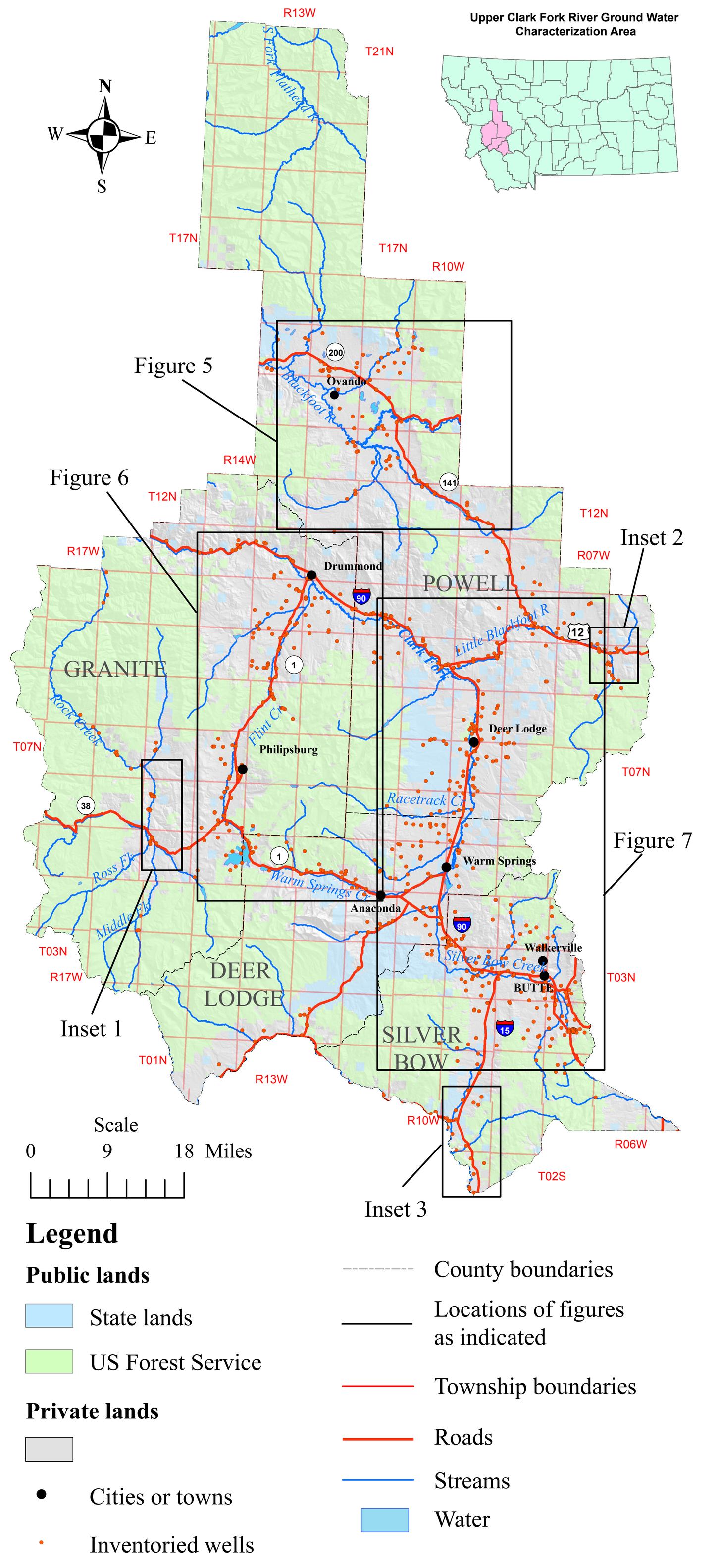

Figure 1. Study area map with land ownership information and key to the locations of selected figures.

Potentiometric Surface Map of Basin Fill and Selected Bedrock Aquifers: Deer Lodge, Granite, Powell, and Silver Bow Counties, Montana

By
Kirk B. Waren and John I. LaFave

Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground Water Assessment Atlas for the Upper Clark Fork River 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 Upper Clark Fork River Area, the reader is referred to other maps and reports of Montana Ground Water Assessment Atlas 5.

Introduction

This map portrays potentiometric surfaces for surficial unconsolidated, basin-fill, and bedrock aquifers at selected locations within the Upper Clark Fork River Ground Water Characterization Area. Figure 1 shows the study area, principal geographic and cultural features, and the extents of maps in figures 5, 6 and 7, and insets 1, 2, and 3.

A potentiometric surface represents the altitude to which water levels will rise in wells completed in an aquifer. In the study area, most wells are completed within the surficial unconsolidated alluvial and Tertiary basin-fill deposits or in fractured rock on the valley margins. The potentiometric surfaces depicted here are based on water levels in wells of the most common depths at any particular location. In general, the potentiometric surface is a subdued representation of the regional topography; the highest groundwater altitudes coincide with the regional topographic highs and the lowest altitudes with the regional topographic lows. Lateral groundwater movement will be in a direction perpendicular to potentiometric contours from higher to lower altitudes.

The maps are based on about 800 measured water-level and spring altitudes gathered during site visits between February 2000 and July 2002. In addition, data from previous groundwater investigations and reports were used where they provided additional detail; reported water levels from driller's well logs and water rights applications were used where measured data were sparse. All the water-level data used to compile this map are available from the MBMG's Ground Water Information Center (GWIC).

Geologic setting

The geologic setting of the Upper Clark Fork River Ground Water Characterization Area is described in detail in Montana Ground Water Assessment Atlas 5, Map 2 (Smith, 2009). The area consists of bedrock-cored mountains that separate large valleys. The valleys are connected by distinct canyons along major streams. Smith (2009) defines three principal categories of geologic materials: surficial unconsolidated sediments, Tertiary sedimentary rocks, and bedrock.

On this plate, areas indicated as bedrock combine many types of consolidated rock. See Smith (2009) for a more complete discussion of the geologic setting and detail on bedrock geology. Bedrock forms most of the mountainous parts of the study area and is also present beneath the basin fill. Within the mountainous areas, there are mapped and unmapped surficial unconsolidated, glacial, and stream-deposited sediments of limited extent.

During the Tertiary period (about 65 to 2.6 million years ago), large, wide valleys in western Montana, such as the Deer Lodge Valley, were structurally down dropped relative to surrounding mountains, and filled with hundreds to thousands of feet of Tertiary and younger sediments (Smith, 2009). Tertiary sediments are typically layered, poorly consolidated deposits that include clay, silt, sand, gravel, conglomerate, shale, sandstone, and volcanic ash; they may include minor amounts of limestone, coal, and volcanic rock. Typically the materials are more consolidated at depth, and if consolidated, are often fractured.

Unconsolidated surficial sediments in the floodplains and under terraces along modern streams typically include sand, gravel, silt, and lesser amounts of clay; in some areas the deposits are glacially deposited till (gravelly clay, silt, sand, and boulders) and outwash (sand and gravel). These surficial deposits are typically less than 70 ft thick, but in a few places, notably in the Blackfoot River and Nevada Creek valleys (fig. 5), the till and outwash may be more than 200 ft thick.

Within the intermontane basins, basin-fill aquifers are saturated Tertiary sedimentary rocks and unconsolidated surficial sediments that can deliver water to wells. Basin-fill aquifers are bounded along the valley margins by fractured-bedrock aquifers. Figure 2 is a diagrammatic cross section showing general relationships between bedrock aquifers and basin-fill materials, and general groundwater flow paths.

Hydrogeologic setting

Precipitation is more abundant in the surrounding mountainous areas than in the inset valleys. Water, seasonally stored and released from mountain snowpack, contributes substantially to spring and summer stream flow. The greatest water use in the Upper Clark Fork River Area is irrigated agriculture. Most of the irrigated acreage is located in the valley bottoms where precipitation is less than in the mountains, but where the growing season is longer.

Mountainous areas surrounding the valleys are typically underlain by consolidated bedrock, such as granite, basalt, meta-sedimentary quartzites, and argillites (Smith, 2009). Permeability in these rocks is through interconnected fractures that typically become less connected with depth (Freeze and Cherry, 1979). Bayuk (1989) noted that specific yields in Belt Supergroup bedrock southwest of Missoula, Montana, decreased by a factor of four at depths greater than 250 ft.

Water that infiltrates into the fractured bedrock in the mountains percolates downward and then moves laterally outward from the mountains to the valleys as permeability allows. The lateral movement of water from the mountains to the valleys is a source of recharge to basin-fill aquifers, and can provide baseflow to streams or appear as springs.

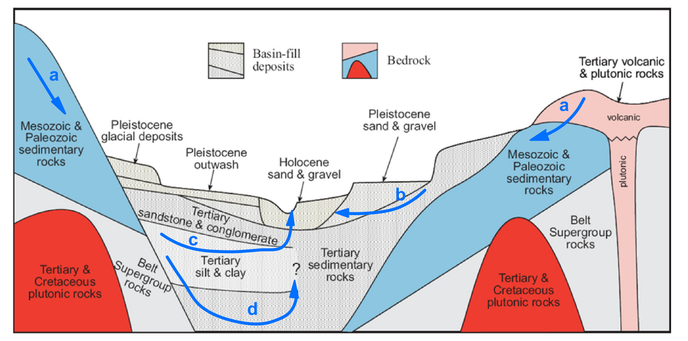

Figure 2. Diagrammatic cross section illustrating stratigraphic relationships between bedrock and basin fill (from Carstarphen and others, 2004). The groundwater-flow paths (blue arrows) added here illustrate examples of how groundwater flows through (a) bedrock materials and (b) shallow, (c) intermediate, and (d) deep paths through basin-fill aquifers.

Each intermontane basin is a somewhat isolated groundwater flow system (Kendy and Tresch, 1996). Depending on thickness and layering of the basin fill, there may be shallow, intermediate, and deep groundwater flow components (fig. 2). Recharge occurs from irrigation practices, stream flow infiltration, direct precipitation, and adjacent bedrock units. The layered Tertiary basin-fill stratigraphy may create numerous stacked water-bearing zones at any particular location.

On a basin scale, the layered sediments generally result in horizontal permeability greatly exceeding vertical permeability, and the entire basin fill and surrounding bedrock often act as a single hydrogeologic unit. Typically, intermontane basins have discernible groundwater discharge areas at their downstream ends where less permeable bedrock forces water upward to the surface to be manifested as springs, marshes, and gaining-stream reaches.

Unconsolidated surficial sediments associated with either modern streams or glacial features are generally coarse-grained and, where sufficiently thick and saturated, make excellent aquifers. They are generally recharged from direct precipitation, irrigation practices, and surface water.

Groundwater levels fluctuate in response to a wide variety of natural and anthropogenic influences occurring at annual, diurnal, seasonal, or multi-year frequencies (Freeze and Cherry, 1979). Water-level changes in any particular well depend on sources and types of recharge, discharge (including pumping), and the aquifer's hydrologic properties. Deep wells, somewhat removed from short-term seasonal and surficial water-level influences, tend to best reflect long-term climate.

Within the study area, many wells display water-level changes clearly associated with seasonal irrigation activity beginning in about mid-April and lasting through the end of September. Leaky irrigation ditches and canals and applied irrigation water not utilized by crops can be a significant source of groundwater recharge. In these areas, water levels tend to rise dramatically at the start of the irrigation season, stay elevated with some irregularities during summer months, and decline after the irrigation season; at some sites the decline continues until the next irrigation cycle begins.

Methods

The maps on this plate were constructed by hand-contouring a combination of inventoried water-level measurements and estimated water levels from driller's logs. Topographic maps were used to guide the contouring, as were potentiometric maps from previous studies in the Drummond and Philipsburg valleys (Voeller and Waren, 1997), the Kleinschmidt Flat northeast of Kleinschmidt Lake (Roberts and Waren, 2001), the Deer Lodge Valley (Konizeski and others, 1968), and in several areas along the Big Hole River (Marvin and Voeller, 2000). The inventoried water-level measurements were collected between February 2000 and July 2002 by the Ground Water Assessment Program (GWAP); the data set included 779 measured water-level altitudes in wells and 19 spring altitudes (Carstarphen and others, 2004). Locations of inventoried sites were determined with hand-held or survey-grade GPS units and are accurate to within 50 ft (15 m). Land-surface altitudes at inventoried well locations were interpreted from U.S. Geological Survey 1:24,000 topographic maps and are generally accurate to +/- 5 to 10 ft (based on 10 and 20 ft contour intervals). These inventoried data were the primary data set used to compile the potentiometric contours. The well locations with measured water levels are represented by the larger symbols on the maps: yellow circles for surficial unconsolidated wells, orange circles for Tertiary basin-fill wells, and green squares for bedrock wells.

The inventoried data set was supplemented by estimated groundwater altitudes determined from driller's logs at 5,810 sites. The estimated groundwater altitudes were used in areas where the measured data were sparse, and helped confirm the shape of the potentiometric surface(s) in areas of better primary data coverage. A geographic information system (GIS) with a digital elevation model (DEM) was used to determine the land-surface altitude at sites with driller-reported water levels. The reported water level was subtracted from the land-surface altitude to determine the groundwater altitude. Because of uncertainties associated with locations and driller's measurements the accuracy of the estimated groundwater-altitude data is much less than the primary data set. Wells with estimated groundwater levels are represented on the maps by the smaller symbols.

Between 2000 and 2003, monthly water-level measurements were obtained from 86 wells to provide insight regarding seasonal fluctuations of groundwater levels. These sites are indicated by a star on the maps. Selected hydrographs from some of these wells are shown in figures 5 through 7, with the border color of the hydrograph matching the legend color for the aquifer in which the well is completed: yellow for surficial unconsolidated, orange for Tertiary basin fill, and green for bedrock. The hydrographs depict the variability with regard to the timing and magnitude of seasonal groundwater fluctuations across the study area and between aquifers.

Geologic maps including the state geologic map (Vuke and others, 2007), Ground-Water Assessment Atlas 5, Map 2 (Smith, 2009), and detailed geologic maps for the Deer Lodge Valley (Berg and Hargrave, 2004) were used to assign source-aquifer codes to the wells. Within the study area, most of the wells (46%) are completed in surficial unconsolidated aquifers, 29% are completed in fractured-bedrock aquifers, and 25% are completed in Tertiary basin-fill aquifers.

Reported information on driller's logs was evaluated to summarize well depth and yields from surficial unconsolidated, Tertiary basin-fill, and fractured-bedrock aquifers (fig. 3). Drillers use a variety of different methods (pumping, air-lift, bailing, etc.) to determine well yields over varying time periods (less than one to several hours). The reported yields are not considered precise measurements but give a general indication of the well, hence aquifer, productivity. The median reported well yield for the surficial unconsolidated and Tertiary basin-fill aquifers is 20 gallons per minute (gpm); however, there is a greater range in reported yields from the surficial unconsolidated aquifers (fig. 3a). The median well yield is about 15 gpm for wells completed in bedrock aquifers. Of the 2,169 surficial aquifer wells with reported yields, 35 exceeded 500 gpm; 21 of 1,265 Tertiary aquifer wells exceeded 500 gpm, and only 8 of 1,620 bedrock-aquifer wells exceeded 500 gpm. Median reported well depths for the three aquifers are: surficial unconsolidated aquifers, 43 ft; Tertiary basin-fill aquifers, 105 ft; and bedrock aquifers, 160 ft. The distribution of reported well depths is illustrated in figure 3b. The lower well yields and wide range in well depths for bedrock wells reflect variable fracture densities and permeabilities in bedrock aquifers.

Map use

Contours on potentiometric surface maps provide estimated directions of the horizontal component of groundwater flow. Groundwater generally moves perpendicular to the contours, from higher to lower altitudes. An estimate of the depth to groundwater can be made by subtracting a potentiometric-surface altitude from the land-surface altitude at a desired location, or by simply noting the depths to water reported on nearby existing well records. For more information, well records for any area can be obtained from the GWIC website (http://mbmggwic.mtech.edu/). The contoured potentiometric surface is expected to be accurate to +/- one-half the contour interval at any given point, or +/- the contour interval where the contours are dashed. For example, where the contoured potentiometric surface is 100 ft, accuracy is expected to be +/- 50 ft at any given point.

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 and map accuracy is greater near points of measurement. In some areas, seasonal groundwater fluctuations approach or exceed 20 ft (see hydrographs for selected wells for magnitudes of observed water-level fluctuations). Large seasonal fluctuations in water levels may result in localized, seasonal variations in groundwater flow direction. Additional details about seasonal water-level changes in areas with supplemental contours is provided in Konizeski and others (1968), Voeller and Waren (1997), Marvin and Voeller (2000), Roberts and Waren (2001), and LaFave (2008).

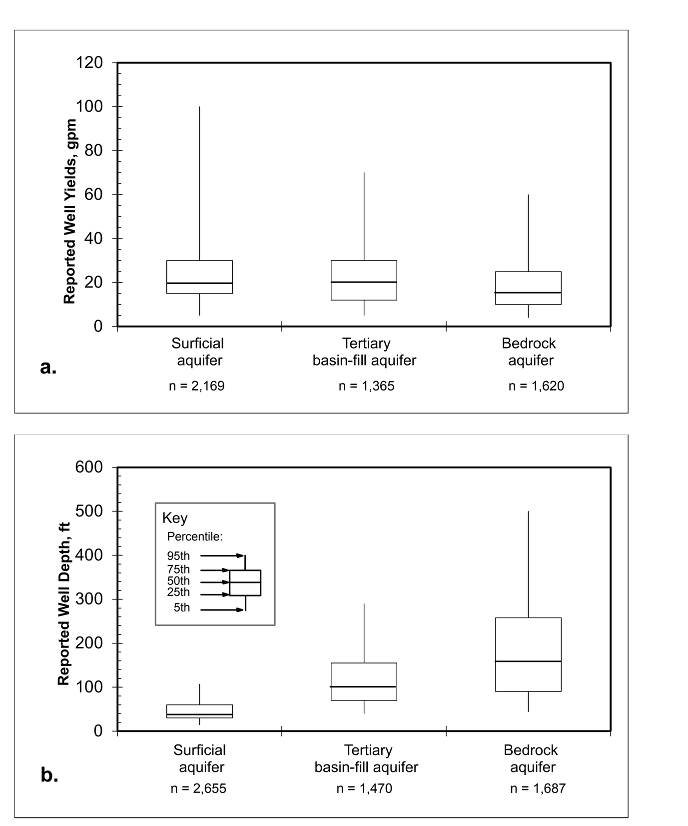

Figure 3. Distribution of (a) well yields, and (b) well depths: among surficial unconsolidated, Tertiary basin-fill, and bedrock aquifers.

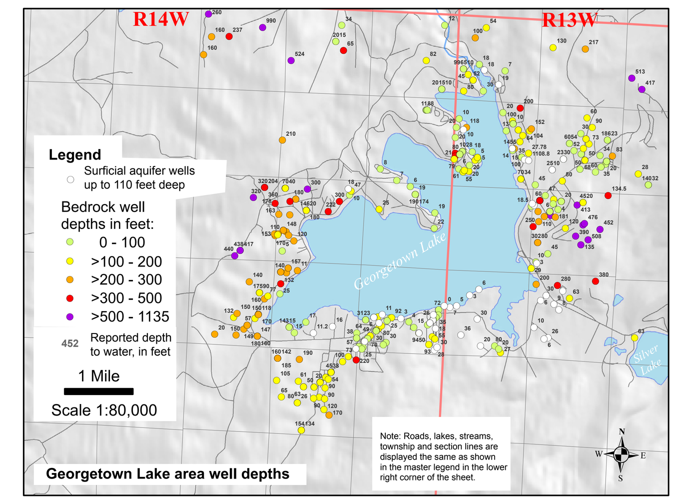

Figure 4. Georgetown Lake area well depths in Township 5 North, Ranges 13 and 14 West.

Descriptions of selected areas

Georgetown Lake

The Georgetown Lake area is shown in figure 4 and in the lower-left part of figure 6. This area contains more than 400 well records, about 67 percent of which have been drilled since 1990. Figure 4 displays the locations of wells reportedly completed in surficial unconsolidated aquifers, generally sand and gravel materials (white circles), and the depth ranges of bedrock wells by color. Static water-level depths are labeled throughout the figure. There are many surficial aquifer and shallow bedrock wells along certain edges of the lake. Deep wells are prevalent along the west shore and east of the lake. The lake altitude on the USGS 1:24,000 topographic map is 6,378 ft, nearly the same as the 6,383-ft mean groundwater-level altitude reported for bedrock wells within about 1.25 miles of the lake (all altitudes are reported as feet above mean sea level). Groundwater-level altitudes in this area range from 6,095 to more than 6,700 ft. About half of the bedrock wells have water-level altitudes within about 50 ft of the lake level, in the range of 6,330 to 6,430 ft. The configuration of the potentiometric surface (fig. 6) indicates that on the northeast and southeast sides regional groundwater flow is toward the lake. The median reported well yield is 18 gpm, with the majority of reported yields ranging from 5 to 40 gpm.

Blackfoot River and Nevada Creek area

The Blackfoot River and Nevada Creek area is shown in figure 5. Much of the valley floor is covered with unconsolidated glacial till. The till typically consists of clay with varying amounts of sand, gravel, and boulders. Till often contains many somewhat separate and disjointed water-bearing zones rather than acting as a single, unified aquifer. Consequently, water levels and well depths are more variable than those observed in coarse, more homogeneous materials.

Kleinschmidt Flat, northeast of Kleinschmidt Lake (fig. 5), is a coarse-grained outwash plain of thick sand, gravel, and conglomerate; the deposits are reportedly cemented at many localities. The outwash aquifer is bounded by relatively impermeable bedrock or till on all sides. Water enters the aquifer as direct losses from the North Fork Blackfoot River and its tributaries at the upper end of the flat, as well as from irrigation losses and direct infiltration of precipitation and snowmelt (Roberts and Waren, 2001). Groundwater levels at the upper, northeast end of Kleinschmidt Flat fluctuate seasonally as much as 45 ft. These fluctuations diminish downgradient toward the discharge area marked by many springs and spring creeks. In the discharge zone, groundwater levels are relatively stable, changing only a few feet annually.

Flint Creek Basin: Drummond and Philipsburg Valleys

The Flint Creek basin is shown in figure 6, with the Drummond Valley shown in the top center and the Philipsburg Valley in the lower left. Predominant aquifers include sand and gravel deposits capping the Tertiary deposits northwest of Hall, alluvial sediments in the floodplains of Flint and Willow creeks, and Tertiary deposits. Logs for deep wells completed in Tertiary sediments typically report siltstone or shale at depth. In many of these wells, groundwater is encountered in either thin sand and gravel layers or fractures in semi-consolidated rock.

The Drummond and Philipsburg Valleys were the subject of a detailed irrigation return flow study in the mid-1990s (Voeller and Waren, 1997). The hydrology of both valleys is highly influenced by irrigation activity and the importation of water from the East Fork Rock Creek reservoir. Groundwater levels in many areas fluctuate seasonally, largely in response to irrigation practices; the hydrograph for well 63339 in the upper-middle part of figure 6 is a good example. Voeller and Waren (1997) provide detailed discussions of the water budget, including irrigation return flows calculated from four separate sub-basins. Irrigation return flow from excess irrigation water in the Flint Creek basin, much of it stored and released from basin-fill aquifers, approaches 100 cubic ft per second after irrigation stops at the end of the summer. This return flow diminishes over a period of months as groundwater levels decline. Hydrographs from a shallow—deep nested well pair located on the valley margin southwest of Drummond (wells 15483 depth water enters [DWE] = 127 ft and 15484 DWE = 40 ft) demonstrate a downward vertical gradient. Downward gradients are common in recharge areas along valley margins. Away from the recharge areas vertical gradients diminish as flow becomes lateral toward the topographically lower discharge areas.

Deer Lodge Valley

The Deer Lodge Valley (fig. 7) is characteristic of the intermontane basins of southwestern Montana. It is approximately thirty miles in length between where Silver Bow Creek enters at its upper end and where the Clark Fork River exits north of Deer Lodge. It is generally less than 15 miles wide. Konizeski and others (1968) provide an overview of the hydrogeology of the valley. Surficial unconsolidated sediments are found in the floodplain of the Clark Fork River and numerous tributary valleys as shown in figure 7. Tertiary basin-fill underlies the surficial deposits and is thousands of feet thick (Smith, 2009). In many parts of the valley, especially high on benches underlain by Tertiary sediments, deep wells tend to have lower altitude water levels, demonstrating downward vertical gradients.

Summit Valley – Butte Area

The Summit Valley in the southeast part of the study area (fig. 7) is surrounded by granitic rock (quartz monzonite). As much as 800 ft of basin-fill sediments overlie bedrock near the valley center. Additional potentiometric-surface contours with a 20 ft contour interval are available for some areas within the gray rectangle shown in figure 7. The rectangle represents the extent of MBMG Ground-Water Open-File Report 22 (LaFave, 2008), which focused on nitrate in groundwater and surface water in the Summit Valley. Unconsolidated surficial sediments in the Summit Valley are sandy with poor soil development due to their granitic source material, so mobile ions like nitrate readily move through the sediment and into the groundwater (LaFave, 2008). The lack of irrigation development in the Summit Valley is reflected by small seasonal fluctuations in local hydrographs. Apparent downward water-level trends shown in Summit Valley hydrographs are related to dry climate during the study period.

Geothermal features

Warm and hot springs are present in the Deer Lodge Valley, to the northwest along the Clark Fork River, and also near Avon (Sonderegger and Bergantino, 1981). The warm springs have temperatures in the range of about 70 to 80 degrees Fahrenheit, while hot springs at Gregson, about 5 miles south of Opportunity and at Warm Springs are 158 and 172 degrees Fahrenheit, respectively. Wells between 300 and 600 ft deep at Gregson provide hot water to Fairmont Hot Springs resort. The Deer Lodge Valley, the Clark Fork Valley in Granite and Powell Counties, and the valley of the Little Blackfoot River are all mapped as areas expected to contain geothermal resources suitable for direct heat applications (Sonderegger and Bergantino, 1981).

Data sources

Base layers of physiography, hydrology, and cultural features were derived from Geographic Information System coverages available at the Montana State Library Natural Resource Information System, Helena, Montana (http://nris.mt.gov/).

Acknowledgments

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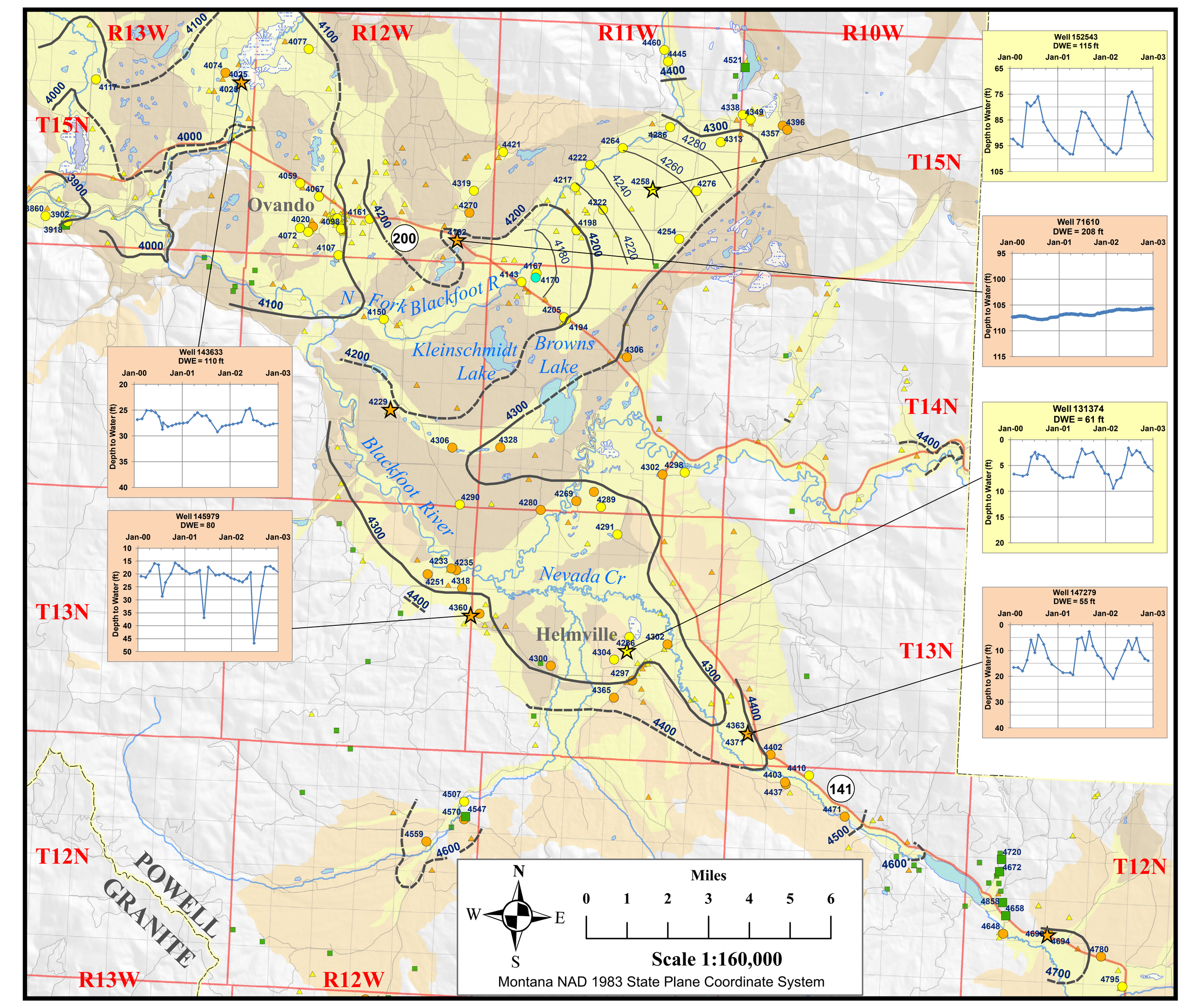

Figure 5. Blackfoot River and Nevada Creek area.

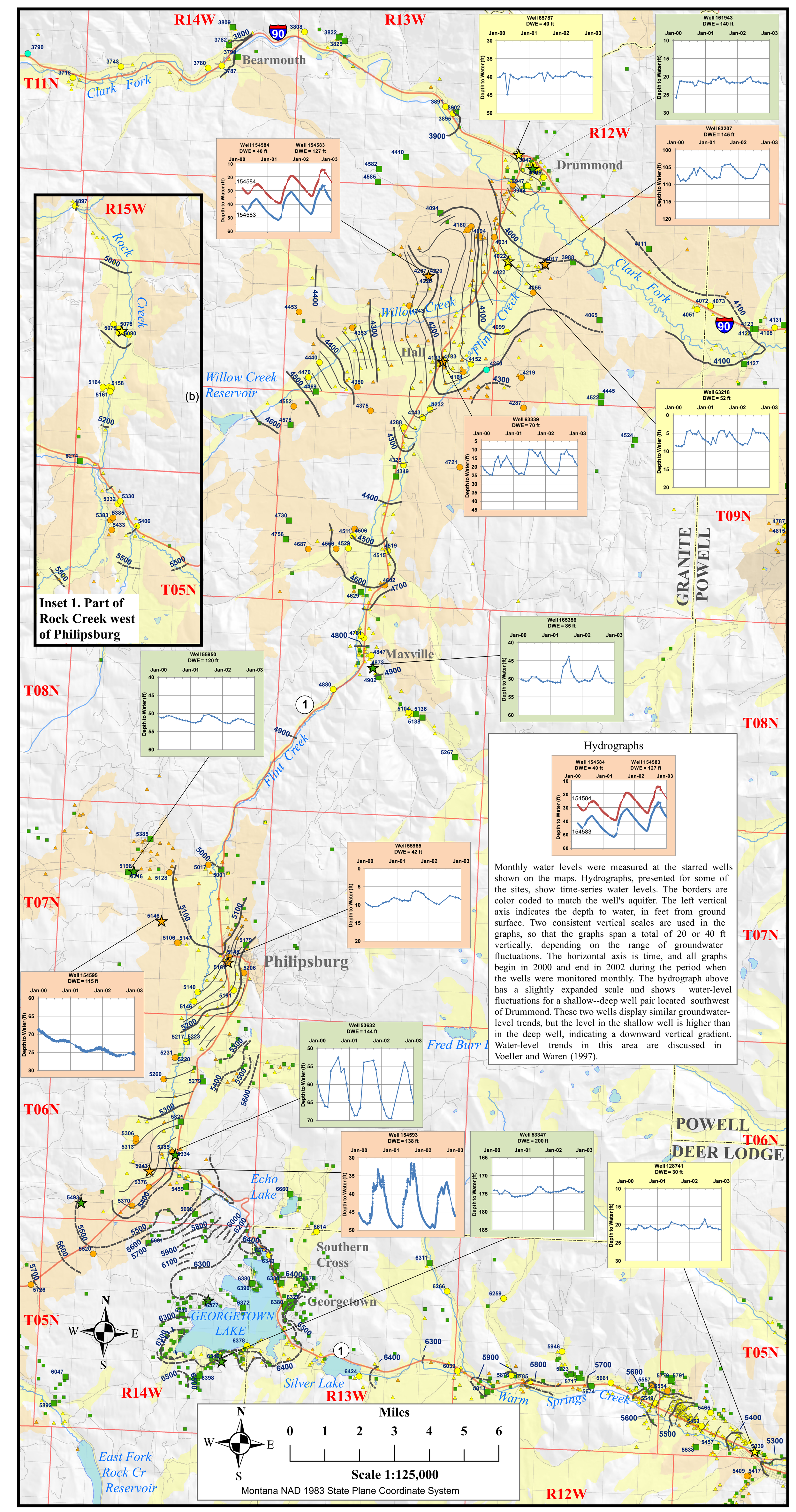

Figure 6. Drummond and Philipsburg Valleys and Georgetown Lake.

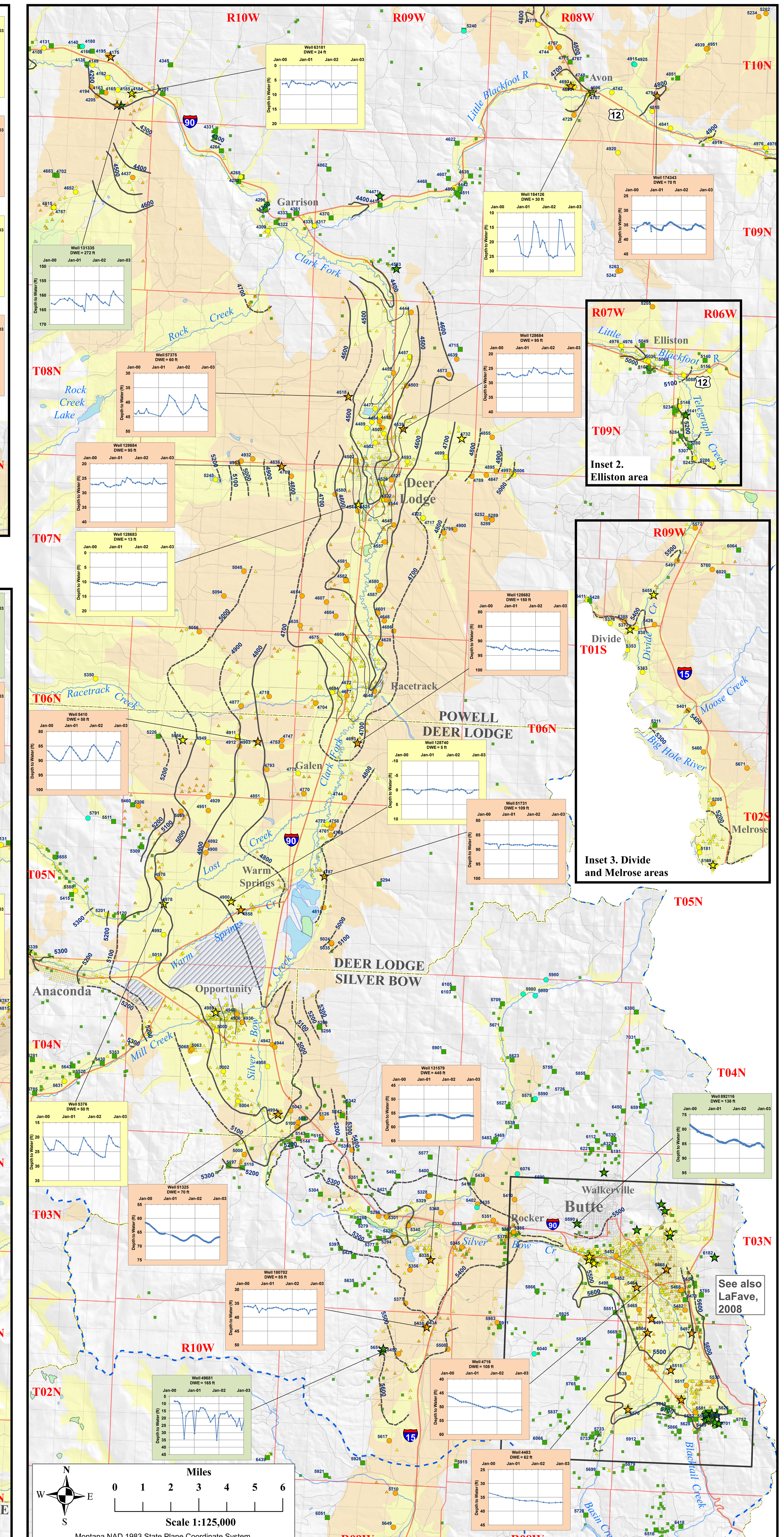

Figure 7. Deer Lodge and Summit Valleys.