and Missouri rivers and their tributaries; and
- Shale of the Fort Union Formation.

Although the SHU consists of a variable sequence of aquifers and non-aquifers, there is sufficient hydraulic continuity to consider it a single entity in terms of ground-water flow.

Records in the Montana Bureau of Mines and Geology's (MBMG) Ground-Water Information Center data base show that almost 7,400 wells (about 70% of total wells) obtain water from the SHU, making it the most utilized ground-water source in the study area. Of these wells, about 4,700 (65%) are completed within 100 feet of the land surface. Reported well yields are variable, reflecting the variable nature of the SHU. In the sand and gravel aquifers, yield average about 3.5 gallons per minute (gpm). However, yields from aquifers in the Fort Union and Hell Creek formations average about 10 gpm. Reported water-level altitudes range between 58 feet above land surface and 180 feet below land surface.

Sample Sites and Water-Quality Data

Three sets of data on dissolved constituents in ground water are presented: laboratory analyses obtained as part of this study, laboratory analyses from earlier studies, and values estimated from field data. Water from 1994 domestic, stock, public supply and monitoring wells was analyzed for major ions and trace metals between September 1994 and May 1996. 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 MBMG Analytical Laboratory. In addition to the samples collected for this study, 213 ground-water samples collected by MBMG



Ground water beneath the localized occurrences of upland terraces along the Yellowstone River valley also has low concentrations of dissolved constituents and a chemical composition similar to that in the Big Sheep Mountain Area. The terraces (indicated on the map with yellow shading), which stand 10s to 100s of feet in altitude above the modern Yellowstone valley floor, are composed mostly of unconsolidated sand and gravel that may be as much as 130 feet thick (Smith, 1998). North of Township 16 North, the terraces may be capped by a silty glacial till that is generally less than 5 feet thick. The sand and gravel terrace deposits have greater permeability and porosity than the underlying sandstones and mudstones of the Fort Union and Hell Creek formations, and represent important recharge areas where water can move easily from the land surface down to the water table. Also, the sand and gravel that compose the terraces are, in general, less chemically reactive than the surrounding bedrock. This is reflected in the water chemistry; the median concentration of dissolved constituents from 33 samples obtained below the upland terraces is 800 mg/L, and the water is a calcium-magnesium-bicarbonate type (see previous illustration and figure 2).

In contrast, ground water in the northern part of the study area, close to the Missouri River, is more mineralized and has a different chemical signature. In the area shaded red on the map, concentrations of dissolved constituents are generally greater than 2,000 mg/L—the median concentration from 41 samples is 2,500 (see previous illustration); the dominant ions in solution are sodium or calcium, and sulfate (figure 3). This area coincides with lower water-table altitudes—generally less than 2,400 feet above mean sea level, and represents a ground-water discharge area for the shallow and deeper ground-water flow systems. The high dissolved-constituents water is probably due to longer flow paths and residence times in the aquifer, giving the water more time to dissolve and react with aquifer materials. The sodium or calcium-sulfate signatures indicate a change in the relative proportion of major ions as compared to the recharge areas discussed above. As water moves down the flow path, it becomes enriched in sodium and sulfate, and depleted in calcium and magnesium. This 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 to other calcium salts—gypsum (CaSO₄) and calcite (CaCO₃)—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.

Across the study area, most of the variability in the dissolved-constituents concentration occurs near the surface (upper 150 ft); however, there is a slight increasing trend in the dissolved-constituents with depth. The high concentration of dissolved constituents in shallow wells reflects the variability of the near surface geologic materials, recharge from more recent localized hydrologic sources, and the influence of the Yellowstone River, irrigation return flows.

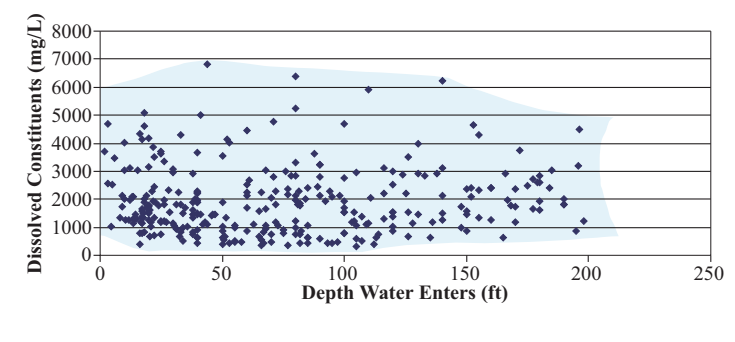


Table 1 summarizes the results of 990 ground-water analyses performed as part of this study. For reference, the U.S. Environmental Protection Agency's recommended maximum contaminant levels and secondary maximum contaminant levels for public water supplies are also presented. Constituents for which maximum levels have been set may pose a health risk if consumed in large quantities. Constituents that do not normally pose a health risk, but that may be a nuisance (bad taste or odor, or staining) but do not normally pose a health risk, are also presented. Despite the relatively high concentration of dissolved constituents (average = 1,700 mg/L), ground water from the SHU is generally suitable for domestic and stock consumption. Recommended maximum levels were exceeded in some samples for nitrate, while nuisance levels of total dissolved solids, sulfate, sodium, iron, and manganese were common. Although most samples did not contain detectable levels of nitrate, the maximum contaminant level of 10 mg/L-N was exceeded in 8 of the samples (about 8%). The concentrations

ranged from non-detectable (57 samples) to 44.5 mg/L-N. Nitrate is an essential nutrient for plant life, yet it is a potentially toxic pollutant when present in drinking water at excessive concentrations. Pregnant women and infants less than one year of age, are most at risk for nitrate poisoning if they ingest water, or formula prepared with water, having nitrate concentrations in excess of 10 mg/L-N. Nitrate poisoning can result in methemoglobinemia, or blue-baby syndrome, in which the ability of the baby's blood supply to carry oxygen is reduced to the point that suffocation can occur. Nitrate has natural as well as human-related sources. However, where nitrate contamination of ground water has been identified, it is usually related to a known or suspected nitrogen source (Madison and Brunet, 1984). Significant human sources of nitrate include septic systems, agricultural activities (fertilizers, irrigation, dry land farming, livestock wastes), land disposal of wastes, and industrial wastes. Natural sources of nitrate include fixation of nitrogen in the soil and nitrogen-rich geologic deposits (generally shales). Nitrate enters the ground water system by leaching of surface or near-surface sources. Aquifers close to the land surface may lack protective overlying low-permeability materials and are susceptible to contamination from surface sources. The open intervals in all wells that had nitrate concentrations above the recommended limits were within 70 feet the land surface.

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 combination with other ions, give water a bitter taste. Ground water from aquifers with higher sulfate concentrations may also have a "rotten egg" smell due to hydrogen sulfide (H₂S) 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."

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. 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 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. In the 90 samples analyzed as part of this study, SAR values ranged from less than 1 and with a mean of 10, the SAR exceeded 10 in 19 of the samples.

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 the 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 60% 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-dissolved constituents water because this is generally the upper limit of water suitability. These data sets are plotted on the map. More than 300 wells are shown from which samples were collected for laboratory analysis. Of these, 90 were sampled as part of this study between November 1994 and May 1996 and represent the primary data set; 213 wells sampled between 1947 and 1994 (61) were sampled since 1973 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 424 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 (LaFave *et al.*, 1998). Therefore, field specific-conductance measurements were multiplied by 0.90 to estimate the dissolved-constituents concentrations in water samples 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 the data collection necessary for this map, and those who collected the data are all gratefully acknowledged. Reviews of this report by Wayne Van Vleet and Peter Norbeck improved its clarity.

Data Sources

Geographic features: Hydrography, 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. Township boundaries digitized from 1:250,000 U.S. Geological Survey mapping also are available from NRIS.

Point data: Well-location and water-quality data for the primary and inventory data sets were obtained by Ground-Water Characterization Program (GWCP) well location and water-quality data for the historic data set was obtained from the U.S. Geological Survey or Montana Bureau of Mines and Geology files. All 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 (HCO₃, CO₃, SO₄, Cl, NO₃, F) expressed in milligrams per liter (mg/L). TDS is traditionally measured by weighing residue remaining after evaporating a known volume of water, or estimated by assuming the major ions after multiplying the bicarbonate (HCO₃) concentration by 0.49 to account for loss to the atmosphere during evaporation. For example, about half of the bicarbonate (HCO₃) 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-solids concentration in solution especially where bicarbonate concentrations are high. A more accurate measure of dissolved constituents is obtained by multiplying the concentrations reported for the various dissolved constituents.

