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Southern Nevada Water Authority

Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems

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Geology of White Pine Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems

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METHODOLOGY

The objectives of the geologic analysis and the methods applied in developing the work products accompanying this report are described in the following sections. Work products developed as part of this analysis include 1:250,000-scale digital geologic maps (Plates 1 and 2), an explanation of map units (Plate 3), and cross sections (Plates 4 and 5). Hydrogeologic units (HGUs) were derived by combining geologic stratigraphic units based on their hydraulic properties and spatial distribution, then the digital geologic maps were simplified accordingly to construct hydrogeologic maps (Plates 6 and 7) and cross sections (Plates 8 and 9). The geologic map area (red line, Figure 2-1) covers most of White Pine County and Lincoln County, Nevada, as well as large parts of adjacent counties in Nevada and Utah.

3.1 OBJECTIVES

The primary objective of this geological analysis is to develop a digital geologic and hydrogeologic framework in support of a groundwater model of a portion of the area covered by this geologic analysis. The geologic information compiled provides data on reasonable model boundaries, reasonable internal boundaries, extents of HGUs, and potential groundwater flow paths and flow barriers. Hydrologic interpretations that depend on these geologic data are given in accompanying hydrologic reports. The geologic framework also provides aquifer and aquitard thickness for the modeled area. Geologic evaluations outside of the model area (black line, Figure 2-1) provide a basis for interpreting groundwater interactions across model boundaries, including potential groundwater interactions between groundwater flow systems internal to the model and groundwater flow systems outside of the modeled area. This geologic analysis was manifested through the creation of geologic and hydrogeologic maps and cross sections of the geologic study area.

The objective of the geologic maps and geologic cross sections is to provide, in digital form, the geologic framework for the eastern carbonate aquifer systems of Nevada and western Utah as an aid in developing numerical models of groundwater flow systems. Framework data that were acquired include the distribution, geometry, thickness, composition, and physical properties of geologic units used to define HGUs and potential aquifers and aquitards (confining units). Such information will assist in ascertaining the rock units that are most likely to provide pathways for groundwater flow and which rock units are most likely to retard or divert flow.

An important aspect of the geologic maps is the portrayal of the distribution and attitude of faults, especially those formed during the youngest (basin-range) episode of deformation. Faults may serve as barriers and/or conduits to groundwater flow. In the geologic study area, most faults trend northerly, parallel to the general southward topographic gradient of the WRFS. Thus for the WRFS, basin-range faults serve as significant conduits to groundwater flow in this direction. In other flow systems in the geologic study area, basin-range faults may either direct groundwater flow through a system of barriers and fault conduits and/or impede groundwater flow toward otherwise down-gradient groundwater basins. Part of the objective of this report is to evaluate the potential for these faults to influence groundwater flow, especially how they may act as either barriers or conduits to groundwater flow. Another objective of this report is to evaluate which faults are most likely to provide conduits and/or barriers to groundwater flow so that they can be properly incorporated into a groundwater model of the region.

3.2 Technical Approach

The approach used in this investigation was to combine published and unpublished geologic information from dozens of references collected, compiled, and reviewed by authors familiar with the geology of the region. In addition, an evaluation was conducted of borehole information from oil and gas test wells, monitor wells, such as those drilled during the U.S. Air Force's MX missile-siting program of the early 1980s, and borehole information from monitor holes drilled by SNWA for the Project. Other sources of information were geophysical studies of the region published by USGS and other entities, particularly data from gravity surveys performed by USGS in 2003 to 2005 (Mankinen et al., 2006; McPhee et al., 2005, 2007; Scheirer, 2005). These latter studies have given insight as to the thickness of basin fill and depth to underlying rocks within several basins in Lincoln and White Pine counties, Nevada. A final source of evidence is geologic field work performed over the area by the authors of this report.

Based on the evaluation of the compiled data and the expertise of the geologists involved in this investigation, geologic maps were constructed for the area of the groundwater model (Plates 1 and 2). Geologic cross sections were constructed (Plates 4 and 5) and tied into the geologic maps. Because of the complexity of the geology of eastern Nevada, these maps and cross sections represent a work in progress, inasmuch as new data on crosscutting faults, bedding surfaces, intrusions, volcanic sequences, and other geologic units and geologic relationships must be continuously evaluated as new information becomes available.

The geologic units were combined into HGUs of similar hydraulic properties and spatial extent. These broad units make up the aquifers, aquitards, and units of intermediate permeability of the area described by this report. These HGUs are displayed in Plates 6 and 7. Cross sections of these units were compiled using the geologic cross sections of Plates 4 and 5 as a basis; these hydrogeologic cross sections are displayed in Plates 8 and 9. Based on the hydrogeologic maps and cross sections, the extents of aquifers, aquitards, and intermediate-permeability rocks could be evaluated, along with potential fault barriers and fault conduits to groundwater flow. The hydrogeologic maps, cross sections, and hydrogeologic interpretations were used to compile the geologic framework for the groundwater model. The hydrogeologic maps and cross sections were also interpreted to evaluate probable groundwater flow paths and flow barriers.

3.3 Geologic Data Compilation

The compilation of geologic data was derived from a number of sources, including literature review, review of State Engineer's records, oil and gas test well and other borehole data, evaluation of drilling data and information from SNWA monitor wells, evaluation of studies performed by USGS, and consultation with geologic experts in the area. This literature was reviewed and compared with other literature and other sources of geologic information prior to incorporation into the geologic maps and cross sections.

Geologic data from wells were compiled from reports to the State Engineer, when available, and data on oil and gas test wells drilled within the geologic study area, and from monitor wells drilled by

SNWA in 2003 and 2005 in upper Moapa, Coyote Spring, Cave, Dry Lake, and Delamar valleys. Not every well had geologic information, but most of them did have useful information to assist in compiling the geologic and hydrogeologic cross sections.

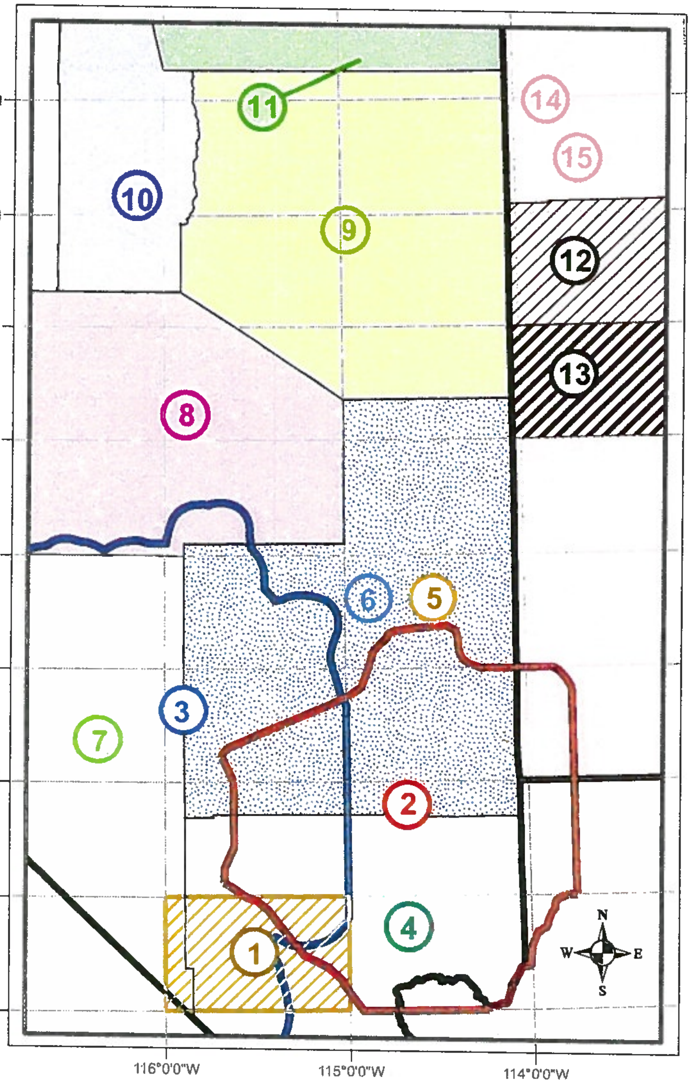
3.4 PREPARATION OF GEOLOGIC MAPS AND SECTIONS

A large portion of the map area is underlain by the WRFS (Figure 2-1). The geology of the southern part of the WRFS and adjacent systems (Figure 3-1) has been discussed by Page et al. (2005a) and in this report is digitally mapped at 1:250,000 scale (Plate 2). The digital geologic and tectonic maps of the DVFS (Figure 3-1), to the west of the WRFS, were also published at a 1:250,000 scale (Workman et al., 2002 and 2003). The DVFS includes much of the southwestern portions of Plates 1 and 2. The geologic maps of both the DVFS and southern WRFS included significant new and unpublished geologic mapping.

For the maps (Plates 1 and 2), much of the surface geology was based on county 1:250,000-scale geologic maps and the Utah 1:500,000-scale state geologic map (Hintze, 1980; Hintze et al., 2000). From west to east and north to south, the Nevada counties covered by these maps are southern Elko County (Roberts et al., 1967), eastern Nye County (Cornwall, 1972; Kleinhampl and Ziony, 1985), White Pine County (Hose and Blake, 1976), Lincoln County (Tschanz and Pampeyan, 1970), and Clark County (Longwell et al., 1965). The Utah counties covered by these maps are southwestern Tooele County, western Juab County, western Millard County (Hintze and Davis, 2002a and b, and 2003), and western Beaver County (Hintze, 1980 and 1988; Hintze and Davis, 2002a).

Nearly all county maps and reports were published decades ago. Many revisions and reinterpretations have been made to the geology of portions of those maps since that time. A significant part of the entire map area was compiled by Terrascan Group, Inc. (1987), but it used the same county maps used in the present map. The entire map area is also covered by state geologic maps at 1:500,000-scale (Stewart and Carlson, 1978; Hintze, 1980; Hintze et al., 2000), but some of the geology on these maps has also been subsequently revised and reinterpreted. These revisions and reinterpretations of the geology are from many more recent, commonly more detailed, published Nevada and Utah geologic maps and reports, and this new information has been incorporated into the maps of Plates 1 and 2 and in the discussions in this report. Not all of these maps and reports are cited in the text because of their large number, although all of them are listed in Section 7.0 of this report. Small-scale geologic maps used for the creation of Plates 1 and 2 are indexed in Figure 3-1. In addition, the present maps (Plates 1 and 2) include some new, unpublished field observations, though no new mapping was conducted specifically for this report and associated maps.

The geologic maps of Plates 1 and 2 include many changes of specific geologic units throughout the geologic study area. In many places, facies changes resulted in major changes in the lithology of a specific unit, and in other places, different formation names were used essentially for the same unit. In some instances, a specific unit thinned in certain areas and was included as a member of another unit or as an inconsequential bed within another unit. An example is the Mississippian Chainman Shale, which is a major shale confining unit in the north, as in White Pine County (Hose and Blake, 1976), but a generally inconsequential shale horizon included within other units in the southern map area, as in Clark County (Longwell et al., 1965). During compilation of the geologic map, separate stratigraphic columns were commonly used for different counties, along with a stratigraphic column for units within western Utah. Correlations between specific geologic units are commonly given in



Source Maps:

1. Page, W.R., Lundstrom, S.C., Harris, A.G., Langenheim, V.E., Workman, J.B., Mahan, S.A., Paces, J.B., Dixon, G.L., Rowley, P.D., Burchfiel, B.C., Bell, J.W., and Smith, E.I., 2005b, Geologic and geophysical maps of the Las Vegas 30' × 60' quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California: U.S. Geological Survey Scientific Investigations Map 2814, 55 p., scale 1:100,000.
2. Page, W.R., Dixon, G.L., Rowley, P.D., and Brickey, D.W., 2005, Geologic map of parts of the Colorado, White River, and Death Valley ground-water flow systems: Nevada Bureau of Mines & Geology Map 150, scale 1:250,000. Digital GIS data provided.
3. Workman, J.B., Menges, C.M., Page, W.R., Taylor, E.M., Ekren, E.B., Rowley, P.D., Dixon, G.L., Thompson, R.A., and Wright, L.A., 2003, Geologic map of the Death Valley ground water model area, Nevada and California: U.S. Geological Survey Miscellaneous Field Studies MF-2381-A, scale 1:250,000. Digital GIS data provided.
4. Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines and Geology Bulletin 62, 218 p., scale 1:250,000.
5. Tschanz, C.M., and Pampeyan, E.H., 1970, Geology and Mineral deposits of Lincoln County, Nevada: Nevada Bureau of Mines and Geology Bulletin 73, 188 p.
6. Ekren, E.B., Orkild, P.P., Sargent, K.A., and Dixon, G.L., 1977, Geologic map of Tertiary rocks, Lincoln County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series Map I-1041, scale 1:250,000.
7. Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 49 p.
8. Kleinhampl, F.J., and Ziony, J.I., 1985, Geology of northern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 99A, 172 p.
9. Hose, R.K., and Blake, M.C., Jr., 1976, Geology and mineral resources of White Pine County, Nevada, Part 1, Geology: Nevada Bureau of Mines and Geology Bulletin 85, p. 1-35.
10. Roberts, R.J., Montgomery, K.M., and Lehner, R.E., 1967, Geology and mineral resources of Eureka County, Nevada: Nevada Bureau of Mines and Geology Bulletin 64, 152 p., scale 1:250,000.
11. Coats, R.R., 1987, Geology of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 101, 112 p., scale 1:250,000.
12. Hintze, L.F., and Davis, F.D., 2002, Geologic map of the Tule Valley 30' × 60' quadrangle and parts of the Ely, Fish Springs, and Kern Mountains 30' × 60' quadrangles, northwest Millard County, Utah: Utah Geological Survey Map 186, scale 1:100,000.
13. Hintze, L.F., and Davis, F.D., 2002, Geologic map of the Wah Wah Mountains North 30' × 60' quadrangle and part of the Garrison 30' × 60' quadrangle, southwest Millard County and part of Beaver County, Utah: Utah Geological Survey Map 182, scale 1:100,000.
14. Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital Geologic Map of Utah, Utah Geological Survey Map 179DM, scale 1:500,000.
15. Hintze, L.F., 1980, Geologic map of Utah: Utah Geological and Mineralogical Survey, scale 1:500,000.

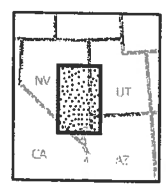


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FIGURE 3-1
INDEX MAP OF PREVIOUS SMALL-SCALE MAPPING USED IN THE GEOLOGIC EVALUATIONS AND TO CREATE THE GEOLOGIC AND HYDROGEOLOGIC MAPS OF Plates 1, 2, 6, AND 7

the literature and these correlations were generally used to associate units of the same or similar age in different parts of the map area. An example is the correlation between the Devonian Guilmette Formation and the Devils Gate Limestones (Hose and Blake, 1976).

During map compilation, a hard copy of the available digital file—generally the county map—was modified by hand, then digitized. Before this compilation, we accumulated, assimilated, and evaluated all available new geologic data about the area. The new data included reports, different concepts, detailed or regional maps, geophysics, and well logs, etc. Conflicts necessarily resulted over interpretations and placement of contacts and faults. Decisions on the eventual linework were based on what appeared to be scientifically the most reasonable and depended primarily on the judgement and experience of the authors.

The maps (Plates 1 and 2) include 25 new geologic cross sections (Plates 4 and 5), most of which generally trend east-west. These cross sections are roughly evenly spaced across the map area at the same scale as the map and at locations chosen to best show specific geologic and structural relationships important to the interpretation of the exposed geology. In addition, hydrogeologic maps (Plates 6 and 7) and hydrogeologic cross sections (Plates 8 and 9) were constructed, where geologic units with similar hydrologic properties such as porosity and permeability were combined into HGUs, distinct from the geologic units that comprise them. Few of the reports and maps used to compile the geologic maps had associated geologic cross sections, so the cross sections for this report are based on interpretations of the county geologic maps along with all other available maps and reports of the map areas. A geologic map by Terrascan Group, Inc. (1987) presented associated cross sections that were referred to in making the cross sections for the maps in this report. In addition, the geologic map of Elko County (Coats, 1987) was used to help interpret Cross Section Y—Y' (Plate 4), along the northern edge of the map area. The cross sections of Page et al. (2006) aided us in making our cross sections in the southern part of the geologic study area. The cross section of Smith et al. (1991) was useful in constructing Cross Section X—X' (Plate 4) near the northern margin of the geologic study area.

Unlike compilation of the geologic map, most cross sections are newly authored for this report, so there was no need to resolve conflicts arising from other work in the area. The first step in the construction of cross sections is to satisfy the three-dimensional geometry of the rocks at depth based on the types, attitudes, and thicknesses of rocks and structures on the surface. The most difficult part of making cross sections is dealing with the near absence of subsurface information. Therefore, geophysics and well logs near the line of section are precious. Fortunately, aeromagnetic and gravity geophysical data were available for much of the area. Unfortunately, well logs and audiomagnetotelluric (AMT) and seismic profiles are rare. Where local information on the third dimension is not available, analogies are made with areas in other parts of the Great Basin where seismic and drill-log data provide ideas about how the rocks and structures look at depth. And here, as in compilation of geologic maps, the judgment and experience of the authors are of paramount importance.

All cross sections incorporated lithologic information from available oil- and water-well logs. Oil-well logs in Nevada are available online from the Nevada Bureau of Mines and Geology or through their publications. Garside et al. (1988) compiled geologic data from oil and gas wells drilled in Nevada from 1907 through 1988. This compilation was supplemented by Hess (2001). This information was supplemented again in 2004 (Hess, 2004). Oil-well logs in Utah were obtained from the Utah Division of Oil, Gas, and Mining website (UDOGM, 2006). Water-well logs in Utah were obtained from the Utah Division of Water Rights website (UDWR, 2006).

Geophysical studies, notably gravity maps (Saltus, 1988a and b; Cook et al., 1989; Ponce, 1992; Saltus and Jachens, 1995; Ponce et al., 1996), aeromagnetic maps (Hildenbrand and Kucks, 1988a and b), and seismic sections (Allmendinger et al., 1983; Hauser et al., 1987), were used to aid in the interpretation of geologic cross sections and structure sections. Gravity maps and electromagnetic profiles were completed by USGS as part of USGS/SNWA joint funding agreements (Mankinen et al., 2006; McPhee et al., 2005 and 2007; Scheirer, 2005). The gravity data were converted to depth-to-basement data and were used to aid in constructing the cross sections.

Appendix A

General Photos of the Study Area

View northwest of Jackmans Narrows cut into folded and faulted Permian carbonate rocks. Towns of Glendale and Moapa in the background.

View north in Jackmans Narrows showing highly fractured and contorted Permian limestone.

View overlooking Muddy River Springs Complex.

View north of east dipping volcanic rocks underlain by Paleozoic rocks in northern Coyote Springs Valley. U.S. Highway 93 in center of photograph.

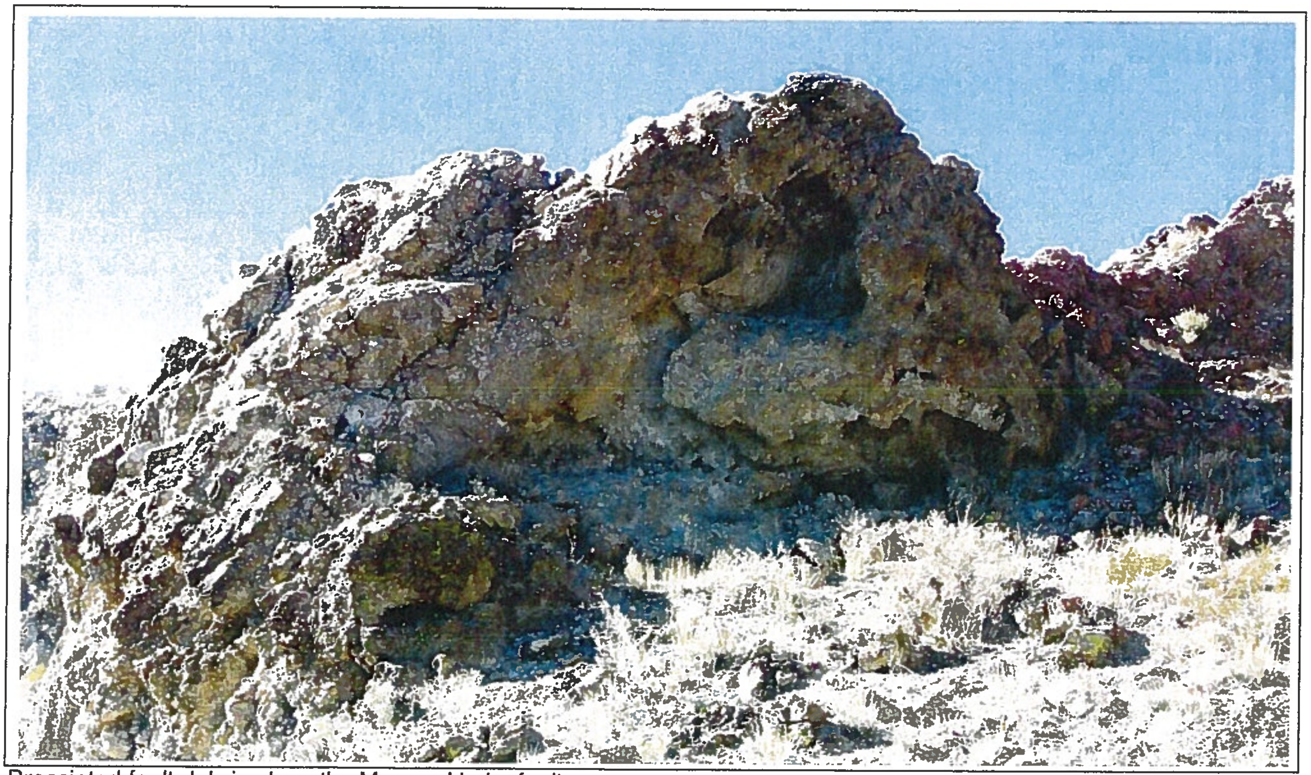
View north into southern Delamar Valley. Delamar Lake in left center of photograph. Maynard Lake strand of the Pahranagat shear zone forms the scarp that is in shadows in the foreground, whereas the Delamar Lake strand passes beneath Delamar Lake and north of the hills on the left side of the photograph.

View west from the Meadow Valley Mountains across the oblique-slip fault scarp of the Kane Springs fault zone at the Kane Springs Wash caldera complex in the Delamar Mountains.

View along the northeast-southwest trace of the Maynard Lake Fault zone. Volcanic rocks highly fractured and faulted along fault zone. Maynard Lake (dry) in bottom of photograph.

View north of Rainbow Canyon, where perennial Meadow Valley Wash here cuts through the Caliente caldera complex.

View north of Maynard Lake left-lateral fault segment of the Pahranagat Shear Zone. Note slickensides in center of photograph and brecciated volcanic rocks adjacent to fault.



Brecciated fault debris along the Maynard Lake fault segment.

View west-northwest of Delamar mining district and northern Delamar Valley. Although Nevada's largest gold district from 1895 to 1910, now only a few walls of buildings remain along the main street.

View north of the Dry Lake Quaternary fault scarp on eastern side of Dry Lake Valley.

View east at drill hole 180W902M in Cave Valley near Sidehill Pass. Devonian and Silurian sedimentary rocks in background.

View to the southwest along the trace of the Shingle Pass fault zone in the southern Egan Range.

View to the south looking at springs in White River Valley.