Hydrogeology and Potential for Ground-Water Development, Carbonate-Rock Aquifers, Southern Nevada and Southeastern California

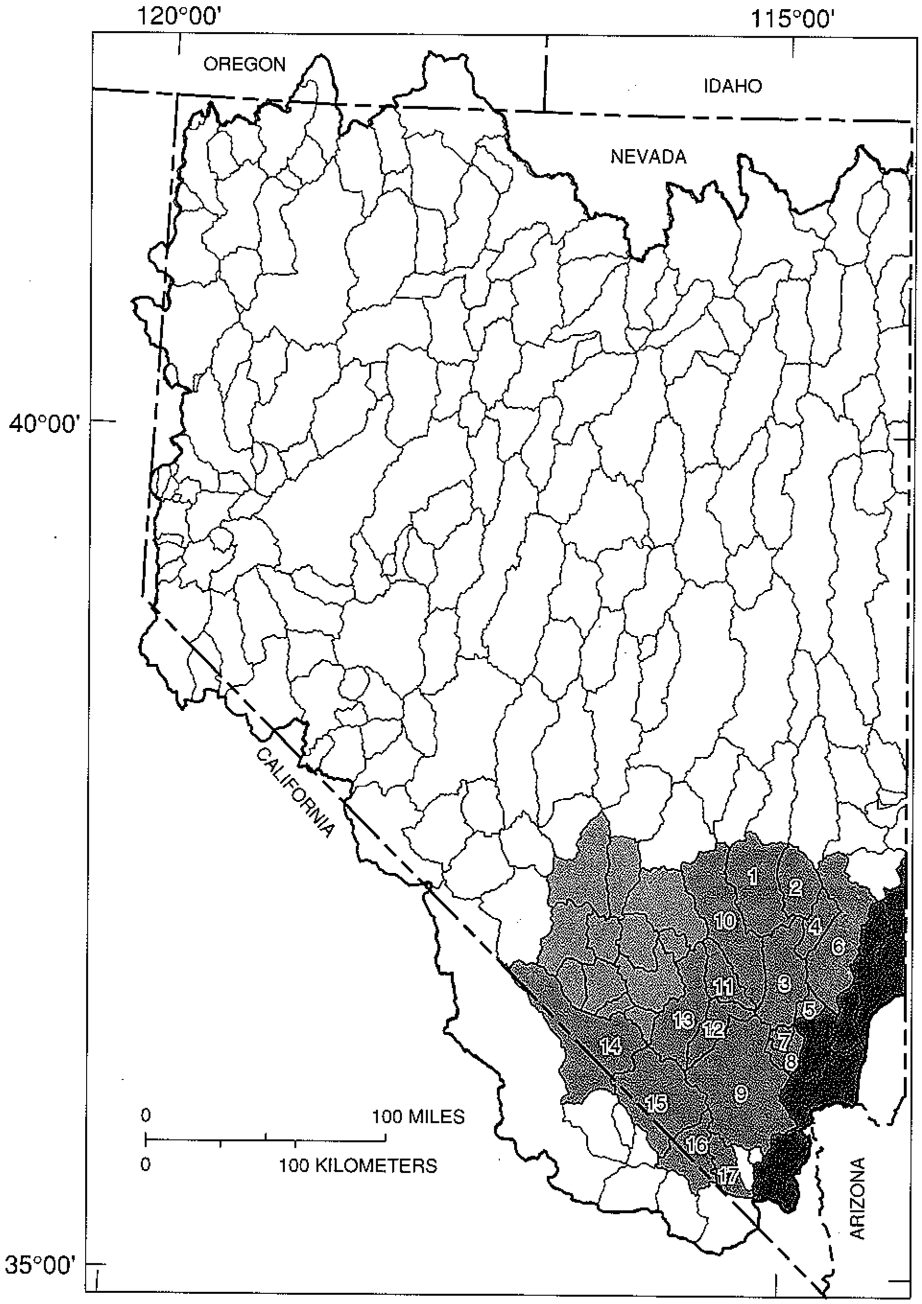
By Thomas J. Burbey

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 95-4168

Prepared in cooperation with the
STATE OF NEVADA

Carson City, Nevada
1997



Base modified from U.S. Geological Survey digital data, 1:100,000 and 1:250,000
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian - 114°

EXPLANATION

Hydrographic areas:

Excluded from study on the basis of sparse information

Excluded from study because of restricted access

Excluded from study because they are dominated by noncarbonate rocks

2 Selected for this study

Map number	Official number[1]	Name
1	209	Pahranagat Valley
2	182	Delamar Valley
3	210	Coyote Spring Valley
4	206	Kane Springs Valley
5	219	Muddy River Springs Area
6	205	Lower Meadow Valley Wash
7	217	Hidden Valley
8	216	Garnet Valley
9	212	Las Vegas Valley
10	169	Tikaboo Valley
11	168	Northern Three Lakes Valley
12	211	Southern Three Lakes Valley
13	161	Indian Springs Valley
14	230	Amargosa Desert
15	162	Pahrump Valley
16	163	Mesquite Valley
17	164	Ivanpah Valley

Boundary of Great Basin Regional Aquifer-System Analysis (RASA) study area

Boundary of hydrographic area or subarea

[1] Rush, 1968b

Figure 4. Hydrographic areas selected for and excluded from this study.

in the total estimate only if a minimum of 2,000 ft of carbonate rock lies within the top 5,000 ft of rock or sediment. Because of the uncertainty in estimating effective porosity, thickness, and extent of carbonate rocks within a given area, estimates of storage should be considered only as approximations. Actual values may vary significantly from those presented here. Basin-fill storage was not estimated for this report, but estimates for all the basins within the state are in State of Nevada Water Planning Report 3 (Scott and others, 1971).

Additional information and discussions of special features or problems specific to a particular hydrographic area are also presented in the following area-by-area assessments.

Criteria Used to Assess Potential for Ground-Water Development

Each selected hydrographic area was individually appraised for potential for development of the carbonate-rock aquifers. Three principal criteria were used in this report to assess the potential of each selected hydrographic area for water development. The most favorable areas would have (1) depth to water less than 500 ft below land surface, (2) depth to carbonate rock beneath the valley floor less than 1,500 ft and thickness of carbonate rock exceeding 2,000 ft, and (3) good water quality within the carbonate rocks, defined by a dissolved-solids concentration of less than 1,000 mg/L. Plate 1 shows areas where one, two, or three of these criteria are met.

In addition to these three criteria, other factors were considered in the selection of potential areas for development. These additional factors, discussed in the individual hydrographic-area appraisals, include (1) long- and short-term effects of development, (2) quantity of potential ground-water storage, (3) geologic controls influencing development, (4) environmental sensitivity of the potential site (such as Devils Hole), and (5) possible access problems in restricted areas.

Appraisal of development potential in many areas is extremely subjective because, for the most part, adequate hydrologic and geologic data are not available. The amount and accuracy of data varies greatly from area to area and no attempt was made to define the magnitude or temporal duration of potential ground-water development. Consequently, appraisal of each selected area (pl. 1) should be viewed as a generalized preliminary evaluation. Additional site-specific information may be needed before making major decisions about the development potential of selected local areas. All ground-water development, regardless of magnitude, is subject to regulation by Nevada water law.

Pahranagat Valley

Hydrographic Setting

Pahranagat Valley is in west-central Lincoln County in south-central Nevada. The hydrographic area encompasses about 768 mi^2 and is bounded on the west by the Pahranagat Range and on the east by the South Pahroc Range (fig. 5). The northern boundary is a bedrock high traversed by the White River at the narrows that separates Pahranagat Valley from Pahroc Valley to the north. To the south, a volcanic-rock canyon defines the hydrographic area boundary. Pahranagat Valley is a southward-sloping, open-drainage system of the presently dry White River (Eakin, 1963b). The most prominent hydrologic features of the basin are three large regional springs aligned in a north-south trend along the eastern margin of the valley. The average hydraulic gradient indicated by well data and springs in the valley is about 26 ft/mi in a southerly direction. The population of Pahranagat Valley is less than 2,000.

Geology

Exposed consolidated rock in the Pahranagat Valley hydrographic area is primarily Paleozoic carbonate rocks and Tertiary volcanic rocks which are composed mostly of ash-flow tuffs. Paleozoic rocks beneath the valley probably exceed 10,000 ft in thickness (Reso, 1963; Dolgoff, 1963; and Stewart, 1980). A section of more than 18,000 ft of Paleozoic carbonate rock has been measured in the Pahranagat Range by Reso (1963). Tertiary volcanic rocks lie unconformably on the thick carbonate-rock section beneath the valley and range in thickness from several hundred feet near the margins of the valley to more than 2,000 ft near the west-central part of the valley (fig. 5). These rocks are probably thickest in the South Pahroc Range (Bedsun, 1980). Thicknesses of basin-fill deposits vary significantly beneath the valley, but reach a maximum of about 2,000 ft near the center of the valley (Bedsun, 1980).

Features associated with both compressional and extensional forces are evident in Pahranagat Valley. Compressional forces have produced a major thrust fault in the Pahranagat Range (Tschanz and Pampeyan, 1970; fig. 5) resulting in significant thickening of the carbonate-rock section that is nearly double the estimated thickness of carbonate rock beneath the valley to the east. There is no conclusive evidence that thickening of the carbonate-rock section beneath Pahranagat Valley occurred.

Volcanic activity probably preceded extensional faulting in the area. Volcanic rocks beneath Pahranagat Valley form a north-trending trough with steep east and west sides, according to geophysical studies by Snyder (1983, p. 6); the trough resembles a "syncline or fault-controlled sag" (fig. 5; Dolgoff, 1963). Following much of the volcanic activity, numerous north-south aligned block faults resulting from extensional forces produced the Pahranagat and Hiko Ranges as well as Pahranagat Valley, but thinning of the carbonate rocks beneath Pahranagat Valley probably was not extensive; hence, the carbonate rocks beneath Pahranagat Valley may represent an extensive (both laterally and vertically) ground-water flow system that is contiguous with the flow system in valleys to the north and south. The structural trough beneath the valley is truncated to the south by the Pahranagat shear zone containing several left-lateral strike-slip faults (fig. 5). Schweikert (University of Nevada, Reno, oral commun., 1988) suggested that this fault system may represent a transitional boundary between extensional movement that occurred at different times north and south of the shear zone. This structural boundary may partially restrict southeastward flow of ground water, but may enhance southwestward flow (Eakin, 1966; Winograd and Thordarson, 1975).

Hydrology

Recharge to Pahranagat Valley from the adjacent ranges has been estimated by the Maxey-Eakin method (Eakin, 1963b) for three different reports (table 2). Values range from 1,500 to 2,000 acre-ft/yr with the differences resulting from calibration of the techniques used by the investigator in developing a water, or isotopic, balance. Discharge within the valley is almost entirely from springs issuing from carbonate rocks and totals about 25,000 acre-ft/yr (tables 2 and 3). The large difference between recharge and discharge reflects throughflow of ground water in the valley, which Eakin (1966) included as part of the much larger White River ground-water flow system that originates in Jakes Valley to the north and extends to the Muddy Springs in the lower part of Moapa Valley to the south. Table 2 lists the recharge and discharge rates, as well as sources and destinations of ground-water flow into and out of Pahranagat Valley as reported by previous investigators. Most of the reported flow occurs in carbonate rocks.

Depth to water along the White River channel is at or near land surface from Hiko south to Maynard Lake. North of Hiko, the depth to ground water increases substantially. In Pahroc Valley to the north, for instance, the depth to ground water is 250 ft or more (Eakin, 1963b). The land-surface gradient from Pahroc Valley into Pahranagat Valley dips more steeply than does the water-table gradient; this, coupled with favorable geologic structure, results in the emergence of the three springs (P1, P2, and P3) along the eastern margin of Pahranagat Valley (fig. 5, table 3).

The potentiometric surface in the carbonate rocks is believed to be nearly coincident with (or is slightly higher than) the water level in the basin fill (Thomas and others, 1986). This coincidence indicates good hydraulic connection between the carbonate rocks and basin fill. The welded tuffs that separate the carbonate rocks from the basin fill are considered as aquifers in other parts of the State because they can transmit large quantities of ground water (Winograd, 1971; Winograd and Thordarson, 1975). The moderate amount of pumping from the basin fill in the past has had no apparent effect on spring discharge rates in the valley (Eakin, 1963b). Inflow from the carbonate rocks probably contributes a significant quantity of recharge to the basin-fill aquifer.

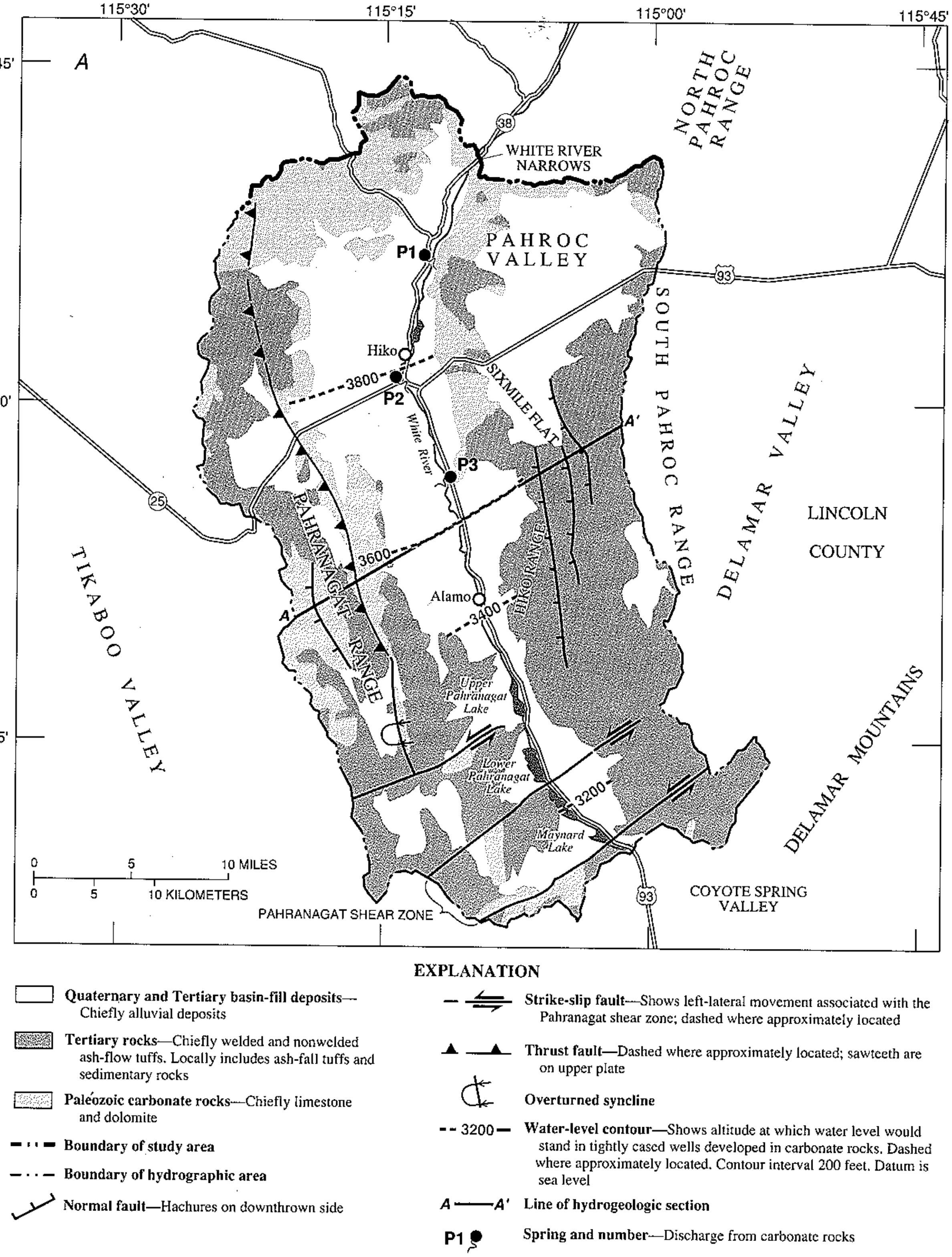


Figure 5. Hydrogeologic map and generalized section through Pahranagat Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, and springs where ground-water data are available (structural geology from Tschanz and Pampeyan, 1970, pl. 3; Ekren and others, 1977; hydrogeology from Thomas and others, 1986). *B*, Generalized hydrogeologic section through Pahranagat Valley. Arrows show direction of relative movement along faults. (Geology modified from Reso, 1963; Dolgoff, 1963; Bedsun, 1980).

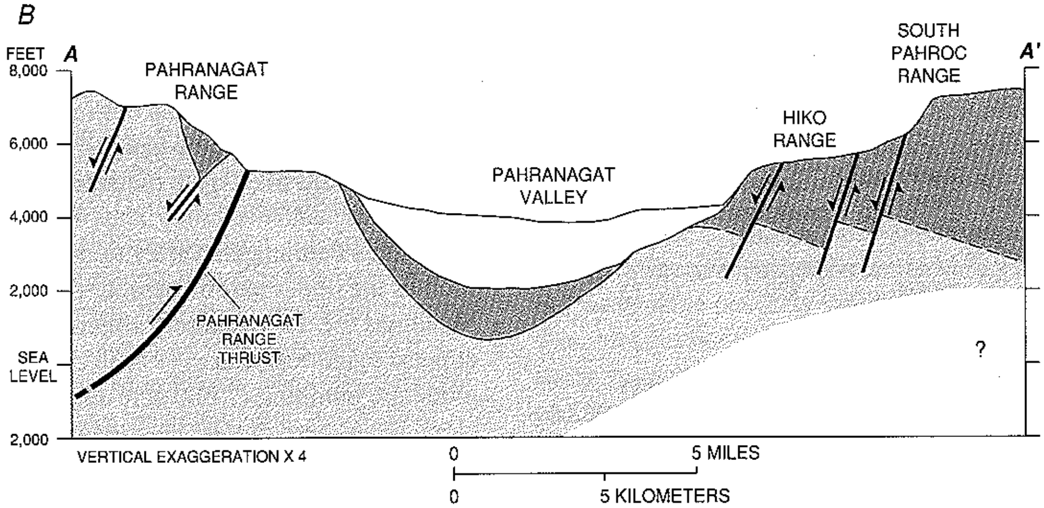


Figure 5. Continued.

Table 2. Recharge and discharge estimates for Pahranagat Valley

Component of recharge or discharge	Quantity (acre-feet per year)
Recharge	
Precipitation in Pahranagat and Hiko Ranges	
Eakin (1963b)	1,800
Welch and Thomas (1984)	2,000
Kirk (1987)	1,500
Subsurface inflow from Pahroc, Coal, Garden, Dry Lake, and Delamar Valleys	
Eakin (1966)	60,000
Welch and Thomas (1984)	51,000
Kirk (1987)	52,000
Discharge	
Evapotranspiration from phreatophytes and bare soils	
Eakin (1963b)	0
Springs issuing from carbonate rocks	
Eakin (1963b)	25,000
Pumpage from basin fill	
Eakin (1963b)	2,000
Frick [a]	250
Evaporation from lakes, ponds, and streams due to spring discharge	0 [b]
Subsurface outflow to Coyote Spring Valley and Ash Meadows flow system	
Eakin (1966)	35,000
Welch and Thomas (1984)	25,000
Kirk (1987)	29,400
Total recharge (rounded)	52,000-62,000
Total discharge (rounded)	50,000-62,000

[a] E.A. Frick, U.S. Geological Survey, oral commun., 1986.

[b] Budget values reflect that lakes, ponds, and streams result from spring discharge.

Table 3. Information on springs issuing from carbonate rocks and used for irrigation in Pahranagat Valley

(Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987)

Number (fig. 5)	Name	Discharge (acre-feet per year)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
P1	Hiko	4,800	320	23
P2	Crystal	8,300	286	24
P3	Ash	11,800	286	32

The Pahranagat shear zone and other structures at the southern end of the valley may restrict subsurface flow from the valley toward the south. Thomas and others (1986) reported a steep hydraulic gradient at the south end of the valley with much lower water levels in Coyote Spring Valley than in southern Pahranagat Valley. Flow from the south end of the valley (about 6,000 acre-ft/yr) toward Ash Meadows has been suggested (Winograd and Friedman, 1972; Winograd and Thordarson, 1975; Welch and Thomas, 1984; Kirk, 1987) and may be coincident with the Pahranagat shear zone.

The quantity of stored ground water within the carbonate rocks in the Pahranagat Valley hydrographic area has been estimated, on the basis of the assumptions made in the introduction of this report, to be 2.9 million acre-ft. Local storage (beneath the basin-fill deposits only) has been estimated to be 1.8 million acre-ft.

Potential for Ground-Water Development

Pahranagat Valley may be a potential site for development of the carbonate-rock aquifers, according to the criteria listed on plate 1. The entire valley is underlain by a thick section of carbonate rock (fig. 5) containing ground water of high quality (table 3). However, depth to water and depth to carbonate rock may limit to some degree the areas most favorable for potential development. Good hydraulic connection between basin fill and carbonate rock suggests that ground water may be induced to flow from the carbonate aquifers to wells drilled in basin fill. The most favorable area for development is a narrow north-trending zone along the White River channel in the northern half of the valley (fig. 5).

Development of the carbonate-rock aquifers beneath the valley could (1) reduce spring discharge in the surrounding area, (2) lower the water table within the basin fill because of the apparently good hydraulic connection between the carbonate rocks and overlying basin fill, (3) tap the potentially large storage reservoir beneath the valley, and (4) divert throughflow that leaves Pahranagat Valley to downgradient areas, such as the upper part of Moapa Valley and Ash Meadows (pl. 1), ultimately affecting spring discharge at these localities. Eakin (1963b) indicated that moderate pumping (2,000 acre-ft/yr) in the basin fill along the eastern part of Pahranagat Valley had no apparent effect on spring discharge, and water-level declines were minimal. Larger pumping volumes (or perhaps much longer pumping times), however, would likely affect storage and lower water levels within the basin fill. In addition, spring discharge in the nearby areas would almost certainly be reduced. The quantity of pumping required for these effects to occur is not known, but the location of development and the hydraulic characteristics of the carbonate rocks at depth would likely influence the quantity and commencement of the effects.

Delamar Valley

Hydrographic Setting

The Delamar Valley hydrographic area encompasses 383 mi^2 in central Lincoln County (fig. 6). The valley is surrounded by mountains except to the north where it is separated from Dry Lake Valley by a low topographic divide in the basin fill. Delamar Valley, however, is not hydrologically isolated from Dry Lake Valley, because ground water flows without restriction southward into Delamar Valley. A surface-drainage gradient in Delamar Valley of about 30 ft/mi terminates at a dry playa in the southernmost part of the area. There are no perennial streams in the valley. Ground-water outflow from Delamar Valley is tributary to the White River ground-water flow system to the southwest (Eakin, 1966), which terminates in the Muddy River Springs area (pl. 1). Development of the valley has been limited to livestock grazing as the depths to water are generally prohibitive for other economic activities.

Geology

The ranges surrounding Delamar Valley are dominated by Tertiary volcanic rocks, primarily ash-flow tuffs which may reach thicknesses of 4,000 ft in the South Pahroc Range (Tschanz and Pampeyan, 1970; fig. 6). However, at the Kane Springs Wash caldera complex in the Delamar Range, basaltic and rhyolitic volcanic rocks are common; thicknesses of volcanic rocks in the caldera complexes are unknown, but are likely to be great. Cambrian crystalline clastic rocks and Paleozoic carbonate rocks occupy parts of northwestern Delamar Mountains. Basin-fill deposits in Delamar Valley have been estimated to be about 4,000 ft thick, by use of geophysical methods (Bedsun, 1980). Bedsun also estimated the depth to Paleozoic carbonate rocks beneath the valley to be approximately 10,000 ft. If correct, the Tertiary volcanic rocks beneath Delamar Valley and overlying the carbonate rocks may be as much as 6,000 ft thick (fig. 6).

Compressional tectonics probably have not greatly affected the original thickness of carbonate rocks in the area, but the units may have undergone extreme extension that possibly thinned the carbonate-rock section in a manner similar to the extension that thinned a section described by Taylor and Bartley (1987) in Dry Lake Valley to the north, where four distinct extensional episodes were recognized. The Paleozoic carbonate-rock section in the Delamar Mountains is thin because only the lower part (Cambrian) of the section is exposed. However, the entire carbonate-rock section is probably present (but significantly thinned) beneath the valley (Taylor and Bartley, 1987). In addition, extension may have dropped the valley relative to the mountains by many thousands of feet as evidenced by the extremely thick basin-fill and Tertiary deposits beneath the valley floor (fig. 6). Consequently, most of the ground-water flow is likely to be through basin fill rather than carbonate rock.

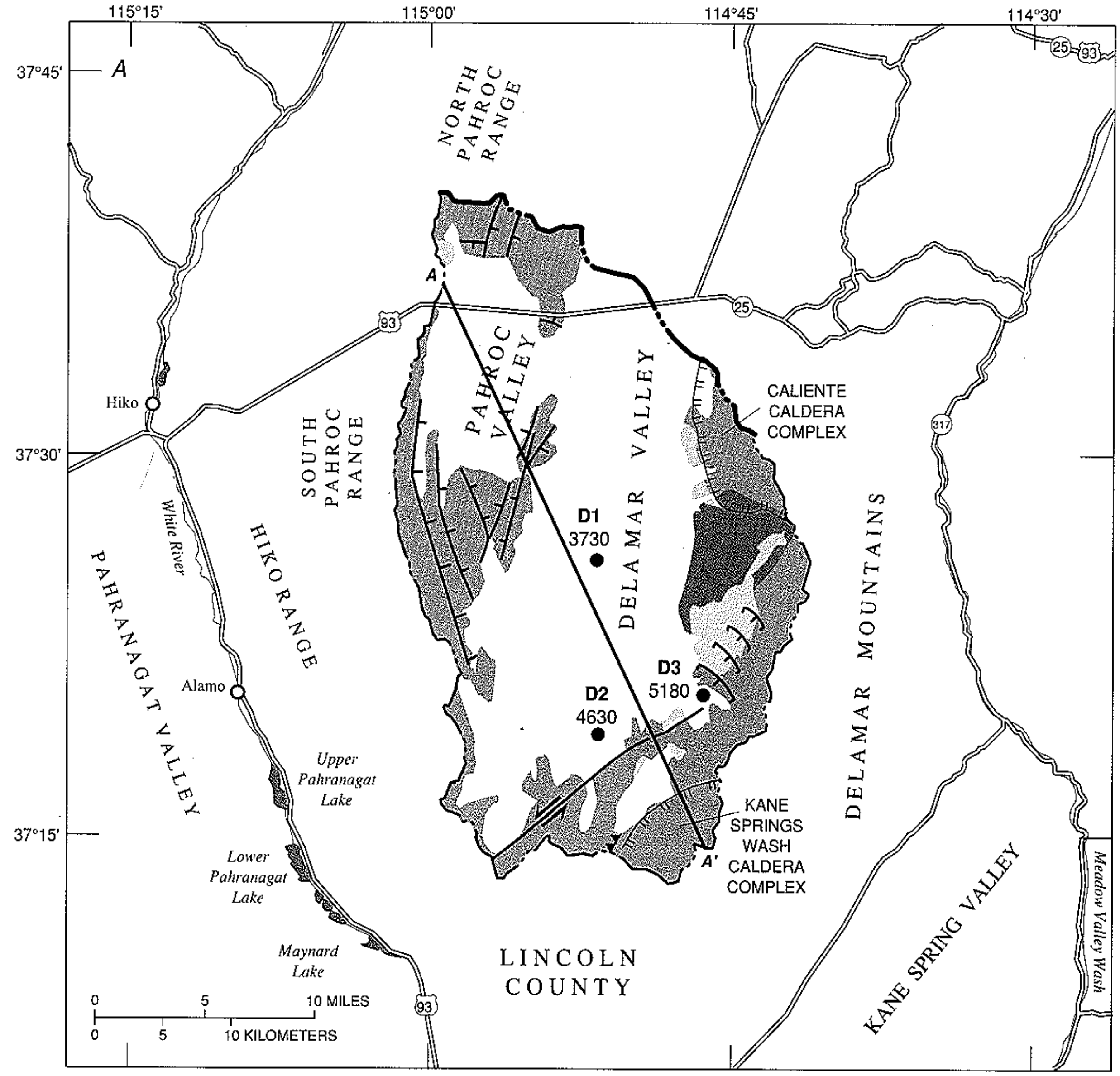
Hydrology

Although no wells penetrate the carbonate rocks beneath Delamar Valley, and only three wells (table 4) reach the water table, much has been inferred about ground-water flow beneath the valley. Local recharge from adjacent ranges has been estimated by Eakin (1963a) to be about 1,000 acre-ft/yr (table 5). Other investigators using this method have obtained estimates of recharge that differ slightly because of differing calibration processes (Welch and Thomas, 1984; Kirk, 1987; table 5). The remainder of the recharge to the valley is from subsurface inflow from Dry Lake Valley to the north. Virtually all discharge from Delamar Valley is by subsurface outflow to areas to the south and southwest, downgradient in the White River ground-water flow system.

The one available water-level measurement within the central part of Delamar Valley indicates that the water table is nearly 900 ft below the valley floor. The thickness of the basin fill and underlying volcanic rocks suggests that much of the subsurface flow probably moves through basin fill and Tertiary rocks rather than through carbonate rocks. Because the basin-fill deposits in valleys to the west and south are not nearly as thick as in Delamar Valley, it is likely that subsurface flow moves through basin-fill and volcanic rocks in Delamar Valley into carbonate rocks as flow moves downgradient within the White River ground-water flow system.

The quantity of subsurface flow beneath Delamar Valley was first estimated by Eakin (1966) to be 6,000 acre-ft/yr, equivalent to the recharge entering the ranges surrounding Dry Lake and Delamar Valleys (table 5). Kirk (1987) needed considerably more recharge from these areas to calibrate his isotopic model of the White River ground-water flow system. If additional underflow through Delamar Valley does occur, the source of water is probably from areas to the north and east of Dry Lake Valley and not from the local mountains. The total quantity of recharge contributed from these more northern areas is unknown and not sufficiently supported by field measurements, but Prudic and others (1993) indicate that it may be significant on the basis of a regional flow model.

The direction of subsurface outflow from Delamar Valley is not fully resolved. Eakin (1966) suggested on the basis of recharge and discharge estimates that the outflow from Delamar Valley enters Pahranagat Valley and may contribute to regional spring discharge there. Welch and Thomas (1984) developed an isotopic and geochemical model which indicates that the outflow from Delamar Valley enters Coyote Spring Valley to the south of Pahranagat Valley and does not contribute to spring discharge in Pahranagat Valley. Kirk (1987) concluded, on the basis of an isotope-mixing model, that most of the discharge from Delamar Valley enters Coyote Spring Valley, but a small quantity enters Pahranagat Valley.



EXPLANATION

Quaternary and Tertiary basin-fill deposits—Chiefly alluvial deposits

Tertiary rocks—Chiefly welded and nonwelded ash-flow tuffs. Locally includes ash-fall tuffs and sedimentary rocks

Paleozoic carbonate rocks—Chiefly limestone and dolomite

Precambrian and Cambrian noncarbonate rocks—Chiefly quartzite, siltstone, and shale with minor amounts of limestone and dolomite

Boundary of study area

Boundary of hydrographic area

Normal fault—Hachures on downthrown side

Strike-slip fault—Shows left-lateral movement associated with the Pahranagat shear zone. Dashed where approximately located

Thrust fault—Sawteeth are on upper plate

Caldera rim

A——A' **Line of hydrogeologic section**

D1 3730 **Well**—Penetrates water table, but does not reach carbonate rock beneath basin fill; upper number is well identifier, lower number is water-level altitude, in feet above sea level

Figure 6. Hydrogeologic map and generalized section through Delamar Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, and water levels in basin fill which are considered equivalent to water levels in carbonate rocks in adjacent valleys (structural geology from Tschanz and Pampeyan, 1970, pl. 3; Ekren and others, 1977; hydrogeology from Thomas and others, 1986). *B*, Generalized hydrogeologic section through Delamar Valley (geology from Tschanz and Pampeyan, 1970; Ekren and others, 1977; Bedsun, 1980; Snyder, 1983).

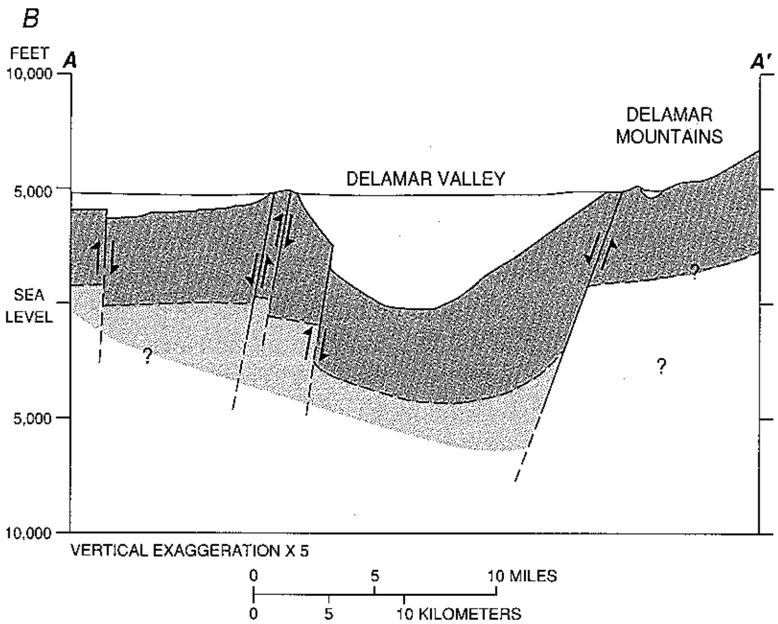


Figure 6. Continued.

There are not sufficient water-level data to determine an accurate water-level gradient that supports or refutes any of the above mentioned conclusions.

The quantity of storage within carbonate rocks beneath Delamar Valley is limited because depths to bedrock are likely to be impractical for development, except in the southeastern part of the valley. Storage for the entire area is estimated to be about 0.5 million acre-ft. Local storage (within the basin fill) is probably less than 0.3 million acre-ft.

Potential for Ground-Water Development

Delamar Valley has a low potential for development of ground water from the carbonate-rock aquifers. The depth to water in much of the valley is nearly 1,000 ft below land surface and the depth to carbonate rocks may be as much as 10,000 ft beneath the valley floor. Only in the southeast part of the valley are water levels moderately shallow; the depth to carbonate rocks there probably is considerably less than the 10,000 ft estimated near the center of the valley (Bedsun, 1980). Hence, potential for development is limited to a narrow area adjacent to the Delamar Mountains. However, even if development of the carbonate rocks

Table 4. Information on wells completed in basin fill in Delamar Valley

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations: D, domestic; N, not used; O, observation]

Number (fig. 6)	Owner	Total depth (feet)	Depth to water (feet below land surface)	Use
D1	USGS-MX Well	1,195	871	O
D2	Gulf Oil Corp.	265	220	N
D3	Private	95	63	D

Table 5. Recharge and discharge estimates for Delamar Valley

Component of recharge or discharge	Quantity (acre-feet per year)
Recharge	
Precipitation primarily in Delamar Range	
Eakin (1963a)	1,000
Welch and Thomas (1984)	1,000
Kirk (1987)	2,000
Subsurface inflow from Dry Lake Valley	
Eakin (1966)	5,000
Welch and Thomas (1984)	5,000
Kirk (1987)	7,000
Discharge	
Evapotranspiration from phreatophytes and bare soils; Eakin (1963a)	0
Springs issuing from carbonate rocks Eakin (1963a)	0
Subsurface outflow to Pahranagat and Coyote Spring Valleys	
Eakin (1966)	6,000
Welch and Thomas (1984)	6,000
Kirk (1987)	9,500
Total recharge (rounded)	6,000-9,000
Total discharge (rounded)	6,000-10,000

in southeastern Delamar Valley was possible, there is no indication that appreciable amounts of ground water flow into this area—either from recharge to the Delamar Mountains, which would be a small quantity, or as throughflow beneath the valley to downgradient areas within the White River ground-water flow system. In addition, the throughflow may not be easily recovered if the flow is deep.

Development of the basin-fill reservoir is a possibility, and effects on areas downgradient at spring discharge locations in Pahranagat Valley or in the Muddy River Springs area probably would not be fully realized for a long period—perhaps hundreds or even thousands of years. However, in order to capture the 6,000 acre-ft/yr of estimated throughflow beneath the valley, Eakin (1963a) indicated that pumping from a depth of at least 1,500 ft would be necessary.

Coyote Spring and Kane Springs Valleys and the Muddy River Springs Area

Hydrographic Setting

The Coyote Spring Valley, Kane Springs Valley, and Muddy River Springs hydrographic areas (1,025 mi^2) in southern Lincoln and northern Clark counties have been combined for this report because the areas are hydrologically related and topographically connected. Coyote Spring Valley contains the ephemeral diminutive channel and flood plain of the White River, which is continuous to Muddy River Springs (fig. 7). Kane Springs Wash is a major tributary to the White River drainage system. Only occasional flood waters flow in either of these streams. Drainage of the hydrographic areas is from the north (Pahranagat Valley) and northeast (Kane Springs Valley) to the south and southeast (Muddy River Springs Area). Ground-water flow likewise is generally in a south and southeast direction.

Ground water issuing from the Muddy River Springs forms the headwaters of the Muddy River that provides irrigation water to farms in the upper and lower parts of Moapa Valley. Coyote Spring and Kane Springs Valleys are used principally for livestock grazing, whereas the Muddy River Springs area has several dairy and other farming operations.

Geology

Tertiary volcanic rocks are dominant in the northern part of the hydrographic area, whereas Paleozoic carbonate rocks dominate the central and southern part of the area (fig. 7). Thick sequences of tuffaceous rocks are predominant throughout the Kane Springs Valley area. The Kane Springs Wash caldera complex, however, contains rhyolitic and basaltic flows that are likely to be many thousands of feet thick. A similar caldera complex at the Nevada Test Site (Blankennagel and Weir, 1973) contains at least 10,000 ft of volcanic rocks. Consequently, if any carbonate rocks are present beneath the complex they are probably at great depths. A rather sharp transition from volcanic to carbonate rocks occurs in the northern part of Coyote Spring Valley (fig. 7). Thicknesses of the dominant carbonate rock have been measured to be more than 10,000 ft in the Sheep Range (Guth, 1981). Basin fill directly overlies carbonate rocks in most areas, and thicknesses generally range from 500 to 1,000 ft throughout most of Coyote Spring Valley, but increase to more than 3,000 ft in the southeast part of the area including the Muddy River Springs area (fig. 7, pl. 1). Tertiary deposits containing evaporite minerals account for a large part of the basin-fill thickness. A sliver of Precambrian and Cambrian clastic rocks exposed adjacent to the Gass Peak thrust in the Sheep Range (fig. 7) probably extends thousands of feet beneath the range.

Thrust faulting and folding during the late Mesozoic deformed the region, especially along the Gass Peak and Dry Lake thrust faults (fig. 7). Along the Gass Peak thrust, Precambrian and Cambrian clastic rocks were thrust over nearly an entire section of Paleozoic carbonate rocks (D.L. Schmidt, U.S. Geological Survey, written commun., 1986). The northern extent of this fault and the thickness of these clastic rocks of low permeability beneath the western part of Coyote Spring Valley are not known, but clastic rocks probably restrict eastward flow from the Sheep Range.

Extensional forces were a major factor in modifying not only the landscape, but influencing the hydrology of the area as well. The central part of the region that includes Coyote Spring Valley and the Muddy River Springs area remained relatively intact (stable) during this time (Wernicke and others, 1984), but abundant intersecting high-angle normal faults probably provided good ground-water conduits toward the Muddy River Springs (D.L. Schmidt, U.S. Geological Survey, written commun., 1985). In contrast, highly extended terrane bounds this stable area to the west (west of the Sheep Range) and east (east of the Muddy River Springs and Meadow Valley Mountains). To the east, extensional faulting produced the deep Meadow Valley Wash basin between the Mormon Mountains to the east and the Muddy River Springs area to the west (H.R. Blank, U.S. Geological Survey, written commun., 1985). This basin is filled with Tertiary basin-fill deposits of low permeability (pl. 1) which are believed to dam regional flow in the thick carbonate-rock aquifer, causing an upward component of flow in the Muddy River Springs Area (M.D. Dettinger, U.S. Geological Survey, written commun., 1987).

The northern boundary of the hydrographic area along the Delamar Mountains consists of Tertiary volcanic rocks underlain by thick carbonate rocks. This area coincides with the southern extent of the Pahranagat shear zone (fig. 5). The Pahranagat shear zone along this northern boundary is probably a partial barrier to southward-trending ground-water flow.

Hydrology

Local recharge in the three hydrographic areas was estimated by Eakin (1964) using empirical techniques to be 2,600 acre-ft/yr. Other investigators using the Maxey-Eakin method have adjusted their estimates of recharge based on geochemical techniques (Welch and Thomas, 1984) and isotopic modeling studies (Kirk, 1987) in this part of the White River ground-water flow system (table 6). More recent geochemical studies suggest that local recharge from the Sheep Range may be considerably larger than estimates obtained from traditional empirical techniques or previous geochemical and isotopic models (J.M. Thomas, U.S. Geological Survey, oral commun., 1988). This recharge is augmented by deep through-flowing water in carbonate rocks beneath Pahranagat and White River Valleys in the north, and possibly Dry Lake and Delamar Valleys in the northeast. An additional component of shallow inflow may come from Meadow Valley Wash to the east (Kirk, 1987; J.M. Thomas, U.S. Geological Survey, oral commun., 1988; table 6). Discharge from these areas is almost entirely by spring discharge at the Muddy River Springs and is 36,000 acre-ft/yr (Eakin and Moore, 1964).

Water levels beneath Coyote Spring Valley are considerably deeper than in Pahranagat Valley to the north (generally about 350-600 ft beneath the valley floor; Berger and others, 1988). The depth to water decreases toward the Muddy River Springs, which issues from basin fill overlying carbonate rocks. The discharge at the springs is probably entirely from carbonate rocks (Eakin, 1964).

Geochemical and isotopic studies (J.M. Thomas, U.S. Geological Survey, oral commun., 1988) suggest that at least one-half of the discharge at the Muddy River Springs is derived in southern Nevada from the Sheep Range and the Meadow Valley Wash ground-water flow system. The remainder of the discharge is throughflow from the White River ground-water flow system to the north. This suggests that recharge from the Sheep Range may be about 12,000-14,000 acre-ft/yr, slightly more than the 11,000 acre-ft/yr estimated as the total recharge from this mountain range, and five times more than the quantity estimated by Eakin (1966) to recharge Coyote Spring Valley. Throughflow from the Meadow Valley Wash area originates in the volcanic mountains south of Caliente (northeast of Kane Springs Wash [Emme, 1986]) and appears, on the basis of geochemical and isotopic data, to enter the area northeast of the deep carbonate wells located in Coyote Spring Valley. Ground water from the Meadow Valley Wash ground-water flow system probably flows beneath the Meadow Valley Mountains (fig. 7).

Estimates of stored water within the carbonate rocks beneath Coyote Spring Valley have been made on the basis of pumping tests (Bunch and Harrill, 1984; M.D. Dettinger, U.S. Geological Survey, written commun., 1988). Based on the assumptions described in this report, the estimated ground-water storage in carbonate rocks beneath the three areas is 8.7 million acre-ft. Of this total, about 80 percent occurs within the Coyote Spring hydrographic area; only small quantities of storage are likely to be present in the other two hydrographic areas. Local storage (beneath the basin fill) has been estimated at 5.0 million acre-ft for the three areas. The ground-water flow system beneath Coyote Spring Valley is probably not well connected with adjacent flow systems except to the east, with the ground-water flow system in the western part of the Lower Meadow Valley Wash area.

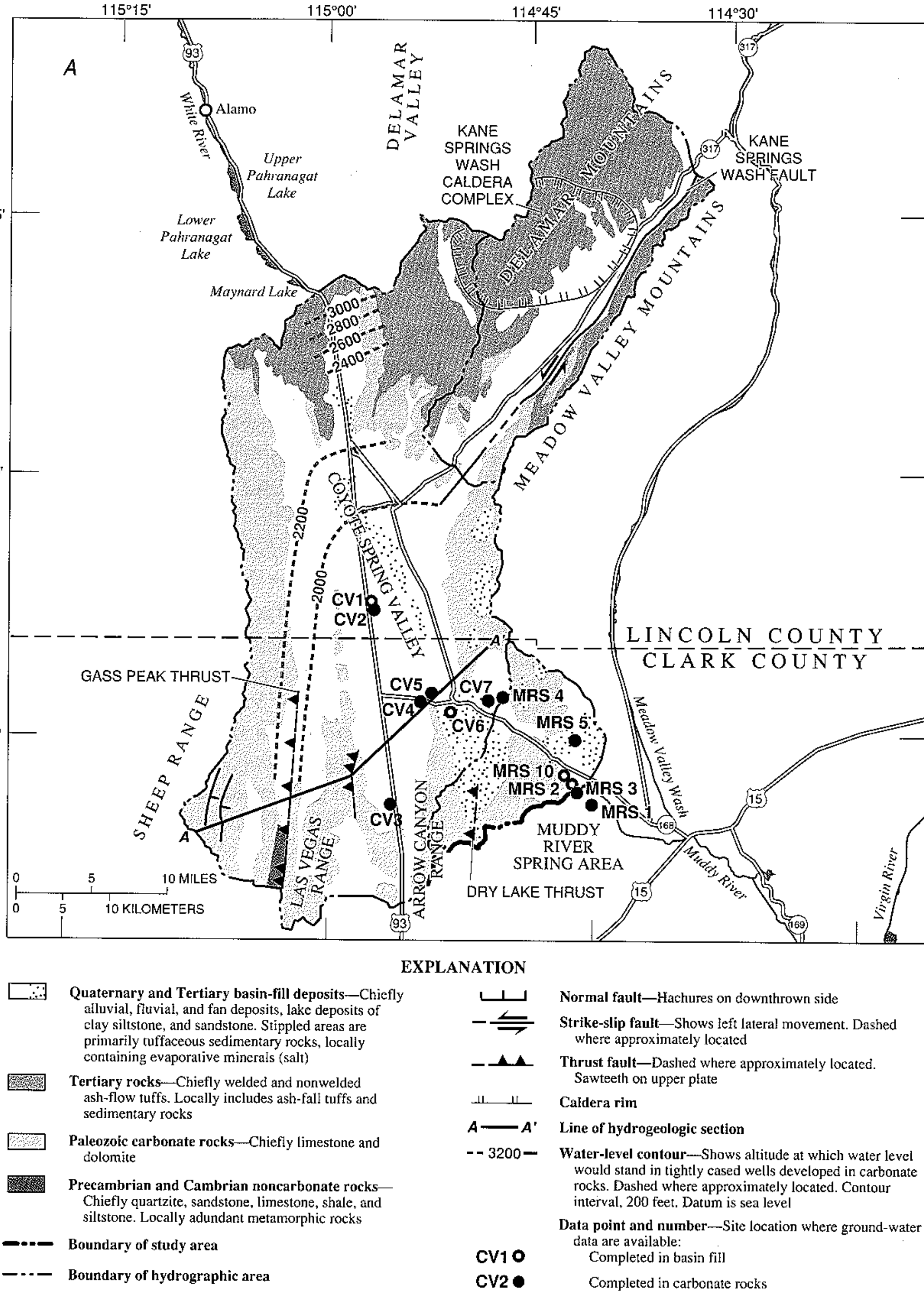


Figure 7. Hydrogeologic map of Coyote Spring Valley, Kane Springs Valley, and Muddy River Springs area and generalized hydrogeologic section through southern Coyote Spring Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, and points where ground-water data are available for carbonate rocks (structural geology from D.L. Schmidt, U.S. Geological Survey, written commun., 1987; Ekren and others, 1977; hydrogeology from Thomas and others, 1986). *B*, generalized hydrogeologic section through the southern part of Coyote Spring Valley (geology from D.H. Schaefer, U.S. Geological Survey, written commun., 1988; D.L. Schmidt, U.S. Geological Survey, written commun., 1988).

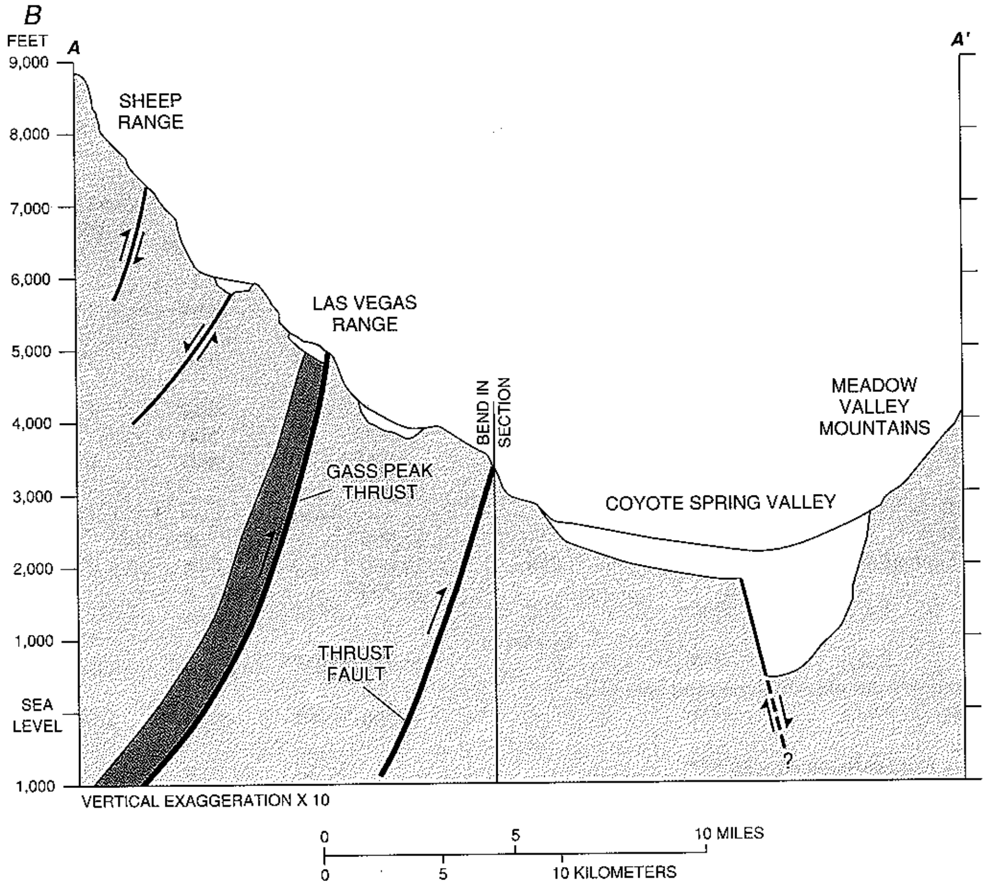


Figure 7. Continued.

Potential for Ground-Water Development

Much of Coyote Spring Valley and the Muddy River Springs area has the potential for development of the carbonate-rock aquifers on the basis of the criteria listed on plate 1. In contrast, Kane Springs Valley is probably not a favorable area for development because of the large depths to water (greater than 1,000 ft) and potentially large depths to carbonate rocks. Other important factors cannot be overlooked if these areas are to be developed because little, if any, water leaves the hydrographic areas as subsurface flow either to the south (to Hidden Valley) or east. The measured discharge at Muddy Springs may represent the entire recharge-plus-inflow to the area; hence, any pumping from the carbonate rocks within this area is likely to affect discharge at Muddy Springs. Well CV7 in carbonate rock (fig. 7) is used as a municipal supply during summer months when water demands are high, but the well has not yet been pumped enough to determine what effect this may have on discharge at Muddy Springs. The Muddy River Springs area contains lower quality water than upgradient areas because of the presence of evaporite minerals in the Tertiary deposits, but the quality (table 7, pl. 1) passes the criteria test developed earlier.

Lower Meadow Valley Wash

Hydrographic Setting

The Lower Meadow Valley Wash hydrographic area occupies approximately 979 mi^2 in eastern Lincoln and northeastern Clark Counties. Perennial streamflow in Meadow Valley Wash, supplied primarily by runoff from the Clover Mountains, brought ranchers to the area more than 120 years ago (Rush, 1964). Later, when the Union Pacific Railroad was built through the area, Caliente became a railroad division point and population center for the area (fig. 8). Today, the community of Caliente has about 1,000 residents.