Montana Ground-Water Assessment Atlas No. 3, Part B, Map 2
Open-File Version October 2007

Montana Bureau of Mines and Geology
A Department of Montana Tech of The University of Montana

Geography and Geology of the Middle Yellowstone River Area, Treasure and Yellowstone Counties, Montana

by

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Atlas organization
The Montana Ground-Water Assessment Atlas for the Middle Yellowstone River Area (Atlas 3) consists of a descriptive overview (Part A) and seven hydrogeologic maps (Part B). This map is intended to be a stand-alone document, and describes the geographic and geologic setting within the study area. To obtain a more integrated understanding of the area’s hydrogeology, see Part A and the other Part B maps.

Introduction
The availability and use of ground-water resources in the Middle Yellowstone River Area are controlled by the region’s geographic and geologic setting. Ground-water recharge is influenced by the climate, land cover, soils, and topography. The geometry of the aquifers is controlled by lithology, subsurface position, faults, and folds.

Climatic influences
For all of the area except the irrigated valleys, precipitation is the only source of ground-water recharge. The region has a semi-arid climate and receives relatively limited precipitation. The 30-year average annual precipitation is about 13 inches at Billings and about 12 inches at Hays. The distribution of precipitation across the region is influenced by topography, with the higher altitudes receiving up to 20 inches and the lower altitudes receiving less than 13 inches (see geographic distribution of precipitation). Most of the precipitation occurs as late spring showers and early summer thunderstorms and the wettest months are typically April, May, and June (see seasonal distribution of precipitation). Most of the precipitation is persistent winds that average about 11 miles per hour (Western Regional Climate Center, 2007). The dry windy conditions promote evaporation which, on average, far exceeds precipitation. The average estimated pan evaporation in Billings is 53 inches per year (Oregon Climate Service, 2007). During the growing season, plants in non-irrigated areas consume nearly all the available precipitation. In irrigated areas plants consume from 2 to 6 times more than the average monthly precipitation. Looking only at average rates of precipitation, transpiration, and evaporation it seems that ground water is not recharged. However, precipitation occurs in concentrated events. Some fraction of the water infiltrates before it can be

Ground-water recharge classification map

The effects of soil permeability, land cover, and slope were considered in delineating the five recharge area types in the recharge classification map (right). This map shows where ground-water recharge is likely to occur and what is its primary source. The major division in the classifications is between areas receiving primarily natural recharge (precipitation) and those primarily receiving artificial recharge (field and yard irrigation and ditch leakage).
Geographic influences

Ground-water recharge varies considerably over the region and is influenced by a number of factors including land cover, soils, and topography. These factors were evaluated to divide the area into various recharge settings which qualitatively describe the distribution of recharge.

Land cover
Precipitation falling over the region first encounters the land cover, which primarily consists of various crops and other vegetation but can also include urban features such as streets, roofs, and parking lots. In the Middle Yellowstone River Area, the dominant land cover features can be grouped into irrigated lands, non-irrigated lands, and urban lands. Land cover on a 90-meter resolution for the area was obtained from the GIP Analysis Project (Wildlife Spatial Analysis Lab, The University of Montana, 1998).

Irrigated lands
Even though the land area for irrigated agriculture is small (about 4 percent), its impact on ground water is very significant because of the large quantity of recharge it receives. Most of the agriculture along the river valleys relies on flood irrigation, which can supply 4–5 times more water in 6 months than in the whole year from precipitation (Olson and Reiten, 2002). More importantly, about 15–20 percent of the flood irrigation water (or about 10–12 inches) infiltrates past the root zone to become recharge. Irrigation ditch leakage also provides significant recharge and the larger canals can provide an annual recharge of about 200–700 acre-ft of water per square mile (Olson and Reiten, 2002).

Non-irrigated lands
Most of the land in this classification occurs in upland areas with low to moderate density grasslands and xeric (low water) shrub vegetation. Plant cover can capture and hold moisture and increase surface area for evaporation. However, the losses to transpiration during the growing season. Pine forests make up about 8 percent of the land area and are usually encountered on north slopes and on the sides of deep coulees. Pine forests can capture and hold much of the precipitation in their canopy and limit recharge. However, it also can hold and shade snow during the winter months. Snow melt occurs before the growing season and so, overall, the pine forests likely assist in recharge. However, forests occur over such a small portion of the area that their regional effects are minimal. Riparian environments are found along stream drainages and tend to be areas of ground-water discharge rather than recharge. Survival of the shrubs and trees growing in these areas depends on ground-water consumption.

Urban lands
Urban areas are minor (about 2 percent of the total area), but they influence recharge in the river valleys where most of the population resides and most of the ground-water use occurs. The primary impacts of urban land cover are two-fold: (1) recharge is reduced by impermeable surfaces such as paved and roofed areas, and (2) recharge is reduced because urban land cover usually occurs over previously irrigated lands. The primary source of recharge is from precipitation, seepage return flows, and lawn irrigation. Irrigation ditches that flow through urban areas also provide much of the recharge. Within the city limits of Billings and Laurel, municipal water is supplied from the Yellowstone River. Therefore, during the growing season most lawn irrigation is a source of recharge. However, in urban fringe areas and in smaller towns most water use is from ground water so lawn irrigation is a net loss of water because much more of it is lost to transpiration and evaporation than returns as recharge.

Additionally, the region experiences relatively low humidity (Billings average afternoon humidity is 44 percent) and transpired or evaporated. Most recharge likely occurs in the spring and fall when plants are dormant and soils are unfrozen.

Geographic distribution of precipitation
The average annual precipitation in the area ranges from 20 inches in the higher altitudes to 13 inches in the lower altitudes (PRISM Group, Oregon State University, http://www.prismclimate.org, created 2006).

Seasonal distribution of precipitation
The average monthly precipitation ranges from 0.44 inches in February to 2.35 inches in June. Evaporation exceeds precipitation every month and plant transpiration consumes nearly all the precipitation during the growing season (pasture grass is shown above as an example).
Soils
Soil mapping and soil property data were obtained from the State Soil Geographic (STATSGO) database (Montana State Library, 1994). The influences of soils on recharge were distinguished primarily on the basis of their USDA hydrologic classification and underlying geology. Three soil groups were delineated: (1) highly to moderately permeable soils, (2) low permeable soils, and (3) impermeable soils. These soil groups were overlain with land use and slope to produce the six classifications used in the recharge setting map (upper right).

Highly to moderately permeable soils have coarse-grained (sandy) texture and allow more infiltration and less runoff. Also, more permeable soils provide a better chance for water to infiltrate below the root zone without being consumed by plants. Soils with low permeability have a fine- to fine-grained (silty to clayey) texture and result in much less infiltration and more runoff. Very little water can infiltrate below the root zone in these soils. Impermeable soils are usually clay-rich and rest on shale bedrock. Essentially, no recharge occurs through these soils and all water runs off or ponds at the surface.

Slope and topography
The land-surface slope influences drainage and water contact time with the soils. In areas with steep slopes, runoff is rapid with less infiltration. Conversely, in areas with flat or gentle slopes, runoff is slower and water can infiltrate. Slopes were evaluated using digital elevation model data (U.S. Geological Survey, 2002). Areas with steep slopes (greater than 9 percent slope) are delineated on the ground-water recharge classification map (upper right).
Geologic influences

The geologic map shown at right was compiled from a variety of sources (Lopez, 2000a;b; Vuk and others, 2000; 2001a,b; 2003; Wilde and Porter, 2000; Olson and Reiten, 2002), and included some additional geologic mapping (shown in more detail on Atlas 3, Part B, Map 3). The ages of the exposed units range from early Cretaceous (about 110 million years ago) to modern. The vertical relationships and unit thicknesses are displayed on cross section A–A’.

Geology significantly controls ground-water availability, well depths, well yields, and water quality. Rock lithology forms much of the basis for delineating aquifers. Aquifers are geologic formations that contain more permeable materials such as sandstone and unconsolidated sand and gravel. The major aquifers in the area are the alluvial, Bull Mountains (Fox Hills, Lance, and Fort Union Formations), Judith River, Eagle, and Pryor Conglomerate (basal Kootenai Formation) aquifers. Outcrops of these units are shown on the geologic map. For more information on these aquifers, please refer to Part A or other Part B maps in this Atlas series. Slate formations typically yield only small amounts of poor quality water. Slate units in the area include: the Bearpaw Shale, Claggett Shale, and the Colorado Group (Niobrara, Carlile, Greenhorn, Belle Fourche, Mowry, and Thermopolis Formations).

Major geologic structures include: the Bull Mountains Basin, the Pryor Mountains uplift, the Lake Basin fault zone, and the Fromberg fault zone. The Bull Mountains Basin is a broad regional feature centered just north of Yellowstone County (Dobbin and Erdmann, 1955). Within the basin, bedrock formations dip gently (at 2–4 degrees) towards the basin center. The Pryor Mountains uplift is centered south of Yellowstone County and forms the core of the Pryor Mountains. As a result of the uplift, the Lower Cretaceous Kootenai Formation is exposed in the far southern part of the county.

The Lake Basin fault zone consists of a roughly 6-mile-wide band of northeast–southwest-trending, high-angle faults. Individual faults are generally oriented perpendicular to the regional fold axes. Displacements of as much as 250 ft have been reported (Hancock, 1920). The faults are a significant feature because they offset sandstone beds, and in some places truncate aquifers. The Fromberg fault zone is a 3 to 5-mile wide band of northeast–southwest-trending faults parallel to the southern edge of the Yellowstone River valley near Billings. The faulting locally controls the Blue Creek drainage system and along the fault trace fractures the otherwise hard siliceous beds in the Mowry Shale. Consequently, increased fracture porosity allows the Mowry Shale to be water-bearing along the faults.

Acknowledgments

Well owners who allowed collection of the data necessary for this map, and the people who collected the data, are gratefully acknowledged. PRISM precipitation data are copyright 2004, PRISM Group, Oregon State University, http://www.prismclimate.org. Reviews by Tom Patton, John Metesh, Ed Deal, and Susan Barth are also appreciated.

References


Explanation of geologic units

Quaternary
Alloviands
Alluvial terrace deposits: Gravel, sand, silt, and clay along active and inactive rivers and creeks; includes few lake deposits. Sediment thicknesses 20–30 ft. Seven alluvial terraces have been recognized, with the highest 900 ft above the Yellowstone River. Ground-water yields are typically 9–30 gpm. Dissolved constituents usually range from 700 to 2,000 mg/L.

Culfaids
Locally derived silty clay, sandy clay, clay-bound gravel and minor sand and gravel deposited by slope-wash, landslides, alluvial fans, and minor streams. Sediment thicknesses typically 30–150 ft. Some terraces are buried by as much as 100 ft of colluvium. Generally not an aquifer.

Tertiary
Tertiary alluvial terrace deposits: Isolated patches of Tertiary terrace deposits have been identified in the area. Sediment thickness in the gravel underlying terraces ranges from 0 to 30 ft.

Fort Union Formation
Tongue River Member: Gray to grayish yellow, fine- to medium-grained sandstone interbedded with brownish-gray shale, siltstone, and coals. Can be as thick as 2,800 ft. Ground-water yields are typically 5–10 gpm; dissolved constituents concentrations range from 1,800 to 1,800 mg/L.

Lebo Member: Dark gray to olive shale with thin interbedded yellowish-gray sandstone, siltstone, and yellowish-gray claystone. Thickness ranges from 200 to 300 ft. Ground-water yields are usually 5–12 gpm and dissolved constituents range from 2,800 to 3,500 mg/L.

Tulip Member: Yellowish gray, fine- to medium-grained sandstone interbedded with gray to grayish claystone, siltstone, and shale. Thickness varies from about 400 to 1,500 ft. Ground-water yields are usually 4–11 gpm and dissolved constituents range from 1,100 to 2,400 mg/L.

Upper Cretaceous
Lance Formation: Light brownish gray, cliff- and ledge-forming, fine-grained, thick-bedded sandstone with some medium gray shale and a few thin beds of coal. The total thickness is about 350 ft. Ground-water yields range from 5 to 10 gpm; dissolved constituents are usually between 1,500 to 2,900 mg/L.

Fox Hills Formation: Tan interbedded sand, silt, and clay overlain by well-sorted very fine- to medium-grained, poorly consolidated sandstone. About 10 to 110 ft thick. Ground-water yields are 2–25 gpm; dissolved constituent concentration ranges from 450 to 4,200 mg/L.

Bearpaw Shale: Dark gray shale. Middle of the formation commonly contains thin greenish gray bentonite beds; thin sandstone beds are common near the top. Thickness is about 800–1,000 ft. The Bearpaw Shale is not typically a source of ground water.

Judith River Formation: Brownish gray sandy shale and light brown to pale yellowish brown, fine- to very fine-grained sandstone. The formation is 250 to 350 ft thick. Well yields usually range from 5 to 15 gpm; dissolved constituents range from 1,400 to 4,100 mg/L.

Clasglett Shale: Brownish gray shale with minor interbeds of light brownish gray sandstone. Thickness ranges from 100 to 400 ft, thinning westward. Typically not a source of ground water.

Eagle Sandstone: Light brownish gray to very pale orange, very fine- to fine-grained sandstone. Can have intervening sandy shale as thick as 50 ft. Thickness ranges from 100 to 350 ft. Ground-water yield typically ranges from 4 to 17 gpm; dissolved constituents typically range from 1,900 to 3,500 mg/L.

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Telegraph Creek Formation: Brownish gray to medium dark gray shale and sandy shale, with thin, interbedded sandstone. Sandstone beds become thicker and more abundant near the top. Maximum thickness of about 150 ft. Well yields range from 3 to 15 gpm; dissolved constituents are typically around 3,300 mg/L.

Niobrara Shale: Olive gray to dark brown shale with abundant, thin bentonites. Near the top, thin beds of sandstone, siltstone, and sandy limestone are present. In the Billings area the formation is about 700 ft thick. This formation is typically not a source of ground water.

Carilie Shale: Dark gray to bluish gray shale. About 250 to 350 ft thick. This formation is not typically a source of ground water.

Greenhorn Formation: Dark bluish gray shale. Thickness is about 30–75 ft. This formation is not typically a source of ground water.

Belle Fourche Shale: Dark gray shale containing several thick bentonite beds in the lower part. Thickness is about 350–400 ft. Generally not an aquifer.

Mowry Shale: Medium dark gray shale interbedded with very fine- to fine-grained sandstone, and light gray to medium gray siltstone. Near the base and top of the formation are 1- to 4-ft-thick bentonite beds. Thickness is about 250 ft. Can be an aquifer where water-saturated fractures exist, such as in stream valleys. The unit is too tight to produce water in most upland areas. A few wells yields produce from 5 to 30 gpm; dissolved constituents are typically 1,000–1,500 mg/L.

Lower Cretaceous
Thermopolis Shale and Fall River Sandstone: Upper 50 ft is dark gray shale, with a few thin bentonite beds. Below this is dark gray to brownish gray shale with thin interbeds of olive gray sandstone and common bentonite beds. The Fall River Sandstone at the base of the Thermopolis Shale is an upward-coarsening, interbedded sequence of medium dark gray, shale and light brownish gray to moderate yellowish brown, fine-grained sandstone. Total thickness is about 600–650 ft. The Fall River Sandstone is likely a potential source of ground water. However, very few wells are completed in this formation.

Kootenai Formation: Reddish brown, olive gray, and dusky purple mudstones interbedded with fine- to coarse-grained sandstones. The basal Pryor Conglomerate Member is brown conglomerate and pebbly coarse-grained sandstone and is 20 to 60 ft thick. Total thickness is about 200–250 ft. Well yields in the Pryor Conglomerate Member typically range from 8 to 24 gpm; dissolved constituents range from 1,900 to 3,300 mg/L.

Other symbols
Fault
Fault, buried
Cross section line (A–A’)

References
Montana Geologic Map 57, scale 1:100,000.