HYDROGEOLOGIC SETTING OF THE SNAKE VALLEY HYDROLOGIC BASIN, MILLARD COUNTY, UTAH, AND WHITE PINE AND LINCOLN COUNTIES, NEVADA -- IMPLICATIONS FOR POSSIBLE EFFECTS OF PROPOSED WATER WELLS

by
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View to the west of central Snake Valley (foreground) and the southern Snake Range (snow-covered peaks in background), eastern White Pine County, Nevada. Wheeler Peak, elevation 13,063 feet, is the highest peak in the southern Snake Range, which contains Great Basin National Park. The Southern Nevada Water Authority has proposed to drill nine new water-supply wells along the eastern margin of the southern Snake Range (sparsely vegetated slopes in middle ground of photo), within 5 miles of the Utah-Nevada state line. This report evaluates the geologic setting of Snake Valley and its influence on the possible effects of these proposed wells on ground-water conditions in Utah.

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ABSTRACT

The Southern Nevada Water Authority has proposed a system of 146 water-supply wells in south-central and south-eastern Nevada to supply water to the Las Vegas area. Nine of the proposed wells, with a total withdrawal of 25,000 acre-feet per year (31 hm^3/yr), are located along the eastern flank of the southern Snake Range in eastern White Pine County, within 5 miles (8 km) of the Utah-Nevada state line. Construction of the wells is set to begin in 2007.

Numeric models show a potential ground-water decline from the proposed wells of greater than 100 feet (31 m) in westernmost Millard County, Utah. This magnitude of drawdown would adversely affect both existing and future spring, surface, and ground-water uses in Utah.

Ground water in the Snake Valley hydrologic basin resides primarily in two main aquifers, Quaternary-Tertiary basin fill and Paleozoic carbonate rocks. Storage and transport of ground water occurs in intergranular pore space in the basin-fill aquifer and in solution-widened joints, faults, and bedding planes in the carbonate bedrock aquifer. Hydraulic parameters of the two primary aquifers are relatively well known, but their subsurface geometries, extent, and the influence of geologic structures on ground-water flow are poorly constrained.

The subsurface structure and hydrologic connectivity of the main aquifers are complex due to the geologic evolution and structural complexity of the area. An important, but unresolved, problem is to determine the pathway of ground water as it moves from recharge areas high in the Snake Range to the principal aquifers below the valley. The recharge areas are in the lower plate of a major, east-dipping, low-angle normal fault zone that is likely a barrier to ground-water flow across its plane. The primary aquifers are in the upper plate of this fault. Water, therefore, must somehow cross this fault in order to enter the aquifers, but the pathways are not well understood. The proposed wells are located in this structurally complex transition zone, where the recharge is actively entering the aquifers. The location and depth of the proposed wells will, therefore, strongly influence whether they capture recharge that would otherwise enter the primary aquifers, and the parts of the aquifers that will be impacted most.

We recommend further work to better constrain the effects of the proposed wells, including quantification of the present hydrologic balance and recharge pathways, detailed gravity surveys, construction of additional cross sections, assessment of other potential aquifers, and quantification of fracture densities and orientations in the carbonate aquifer.

INTRODUCTION AND PURPOSE

The Southern Nevada Water Authority (SNWA) has proposed a system of 146 water-supply wells and interconnecting pipelines in south-central and southeastern Nevada to supply 180,000 acre-feet of water per year (222 hm^3/yr) to the Las Vegas area (Schaefer and Harrill, 1995; SNWA, 2004) (figure 1). Most of these wells will be located within Nevada more than 30 miles (48 kilometers) from the Utah-Nevada state line. However, nine of the proposed wells are located in easternmost White Pine County within 5 miles (8 km) of the Utah-Nevada state line, along the eastern flank of the southern Snake Range (figure 2). Collective withdrawal from these wells could reach 25,000 acre-feet per year (31 hm^3/yr) (Schaefer and Harrill, 1995). The project is currently in the planning and analysis phase with construction set to begin in 2007 (SNWA, 2004) (figure 3).

Ground-water users and managers in Utah are concerned about decreased spring flows and ground-water levels in western Millard County, east of the proposed well field, which could result from this new ground-water withdrawal. Regional-scale ground-water flow models indicate that ground-water levels will decrease by over 100 feet (31 m) in both unconsolidated and bedrock aquifers, leading to measurably decreased spring flow once pumping begins and the ground-water system has reached a new equilibrium (Schaefer and Harrill, 1995). In Utah, 185 active wells are completed primarily in the unconsolidated valley fill within 15 miles (24 km) of the proposed withdrawal wells, as

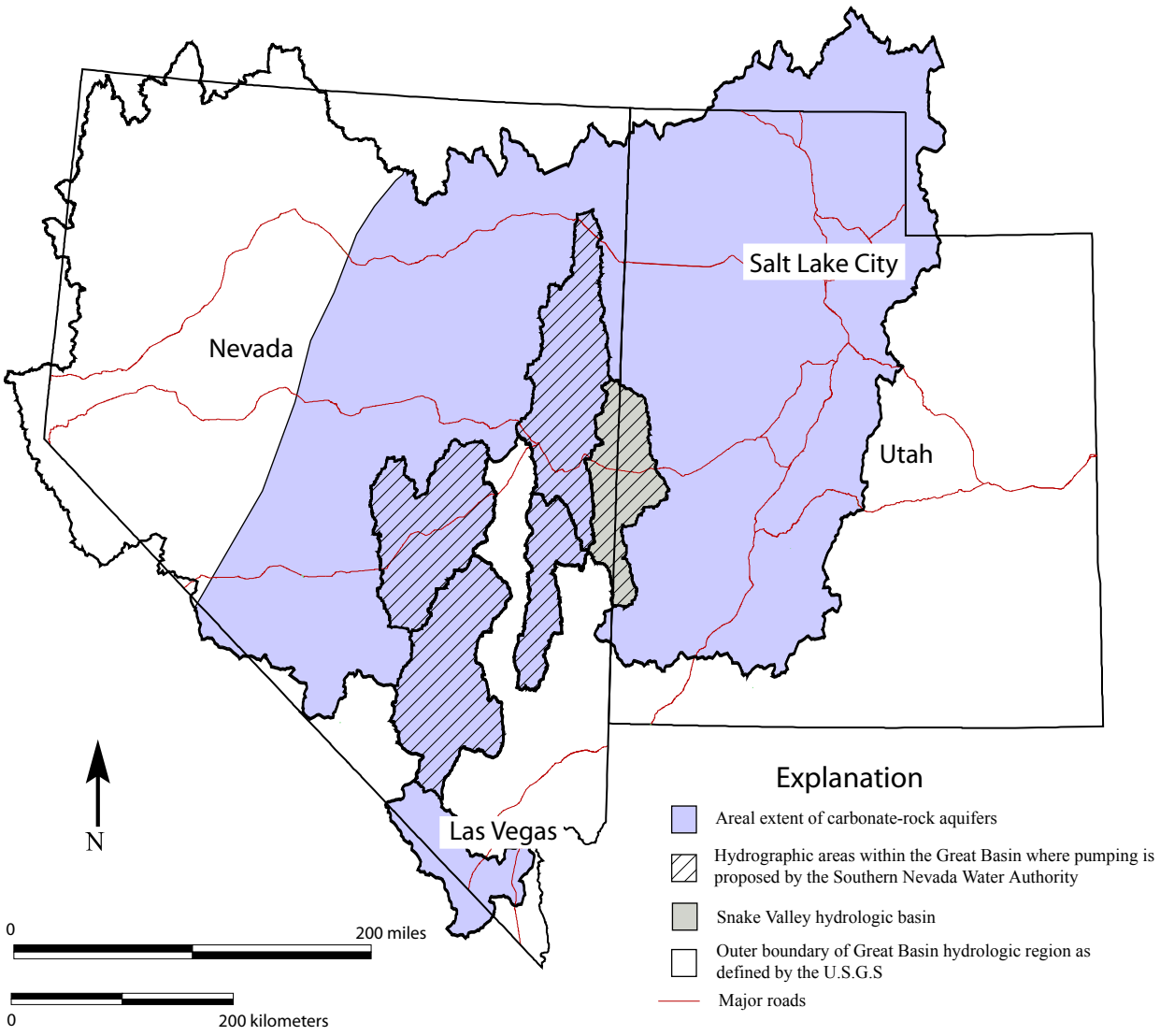

Figure 1. *Map of the Utah and Nevada area showing the Snake Valley hydrologic basin in the Great Basin hydrologic region. Blue shade shows the extent of the Paleozoic carbonate aquifer from Plume (1996). Extent of proposed new pumping by the Southern Nevada Water Authority is from Schaefer and Harrill (1995).*

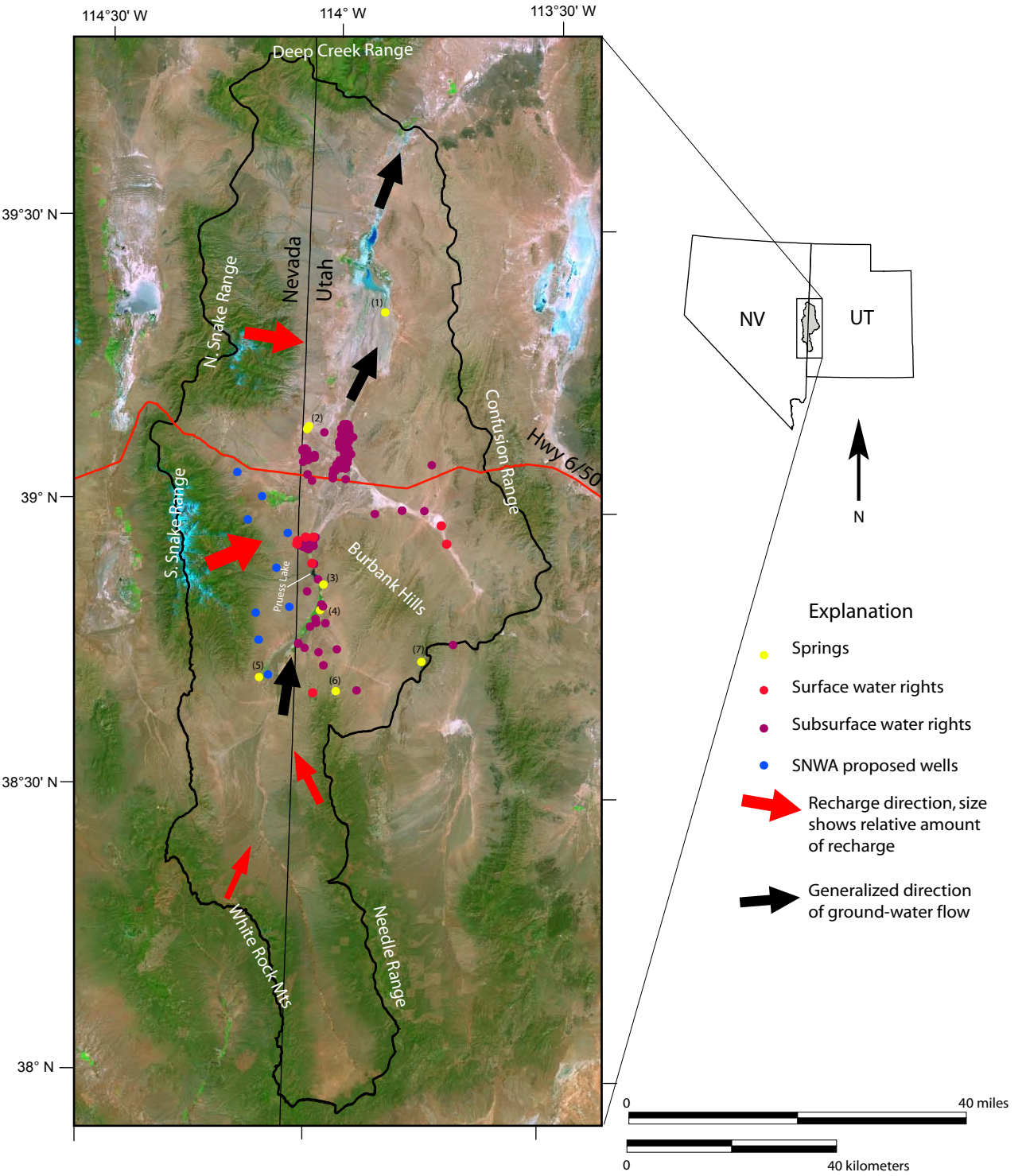

Figure 2. *False-color Landsat image of the Snake Valley hydrologic basin (outlined in black). Wells proposed by the Southern Nevada Water Authority shown in blue. Existing points of diversion in Utah include underground rights shown in purple, surface rights shown in red, and springs shown in yellow, including (1) Twin Spring, (2) Cane Spring, (3) Clay Spring, (4) Blind Spring, (5) Big Spring, (6) Needle Point Spring, and (7) Tunnel Spring. Major sources, generalized direction, and amount of recharge shown by red arrows (Carlton, 1985). Black arrows show generalized direction of ground-water flow for both the carbonate and basin-fill aquifers (Hood and Rush, 1965; Carlton, 1985; Schaefer and Harrill, 1995). Areas of high evapotranspiration including irrigated fields, wetlands, and riparian vegetation are bright green.*

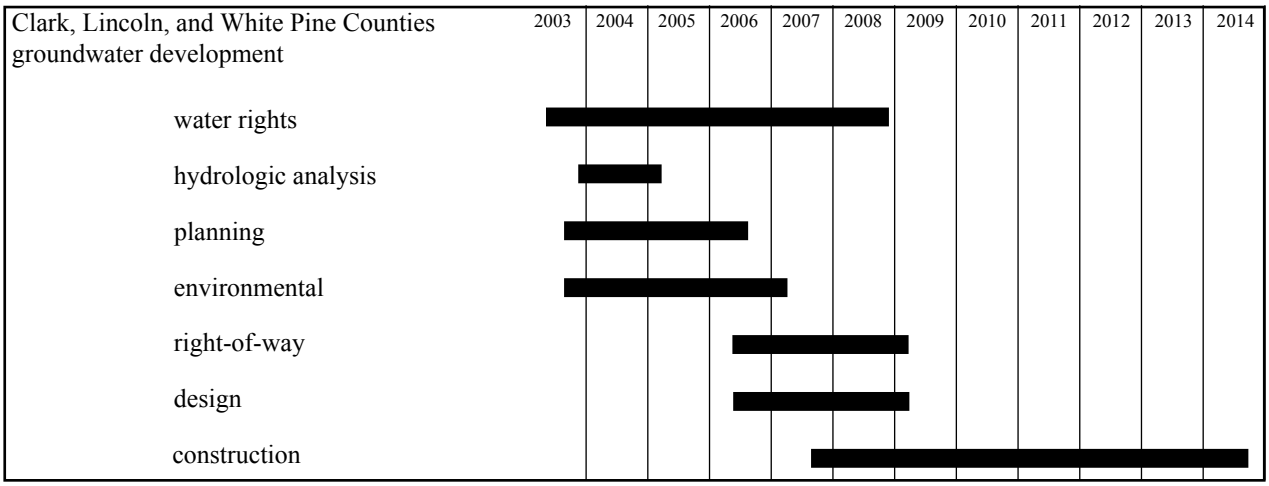

Figure 3. *Project timeline for development of the ground-water withdrawal system proposed by the Southern Nevada Water Authority. Construction is set to begin in 2007. Hydrologic analysis for the proposed wells is minor compared to all other project phases. From the Southern Nevada Water Authority (2004).*

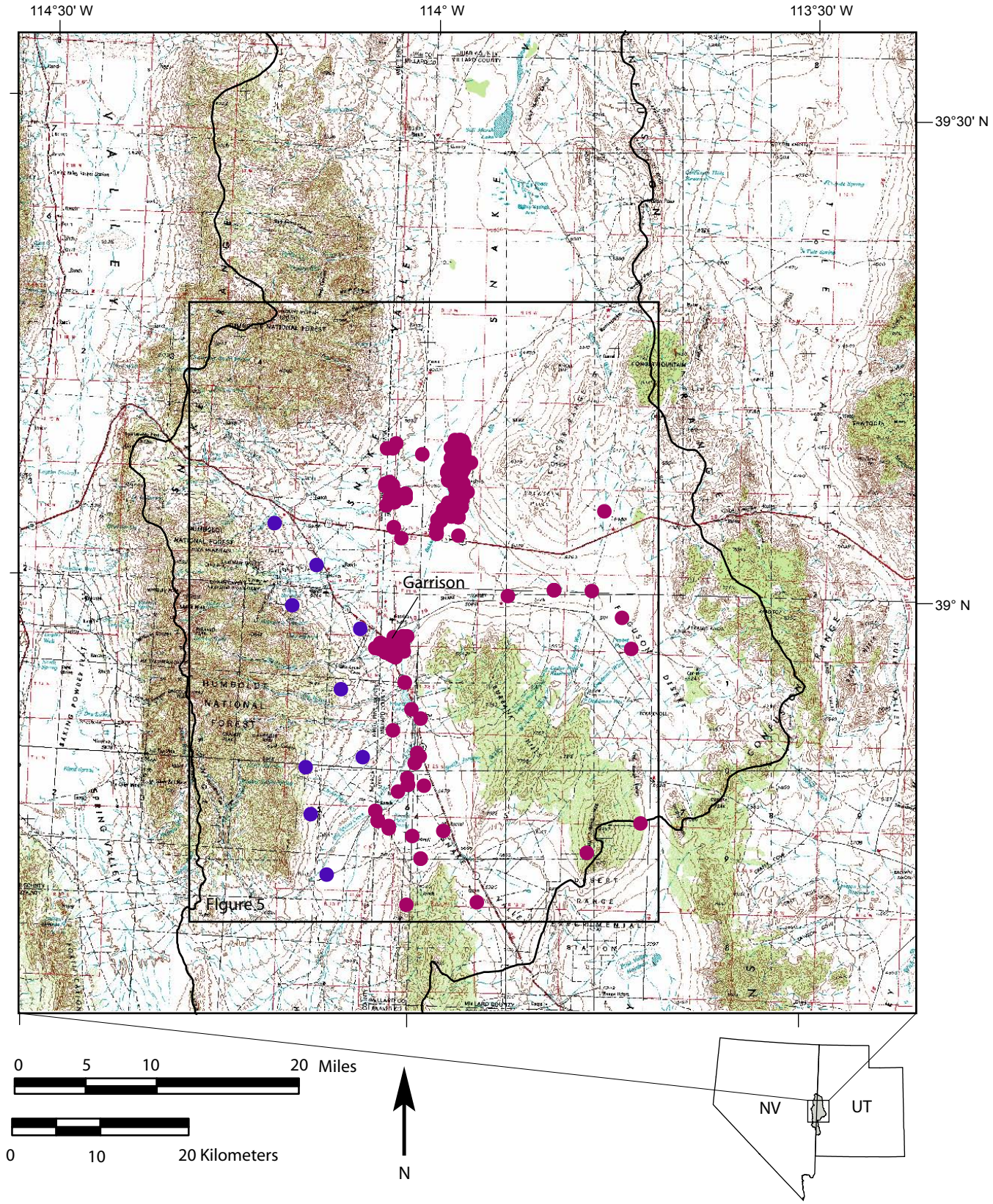

Figure 4. *Location map for Snake Valley showing wells proposed by the Southern Nevada Water Authority in blue. Location of Utah surface and subsurface points of diversion shown in purple. Black line is the extent of the Snake Valley hydrologic basin. Inset black box is the area shown in figure 5. 1:250,000 scale topographic base maps (Richfield, Delta, Ely, and Lund) from the U.S.G.S.*

well as numerous springs and seeps, which could be affected by these new wells (Utah Division of Water Rights, 2004) (figures 2 and 4).

This study provides a preliminary assessment of the basin-scale hydrogeologic framework of Snake Valley based on previous work. The goals are to assess the potential impacts of the proposed SNWA well field on ground-water resources in Utah based on the basin-scale geologic framework and existing hydrologic modeling, and to recommend future work to understand these relationships more thoroughly.

LOCATION AND GEOGRAPHY

The north-south trending Snake Valley hydrologic basin straddles the Utah-Nevada state line for approximately 135 miles (217 km) in the east-central part of the Great Basin (figures 1 and 4). Several north-south-trending mountain ranges bound Snake Valley, including the Snake Range and Deep Creek Range on the west, and the Confusion Range, Needles Range, and Burbank Hills on the east (figure 2). The basin covers parts of western Tooele, Juab, Millard, Beaver, and Iron Counties in Utah, and eastern White Pine and Lincoln Counties in Nevada, and has a total surface area of 3,480 square miles (9,013 km^2) (Hood and Rush, 1965) (figure 4). This study focuses on the part of Snake Valley immediately adjacent to the proposed well field in White Pine and Millard Counties.

Western Millard County, including the small community of Garrison, is sparsely populated and rural. The local economy is dominated by irrigated agriculture and ranching, with lesser tourism related to nearby Great Basin National Park. Total yearly ground-water withdrawal in this part of Snake Valley was 14,500 acre-feet (18 hm^3/yr) for the 2002 water year (Fisher, 2003); nearly all of the withdrawal was for irrigation.

GEOLOGIC SETTING

The bedrock of Snake Valley and surrounding ranges consists primarily of a late Precambrian to early Mesozoic sedimentary succession up to 33,000 feet (10,058 m) thick (Gans and Miller, 1983) (figures 5 and 6). Paleozoic-age continental-shelf carbonates dominate the middle and upper parts of the section, and quartzites and clastics of Early Cambrian and Precambrian age dominate the lower part of the section (Miller and others, 1983) (figures 5, 6, and 7). Deposition of these rocks was mostly continuous and records a period of relative tectonic quiescence and gradual subsidence along the continental margin of western North America (Gans and Miller, 1983). The carbonate part of the section forms a regionally extensive and important aquifer that covers much of the eastern and southern Great Basin (Plume, 1996; Harrill and Prudic, 1998) (figure 1).

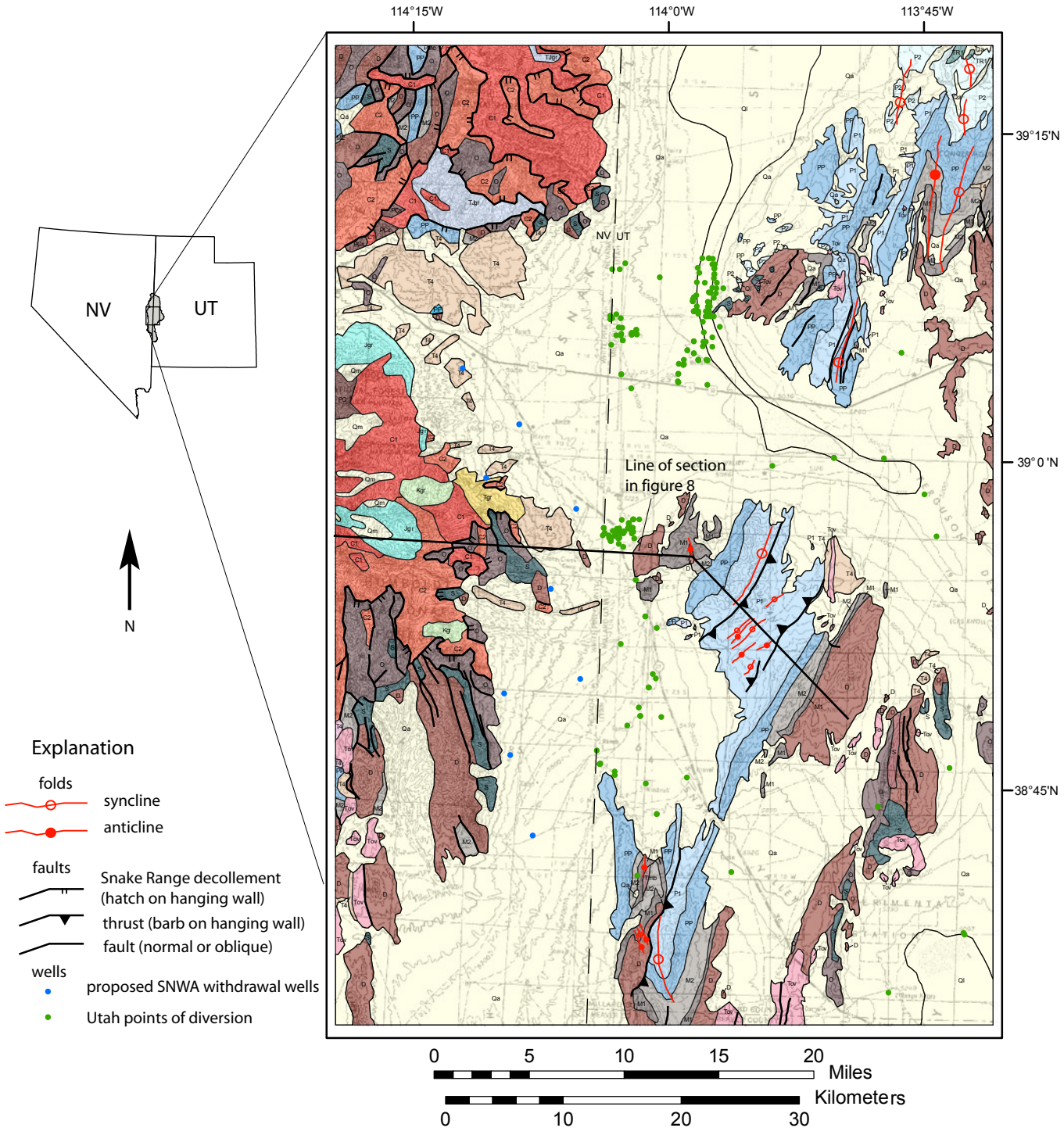

Figure 5. *Generalized geology of central Snake Valley showing the Snake Range decollement in the northern and southern Snake Range and the Confusion Range synclinorium to the east. Unit symbols correspond with those shown in the stratigraphic column in figure 6. Map compiled from Hose and Blake (1970), Gans and Miller (1983), McGrew (1986), Hintze and others (2000), Hintze and Davis (2002a, 2002b), and Kirby and Pohs (2004).*

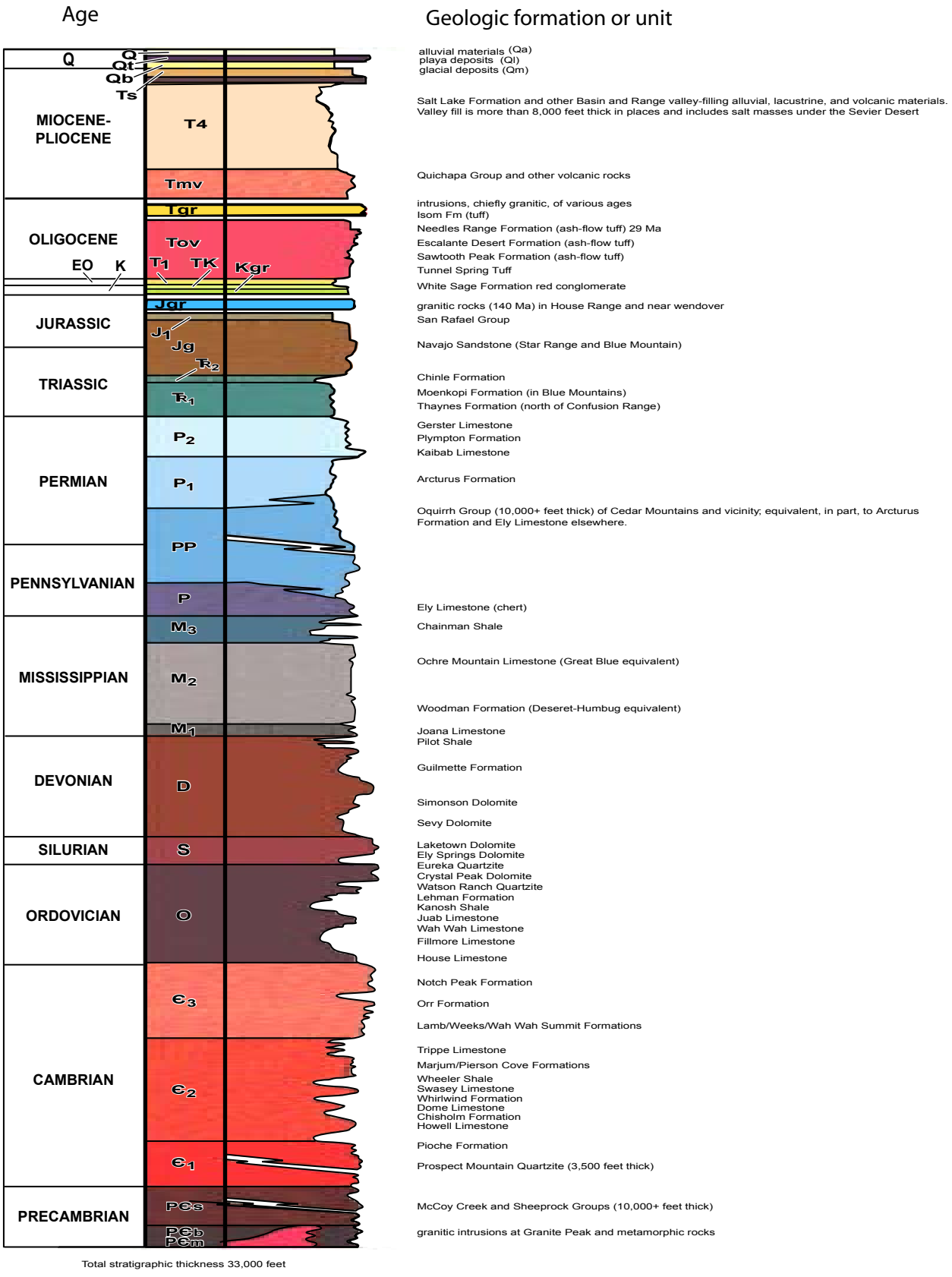

Figure 6. *Generalized stratigraphic column for west-central Utah. Colors and unit symbols correspond with figure 5. Modified from Hintze and others (2000). Not all units shown in column are in figure 5.*

***Figure 7**. Carbonate sedimentary rocks in the Burbank Hills in the study area. These rocks comprise the regional carbonate aquifer where they exist below the land surface and are saturated. A. Layered limestone of the Devonian-age Guilmette Formation. Wheeler Peak is in the background. B. Closer view of Guilmette Formation. Note vertical joints and partings along bedding planes. These features transmit ground water where present in the carbonate aquifer. C. Outcrop of Mississippian-age Joana Limestone, showing caves formed from dissolution by ground water when these rocks were buried below the surface, and faults (white, subvertical lines).*

These rocks were deformed into large-scale north-south-trending folds during Late Jurassic to early Tertiary time by slip on underlying, east-directed thrust faults of the Sevier fold and thrust belt (Miller and others, 1999). Lower and mid-crustal metamorphism occurred during the emplacement of plutons during the Jurassic, Cretaceous, and Tertiary in the northern and southern Snake Range (Gans and Miller, 1983; McGrew, 1993; Miller and others, 1999) (figure 5). Following this long-lived period of crustal shortening and thickening, extension and widespread volcanism began during the latest Eocene and early Oligocene (Axen and others, 1993; Miller and others, 1999).

Extension and crustal thinning during the Oligocene was accommodated along the Snake Range decollement, a regionally continuous, shallowly east-dipping fault exposed in the Snake Range and imaged in the subsurface by seismic-reflection lines (Allmendinger and others, 1983; Gans and Miller, 1983; Bartley and Wernicke, 1984; Shah Alam, 1990; McGrew, 1993) (figures 5 and 8). During extension, footwall rocks were dramatically thinned and metamorphosed to greenschist facies (Miller and others, 1983; McGrew, 1993). The total displacement, kinematics of slip, and relation of ductile fabrics in the footwall of this fault to overall extension magnitude have been debated (Bartley and Wernicke, 1984; Gans and Miller, 1984). Based on reconstructed cross sections and other structural data in the southern Snake Range, McGrew (1993) estimated between 8 and 24 kilometers (5 - 15 mi) of east-southeast extension across the southern Snake Range and adjacent Snake Valley. A later period of extension involving slip on both the low-angle Snake Range decollement and other high-angle faults to the north and

Units include: pC - McCoy Creek Group, Cpm - Prospect Mountain Quartzite, Cpi - Pioche Formation, Cpc - Pole Canyon Limestone, Clp - Lincoln Peak Formation, Cnp - Johns Wash Limestone, Op - Pogonip Group, Oe - Eureka Quartzite, OS - Laketown and Fish Haven Dolomite, Dse - Sevy Dolomite, Dsl - Simonson Dolomite, Dg - Guilmette Formation, Dp - Pilot Shale, Mi - Hanna Limestone, Mc - Chainman Formation, MPi - Illipah Formation, Pe - Ely Limestone, Prh - Rib Hill Formation, Pa - Arcturus Formation, Jgr - Snake Creek-Williams Canyon Pluton, Tgr - Young Canyon-Kious Basin Pluton, Tc - Tertiary Conglomerate, Qal - Alluvium

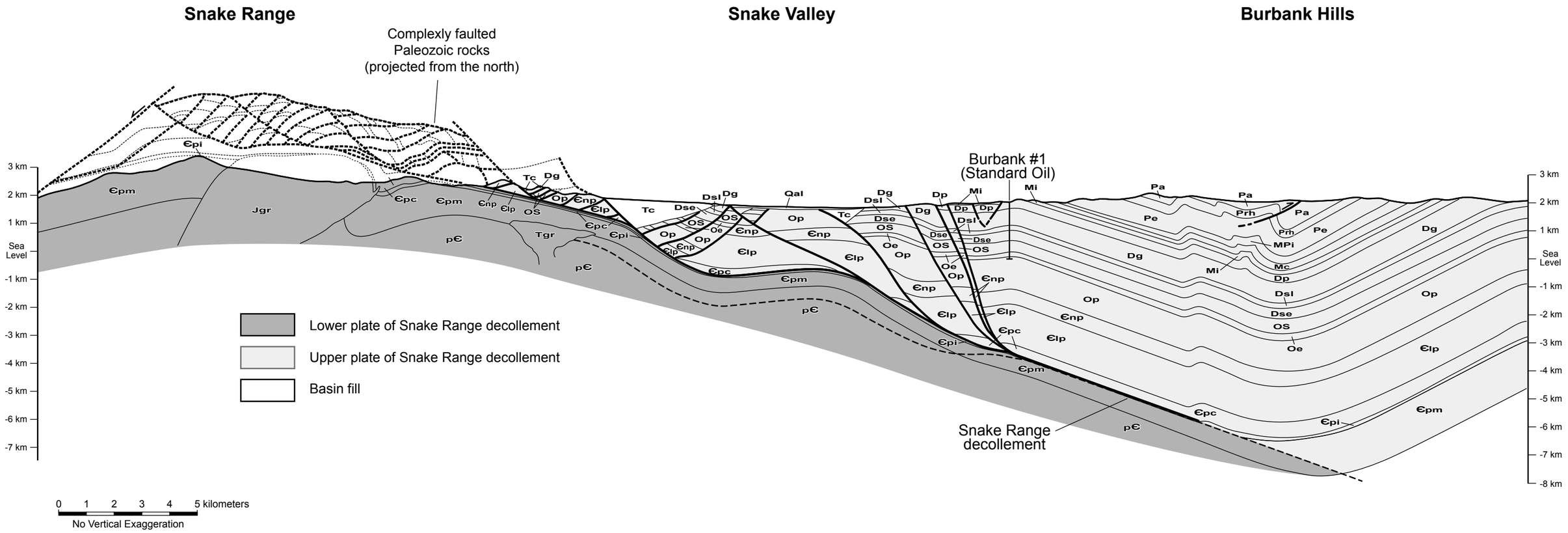

Figure 8. *Geologic cross section through the southern Snake Range, Snake Valley, and Burbank Hills showing complex structural compartmentalization of the upper plate of the Snake Range decollement. Tertiary basin fill is asymmetric and west-thickening beneath Snake Valley. Cross section is based on surface geology, well logs, and retrodeformational balancing (from plate 2 of McGrew, 1993). See figure 5 for location of cross section.*

south occurred in the Miocene; volcanic rocks and clastic basin fill were deposited and regional doming of the Snake Range occurred (Miller and others, 1999).

Sedimentary basins developed in the hanging walls of the Snake Range decollement and the steeply dipping faults. These basins underlie the present-day valley surface (figure 8). Early Tertiary basin fill includes locally derived clastic, volcanic, and volcaniclastic deposits (Gans and Miller, 1983; Shah Alam, 1990). These rocks overlie the older Precambrian to Triassic-age rocks along a regional disconformity or local angular unconformity, suggesting a gently folded low-relief surface just prior to onset of extension (Miller and others, 1983). Seismic-reflection profiles show three distinct unconformity-bounded packages of basin fill, which record the different episodes of extension (Shah Alam, 1990).

Modern basins, filled with clastics and lesser fine-grained deposits derived from the nearby basin-bounding ranges, developed in the late Miocene (McGrew, 1986; Miller and others, 1999). Total thickness of basin fill modeled from gravity and well data ranges between 0 and 3.8 kilometers (0 - 2.4 mi) (Saltus and Jachens, 1995) (figure 9). Cross sections, seismic and gravity data, and well data show asymmetric basins, which thicken generally to the west toward the Snake Range (Almendinger and others, 1983; Shah Alam, 1990; McGrew, 1993). Basin-fill geometry is irregular north to south, defining several distinct pockets of thick basin fill (Saltus and Jachens, 1995) (figure 9). The youngest basin-fill deposits form an extensive aquifer beneath the valley floor and margins (Hood and Rush, 1965; Harrill and Prudic, 1998).

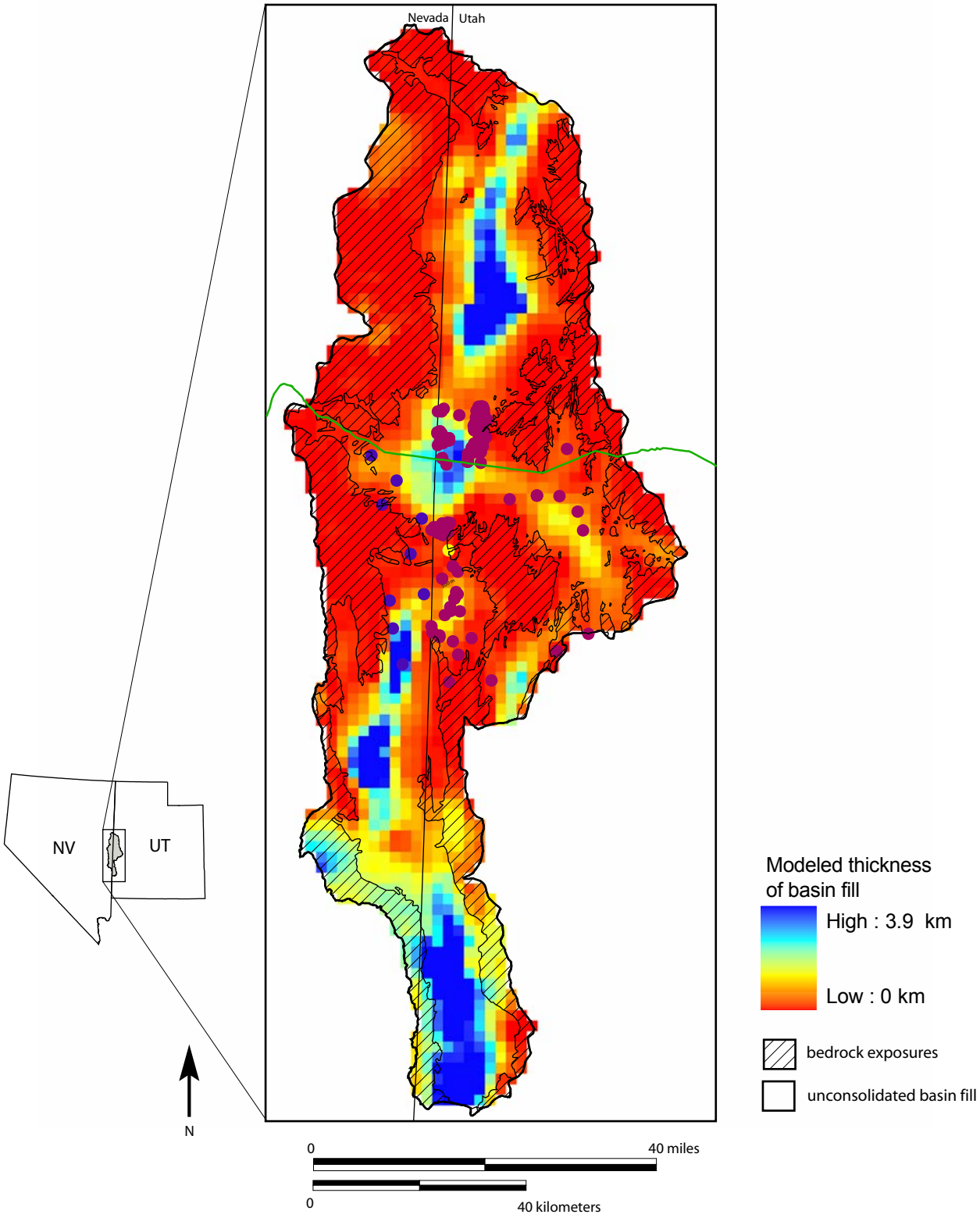

Figure 9. *Thickness of the unconsolidated basin fill in Snake Valley, modeled from isostatic gravity data and well data (Saltus and Jachens, 1995). Maximum thickness of basin fill is over 3.5 km. The wells proposed by the Southern Nevada Water Authority are shown in blue. Location of existing Utah water rights are shown in purple. Highway 6/50 shown in green.*

HYDROGEOLOGIC SETTING

Introduction

The two main aquifers in the Snake Valley hydrologic basin are the regionally extensive Paleozoic carbonate aquifer and the local unconsolidated basin-fill aquifer (Gates, 1984; Plume, 1996; Harrill and Prudic, 1998). Lesser but locally important aquifers may exist in the Early Cambrian and upper Precambrian clastic parts of the section. Important aquitards include the Mesozoic to Tertiary-aged igneous and metamorphic rocks of the lower plate of the Snake Range decollement (Plume, 1996).

Transmissivity in the basin-fill aquifer results from primary permeability of the aquifer matrix, whereas transmissivity in the carbonate aquifer is controlled by secondary permeability from solution-widened joints, fractures, faults, and dissolution cavities (Carlton, 1985; Plume, 1996). Secondary fracture permeability may also dominate the Precambrian and Early Cambrian clastics; however, local aquifer characteristics of these units are unknown.

Lateral hydraulic conductivity of the basin-fill aquifer estimated from regional studies ranges between 3.8×10^{-3} and 2.7×10^{-7} ft/s (1.16×10^{-3} - 8.23×10^{-8} m/s) (Carlton, 1985). Average lateral hydraulic conductivity for both pumping and recovery is 8.2×10^{-4} ft/s (2.5×10^{-4} m/s) (Bunch and Harrill, 1984). Vertical hydraulic conductivity is not well constrained but is estimated between 1.0×10^{-4} and 1.0×10^{-6} ft/s (3.1×10^{-5} - 3.1×10^{-7} m/s) (Bunch and Harrill, 1984). Tertiary basin fill may have conductivity

values roughly half of those of the younger basin fill due to increased lithification of these older sediments (Carlton, 1985).

The hydraulic properties of the carbonate aquifer are highly variable due to the dominant secondary permeability of joints, fractures, faults, and dissolution voids (Plume, 1996). Regional studies found horizontal hydraulic conductivity ranging from 5.8×10^{-3} to 9.4×10^{-7} ft/s (1.8×10^{-3} - 3.0×10^{-7} m/s) (Bunch and Harrill, 1984). Data from petroleum drill-stem tests show a much higher variance in horizontal hydraulic conductivity ranging from 5.8×10^{-9} to 1.0×10^{-2} ft/s (1.8×10^{-9} - 3.2×10^{-3} m/s) (Carlton, 1985). The higher values of conductivity likely represent fluid flow in highly fractured carbonate rocks and lower values represent unfractured carbonate rocks (Plume, 1996). Previous work has not constrained average fracture densities or orientation for the principal carbonate aquifer in the hanging wall of the Snake Range decollement. Vertical hydraulic conductivity is unquantified, but is assumed to be equal to or less than horizontal hydraulic conductivity depending on lithology, bedding, and fracture relationships (Carlton, 1985).

Hydrologic Balance

Recharge of the basin-fill and carbonate aquifers occurs primarily locally from surface infiltration and runoff, and secondarily from interbasin flow in the carbonate bedrock aquifer (Carlton, 1985; Schaefer and Harrill, 1995; Plume, 1996) (figures 2 and 10). Total recharge is estimated at 108,000 acre-feet per year (133 hm^3/yr) for the entire Snake Valley hydrologic basin, based on estimated precipitation, elevation, and areal extent (Carlton, 1985). Hood and Rush (1965) calculated recharge at 100,000 acre-feet per year (123 hm^3/yr) using different precipitation data. Average precipitation was estimated from approximately 30 years of data at several recording stations (Carlton, 1985). Interbasin flow from Spring Valley to the east into Snake Valley, primarily in the carbonate bedrock aquifer south of the Snake Range, may supply up to 4,000 acre-feet per year (5 hm^3/yr) of the total recharge (Carlton, 1985). The southern part of the Snake Range upslope of the proposed well field is estimated to supply 40,000 acre-feet per year (49 hm^3/yr) to aquifers below Snake Valley through surface runoff and direct infiltration in the exposed carbonate rocks (Carlton, 1985). Other significant recharge comes from the northern part of the Snake Range and the Needle Range (figure 2). The remainder of the recharge occurs from infiltration of precipitation and surface runoff throughout the topographically lower parts of Snake Valley (Hood and Rush, 1965; Carlton, 1985).

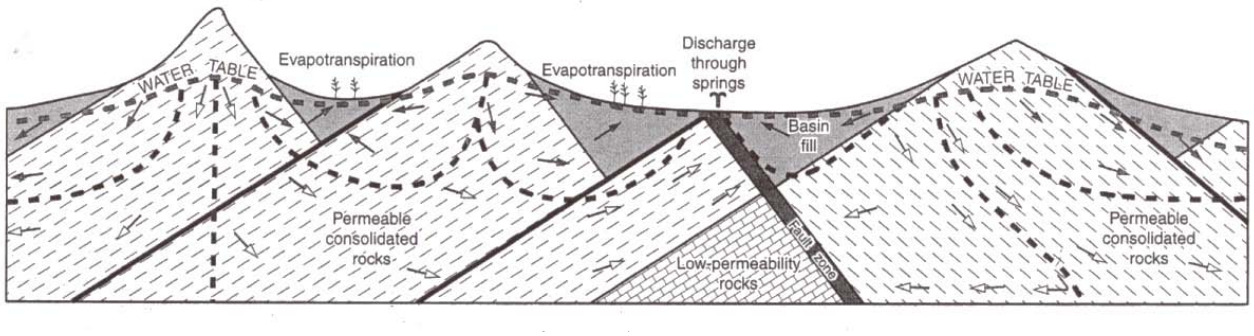

Figure 10. *Schematic diagram showing patterns of ground-water recharge and flow in the main aquifers in the east-central Great Basin. Permeable consolidated rocks comprise the regional carbonate aquifer. Solid black arrows represent shallow ground-water flow, and white arrows represent deep ground-water flow. Dashed lines bound distinct flow systems (from Harrill and Prudic, 1998).*

Discharge in the basin occurs primarily via evapotranspiration, which includes evaporation of standing and soil water, transpiration by plants, and discharge through springs and seeps. Evapotranspiration calculated by previous workers varies. Total evapotranspiration is estimated at 80,000 acre-feet per year (99 hm^3/yr) by Hood and Rush (1965), whereas Gates and Kruer (1981) calculated 64,000 acre-feet per year (79 hm^3/yr) of evapotranspiration. Discharge from ground-water pumping, primarily for irrigation, currently totals 14,500 acre-feet per year (18 hm^3/yr) (Fisher, 2003). Ground water withdrawal from the nine wells proposed by the SNWA is an additional 25,000 acre-feet per year (31 hm^3/yr) (Schaefer and Harrill, 1995).

Withdrawal from the nine wells in western Snake Valley and from other wells in the proposed SNWA well system, especially those in Spring Valley, will significantly affect the dynamics and overall budget of the Snake Valley ground-water system (Schaeffer and Harrill, 1995). The effects cannot be precisely predicted with available data, but the following changes are likely to occur:

(1) Ground-water levels will decline in both the basin-fill and carbonate aquifers (see following section).

(2) Recharge to the Snake Valley ground-water system will decrease by the 25,000 acre-feet per year (31 hm^3/yr) withdrawn from the SNWA wells and by 4,000 acre-feet per year (5 hm^3/yr) that presently enters the Snake Valley ground-water system as underflow from Spring Valley to the west (Carlton, 1985). The

underflow will likely be eliminated due to reversal of current potentiometric-surface gradients.

(3) Discharge at major springs will decrease by at least 10 percent, as indicated by the example of Twin Springs in northeastern Snake Valley (Schaffer and Harrill, 1995, p. 33) (figure 2). Discharge at other springs closer to the well field, such as the Big Spring complex (figure 2) in western Snake Valley, will likely decrease by a greater amount. Big Spring originates in Nevada, and its outflow stream flows into Utah where it supports riparian plant communities along its channel and supplies water to Pruess Lake.

(4) Evapotranspiration in Snake Valley will decrease by about 40 percent (Schaeffer and Harrill, 1995, p. 34). Although decreased evapotranspiration may result in more ground water available for withdrawal, the ecological impact of this decrease would be substantial and water rights at the affected springs could be adversely impacted.

(5) Subsurface outflow from Snake Valley, estimated at about 25,000 to 35,000 acre-feet per year (31 - 43 hm^3/yr) (Carlton, 1985), would be reduced due to reversal of potentiometric-surface gradients in Snake Valley. This reduction in subsurface outflow may eventually cause decreased discharge at important regional springs north and northeast of Snake Valley.

Potentiometric Surfaces and Depth to Ground Water

Depth to ground water increases to the east-northeast across Snake Valley in both the shallow basin-fill aquifer and the deeper carbonate aquifer (figure 11) (Gates, 1987; Carlton, 1985; Harrill and Prudic, 1998). Ground-water gradients are steepest immediately to the east and north of the southern Snake Range, flattening to the north and east (Carlton, 1985; Harrill and Prudic, 1998) (figure 11). Both the northern and southern parts of the Snake Range are relative highs in the regional potentiometric surface. Subsurface outflow along the eastern and northern margin of Snake Valley is suggested by all available data (Gates, 1987; Carlton, 1985).

Time-step models of the effect of the proposed ground-water withdrawals on ground-water levels show downward deflection of the local potentiometric surface within Snake Valley (Schaefer and Harrill, 1995) (figure 12). The magnitude of the modeled drawdown cone is greater than 100 feet (31 m) for parts of western Millard County near Garrison. Local ground-water level drawdown, near Baker, Nevada reaches 100 feet (31 m) just after the 10-year time step (figure 12). Sequential time steps show a broadening cone of drawdown, which extends up to 30 miles (42 km) east into Utah (Schaefer and Harrill, 1995) (figure 12). Discharge at important springs in Wah Wah Valley and Tule Valley may also decrease. The ground-water model of Schaefer and Harrill (1995) assumes a simplified regional aquifer system consisting of upper and lower layers, which correspond to the unconsolidated basin-fill and carbonate aquifers, respectively.

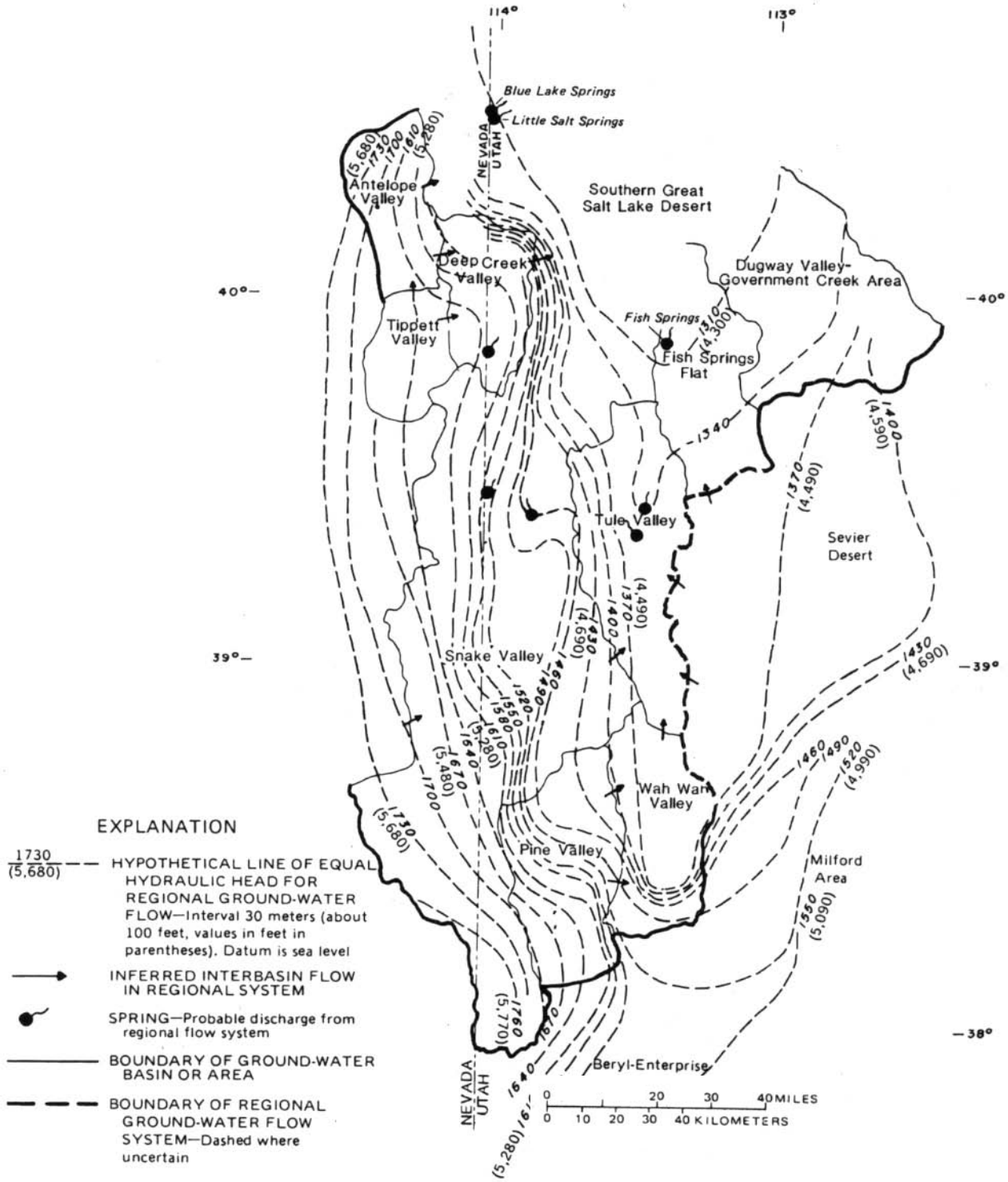

Figure 11. *Hypothetical potentiometric surface for west-central Utah and east-central Nevada including Snake Valley. Potentiometric contours are for the unconsolidated and carbonate bedrock aquifers combined. Based on data from shallow wells less than 500 feet deep and springs (from Gates, 1987).*

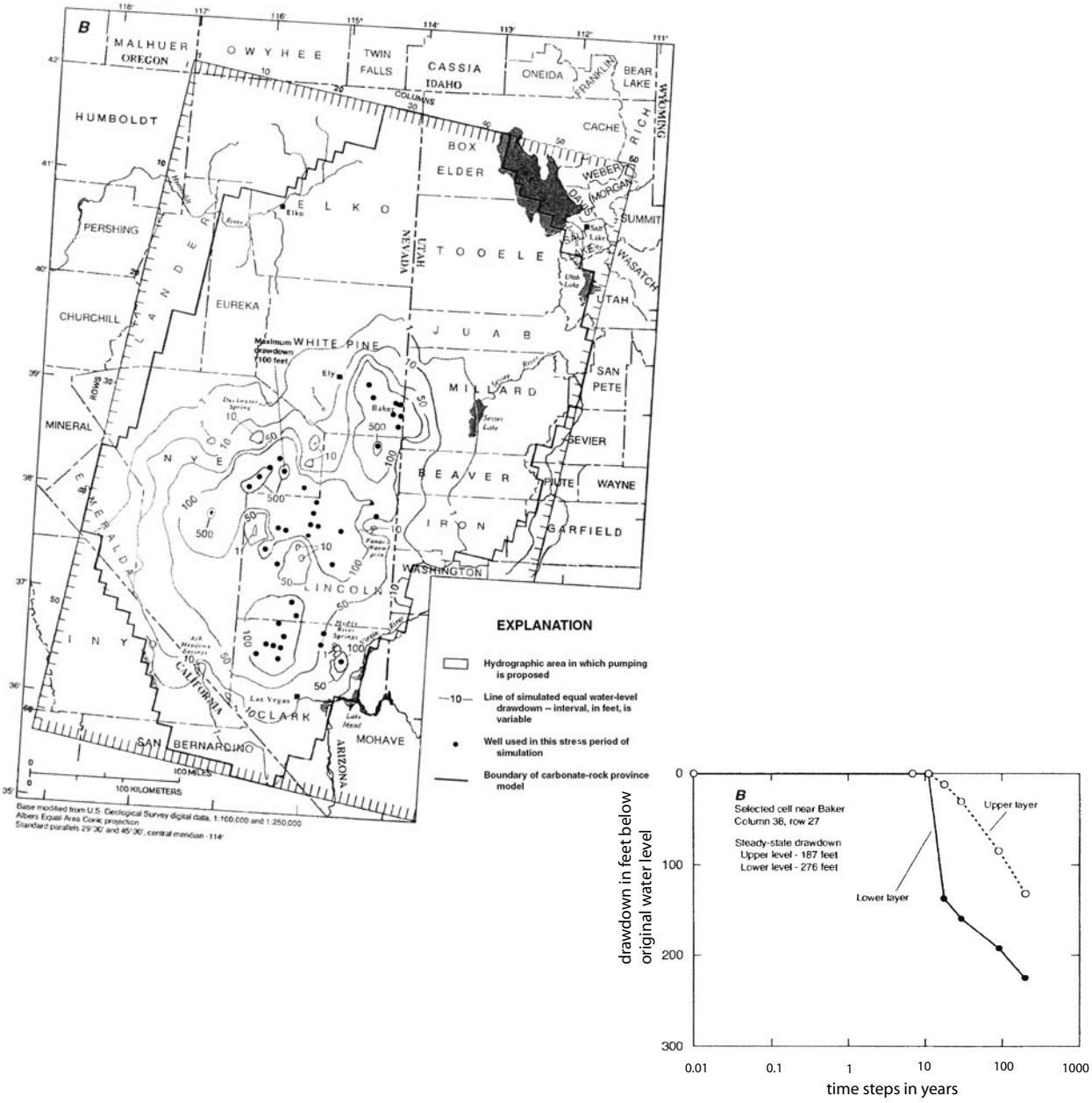

Figure 12. *Modeled drawdown based on the proposed withdrawals from the Southern Nevada Water Authority. Drawdown was modeled for upper and lower layers which correspond to the unconsolidated basin-fill and carbonate aquifers, respectively. Model was constructed for time steps until steady state was reached. Inset graph is modeled drawdown for upper and lower layers for a model cell near Baker, Nevada very near the Utah-Nevada state border in the Snake Valley (from Schaefer and Harrill, 1995).*

Modeled ground-water withdrawals are increased stepwise with time until maximum withdrawal of 25,000 acre-feet per year (31 hm^3/yr) is reached for the nine wells in eastern White Pine County (Schaefer and Harrill, 1995).

Structural Control on Ground-Water Movement

None of the previous regional-framework or aquifer modeling studies have taken into account the effect of the major and minor faults and fractures and large-scale structure on the movement and occurrence of ground water (Carlton, 1985; Schaeffer, 1995; Plume, 1996). Rocks and sedimentary deposits in the study area are structurally disrupted and have complex subsurface geometry and distribution as illustrated in figure 8, due to the tectonic events outlined in the Geologic Setting section. This structural complexity must influence ground-water flow paths from the recharge area in the high northern and southern Snake Range to the main basin-fill and carbonate aquifers, but the specific nature of this influence is poorly known.

The geologic structure is most complex along the eastern margins of the southern and northern parts of the Snake Range, where water likely first enters the principal aquifers. Here, rocks of the carbonate aquifer in the upper plate of the Snake Range decollement are cut by numerous high- and low-angle faults into a large number of fault-bounded blocks (figure 8). The Snake Range decollement consists of a zone, several hundred feet thick, of relatively gently dipping, anastomosing fault surfaces. These faults typically contain scaly, clay-rich fault gouge, cemented fault breccia, and veins (figure

13). In the northern Snake Range, the lower part of the decollement contains planar fabrics formed by plastic flow of the rocks during displacement, due to relatively high temperatures there (Gans and Miller, 1983). The fault-zone fabrics in the decollement zone likely impede ground-water flow transverse to its plane (Caine and others, 1996). Joints and faults adjacent to the decollement zone may, however, enhance ground-water flow parallel to the zone.

The vast majority of precipitation in the Snake Valley hydrologic basin falls in the high country of the Snake Range (Carlton, 1985; Schaeffer and Harrill, 1995), which is in the lower plate of the Snake Range decollement. Ground water must, therefore, either flow from the lower plate into the upper plate across the relatively impermeable decollement or bypass the decollement somehow in order to recharge the regional carbonate aquifer. Flow paths are likely complex and varied in this area.

Displacement on the decollement decreases eastward (Miller and others, 1983; McGrew, 1993), and the intensity of associated fault-zone fabrics must likewise decrease eastward. Ground water may, therefore, cross from the lower to upper plate below Snake Valley and the ranges bounding it on the east, where the Snake Range decollement dies out as a significant structural feature (figure 8). The basin-fill aquifer likely receives most of its recharge from infiltration of streams as they cross from the ranges into the valley. Some of this water may also enter rocks of the carbonate aquifer in the upper plate of the Snake Range decollement. This ground water may then follow a tortuous

Figure 13. *Fault-zone fabrics in the Snake Range decollement zone, northeastern part of the southern Snake Range. The fabrics shown are relatively impermeable to ground-water flow across their planes. These fabrics are pervasive in the decollement zone, so the decollement is itself likely a barrier to transverse ground-water flow.*
A. Clay-rich fault gouge and cemented breccia in a gently dipping fault within Cambrian-age limestone. B. Closer view of cemented fault breccia shown in A. C. Gently dipping fault filled with white calcite veins.

path from the highly disrupted part of the carbonate aquifer eastward into the less disrupted part. Ground water may also enter the carbonate aquifer from the overlying basin-fill aquifer below Snake Valley, although this process may not contribute a significant amount of recharge due to the low transmissivity of Tertiary deposits in the lower part of the basin-fill aquifer (Carlton, 1985; Schaefer and Harrill, 1995). The impermeable layer formed by the decollement may be breached in places by younger, steeply dipping faults that may form conduits for upward flow of ground water from the lower to upper structural plate. These scenarios are highly speculative and require further evaluation, including detailed analysis of the structure of the range margins and ground-water data designed to delineate possible recharge pathways.

In the more structurally intact parts of the carbonate aquifer, fractures, faults, and folds may exert significant control over ground-water recharge and movement patterns, both locally and regionally in the carbonate aquifer. Faults and joints provide pathways for relatively fast ground-water flow parallel to their planes, especially where they have been widened by dissolution by ground water. Joints parallel to and within anticlinal hinge zones typically form good conduits for regional-scale flow (Huntoon, 1993). Structural control on ground-water flow in the lower plate of the Snake Range decollement is poorly known and likely complex. Secondary structural control on the bedrock aquifer may be produced by large- and small-scale folding. Carlton (1985) assumed the Confusion Range synclinorium has decreased lateral transmissivity based on interbasin flow models.

DISCUSSION

Proposed ground-water withdrawal along the eastern slope of the southern Snake Range will affect existing and future ground-water use in western Utah. The proposed wells are located in the zone in which ground water moves from the recharge area in the high country of the Snake Range into the basin-fill and regional carbonate aquifers. The pathways for this movement are, as discussed above, likely complex and poorly known due to the structural complexity of the geology along the range margins. Whereas withdrawal by the wells clearly will capture ground water that would otherwise provide recharge to the primary aquifers (Schaefer and Harrill, 1995), the specific nature and magnitude of this impact cannot be confidently predicted from existing geologic and hydrologic data due to the complexity of these systems.

Withdrawal by the proposed wells could produce ground-water-level declines greater than 100 feet (31 m) and reduction or cessation of spring flow in Snake Valley (Schaefer and Harrill, 1995). The modeled regional cone of depression represents a near reversal of current potentiometric surfaces (Schaefer and Harrill, 1995). Pumping of the proposed wells may lead to local reversals of ground-water flow in the regional carbonate aquifer and, therefore, vastly reduced subsurface outflow along the eastern and northern part of the basin (Schaefer and Harrill, 1995). Reduced subsurface outflow in the carbonate aquifer would significantly impact other important regional springs in western

Utah which discharge from this aquifer. Evapotranspiration within the Snake Valley will also decrease (Schaefer and Harrill, 1995).

All existing models for ground-water flow in Snake Valley fail to account for the effect of regional-scale structures, including the Snake Range decollement, on the movement of ground water. Previous workers have assumed that the carbonate aquifer is laterally continuous; however, geologic maps and cross sections suggest it may be locally absent or greatly reduced in extent in the upper plate of the Snake Range decollement (Gans and Miller, 1983; McGrew, 1986, 1993) (figures 5 and 8). The hydrologic properties of the carbonate aquifer are controlled by fractures and dissolution voids which have not been quantified locally (Plume, 1996). Further work is recommended to better constrain the extent, densities, and orientations of the fractures in the carbonate aquifer. This information will help to evaluate the local and regional connectivity of the carbonate aquifer.

The general extent of the unconsolidated basin-fill aquifer is relatively well constrained over much of Snake Valley, but the local geometry and facies characteristics of this aquifer could be better constrained, especially near the proposed wells. We recommend detailed gravity studies in and near the proposed well field and new cross sections based on well logs in the unconsolidated basin fill.

Based on existing data for recharge and discharge in the Snake Valley hydrologic basin, the overall water balance will change. Recharge and evapotranspiration will be

reduced after pumping begins. More accurate constraints on the hydrologic balance within Snake Valley, especially for evapotranspiration, are required to determine the effect of the proposed pumping on ground water in Snake Valley. Flow and recharge pathways are poorly known for the basin-fill and carbonate bedrock aquifers and also warrant investigation.

SUMMARY AND CONCLUSIONS

Nine new water-supply wells have been proposed by the Southern Nevada Water Authority along the eastern flank of the southern Snake Range and the adjoining Snake Valley within 5 miles (8 km) of the Utah-Nevada border. Total proposed withdrawal from these wells is up to 25,000 acre-feet per year (31 hm^3/yr). The project is currently in the planning phase with construction set to begin in 2007. Existing numeric models suggest that this withdrawal will produce up to 100 feet (31 m) of drawdown of the ground-water table extending into western Millard county in Utah. This magnitude of drawdown would adversely affect both existing and future ground-water uses in Utah. Flow from springs and seeps and the quantity of ground water available for use by surface vegetation will likely decrease. The decline in ground-water levels could produce lasting and irreversible effects on both the agriculture and native vegetation of the Snake Valley. If the basin-fill aquifer is substantially dewatered, ground subsidence, cracking, and permanent degradation of its hydraulic properties may occur. The hydrologic balance of discharge and recharge in Snake Valley currently has a yearly outflow of

ground water (Carlton, 1985). Proposed additional withdrawals could change this balance to a relatively small outflow or a net deficit.

Quantification of the specific effects of withdrawal by the SNWA wells cannot presently be accomplished because detailed information about the aquifers and basin-scale hydrogeology of the area is lacking. Aspects of the hydrogeologic system that are poorly known include (1) the structural geometries of basin-fill and carbonate aquifers beneath the Snake Valley, (2) the fracture characteristics of the upper-plate rocks of the Snake Range decollement, and (3) the thickness and lithologies of the basin-fill aquifer near the proposed well field. Additional work, including detailed map compilation, construction of additional cross sections, detailed gravity profiles, and detailed quantification of hydrologic balance, is recommended to assess the impact of the proposed ground-water withdrawals, and to evaluate the regional structural and hydrologic connectivity of the carbonate aquifer.

We conclude the following:

- Wells proposed by the Southern Nevada Water Authority will likely adversely affect ground-water conditions in nearby Utah.
- Total drawdown of ground water near Garrison in western Millard County could be greater than 100 feet (31 m).
- The proposed pumping may change or reverse ground-water flow patterns for much of the east-central Great Basin in Utah and Nevada. The effects may

eventually propagate eastward, and impact discharge at important regional springs in Wah Wah Valley and Tule Valley.

- Discharge of agriculturally and ecologically important springs will decrease.
- Further work is warranted to quantify both the hydrogeologic framework and hydrologic balance of the Snake Valley to accurately predict the effects of the proposed wells.

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