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CHALLENGES OF BASIN-AND-RANGE HYDROGEOLOGY—EXAMPLES FROM HIDALGO COUNTY, NEW MEXICO

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Abstract—Hydrogeologic studies in basin-and-range country face challenges beyond those normally met in other regions. Challenges to characterizing ground-water occurrence include sparsity of wells in the ranges and stratigraphic variability of the basin-fill aquifers over short distances. Challenges to determining ground-water movement include the sparsity of water-level data in the ranges, the difficulty in analyzing the water balance owing to infrequent but intense runoff events, and the uncertain role of playas in discharge. Challenges to describing ground-water quality include the sparsity of data for the ranges and the impact of mixing with geothermal waters. Challenges to interpreting geologic controls of hydrologic phenomena include the sparsity of wells in the ranges and assessing the role of any Quaternary-lake history in shaping the modern hydrogeologic system. Some of these challenges can be overcome by (1) utilizing alternative data sources, such as mining and petroleum exploration wells in the ranges, (2) collecting long-term data for various water-balance parameters, and (3) modeling the hydrogeologic and hydrochemical system(s).

INTRODUCTION

Hydrogeologic studies seek to characterize the occurrence, movement, and quality of ground water in the subject area, as well as their relationship to the geologic setting (Stone, 1999). Such studies typically face many common challenges, regardless of physiographic province (Table 1). Various hydrogeologic projects in Hidalgo County, especially in the Animas Valley and Pyramid Mountains (Fleischhauer and Stone, 1982; O'Brien and Stone, 1981, 1982a, b, 1983, 1984; Stone and O'Brien, 1990) met with some challenges beyond those normally faced. The purpose of this paper is to briefly summarize the main results of those studies, noting the challenges presented by the Basin-and-Range setting.

Numerous studies on the geology of southwestern New Mexico have been done (Stone et al., 1979). A comprehensive listing of previous geologic and hydrologic works on the basins and ranges in Hidalgo County was given by Stone (1990) and is not repeated here. This paper draws heavily on results of the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) projects cited above, especially the synthesis by Stone and O'Brien (1990).

GENERAL SETTING

Hidalgo County lies wholly within the Mexican Highlands section of the Basin-and-Range physiographic province. All or parts of eight rugged mountain ranges and all or parts of six nearly flat intermontane basins with playas characterize the region (Fig. 1). Maximum relief for the county is 4831 ft. The continental divide splits the county unevenly with the western 64% of the area lying in the Colorado River drainage basin and the eastern 36% of the area lying in the Rio Grande drainage area. However, drainage is largely ephemeral into closed basins and runoff does not reach these master streams. Average annual precipitation varies with elevation and ranges from approximately 7–23 in./yr (V. L. Gabin and L. E. Lesperance, unpubl. report for W. K. Summers and Associates, Socorro, New Mexico, 1977). Data for the village of Animas indicate that the average annual pan-evaporation rate in the Animas Valley is ten times the mean annual precipitation rate.

The age of rocks and unconsolidated sediments at or near the surface in Hidalgo County ranges from Precambrian to Quaternary. However, rocks of Silurian, Triassic, and Eocene age are missing, due either to nondeposition or sufficient erosion prior to burial to remove all trace of a rock record for these time intervals.

TABLE 1. General challenges to hydrogeologic studies, regardless of physiographic province.

TOPIC	General challenge
GROUND-WATER OCCURRENCE	Surface geology unavailable or incompatible between areas.
GROUND-WATER MOVEMENT	Data for various parameters, needed for modeling (recharge, evapotranspiration, runoff, etc.), are not available. Water level not measured during drilling for documenting vertical gradient. Water-level observations for different wells were made in different years. Many wells have long screened intervals for water-supply purposes and thus give composite values for water level.
GROUND-WATER QUALITY	Waters from different zones co-mingle and water-quality data are composite results. Data for different wells were obtained in different years.
MISCELLANEOUS	Existing hydrogeologic data contain mistakes: erroneous well locations, incorrect aquifer identification, inaccurate water-level measurements. Well-construction information may be incomplete or lacking altogether.

GROUND-WATER OCCURRENCE

Ground-water occurrence refers to the geographic location of productive areas, the geologic location of saturated zones, and hydraulic conditions under which the water exists. Geographic location is described in terms of position relative to familiar landmarks. The upper (southern) Animas Valley is the most productive, supporting extensive irrigated agriculture for many years. Geologic location is usually described in terms of hydrostratigraphic units. Hydraulic conditions include perched or regional and confined or unconfined.

Hydrostratigraphic units

Although ground water occurs in various geologic units in Hidalgo County (Table 2), only two materials are classified as aquifers, based on available information: the bolson fill of the major basins and the alluvium of the Gila River valley. The bolson fill is the more productive of the two aquifers. It includes alluvial, fluvial, and lacustrine deposits. More specifically, it consists of interbedded gravel, sand, silt, and clay. Geologic and geophysical data suggest the total thickness of the fill may be as much as 6000 ft. Thickness of water-yielding sediments may be as much as 2600 ft. The Gila River valley aquifer is restricted to the channel and floodplain of the Gila River in the northern or panhandle region of the county. It consists of fluvial gravel, sand, and silt. Thickness of the Gila River valley aquifer is poorly known.

Hydraulic conditions

Water in both the bolson fill and Gila River valley alluvium aquifers is part of the regional zone of saturation. Furthermore, the water is unconfined. That is, there is no overlying impermeable or confining bed and the water is in direct contact vertically with the atmosphere. Thus, the water level in wells remains at essentially the same depth at which it is encountered during drilling. As these aquifers lie at the surface, the

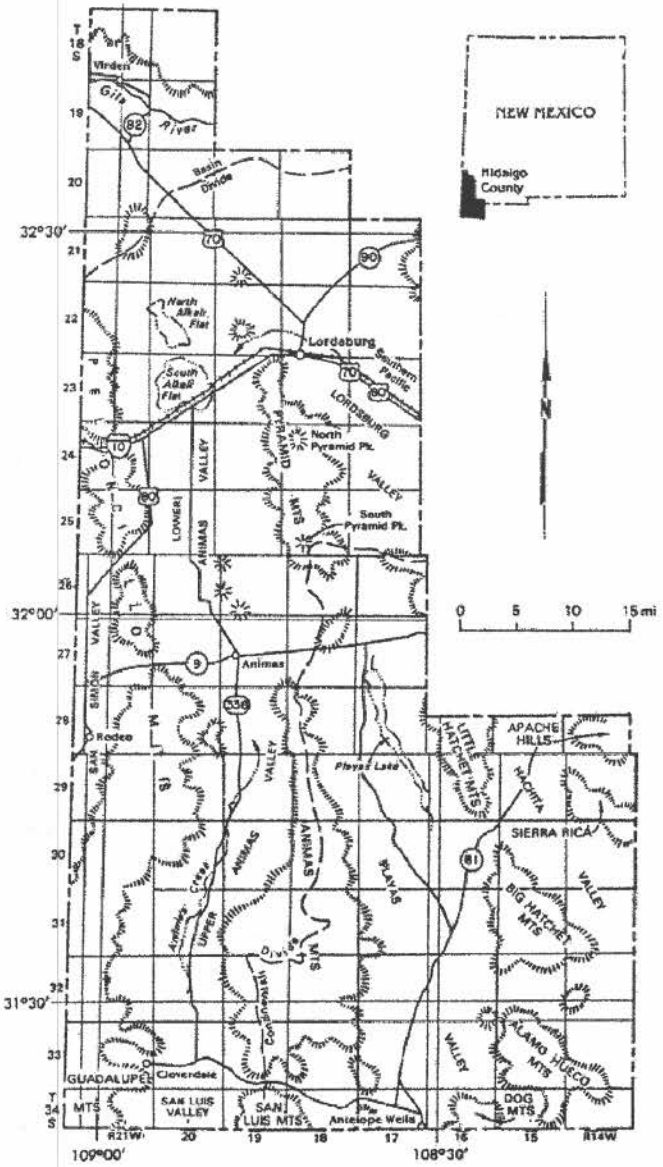


FIGURE 1. Location of places and features of interest in Hidalgo County, New Mexico (Stone and O'Brien, 1990, fig. 1).

water table is generally within easy reach of domestic, irrigation, and stock wells in the area.

Challenges to characterizing ground-water occurrence

The main challenge to determining ground-water occurrence is the uneven distribution of wells. That is, most wells are located in the basins. This is logical in view of the location of the bolson-fill aquifer and the agricultural land use in the basins. However, it makes characterizing the occurrence of ground water in the ranges and evaluating its possible connection with that in the basins difficult, if not impossible.

Another challenge associated with determining ground-water occurrence in this Basin-and-Range setting is the difficulty in defining the extent of productive intervals within the bolson-fill aquifer. As might be expected of such deposits, the stratigraphic record varies both horizontally and vertically, as a result of rapidly changing energies and constantly shifting depositional environments. In one of the earliest studies in the county, Schwennesen (1918) noted the difficulty in correlating units between even closely spaced basin wells. O'Brien and Stone (1982b) found that even clay horizons, which presumably represent stable periods of lacustrine deposition over large areas, could not be correlated across the Animas Valley.

TABLE 2. Hydrostratigraphic units in Hidalgo County (modified from Stone and O'Brien, 1990, fig. 8).

Age	Lithostratigraphic unit	Description (thickness in ft)	Hydrogeologic unit
Quaternary	bolson fill; (alluvial, eolian, lacustrine deposits)	gravel, sand, silt, clay (to 3000?)	bolson aquifer
Tertiary/ Quaternary	fan/pediment deposits	gravel, sand (to 3000?)	
	Gila Conglomerate	Unconsolidated/ consolidated gravel, sand, silt, clay	Gila aquifer
	flows, plugs, cinders	basalt (<1000?)	generally above water table
Cretaceous/ Tertiary	younger bedrock	igneous and sedimentary rocks (to 12,000?)	unknown
Precambrian through Permian	older bedrock	igneous, metamorphic, and sedimentary rocks (Paleozoic to 12,000?)	unknown except for petroleum tests

GROUND-WATER MOVEMENT

Ground-water movement is an important part of the hydrologic cycle. More specifically, it consists of three components: recharge, flow, and discharge.

Recharge

Recharge is the addition of water to a saturated zone. Most commonly the water is downward percolating soil moisture that has escaped evapotranspiration. Recharge may be thought of in terms of an area, a process and a rate. Although ground-water recharge was not measured in Hidalgo County, three types of recharge are assumed to be at work: mountainfront recharge, channel recharge, and regional recharge. Mountainfront recharge is that occurring at the break in slope between the ranges and the basins, marking the change from bedrock to unconsolidated bolson fill. Channel recharge is that associated with transmission loss along arroyos during ephemeral flow events. Regional recharge is that occurring in areas away from the other two settings as a direct result of precipitation. Attempts to address the percentage of precipitation that becomes recharge suggest that it is lower in basins than in ranges: 2% in the Animas Valley (Hawkins, 1981) as compared to 8% in the Pyramid Mountains and 16% in the Peloncillo Mountains (O'Brien and Stone, 1983).

Flow

Ground-water flow has both a direction and a rate. Flow direction is determined from water-level maps, whereas rate is determined from field tests or laboratory measurements.

As a general rule, ground-water-flow direction is from the ranges toward the basins. In some cases, flow continues, parallel to the basin axis, toward discharge areas. For example, once ground water reaches the Animas Valley, it flows northward toward the Gila River.

Flow rate depends in large part on the hydraulic properties of the aquifer and they include porosity (percent void space), hydraulic conductivity (ability of a saturated medium to transmit ground water) and transmissivity (hydraulic conductivity of the aquifer times its thickness). Porosity is determined by analyses of core samples in the laboratory, whereas transmissivity is determined from aquifer tests conducted in the field. Hydraulic conductivity may be determined by either lab analysis of core or field aquifer tests. Aquifer tests by various workers in the Animas Valley (Reeder, 1957; Summers, 1967; Aras, 1979) have yielded transmissivity values for the bolson fill ranging from 2940 to 32,890 ft^2/d. Reeder (1957) reported an average transmissivity value for

such deposits in the Animas Valley of 6685 ft^2/d.

In modeling the Animas Valley, O'Brien and Stone (1984) assigned aquifer properties based on all available geologic and geophysical data. More specifically, they adjusted transmissivity values in view of apparent gravity data/aquifer thickness relationships. That is, gravity highs were interpreted as bedrock highs, and thus areas of thinner bolson fill, so were assigned lower transmissivity values. The reverse logic was applied to assigning values to areas of low gravity.

Discharge

Discharge is the loss of ground water from a zone of saturation, usually to the ground surface. Like recharge, discharge is characterized by an area, a process and a rate. Although discharge was not measured, a small amount of the ground water in the ranges presumably surfaces at springs, while most of the ground water flows to the basins where it remains or flows toward perennial streams where it is discharged. For example, ground water in Animas Valley discharges to the Gila River. Area wells are sites of artificial discharge.

Challenges to characterizing ground water movement

Recharge is essentially that water moving downward in the subsurface that has escaped runoff and evapotranspiration. Various water-balance parameters can be used to determine recharge. The main challenge associated with characterizing recharge in Basin-and-Range settings is that precipitation and runoff events are infrequent, but can be intense. For example, instruments installed to measure runoff often collect nothing for months, but then are destroyed by the first storm that comes along. Even if a means can be found to protect runoff equipment from damage, it can take a long time to collect enough other information (precipitation, soil moisture, and evapotranspiration) to characterize recharge on an annual basis. Indirect means of evaluating recharge, such as the chloride-mass-balance method, require coring the upper 100 ft (or less) of the unsaturated zone with hollowstem auger equipment (Stone, 1990). Funding is not available for this in most studies.

The challenge to characterizing ground-water-flow direction is the lack of sufficient water-level data in the ranges. That is, it is difficult to prepare water-table maps from which flow direction can be determined. Springs may fill in some of the gaps; however, not all represent the regional water table. This lack of wells also makes it difficult to determine flow between basins.

A challenge to characterizing flow rate is the fact that the rocks in the ranges are dominated by fracture permeability, whereas the unconsolidated sediments in the basins are dominated by intergranular permeability. The resulting ground-water-flow velocities can be quite different.

Discharge to perennial streams is commonly determined by analyzing data collected by gages placed upstream and downstream of the reach where ground-water discharge is suspected to occur. Discharge to playas (the flat, ephemerally flooded areas in the lowest portions of desert basins) is more of a challenge. There are two main types of playas: those resulting merely from the surface ponding of runoff and those resulting from upwelling ground water and thus discharge areas. Hand augering is often sufficient to distinguish the two types. If the playa is of the discharge type, material below the ground surface will be saturated or nearly so; if the playa is the result of runoff, material below the ground surface will be dry, even if there is standing water in the playa. Animas valley playas are of the runoff type.

GROUND-WATER QUALITY

Water chemistry becomes water quality when its usefulness for various purposes is considered. Although one may investigate the concentration of a wide range of constituents in ground-water samples, their dissolved-solids content is a good indication of water quality. In geothermal areas, temperature is an additional quality parameter.

Dissolved solids content

One measure of the quality of a ground water is its specific conductance (SC), an electrical measure of its dissolved-solids or salt content. As dissolved-solids load generally increases along flow paths, the best quality ground water (low SC values) is generally associated with recharge areas and the worst quality ground water (high SC values) is generally associated with discharge areas. For example, ground water in the upper (southern) Animas Valley has an SC value of 300–500 umhos whereas that downgradient (north of there) has an SC value of 1800–3000 umhos.

Variation in water chemistry along flow path may also be shown by variations in its classification, based on major-ion composition. For example, in the upper (southern) Animas Valley, ground water is mainly a calcium-bicarbonate type, that in the middle of the valley is a sodium/bicarbonate-sulfate type and that in the lower (northern) part of the valley is a sodium/sulfate-chloride type.

Geothermal activity

Considerable previous work has been done on the geothermal phenomena of the Animas Valley. Interested readers are directed to Stone (1990) for references to those works. Only a brief summary, drawn largely from Elston et al. (1983), is presented here.

Geothermal activity was discovered on the east side of the Animas Valley in 1948 when drilling produced boiling water from rhyolite at a depth of 87 ft. Since then other wells have been drilled around this "hot spot" (now designated the Lightning Dock Known Geothermal Resource Area) and it has been found to extend over an area of more than 2 mi^2. Although the geothermal water is apparently heated to a temperature of nearly 485°F, possibly by deep basaltic magma, mixing with local ground water results in a cooling to 200–300°F. In the vicinity of the Known Geothermal Resource Area, hot and cold waters freely mix. Geochemical modeling has suggested that the hot water produced there is a mixture of 25% deep geothermal water and 75% cold meteoric ground water (Elston et al., 1983). The hot water is utilized for space-heating of greenhouses (see first-day road log).

Challenges to characterizing ground-water quality

The main challenge to characterizing ground-water quality is the small number of wells, especially in the ranges. Even where wells are reasonably abundant, they may have been installed for irrigation or livestock supplies and water chemistry may not ever have been analyzed. Funds for analyzing samples to fill such gaps in water-quality-data coverage may not be available. Furthermore, domestic and irrigation wells usually have long screens along which water becomes mixed and chemistry of samples from such wells is not representative.

Another challenge is the presence of geothermal waters. Geothermal activity is common in Basin-and-Range country, where faults provide a conduit for the upwelling of deep hot waters (Elston et al., 1983; Stone et al., unpubl. report for Hydrology Department, Newmont Gold, 1991). As thermal waters are highly mineralized, water quality is impacted, at least locally. Determining the geographic extent of such impact is an additional task in some Basin-and-Range hydrogeologic studies.

GEOLOGIC CONTROLS OF HYDROLOGY

The geologic setting of an area imposes a strong control on the hydrologic system(s) operating there. An understanding of the relationship between ground-water occurrence, movement, and quality and the geologic framework is the desired end result of hydrogeologic studies. This relationship is formulated into a conceptual hydrogeologic model of the study area.

Controls of ground-water occurrence

Ground water occurs everywhere below the regional water table. However, the most productive occurrences are those associated with good porosity and permeability. Such conditions are provided in the ranges by fractured bedrock of various types and in the basins they are provided by the coarser materials in the bolson fill. The geothermal water rises along the intersection of the Animas Valley fault and the Muir cauldron ring-fracture zone (Elston et al., 1983).

Controls of ground-water movement

Recharge is facilitated by the topographic expression and bedrock composition of the ranges. There is more precipitation in the ranges owing to their elevation. Water readily runs off the dense bedrock materials, but soaks into the bolson fill. The fracture porosity of the bedrock permits some water to percolate to depths where it may escape evapotranspiration and flow to the basins. The intergranular porosity of the bolson-fill materials further facilitates recharge.

These contrasting hydraulic properties also control ground-water flow. Movement is slow in the ranges, unless the bedrock is limestone and dissolution has significantly widened fractures, and more rapid in the bolson fill, especially the coarser materials. By definition, transmissivity depends on thickness of the aquifer. The presence or absence of bedrock highs in the bolson fill therefore controls the volume of water moving though this aquifer at a given point.

Topography as well as the presence and location of faults are the main controls of ground-water discharge. The water table intersects the ground surface in low-lying areas, such as stream valleys and playas. Deep ground water may rise to the surface along major faults. If the depth is great enough and the heat flow adequate, such water will be geothermal.

Controls of ground-water quality

The main control of water quality is the composition of the geologic materials through which the water flows. The dominant dissolved ions reflect the rock types in the ranges as well as the bolson fill, generally derived from the ranges. Residence time or distance traveled is responsible for changes in water chemistry along flow paths. In some cases, hydrochemistry and certainly temperature depend on the degree of mixing with geothermal waters.

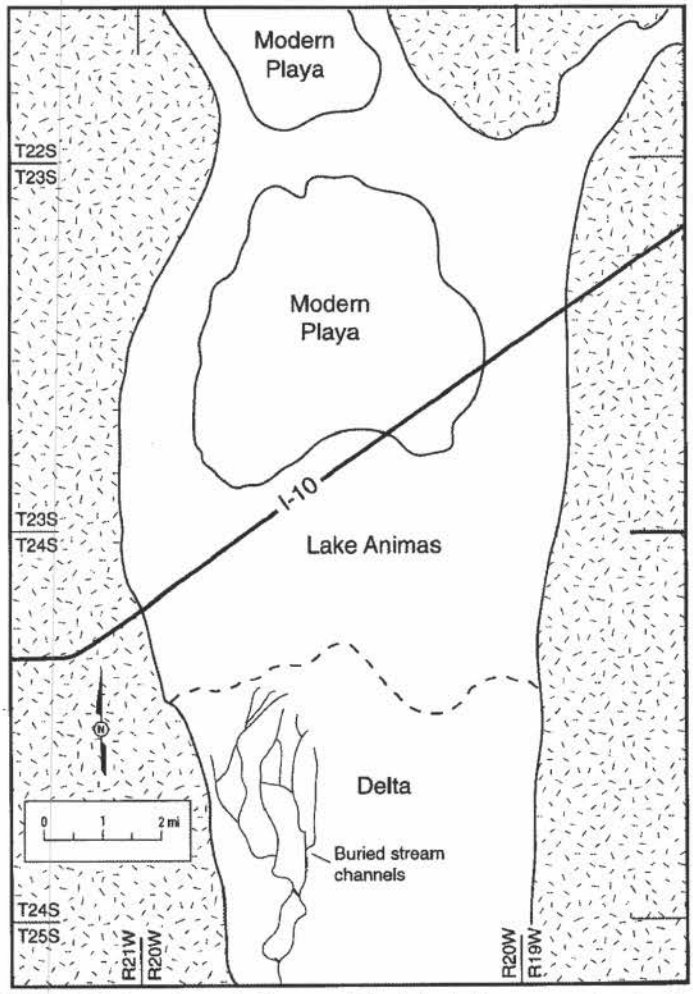


FIGURE 2. Location and features of hydrologic interest associated with Quaternary Lake Animas, Hidalgo County, New Mexico (modified from Stone and O'Brien, 1990, fig. 13).

Challenges to interpreting geologic controls

The formulation of a sound conceptual hydrogeologic model requires as complete a data set as possible. The challenge in Basin-and-Range country is to fill in the data gaps in the ranges. In view of the lack of water wells in the ranges, nontraditional sources of subsurface geologic and hydrologic data must be used. The exploration holes drilled by both the mining and petroleum industries can provide such supplementary information. Fifteen oil wells were identified in Hidalgo County for which stratigraphic information was available (Stone, 1990). Of special interest are oil tests that made water. For example, Iverson Estate State No. 136, drilled in 1989 in Hachita Valley (NW sec. 35, T29S, R15W), encountered fresh water in highly fractured Horquilla Limestone between the depths of 1107 and 1450 ft. Maximum flow rate was measured at 70 gpm. Chloride content of this water was reported to be 200–500 ppm. Only petroleum exploration holes provide such information, because water wells would not normally be drilled this deep in this setting.

Another factor to keep in mind is that the basins were often the sites of pluvial lakes during the Pleistocene. The portion of the bolson fill resulting from deposition during such lacustrine intervals may include excellent water-producing materials. Thus, an understanding of the Quaternary history of the basin is important to understanding the modern hydrogeologic system. For example, the Animas Valley was the site of Quaternary Lake Animas (Fleischhauer and Stone, 1982). The most productive saturated material is that associated with the delta formed where north-flowing drainage entered the southern end of Quaternary Lake Animas (Fig. 2).

CONCLUSIONS

Hydrogeologic studies in Basin-and-Range country face challenges not encountered in other physiographic provinces. These are summarized in Table 3.

Experience in Hidalgo County suggests these challenges may be met in various ways:

1. Information on ground-water occurrence and geologic controls of hydrology for the ranges may be supplemented by using nontraditional data sources, such as mining or petroleum exploration wells.
2. The picture of ground-water movement in the bolson fill could be improved by collecting specific water-balance data: direct or indirect measurements of recharge, long-term observations of runoff, and possibly calculating discharge from stream-flow records for or seepage runs on the Gila River.
3. Ground-water modeling of basins is facilitated by utilizing all available geologic and geophysical data.
4. Modeling two adjacent basins may shed light on flow between them, where the sparsity of wells in the intervening range does not allow for such a determination.
5. Further hydrochemical modeling could enhance present understanding of the impact of geothermal activity on ground-water quality in the Animas Valley.

TABLE 3. Additional challenges to hydrogeologic studies in Basin-and-Range settings.

Topic	Basin-and-Range challenge
GROUND-WATER OCCURRENCE	Few wells in ranges. Variable stratigraphy in basin fill
GROUND-WATER MOVEMENT	
Recharge	Precipitation/runoff events infrequent but intense
Flow	Sparsity of data for ranges
Discharge	Role of playas
GROUND-WATER QUALITY	Few wells in ranges. Impact of geothermal activity

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