Regional Potentiometric-Surface Map of the Great Basin Carbonate and Alluvial Aquifer System in Snake Valley and Surrounding Areas, Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada

By
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Abstract

Water-level measurements from 190 wells were used to develop a potentiometric-surface map of the east-central portion of the regional Great Basin carbonate and alluvial aquifer system in and around Snake Valley, eastern Nevada and western Utah. The map area covers approximately 9,000 square miles in Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada. Recent (2007–2010) drilling by the Utah Geological Survey and U.S. Geological Survey has provided new data for areas where water-level measurements were previously unavailable. New water-level data were used to refine mapping of the pathways of intrabasin and interbasin groundwater flow. At 20 of these locations, nested observation wells provide vertical hydraulic gradient data and information related to the degree of connection between basin-fill aquifers and consolidated-rock aquifers. Multiple-year water-level hydrographs are also presented for 32 wells to illustrate the aquifer system's response to interannual climate variations and well withdrawals.

Introduction

The study area includes Snake Valley and surrounding areas and is located in the east-central portion of the regional Great Basin carbonate and alluvial aquifer system along the Utah-Nevada border. The carbonate and alluvial aquifer system in and around Snake Valley includes carbonate-rock and basin-fill aquifers defined by Reilly and others (2008, fig. 2, sheet 1), in the Basin and Range Province. The aquifer system is generally comprised of aquifers and confining units in unconsolidated basin fill, volcanic deposits in the basins, and volcanic, carbonate, and other consolidated-rock units in the mountain ranges that separate the basins. Consolidated-rock units also underlie the basins. In this study, basins are defined by hydrographic area (HA) boundaries. Generally, HA boundaries coincide with topographic basin divides (Welch and others, 2007), and most HAs represent a single watershed, including both basin fill and adjacent mountain blocks up to the topographic divide (Harrill and Prudic, 1998). In areas along HA boundaries, where basin fill is sufficiently thick or consolidated rock is permeable, the aquifers are hydraulically connected between HAs and "collectively constitute a significant regional groundwater resource" (Harrill and Prudic, 1998). In other areas, less permeable rock units likely impede groundwater flow between HAs.

Portions of the Great Basin have experienced rapid population growth in recent decades and have some of the highest per-capita water use in the nation. The U.S. Census Bureau (2005) found that Nevada and Utah were among the fastest growing states in the United States, with a projected population increase of more than 50 percent between 2000 and 2030. Populous urban areas in the Great Basin include Las Vegas in southern Nevada and the cities and towns along the Wasatch Front in Utah (fig. 1, sheet 2). The combination of rapid population growth, high water use, and arid climate in urban areas has led to an increased dependence upon groundwater resources during the past 60 years (Gates, 2004; Heilweil and others, 2011) and to predictions of future water shortages (U.S. Water News, June 2005). This has resulted in the targeting of portions of the Great Basin, such as Snake Valley, for groundwater development to supply burgeoning urban areas and a recent increase in applications for water rights that propose to divert groundwater for use outside Snake Valley and adjacent HAs to meet the demands of these regional population centers.

Snake Valley and the surrounding areas include lands managed by federal and state agencies. These lands include national parks, monuments, historic sites, and wilderness areas; state parks, recreation areas, and wildlife refuges; and large areas managed by the Bureau of Land Management. Groundwater is also the primary source of water for most uses on these public lands. Because of the reliance upon groundwater to concurrently meet the demands of urban populations, agriculture, and native habitats, there remains ongoing interest in improving the understanding of groundwater flow in Snake Valley and the surrounding areas.

The purpose of this report is to present maps showing an updated potentiometric-surface map (fig. 1) and multiple-year water-level hydrographs (fig. 2) for the study area. The map area covers approximately 9,000 square miles and includes HAs in Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada. In addition to Snake Valley (HA 254), the study area includes at least portions of the following: Spring Valley (HA 184), Pine Valley (HA 255), Wah Wah Valley (HA 256), Tule Valley (HA 257), Fish Springs Flat (HA 258), and Sevier Desert (HA 287), and is almost entirely within the Great Salt Lake Desert regional groundwater flow system (Harrill and others, 1988).

Several potentiometric-surface maps have been published that include the area covered by this map (Thomas and others, 1986, pl. 1 and 2; Wilson, 2007, pl. 1 and 2; Sweetkind and others, 2011b). The previous maps were constructed using water-level measurements spanning decades and include few water levels measured in wells completed in consolidated rock. Furthermore, water-level measurements on these maps were contoured at 100- to 500-foot intervals to depict generalized directions of potential groundwater flow. Recent (2007–2010) drilling by the Utah Geological Survey and U.S. Geological Survey has provided 68 new observation wells at 29 separate locations. These well sites include 18 locations where water levels in consolidated rock can be measured and 20 locations where nested observation wells (clusters of wells located together but screened at different depths) can be used to examine the direction and magnitude of vertical hydraulic gradients. The drilling also provided new subsurface geologic information. These data, combined with new wells drilled by the Southern Nevada Water Authority (SNWA), allowed for the construction of an updated and more detailed potentiometric-surface map of the study area using 50-foot contour intervals. Multiple-year hydrographs also were compiled and examined during construction of the potentiometric-surface map to better understand if the water levels used to construct the potentiometric-surface map are representative of long-term average conditions and to illustrate general trends in rising or declining groundwater levels.

Hydrogeology of the Groundwater Flow System

Groundwater in the study area generally moves through permeable basin fill and other geologic formations from high-altitude recharge areas toward low-altitude discharge areas. Because of the large extent and geologic complexity of the groundwater flow system, the geologic units are grouped into simplified hydrogeologic units (HGUs) to help conceptualize the aquifer system. The HGUs in the study area extend over large areas and each includes geologic units that have similar physical characteristics with respect to their capacity to store and transmit water. Five regionally important consolidated-rock HGUs defined by Sweetkind and others (2011a) for the Great Basin carbonate and alluvial aquifer system were used in this study and are depicted on the potentiometric-surface map (fig. 1). These consolidated-rock units include: (1) a non-carbonate confining unit (NCCU), representing low-permeability Precambrian siliciclastic formations; (2) a lower carbonate aquifer unit (LCAU), representing high-permeability Cambrian through Devonian limestone and dolomite; (3) an upper siliciclastic confining unit (USCU), representing low-permeability Mississippian shale; (4) an upper carbonate aquifer unit (UCAU), representing high-permeability Pennsylvanian and Permian carbonate rocks; and (5) a volcanic unit (VU), representing areas of volcanic rocks with highly variable permeability.

Large portions of the Great Basin carbonate and alluvial aquifer system are conceptualized as being hydraulically connected, where recharge that occurs through consolidated rock in the mountains can enter and move through basin fill in the adjoining valleys, or move through consolidated rock that underlies the basin fill. Aquifers in Snake Valley and surrounding areas typically occur in permeable portions of the basin fill, the LCAU and UCAU, and the VU. Throughout most of the study area, basin-fill aquifers most often overlie or adjoin the LCAU or UCAU. Aquifers within the LCAU and UCAU are separated by the intervening low-permeability shale of the USCU and underlain at depth by the lower permeability NCCU.

Groundwater flow in the Snake Valley area is also affected by HGU thickness, geologic structures, and fault-juxtaposition of HGUs with contrasting hydrologic properties. Areas of low hydraulic gradient are often associated with large thicknesses of the most permeable HGUs (basin fill, UCAU, and LCAU). In other areas, low hydraulic gradients can be attributed to a combination of factors such as large areas of discharge in areas with a flat land-surface topography and little recharge. In places, the lateral continuity of HGUs is disrupted by large-magnitude faults or geologic structures (anticlines and synclines), resulting in a complex distribution of rocks, which can alter the direction of groundwater flow paths. The juxtaposition of low-permeability siliciclastic-rock strata against higher permeability carbonate rock or basin-fill aquifers can form barriers to groundwater flow and greatly influence the shape of the potentiometric surface (Winograd and Thordarson, 1975; Thomas and others, 1986; McKee and others, 1998).

Data and Methods

The potentiometric-surface map of the carbonate and alluvial aquifer system (fig. 1) was constructed mostly from water-level measurements made during the early spring of 2010. In a few locations, water levels measured before or after this time period were included if their location provided valuable control on the potentiometric surface. In addition to water-level data, the distribution and magnitude of groundwater recharge and discharge (Masbruch and others, 2011) and the influence of geology on groundwater flow across HA boundaries (Sweetkind and others, 2011b) were considered in the development of the potentiometric-surface map.

Static (non-pumping) water-level altitudes from 190 wells were used to construct the potentiometric-surface contours of the carbonate and alluvial aquifer system. Water-level sites shown on figure 1 are symbolized by color according to the HGU that the water level represents. For sites where geologic or well-log information was unavailable, the HGU was interpreted based on the well screen interval or well depth and according to the well's proximity to consolidated-rock outcrops. These sites are qualified as "uncertain" and designated by a red outline on figure 1. One hundred fifty-three wells represent water levels in basin fill; 59 of these wells are qualified as uncertain. The remaining 37 wells represent water levels in consolidated rock; 2 of these wells are qualified as uncertain (fig. 2). At 20 of the sites, water levels were measured in several nested wells, including 8 sites where the nested wells are all in either consolidated rock or basin fill, and 4 sites where the nested wells are screened in both basin fill and consolidated rock. Water-level data at nested well sites were used to examine vertical differences in hydraulic head. While one location had an upward vertical gradient of 0.3, vertical hydraulic gradients were generally less than 0.05. These small vertical gradients indicate a hydraulic connection between basin fill and consolidated rock.

In addition to the potentiometric surface, water-level hydrographs are presented for 32 wells to illustrate the groundwater system's response to variations in recharge and discharge (fig. 2). Water-level measurements that appeared to be influenced by ongoing or recent pumping at the well were considered outliers and omitted from the hydrographs.

All water-level measurements used in this report were made using calibrated steel or electric tapes. The accuracy of the depth-to-water measurements for most wells is within 0.1 foot, or less, of the actual depth. However, because the land-surface altitude at many of the wells was determined from their location on 1:24,000-scale topographic maps, the altitude is only accurate to one-half of the altitude contour interval. Consequently, the uncertainty in water-level altitudes used to construct the potentiometric contours generally is less than 10 feet but can be as much as 50 feet for a few of the water-level measurements. The water-level measurements and well information used to construct the potentiometric-surface map (fig. 1) are available from the USGS for download at URL: http://pubs.water.usgs.gov/sim/3193. The multiple-year water-level data used to construct the hydrographs (fig. 2) are available from the USGS National Water Information System (NWIS) database at URL: http://waterdata.usgs.gov/nwis. For more information about the NWIS database, refer to Mathey (1998).

Groundwater Flow in the Carbonate and Alluvial Aquifer System

A potentiometric-surface map showing spatially interpolated contours of equal groundwater altitude (hydraulic head) was constructed to illustrate generalized horizontal hydraulic gradients affecting both intrabasin and interbasin groundwater flow in Snake Valley and the surrounding region (fig. 1). This map presents new data for this region of the Great Basin carbonate and alluvial aquifer system that allows for higher resolution potentiometric contours and a more comprehensive comparison of bedrock and alluvial aquifer water levels than was possible when previous potentiometric-surface maps of the area were constructed. Furthermore, the availability of new geologic information from recently drilled wells allowed for additional interpretation of geologic controls on the flow of groundwater.

Throughout the study area, water levels in neighboring consolidated-rock and basin-fill wells, and in nested observation wells, were found to be similar, indicating that consolidated-rock and basin-fill aquifers are hydraulically connected. The current map, therefore, is assumed to represent a single aquifer system. This assumption is consistent with the conceptualization of Sweetkind and others (2011b) in which water levels in shallow alluvium were considered to be in hydraulic connection with the underlying permeable bedrock.

Potentiometric-surface contours range from 5,900 feet in Spring Valley in Nevada, to 4,350 feet in northern Snake Valley and Fish Springs Flat in Utah (fig. 1). Groundwater flow is assumed to occur from higher to lower water-level altitudes, generally perpendicular to the potentiometric contours. Contours indicate that groundwater flows away from the high-altitude Snake Range and Deep Creek Range and into the adjacent valleys.

The potentiometric map shows a groundwater divide in southern Spring Valley just north of the Lincoln County/White Pine County line. North of the groundwater divide, flow is generally toward the center of Spring Valley and northward. South of this divide, groundwater flows southeastward, passing through the Limestone Hills at the southern end of the Snake Range and into Snake Valley. Water-level data are not available for the southernmost portion of Hamlin Valley, but groundwater is assumed to move northward away from the higher-altitude areas that border the southern end of Hamlin Valley.

From the southern end of the Snake Range northward to approximately the north end of the Conger Range in Utah, groundwater flow in Snake Valley is primarily northeastward. Water-level and geologic data indicate that a steeply dipping northeast-trending section of the USCU (mostly Chainman Shale) acts as a barrier to eastward flow and directs most groundwater northeastward through basin fill and carbonate rocks (UCAU and LCAU) toward large areas of evapotranspiration and spring discharge in northern Snake Valley. Geologic cross sections indicate that this USCU barrier is concealed at shallow depths beneath basin fill to the south of Conger Mountain (Hintze and Fitzhugh, 2002). This and other areas where the concealed USCU is thought to act as a barrier to groundwater flow are shown as heavy dashed black lines on figure 1. South of Conger Mountain, in the vicinity of Little Valley, water-level altitudes are 465 feet different on either side of the buried USCU, providing evidence that this feature impedes groundwater flow. The 4,892 foot water-level altitude (well 113) on the west side of the buried USCU is similar to water-level altitudes in Snake Valley north of Eskdale. The 4,427 foot water-level altitude (well 123) on the east side of the buried USCU is similar to water-level altitudes throughout Tule Valley.

The orientation of outcrops of USCU through the Burbank Hills and in the northern Mountain Home Range, combined with the difference in water-level altitude between Hamlin Valley and Pine Valley, indicate that this steeply dipping USCU acts as a nearly continuous north-south trending barrier for approximately 60 miles. The only break in the barrier seems to be south of Highway 50 in the Ferguson Desert where drillers' logs indicate that the USCU may be buried beneath significant basin fill (more than 1,400 feet at well 100 and 300 feet at well 91). The west-to-east hydraulic gradient across the Ferguson Desert in basin fill is evidence that some amount of groundwater moves eastward through basin fill in this area.

There remains some uncertainty as to whether the northern Confusion Range (north of the USCU flow barrier and east of Gandy, Utah) is a significant interbasin flowpath between Snake and Tule Valleys. The bedrock separating Snake Valley from Tule Valley in this area is all carbonate and may be permeable. Also, potentiometric contours based on several water levels in the neighboring valleys suggest the potential for groundwater movement from Snake Valley through the UCAU and LCAU of the Confusion Range into Tule Valley, and subsequently toward Fish Springs. However, existing water-level data in this area are insufficient to conclude that this groundwater movement is occurring. Therefore, potentiometric contours across the Confusion Range are shown as dashed to indicate that they are inferred (fig. 1). Groundwater in the northernmost part of Snake Valley moves both northward to discharge by evapotranspiration along the southern edge of the Great Salt Lake Desert north of Callao, Utah, and eastward as indicated by the hydraulic gradient between the valley bottom (wells 171, 173, and 177) and the bedrock highlands to the east (near well 172).

Water-level data are sparse in Pine and Wah Wah Valleys, in western Sevier Desert, and in the Ferguson Desert area of Snake Valley. Available data, however, indicate that flow is generally northward through Pine and Wah Wah Valleys and westward through Sevier Desert. Potentiometric contours suggest that flow from each of these basins moves through the LCAU toward Tule Valley and subsequently toward Fish Springs at the north end of Fish Springs Flat or the Great Salt Lake Desert to the north of the map area. In Tule Valley, a very flat hydraulic gradient exists where water-level altitudes are approximately 4,430 feet for more than 50 miles paralleling the House Range in a north-south direction. This long, flat gradient is likely due to a combination of low recharge rates and relatively high permeability aquifer materials underlying the valley.

The southern parts of Snake, Pine, and Wah Wah Valleys are underlain by volcanic rocks, and most groundwater flow occurs primarily in the unconsolidated basin fill. The low permeability of the intervening volcanic mountain blocks in these areas is thought to limit interbasin flow. However, additional water-level data are required to clarify the degree of connection or separation between the upgradient parts of these HAs.

Long-Term Water-Level Fluctuations

Water levels in wells fluctuate in response to imbalances between groundwater recharge and discharge. Water levels rise when recharge exceeds discharge for a period of time and water levels decline when the opposite occurs. Water-level variations are driven by both natural and anthropogenic processes. Examples of natural processes include groundwater recharge from the infiltration of precipitation and groundwater discharge as evapotranspiration in a marsh or wetland; an example of an anthropogenic process is discharge of groundwater by withdrawal from wells. Multiple-year water-level hydrographs are presented for 32 wells within the study area (fig. 2). All hydrographs shown are from wells completed in basin fill because no long-term water-level records are available for bedrock wells.

Water-level hydrographs are distinctly different in the eastern and western parts of the study area. In the eastern part of the study area, water-level fluctuations are minimal (less than about 2 feet) over the period of record for all wells in Tule Valley, Pine Valley, Wah Wah Valley, Fish Springs Flat, and Sevier Desert (fig. 2). The steady water levels are likely due to a combination of these valleys receiving little direct recharge from nearby mountains and experiencing negligible groundwater pumping. Conversely, in the western portion of the study area, in Spring and Snake Valleys, wells experience noticeably greater water-level variations. Many of the wells in these valleys are located close to areas of substantial mountain recharge and respond to annual recharge or multiple-year periods of above or below average precipitation. Wells located close to the Snake and Deep Creek Ranges (for example, wells 74, 139, 145, and 177) showed water-level fluctuations of 10 to 20 feet over periods of only a few years. The sudden water-level rise of nearly 15 feet in well 139 illustrates a rapid response to seasonal recharge in this area. While most water levels that comprise the hydrographs were measured in the spring or fall of a given year, the final water level shown for this well was measured in the middle of June 2010 and corresponds directly with the period of peak snowmelt runoff in 2010, as indicated by a continuous streamflow record for Lehman Creek near Baker, Nevada (USGS Station 10243260). The magnitude of water-level variation shown in other parts of Spring and Snake Valleys is not as great. However, water levels in wells throughout Spring and Snake Valleys also appear to respond to interannual climate variations.

Most water-level records in the study area show no distinct, long-term monotonic trends (rises or declines). However, in the area north of Highway 50 in Snake Valley, water levels in five wells (108, 114, 120, 129, and 136) have been declining since about the mid- to late-1980s. Water levels in these wells rose in response to a period of above average precipitation the mid-1980s (Wilkowske and others, 2003) and reached a maximum around the late 1980s to early 1990s. Since that time, water levels in these wells have fallen steadily and show little to no recovery during subsequent periods of above average precipitation (for example, 1996–1998 and 2004–2005). These water-level declines are most likely caused by groundwater withdrawal for irrigation in this area.

Summary

Water-level measurements from 190 wells were used to develop a potentiometric-surface map of Snake Valley and surrounding areas in eastern Nevada and western Utah. The water-level map covers approximately 9,000 square miles in the east-central portion of the regional Great Basin carbonate and alluvial aquifer system in Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada. The map includes new water-level data from 68 observation wells drilled during 2007–2010 at 29 locations. Most measurements used to construct the map were made during the spring of 2010. These data help to refine conceptual pathways of intrabasin and interbasin groundwater flow.

Comparison of water levels at nested observation well sites and in neighboring wells completed in consolidated-rock and basin fill confirm that the carbonate and alluvial aquifers are hydraulically connected. Potentiometric contours indicate that a groundwater divide exists in southern Spring Valley where groundwater moving from the mountainous recharge areas on both sides of the valley diverges toward the north and south. South of the groundwater divide, the direction of flow is southeastward around the southern end of the Snake Range into southern Snake Valley. Groundwater flow in Snake Valley is primarily northeastward. Eastward interbasin flow out of the valley is restricted by steeply dipping, northeast trending, siliciclastic rocks extending from the Mountain Home Range as far north as the Confusion Range.

Although water-level data throughout the eastern half of the study area are sparse, the limited data indicate that flow is generally northward through Pine and Wah Wah Valleys, and westward through Sevier Desert toward Tule Valley. A distinct, nearly flat hydraulic gradient exists in Tule Valley where water-level altitudes do not vary significantly for more than 50 miles from south to north. Potentiometric contours also indicate little or no interbasin flow between the southern portions of Hamlin, Pine, and Wah Wah Valleys, possibly due to low permeability volcanic and siliciclastic rocks along the HA boundaries.

Long-term water-level hydrographs presented for 32 wells show minimal water-level fluctuations throughout the eastern part of the study area where recharge rates are low and where the current levels of groundwater pumping are negligible. The western portion of the study area experiences noticeably greater water-level variations, indicating that the aquifer system in this area responds to interannual climate variation and to pumping. Except for the area north of Highway 50 in Snake Valley, the water levels used in this study respond primarily to climatic conditions and have not yet shown long-term decline from well withdrawals.

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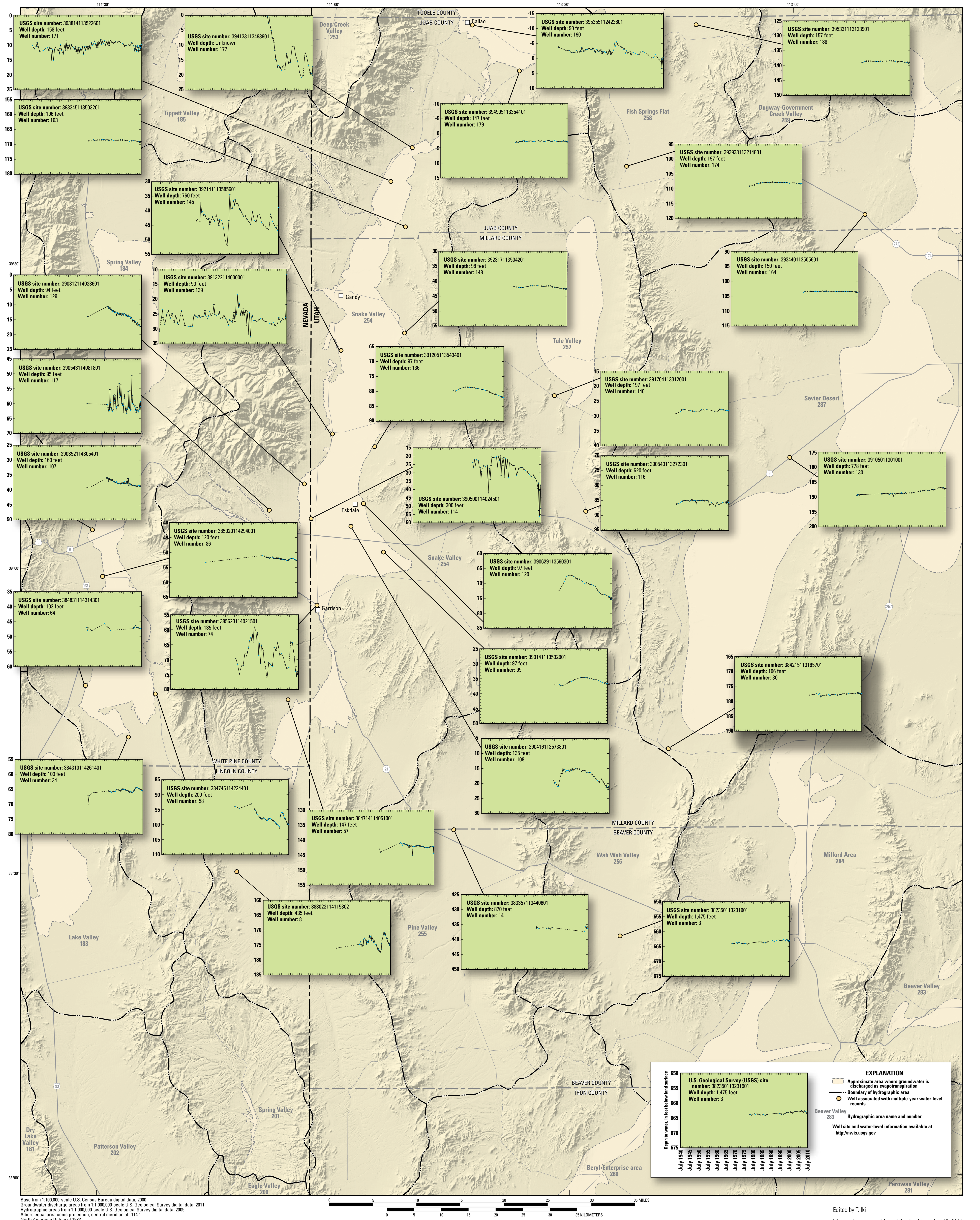

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Groundwater discharge areas from 1:1,000,000-scale U.S. Geological Survey digital data, 2011
Hydrographic areas from 1:1,000,000-scale U.S. Geological Survey digital data, 2009
Albers equal area conic projection, central meridian at -114°
North American Datum of 1983

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Figure 2. Multiple-year water-level hydrographs from selected wells in and around Snake Valley, Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada.

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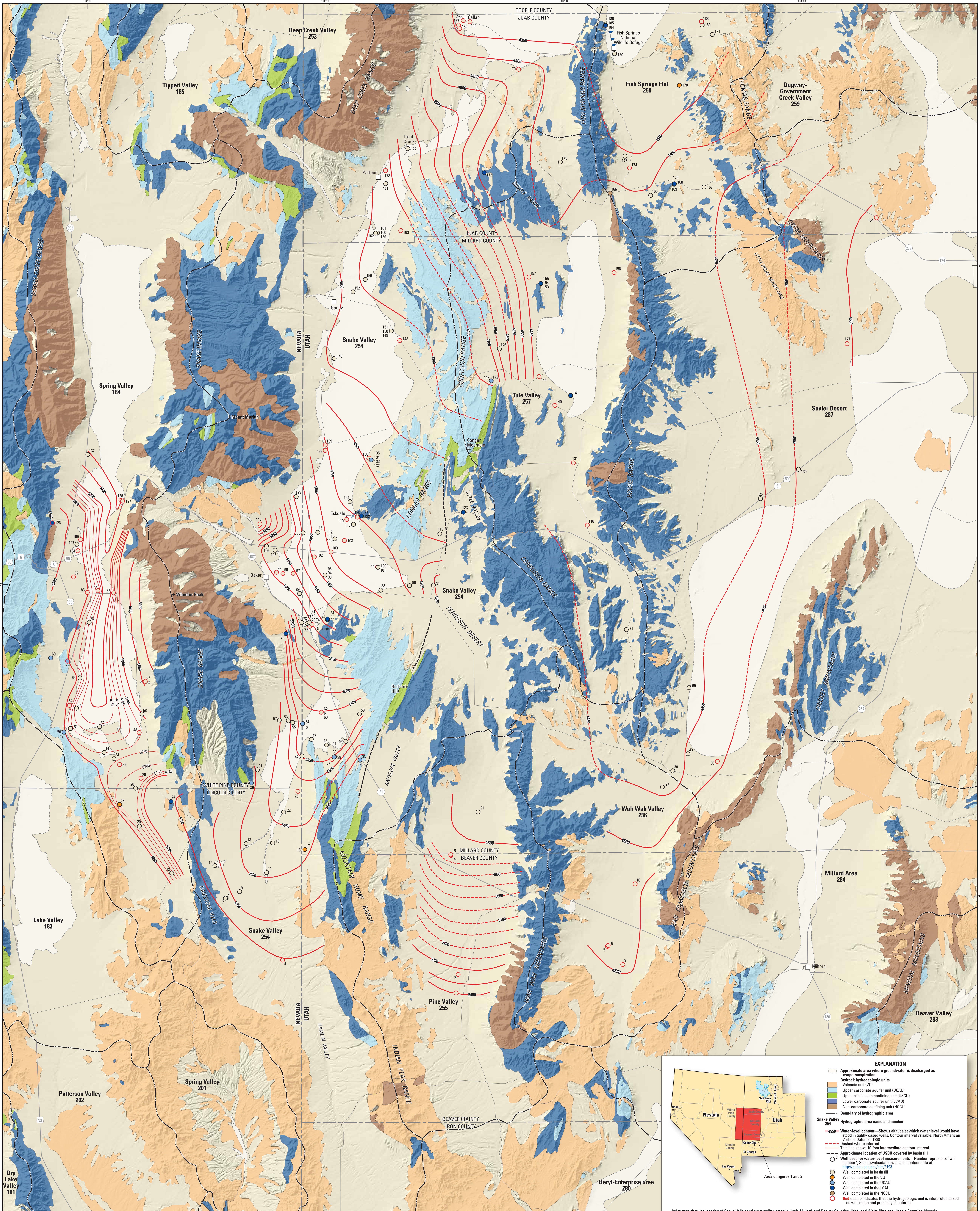

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Figure 1. Potentiometric-surface map of Snake Valley and surrounding areas in Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada.

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