HYDROGEOLOGIC FRAMEWORK OF CASCADE AND TETON COUNTIES, MONTANA

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Front photo: Smith River outcrop with Morrison shale. Photo by Camela Carstarphen, MBMG.

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Ground Water Assessment Atlas 7, Map 2

Accompanying Pamphlet

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FIGURES

This report and accompanying map are part of the Groundwater Assessment Atlas 7 for the Cascade–Teton Area groundwater 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. Companion maps in Atlas 7 include a structure contour map on top of the Madison Group in Cascade County (Smith, 2008), a compilation of sites visited during these investigations (Carstarphen and others, 2011), and a regional potentiometric map of the Madison Group Aquifer in Cascade County (Madison, 2016).

INTRODUCTION

The Cascade–Teton Groundwater Characterization area includes all of Cascade and Teton Counties and underlies about 5,000 mi^2 in north-central Montana (figs. 1A, 1B). The 2020 population of Cascade and Teton Counties was about 90,640 (United States Census Bureau, 2023). Most of the population (67,000 people) live within about a 21-mi^2 area around Great Falls and are supplied by surface water; throughout the rest of the study area, groundwater is used for domestic supply, although some households haul water because groundwater is not available or the quality is too poor (Dieter and others, 2018). Surface water also supplies most irrigation and stockwater uses, but where it is not available, ranchers and farmers depend on wells.

This pamphlet and accompanying map describe and show the distribution of aquifers in the Cascade–Teton characterization area. Interpretations were based on existing geologic maps compiled in a Geographical Information System (GIS) and interpreting hydrostratigraphic units (aquifers and non-aquifers) from rock units of similar hydrogeologic properties.

GEOGRAPHIC SETTING

Cascade and Teton Counties include the Missouri plateau glaciated and unglaciated sections of the Great Plains and the Rocky Mountains physiographic provinces (Fenneman and Johnson, 1946). The counties are characterized by broad, gently sloping plateaus and terraces that are bordered by the Little Belt Mountains to the south, the Adel Mountain volcanic field to the southwest, and the Rocky Mountains to the west (fig. 1). The plains are underlain by sedimentary rocks that dip gently to the north. They consist mostly of mudstone, shale, sandstone, and limestone that were dissected by major drainages, principally the Teton, Sun, and Missouri Rivers (fig. 1; cross-section B–B′ in Vuke, 2000). Thrust faulting in the Rocky Mountains in northwest Teton County resulted in stacked, repeated rock units (imbricate faults) that form spectacular and complex geologic structures with large topographic relief relative to the adjacent plains; this area is referred to as the Montana Disturbed Belt (fig. 1). With the exception of a few private inholdings, land within the Disturbed Belt is public and does not contain wells.

Although there are numerous small springs issuing along bench escarpments at the contact between gravel and underlying shale, they pale in comparison to Giant Springs, which is located on the Missouri River near Great Falls, just downstream from Black Eagle Dam. Giant Springs, one of the largest springs in the United States (Meinzer, 1927), flows from numerous joints in the Kootenai Formation located along and within the channel of the Missouri River. The discharge of Giant Springs was estimated to be about 298 ft3 per second on September 27, 1973, when dam maintenance allowed for indirect measurements (U.S. Geological Survey, 1974). Giant Springs is fed from the underlying Madison Group aquifer.

The Missouri River enters Cascade County near Adel Mountain and flows northeasterly, exiting the study area near the northeast corner of the county (fig. 1). The Great Falls of the Missouri River are a series of waterfalls and rapids that occur along a 10-mi reach of the Missouri River. They developed over resistant sandstone beds within the Kootenai Formation. The falls marked the upper limit of navigable travel on the Missouri River for the Lewis and Clark expedition before portaging around them. Currently, there are five dams and hydroelectric generation facilities on the Missouri River along a 10-mi reach near Great Falls. The Sun River flows east from headwaters near the Continental Divide and joins the Missouri River at Great Falls.

The Smith River, Sand Coulee Creek, and Belt Creek drain the northern part of the Little Belt Mountains and are tributaries of the Missouri River; the Smith River and Belt Creek may be important sources of groundwater recharge to the Madison aquifer, where they flow directly over outcrop areas in the Little Belt

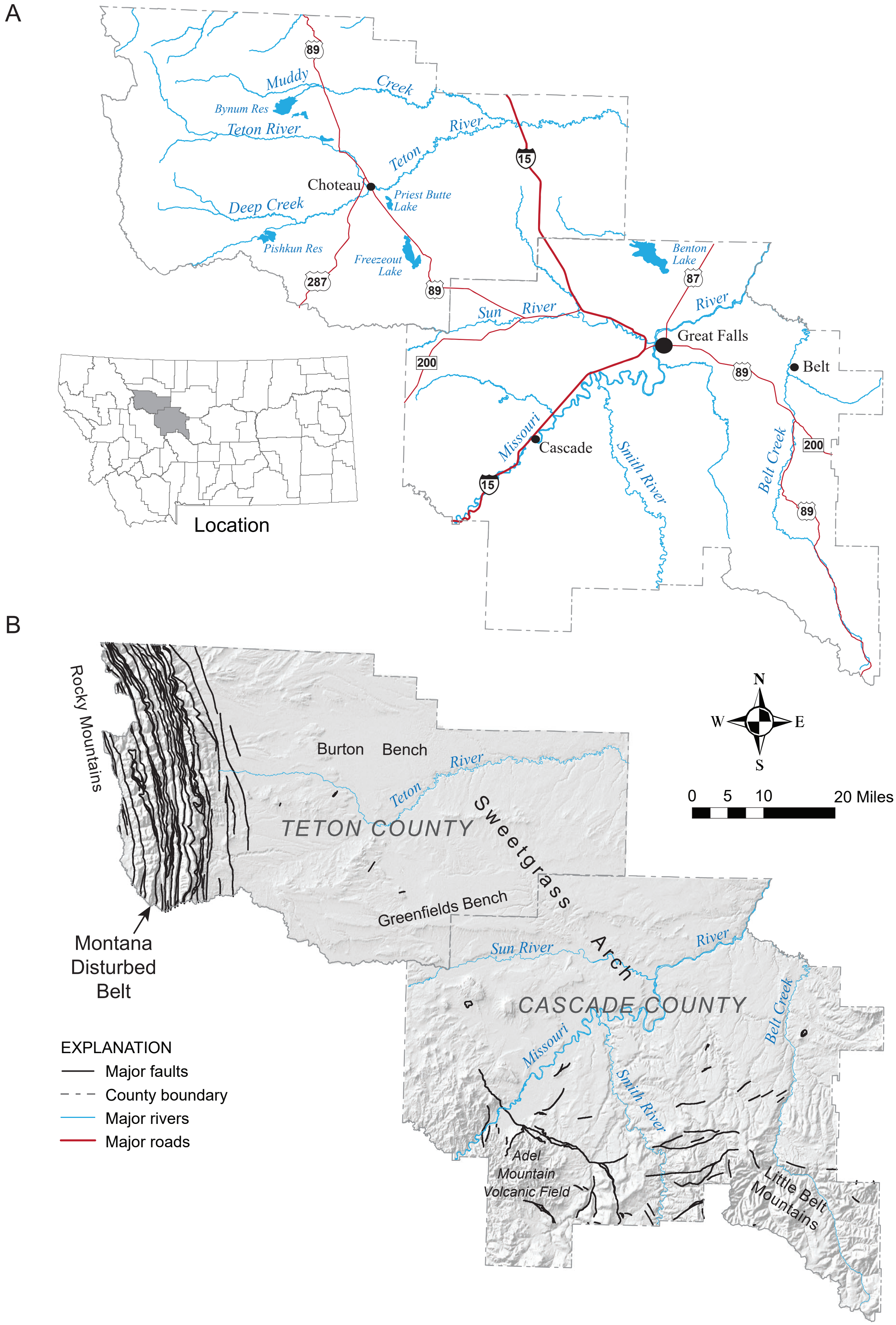


Figure 1. Cascade–Teton study area location (A) and structural and physiographic features (B).

Mountains. The Teton River heads in the Disturbed Belt and flows eastwardly, exiting the study area in the northeast corner of Teton County. Deep and Muddy Creeks are tributaries to the Teton River (fig. 1).

MAP CONSTRUCTION AND DATA SOURCES

The hydrostratigraphic units depicted on the Hydrogeologic Framework map were compiled, melded, and simplified from published 30′ x 60′ quadrangle geologic maps (1:100,000 scale) that are indexed on the accompanying map. The aquifers and confining units described in the framework include geologic formations that may be named differently from one map to another; the geologic units that were combined to form the hydrostratigraphic units are identified on the accompanying map. The geologic map units on the 1:100,000-scale maps were used to identify and assign source-aquifer codes to about 6,900 water wells (wells used for domestic, stockwater, irrigation, public water supply, and industrial purposes and that had lithology, total depth, and location information) in the MBMG Ground Water Information Center database (GWIC; MBMG, 2020). Cross-sections were constructed from geologic maps and lithologic data from GWIC water-well logs.

GEOLOGIC SETTING

Previous investigations and maps of the study are included in work by Weed (1899), Alden (1932), Fisher (1909), Fox (1966), Lemke (1977), Lemke and others (1954), Lemke and Maughan (1977), Maughan (1961), and Feltis (1980a,b,c). Original field mapping and compilation at the 1:100,000 scale as part of the MBMG's participation in the USGS STATEMAP program that produced the maps and GIS products that were used to compile the hydrostratigraphic units, and include Berg (2002, 2008), Berg and Vuke (2002), Lopez (2002), Vuke (2000, 2014), and Vuke and others (2002a, 2002b). Small areas of Cascade County are from 1:100,000-scale U.S. Geological Survey mapping by Reynolds and Brandt (2005, 2007).

Unconsolidated units include Quaternary glacial till, glacial lake, glacial outwash, modern alluvial deposits, and older Quaternary–Tertiary terraces and braid-plain deposits. The till, deposited by continental ice sheets, covers large areas (1,150 mi^2) mostly east and north of Great Falls and consists of up to 50 ft of an unstratified, compact mixture of clay, silt, and sand with scattered gravel. Glacial lake deposits resulted from the damming of the ancestral Missouri and Sun Rivers to create Glacial Lake Great Falls. The lake deposits consist of clay, silt, and fine sand, and can be as thick as 200 ft in the Missouri River, Sun River, and ancestral Missouri River Valley that is now occupied by the lower, underfit part of Sand Coulee Creek (cross-section B–B′); the lake deposits may overlie up to 20 ft of "lag" gravel on the bedrock surface. Prior to glaciation, the Missouri River flowed through an entrenched canyon, south of its present location, which was cut down through the Kootenai, Morrison, and Swift Formations into the Madison Group. The glacial lake sediments backfilled the canyon. Deglaciation and lake drainage resulted in stream-course rearrangements of the Sun and Missouri Rivers to their present locations. Lemke and Maughan (1977) show the subsurface trace of the ancestral Missouri extending from lower Sand Coulee Creek through Gibson Flats, Johnson Flats, and northeastward to the Morony Dam (fig. 1). Alluvium consists of sand, silt, and minor amounts of gravel and clay, and was deposited by modern streams. Alluvium of the Sun River, Teton River, Missouri River, and tributary valleys is about 10–40 ft thick, and it occurs primarily on the floodplains. The alluvium generally overlies glacial lake deposits in the Sun River and Missouri River Valleys, and overlies bedrock along the Teton River Valley.

Remnants of older Quaternary–Tertiary terraces (QTsc) characterize the plains of Teton County. Many of the remnants are parts of at least four bench surfaces or terraces (Vuke, 2014) that may be as much as 820 ft above modern drainages. Most remnants are less than 1 mi^2 in area, but there are much larger remnants in the northern and southern parts of the Teton County. Of note is Greenfields Bench (fig. 1), which consists of at least three bench surfaces that step down to the north. Gravel on the Greenfields Bench may be up to 40 ft thick.

Glacial drift or till also was deposited in areas along the Rocky Mountain Front where alpine glaciers moved out onto the plains. The melting alpine glaciers produced outwash that formed large gravel plains along the Rocky Mountain Front. The Burton Bench (fig. 1) is the most extensive outwash deposit and may be up to 70 ft thick (Patton, 1991; Madison, 2004).

Most exposed bedrock in the Cascade–Teton area consists of Cretaceous sedimentary rocks with a gentle northward dip, and includes (in ascending order) the Kootenai Formation (Kk), Colorado Group (Kc), and Two Medicine Formation (Kthb). In the southeast corner of the study area, along the foothills and within the Little Belt Mountains, rocks at the surface include (in ascending order): Precambrian crystalline basement and intrusive rocks, Cambrian through Mississippian sedimentary rocks (preMm), Mississippian Madison Group (Mm), and Mississippian through Pennsylvanian sedimentary rocks (IPMs and KJs). Cross section A–A′ shows the steeper dips of the rocks in the Little Belt Mountains relative to the gently dipping rocks underlying the plains to the north. Within the subsurface north of the Little Belt Mountains, the Pennsylvanian through Mississippian rocks (IPMs) were completely eroded off of the Madison Group because this area was subaerially exposed due to uplift along the Sweetgrass Arch (cross section A–A′).

The Sweetgrass Arch (fig. 1) is a relevant feature that controls the depth of the Madison Group and other strata in the subsurface as well as controlling the distribution of rocks at the surface. The Sweetgrass Arch is a broad northwest-plunging anticlinal structure that trends from the Little Belt Mountains through Great Falls and northward into Canada. The top of the Madison Group is shallowest along the axis of the arch, and explains why many wells in Cascade County tapping the Madison aquifer within a few miles of the arch's axis are less than 500 ft deep, but some wells on the flanks of the arch must penetrate more than 1,000 ft of overlying Cretaceous and Jurassic rocks to reach the top of the Madison.

The northwest part of the study area is dominated by the Montana Disturbed Belt, where sedimentary beds ranging in age from Precambrian through Cretaceous have been thrust eastward along imbricate thrust faults. In the Disturbed Belt, north–south ridges that are predominantly Madison Group are separated by strike valleys formed in the less resistant Cretaceous sedimentary rocks. Rocks in the Disturbed Belt dip to the west and are not hydraulically connected with equivalent rocks to the east. Land within the Disturbed Belt in the study area is public and does not contain wells.

HYDROGEOLOGY

Aquifers are saturated geologic materials that store and transmit groundwater to wells in usable amounts. An aquifer has quantifiable thickness and lateral extent, and because of geologic mapping, its position in the subsurface is typically known or can be deduced (Crowley and others, 2017). Non-aquifers (aquitards), on the other hand, are composed of fine-grained material that generally do not yield water to wells; locally, however, there may be sandy lenses or zones that yield usable quantities of water to wells, but often the yields are small and the quality is poor.

Within the study area, unconsolidated sediments and sedimentary bedrock formations form the primary aquifers (Wilke, 1983). Based on about 6,900 well records in GWIC, about half (47%) are completed in unconsolidated sediments (Qsf, Qsc, and QTsc) and the other half in various bedrock units (fig. 2). Most wells are reportedly used for domestic (79 percent) and stockwater (13 percent) supplies (fig. 3) and completed at depths less than 200 ft in near-surface aquifers; the exception is the Madison Group aquifer around Great Falls, where wells are completed at deeper depths (median depth 400 ft) because of predictable good-quality water and higher yields (fig. 4). Most reported median well yields are greater than 10 gpm, which can easily supply domestic uses.

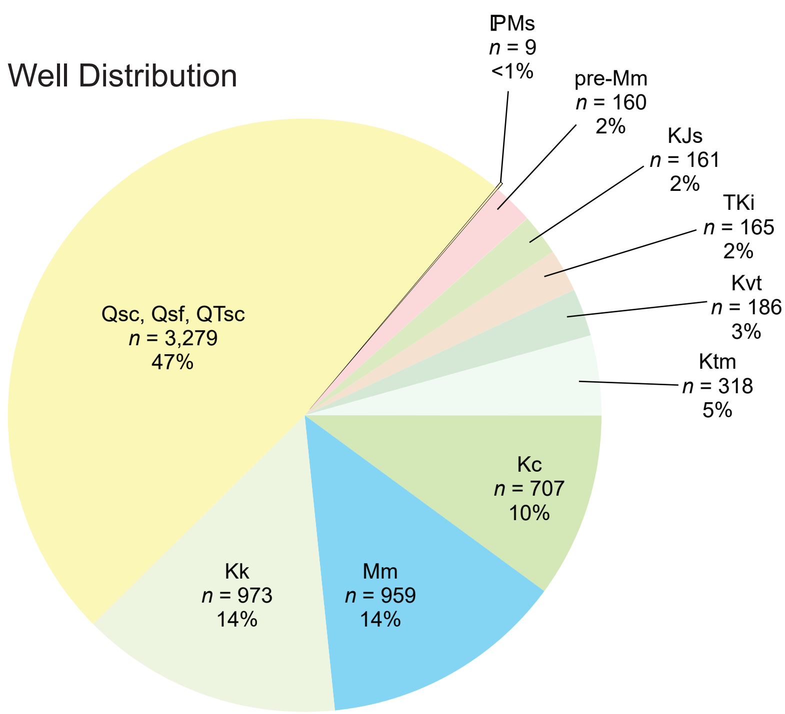


Figure 2. Percentage of water wells by aquifer in Cascade–Teton Counties (based on ~6,800 wells in GWIC).

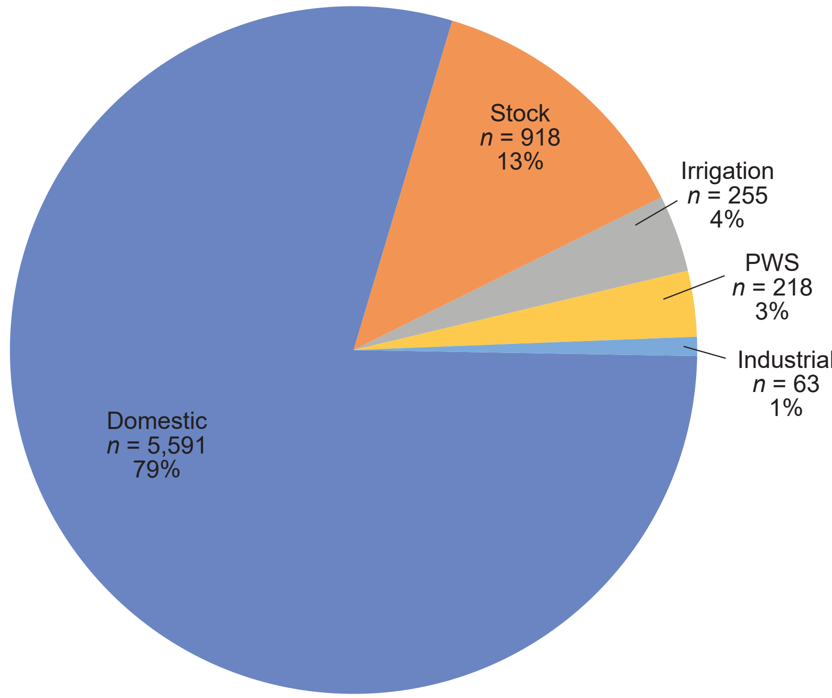


Figure 3. Percentage of wells by reported use in Cascade–Teton Counties.

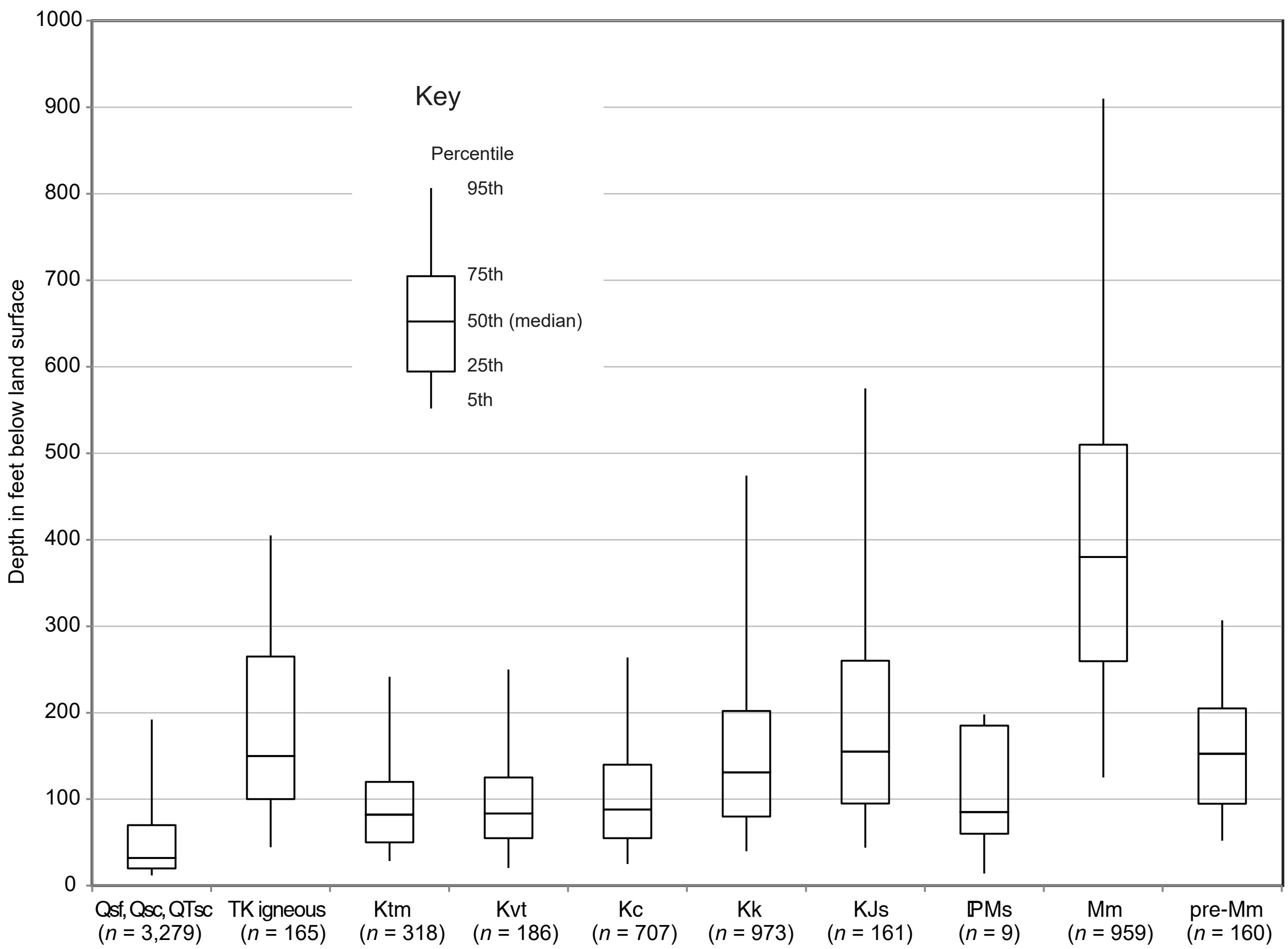


Figure 4. Box plots of driller-reported total depths by aquifer.

The Quaternary and older Quaternary–Tertiary unconsolidated deposits form the alluvial and terrace aquifers. Although most wells are completed within floodplains of the Sun River, Teton River, Missouri River, and tributaries, recharge from leaky irrigation on Burton Bench (cross-section D–D′) and Greenfields Bench (cross-section C–C′) saturate enough of the gravel on these benches to form aquifers (Miller and others, 2002). Without irrigation, other gravel benches may only be saturated with water episodically due to anomalously large precipitation events; wells completed in these benches are not dependable (Patton, 1991; Madison, 2004).

Aquifers in bedrock formations consist mostly of Cretaceous sandstone beds and Paleozoic limestone. The primary sandstone aquifers occur in the Cretaceous Kootenai Formation and the Virgelle–Telegraph Creek Formations. The Cretaceous bedrock aquifers are separated by shale layers that act as confining units; locally, however, near outcrops or where there are transitional contacts with sandstone units, shale formations may yield usable quantities of water to wells that are less than 200 ft deep; drilling deeper in shale units becomes speculative with regard to well yield (small) and/or water quality (poor). The Paleozoic limestone aquifer consists of the Mississippian Madison Group, whose relatively shallow position (less than 500 ft deep) in the subsurface between the Little Belt Mountains and Great Falls has made it a target for well development even when shallower Cretaceous and Jurassic sandstone units exist above it (cross-section A–A′). The Pennsylvanian–Mississippian rocks that crop out in a narrow band along the foothills of the Little Belt Mountains only extend about 6 mi north in the subsurface from where they crop out, because they were mostly eroded off of the Sweetgrass arch (map and cross-section A–A′). Mississippian and older rocks (pre-Mm) below the Madison Group form a minor fractured-rock aquifer in the Little Belt Mountains. Although utilized in the southeastern part of Cascade County, the older units are deeply buried and not utilized throughout the rest of the study area (map and cross-section A–A′).

Unconsolidated Deposits (Qsf, Qsc, and QTsc)

Almost half (47%) of the wells in the study area are completed in the unconsolidated aquifers (fig. 2). Total depth ranges between 12 and 192 ft with a median value of 32 ft (fig. 4). Most reported yields range from about 4 to 100 gpm. About 50 wells have reported yields greater than 500 gpm and are used for irrigation and public-water supply. The median reported yield is 20 gpm (fig. 5).

For this map, Quaternary fine-grained sediment (Qsf), Quaternary coarse-grained sediment (Qsc), and Quaternary–Tertiary coarse-grained sediment (QTsc) were combined into a single unit. Most of the wells in unconsolidated deposits are located in the major river valleys, the Greenfields Bench, and Burton Bench (fig. 6). The modern alluvium associated with the Teton, Sun, and Missouri Rivers comprises a shallow productive aquifer (Qsc). Within the river valleys, a deeper aquifer (Qsc) composed of about a 20 ft thickness of sand and gravel may be buried and confined by almost 200 ft of Glacial Lake Great Falls sediments (Qsf); water in the deeper aquifer is artesian/flowing artesian and may be poor quality, reflecting inflow from subjacent Cretaceous shale units.

The alluvial aquifers of Greenfields Bench (QTsc) and Burton Bench (Qsc) are relatively thin (less than 100 ft thick; cross sections C–C′ and D–D′). Irrigation water associated with agricultural land use provides most groundwater recharge to these two aquifers (Osborne and others, 1983; Patton, 1991; Madison, 2004). The eastern part of the Burton Bench aquifer is buried by lake silt and till that confines the aquifer; wells tapping the aquifer there are either artesian or flowing artesian.

Tertiary–Cretaceous Igneous Rocks (TKi)

Tertiary and Cretaceous igneous rocks were combined into the unit TKi and form a fractured rock aquifer. Rocks include minor dome-shaped Tertiary–Cretaceous intrusives within the Little Belt Mountains and the Adel Mountain Volcanics in the southwest part of Cascade County. The Adel Mountain Volcanics consist of volcanic flows intruded by younger igneous rocks. Lithologies include basalt, monzonite, latite, and shonkonite. The Adel Mountain Volcanics overlie the Two Medicine Formation [included in Ktm and Colorado Group (Kc)], and some water wells have penetrated through the volcanics and into these underlying sedimentary units. Drilling a well into the Adel Mountain Volcanics is speculative with respect to yield and depth, and often, the borehole is unstable (Mark Miller, A-10 Drilling, Helena, Mont., oral commun., 2021). Water yield and availability are dependent upon fractures and fracture networks.

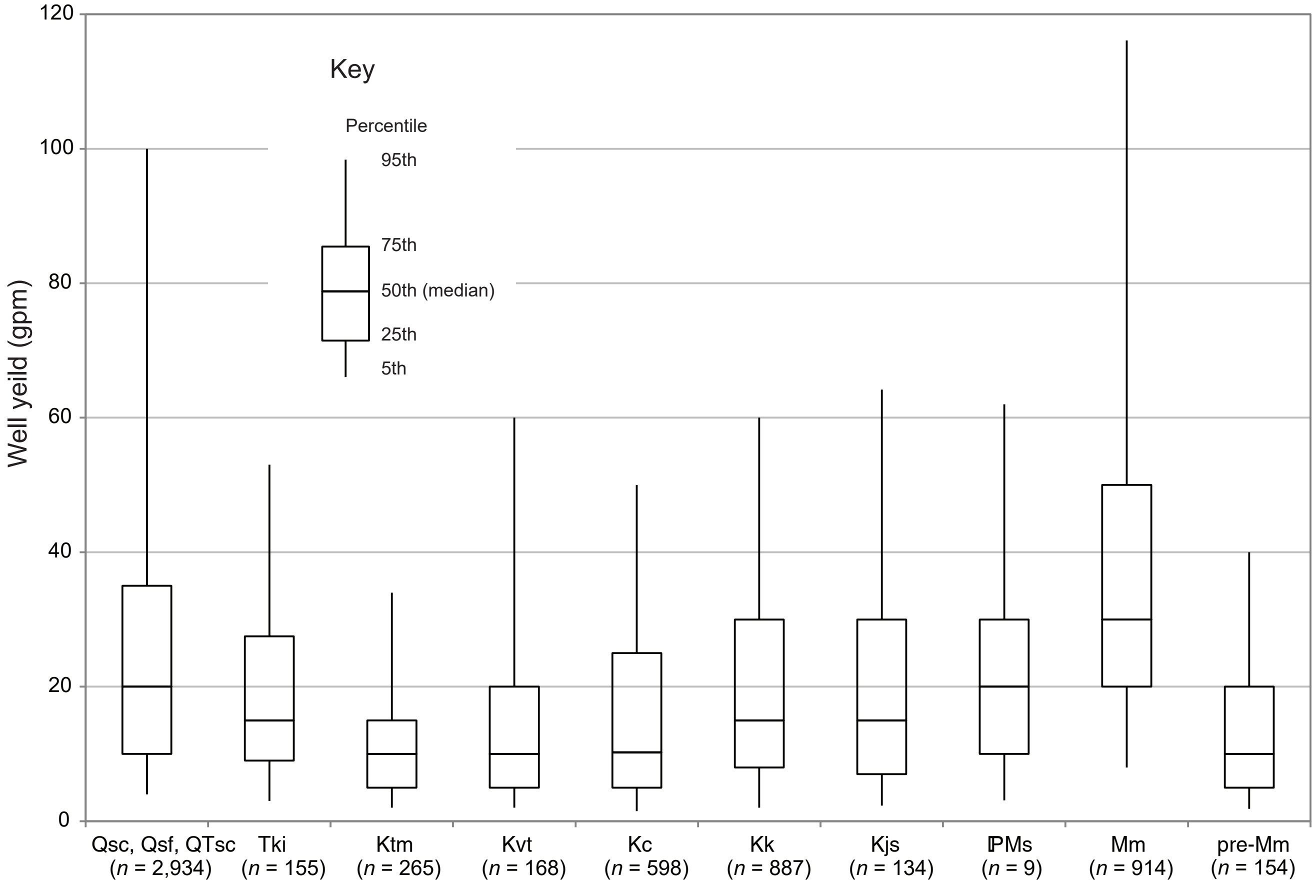


Figure 5. Box plots of driller-reported yield by aquifer.

Within the study area, about three percent of the wells (n = 165) are completed in TKi (fig. 7). Most depths range between 44 and 405 ft, but a depth of 1,007 ft has been reported. Median depth is 152 ft (fig. 4). The maximum reported is 300 gpm, but most yields range between 3 and 53 gpm., with a median of 15 gpm (fig. 5).

Two Medicine Formation and Other Minor Formations (Ktm)

The Cretaceous Two Medicine (Ktm) unit is mostly limited to Teton County and is underlain by the Virgelle and Telegraph Creek Formation (Kvt). Crowley and others (2017) considered the Two Medicine Formation as a regional confining unit; Ktm includes the Two Medicine, St. Mary River, and Horsethief Formations. Only minor remnants of St. Mary River Formation, and Horsethief Formation are exposed in the map area, and their distribution in the subsurface is complicated because of faulting and folding associated with the Montana Disturbed Belt. The Two Medicine Formation is equivalent to the Judith River, Claggett, and upper Eagle Formations on and to the east of the Sweetgrass Arch (Balster, 1980); it is composed predominantly of mudstone with sandstone interbeds, and may be up to 2,200 ft thick (Mudge and others, 1982).

There are records of 318 wells (about 5 percent) completed in the Ktm (fig. 8), mostly between 29 and 242 ft deep (fig. 4), with a median depth of 82 ft. Well yields from most wells in Ktm range between 2 and 34 gpm with a median yield of 10 gpm (fig. 5).

Virgelle and Telegraph Creek Formations (Kvt)

The Cretaceous Virgelle and Telegraph Creek Formations were combined into the hydrostratigraphic unit Kvt. In Cascade and Teton Counties, the Virgelle Formation is equivalent to the Virgelle Member of the Eagle Formation recognized in other parts of the State (Balster, 1980). The Virgelle is moderately thick-bedded, fine-grained sandstone. The Virgelle and Telegraph Creek Formations crop out along the western flank of the Sweetgrass Arch and dip west/northwest into the subsurface where they are deeply buried by the Two Medicine Formation and other units (fig. 7).

The Virgelle Formation ranges from 150 to180 ft thick. The Telegraph Creek is a transitional unit between the overlying Virgelle Formation and the

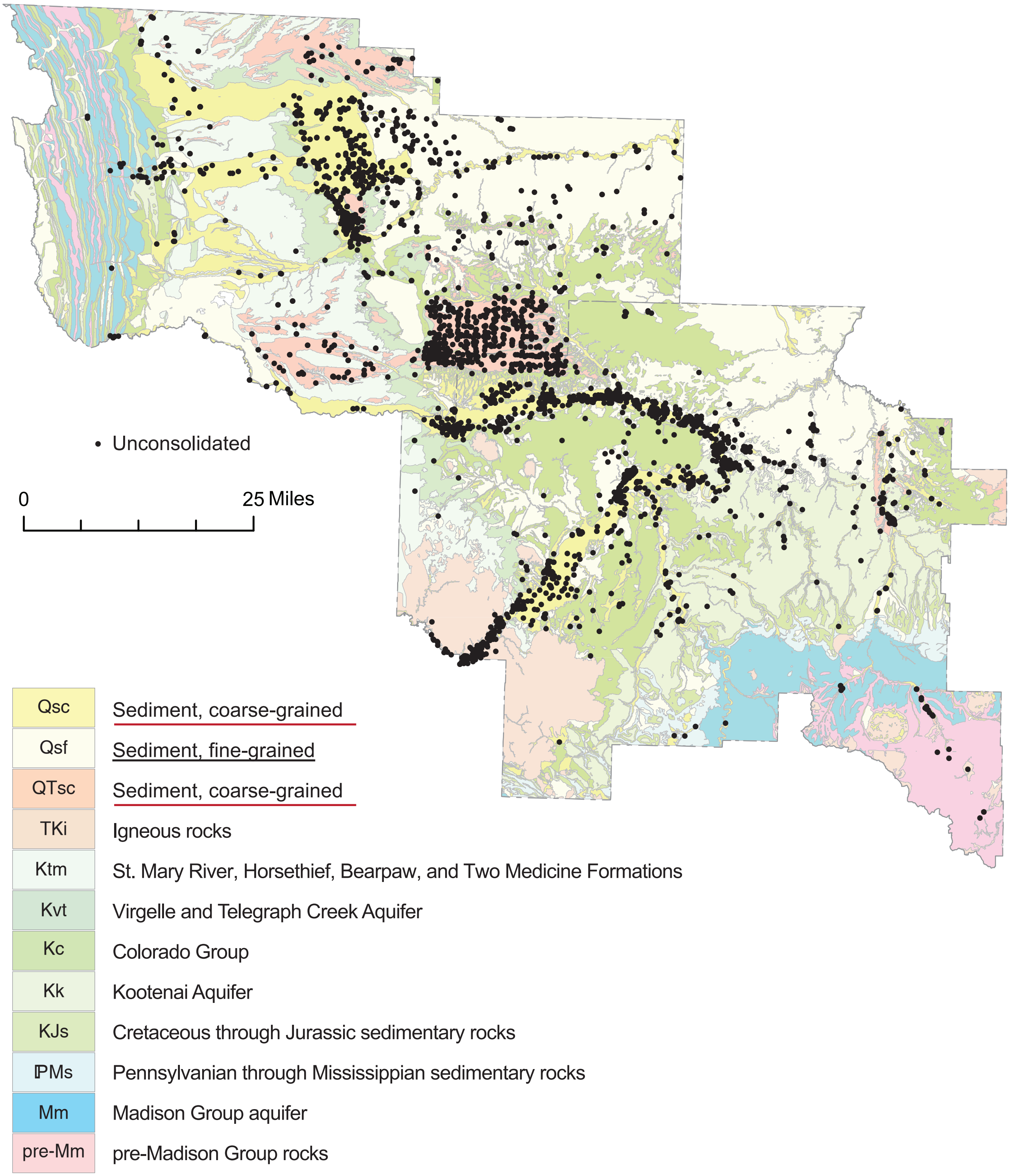


Figure 6. Distribution of water wells in the alluvial aquifers.

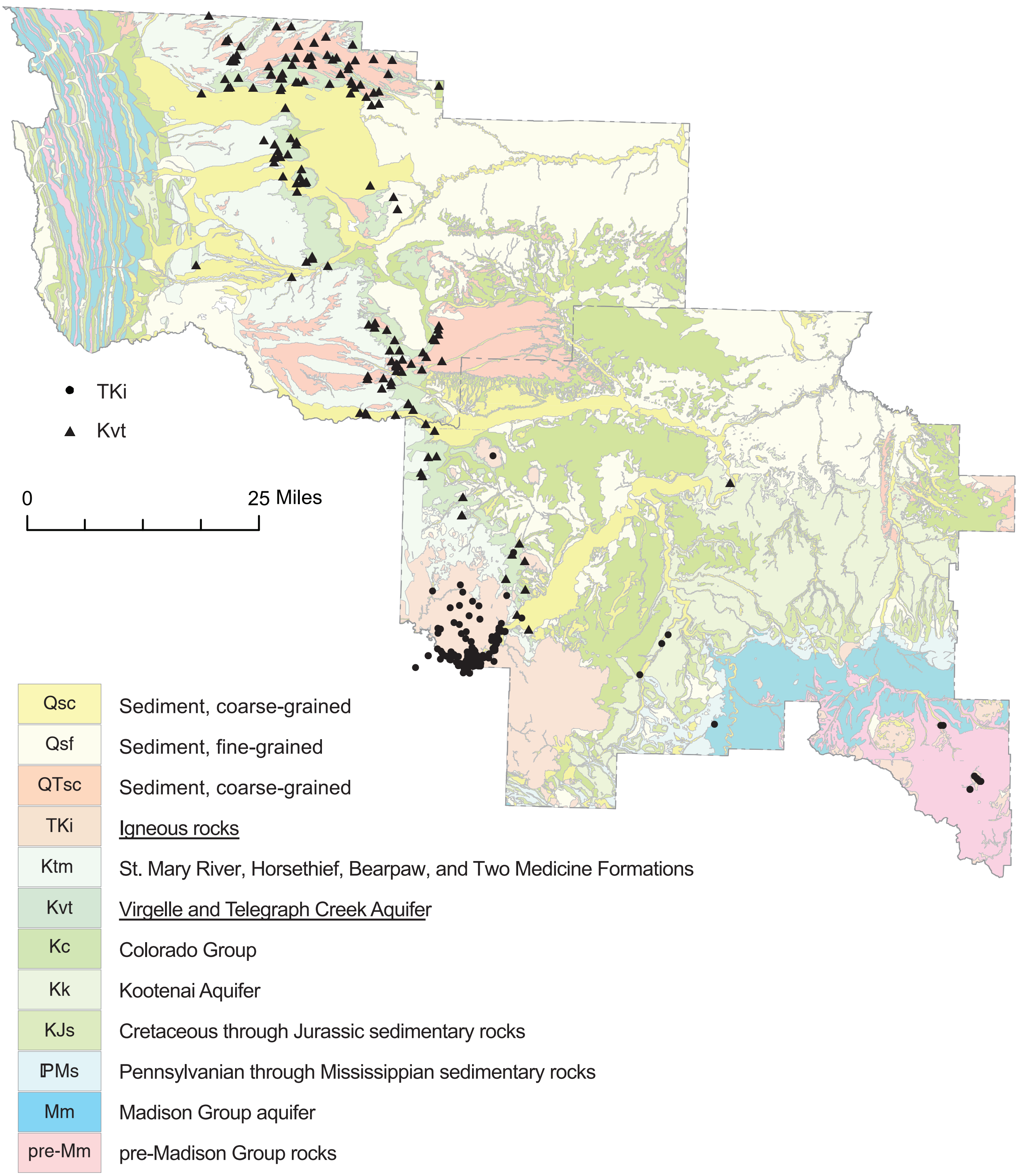


Figure 7. Distribution of water wells in the Adel Mountain Volcanics (TKi) and Virgelle/Telegraph Creek (Kvt) Formation.

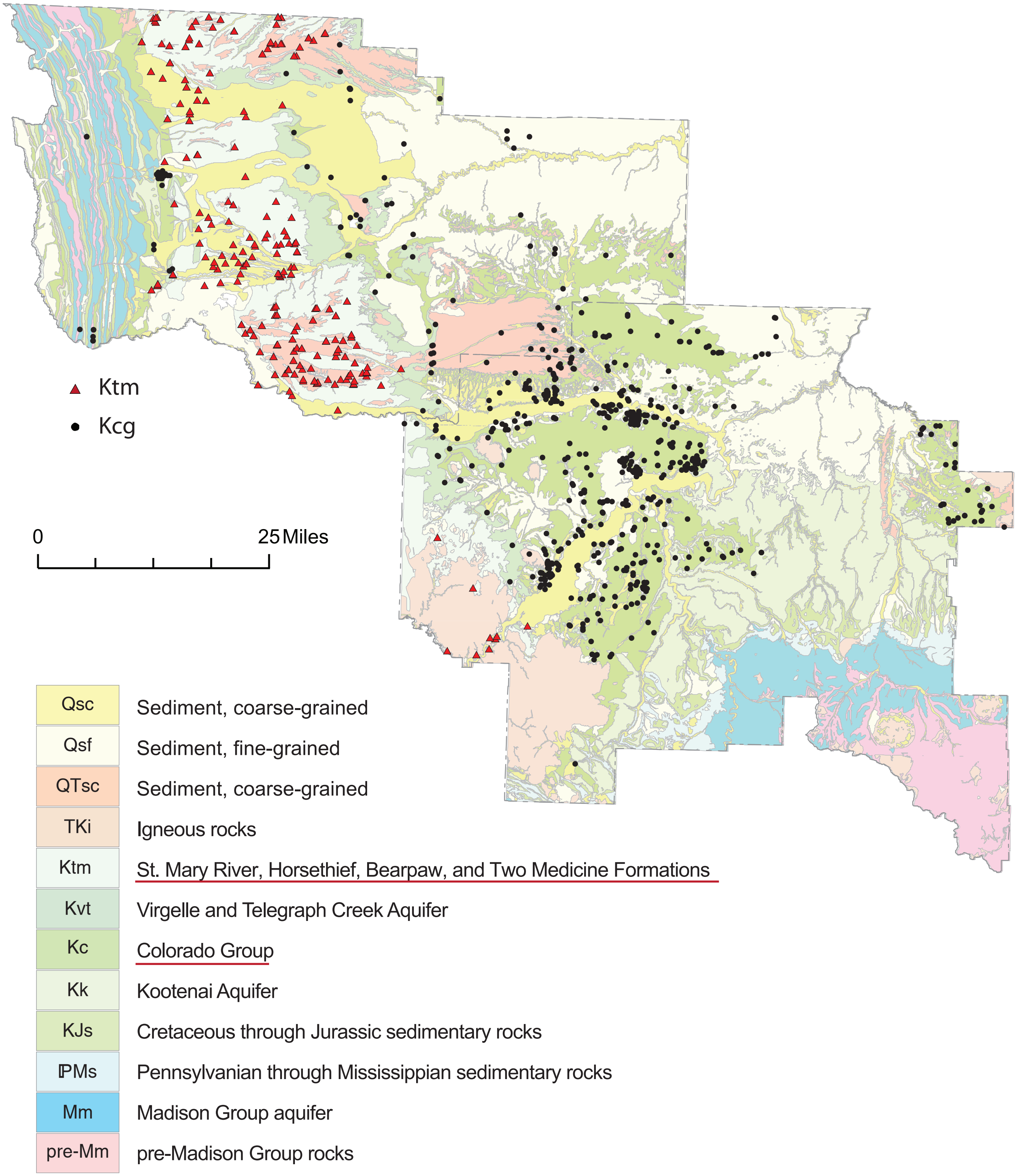


Figure 8. Distribution of water wells in the St. Mary River, Horsethief, Bearpaw, and Two Medicine Formations (Ktm) and Colorado Group (Kc).

underlying Colorado Group. The Telegraph Creek Formation is mainly beds of mudstone interbedded with fine-grained sandstone. The interbeds of sandstone become thicker towards the top of the formation. The Telegraph Creek Formation ranges from 270 to 500 ft thick.

There are records of 186 (3%) wells completed in Kvt (fig. 2); depths range between 21 and 250 ft with a median of 80 ft (fig. 4). The reported yields range between 2 and 60 gpm, with a median of 10 gpm (fig. 5).

Colorado Group (Kc)

The Colorado Group in Cascade–Teton Counties consists of three regional shale-dominated formations that underlie the Telegraph Creek Formation. In descending order they are the Marias River, Mowry, and Blackleaf Formations. Although the Colorado Group is predominantly shale, sandstone interbeds occur locally and may yield water to wells. Together, these units are about 3,200 ft thick (Vuke and others, 2002) and crop out in a broad area in western and eastern Cascade, and southern Teton Counties before dipping northwest along the western Sweetgrass Arch. In northeastern Cascade and Teton Counties, the Colorado Group is buried by 15–30 ft of glacial till (Qsf); few wells are completed in the Colorado Group in this area. The Blackleaf is the lower formation of the Colorado Group. The Flood Member at its base contains a basal sandstone bed that is unofficially called the First Cat Creek sandstone and is sometimes targeted by well drillers where it is at or near the surface.

Most wells completed in the Colorado Group are located in Cascade County (fig. 8). Crowley and others (2017) considered the Colorado Group as a regional confining unit interbedded with localized sand units that may produce water. There are records of 707 (10%) water wells completed in the Colorado Group, mostly between 25 and 264 ft deep, with a median depth of 88 ft (fig. 4). Well yields range between 2 and 50 gpm with a median yield of 10 gpm (fig. 5).

Kootenai Aquifer (Kk)

The Kootenai Formation is an important aquifer in central Montana, especially north of the Little Belt Mountains and the Big Snowy Mountains to the east (Crowley and others, 2017). Within the study area, the Kootenai is composed of five members (Vuke, 2000) consisting of lenticular fluvial or conglomeratic sandstone, siltstone, limestone, and shale. The top member is a red mudstone containing lenses of limestone and sandstone. The red mudstone serves as a marker bed for well drillers where they may stop to cement in steel casing to seal out shallower poor-quality water from the deeper Kootenai sandstone units.

Deeper sandstone units targeted for well completion include the Sunburst and Cutbank Members. The Sunburst Member is the middle member and is informally called the Second Cat Creek sandstone. The Cutbank Member is the basal member and is also informally called the Third Cat Creek sandstone. The Cutbank Member is characterized by black chert grains that give the sandstone a “salt and pepper” appearance. Well drillers target the Cutbank and Sunburst Members around Great Falls for good-quality water and yields suitable for domestic and/or stock purposes.

The Kootenai Formation crops out in a broad area between the Little Belt Mountains and the Missouri River at Great Falls, where it dips northwest into the subsurface (cross-section A–A′). The position in the subsurface is largely controlled by the Sweetgrass Arch, and is shallowest along the axis of the Sweetgrass (fig. 1; cross-section C–C′).

Most Kootenai wells are located within or near Kootenai outcrops and near the axis of the Sweetgrass Arch in Cascade County (*n* = 973). With increasing distance from the axis, the Kootenai becomes more deeply buried and drilling a well becomes more speculative (cross-section C–C′). GWIC has records for seven wells that are completed in the Kootenai in Teton County (fig. 9): the deepest is 1,300 ft deep (cross section C-C’); most Kootenai wells range between 40 and 474 ft deep; the median well depth is 131 ft, reflecting the majority of wells completed in outcrop areas (fig. 4). Reported well yields are between 2 and 60 gpm, with a median yield of 15 gpm (fig. 5).

Morrison and Swift Formations (KJs)

Other Cretaceous and Jurassic (KJs) water-bearing units are the Morrison and Swift Formations, which crop out in a narrow band along the Little Belt Mountains and extend northward in the subsurface to at least north of Great Falls (fig. 10). They also crop out in the thrust belt. The Morrison Formation consists of a coalbed or carbonaceous shale up to 12 ft thick near the top, grading into a sandstone near the base that is

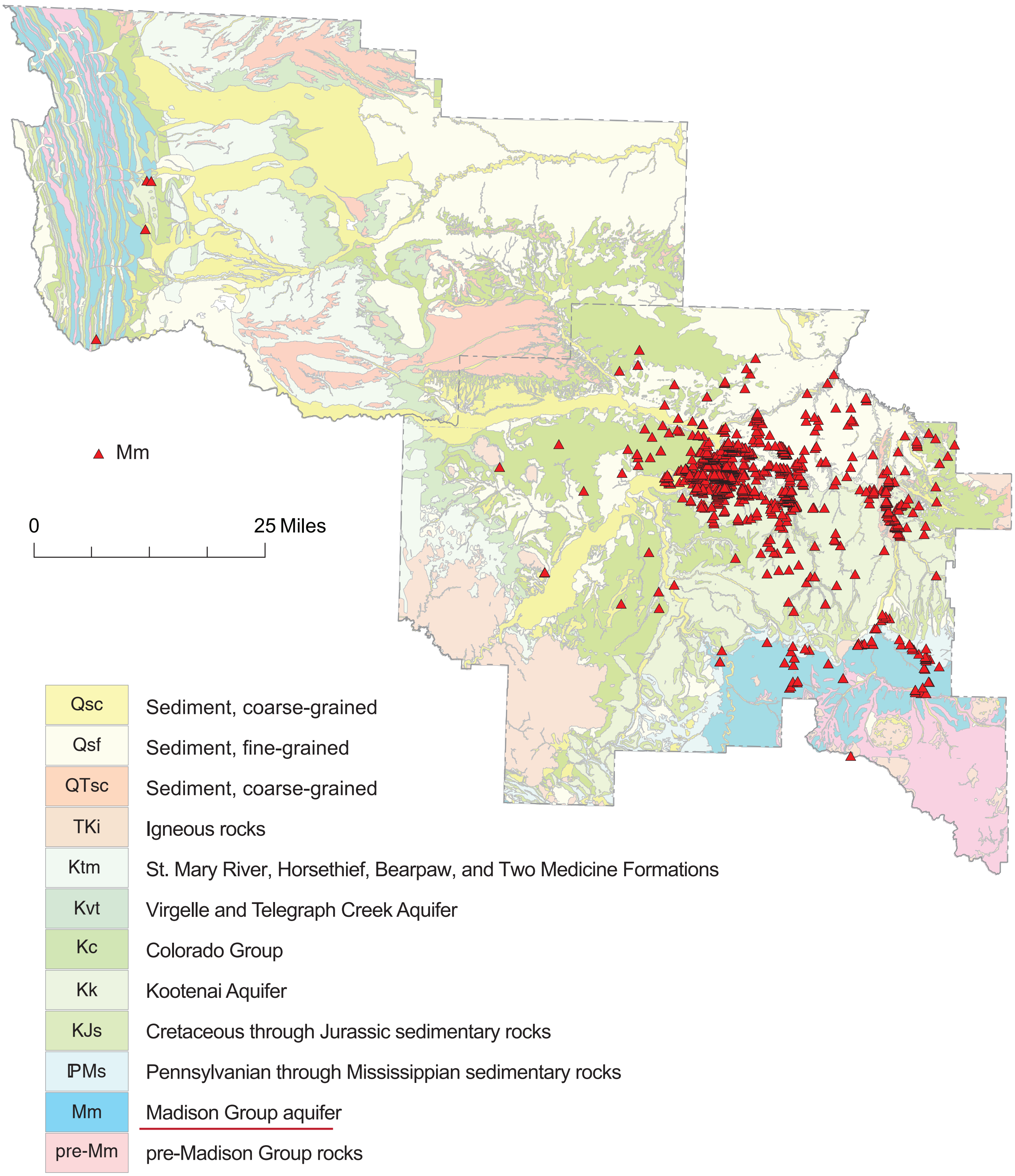


Figure 9. Distribution of water wells in the Madison Group (Mm).

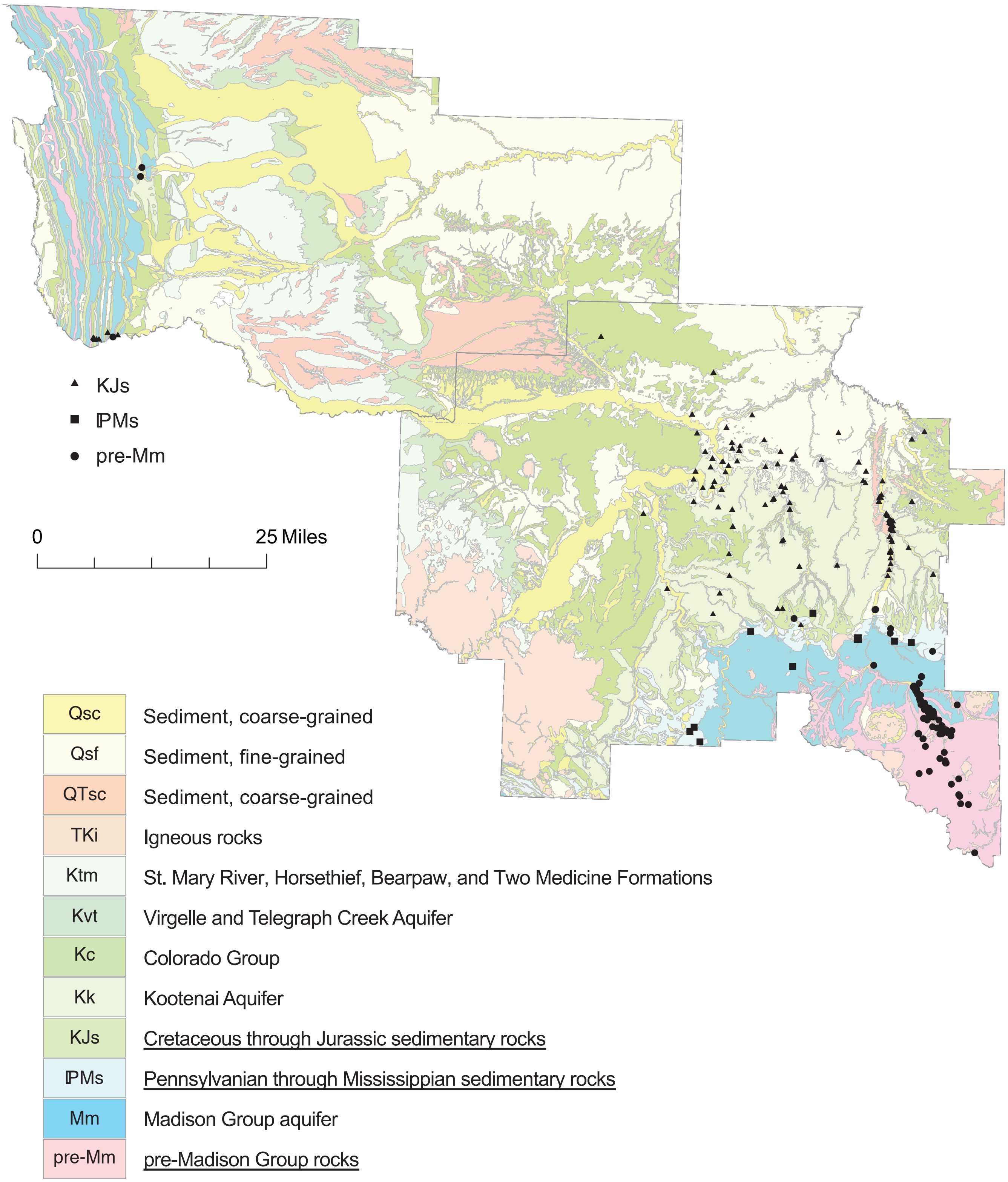


Figure 10. Distribution of water wells in the Morrison/Swift Formations (KJs), Pennsylvanian/Mississippian rocks above the Madison Group (ℙMs), and pre-Madison Group Rocks (preMm).

similar to the underlying upper sandstone unit of the Swift Formation. The upper Swift Sandstone may be up to 40 ft thick, but is not present in the subsurface near Great Falls. Because these units rest on top of the Madison Group between Little Belt Mountain and Great Falls, drillers will often drill through them into the Madison Group to get better quality water and greater yield (Tory Wing, 4A Drilling, oral commun., 2021).

There are records of 161 wells in GWIC completed in KJs, mostly between 44 and 575 ft deep; the median well depth is 155 ft (fig. 4). Most yields are between 2 and 64 gpm, with a median of 15 gpm (fig. 5).

Pennsylvanian–Mississippian Fractured Rocks (ℙMs)

Pennsylvanian and Mississippian rocks (excluding the Madison group) crop out in a narrow band along the foothills of the Little Belt Mountains and only extend a few miles northward in the subsurface; erosional thinning on the Sweetgrass Arch has in part or completely removed them (cross-section A–A′). These units include the Quadrant, Amsden, and Tyler Formations, and Big Snowy Group.

Few wells (n = 9) are completed in ℙMs; well depths range between 14 and 198 ft, with a median of 85 ft. Yield ranges between 3 and 62 gpm, and median yield is 20 gpm.

Madison Group Aquifer (Mm)

The Mississippian Madison Group in the Cascade–Teton area is a marine carbonate sequence composed of the upper Mission Canyon and lower Lodgepole Formations. Total thickness of the Madison Group in Cascade County is estimated to be about 1,000–1,500 ft (Weed, 1899; Witkind, 1971; Peterson, 1966; Noble and others, 1982; Downey, 1986). The Lodgepole Limestone consists of thin- to medium-bedded fossiliferous dolomite and limestone units and shale (Weed, 1899); the thin bedding characteristic of the Lodgepole Formation distinguishes it from the overlying Mission Canyon Formation. The Mission Canyon consists of alternating thin, argillaceous dolomite beds and massive fossiliferous limestone (Peterson, 1966). From a groundwater perspective, an important part of the geologic history of the Mission Canyon Formation is regional uplift by Sweetgrass Arch and erosion of the Mission Canyon Limestone to form a land of low relief upon which karst topography developed (fig. 11).

Karst refers to the dissolution of soluble bedrock. Karst features recognized in the Mission Canyon include enlarged joints, sinkholes, caves, and solution breccia (Maughan, 1954; Sando, 1974; Carriere and others, 2009); these features occur in the upper 400 ft of the Madison Group, and the interconnectedness of these features is responsible for the large yield of water to Giant Springs, estimated as high as 133,700 gpm (USGS, 1974), and some wells.

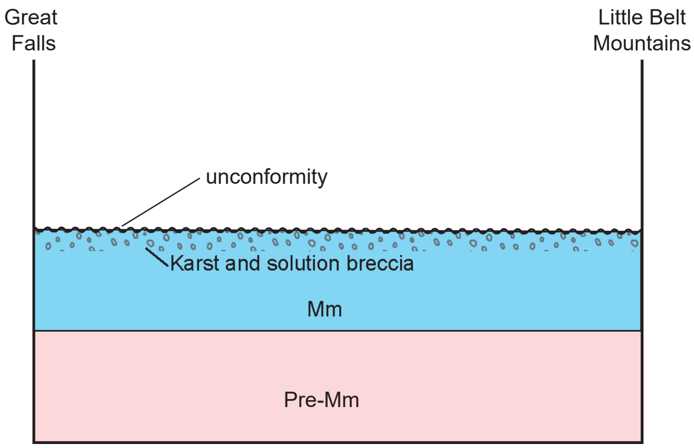
Patton (2005) estimated the regional transmissivity of the Madison Group aquifer near Giant Springs to be about 392,000 ft2/d. Below about 400 ft from the top of the Madison Group, permeability is not influenced by karst features but rather by fractures in the rock, similar to other fractured bedrock units.

The Madison Group is exposed in the Little Belt Mountains and dips gently to the northwest. Between the Little Belt Mountains and Great Falls, the top of the Madison Group Aquifer, due to uplift by Sweetgrass Arch and erosion of younger units (cross-section A–A′), is less than 500 ft below land surface, making it a target for well completions (figs. 12, 13). On the flanks of the Sweetgrass Arch, the top of the Madison Group may be more than 1,500 ft below land surface (fig. 13). Mapping of total dissolved solids by Feltis (1980a) shows that water in the Madison Group north of the Sun River and Missouri River near Great Falls quickly deteriorates and may not be suitable for domestic needs, making a Madison Group well speculative with regard to water quality and productivity.

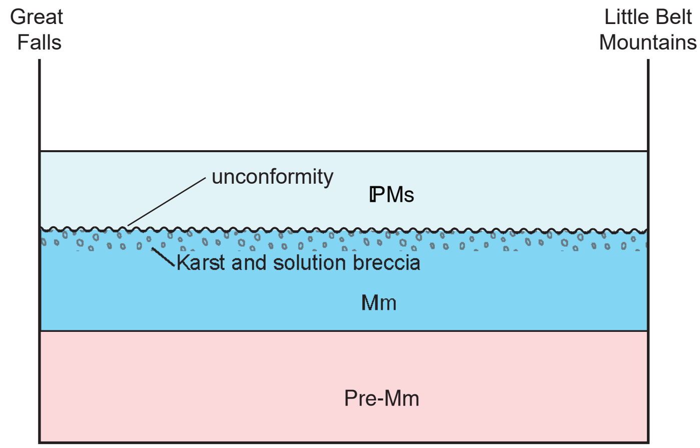
The Madison Group aquifer is the second most utilized aquifer in the study area (fig. 2). Most well depths (n = 959) range between 125 and 910 ft, with a well near Cascade, MT, about 2,300 ft deep. The median depth is 380 ft (fig. 4). Reported well yields range between 8 and 116 gpm, with a median of 30 gpm, the highest of the hydrogeologic units in the study area (fig. 5).

Pre-Mississippian Madison Group (preMm)

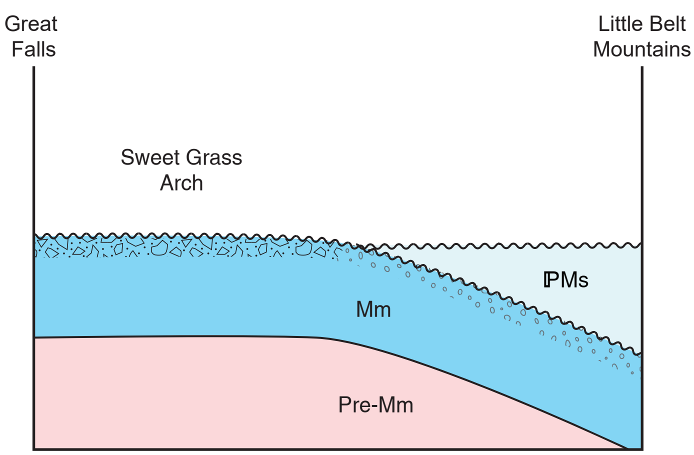
Stratigraphic units below the Madison Group were lumped into a single hydrostratigraphic unit (preMm) for this map. Within the characterization area, these rocks crop out in the Little Belt Mountains and the Disturbed Belt but are used only as an aquifer in the



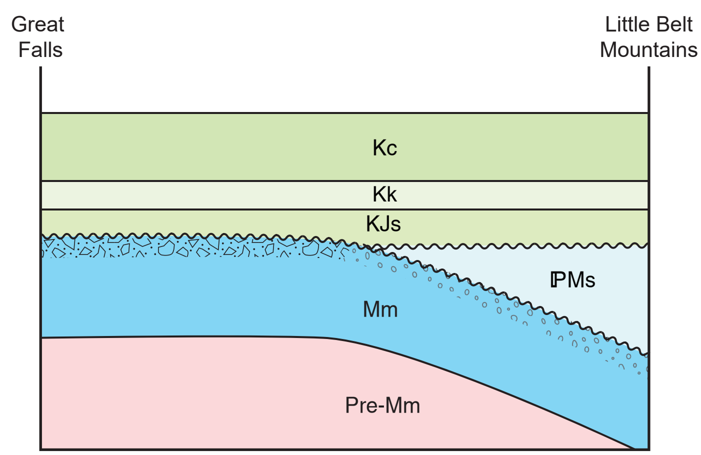
A. Madison sea retreats and subaerially exposes the Madison Group where karst and solution breccia form. The karst and solution breccia is a widespread feature recognized throughout Montana and the Rocky Mountain region (Roberts, 1966; Sando, 1974).



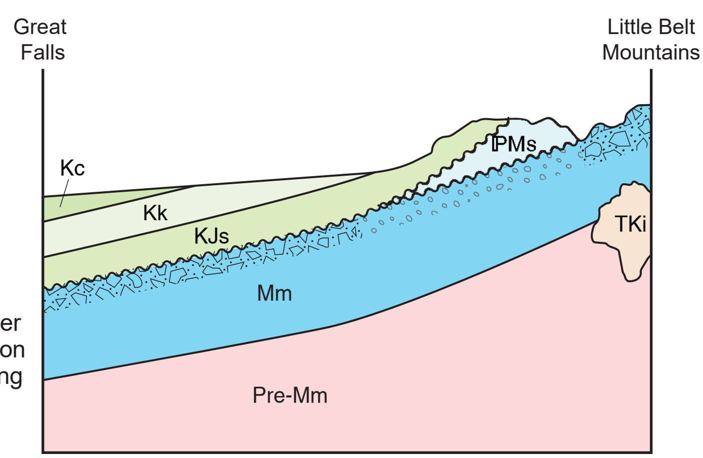
B. Sea level rises and deposits ℙMs sediments, filling some of the karst features.



C. Rocks are folded downward into Central Montana Trough and/or uplifted along Sweetgrass Arch. Sea-level drop and/or Sweetgrass Arch uplift subaerially exposed sediment. ℙMs eroded off the Mm along the Sweetgrass Arch, and preserved in the Central Montana trough. This was the second karstification of Mm but restrained locally to the Sweetgrass Arch. The second karstification created the high transmissivity (392,000 ft^2/day, Patton, 2006) that currently characterizes the Madison Group aquifer in the Great Falls Area.



D. Sea level rises and deposits KJs over Mm and ℙMs.



E. Uplift and erosion in the Little Belt Mountains (as well as other areas in Montana) have exposed Mmu where locally karstification has created caves, sinkholes and other karst features. Ascending hydrothermal solutions associated with igneous intrusions also aided in local cave formation (Carriere and others, 2010).

Figure 11. Geologic evolution and karstification history of the Madison Group in the Great Falls area is different than in other parts of the State.

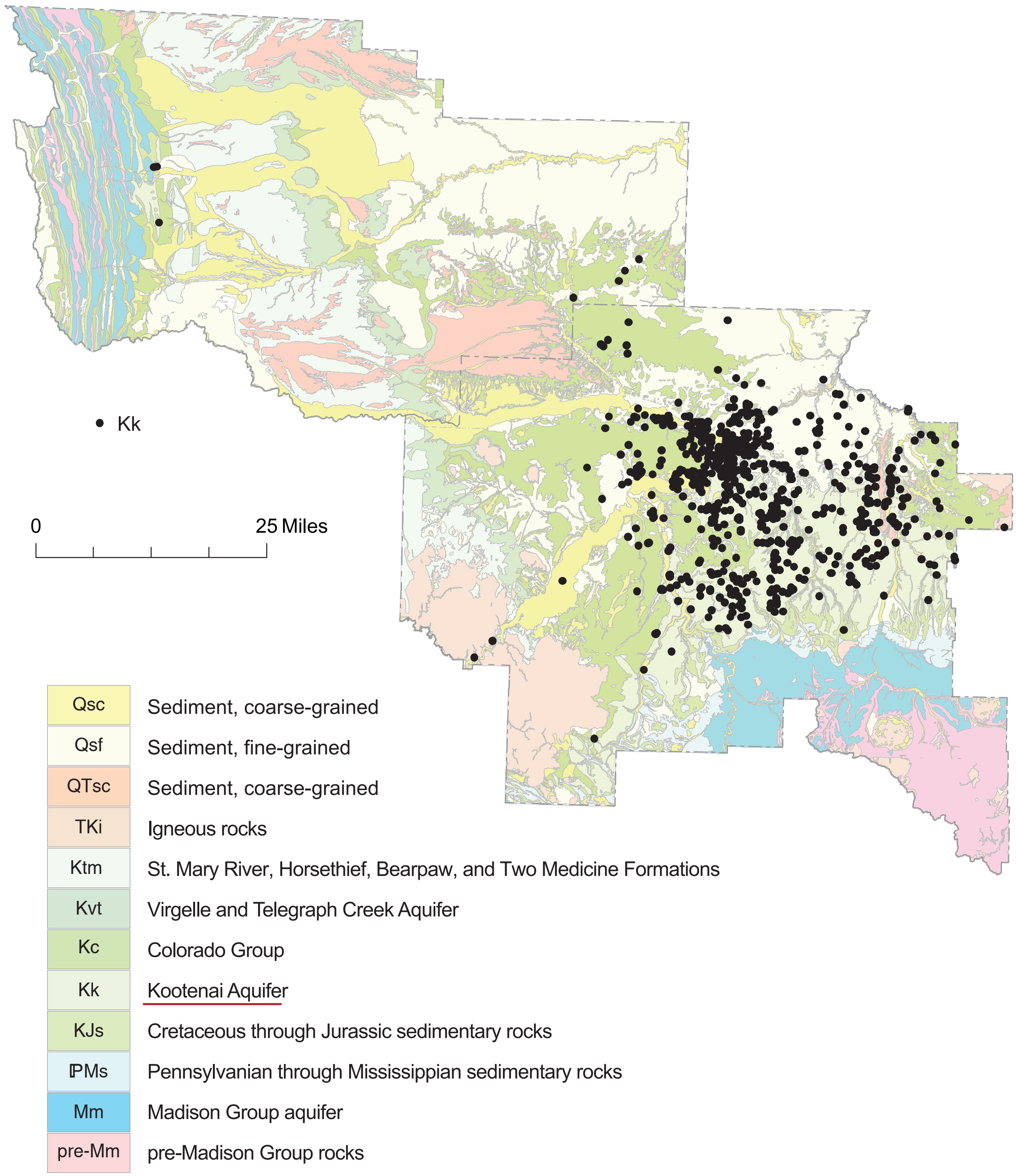


Figure 12. Distribution of water wells in the Kootenai Formation (Kk).

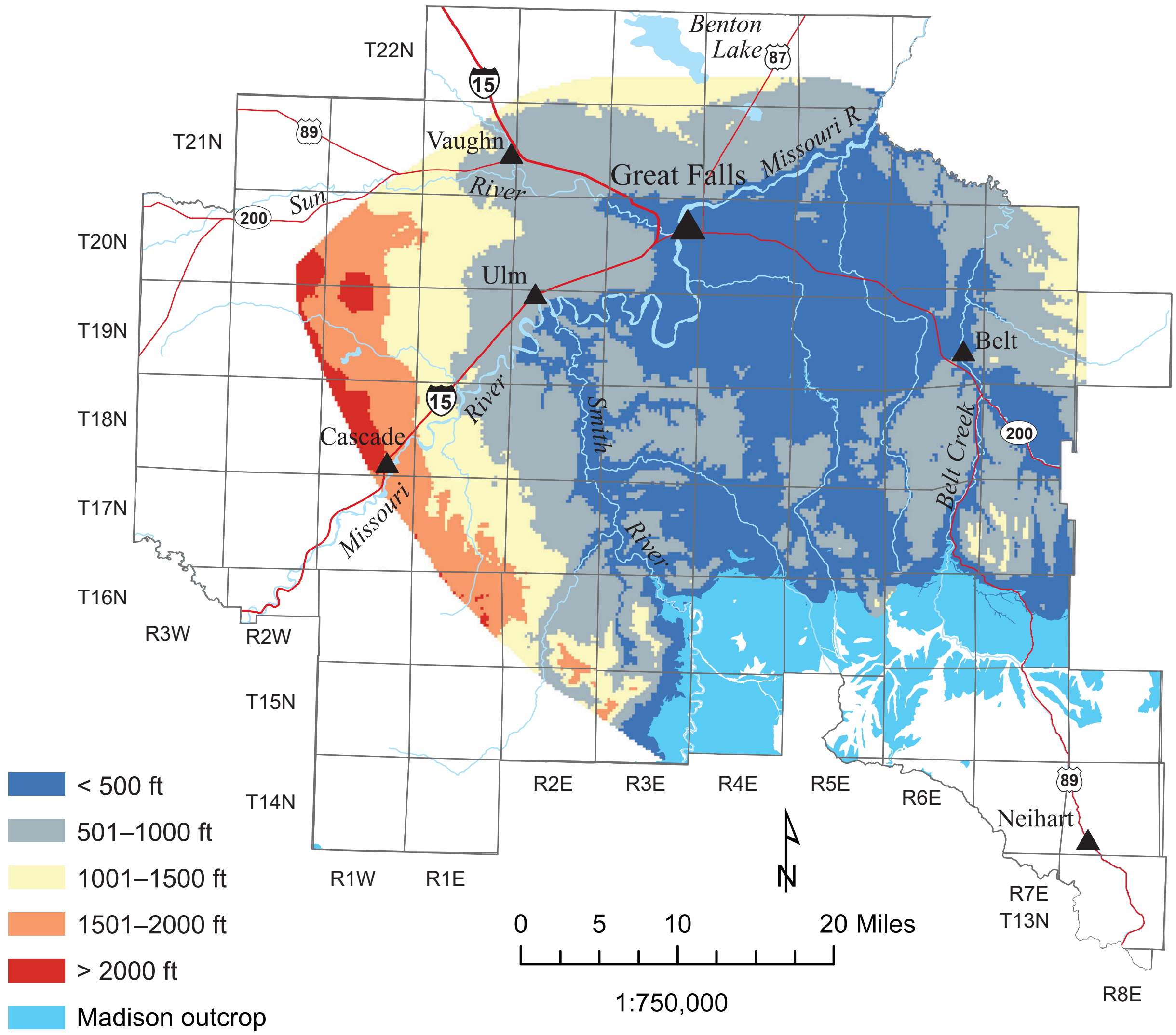


Figure 13. Depth to the top of the Madison Group.

Little Belt Mountains, where joints and other fractures provide secondary porosity and permeability for the storage and transmittal of water (fig. 10). Rock units lumped together include the Three Forks Formation, Jefferson Dolomite, Maywood Formation, Pilgrim Limestone, Park Shale, Meagher Limestone, and Wolsey Shale, all Paleozoic rocks. Precambrian rocks lumped into preMm include the Newland Formation, Chamberlain Formation, Neihart Quartzite, igneous intrusive rocks, and metamorphic rocks. Outside of the Little Belt Mountains and Disturbed Belt, these units are too deep and water quality is unknown. Within the Cascade–Teton characterization area, the GWIC database contains about 160 (2%) records of preMm wells completed in outcrop areas (fig. 10). Well depths range between 52 and 307 ft with a median depth of 153 ft (fig. 4). The reported yields range between 2 and 40 gpm, with a median of 10 gpm (fig. 5).

MAP USE AND LIMITATIONS

Descriptions of aquifers and confining units are based on the mapped geology and reported data on drillers' logs. Some errors may exist due to variations in the quality and precision of driller-reported data. However, the large number of well records in this study area support the reliability of information on well and aquifer characteristics presented here.

Water well and borehole records are continuously updated in GWIC. The records shown in this map largely reflect the GWIC database on February 21, 2021. To supplement the data shown here, current water well information can be accessed at http//mbmg-gwic.mtech.edu.

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