Montana Ground Water Assessment Atlas 8, Map 3, Sheet 1 of 2

Groundwater Quality of Gallatin and Madison Counties, Southwest Montana

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2018

Author's Note: This map (sheet 1 and 2) is part of the Montana Bureau of Mines and Geology (MBMG) Ground Water Assessment Atlas for the Gallatin–Madison Groundwater Characterization Study Area. It is intended to stand alone and describe a single hydrogeologic aspect of the area, although many of the area's hydrogeologic features are interrelated. For an integrated view of the hydrogeology of the Gallatin–Madison Study Area, the reader is referred to other maps of the Montana Ground Water Assessment Atlas 8.

Gallatin–Madison Ground Water Characterization Study Area

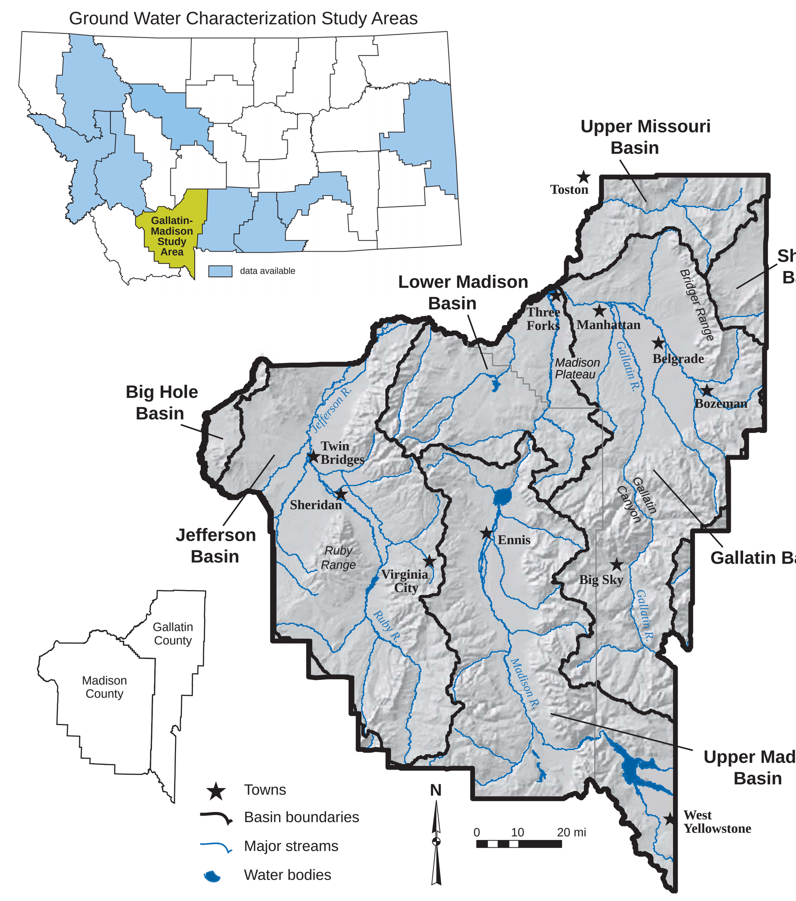

Figure 1. The study area encompasses all of Gallatin and Madison counties. Major drainage basins include the Jefferson, lower Madison, upper Madison, and Gallatin. Water samples were collected from all major aquifers.

INTRODUCTION

This map (sheets 1 and 2) describes groundwater quality from the principal aquifers in the Gallatin–Madison Groundwater Characterization Study Area (fig. 1). In these counties, fractured bedrock and unconsolidated basin-fill aquifers provide about 24 million gallons of groundwater per day (74 acre-feet per day) for public water supply, irrigation, stock watering, and domestic uses (Maupin and others, 2014). The figures on this map describe the distribution of total dissolved solids, water types, arsenic, nitrate, radon, and selected environmental isotopes in the principal aquifers. These data represent baseline information for assessment of groundwater resources in Gallatin and Madison Counties.

GALLATIN AND MADISON STUDY AREA

Gallatin and Madison Counties are similar in size—2,632 and 3,602 square miles respectively—but differ in population. Madison County has about 7,700 residents with no large population centers; Gallatin County has an estimated population of 95,000 with large communities in the Gallatin Valley (cities of Bozeman and Belgrade).

Within Gallatin and Madison Counties are four intermontane basins delineated on the basis of topography. The basins are mostly north–northwest trending with perennial streams that have broad floodplains and are bounded by mountain ranges; they include: the Jefferson Basin, the upper and lower Madison Basins, and the Gallatin Basin. Minor parts of the Big Hole, Shields, and upper Missouri basins also fall within the study area (fig. 1).

The basins contain thousands of feet of unconsolidated to semi-consolidated Quaternary and Tertiary basin-fill deposits that form the major aquifers in the study area. The surrounding mountains consist of older sedimentary, igneous, and metamorphic rocks that also occur at depth below the basin-fill. The mountainous bedrock contains sufficient fracture permeability in most places to yield water to wells.

Figure 2 (Crowley and others, 2017) shows the distribution of the principal basin-fill and bedrock aquifers in Gallatin and Madison Counties. Table 1 describes this hydrogeologic framework. For the purpose of this map, these hydrogeologic units were generalized as four aquifers (fig. 3), two "basin-fill" aquifers (unconsolidated Cenozoic and consolidated Tertiary) and two "bedrock" aquifers (Quaternary/Tertiary igneous and older sedimentary-metasedimentary rocks).

GROUNDWATER SAMPLING

Sample sites were selected to assess the background water-quality conditions in the principal aquifers in Gallatin and Madison Counties between August 2006 and November 2013. Samples were collected from 20 springs and 298 wells (Carstarphen and others, 2015). The samples were analyzed by the MBMG Analytical Laboratory for major-ion, nitrate, and trace-element concentrations. Between 1994 and 2015, 65 sites were sampled for radon. Samples for tritium (108), deuterium, and oxygen-18 (157) were analyzed by the University of Waterloo Environmental Isotope Laboratory.

At each sample site, field measurements of specific conductance, pH, dissolved oxygen, oxidation-reduction potential, and temperature were recorded. Samples were collected after the field measurements stabilized and/or three well volumes had been purged. The analytical results and field data can be retrieved from the Montana Ground Water Information Center (GWIC), http://mbmggwic.mtech.edu/.

GROUNDWATER QUALITY

Concentrations of total dissolved solids (TDS), arsenic, nitrate, radon, and selected isotopes are presented on the following maps and figures. The results are summarized with regard to the major basins and aquifer types. To assess groundwater quality, concentrations are compared to the U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCL) established for health reasons, and the secondary maximum contaminant levels (SMCL) established for aesthetic considerations, such as taste, color, and odor (EPA, 2015). Summary statistics (median and percentile concentrations) and box plots are also presented. For sites with more than one analysis, the highest concentration was used to calculate summary statistics.

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PRINCIPAL AQUIFERS

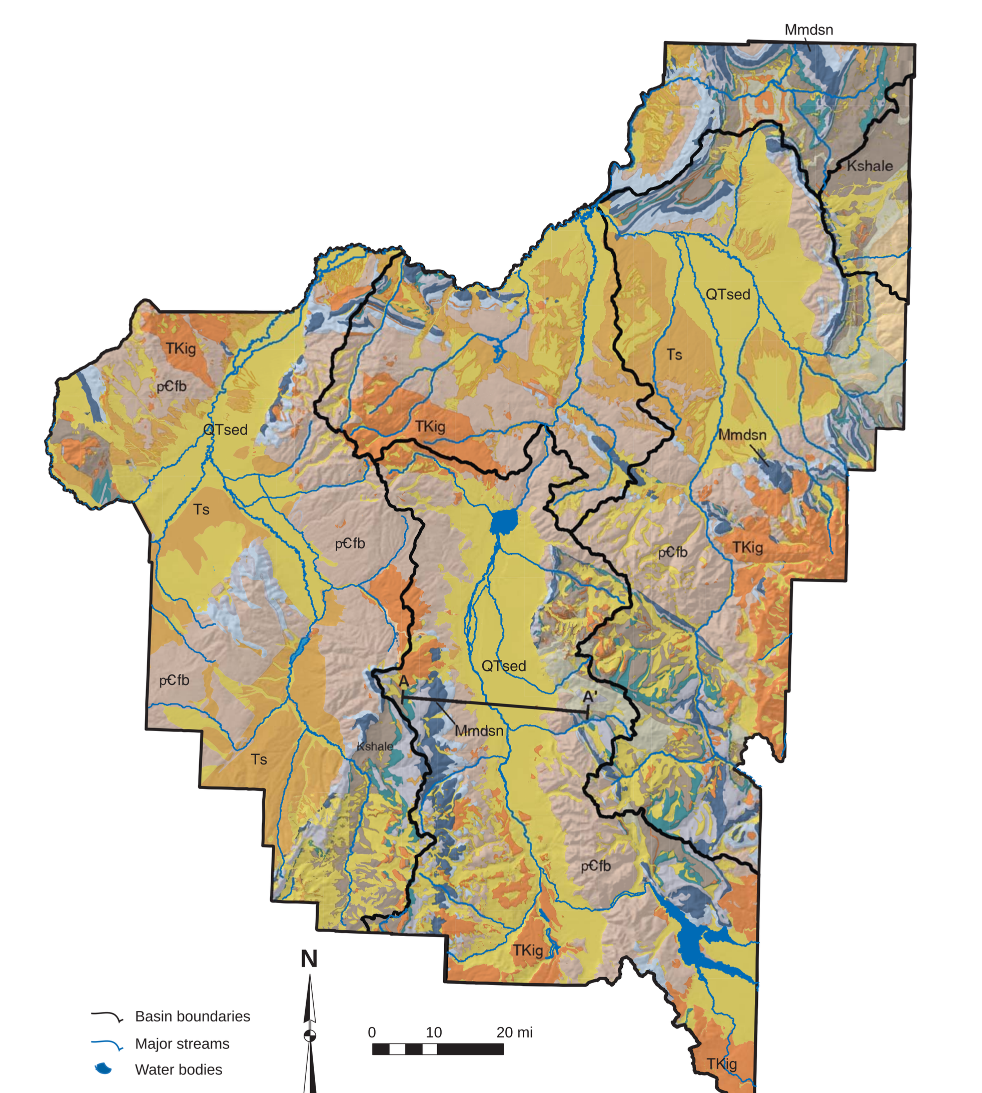

Figure 2. Principal aquifers in Gallatin and Madison Counties. Unit descriptions are presented in table 1. Location of schematic cross-section A–A' (fig. 3) shown on map with a black line (Crowley and others, 2017).

Table 1. Hydrogeologic Unit Description and Key

	Era	Period	Unit Symbol	Unit Name	Occurence and Description of Map Units
Basin-Fill	CENOZOIC	Quaternary Tertiary	QTsed	Cenozoic basin-fill and alluvial aquifers	Quaternary and Tertiary alluvial and basin-fill deposits. Unconsolidated sand, gravel, silt, and clay. Unconfined surficial aquifers with semi-confined to confined aquifers in deep basin-fill.
Basin-Fill	CENOZOIC	Quaternary Tertiary	Ts	Tertiary consolidated sedimentary rock aquifer	Consolidated sandstone, siltstone, and mudstone. Includes the Renova and Six Mile Creek Formations. Occurs on the Madison Plateau and north of the Ruby Range but also notably a large area SE of the Ruby Range.
Bedrock	CENOZOIC	Quaternary Tertiary	Tfu	Tertiary Fort Union aquifer	Consolidated sandstone, silt, clay, and coalbeds of the Fort Union Formation. Middle member (Lebo) often is an aquitard. Occurs in outcrops northeast of the Bridger Range.
Bedrock	CENOZOIC / MESOZOIC	Quaternary Tertiary / Cretaceous	TKig	Tertiary and Cretaceous igneous fractured-rock aquifers	Volcanic and volcaniclastic rocks, flows, tuffs, and igneous intrusive rocks. Generally characterized by fractured flow.
Bedrock	MESOZOIC	Cretaceous	Kegle	Cretaceous Eagle aquifer	Very fine- to medium-grained sandstone, shale, and siltstone. Limited in extent; includes the Livingston Group, an important aquifer in the northeast section of the study area where it is exposed. The Eagle Formation is thin bedded sandstone interbedded with siltstone, bracketted by shales and coalbeds on top and bottom. Crops out in the northeast part of the study area. In some areas the Eagle and the Telegraph Creek Formations are mapped as one unit.
Bedrock	MESOZOIC	Cretaceous	Kshale	Cretaceous Cody, Frontier, and Colorado Group shale confining unit	Black shale interbedded with fine-grained sandstone (Cody Shale), or with alternating sandstone beds up to 3 m thick (Frontier Fm). Gray mudstone and shale with thin sandstone interbeds to brownish gray, clayey sandstone (Mowry Fm and Muddy Sandstone of Colorado Group). Generally a confining unit, but in the Big Sky area sandstone beds produce water.
Bedrock	MESOZOIC	Cretaceous	Kkotn	Cretaceous Kootenai aquifer	Fine- to coarse-grained sandstone, light gray limestone and mudstone, and conglomerate. Basal unit has a characteristic salt and pepper appearance and commonly produces water. Almost all wells completed in the Kkotn aquifer are located near Big Sky. Characterized mostly by primary porosity with some secondary features.
Bedrock	MESOZOIC / PALEOZOIC	Jurassic Triassic / Permian Pennsylvanian	MPsed	Jurassic through Pennsylvanian consolidated sedimentary-rock aquifers	The Mesozoic units include sandstone, mudstone, limestone, and dolomite. Exposed in the very southern part of study area with limited development. The upper Paleozoic units vary from sandstone to limestone to dolomite. Utilized as an aquifer where present in outcrop; Gallatin River Canyon and Toston areas.
Bedrock	PALEOZOIC	Mississippian	Mmdsn	Mississippian Madison aquifer	An important limestone aquifer where exposed or close to the surface, with good productivity and water quality. The exposure is limited to the Big Sky area but uplifted along much of the range front in the study area. Porosity is either secondary or due to fractures.
Bedrock	PALEOZOIC	Devonian Silurian Ordovician Cambrian	Pzl	Lower Paleozoic aquifer	Variable sandstone, limestone, and dolomite, which are utilized as an aquifer where present in outcrop; Gallatin River Canyon and Toston area.
Bedrock	PRECAMBRIAN	Proterozoic Archean	p€fb	Precambrian fractured-rock aquifers	Metasedimentary and archean metamorphic rock that are aquifers where they are sufficiently fractured; bounds many of the intermontane valleys in the study area.

(Crowley and others, 2017)

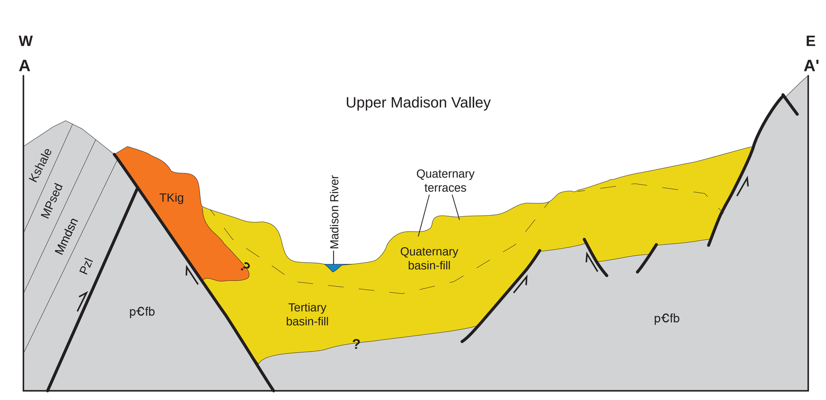

Figure 3. The hydrogeologic framework for the study is generalized as four aquifer types. This schematic cross section, located in the upper Madison Valley area (see fig. 2), illustrates three of the four aquifer types and the general aquifer relationships.

ACKNOWLEDGMENTS
Those who performed the field-data collection are gratefully acknowledged: Don Mason, Mike Richter, Jeremy Crowley, and Camela Carstarphen. Many thanks to the landowners who allowed us to sample wells and springs on their property; our work would be impossible without their help. Thank you to reviewers: Dick Gibson, Luke Buckley, Jeremy Crowley, Alan English, John Metesh, and Susan Barth. Map production and layout was greatly assisted by the help and direction of Susan Smith.

Maps may be obtained from:
Publications Office
Montana Bureau of Mines and Geology
1300 West Park Street
Butte, Montana 59701-8997
Phone: (406) 496-4167 Fax: (406) 496-4451
http://mbmg.mtech.edu

TOTAL DISSOLVED SOLIDS (TDS)

The total dissolved solids (TDS) concentration is the sum of the major cations and anions expressed in milligrams per liter (mg/L); it is a general indicator of water quality and suitability for use: the lower the total, the better the water quality. The laboratory data from 318 samples were used to estimate TDS from specific-conductance measurements made at an additional 743 sites (Hem, 1992). The results are shown in figure 4.

The SMCL for TDS is 500 mg/L; 78 percent of the sites visited were less than this value. The median TDS for all sites visited is 364 mg/L (fig. 5). Medians for basin-fill and bedrock aquifer samples were similar (370 and 354 mg/L, respectively). In three of the basins the median TDS of bedrock samples was slightly higher than the basin-fill (fig. 6). The Lower Madison Basin has a lower bedrock median than basin-fill.

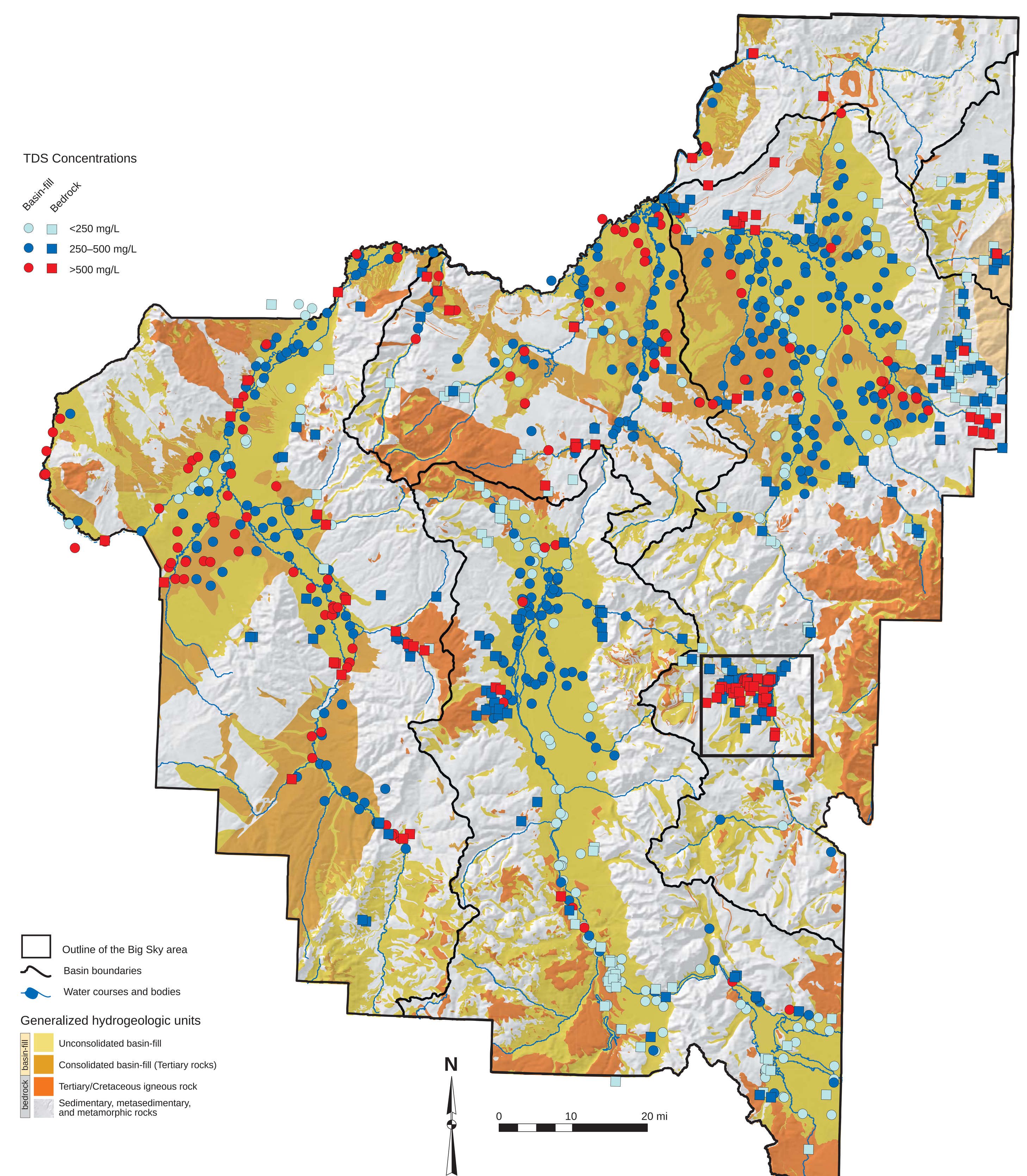

Figure 4. Seventy-eight percent of sites visited (1,061) have TDS below the SMCL of 500 mg/L (blue circles and squares). The bedrock aquifers in the Big Sky area have TDS above this value (see area outline on map). Three hundred and eighteen of these visited sites were sampled.

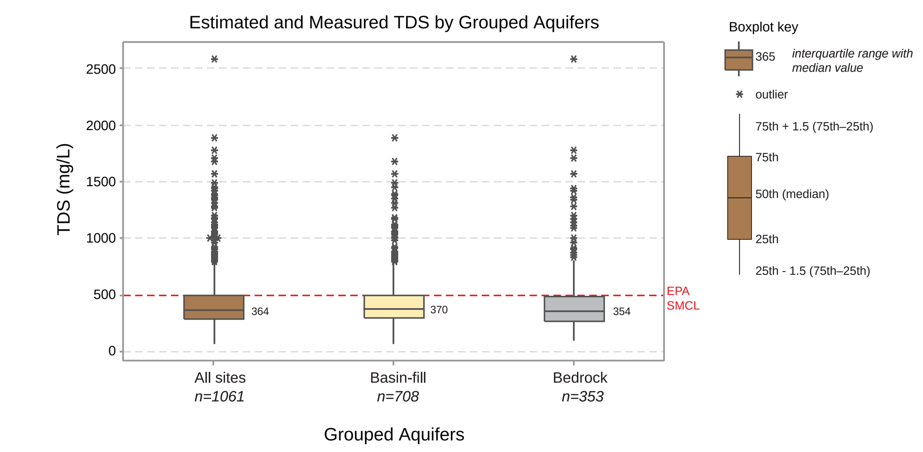

Figure 5. TDS throughout the study area is uniform.

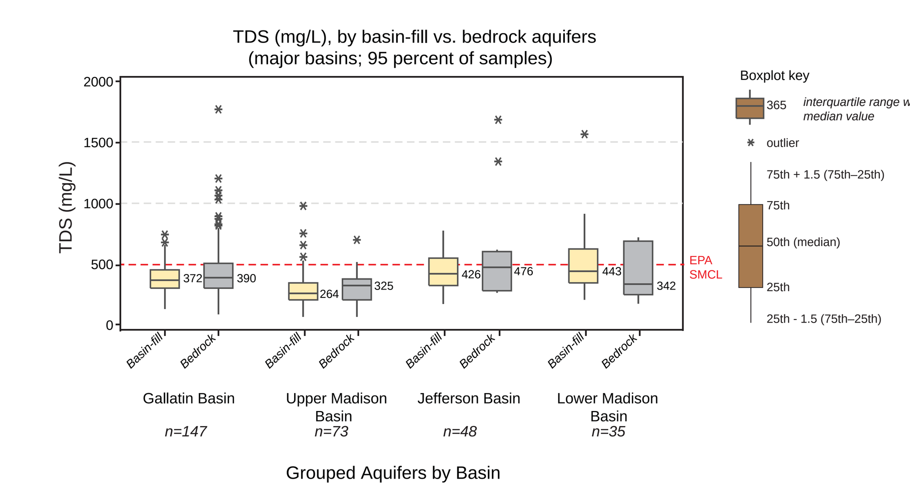

Figure 6. TDS concentrations for each basin are similar. Median concentrations of basin-fill and bedrock samples from each basin are below EPA's SMCL of 500 mg/L.

GROUNDWATER TYPES

Groundwater can be classified by the relative percentages of major ions in solution (fig. 7). Based on the 318 groundwater analyses evaluated for this study, Ca^{2+} and Na^{+} are the dominant cations in solution, and HCO_3^- is the dominant anion. Most of the sampled groundwater (74 percent of samples) is a calcium-bicarbonate ($Ca\text{-}HCO_3$) type, followed by sodium-bicarbonate ($Na\text{-}HCO_3$) type (fig. 8). Low TDS values are associated with calcium-bicarbonate waters (fig. 9). The uniform chemical signature and the low TDS concentrations suggest that recharge water is of good quality and that the aquifer materials are not very reactive.

Water from the Gallatin Basin displayed the most variability (fig. 7), 78 percent of the samples were a $Ca\text{-}HCO_3$ type, while 19 percent had a $Na\text{-}HCO_3$ signature. All of the $Na\text{-}HCO_3$ type water was detected in the Cretaceous sandstone and shale bedrock aquifers of Big Sky and along the eastern flank of the Bridger Mountains.

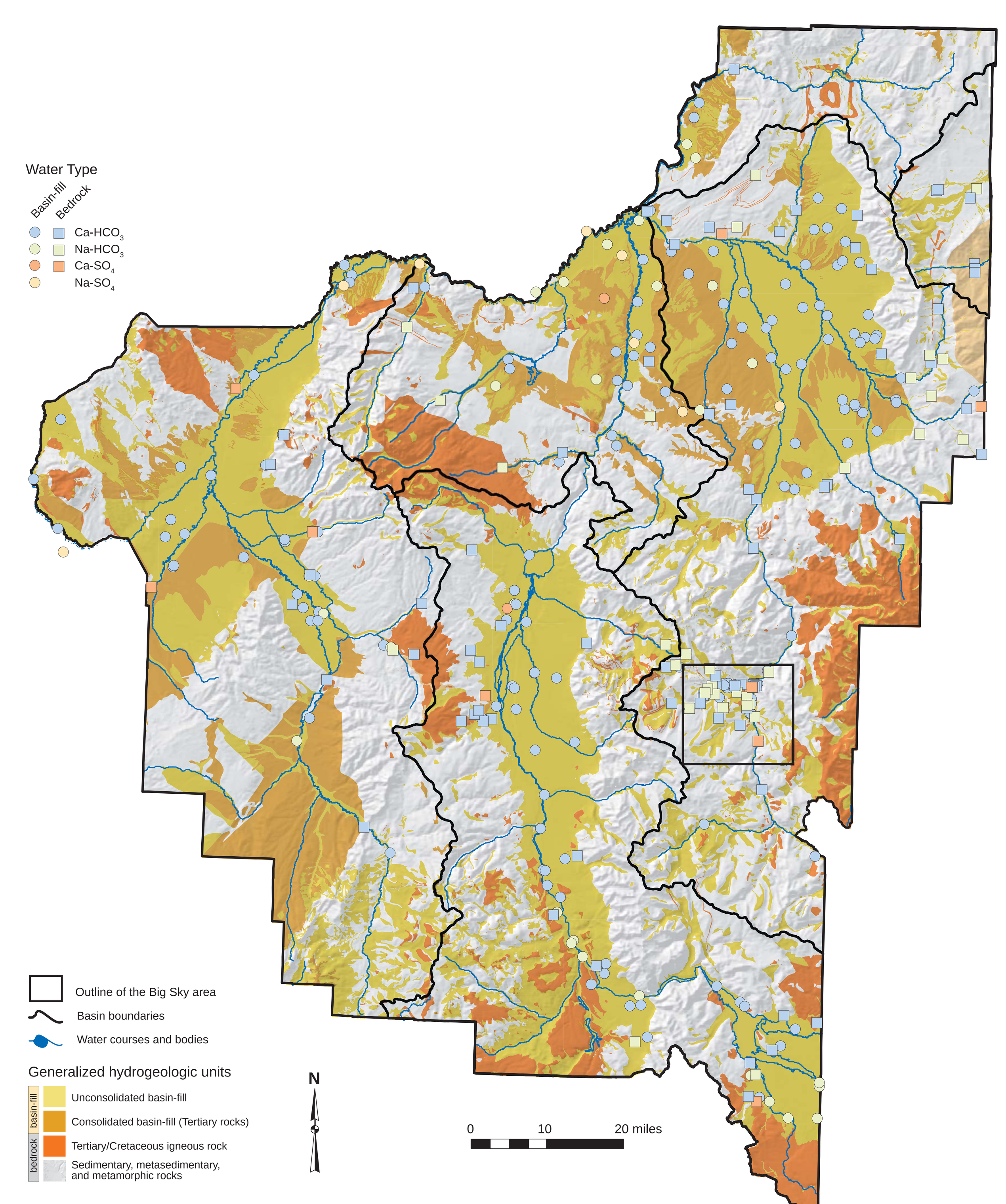

Figure 7. Calcium-bicarbonate water dominates the study area's aquifers; 74 percent of samples (318) are a calcium-bicarbonate type and 19 percent of samples are a sodium-bicarbonate type.

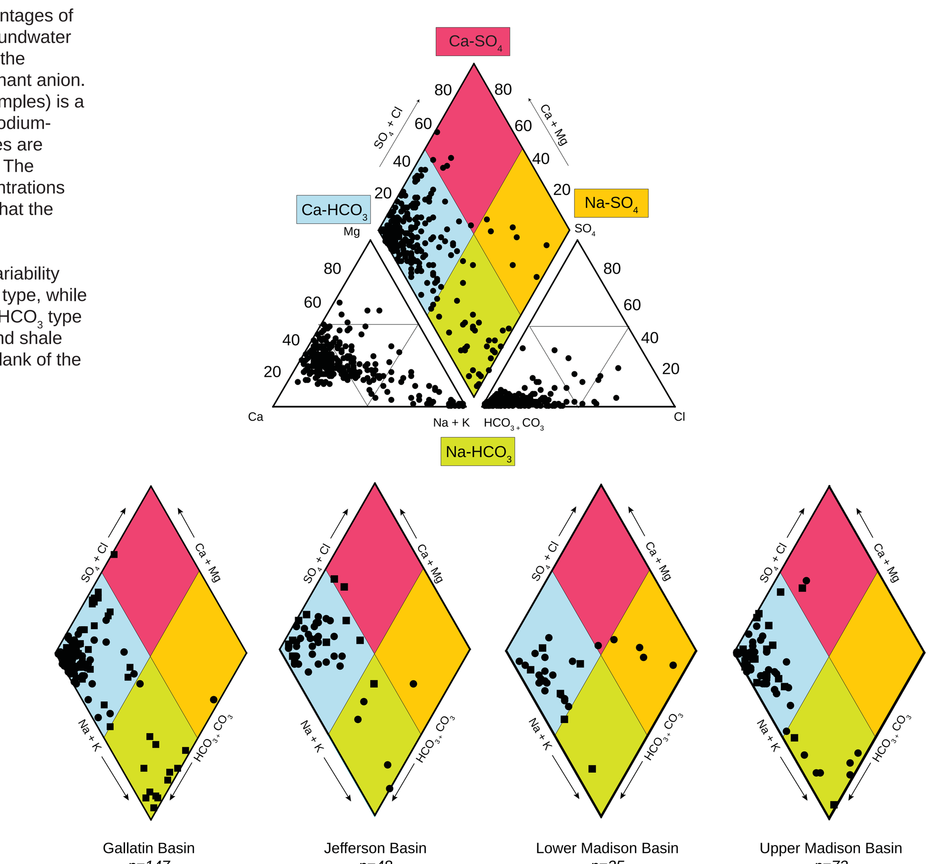

Figure 8. Most groundwater samples are of a $Ca\text{-}HCO_3$ type. In the Gallatin Basin, $Na\text{-}HCO_3$ type water was found in the Big Sky area's Cretaceous-sandstone aquifers (see area on fig. 6).

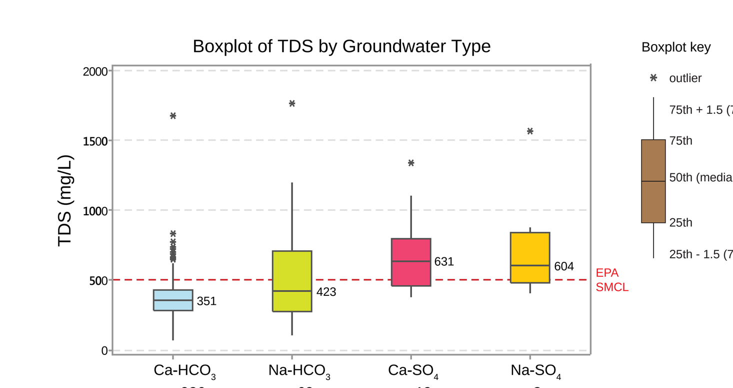

Figure 9. $Ca\text{-}HCO_3$ and $Na\text{-}HCO_3$ groundwater is lower in TDS than the $Ca\text{-}SO_4$ and $Na\text{-}SO_4$ groundwater.