Table of Contents

Preface and Acknowledgments 3

Terms 4

Introduction 5

Basic Ground-Water Principles 5
- The Water Cycle and Ground Water 5
- Porosity and Hydraulic Conductivity 6
- Aquifers and Confining Beds 6
- Aquifer Recharge and Discharge 6
- Ground-Water and Surface-Water Interactions 7

Montana's Ground-Water Resources 8
- Land Forms and Ground-Water Regions - Map 1 8
- Geologic Units - Map 2 10
- Surficial Aquifers - Map 3 12
- General Water Quality of Surficial Aquifers - Map 4 14
- Bedrock Aquifers - Map 5 16
- General Water Quality of Bedrock Aquifers - Map 6 16

Population Density, Ground-Water Use, and the Distribution of Wells. 20
- Population Density - Map 7 20
- Distribution of Wells - Maps 8, 9, and 10 22

Potential Threats to Water Quality and Public Use of Ground Water 26
- Under Ground Storage Tanks and Public Water Supply Wells - Map 11 26

Montana's Ground Water Assessment Act 28
- Montana's Ground-Water Monitoring Network - Map 12 28
- Montana's Aquifer Characterization Study Areas - Map 13 28

REFERENCES 28

List of Figures

Figure 1. The Water Cycle 5
Figure 2. Ground-water movement within aquifers. 6
Figure 3. Ground-water and surface-water interactions. 7
Figure 4. Generalized geologic cross-section for Montana. 8
Figure 5. General geologic time scale and principal aquifers. 10
Figure 6. Generalized cross-section of a "typical" western alluvial basin. 12
Figure 7. Generalized cross-section of a "typical" river valley in eastern Montana. 12

List of Additional Information Boxes

Box 1 - Ground Water from a Global Perspective 3
Box 2 - Ground Water Information Center 14
Box 3 - Depth of Wells in Montana 14
Box 4 - Well Completion Rates in Montana 16
Boxes 5 and 6 - Population Served by Public Water Supply Wells 20
Boxes 7 and 8 - Total Number of Wells per County 22
Box 9 - Water Quality Districts 26

List of Tables

Table 1 - Aquifers in Surficial Deposits. 17
Table 2 - Aquifers in Cenozoic Rocks. 17
Table 3 - Aquifers in Mesozoic Rocks. 17
Table 4 - Aquifers in Paleozoic Rocks 17

Preface and Acknowledgments

The Montana Ground-Water Data Task Force determined in 1990, that much of the information required to help characterize and manage the state's ground-water resources did not exist, was inaccessible, or was unavailable in a useable format. In addition, the Task Force concluded that adequate maps showing the location of major aquifers and potential threats to ground-water quality did not exist. These findings helped initiate several projects to make information more accessible, and to generate maps of general ground-water characteristics using a geographic information system (GIS). In January of 1993 some ground-water data in GIS format became available from the Montana Bureau of Mines and Geology (MBMG). The map information was generated from geologic and hydrologic maps ranging in scale from 1:500,000 to 1:1,000,000. Although maps of this scale show only general features, they are useful for providing an overview of Montana's ground-water resources. The Montana Ground-Water Atlas uses the maps to address the following questions:

1) What are the sources of Montana's ground water?

2) Where is ground water used most intensively?

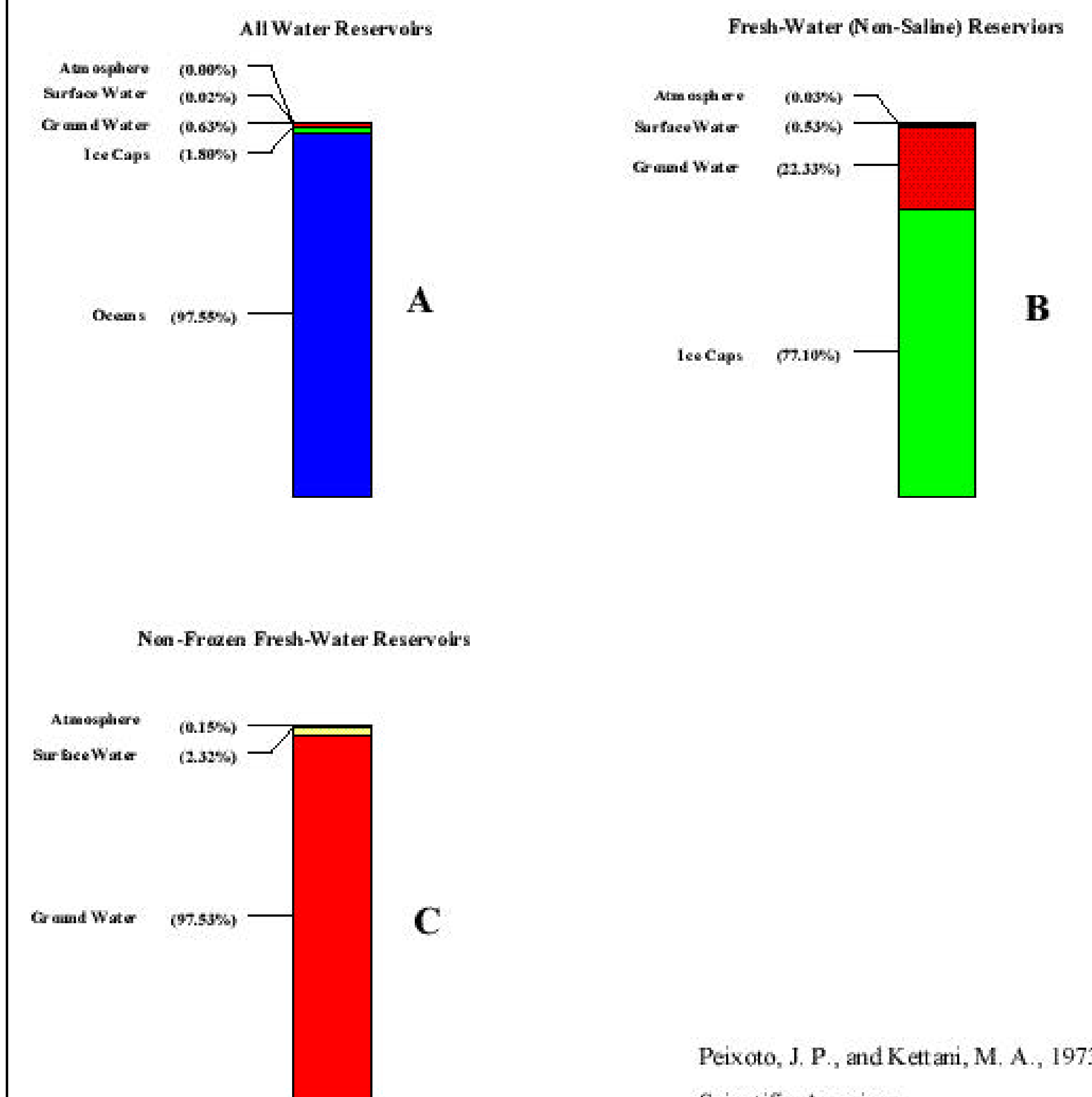
3) What is the general quality of the state's ground water?

4) What are the potential threats to ground-water quality?

The intent of this atlas is to help raise awareness of Montana's ground-water resources and its importance to Montana's citizens.

The Montana Ground-Water Atlas project has benefitted from the efforts of many individuals. The Ground-Water Data Task Force laid much of the foundation for this work and articulated the need for better map information. The Montana Department of Health and Environmental Sciences, now called the Department of Environmental Quality (DEQ), and U.S. Environmental Protection Agency (EPA) Region VIII provided funding to develop GIS map data and to compile the Ground-Water Atlas. Original base maps were prepared and digitized under the direction of Bob Bergantino (MBMG). Comments and suggestions from several individuals improved the atlas maps, text, and the overall design. Reviewers included John Arrigo (DEQ), David Briar (USGS), Steve Craigg (USGS), Fred Gifford (NRIS), Dennis McKenna (MBMG), Tom Patton (MBMG), and Mike Wireman (EPA Region VIII). Sheryl Motl and Helga Stimson also reviewed the atlas and provided suggestions that improved how technical material was presented for a general audience. GIS map compositions were designed by Gerry Daumiller, Duane Lund, John Jarvie, and Jim Stimson (NRIS). Map compositions were reviewed by Allan Cox and Fred Gifford (NRIS). Final layout and formatting for publication was done by Ed Madej (NRIS). Existing publications from the U. S. Geological Survey, MBMG, and Montana State University (MSU) Extension Service were used to develop the atlas text. These publications are excellent sources of information for those desiring to learn more about Montana's ground-water resources. The text for the Ground-Water Atlas draws freely from these publications and was written by Jim Stimson.

Additional Information
Box 1 - Ground Water from a Global Perspective



Peixoto, J. P., and Kettani, M. A., 1973, Scientific American.

Terms

Alluvium
Unconsolidated sediments deposited by streams and rivers.

Aquifer
Unconsolidated sediments or rock formations that have sufficient hydraulic conductivity to yield economically significant quantities of water to wells or springs.

Baseflow
The component of stream discharge that originates from ground water seeping into the stream.

Bedrock Aquifer
An aquifer composed of consolidated rock.

Confined Aquifer
An aquifer overlain by a confining bed.

Confining Bed
Unconsolidated sediments or rocks that do not transmit water readily and occur above or below aquifers. The confining bed can be an Aquiclude that does not transmit water and prevents flow to or from an aquifer, or an Aquitard that transmits water slowly and retards flow to or from an aquifer.

Contaminant
An undesirable substance that enters the hydrologic system. Some texts and workers restrict the term contamination to substances that enter the hydrologic system due to human activities, as opposed to originating from natural causes or processes. When contaminants occur in sufficient concentrations, they may be harmful to human health or the environment.

Discharge Area
An area where ground water leaves an aquifer by flowing to the land surface. The water may reach the land surface as seeps, springs, baseflow to a stream, evaporation from sediments, and/or transpiration from plants.

Fresh Water
Water containing only small amounts of dissolved minerals, usually less than 1000 milligrams per liter (mg/L).

Glacial Till
Sediments deposited directly by glacial ice. Till is a complex mixture of unstratified clay, silt, sand, and gravel.

Glacial Outwash
Sand and gravel deposited by glacial meltwater. Outwash tends to be better sorted and stratified than till and can be use to supply ground water.

Ground Water
In general, any water that is beneath the land surface. Some texts and workers restrict this term to that part of the subsurface water that is in the zone of saturation.

Hydraulic conductivity
A measurement describing the rate at which water can move through sediments or rock. It is expressed as the volume of water that will move in a unit of time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Pediment Surface
A gently sloping erosional surface cut into bedrock and usually covered by a veneer of gravel.

Permeability
A more generic measure of a sediment's or rock's ability to transmit fluids, such as water and hydrocarbons. Permeability refers only to the properties of the sediment or rock, not the fluid.

Pollutant
See "Contaminant."

Porosity
The amount of open space within soil, sediments, and rock. Open spaces occur as caverns and fractures, or as pores between individual sediment grains. Porosity is usually expressed as a percent of the total volume of sediment or rock.

Potable Water
Water that is considered suitable for drinking.

Potentiometric Surface
The surface representing the level to which water will rise in a well that is completed in a confined aquifer.

Recharge Area
An area where water enters an aquifer. Aquifers are typically exposed at the land surface in the recharge area.

Saturated Zone
The zone below the water table in which all pore spaces are filled with water.

Specific Conductance
A measure of water's ability to transmit electrical current. Specific conductance data serve as a general measure of water's salinity, the amount of dissolved solids (salts and minerals) in the water. Low specific conductance values indicate low salinity water that would be considered better quality water. Higher specific conductance values indicate poorer water quality.

Surficial Aquifers
Aquifers composed largely of younger unconsolidated sedimentary deposits that are found near the land surface. These accumulations of sediment can be deposited by streams (deposit name: alluvium), glacial ice (deposit name: till), or glacial meltwater (deposit name: outwash). Surficial aquifers are often unconfined or partially confined. In this atlas the terms unconsolidated sedimentary deposits, unconsolidated deposits, and surficial aquifers are used interchangeably.

Terrace
Gently sloping surfaces on the flanks of basins; they also can occur as isolated flat-topped hills. Terraces can be underlain by sedimentary deposits including gravels deposited by rivers or meltwater from glacial ice.

Unsaturated Zone
The zone immediately below the land surface in which pore spaces are filled with air and water.

Water Table
The water level in an unconfined aquifer. The water table represents the top of the saturated zone.

Introduction

Ground water is an essential resource in Montana. About 445,000 Montanans depend on ground water for their primary water supply. This represents more than one-half of the state's total population. Ground water provides 94 percent of Montana's rural domestic-water supply and 39 percent of the public-water supply. Every day approximately 90 million gallons of ground water are used for irrigation, 16 million gallons are used to supply water for livestock, and 20 million gallons per day are used to support industry (Solley and others, 1990).

Although ground water is readily available and widely used in nearly every part of Montana, it currently represents only about two percent of the state's total water withdrawals. The demand for high quality water will no doubt increase in the future as the state's population and industries continue to grow. In practical terms, this means the use of ground water must increase since most of the state's surface water supply is already legally allocated, or in the process of being allocated. Much of Montana's population growth is in rural areas near urban centers. Many of these new bedroom communities are not supported by existing municipal water supplies and will have to rely on ground water. Another factor that encourages increased use of ground water is recurring drought. It has been estimated that Montana experienced drought in nine of the last seventeen years (DNRC, 1997, personal communication). During drought years the availability of surface water is substantially reduced and citizens are forced to increase their use of ground water. With the availability of surface water being limited, or uncertain, it is clear that Montana's ground-water resources will play a major role in the state's economic development in the future.

In light of the increased need for ground water, some important questions must be asked. Can Montana's ground-water resource support expanded use? Where can use be expanded without detrimental effects? And, how much additional use can the resource sustain in the long term? Unfortunately, no one knows the complete answers to these questions. The volume of ground water stored in the soil and rock beneath Montana is unknown. What is known is this: Montana is a large state, it has a land surface area of 145,392 square miles, the fourth largest in the United States. The area east of the Rocky Mountains (roughly two thirds of the state) is underlain by at least eight geologic formations that store and transmit water suitable for public, domestic, and stock supply. Large intermontane basins in western Montana and major stream valleys in central and eastern Montana are known to contain highly productive aquifers as well. Considering the size of all of these sources of ground water, it becomes clear that Montana's ground-water resource is enormous. Surface and ground-water specialists agree that the volume of ground water stored in Montana's aquifers is much greater than the total volume of the state's surface water resources. It seems reasonable to assume that the ground-water resource can support increased use in many parts of the state.

However, the potential consequences of expanded use should be thoroughly examined before the resource is pressed into service. Ground-water systems are complex, and often, delicately balanced. Many aquifers are prone to contamination from human activities and they can also be seriously damaged if they are over developed. It is important to understand that shallow ground-water and surface-water systems are connected in most areas. Expanding the use of shallow ground water in an area where surface water is already in short supply may only make existing problems worse. Thorough study of the state's ground-water resources is needed to help identify where use can be safely expanded, and under what conditions. Thorough study will also help to identify where the resource is vulnerable to contamination. In 1991, Montana initiated a systematic study of ground-water resources by passing the Montana Ground Water Assessment Act. Under this legislation, the Montana Bureau of Mines and Geology (MBMG) will assess and monitor ground-water resources on a statewide basis. This task is ongoing and will produce much needed information to address important issues, including expanding the use of ground water. To complete the work for the entire state will require about twenty years at the current funding level.

Basic Ground-Water Principles

The Water Cycle and Ground Water

Figure 1 is a generalized diagram of the water cycle. The cycle begins with water evaporating from oceans and forming clouds that move over the continents. The clouds rise and cool which causes water vapor to condense and fall as rain or snow. Water from rain or snowmelt soaks into the ground, finds its way into streams, or evaporates back into the atmosphere. The ground (sediments and rock), stream networks, and the atmosphere can be thought of as temporary storage reservoirs for the water. The water cycle shows how water moves from one reservoir to another on the global scale. Sediment and rock at the Earth's surface represent an important reservoir for fresh water, although this may not be obvious from Figure 1, or other diagrams of the global water cycle. On the global scale, water stored beneath the land surface (ground water) accounts for only 0.63 percent of Earth's total water budget. However, when the fresh water portion of the water budget is considered (atmosphere, lakes and streams, ground water, and ice caps), ground water accounts for over 22 percent of the total volume. If only unfrozen fresh water sources are considered (by throwing out the water tied up in the ice caps) ground water accounts for more than 97 percent of the total volume of fresh water on Earth. In reality, ground water is

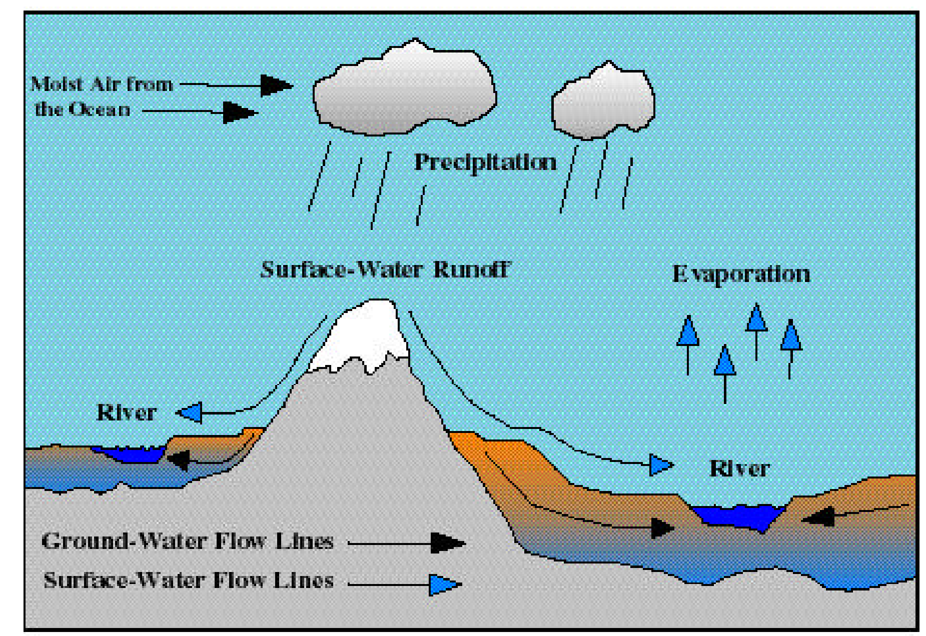


Figure 1 - The Water Cycle

THE major source of fresh water on Earth (See Box 1).

Porosity and Hydraulic Conductivity

While the word “rock” brings to mind material that is hard, dense, and solid, in reality most rocks contain some open space as pores between individual sediment grains, or as fractures within the rock’s fabric (sediment grains, fossils, pore-filling cements, etc.). Open space in rock is called porosity and is measured as a percent of the rock’s total volume. Porosity can range from one or two percent to more than 40 percent. The greater the porosity, the more water a rock can hold. In addition, if the pores are interconnected, water will flow through the rock. Rock that allows water to flow, or transmits water, is said to be “permeable.” If pores are small, or are not interconnected, the flow of water will be impeded. Rock that does not transmit water very easily has low permeability. Permeability is a useful qualitative term but it is not a quantitative measure of a rock’s ability to transmit water. When a rock’s ability to transmit water is measured, it is expressed as hydraulic conductivity. Hydraulic conductivity is the volume of water that will flow in a given amount of time through a given area (cross-section) of rock. It is important to remember that the greater a rock’s hydraulic conductivity, the easier it is for water to flow through the rock. The velocity at which ground water moves through sediments and rock is directly related to hydraulic conductivity and the slope of the water table (for unconfined aquifers) or the potentiometric surface (for confined aquifers). Ground-water velocities can be as low as 0.0000001 feet per day for unfractured igneous rocks, or they can range from 0.1 to 1000 feet per day in silty sand to clean sand (Heath, 1987).

Aquifers and Confining Beds

In practical terms, unconsolidated sediments and the consolidated rocks that make up geologic formations can be thought of as either aquifers or confining layers. Aquifers possess sufficient hydraulic conductivity to allow water to flow readily, whereas confining layers do not. If an aquifer is overlain by a confining layer, it is classified as a confined aquifer. Confined aquifers usually occur at some depth below the land surface. In addition, water within confined aquifers is often under pressure so that water levels in wells will rise above the top of the aquifer. If no confining bed is present, the aquifer is classified as an unconfined aquifer (Figure 2). This distinction is important. Unconfined aquifers generally occur near the land surface and are widely used to supply ground water. Without a confining bed, these aquifers are more vulnerable to contamination from the land surface. Confined aquifers, on the other hand, are less vulnerable to pollution from the surface because the confining bed retards the flow of pollutants from the surface into the aquifer.

Aquifer Recharge and Discharge

Aquifers are natural reservoirs that collect and store water that comes from precipitation, snowmelt runoff, and streamflow. The water that seeps into an aquifer is called ground-water recharge, and places where recharge occurs are called recharge areas or zones (Figure 2). In addition, it is important to understand that aquifers act as conduits through which ground water flows. Some water flowing through shallow near-surface aquifers will eventually emerge at the land surface and contribute to seeps, springs, wetlands, ponds, lakes, and streamflow. The water that reaches the surface is called ground-water discharge and places where aquifers deliver water to the surface are called discharge areas or zones. In general, ground water flows away from recharge zones toward discharge zones (Figure 2).

Identifying recharge and discharge zones, and determining the direction of ground-water flow, are necessary to properly manage and protect ground-water resources. Human activities in recharge areas can limit an aquifer’s ability to function as a natural reservoir and can result in ground-water contamination. For example, if urban expansion is allowed to take place on top of a recharge zone, much of the natural land surface will be covered by asphalt for streets, driveways, and parking lots. These artificial surfaces are impermeable and force precipitation and snowmelt water to runoff before they can seep into the ground. This reduces the amount of recharge and, when combined with continual ground-water withdrawals, will eventually diminish the total volume of water stored within the aquifer. As a result, water levels will decline causing some wells to “go dry.” The dry wells must be replaced with deeper wells. In other words, the cost of obtaining ground water from the aquifers will increase, sometimes, substantially.
Identifying and actively managing recharge zones can help prevent this example from becoming a reality. Proper management can also help prevent contamination of the ground-water resources by protecting recharge zones from human activities that can cause contamination. Examples of these sources of contamination are discussed in more detail in the section entitled “Potential Threats to Water Quality, and Public Use of Ground Water.”

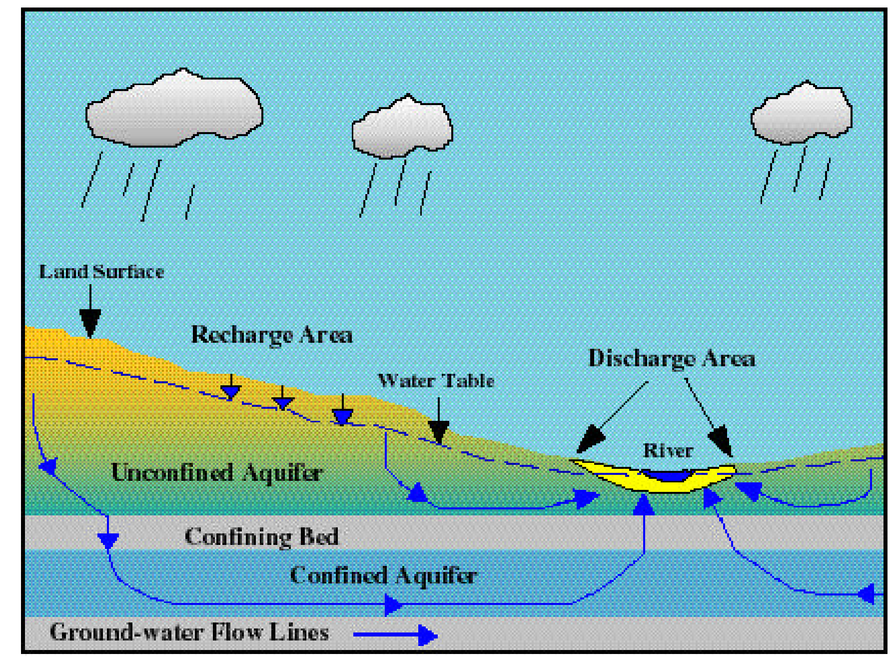


Figure 2 - Ground-water movement within aquifers.

The ability to identify discharge zones also has a practical application. There is a better chance of obtaining ground water from shallow wells drilled in or near a discharge zone, as opposed to locations outside the discharge zone. The reason for this is that discharge zones are places where ground-water flow is directed toward the land surface and the ground-water level is often nearer the land surface. Selecting a well site near a discharge zone can help to reduce drilling costs and reduce the risks of drilling a “dry hole.”

Considering these examples, how can recharge and discharge zones be recognized, and how can the direction of ground-water flow be determined? Figure 2 shows that recharge can take place in upland areas above the aquifers. Once water gets into an unconfined aquifer, gravity causes it to flow toward the discharge zones. The water flows from higher to lower water table elevations. The water table often "mimics" the land surface topography so that water in an unconfined aquifer basically flows "down hill" like surface water. In confined aquifers the picture is more complicated. Ground water still flows from areas of higher water level elevations to areas of lower elevations. However, the water level elevations are controlled by the water pressure that exists in the confined aquifer. As a result, water level elevations in a confined aquifer may not reflect the land surface topography at all and the ground water may in fact flow "uphill" or "down hill." To determine the direction of flow in unconfined or confined aquifers requires measuring the water level in wells. Water levels are determined by lowering a steel measuring tape down a well casing and measuring the distance from the land surface down to the water level inside the casing. That distance can then be subtracted from the land surface elevation to determine the water level's elevation above sea level. Contour maps can be made from the water elevation data and flow lines can be drawn perpendicular to the contours to show the direction of ground-water flow. Discharge occurs where flow lines converge toward the land surface. Discharge areas are often marked by increased and more flourishing vegetation. Other evidence of ground-water discharge includes the presence of seeps, springs, wetlands, ponds, and lakes. Some stream reaches, riparian areas, and flood planes occur within ground-water discharge zones as well.

Ground-Water and Surface-Water Interactions

Ground-water systems are usually hydraulically connected to surface water systems (Figure 2). The degree of this connection varies. Shallow unconfined aquifers often have a high degree of interaction with streams that flow on top of the aquifer; hence, the aquifer and the streams have water flowing between them. Deeper aquifers typically have a lesser degree of interaction with the surface water system.

During the fall and winter months when streams receive minimal runoff from snowmelt and rain, ground-water discharge to streams is the primary source of water for streamflow. This component of streamflow is called baseflow (Figure 3A). A stream reach that receives discharge from ground-water is called a "gaining stream reach." In spring and early summer, when streamflow is high, surface water can move from the stream bed into the adjacent aquifer. During periods of high flow the water table can slope away from the stream channel (Figure 3B). Flow is directed into the adjacent aquifer because water flows from higher to lower water table elevations. Sometime after high flow conditions subside the flow direction will reverse and ground water will flow toward the stream channel.

Some stream channels lose water to aquifers throughout the year. This happens when the stream channel lies above the local water table and is located within permeable sediments or rocks (Figure 3C). A length of stream that loses water in this manner is referred to as a "losing reach." In some cases, a significant part of the streamflow is lost to the aquifer and results in low flow conditions or complete dewatering. Losing reaches represent an aberrant condition because typically, streamflow increases downstream. Losing reaches can be identified by measuring flow at multiple locations along a stream and observing where streamflow decreases downstream. Human activities can also cause water to flow from stream channels into shallow aquifers. For example, pumping water from wells near a stream can cause the water table to slope away from the stream channel and induce flow into the adjacent aquifer (Figure 3D). Under these circumstances ground-water withdrawals can result in a significant reduction in streamflow.

It is important to recognize ground-water and surface-water interactions when water supply problems (quantity and quality) are being addressed within a watershed. The interactions can have significant impacts on ground-water and surface-water supplies. In addition, there may be times when several of the processes shown in Figure 3 operate simultaneously. In other words, water supply problems can result from multiple causes that need to be identified and addressed if mitigation efforts are to be successful. For example, when a stream is dewatered, it is often assumed to be caused by the cumulative effects of surface-water diversions for irrigation or municipal water supply. However, this assumption is too simplistic given that ground-water withdrawals, natural water loss through stream channels, and surface water diversions can all contribute to dewatering.

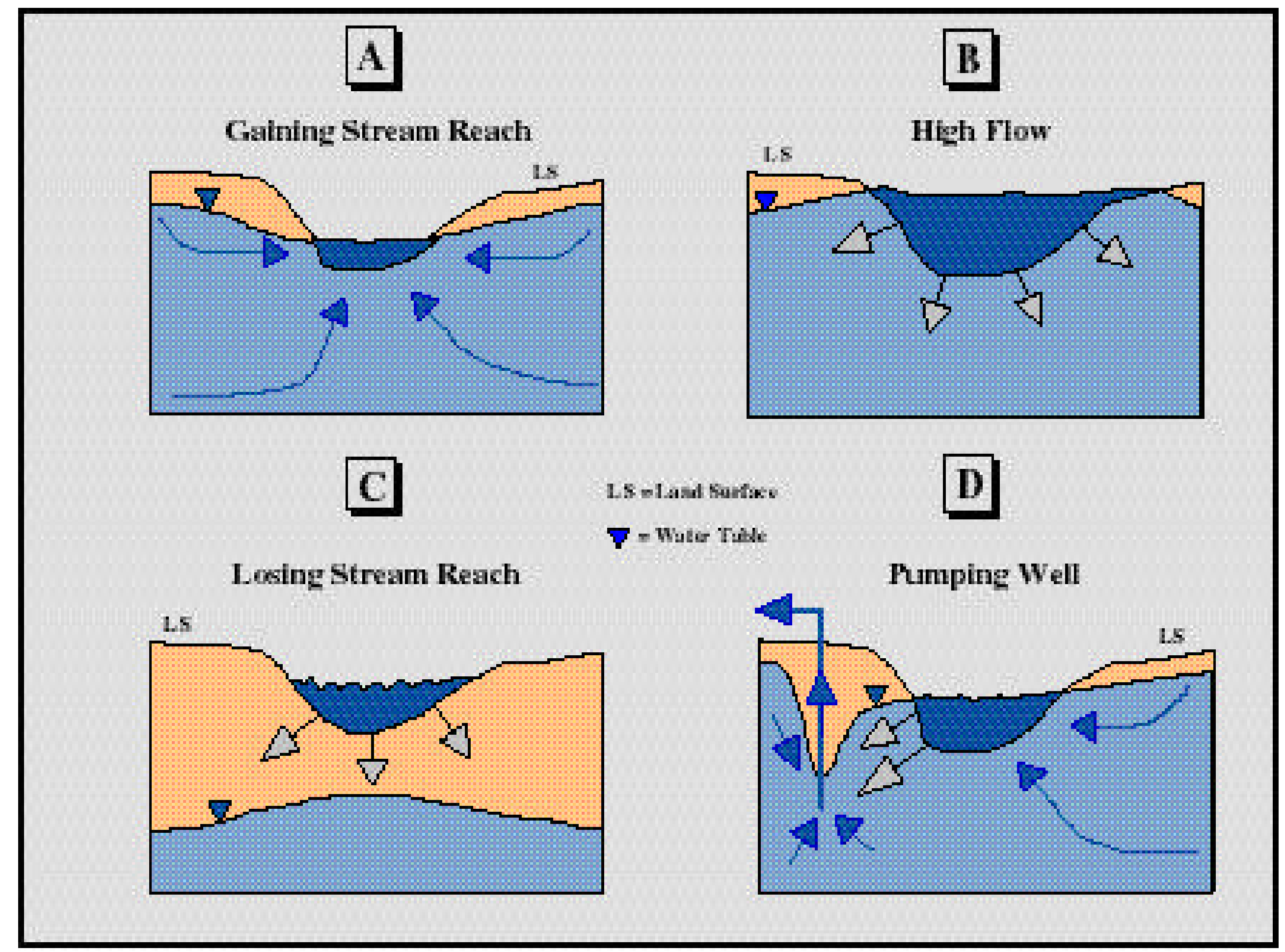


Figure 3 - Ground-water and surface-water interactions.

Montana's Ground-Water Resources

Land Forms and Ground-Water Regions - Map 1

The shaded relief map of Montana depicts the land surface from an aerial view. Western Montana is dominated by mountain ranges with intervening valleys that are often referred to as intermontane basins or western alluvial basins. The mountains are part of the Rocky Mountain chain that extends northwest and southeast through the state. East of the Rocky Mountain Front and west of the Little Rocky Mountains, the land is relatively flat with small isolated mountain ranges scattered throughout the area. These isolated mountains include; the Sweetgrass Hills, Bearpaws, Little Rocky Mountains, Highwoods, Moccasins, and Judiths. East of the Little Rocky Mountains out to the Montana-North Dakota border, there is a large area consisting almost solely of lowland plains. This area is part of the Northern Great Plains that extends over much of the upper midwestern United States.

Montana's land forms differ significantly from one part of the state to the other (Map 1). The different land forms reflect differences in geology and climate. These factors strongly influence where ground water can be found, the volume of water that is readily accessible, and the natural quality of the water. Montana can be divided into three ground-water regions based on the different land forms and geology (Heath, 1984). Ground-water regions are helpful in understanding the kinds of sedimentary deposits and rocks that are available as potential aquifers in a given area. For more detail on the ground-water regions see Heath, 1984. Differences among the three regions in Montana are highlighted in the following paragraphs.

The western third of Montana and the Bighorn Mountains that cross the Montana-Wyoming border south of Billings, lies within the Western Mountain Ranges Region (Map 1). As the name implies, this region is dominated by mountains. The mountains are geologically complex, and consist of metamorphic and igneous rocks, and are often flanked by consolidated sedimentary rocks. Many mountain ranges were heavily glaciated about 10,000 years ago. When the glaciers melted, they left behind deposits composed of a complex mixture of coarse and fine grained unconsolidated sediments. Most of these deposits are restricted to valleys within the mountain ranges but some glacial deposits extend well into the intermontane basins. For the most part, the intermontane basins are filled with thick deposits of unconsolidated sediments (alluvium) deposited by streams. Aquifers within these unconsolidated deposits are by far the most productive and most intensively used for water supply in this region. Other sources of ground water within this region include the fractured metamorphic and igneous rocks, fractured consolidated sedimentary rocks, and some permeable glacial deposits.

The Glaciated Central Region includes an area in northern Montana that extends east roughly from the Rocky Mountain Front to the North Dakota border (Map 1). Continental glaciers extended into this region during several episodes of glaciation. Deposits of till and outwash sediments were left behind as the continental glaciers retreated. In some places glacial debris buried older stream valleys and the alluvium within the valleys. Buried alluvial deposits represent potentially significant sources of ground water when they can be located. Overall, the glacial deposits in this region are not as well developed or as extensive as those in the upper midwestern United States and are not highly productive sources of ground water. Most of the Glaciated Central Region in Montana is underlain by relatively flat-lying sedimentary rocks that are important sources of ground water in some areas (Heath, 1984). Rivers and smaller streams have cut down through glacial sediments and sedimentary rocks. These modern day rivers and streams have accumulated significant deposits of alluvium. Aquifers within the alluvial sediments are the most productive sources of ground water in the region.

A large portion of Montana lies within the Non-Glaciated Central Region (Map 1). This region lacks large mountain ranges and was not covered by continental glaciers. Small isolated mountain ranges are scattered throughout the west-central part of the region. Sedimentary rocks crop out on the flanks of many of the ranges and plunge into the subsurface away from the mountain front. East of the isolated ranges the sedimentary rocks are relatively flat-lying. Terrace gravels, and substantial alluvial deposits in major stream valleys, are also present. Alluvial aquifers are the most productive sources of ground water.

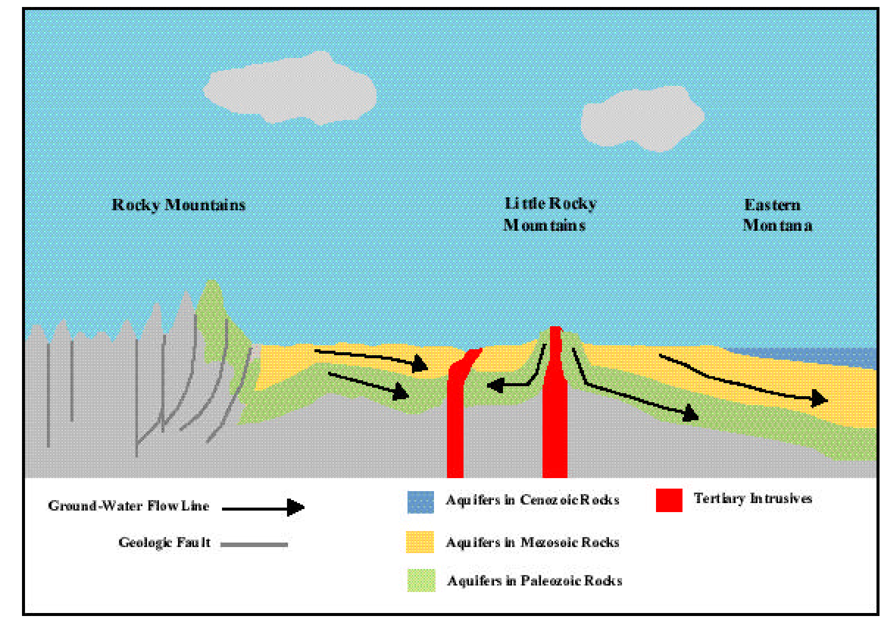
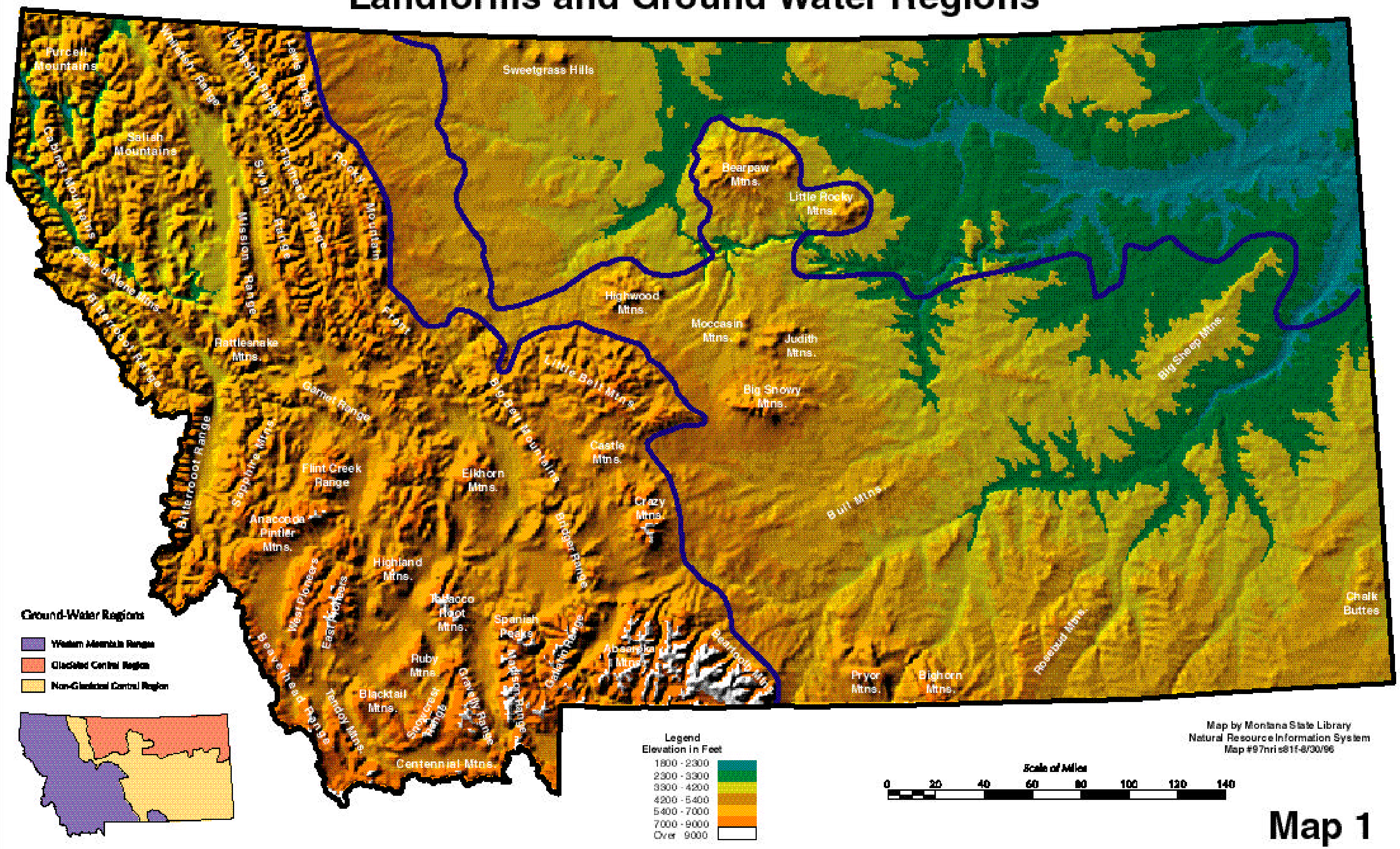


Figure 4 - Generalized geologic cross-section for Montana

It is important to note that Montana's mountains play an important role in providing water to recharge aquifers within bedrock (including sedimentary rocks). Mountains in the western U.S. have been aptly described as moist islands in a sea of desert to semidesert land (McGuinness, 1963). Montana's mountains can receive two to three times as much precipitation as nearby lowland areas. This happens because mountains force clouds containing moist air to higher and cooler altitudes where water condenses and falls as rain or snow. Many of the sedimentary rocks that extend beneath eastern Montana are folded upward and exposed along the Rocky Mountain Front, and along the flanks of isolated ranges, such as the Little Rocky Mountains in central Montana. Part of the rainfall and snowmelt generated in the mountain areas seeps into the bedrock and flows away from the mountains. As a result, some ground water in eastern Montana comes from mountainous areas to the west. A generalized geologic cross-section of Montana is shown in Figure 4. The Figure shows how bedrock is folded upward in mountainous regions and the general path ground water takes as it moves into the subsurface.

Landforms and Ground Water Regions



Geologic Units - Map 2

There are about a dozen aquifers that are widely used and considered the state's principal sources of ground water. Figure 5 lists the principal aquifers. The aquifers consist of unconsolidated sediments and consolidated sedimentary rocks. Aquifers can occur as individual geologic layers, entire geologic formations, or groups of formations. In publications, such as ground-water reports and maps, aquifers are often referred to by their formal stratigraphic names. For example, the Fort Union Formation is used as an aquifer in eastern Montana, and the Madison Group is the source of several perennial springs in central Montana. Some sedimentary deposits do not have formal stratigraphic names. As a result, the aquifers within these deposits are often referred to by using descriptive terms like "unconsolidated sedimentary deposits," or simply "unconsolidated deposits." In some cases, the name of the geologic process that created the deposit is used when referring to the aquifer. For example, "fluvial" or "alluvial" deposits are important aquifers throughout the state and were laid down by running water within stream channels.

Figure 5 also shows how the principal aquifers are grouped according to their geologic age. It is important to note that there are other geologic formations within the three general age groups that are not listed in Figure 5 because they are not used as aquifers. They are either impermeable and do not transmit water readily, or they contain water that it unfit for public, domestic, stock, or industrial use. The age groups from Figure 5 are used in Map 2 to show the areal distribution of the principal aquifers, and other formations. The age groups are also used in the general geologic cross-section (Figure 4) to help illustrate the distribution of aquifers below the land surface.

Gray areas on Map 2 are designated as "Rocks without a principal aquifer." In general, these areas are underlain by consolidated sedimentary rocks or igneous and metamorphic rocks that are much less permeable than the principal aquifers listed in Figure 5. However, sometimes bedrock will yield water to wells but usually at lower rates and volumes than the principal aquifers. As a result, bedrock is used for water supply primarily where the principal aquifers are thin or absent. East of the Rocky Mountain Front, there are large expanses of land underlain by impermeable shale. One these areas is north of Great Falls. The shale outcrops are also included in the grey areas on Map 2.

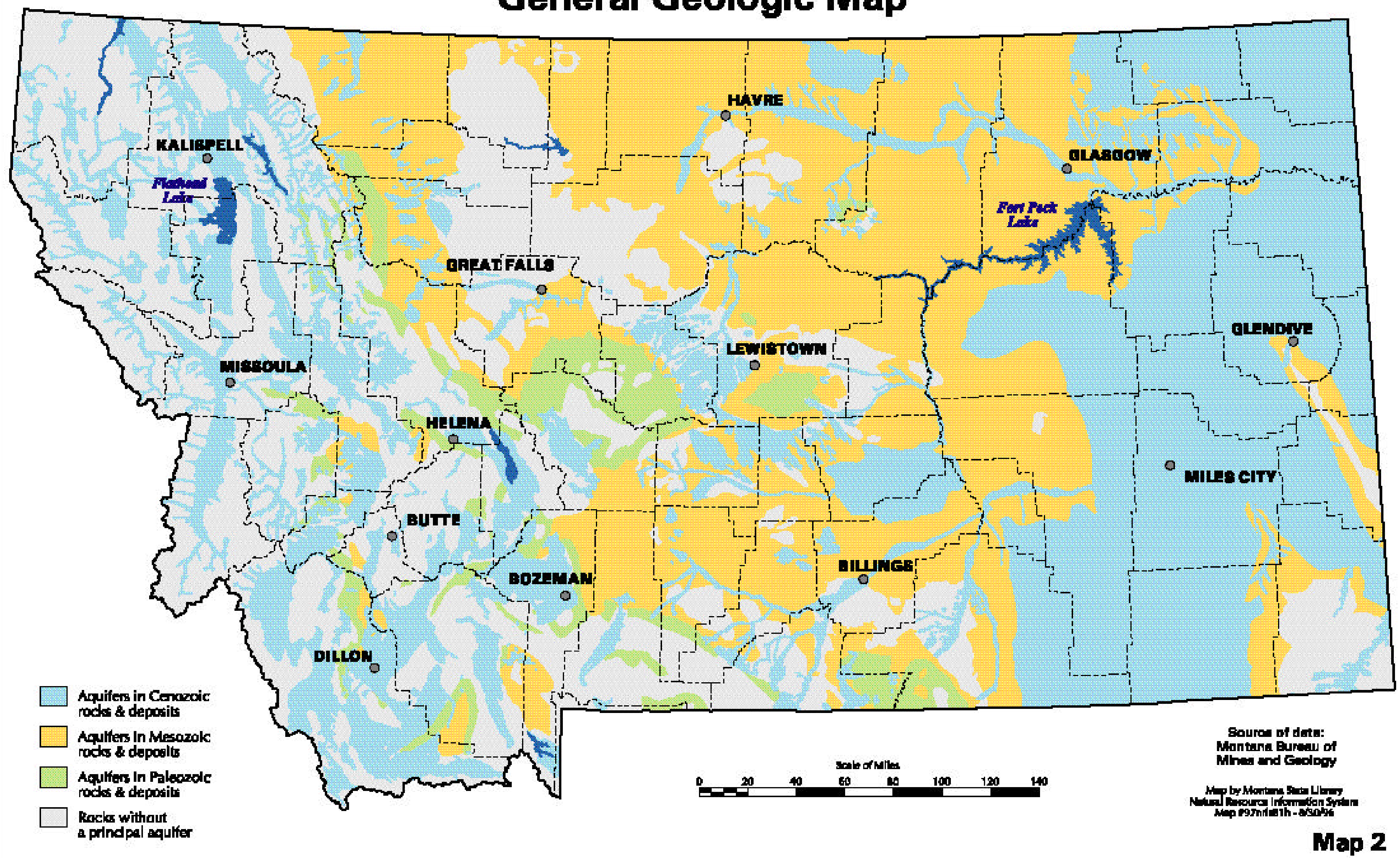
Another useful way to examine Montana's ground-water resources is to separate the aquifers that occur within Quaternary unconsolidated sedimentary deposits from the aquifers that are found within older consolidated rocks (bedrock). The former are often very productive aquifers, yield high quality water, and are discussed in the next section entitled Surficial Aquifers. The latter, although widely used throughout Montana, are generally less productive and yield lower quality water. These aquifers are discussed in the section entitled Bedrock Aquifers.

ERA	Period	Principal Aquifers	Age:
			10,000 Years
CENOZOIC	Quaternary	Alluvium & Fluvial-Glacial Gravels	1.6 MYBP
	Tertiary	Alluvium Fluvial-Glacial Gravels (and equivalents) Terraces Fort Union Formation	66.4 MYBP
MESOZOIC	Cretaceous	Hell Creek-Fox Hills Formation Judith River Formation Eagle Formation	
	Jurassic	Kootenai Formation	
	Triassic	Ellis Group	245 MYBP
PALEOZOIC	Permian	No Principal Aquifers	
	Pennsylvanian	No Principal Aquifers	
	Mississippian	Madison Group	
	Devonian Silurian Ordovician Cambrian	No Principal Aquifers	570 MYBP

MYBP = Millions of Years Before Present

Figure 5 - General geologic time scale and principal aquifers.

General Geologic Map



Surficial Aquifers - Map 3

In general, the highest quality and most accessible water comes from aquifers contained in unconsolidated deposits of Cenozoic age in the western intermontane basins, in major stream valleys and their tributaries, and beneath terrace and pediment surfaces. All these aquifers are at, or near, the land surface, and are called surficial aquifers. The aquifers shown on Map 3 are composed mostly of unconsolidated sediments deposited by streams, glaciers, or by meltwater from glaciers. Included in this group are alluvial aquifers found in major stream valleys throughout the state (yellow areas); glacial till and outwash aquifers found in many tributary stream valleys and in some intermontane basins in western Montana (included in yellow areas in the west); and terrace and pediment gravel aquifers scattered throughout central and eastern Montana (orange-brown areas). Surficial aquifers are very important in Montana because they can be tapped by shallow wells and provide adequate water supply for most domestic and agricultural purposes. Surficial aquifers can be unconfined or partially confined.

When discussing the ground-water resources of the western intermontane basins, it is important to draw attention to the Tertiary sediments. The Tertiary sediments are not distinguished from the younger Quaternary alluvial deposits on Map 3 because detailed mapping in the western basins is not currently available in a form that can be included in this atlas. Even though Tertiary sediments are not formally grouped with the alluvial deposits, discussing them at this point is appropriate. Tertiary deposits consist of semi-consolidated beds of silt, sand, and gravel exposed on the flanks of most western basins. They are exceedingly thick, extending to more than 15,000 feet into the subsurface in some intermontane basins. While the Tertiary deposits represent important sources of ground water in the western basins, they usually yield less water to wells than younger Quaternary alluvial aquifers. Despite this fact, the use of Tertiary sediments to supply ground water is increasing as communities encroach onto the sides of the western basins. It is important to note that drilling wells in the Tertiary deposits is more risky than it is for alluvial sediments. It is not uncommon to drill deep into the Tertiary sediments and end up with a "dry hole." This underscores the need for thorough evaluation of ground-water resources before building individual homes or establishing subdivisions on the Tertiary sediments in the western basins.

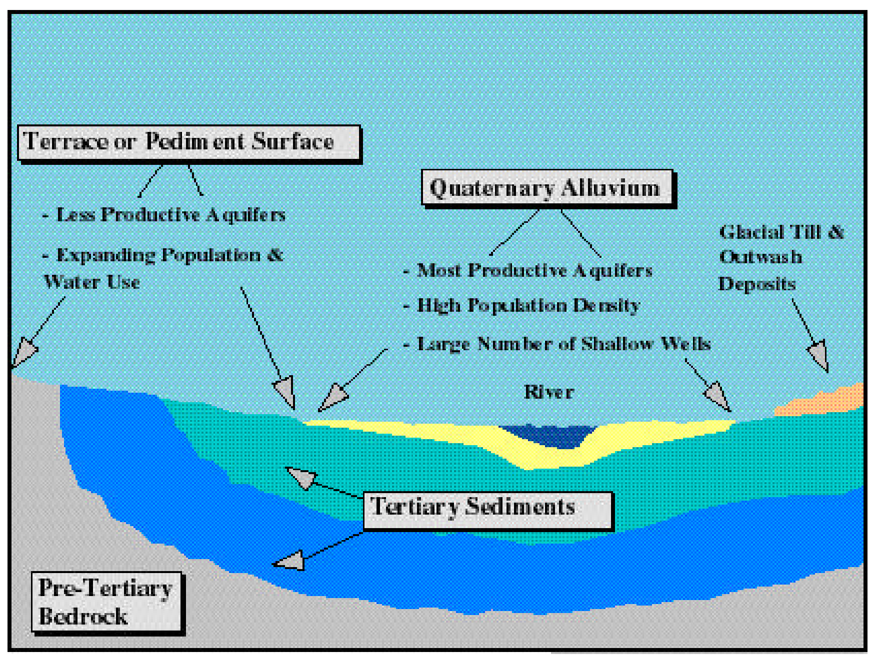


Figure 6 - Generalized cross-section of a "typical" western alluvial basin.

As mentioned previously, Map 3 shows the general outline the western basins but does not show the distribution of the Quaternary alluvium and Tertiary sediments within the basins. If detailed mapping were available, it would show that most basins have alluvial deposits in their central part. Sometimes the alluvium is restricted to areas near stream channels. In other instances, the alluvium is quite extensive and covers much of the basin's land surface. The flanks of most western basins have Tertiary sediments beneath pediment surfaces. Detailed mapping in the Swan River and Kalispell valleys indicates that, unlike most western basins, glacial till and outwash deposits cover much of the valley floor. The glacial deposits overlie alluvial aquifers. Glacial outwash deposits, where thick enough, yield large volumes of water to wells. Figure 6 is a generalized geologic cross-section showing the relations between the surficial aquifers and Tertiary deposits in a "typical" western basin.

In central and eastern Montana, surficial aquifers are found within the valleys of major rivers and their tributaries (yellow areas). These include the following rivers; Clarks Fork of the Yellowstone, Bighorn, Powder, Tongue, Yellowstone, Missouri, Judith, Musselshell, and Sun. Alluvium in the river valleys consists of gravel, sand, silt, and clay. Deposits of these sediments vary in thickness from a few feet to over 100 feet, and in many larger stream valleys, are several miles in width. These unconsolidated deposits represent a very important source of water. Figure 7 is a generalized cross-section of a "typical" river valley in eastern Montana. The Figure shows an alluvial aquifer overlying less productive bedrock aquifers.

Gravel deposits are also tapped to supply ground water in central and eastern Montana (orange-brown areas on Map 3). These deposits are found primarily beneath terrace and pediment surfaces. Some of these gravel deposits can be productive aquifers. Other gravel deposits near Lewistown, also supply ground water. The gravels represent important surficial aquifers in central and eastern Montana. Table 1 summarizes characteristics of the important surficial aquifers.

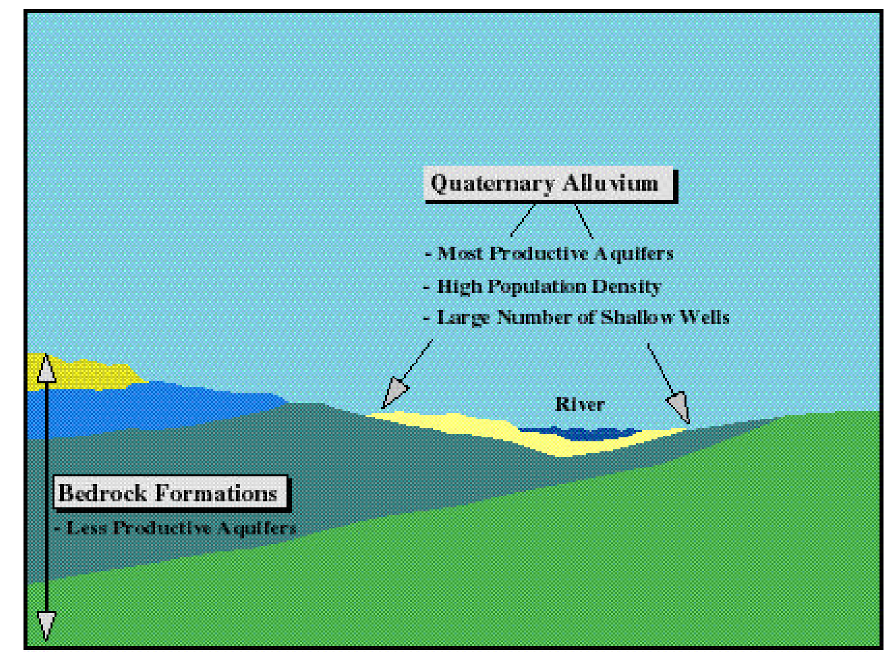
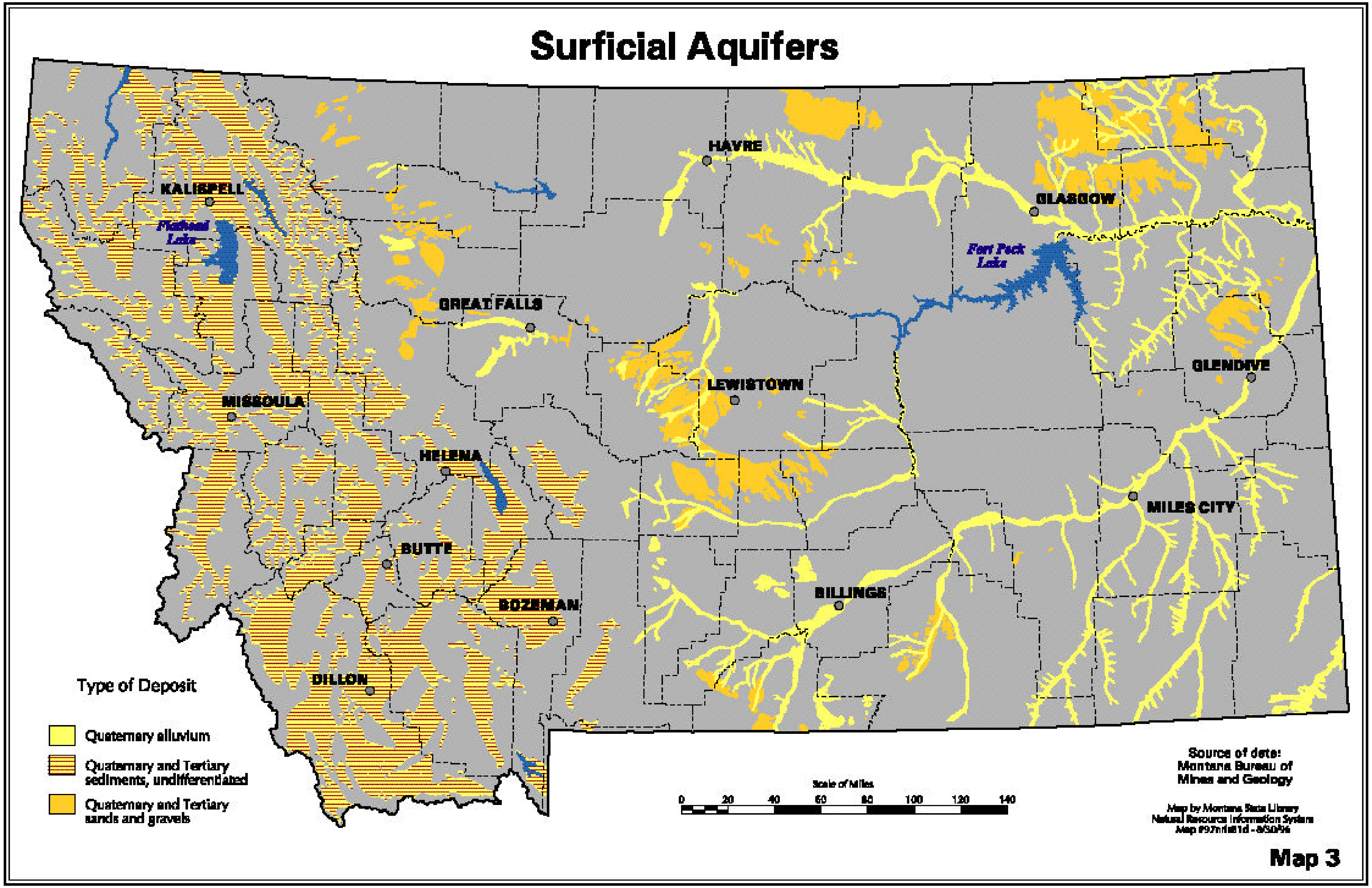


Figure 7 - Generalized cross-section of a "typical" river valley in eastern Montana.



Surficial Aquifers
HAVRE
KALISPELL
Flathead Lake
GLASGOW
Fort Peck Lake
GREAT FALLS
LEWISTOWN
GLENDIVE
MISSOULA
HELENA
MILES CITY
BUTTE
BOZEMAN
BILLINGS
DILLON
Type of Deposit
Quaternary alluvium
Quaternary and Tertiary sediments, undifferentiated
Quaternary and Tertiary sands and gravels
Scale of Miles
0 20 40 60 80 100 120 140
Source of data: Montana Bureau of Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 3

General Water Quality of Surficial Aquifers - Map 4

Map 4 shows the location of wells with water quality information. For the purpose of this atlas, specific conductance is used as a general indicator of water quality. Specific conductance is a measurement of the ability of water to conduct electrical current and is a general measure of the water's salinity, or the amount of dissolved solids in the water (salts and minerals). Low specific conductance indicates low dissolved solids concentration and would imply good quality water. Higher specific conductance values indicate greater amounts of dissolved solids. In general, the larger the specific conductance, the poorer the quality of water. It is important to understand, however, that specific conductance does not identify individual constituents dissolved in the water; it only indicates the relative abundance of dissolved solids. For example, it is possible for water contaminated with arsenic or lead to have relatively low specific conductance.

Map 4 shows specific conductance values grouped into four classes, blue (Class 1) and green (Class 2) are the best quality water, brown (Class 3) and red (Class 4) the poorest. Water in Class 1 could be used for public and private water supplies, Class 2 is marginally suitable for public and private water supplies but is acceptable for agricultural and stock supply. Most of the water sample points shown on the map came from wells completed in surficial aquifers. Surficial aquifers, as a whole, have very good quality water. This is especially true in western Montana. In the eastern part of the state there is more variability but water quality is, overall, good. Several factors influence the natural quality of ground water including the chemical composition of precipitation and snowmelt water that serves as recharge, chemical reactions occurring at the land surface and in the soil zone, and the mineral composition of sediments and rocks that comprise aquifers and confining beds (Heath, 1987). Another factor that strongly influences the natural water quality in surficial aquifers is their high hydraulic conductivity that allows water to flow relatively fast. As a result, the water does not remain in the surficial aquifers for extensive periods. This means that the water has less time to dissolve soluble salts and other minerals that are present in these aquifers. As a result, the concentration of dissolved solids remains relatively low and the water is "fresh."

Additional Information
Box 2 - Ground Water Information Center
(GWIC)

The GWIC data base is maintained by the Montana Bureau of Mines and Geology (MBMG) in Butte, Montana. GWIC contains more than 140,000 well log records. GWIC can be used to help answer important questions concerning the use of ground water in Montana. Boxes 3, 4, 7, and 8 present GWIC data that can be used with the maps in this atlas to help answer the following questions:

1.How many wells are completed each year?

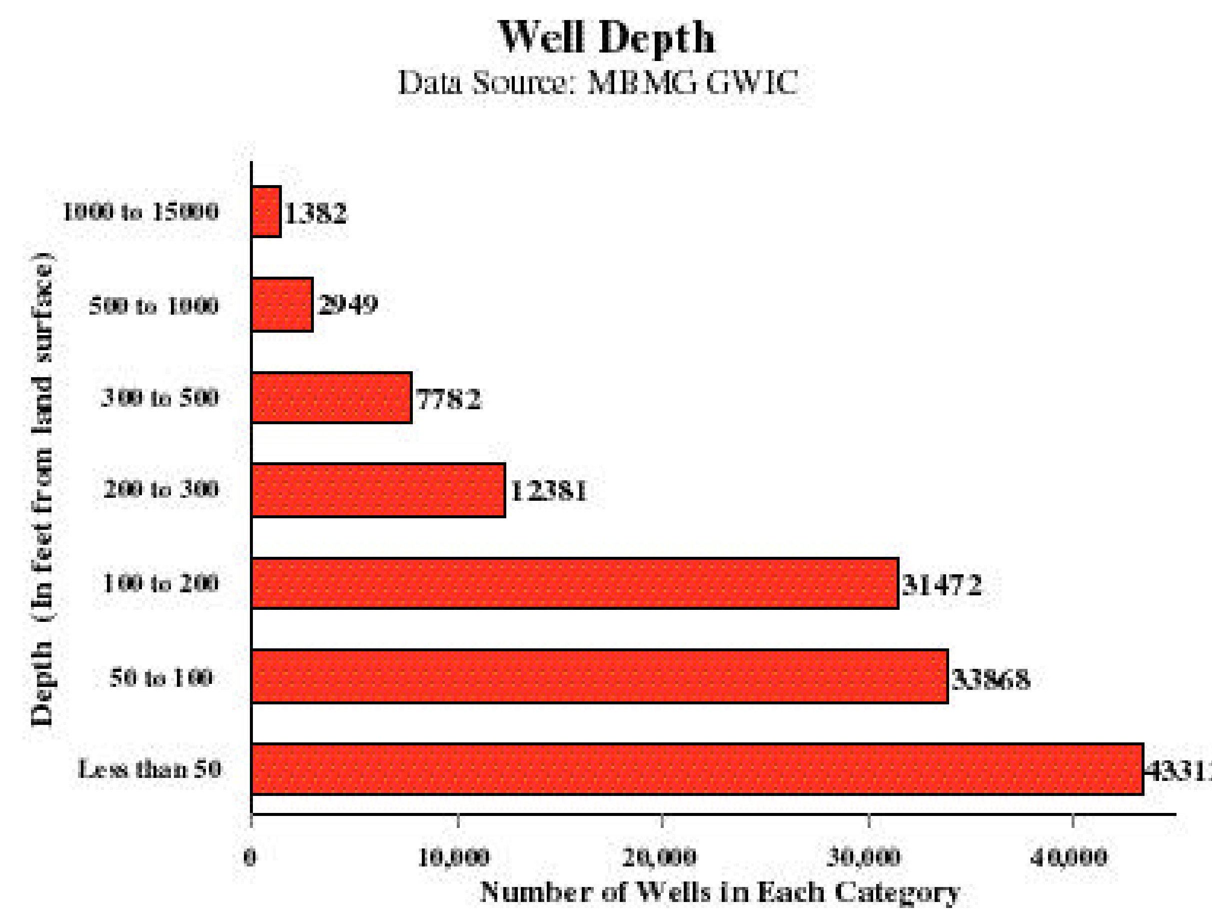
2.Are shallow or deep aquifers most frequently used to supply ground water?

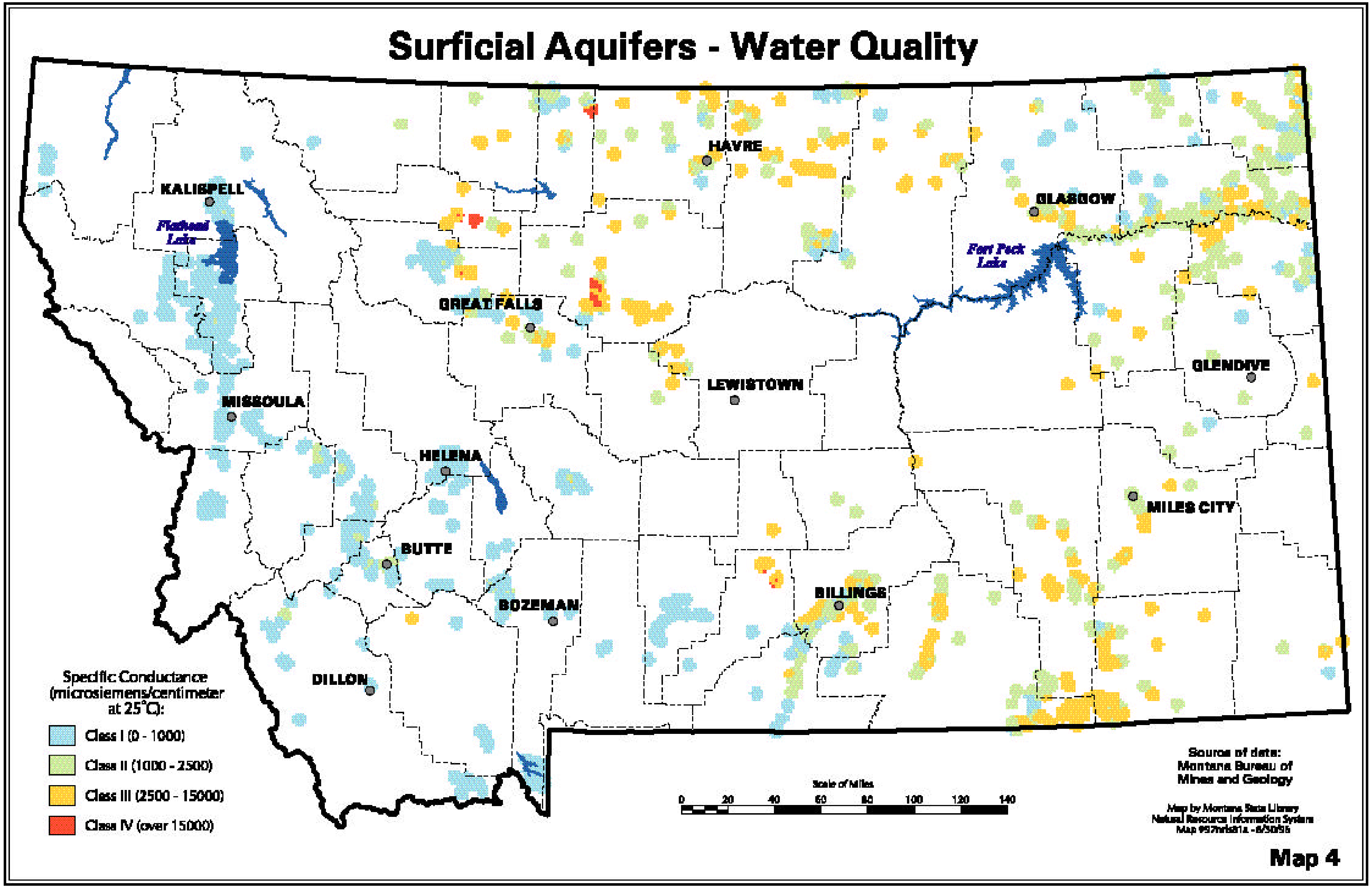
3.Where is ground water used for water supply? Where are the wells located?

In using GWIC to help address these questions, it must be kept in mind that not every well in Montana is recorded in GWIC. It is assumed that GWIC data accurately represent well completion rates, drilling depths, and the geographic distribution of wells for the state as a whole. However, there may be instances where this is not true and other sources of information must be used with the GWIC data to help answer the questions above.

Additional Information
Box 3 - Depth of Wells in Montana

The bar chart shows depth of wells in seven depth categories. A large number of wells are very shallow, less than 50 feet deep. More than 80 percent of the wells are relatively shallow being less than 200 feet deep. In general, the chart indicates that shallow aquifers are used more frequently than deep aquifers to supply ground water.




Surficial Aquifers - Water Quality
KALISPELL
Flathead Lake
HAVRE
GLASGOW
Fort Peck Lake
GREAT FALLS
LEWISTOWN
GLENDIVE
MISSOULA
HELENA
MILES CITY
BUTTE
BILLINGS
BOZEMAN
DILLON
Specific Conductance (microsiemens/centimeter at 25°C):
Class I (0 - 1000)
Class II (1000 - 2500)
Class III (2500 - 15000)
Class IV (over 15000)
Scale of Miles
0 20 40 60 80 100 120 140
Source of data: Montana Bureau of Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 4

Bedrock Aquifers - Map 5

Aquifers within consolidated geologic formations are called bedrock aquifers. Map 5 is based on Map 2 and shows geologic units that contain bedrock aquifers. The aquifers shown are within consolidated sedimentary rocks. Specifically, they are composed of siltstone, sandstone, and limestone. These geologic formations are found at various depths below the land surface, sometimes hundreds or even thousands of feet.

Bedrock aquifers are very important for water supply in central and eastern Montana. In general, water quality is best near recharge areas where the aquifers are close to the land surface. The factors that influence the water quality mentioned previously for surficial aquifers also apply to bedrock aquifers. However, one factor that strongly influences water quality in bedrock is the proximity to recharge zones. For example, a well that taps an aquifer near its recharge zone will yield water that has been in the aquifer for a relatively short time. As a result, the water has not had time to dissolve substantial amounts of soluble salts and minerals, so it remains fresh. The longer the water is in the aquifer, the more time it will have to dissolve salts and minerals. In general, the concentration of total dissolved solids increases with distance from the recharge zone.

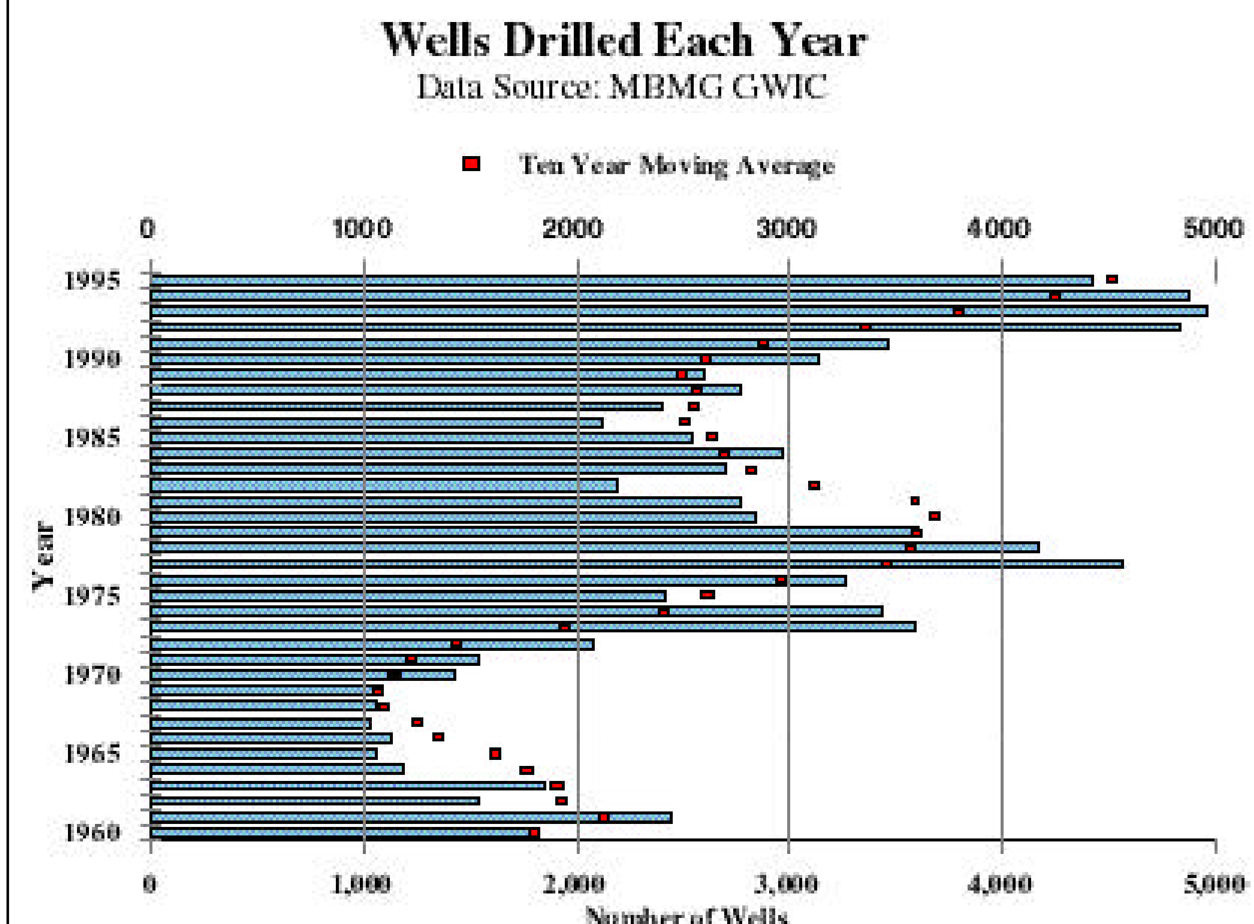
Where the bedrock aquifers are close to the land surface in recharge zones, they can sometimes be tapped with shallow wells and, because of lower drilling costs, they may be as economical to use as surficial unconsolidated aquifers in the region. However, many bedrock aquifers dip away from their recharge areas and plunge into the subsurface. As a result, the cost of drilling a well into these aquifers increases substantially farther from the recharge zones. Bedrock aquifers are used in many parts of the state where the surficial unconsolidated aquifers are limited in thickness or absent. Tables 2, 3 and 4 lists general information on individual bedrock aquifers.

General Water Quality of Bedrock Aquifers - Map 6

Map 6 shows specific conductance data from wells completed in bedrock. These data represent samples from a number of bedrock aquifers of different ages. No attempt has been made to group the samples by aquifer. The map can be considered as a broad sampling of bedrock water quality. Water quality in a bedrock aquifer is typically more variable than water quality in an unconsolidated aquifer. Water quality is generally best near recharge areas. For example, Map 6 shows a cluster of wells with good quality water near Lewistown. The bulk of these wells tap geologic formations of Jurassic age exposed in the Judith Mountains to the north, and in the Moccasin Mountains to the south. These outcrops are recharge zones for the Jurassic formations, so the water quality is quite good. Farther away from the two mountain ranges water quality declines appreciably because the ground water has picked up dissolved solids from the rocks. As a result, the Jurassic formations are not widely used for water supply farther away from the recharge zone.

Additional Information
Box 4 - Well Completion Rates in Montana

How many wells are drilled each year? The chart indicates that well completions can range from 1,000 to 5,000 annually. The ten year moving average provides an indication of the rate of completions for the previous ten year period. The chart shows a substantial increase in drilling activitiy during the first half of the decade 1990 - 2000.



Aquifer Characteristics Tables

Table 1 - Aquifers in Surficial Deposits. (Alluvium, Fluvial-Glacial Gravels, Terrace gravels, and Flaxville Formation Gravels and equivalents)

Common Drilling Depth	Geologic Materials	Aquifer Type	Production or Yield	Total Dissolved Solids	General Comments
20 to 40 ft. May exceed: 250 ft.	Unconsolidated clay, silt, sand, gravel.	Commonly unconfined, can be partially confined to completely confined in some areas.	Typically 5 to 50 gallons per minute (gpm). May exceed 1,500 gpm.	Range 300 to 2,200 milligrams/liter (mg/L).	Widely used aquifer systems. Alluvial aquifers are most often used because they lie near the surface and are accessible via shallow wells, and water yield is routinely quite good. Yields from gravel deposits are more variable but water quality is usually quite good. Alluvial aquifers are vulnerable to human caused contamination in a variety of settings.

Table 2 - Aquifers in Cenozoic Rocks.

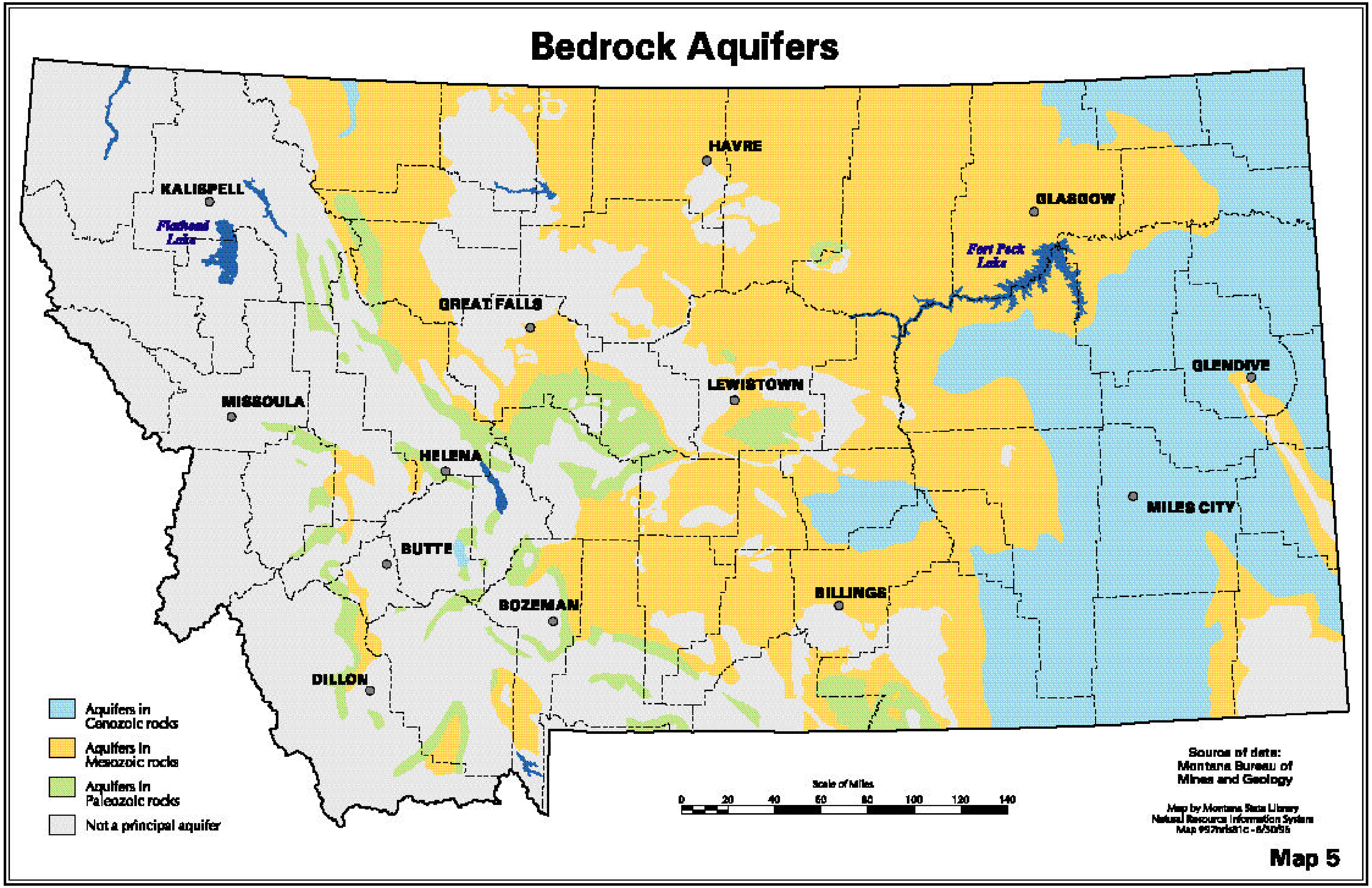
Aquifer	Common Drilling Depth	Geologic Materials	Aquifer Type	Production or Yield	Total Dissolved Solids	General Comments
Fort Union Formation	50 to 300 ft. May exceed 1000 ft.	Interbedded shale, siltstone, sandstone, and coal.	Commonly confined, except near the surface.	15 to 25 gpm. May exceed 100 gpm.	Range 500 to 5000 mg/L.	The Fort Union is a major source of ground water for eastern Montana.

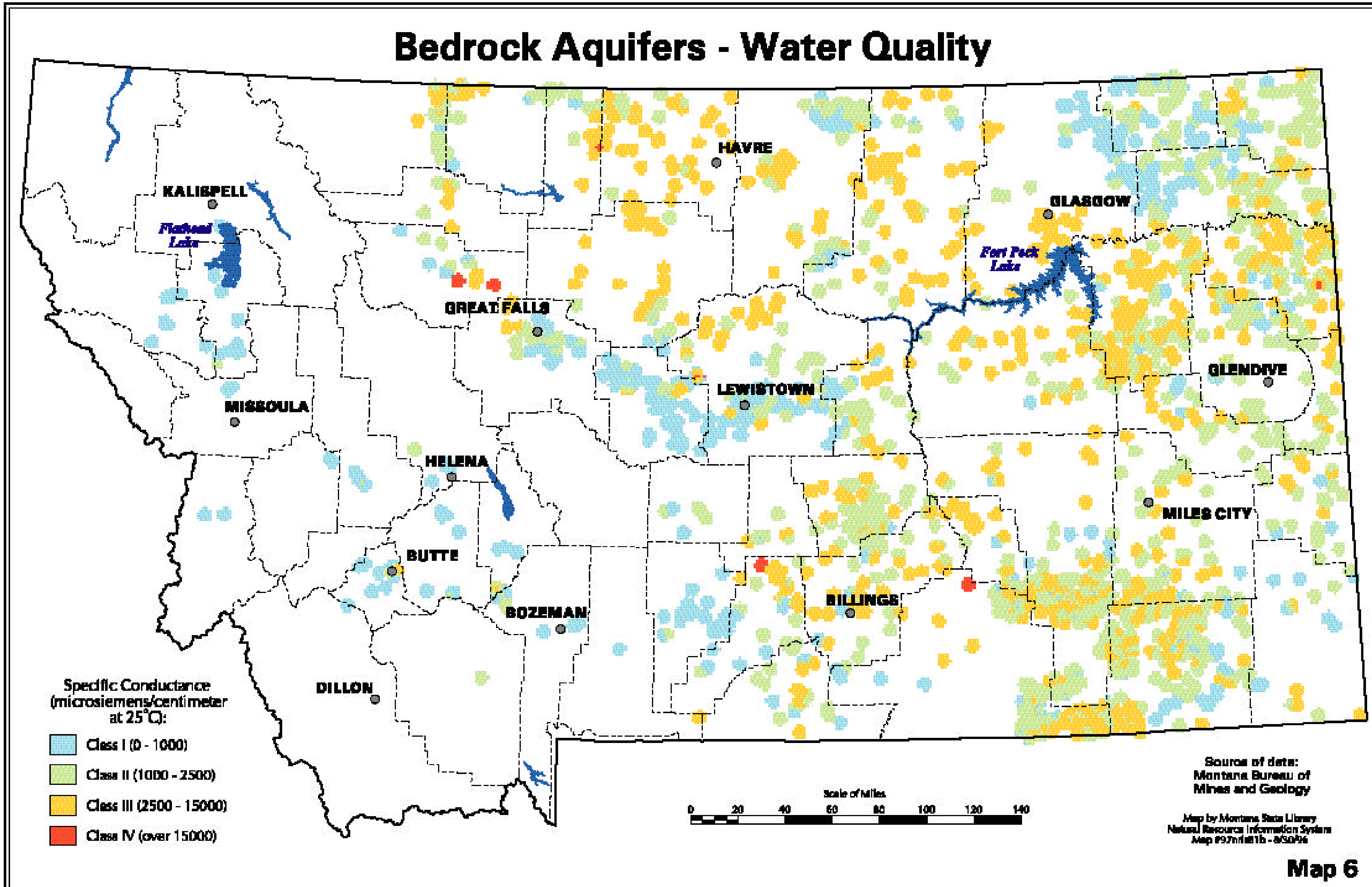
Table 3 - Aquifers in Mesozoic Rocks.

Aquifer	Common Drilling Depth	Geologic Materials	Aquifer Type	Production or Yield	Total Dissolved Solids	General Comments
Hell Creek-Fox Hills Formations	150 to 500 ft. May exceed 1000 ft.	Mainly sandstone with some siltstone and shale.	Confined.	5 to 20 gpm. May exceed 200 gpm.	Range 500 to 1,800 mg/L, commonly less than 1,800.	Although the Fort Union overlies the Hell Creek-Fox Hills, the latter is often the target for drilling as a result of its higher quality of water.
Judith River Formation	200 to 600 ft. May exceed: 1000 ft.	Sandstone, siltstone, with some coal.	Confined.	5 to 15 gpm. May exceed 100 gpm.	Range 160 to 27,000 mg/L.	
Eagle-Virgelle Formation	100 to 800 ft. May exceed: 2000 ft.	Interbedded sandstone and shale.	Confined.	10 to 20 gpm. May exceed 200 gpm.	Range 800 to 1,500 mg/L.	Water quality is best in central Montana, poorer in eastern Montana.
Kootenai Formation	100 to 1000 ft. May exceed: 3000 ft.	Interbedded sandstone, siltstone, and shale.	Confined.	10 to 30 gpm. may exceed 100 gpm.	Range 200 to 500 mg/L. May exceed 14,000 mg/L.	Used heavily in near the Belt Mountains where water quality is good.
Ellis Group	300 to 2,000 ft. May exceed: 5000 ft.	Sandstone, shale, limestone, and dolomite.	Confined	No Data.	Generally less than 600 mg/L.	Water quality is best near outcrop areas.

Table 4 - Aquifers in Paleozoic Rocks

Aquifer	Common Drilling Depth	Geologic Materials	Aquifer Type	Production or Yield	Total Dissolved Solids	General Comments
Madison Group	500 to 3,000 ft. May exceed: 7000 ft.	Limestone, dolomite, anhydrite, and halite	Confined.	20 to 6,000 gpm. High er in karst areas.	Range 500 to 300,000 mg/L.	Very extensive aquifer, it underlies the entire Great Plains. Water quality can be very high near recharge areas and is poorest in northeastern Montana.


Bedrock Aquifers
HAVRE
KALISPELL
Flathead Lake
GLASGOW
Fort Peck Lake
GREAT FALLS
GLENDIVE
LEWISTOWN
MISSOULA
HELENA
MILES CITY
BUTTE
BILLINGS
BOZEMAN
DILLON
Aquifers in Cenozoic rocks
Aquifers in Mesozoic rocks
Aquifers in Paleozoic rocks
Not a principal aquifer
Scale of Miles
0 20 40 60 80 100 120 140
Source of data: Montana Bureau of Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 5


Bedrock Aquifers - Water Quality
KALISPELL
Flathead Lake
HAVRE
GLASGOW
Fort Peck Lake
GREAT FALLS
LEWISTOWN
GLENDIVE
MISSOULA
HELENA
MILES CITY
BUTTE
BILLINGS
BOZEMAN
DILLON
Specific Conductance
(microsiemens/centimeter
at 25°C):
Class I (0 - 1000)
Class II (1000 - 2500)
Class III (2500 - 15000)
Class IV (over 15000)
Scale of Miles
0 20 40 60 80 100 120 140
Source of data:
Montana Bureau of
Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 6

Population Density, Ground-Water Use, and the Distribution of Wells.

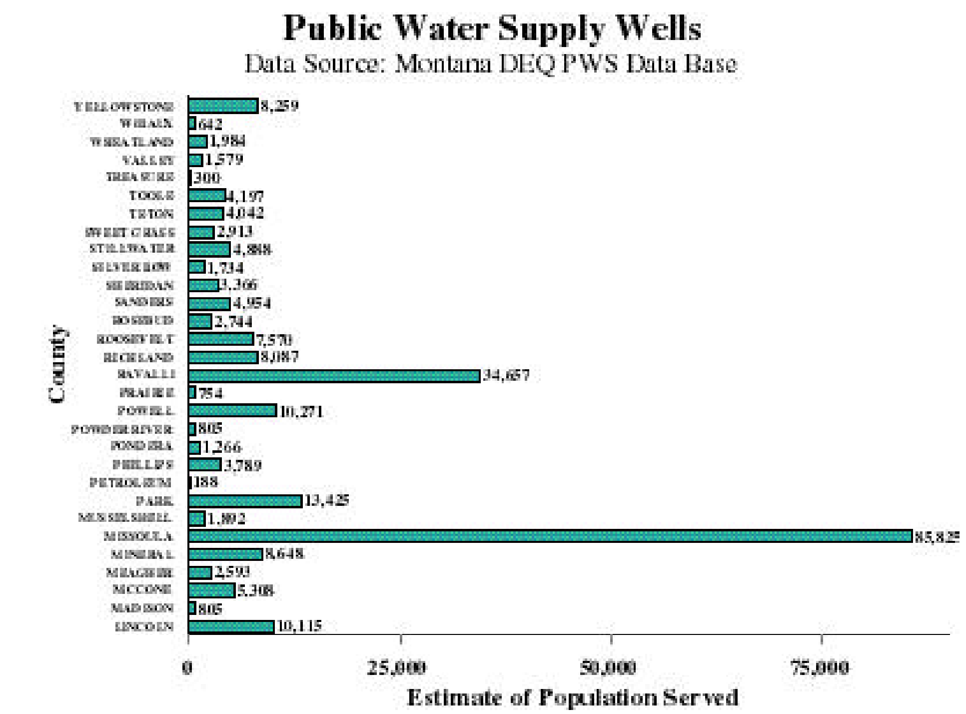
Population Density - Map 7

Montana has a total population of nearly 799,000 (1990 Census). Map 7 shows that most of the population is concentrated along major stream valleys, and many of the state's urban centers are near large rivers. This places a large part of the state's population within recharge zones associated with alluvial aquifers. Examining Map 3 and Map 7 together confirms that a large number of Montanans live on top of the same aquifers they use for their water supply. In addition, many potential contaminants associated with urban centers and agricultural areas are used, stored, and disposed of in these recharge zones. This is a precarious situation that underscores the need to be proactive in protecting sources of ground water from contamination. Maps 3 and 7 also make it clear that everyone in Montana should be interested in protecting ground-water quality. Even if you do not use ground water for your water supply, chances are you know some one who does. The following sections present additional information related to the issues of population, ground-water use, and potential threats to ground-water quality. Maps in the following sections show specifically where ground water is used, where that use is most intense, and where some threats to ground-water quality are greatest.

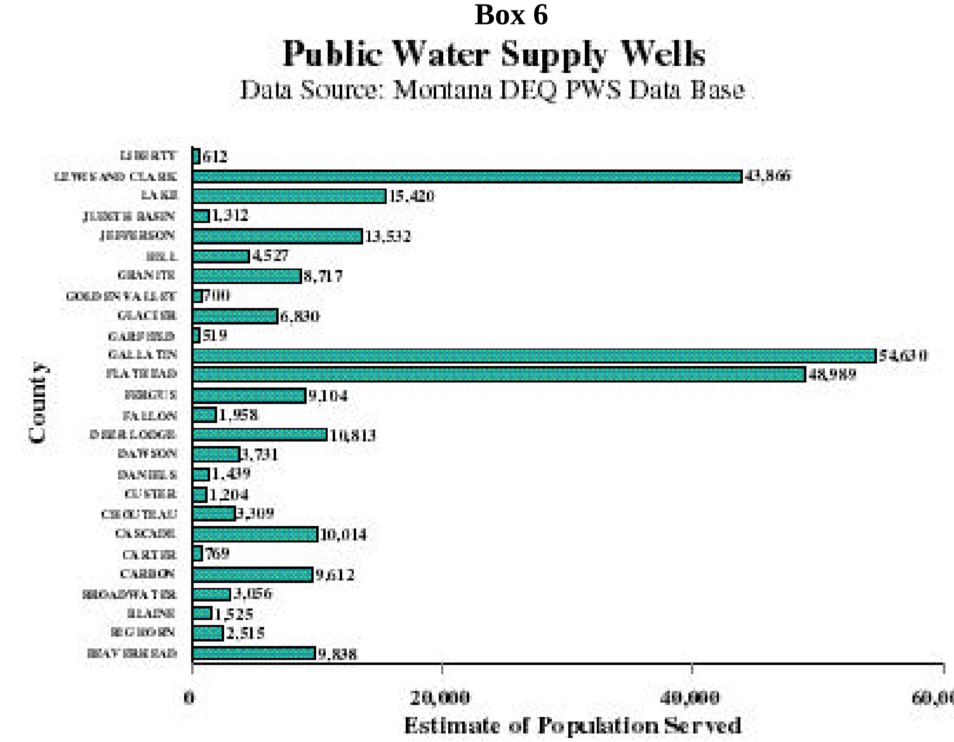
Additional Information
Boxes 5 and 6 - Population Served by Public Water Supply Wells

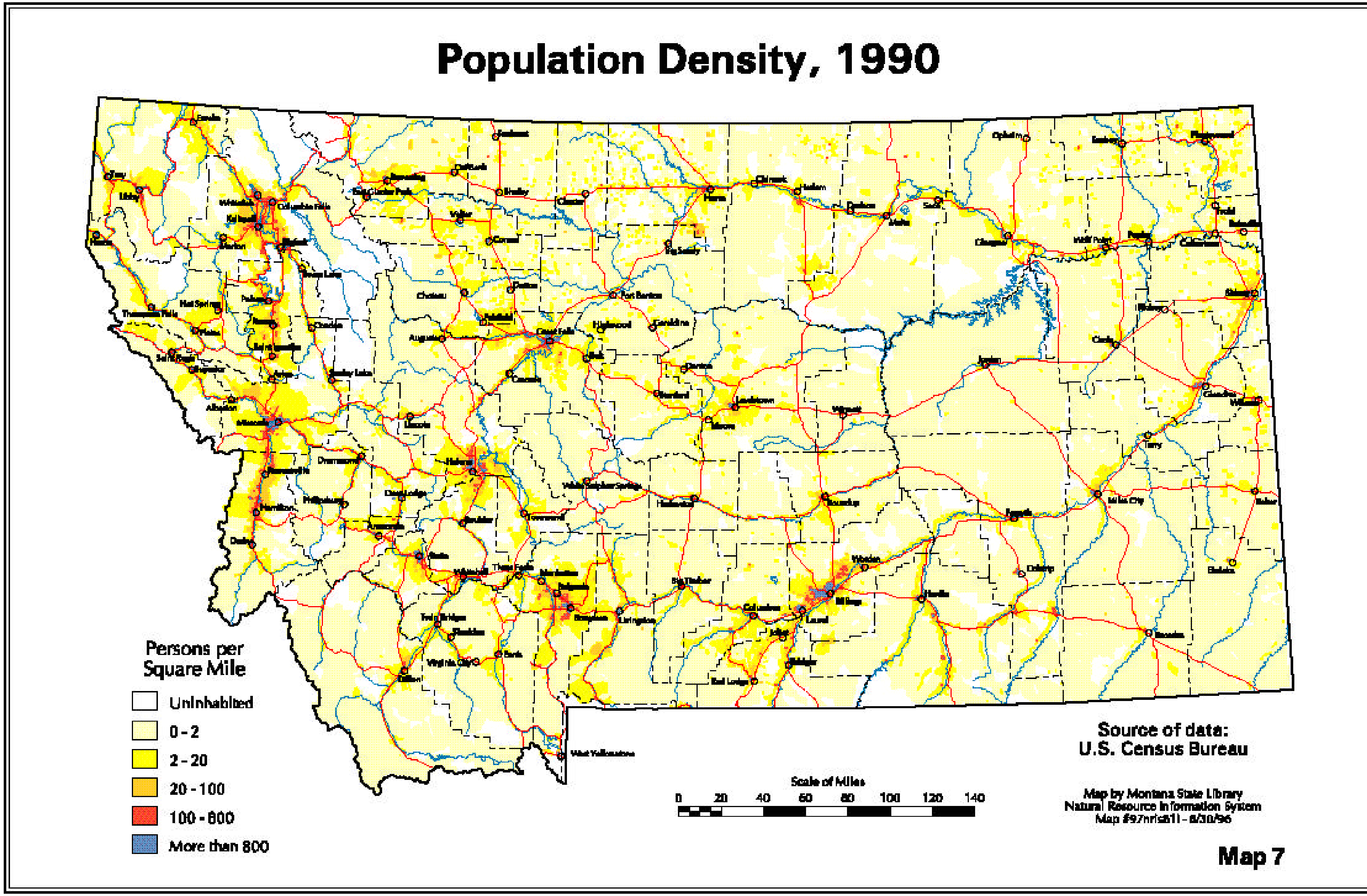
Public water supply systems provide water for human consumption. For a well to be classified as a public water supply it must have at least 15 service connections or regularly serve at least 25 persons daily for 60 days or more each calendar year. Wells that service communities, restaurant, water bottling plants, and schools can be classified as public water supplies. The Montana Department of Environmental Quality (DEQ) maintains the Public Water Supply (PWS) data base. The data base tracks the number of public water supplies, including those that rely on ground water, and estimates the population served by each water system. The bar charts present this information and provide another indication of where ground water is used in Montana. Several counties rely heavily upon ground water for their public water supply.

Box 5



Box 6




Population Density, 1990
Persons per Square Mile
Uninhabited
0 - 2
2 - 20
20 - 100
100 - 800
More than 800
Scale of Miles
0 20 40 60 80 100 120 140
Source of data:
U.S. Census Bureau
Map by Montana State Library
Natural Resource Information System
Map #97nris611 - 8/30/96
Map 7

Distribution of Wells - Maps 8, 9, and 10

These maps show the number of wells per square mile and show where ground water is being used, and the intensity of use. Map 8 shows that wells within the intermontane basins of western Montana are almost exclusively in the surficial unconsolidated aquifers associated with major rivers and their tributaries. The highest well density occurs in urban centers like the Missoula-Bitterroot and Kalispell valleys. Areas around Anaconda, Butte, Deer Lodge, and Dillon also have significant use of ground water. Alluvial aquifers are the most commonly used throughout this region. The exception is near Choteau, where glacial outwash and stream gravel terraces are developed for water supply. Map 8 demonstrates that stream networks and the surficial aquifers should be considered important components of the same water supply system. Protecting the quality of water in the system will require protecting both surface and subsurface water sources.

Map 9 shows the distribution of wells for the central part of Montana. The most intensive use of ground water occurs around Bozeman, Billings, Great Falls, and Helena. Wells are also concentrated around many smaller communities and within major stream valleys, just as they are in western Montana. However, unlike western Montana, many wells in the region are outside the boundaries of surficial aquifers (striped areas). The only other reliable sources for ground water in these areas are the bedrock aquifers. Another important observation from Map 9 is that glacial outwash and gravel deposits are more abundant in the central region than in western Montana. These deposits are important aquifers northeast of Chinook, and north of Harlowton, Ryegate, and Roundup.

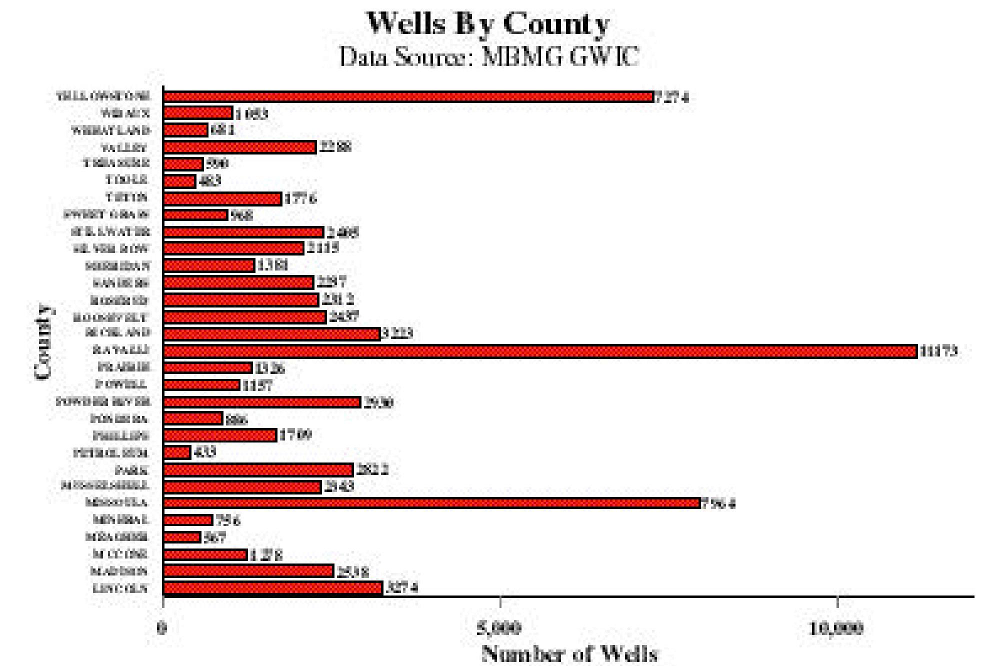
Map 10 shows the distribution of wells in eastern Montana. In this region, ground-water use is heavily concentrated along stream valleys and tributaries, similar to the other two regions (Map 8 and 9). This underscores the importance of surficial aquifers throughout the state. The majority of ground-water use in Montana comes from surficial unconsolidated aquifers and makes protecting the quality of water in these aquifers a high priority. In addition, Map 10 reveals that use of the bedrock aquifers is more common in eastern Montana. This is shown by the large number of wells located beyond the surficial aquifer boundaries. The reason for the high level of use is basically the same as for the central region; bedrock aquifers are the only reliable sources of water away from the alluvial valleys. Besides alluvial and bedrock aquifers, upper Tertiary and lower Quaternary unconsolidated deposits are used to supply water north of the Missouri River.

Additional Information

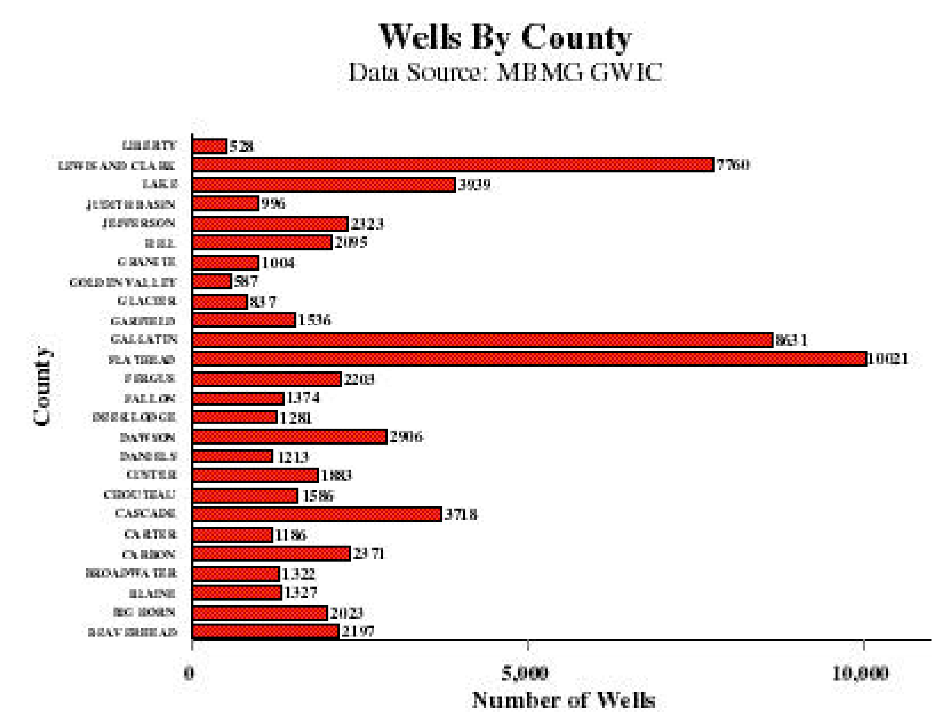
Boxes 7 and 8 - Total Number of Wells per County

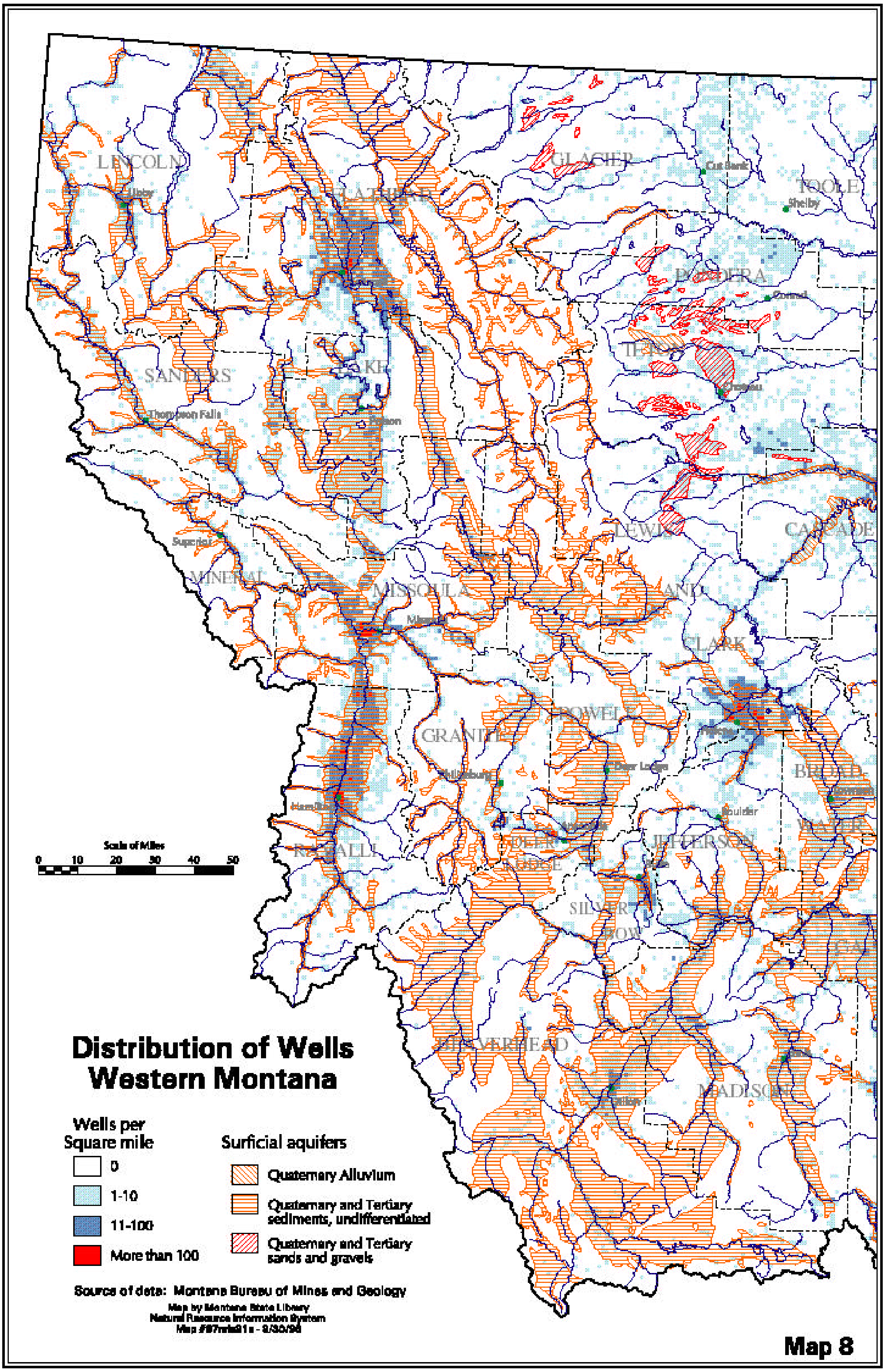
There are several ways of looking at the well log data from GWIC. Maps 8 through 10 show wells per square mile and help identify where ground-water use is concentrated. Boxes 6 and 7 provide another way to examine GWIC information. The bar charts show the total number of GWIC well log records for each county. The actual number of wells in each county is probably larger than shown on the charts. Nevertheless, the bar charts are helpful in identifying counties that are more dependant on ground water.

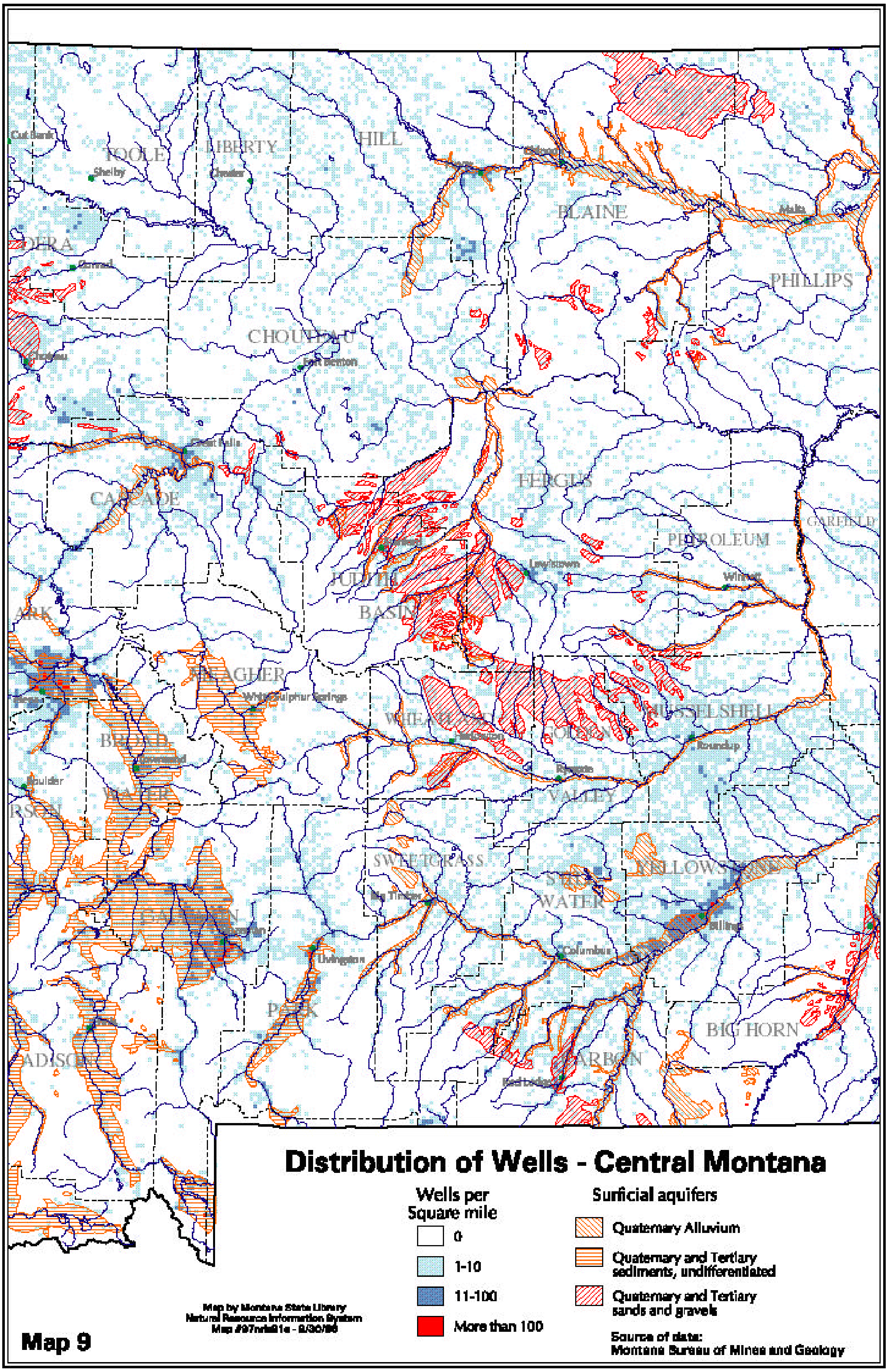
Box 7



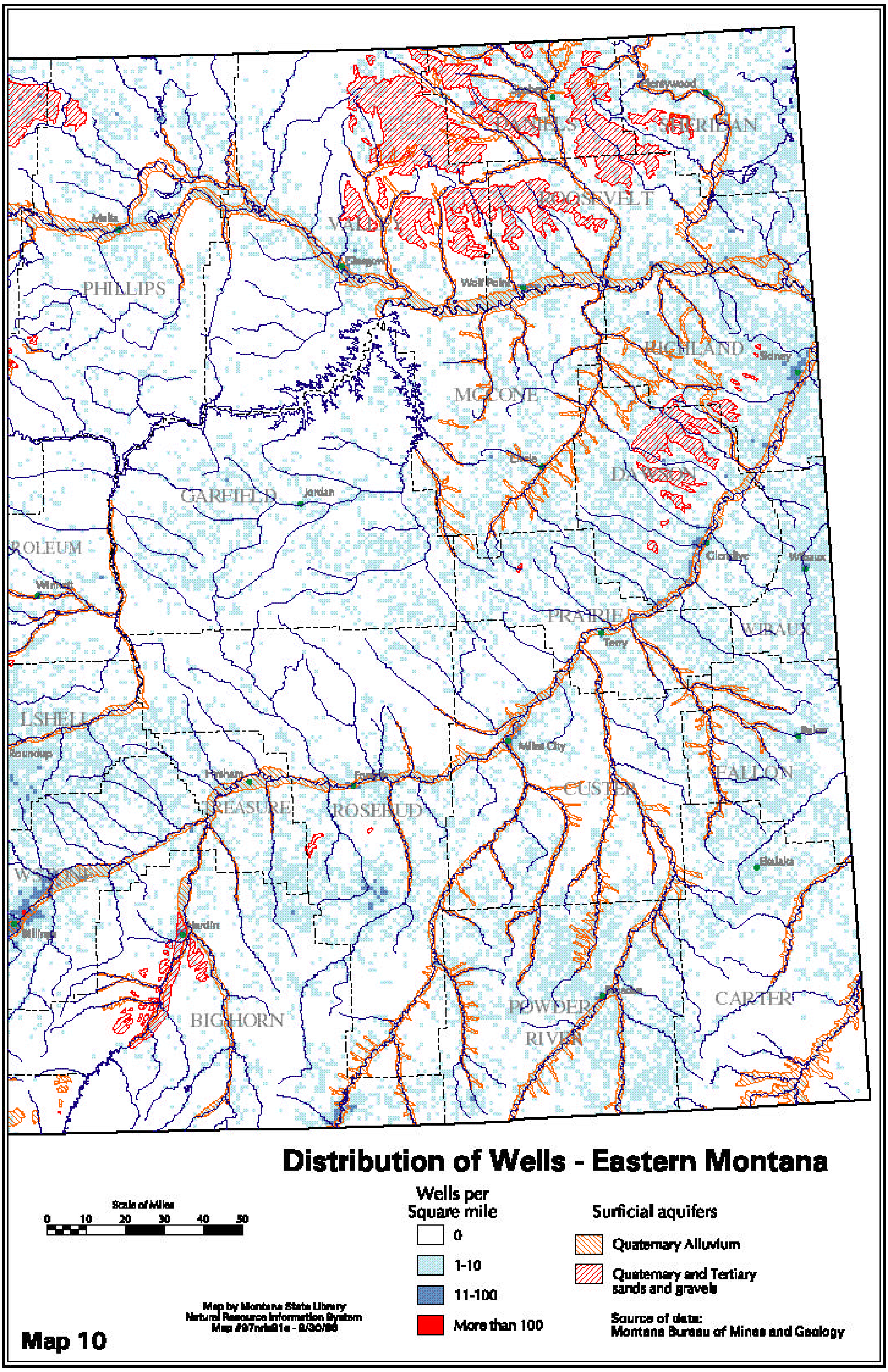
Box 8




Distribution of Wells
Western Montana
Wells per Square mile
0
1-10
11-100
More than 100
Surficial aquifers
Quaternary Alluvium
Quaternary and Tertiary sediments, undifferentiated
Quaternary and Tertiary sands and gravels
Source of data: Montana Bureau of Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 8
Scale of Miles
0 10 20 30 40 50
LINCOLN
GLACIER
TOOLE
SANDERS
MINERAL
MISSOULA
CASCADE
CLARK
POWELL
GRANITE
JEFFERSON
MADISON
Libby
Cut Bank
Shelby
Conrad
Choteau
Thompson Falls
Superior
Missoula
Deer Lodge
Boulder
Hamilton
Philipsburg
Dillon



Distribution of Wells - Central Montana
Wells per Square mile
0
1-10
11-100
More than 100
Surficial aquifers
Quaternary Alluvium
Quaternary and Tertiary sediments, undifferentiated
Quaternary and Tertiary sands and gravels
Source of data: Montana Bureau of Mines and Geology
Map by Montana State Library
Natural Resource Information System
Map 9
TOOLE
LIBERTY
HILL
BLAINE
PHILLIPS
CHOUTEAU
CASCADE
FERGUS
PETROLEUM
GARFIELD
JUDITH BASIN
MEAGHER
WHEATLAND
GOLDEN
MUSSELSHELL
BROAD WATER
VALLEY
SWEETGRASS
STILL WATER
YELLOWSTONE
GALLATIN
PARK
CARBON
BIG HORN
Cut Bank
Shelby
Chester
Malta
Fort Benton
Great Falls
Lewistown
White Sulphur Springs
Roundup
Big Timber
Livingston
Columbus
Billings
Boulder



Distribution of Wells - Eastern Montana

Map 10

Potential Threats to Water Quality and Public Use of Ground Water

There are very few natural sources of ground-water contamination. Most threats to ground-water quality are linked directly, or indirectly, to a variety of human activities. Ground water can be contaminated by; leaks from underground fuel storage tanks and pipes, leaks from cemeteries, leaks from waste disposal sites such as landfills, seepage from septic systems and cess pools, accidental spills from truck and train mishaps, saline runoff from roads and highways, seepage from animal feed lots, irrigation return flow, leaching and seepage from mine spoils and tailings, and improper operation of injection wells (Keller, 1992). Pollutants from these sources can include; petroleum and related chemical products, heavy metals, nitrates, human and animal wastes, fertilizers, pesticides, soluble salts, acid mine drainage and other toxic substances. Sources of contamination can be found in any part of the state which implies that protection of ground-water quality is the concern and responsibility of all Montanans.

The sources of contamination listed above pose a serious threat to the surficial aquifers (Map 3). The threat is greatest where urban centers, industrial sites, or agricultural regions overlie the surficial aquifers. A comparison of Map 3 with population and well distribution maps (Maps 7 through 10) reveals that most of the larger urban centers are, in fact, on top of important surficial aquifers. This is the case in western intermontane basins and along the Missouri and Yellowstone river valleys in central and eastern Montana. In addition, most irrigated crop land is within, or near, major river valleys where the surficial aquifers are present. This pattern of land use occurs in both western and eastern Montana. Many of the contamination sources listed previously are immediately above unconfined and partially confined surficial aquifers. Sewage, petroleum products, cleaning chemicals, agri-chemicals, and other substances from these sources can leak into shallow aquifers. This situation poses a potentially serious problem because many urban centers and agricultural regions rely heavily on ground water from the surficial aquifers for domestic, stock water, and for irrigation supplies.

Ground-water contamination has been documented in all of the larger urban centers and in many rural areas as well. The number of leaks from underground fuel storage tanks has increased each year since information on leaks has been collected. Contamination from pesticides and herbicides is apparently not wide spread in Montana but has been documented in some agricultural areas (Montana Department of Agriculture, 1994). Whether widespread or limited, once contamination occurs, cleanup is expensive. Sometimes, cleanup is not feasible and other sources of water have to be found.

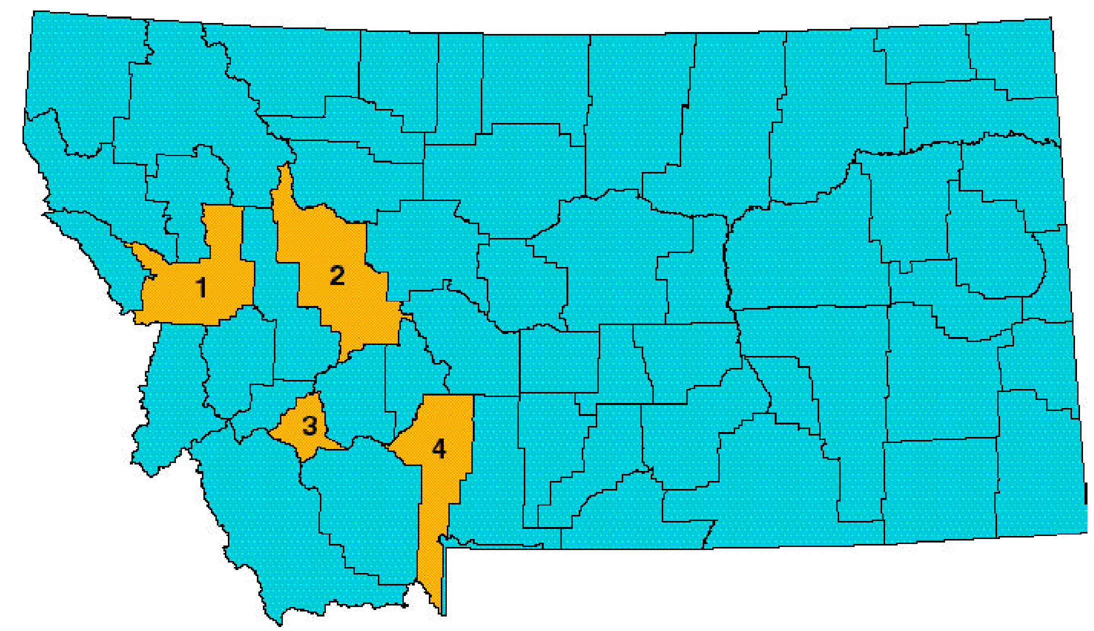
Under Ground Storage Tanks and Public Water Supply Wells - Map 11

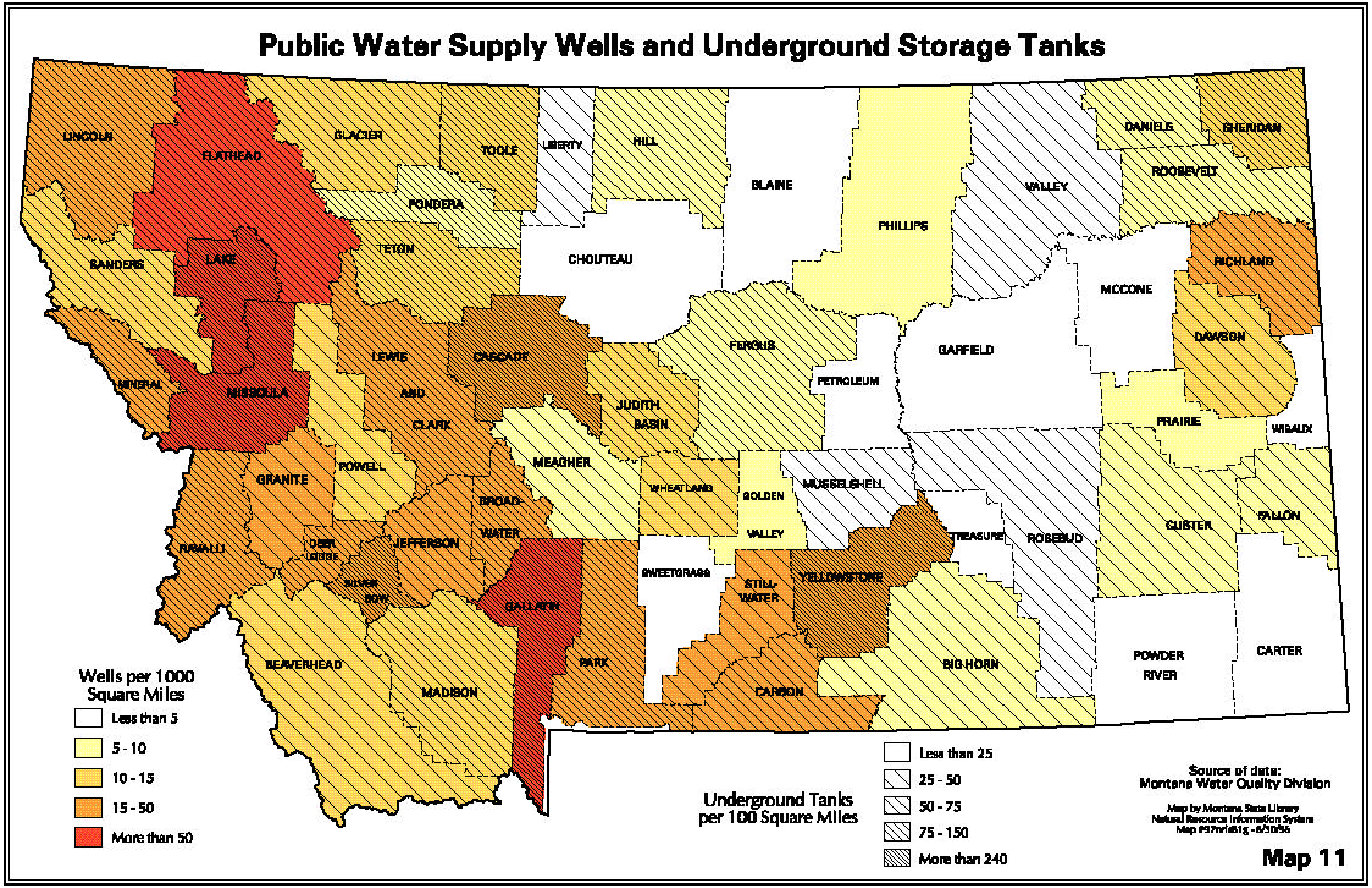
Specific information on most potential contamination sources in Montana is still limited or not available in a format that permits detailed mapping. For example, information on leaking underground fuel storage tanks is available but can only be mapped by county. Map 11 shows the number of underground tanks per 100 square miles and number of public water supply wells per 1000 square miles. The map can be used to identify counties that depend heavily on ground water for public water supply and that also possess a potential threat to ground-water quality. Clearly, the counties with high concentrations of wells and underground storage tanks should place high priority on protecting shallow ground water from leaking tanks.

Additional Information

Box 9 - Water Quality Districts

Several counties have established Water Quality Districts to formalize efforts to assess local ground-water resources, identify potential sources of contamination, and to protect water supply sources. Districts are shown by county: 1. Missoula; 2. Lewis and Clark; 3. Butte-Silver Bow; and 4. Gallatin.




Public Water Supply Wells and Underground Storage Tanks
LINCOLN
FLATHEAD
GLACIER
TOOLE
LIBERTY
HILL
BLAINE
PHILLIPS
VALLEY
DANIELS
SHERIDAN
ROOSEVELT
PONDERA
TETON
CHOUTEAU
SANDERS
LAKE
RICHLAND
MCCONE
GARFIELD
DAWSON
LEWIS
AND
CLARK
CASCADE
FERGUS
PETROLEUM
MINERAL
MISSOULA
JUDITH
BASIN
PRAIRIE
WIBAUX
MEAGHER
POWELL
GRANITE
WHEATLAND
GOLDEN
VALLEY
MUSSELSHELL
BROAD-
WATER
TREASURE
ROSEBUD
CUSTER
FALLON
RAVALLI
DEER
LODGE
JEFFERSON
SWEETGRASS
STILL-
WATER
YELLOWSTONE
SILVER
BOW
GALLATIN
BEAVERHEAD
MADISON
PARK
CARBON
BIG HORN
POWDER
RIVER
CARTER
Wells per 1000
Square Miles
Less than 5
5 - 10
10 - 15
15 - 50
More than 50
Underground Tanks
per 100 Square Miles
Less than 25
25 - 50
50 - 75
75 - 150
More than 240
Source of data:
Montana Water Quality Division
Map by Montana State Library
Natural Resource Information System
Map 11

Montana's Ground Water Assessment Act

A turning point in ground-water management for Montana occurred in 1991, when Montana's Legislature passed the Ground Water Assessment Act (section 2-85-901 et seq MCA). The Act established a comprehensive program to assess and monitor the state's ground-water resources for the long term. This effort consists of two parts; the Ground-water Monitoring Program, that will establish a network of up to 730 wells statewide, and the Aquifer Characterization Program that will identify and characterize important aquifers throughout the state. Both programs are conducted from the Montana Bureau of Mines and Geology (MBMG) and receive guidance and oversight from the Montana Ground Water Assessment Steering Committee, also established by the Act.

Montana's Ground-Water Monitoring Network - Map 12

Map 12 shows the monitoring well network as of December 1996. Wells are selected to represent the principal surficial and bedrock aquifers that are widely used for water supply. There are approximately 550 wells shown on the map. The water level from each well on the map is measured quarterly. About ten percent of the wells have continuous water-level recorders installed on them. Information collected by the program is entered into a data base and is available from the MBMG Ground-Water Information Center (GWIC) in Butte, Montana. For more information on the Monitoring Program, or GWIC, contact the MBMG.

Montana's Aquifer Characterization Study Areas - Map 13

Map 13 shows the 21 aquifer characterization study areas for the state. Study areas are based on county boundaries and on general watersheds. Shaded basins show where work is under way. A preliminary assessment report for the Glendive area of eastern Montana was produced in October 1994. This publication, MBMG Open-File Report 323, is available from the MBMG. For more information on the Assessment Program contact the MBMG.

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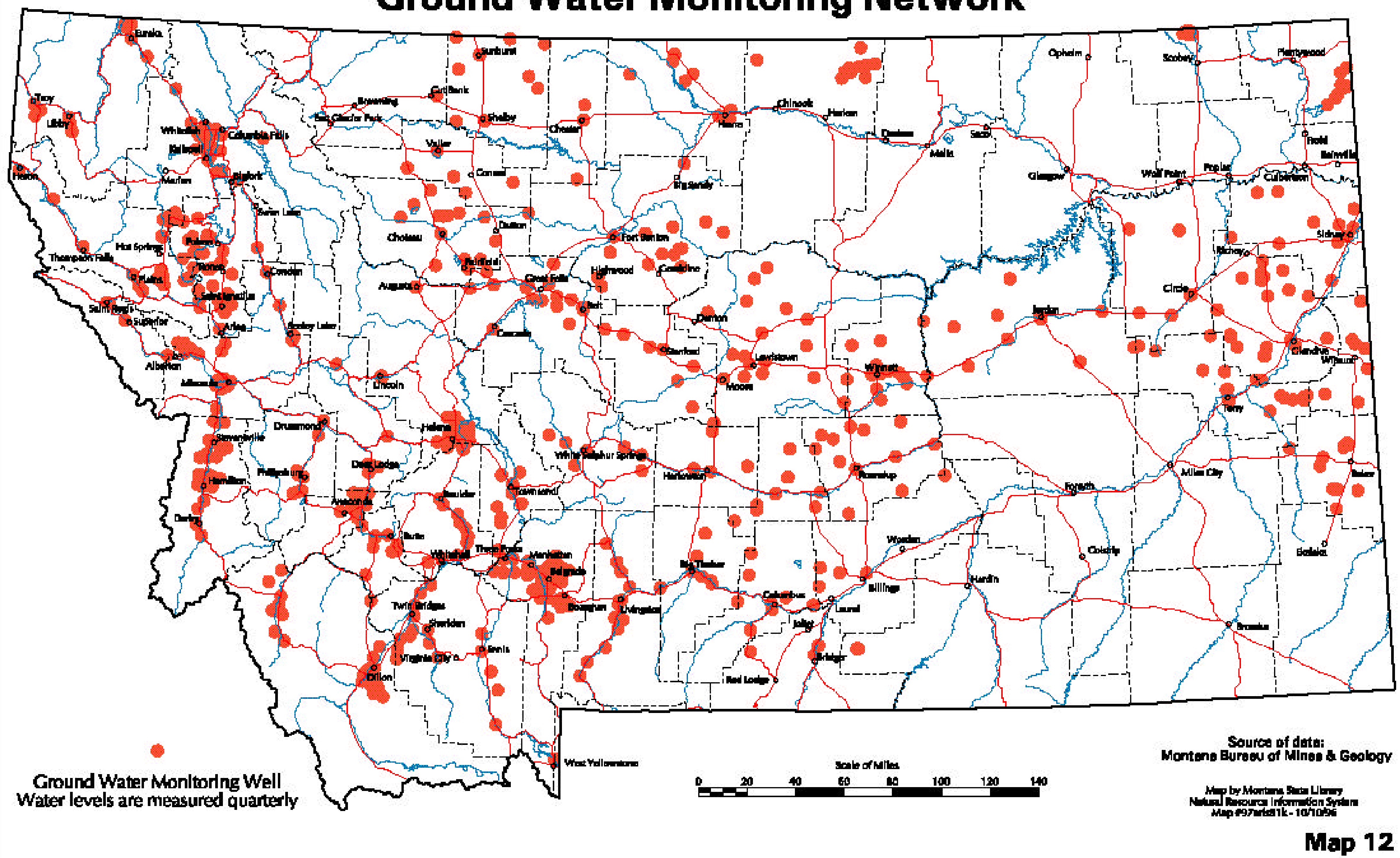
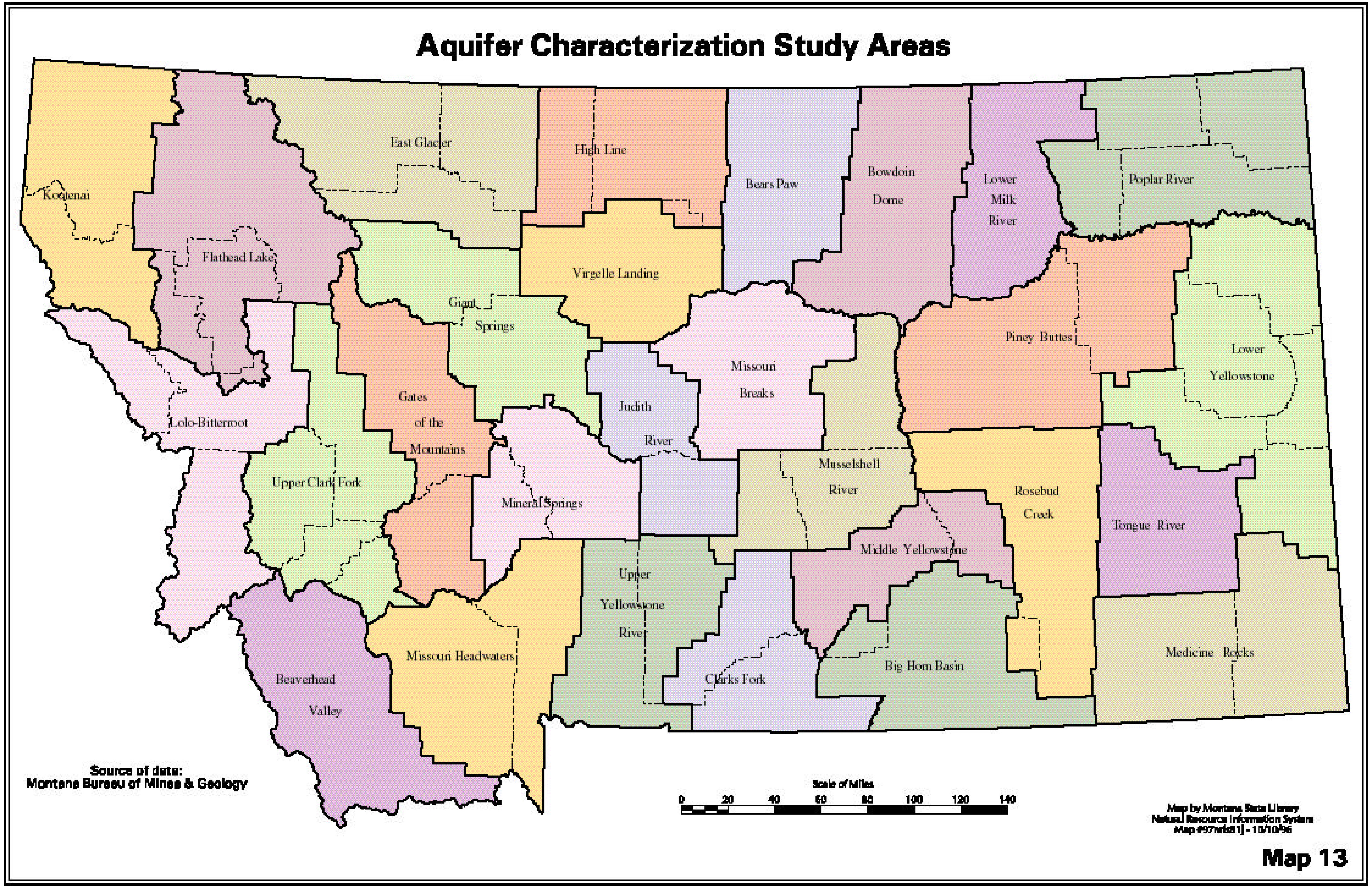
Ground Water Monitoring Network




Aquifer Characterization Study Areas
Kootenai
Flathead Lake
East Glacier
High Line
Bears Paw
Bowdoin
Dome
Lower
Milk
River
Poplar River
Virgelle Landing
Giant
Springs
Piney Buttes
Lower
Yellowstone
Missouri
Breaks
Judith
River
Lolo-Bitterroot
Gates
of the
Mountains
Upper Clark Fork
Mineral Springs
Musselshell
River
Rosebud
Creek
Tongue River
Middle Yellowstone
Upper
Yellowstone
River
Missouri Headwaters
Beaverhead
Valley
Clarks Fork
Big Horn Basin
Medicine Rocks
Source of data:
Montana Bureau of Mines & Geology
Scale of Miles
0 20 40 60 80 100 120 140
Map by Montana State Library
Natural Resource Information System
Map 13

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