Montana Bureau of Mines and Geology
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Montana Ground-Water Assessment Atlas 4, Part B, Map 8
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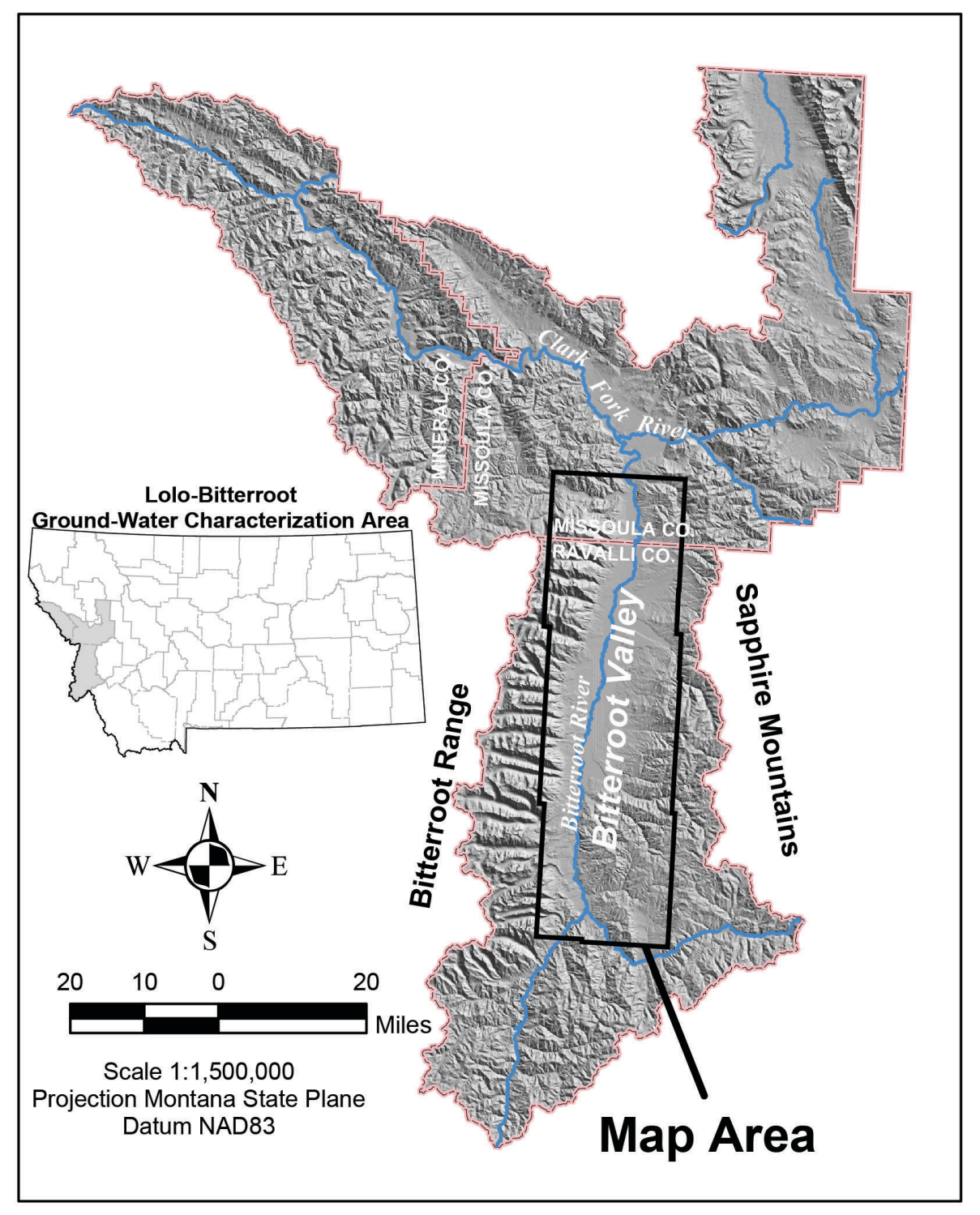
Lolo-Bitterroot Area



Potentiometric Surface of the Shallow Basin-Fill, Deep Basin-Fill, and Bedrock Aquifers, Bitterroot Valley, Missoula and Ravalli Counties, Western Montana

by
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Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground-Water Assessment Atlas for the Lolo-Bitterroot Area. It is intended to stand alone and describe a single hydrogeologic aspect of the study area, although many of the area's hydrogeologic features are interrelated. For an integrated view of the hydrogeology of the Lolo-Bitterroot Area the reader is referred to Part A (descriptive overview) and Part B (maps) of Montana Ground-Water Assessment Atlas 4.

INTRODUCTION

As part of the Montana Ground-Water Assessment Program, water levels were measured in the bedrock and basin-fill aquifers in the Bitterroot Valley in western Montana to assess directions of regional ground-water flow. This plate presents potentiometric surface maps for the shallow, deep, and bedrock aquifers of the Bitterroot Valley constructed from water-level measurements made mostly between 1998 and 2000.

The north-flowing Bitterroot River drains the 2,860 mi^2 valley in Ravalli County and part of Missoula County. The Bitterroot Valley is a structurally controlled intermontane basin framed by the Bitterroot Range on the west and the Sapphire Mountains on the east; the western and southern valley boundary is part of the Montana/Idaho border. Much of the Bitterroot drainage is within the Bitterroot National Forest. The Bitterroot Valley is an area of rapidly growing population; the population of Ravalli County increased 44 percent (from 25,010 to 36,070) between 1990 and 2000. Most of the residents live on the valley floor between the towns of Darby in the south and Lolo in the north. Ground water supplies most domestic and public water supply needs.

Land use has long been dominated by irrigated agriculture (Kendy and Tresch, 1996). However, as noted by Briar and Dutton (2000), the conversion of agricultural land to residential home sites is the major land-use change occurring in the Bitterroot Valley. In Ravalli County, the amount of land in irrigated acreage has declined about 7 percent between 1993 and 2003 (Montana Agricultural Statistics Service, www.nass.usda.gov/mt).

These maps depict ground-water flow systems in the shallow and deep basin-fill aquifers within the Bitterroot Valley and the surrounding bedrock aquifers. The potentiometric surface represents altitudes to which water will rise in wells penetrating the aquifer. Ground water moves down the slope of the potentiometric surface, from higher altitude to lower altitude, perpendicular to the contours. Ground-water flow paths are generally away from the mountains toward the center of the valley, and in the valley center ground-water flow is generally northward.

GEOLOGIC SETTING

The Bitterroot Range rises prominently on the west side of the valley, with rugged peaks ranging from 9,000 ft in the north to 10,000 ft above sea level in the south. The Sapphire Mountains on the east side of the valley are more subdued, with rounded peaks generally less than 8,500 ft above sea level. The valley floor is characterized by a relatively flat Bitterroot River floodplain and nearby low river terraces 1 to 4 miles wide. The low terraces adjacent to the river are flanked by "high terraces" (McMurtrey and others, 1972), or "high benches" (Briar and Dutton, 2000) along the valley margin. The high benches are prominent topographic features, especially on the valley's east side. The benches are about 3 to 6 miles in width, characterized by a gentle valley-ward slope from the mountain fronts, and their lower ends are truncated by scarps 50 to 150 ft high. The benches are remnants of Tertiary alluvial fans that have been deeply incised by the Bitterroot River and its tributaries. Some of the tributary stream valleys that separate the benches are 1 to 2 miles wide and relatively flat-floored.

The bedrock exposed in the mountains surrounding the Bitterroot Valley also underlies the valley (fig. 1). Bedrock, as defined here, consists of well-cemented or indurated rock that is commonly fractured. The bedrock of the valley's west side is composed of granite and layered gneiss of the Idaho Batholith. The Sapphire Mountains to the east and the northern Bitterroot Range are made up of metacarbonates, argillites, and quartzites of the Belt Supergroup (Smith, 2006).

The basin-fill deposits consist of unconsolidated to semiconsolidated Tertiary and Quaternary sediments that are as much as 3,000 ft thick (Smith, 2006). Tertiary deposits occur at the surface along the valley margin and overlie the bedrock at depth; along the valley margin the deposits are dominated by clay-rich sediments (often described as "blue clay" in driller's logs) with interbeds of poorly sorted sand and gravel (fig. 1). Near the valley center coarse-grained alluvium deposited by an ancestral Bitterroot River occurs at depth and, in places, at or near the land surface (Lonn and Sears, 2001). Quaternary basin-fill deposits include Pleistocene glacial outwash, alluvial and terrace deposits associated with major drainages in the valley, and recent sand and gravel deposits in the floodplain of the Bitterroot River and its tributaries.

HYDROGEOLOGIC SETTING

Exploitable ground-water resources in the Bitterroot Valley occur in the fractured bedrock (igneous intrusive rocks, meta-sedimentary rocks) and the basin-fill deposits. For the purposes of this plate, aquifers were generalized into three units based on the properties of the aquifer material (primary porosity vs. secondary porosity in fractured rock), ground-water conditions (confined vs. unconfined), and position within the geologic framework. The three hydrogeologic units recognized are: 1) shallow basin fill, 2) deep basin fill, and 3) bedrock. Surficial geologic maps as well as lithologic logs, well construction information and static water-level data from well reports were used to distinguish between wells completed in the shallow, deep, and bedrock aquifers.

The shallow basin-fill potentiometric surface map portrays the altitude of the water table and the locations of wells completed in shallow basin-fill aquifers that have a measured or reported (driller's) water level. The well locations indicate where the shallow aquifers occur and are utilized within the valley. The water table is a subdued representation of the land surface and is typically within 5 to 40 ft of the land surface. Ground water in the shallow aquifers is under unconfined conditions and is characterized by local flow systems where ground water moves from local drainage divides toward adjacent valley bottoms.

The most productive and extensive aquifers within the shallow basin fill are in the Quaternary sediments (alluvium, outwash, and alluvial fan sediments) along the floodplain of the Bitterroot River and its tributaries, generally within 50 ft of the land surface. These aquifers are highly permeable; reported yields range up to 2,700 gallons per minute (gpm). About 90 percent of the reported yields are between 5 and 100 gpm, with a median of 25 gpm (average 50 gpm) (fig. 2). Infiltration of irrigation water is a significant source of recharge to the shallow aquifers (fig. 3); other recharge sources include losses from streams along the base of the Bitterroot Range and the Sapphire Mountains, and infiltration of precipitation. The Bitterroot River gains water from the shallow aquifer and is the primary discharge zone in the valley.

Shallow aquifers are also developed within some of the Tertiary alluvial fan deposits on the high benches. These aquifers, mostly on the east side of the valley, are localized within the extent of the bench and may be perched above deeper aquifers. They are strongly dependent on irrigation recharge. Discharge from these aquifers occurs as springs and seeps at the break in slope along the base of the benches; some of the water also moves downward to recharge the deep basin-fill aquifers. Discharge from irrigation-supported shallow aquifers also supports numerous palustrine wetlands (U.S. Fish & Wildlife Service, 2006) located on or along the base of the benches.

The deep basin-fill map portrays the regional potentiometric surface of semi-confined to confined aquifers that occur below the shallow aquifers, and the locations of wells completed in deep basin-fill aquifers that have a measured or reported (driller's) water level. The well locations indicate where the deep aquifers occur and are utilized within the valley. Depths to the deep aquifers vary. On the west side of the valley, the deep aquifers generally occur within 150 ft of the land surface. On the east side of the valley aquifer depths are greater, generally within 200 ft of the land surface. In places, such as on the Sunset Bench and in the terraces north of Threemile Creek aquifer, depths of greater than 350 ft are common.

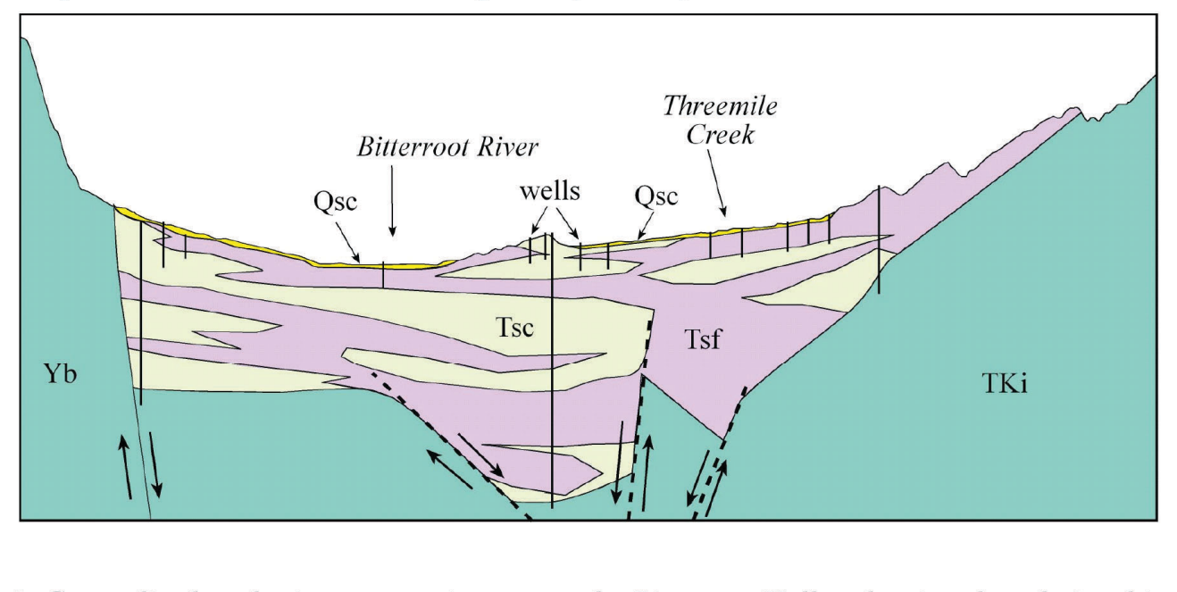
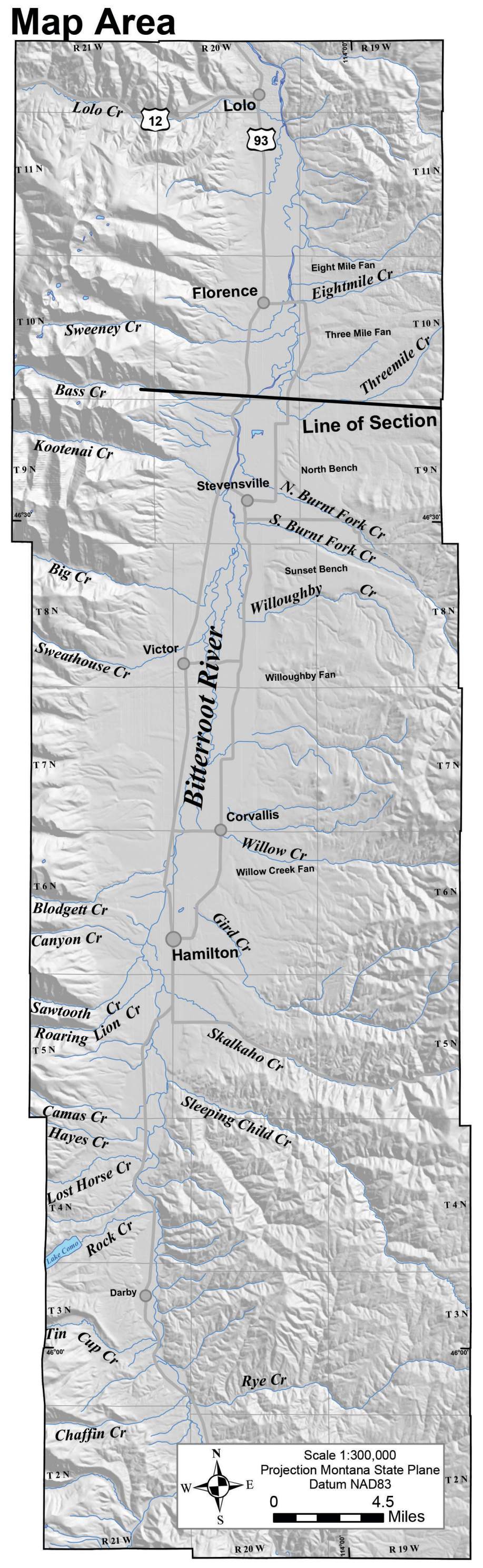


Figure 1. Generalized geologic cross section across the Bitterroot Valley showing the relationship between bedrock (Yb: Belt Super Group, TKi: Tertiary and Cretaceous intrusives) and basin-fill deposits (Tsc: Tertiary coarse-grained, Tsf: Tertiary fine-grained, Qsc: Quaternary coarse-grained). See Map Area for the location of the cross-section line.

Map Area



EXPLANATION FOR ALL MAPS

Road

Stream

Lake

Irrigation canal

Township boundary

Section boundary

Potentiometric contour (ft)
4000
-Contour interval 100 ft
Dashed where inferred

Description of simplified geologic units on potentiometric surface maps

- 🟨 **Quaternary sediments**
  - **- alluvium, outwash**
  - **- alluvial fan deposits**
- 🟥 **Tertiary sediments and sedimentary rocks**
  - **- alluvium**
  - **- alluvial fan deposits**
- ⬜ **Bedrock**
  - **- Tertiary and Cretaceous igneous rocks**
  - **- Proterozoic Belt Supergroup rocks**

The deep basin-fill aquifer system is complex because it consists of multiple permeable zones, or aquifers, separated by confining units. Confining units consist of fine-grained material that is distinctly less permeable than adjacent aquifers. These low permeability units inhibit the downward movement of water and the movement of water between aquifers. The degree of confinement is variable; deep aquifers near the mountain fronts are more likely to be semi-confined to nearly unconfined, while near the valley center the aquifers are fully confined.

Although aquifers in the deep basin fill may not be contiguous over large areas, there is sufficient hydraulic continuity between the sand and gravel layers to be considered a single entity in terms of ground-water flow on a valley-wide scale. Ground-water flow is regional, with water moving from the valley margins toward the Bitterroot River where it discharges by upward leakage to shallow unconfined aquifers and ultimately to surface water or evapotranspiration.

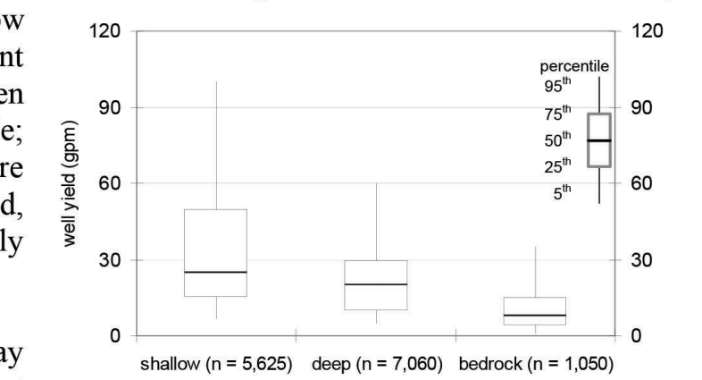


Figure 2. Well yields in the shallow aquifers tend to be slightly greater than in the deep aquifers, reflecting the greater permeability of the shallow alluvial sediments. Fractured-bedrock well yields are generally low.

A principal aquifer in the deep basin fill is alluvium associated with the ancestral Bitterroot River (Lonn and Sears, 2001). The alluvium is generally coarser-grained and more permeable than other deep basin-fill deposits (for example, Tertiary alluvial fan deposits). Reported yields in the deep hydrologic unit range up to 1,600 gpm, with a median of 20 gpm (fig. 2).

The primary recharge area for the deep basin-fill aquifers is the perimeter of the valley along the mountain fronts. On the west side of the valley, tributary streams that flow from the Bitterroot Mountains are important recharge sources where there is a sharp break in slope and a change in surficial geology from bedrock to basin-fill material. On the east side of the valley, recharge occurs between the mountain fronts and the floodplain, and below the benches by leakage from overlying shallow aquifers. Where conditions allow (e.g., a downward gradient and hydrologic connection), irrigation water can move downward from shallow aquifers to underlying deep aquifers (fig. 4).

The bedrock map portrays the regional potentiometric surface of bedrock aquifers that occur along the valley margin, and the locations of wells completed in bedrock aquifers that have a measured or reported (driller's) water level. The well locations indicate where the bedrock aquifers have been exploited and are utilized within the valley. The mountains surrounding the valley are composed of bedrock formations. Ground water in the mountainous areas is stored in and flows through fractures. In general, the bedrock has sufficient fracture permeability to yield water to wells; however, the number, size, and orientation of the openings is unpredictable and can change abruptly over short distances, resulting in large variations in well yields and depths. There has been a significant increase in the development of fractured-rock aquifers in the past few years. In the Bitterroot Valley about half of the roughly 900 wells completed in the fractured bedrock have been drilled between 1994 and 2004. The relatively low fracture permeability in the bedrock results in lower well yields than in the basin-fill aquifers. Yields up to 300 gpm have been reported, however; the median reported yield is 8 gpm (fig. 2).

The bedrock aquifers are recharged by infiltration of rainfall and snowmelt. The low storage capacities inherent to fractured-rock aquifers make them sensitive to climatic changes and development stresses. Large seasonal and long-term water-level fluctuations reflect the small storage capacities (fig. 5). In places, ground water in the bedrock appears to be hydraulically connected to the basin-fill aquifers; therefore, the fractured bedrock transfers mountain-front recharge to the basin-fill deposits and represents an important recharge area to the deep basin fill.

MAP USE

The maps are useful for estimating the general direction of ground-water flow, identifying areas where flowing artesian wells might occur, estimating the water-level altitude in non-flowing wells, and identifying recharge areas. Ground water flows from high altitude to low altitude; the direction of ground-water flow is generally perpendicular to the contours. If the approximate land-surface altitude at a location is known (for example, determined from a topographic map), the corresponding point on the potentiometric surface map can be found and the altitude of the potentiometric surface estimated. Subtracting the potentiometric surface altitude from the land-surface altitude yields the approximate level at which water will stand in, or rise above, a well.

METHODS

The maps were constructed by hand-contouring between measured water-level altitudes. The primary data were obtained from 390 wells visited in 1999 or 2000 (Carstarphen and others, 2003). Wells for data collection were selected on the basis of availability and information on well logs, access, geographic location, and geologic setting. Well locations were determined using a Global Positioning System (GPS). Land-surface altitudes at well locations were interpreted from U.S. Geological Survey (USGS) 1:24,000 topographic maps and are generally accurate to +/- 5 to 10 ft (based on 10- and 20-ft contour intervals).

These data were supplemented by water-level measurements from previous investigations by the USGS and University of Montana master's students (Briar and Dutton, 2000; Uthman, 1988). Additionally, reported water levels from driller's logs were used to estimate ground-water elevations. The supplemental data were used in areas where the primary data were sparse, and also helped confirm the shape of the potentiometric surface(s) in areas of better primary data coverage. Map accuracy is affected by data distribution, field measurement errors, accuracy of well locations, and errors in interpretation. Points at which water levels have been measured are distributed unevenly across the map, and map accuracy is greater near points of measurement. Water well logs and inventory data are available from the Montana Ground-Water Information Center (GWIC, http://mbmggwic.mtech.edu/).

Shallow Basin-Fill Potentiometric Surface

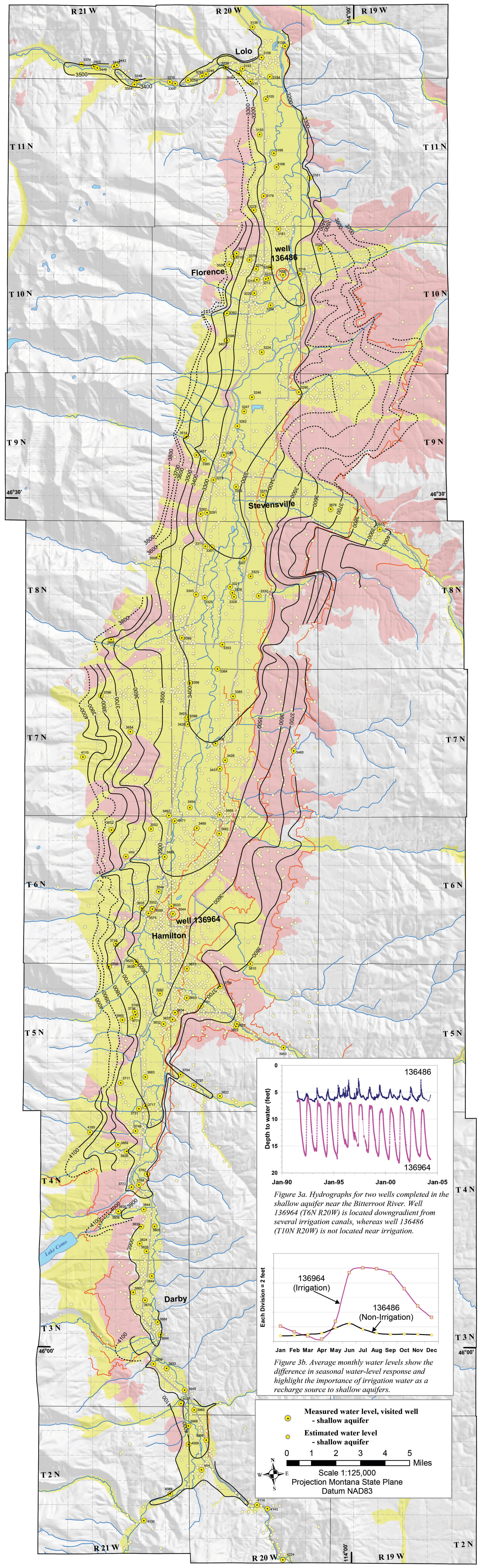


Figure 3a. Hydrographs for two wells completed in the shallow aquifer near the Bitterroot River. Well 136964 (T6N R20W) is located downgradient from several irrigation canals, whereas well 136486 (T10N R20W) is not located near irrigation.

Figure 3b. Average monthly water levels show the difference in seasonal water-level response and highlight the importance of irrigation water as a recharge source to shallow aquifers.

Measured water level, visited well
- shallow aquifer

Estimated water level
- shallow aquifer

0 1 2 3 4 5 Miles
Scale 1:125,000
Projection Montana State Plane
Datum NAD83

Deep Basin-Fill Potentiometric Surface

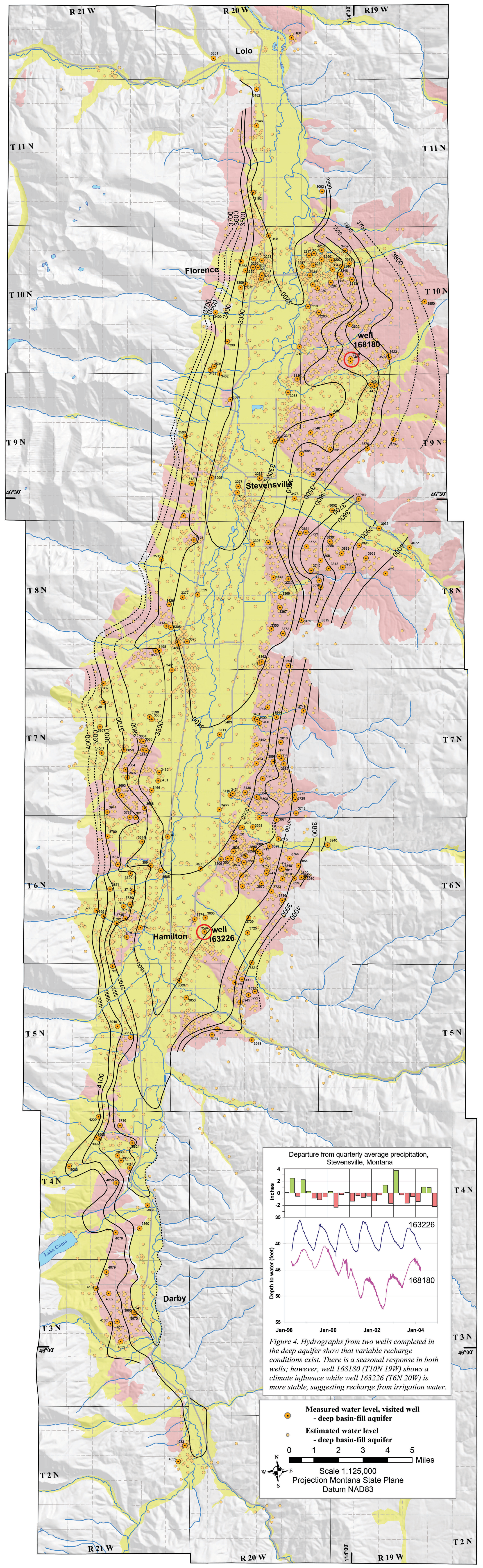


Figure 4. Hydrographs from two wells completed in the deep aquifer show that variable recharge conditions exist. There is a seasonal response in both wells; however, well 168180 (T10N 19W) shows a climate influence while well 163226 (T6N 20W) is more stable, suggesting recharge from irrigation water.

Measured water level, visited well
- deep basin-fill aquifer

Estimated water level
- deep basin-fill aquifer

0 1 2 3 4 5 Miles
Scale 1:125,000
Projection Montana State Plane
Datum NAD83

Bedrock Potentiometric Surface

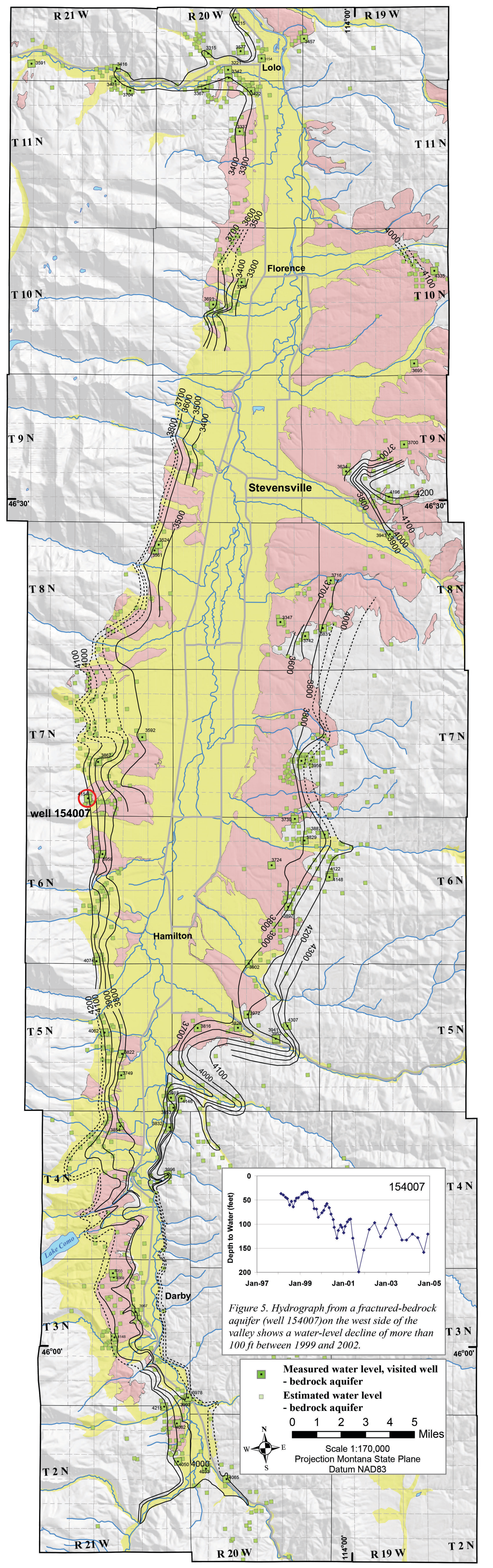


Figure 5. Hydrograph from a fractured-bedrock aquifer (well 154007)on the west side of the valley shows a water-level decline of more than 100 ft between 1999 and 2002.

Measured water level, visited well
- bedrock aquifer

Estimated water level
- bedrock aquifer

0 1 2 3 4 5 Miles
Scale 1:170,000
Projection Montana State Plane
Datum NAD83

ACKNOWLEDGMENTS

Well owners who allowed collection of the data necessary for the maps and the people who collected the data are all gratefully acknowledged. Reviews of this report by Tom Patton and John Metesh improved its clarity.

DATA SOURCES

Population centers and roads are from 1:100,000-scale USGS Digital Line Graph files available from the Natural Resources Information System (NRIS) at the Montana State Library, Helena, Montana. Hydrography has been simplified from the 1:100,000 Digital Line Graph files. Township boundaries are from the U.S. Forest Service. The hillshade base was compiled from USGS digital elevation models (DEMs) for 1:24,000 quadrangle maps available from NRIS. Differences in the quality of the DEMs may result in artifacts such as mottled surfaces and horizontal striping in the hillshade base. Geological data was simplified from MBMG digital 1:48,000-scale digital coverages.

Well-location and water-level altitude data were obtained by Ground-Water Characterization Program personnel. Altitudes of the points were determined from USGS 1:24,000 topographic maps. All point data used on this map are available from the Ground-Water Information Center at the Montana Bureau of Mines and Geology, Montana Tech of The University of Montana, Butte, Montana (http://mbmggwic.mtech.edu).

REFERENCES

Briar, D.W., and Dutton, D.M., 2000, Hydrogeology and aquifer sensitivity of the Bitterroot Valley, Ravalli County, Montana: U.S. Geological Survey Water-Resources Investigations Report 99-4219, 114 p.

Carstarphen, C.A., Mason, D.M., Smith, L.N., LaFave, J.I., and Richter, M.G., 2003, Data for water wells visited during the Lolo-Bitterroot Area Ground-Water Characterization Study: Montana Bureau of Mines and Geology Ground-Water Assessment Atlas 4, Part B, Map 1, scale 1:250,000.

Kendy, E., and Tresch, R.E., 1996, Geographic, geologic, and hydrologic summaries of intermontane basins of the northern Rocky Mountains, Montana: U.S. Geological Survey Water-Resources Investigations Report 96-4025, 233 p.

Lonn, J.D., and Sears, J.W., 2001, Geology of the Bitterroot Valley: Montana Bureau of Mines and Geology Open-File Report 441C, scale 1:48,000.

McMurtrey, R.G., Konizeski, R.L., Johnson, M.V., and Bartells, J.H., 1972, Geology and water resources of the Bitterroot Valley, southwestern Montana: U.S. Geological Survey Water-Supply Paper 1889, 80 p.

Smith, L.N., 2006, Altitude of the bedrock surface in the Bitterroot Valley: Southern Lolo-Bitterroot Area, Missoula and Ravalli Counties, Montana: Montana Bureau of Mines and Geology Ground-Water Assessment Atlas 4, Part B, Map 5, scale 1:125,000.

U.S. Fish & Wildlife Service, 2006, National Wetlands Inventory, http://nris.mt.gov/wis/wetlands/mtnwi.html.

Uthman, W., 1988, Hydrogeology of the Hamilton North and Corvallis quadrangles, Bitterroot Valley, southwestern Montana: University of Montana, M.S. thesis, 323 p.