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

By Thomas J. Burbey

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CONTENTS

PLATE

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FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNIT

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-feet per foot (acre-ft/ft)	0.004047	cubic hectometer per meter
acre-feet per year (acre-ft/yr)	0.001233	cubic hectometer per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556(°F-32).

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Abbreviated Water-Quality Unit Used in this Report

mg/L (milligram per liter)

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Abstract

In southern Nevada, 17 hydrographic areas were selected by the U.S. Geological Survey to assess the potential for development of ground water in the underlying carbonate-rock aquifers. The assessment was based on a summary of geologic and hydrologic information developed as part of the Nevada Carbonate Aquifers Study and information compiled from previous investigations.

The 17 hydrographic areas were selected from among 48 hydrographic areas in southern Nevada on the basis of an evaluation of the geologic framework, hydrologic setting, and public accessibility. All selected hydrographic areas lie within the miogeoclinal belt where thick sequences of carbonate rock accumulated for hundreds of millions of years. Major deformational episodes greatly modified the area, but in general, the less-extended areas tend to contain the thickest continuous sequences of carbonate rock at depth. Most of the selected hydrographic areas lie within these less-extended terranes; however, several areas, or parts of areas, lie within severely extended terranes where deformed blocks of carbonate rock are discontinuous and isolated from surrounding carbonate rock or where little or no carbonate rock remains at depth.

Three principal criteria were used to assess the development potential beneath the basin-fill deposits of each selected hydrographic area. These quantitative criteria are (1) depth to water, (2) depth to and thickness of carbonate rocks, and (3) water quality. Other site-specific factors such as accessibility and effects of ground-water development are also discussed. However, water-right availability under Nevada water law was not considered.

Results of the hydrographic-area appraisals based on available geologic and hydrologic information suggest that sites with high potential for development of ground water in carbonate rocks may be scarce in southern Nevada. Areas described as favorable by using the three criteria were assessed qualitatively on the basis of possible short- and long-term effects associated with development and on the amount of available data used to make the assessment. These results suggest that many sites classified as favorable from the quantitative assessment were deemed unfavorable on the basis of the qualitative criteria. The most favorable sites appear to be in more severely extended terranes where development of isolated areas of carbonate-rock aquifers would be less likely to affect adjacent areas.

INTRODUCTION

As the population of Nevada continues to grow at a rapid rate, the Nation's driest State faces increasing demands for water. Sources of ground water from basin-fill aquifers are fully or over appropriated in many areas in southern Nevada. The possibility, therefore, of tapping the relatively unexplored carbonate-rock aquifers as a source of potable ground water has been the focus of much interest in recent years.

In 1985, a cooperative effort began with the State of Nevada, Las Vegas Valley Water District, Desert Research Institute, City of North Las Vegas, and U.S. Department of the Interior (U.S. Geological Survey and Bureau of Reclamation) to study and test the carbonate-rock aquifers to assess their potential for development (known as the Nevada Carbonate Aquifers Study). As one of several reports from the study, this publication is intended to provide water managers, landowners, scientists, and policy makers with a reference that summarizes hydrogeologic information for specific hydrographic areas.

Purpose and Scope

The purpose of this report is (1) to describe the geology and hydrology of the carbonate-rock aquifers in southern Nevada, and (2) to evaluate the potential for development of their water resources. To achieve these objectives, 17 hydrographic areas were selected by the U.S. Geological Survey from the 48 such areas that constitute the southern part of the State. The 17 areas were selected on the basis of the presence of thick sections of carbonate rock within the hydrographic area, the availability of geologic and hydrologic information needed to adequately evaluate the potential for development, and the accessibility to the area. The potential for development of each selected area was determined on the basis of depth to water, depth and thickness of carbonate rocks, and water quality.

In addition, this report describes the geologic processes that have affected each of the selected areas and provides such information as the depth to, and the thickness and extent of, carbonate rocks beneath basin fill. The hydrologic framework of each area is described and pertinent data such as estimates of recharge and discharge, depth to water, water quality, and location of wells and springs tapping basin fill and carbonate rocks are provided. Geologic controls that affect the location and movement of ground water are also described.

Hydrogeology of Southern Nevada

The area that includes the present southern Great Basin has undergone a diverse and complex geologic history that has spanned hundreds of millions of years. The fault-block mountains and alluvial basins that are dominant in the area today are a result of only the past 20 million years of geologic activity (Stewart, 1980; Guth and others, 1988; Smith and others, 1987a, b; Wernicke and others, 1988a). Most of the geologic past has been pieced together from the structure and composition of the rocks exposed at the surface. This formidable task was somewhat simplified in this study by segregating the numerous lithologic units into five hydrogeologic units on the basis of their ability to transmit ground water and their effect on ground-water quality. The five units are described in chronological order beginning with the youngest unit (see table 1 for approximate ages).

Quaternary and Tertiary basin-fill deposits—includes alluvial, fluvial, fanglomerate, lake, and mudflow deposits. These deposits also include the Muddy Creek and Horse Spring Formations of Tertiary age. These Tertiary formations include siltstone, gypsiferous sandstone, conglomerate, gypsum, and tuffaceous sedimentary rocks. Basin-fill deposits generally are of high permeability and constitute the primary aquifers in the State, but may produce low-quality ground water in areas where evaporite minerals (for example, Tertiary deposits containing gypsum) are present.

Tertiary rocks—chiefly volcanic rocks consisting of welded to nonwelded ash-flow and ash-fall tuffs, basalt, and rhyolite flows. The unit may also contain varying amounts of sandstone, siltstone, and conglomerate, as well as intrusive rocks. This unit is generally of low permeability, although some welded tuffs are effective aquifers (Winograd, 1971). Generally, this unit tends to act as a barrier to ground-water flow.

Table 1. Geologic time scale showing eras, periods, and approximate ages used by the U.S. Geological Survey

Era	Period	Age (approximate millions of years before present)
Cenozoic	Quaternary	0-1.7
	Tertiary	1.7-66
Mesozoic	Cretaceous	66-138
	Jurassic	138-205
	Triassic	205-240
Paleozoic	Permian	240-290
	Pennsylvanian	290-330
	Mississippian	330-360
	Devonian	360-410
	Silurian	410-435
	Ordovician	435-500
	Cambrian	500-570
Precambrian		Greater than about 570

Late Paleozoic and Mesozoic sedimentary rocks—chiefly siltstone, sandstone, shale, limestone, dolomite, and gypsum. This unit can vary from mostly carbonate to mostly noncarbonate in composition. The permeability of this unit varies from very low in shale layers to very high in fractured dolomites with solution cavities (resulting from dissolving gypsum). However, due to the presence of gypsum (an evaporite), the ground-water quality within this unit is generally unsuitable for most water uses.

Paleozoic carbonate rocks—primarily limestone and dolomite containing varying amounts of silt with interbedded shale. These rocks constitute the regional aquifer systems upon which this study is based. The carbonate rocks tend to be of low permeability except where fractured and jointed. The sequences of carbonate rock in most areas are likely to have a large number of fractures and joints.

Precambrian and Cambrian noncarbonate rocks—chiefly siltstone, sandstone, granite, and metamorphic rocks such as quartzite, gneiss, and schist. These rocks are generally of very low permeability and tend to form barriers to ground-water flow.

A short summary of the geologic history pertinent to the current hydrologic setting of the area is provided to (1) familiarize the reader with the terminology, events, and chronology that have led to the formation of the present-day Basin and Range Province (Fiero, 1986), and (2) build a hydrologic framework from which the reader can better understand the structural processes that have influenced regional ground-water flow and accessibility of water resources in carbonate-rock aquifers. A glossary of the geologic and hydrologic terminology used in this and subsequent discussions is at the end of this report.

Although the present-day fault-block structure evolved during only the past 20 million years of geologic time, the entire geologic history is much longer and more complex. It dates back to Precambrian time (table 1). Until Cambrian time, most of the geologic activity involved accretion of land masses at the continental margins resulting from merging of island arc systems (see glossary) with the continent. These deposits make up the Precambrian and Cambrian noncarbonate unit described above and are considered to be barriers to ground-water flow. Because these rocks make up the bottom or lowest unit, geologists commonly refer to these rocks in a broad sense as "basement."

Beginning in Late Cambrian time, eastern Nevada became a continental shelf (fig. 1) where carbonate rocks were deposited and accumulated to thicknesses of as much as 30,000 ft. This region is referred to as the Cordilleran miogeocline which has produced the present carbonate-rock province. This thick wedge of deposits makes up the Paleozoic carbonate-rock hydrogeologic unit that forms the carbonate-rock aquifers being evaluated for development in this report.

The Permian Period marked the end of thick accumulations of carbonate rock when compressional forces began affecting the region, resulting in the deposition of thick sequences of clastic rocks. These deposits from Permian through Cretaceous time constitute the upper Paleozoic and Mesozoic sedimentary-rock hydrogeologic unit. This unit can be a confining unit where appreciable thicknesses of clay or shale have accumulated. Structurally, the crust was greatly deformed during this episode of compression, causing thick sheets of sediment and carbonate (and basement, in some instances) rock to be thrust over one another in an eastward direction. Thrusting also produced folds in the previously flat-lying rocks. In places, the total thickness of carbonate rock was doubled or tripled. These areas today can constitute massively thick aquifer systems. Figure 2 shows how compressional forces affected the physiography of the southern Great Basin.

Beginning in the middle Tertiary period, stretching or extension of the crust occurred, resulting in large-scale faulting that caused huge blocks to be dropped, tilted, or rotated in response to being pulled apart or thinned. Figure 3 shows a schematic diagram of how extension has modified the geologic structure of the southern Great Basin. In some areas the regional carbonate aquifer system is disrupted and smaller local aquifer systems may predominate. In other areas, initially thick sections of carbonate-rock aquifer may have been thinned and fractured, but today represent prolific regional aquifer systems. Coincident with extension during the Tertiary period was widespread volcanic activity that produced rhyolitic, andesitic, and basaltic volcanic rocks. These volcanic rocks make up the Tertiary rock hydrogeologic unit defined above. Volcanic rocks can be prolific aquifers in some settings and impermeable barriers in others. In general, this unit is less permeable than the Paleozoic carbonate-rock unit.

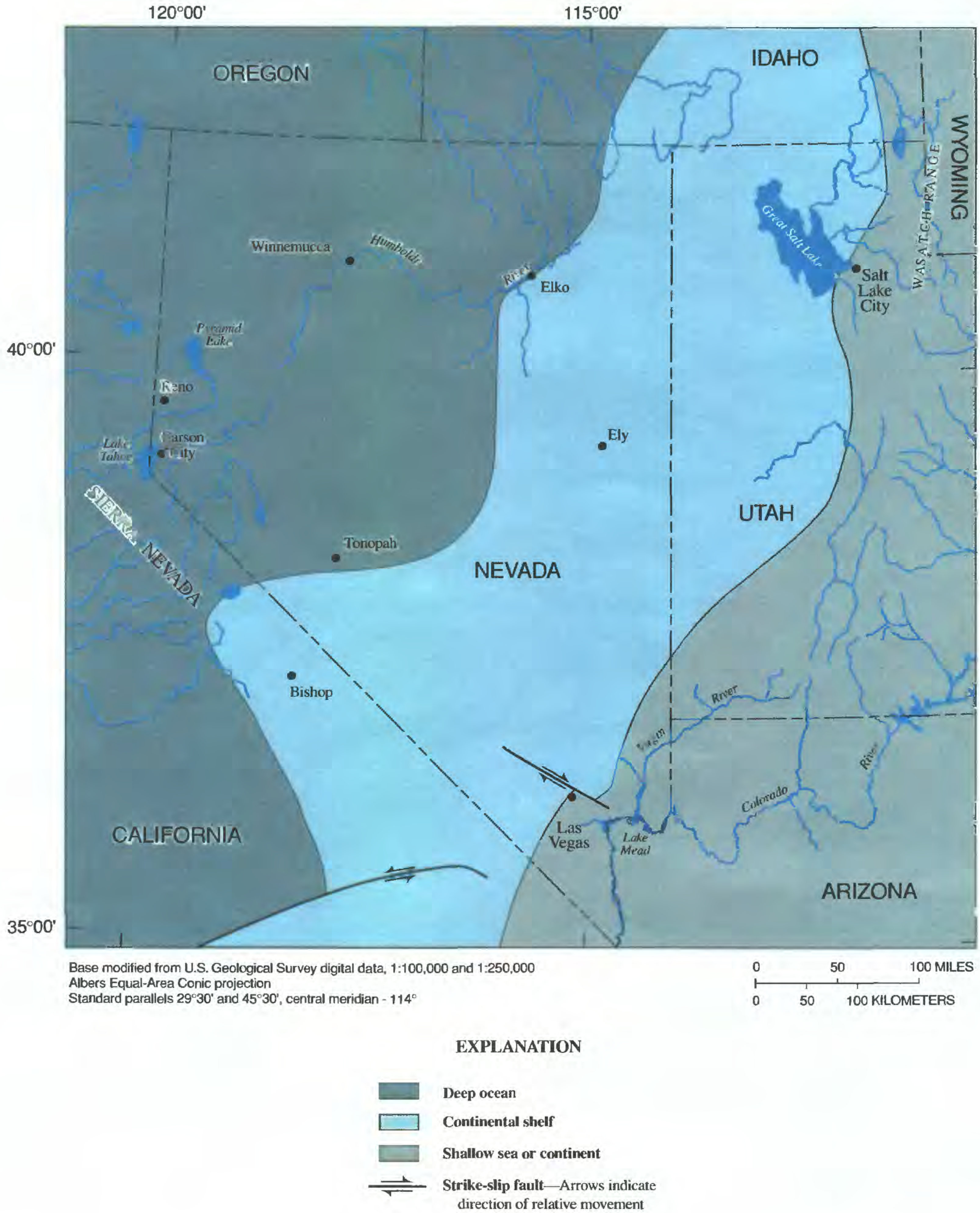
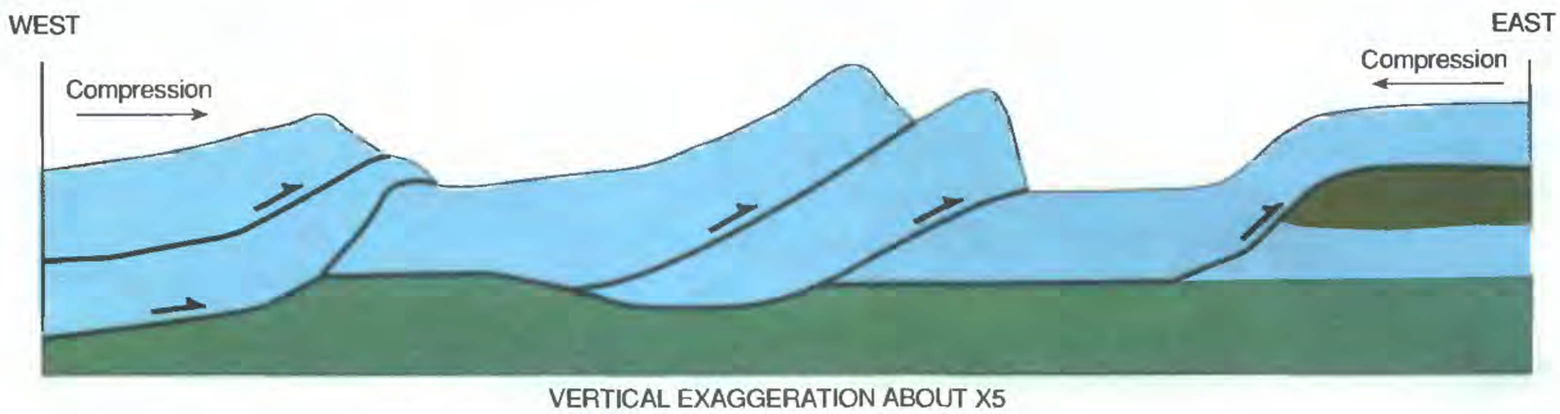


Figure 1. Extent of encroachment of ocean upon the continent during Cambrian time. The continental shelf was an area of carbonate-mineral deposition. Location is approximately coincident with the carbonate-rock province of today (Modified from Fiero, 1986).



EXPLANATION

Upper Paleozoic and Mesozoic sedimentary rock

Carbonate rock

Precambrian and Cambrian noncarbonate rock

Low-angle fault—Arrow indicates direction of block movement

Figure 2. Diagrammatic section depicting how compressional forces caused thrust faulting and subsequent thickening of the crust in the southern Great Basin.

EXPLANATION

Tertiary and Quaternary basin fill

Paleozoic carbonate rock

Precambrian and Cambrian noncarbonate rock

Fault—Arrow indicates direction of block movement

Figure 3. Diagrammatic section depicting how extensional forces caused normal faulting and thinning of the crust in the southern Great Basin.

During the later stages of extension, block faulting produced the north-trending mountain ranges characteristic of the Great Basin. Erosion of these mountain ranges and subsequent deposition filled the valleys with several hundred to more than 10,000 ft of sediment, which constitutes the uppermost and most recent hydrogeologic unit. Most of the production wells are completed in this unit because of its ease of accessibility and usually high yield. Where extension was greatest, basin fill generally is thickest. Basin fill commonly lies directly on carbonate rock, but Tertiary volcanic rocks may be interlayered between the basin fill and the carbonate rocks, especially in the northern part of the study area. Hence, developing water supplies from the carbonate rocks may require drilling through thousands of feet of saturated basin fill and volcanic rock before reaching carbonate-rock aquifers. Consequently, selection of potential sites requires an understanding of the geologic structure of southern Nevada. The once flat-lying carbonate rocks are today an aggregate of greatly deformed and faulted rock masses intermingled with noncarbonate rock types.

Acknowledgments

The author thanks the State of Nevada and the Las Vegas Valley Water District for their contributions to this study.

POTENTIAL FOR GROUND-WATER DEVELOPMENT OF CARBONATE-ROCK AQUIFERS IN SELECTED HYDROGRAPHIC AREAS

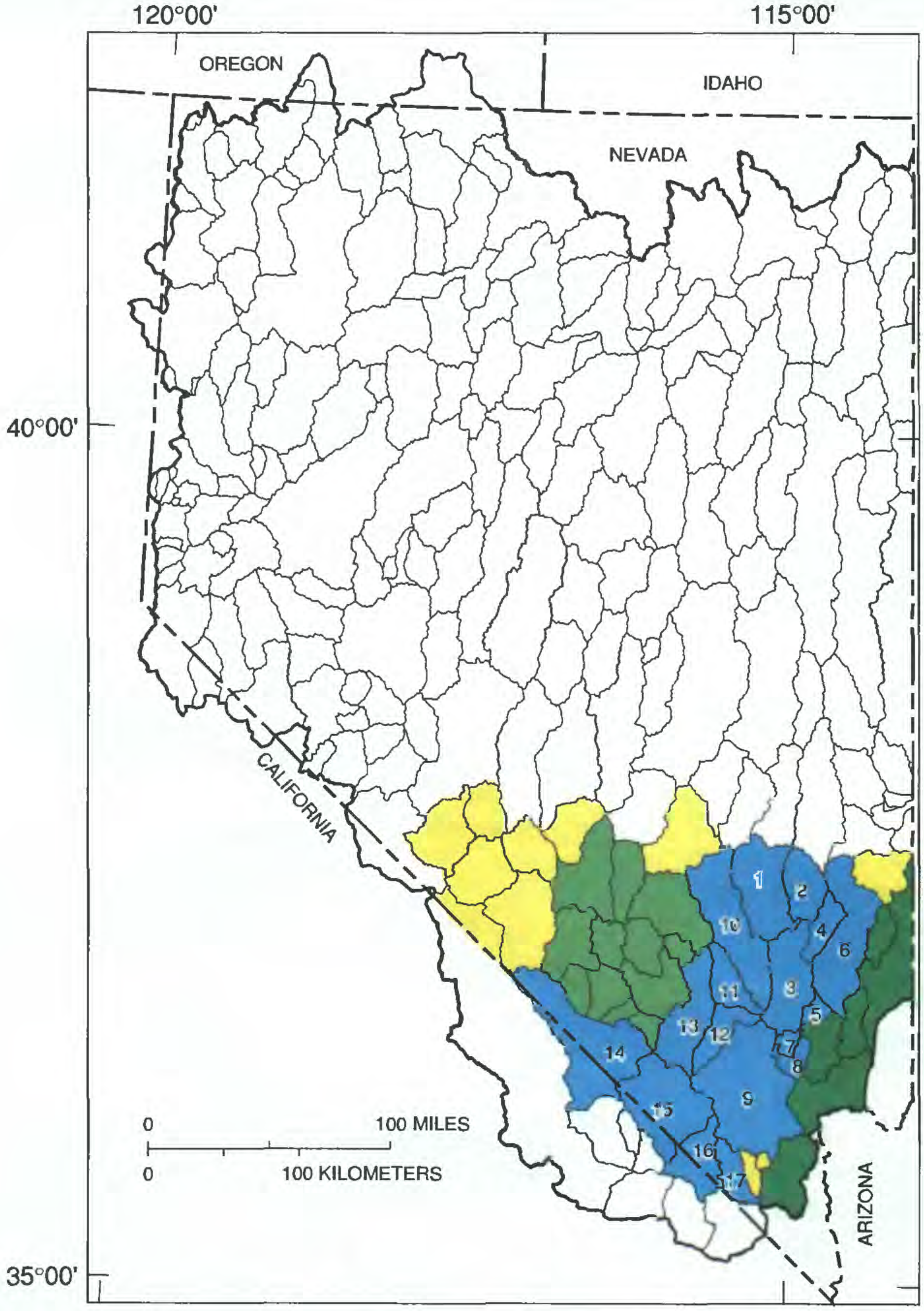
The term "hydrographic area" was first used and defined by Rush (1968b, p. 4) in place of "valley," but it also applies to areas that are called flat, desert, basin, meadow, wash, plain, area, canyon, and mesa. The names of most of the hydrographic areas are the names used by the people who live in and near the areas, and that are found on topographic maps. The boundaries of each hydrographic area generally are drawn along topographic ridges. In some localities, the lines are drawn across nearly flat alluvial terrain. Aerial photographs were used to aid in locating a suitable boundary in these flat-lying areas. Hydrographic-area boundaries are used by the Nevada State Engineer's office for water-management purposes throughout the State.

Selection of Hydrographic Areas for Analysis

The southern part of Nevada is divided into 48 hydrographic areas (Rush, 1968b). Of these, 17 were selected for analysis of their potential for ground-water development (fig. 4). The 17 areas were selected on the basis of (1) presence of thick sections of carbonate rock within the hydrographic area, (2) availability of geologic and hydrologic information needed to adequately evaluate development potential, and (3) accessibility (the Nevada Test Site and most of the Nellis Bombing Range are restricted areas).

The location and name of each selected hydrographic area is shown in figure 4. The format for discussion of selected areas consists of the hydrographic setting, geology, hydrology, and potential for development of the carbonate-rock aquifers underlying the valley within the hydrographic area. The hydrographic setting section includes a brief discussion of the physiographic features. The geology section describes the thickness and distribution of rock types found in the area, as well as a simplified discussion of how extensional and compressional forces have modified the structural setting and consequently the redistribution of carbonate rocks and the resulting aquifer systems. The hydrology section contains a summary of available hydrologic information including estimates of recharge and discharge, depth to water, direction and magnitude of ground-water flow, and geologic controls on the movement and occurrence of flow. The last section pertains to the potential for development and is based on all available geologic and hydrologic information. Finally, the available information is used to determine how short- and long-term development may affect the immediate area as well as surrounding areas.

Ground-water storage in the carbonate rocks of each hydrographic area in southern Nevada was estimated using the following assumptions. (1) Only unconfined storage is considered significant and a uniform specific yield of 1 percent is used for all carbonate rocks within each hydrographic area. This value is a combination of both effective interstitial porosity and fracture porosity in the carbonate rocks. Details of how this value was obtained are discussed in a report by Dettinger and others (1995). (2) Carbonate rocks in mountainous areas are at least 2,000 ft thick within the saturated zone (beneath the potentiometric surface). (3) Storage within the valley of each area is included



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.

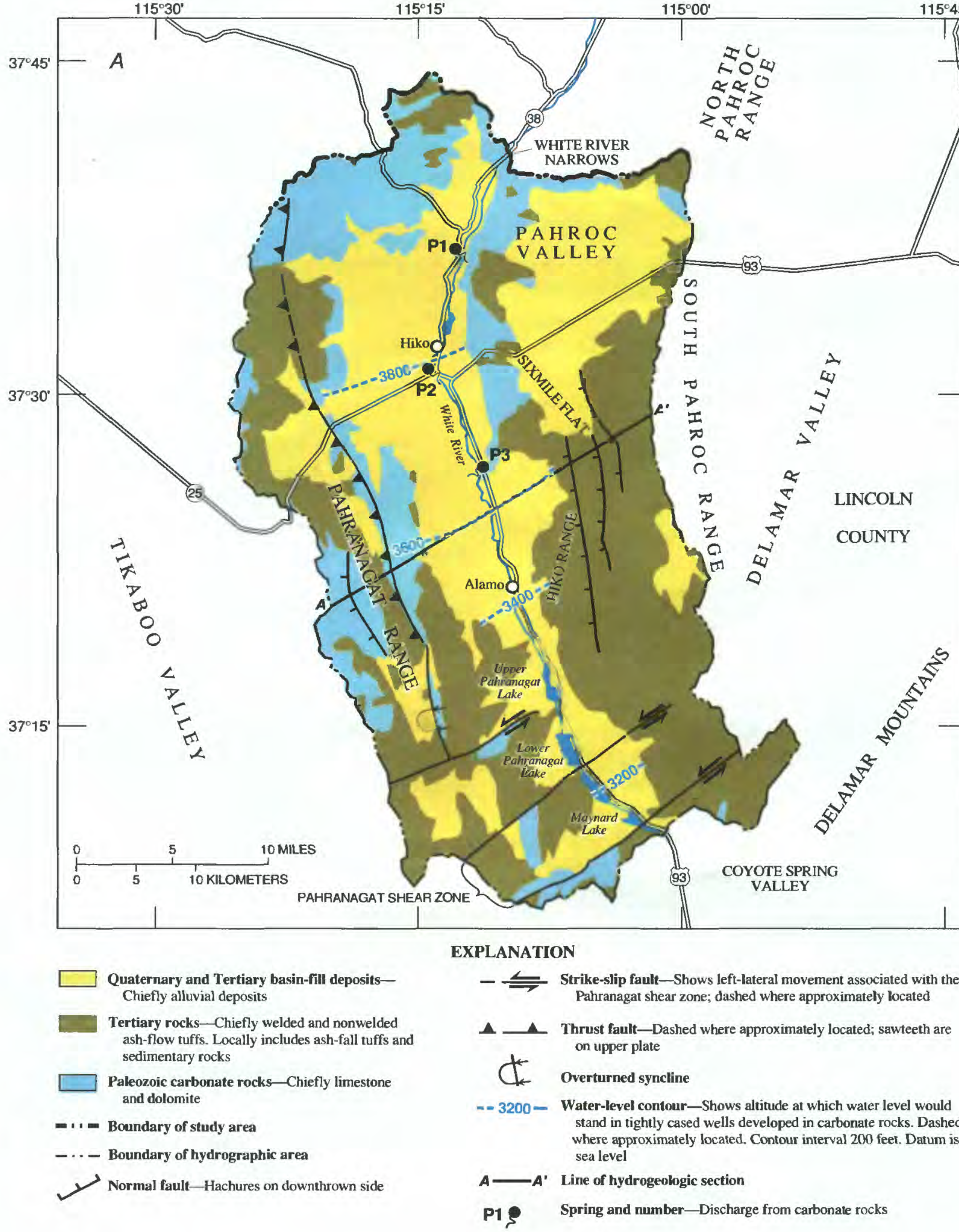


Figure 5. Hydrogeologic map and generalized section through Pahranagat Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, and springs where ground-water data are available (structural geology from Tschanz and Pampeyan, 1970, 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).

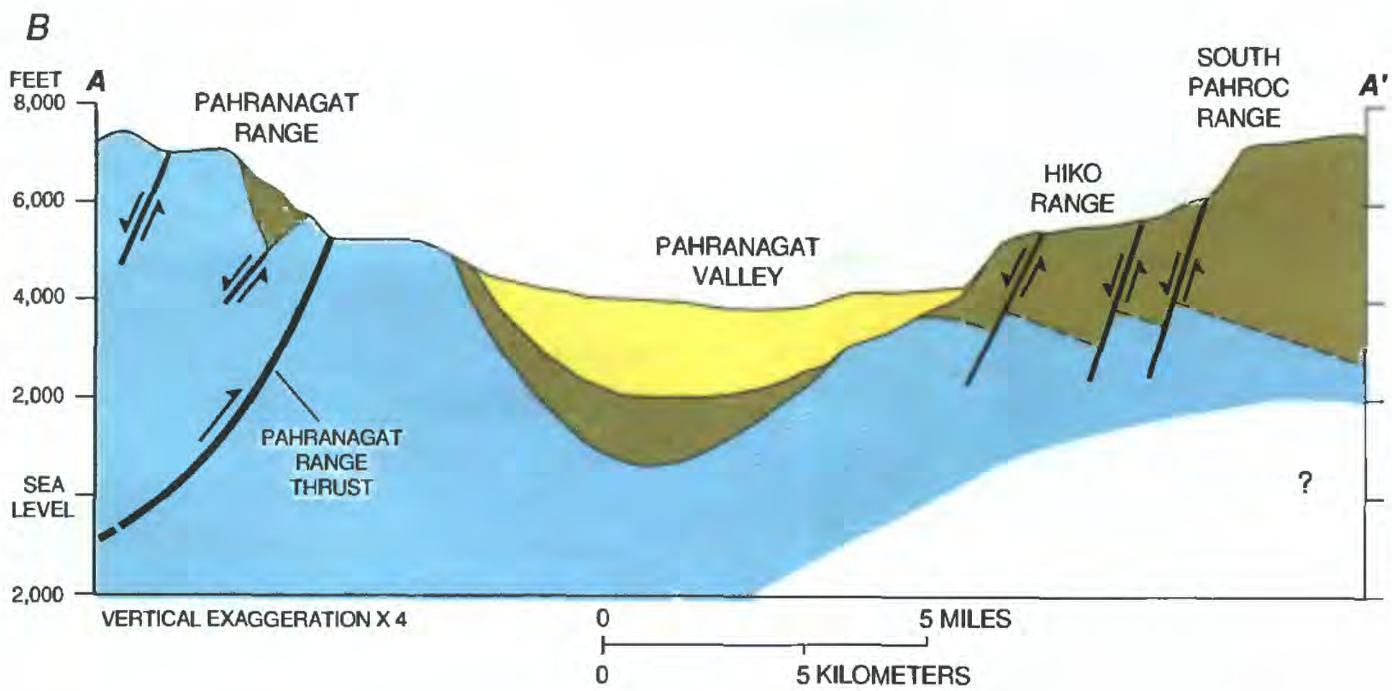


Figure 5. Continued.

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.

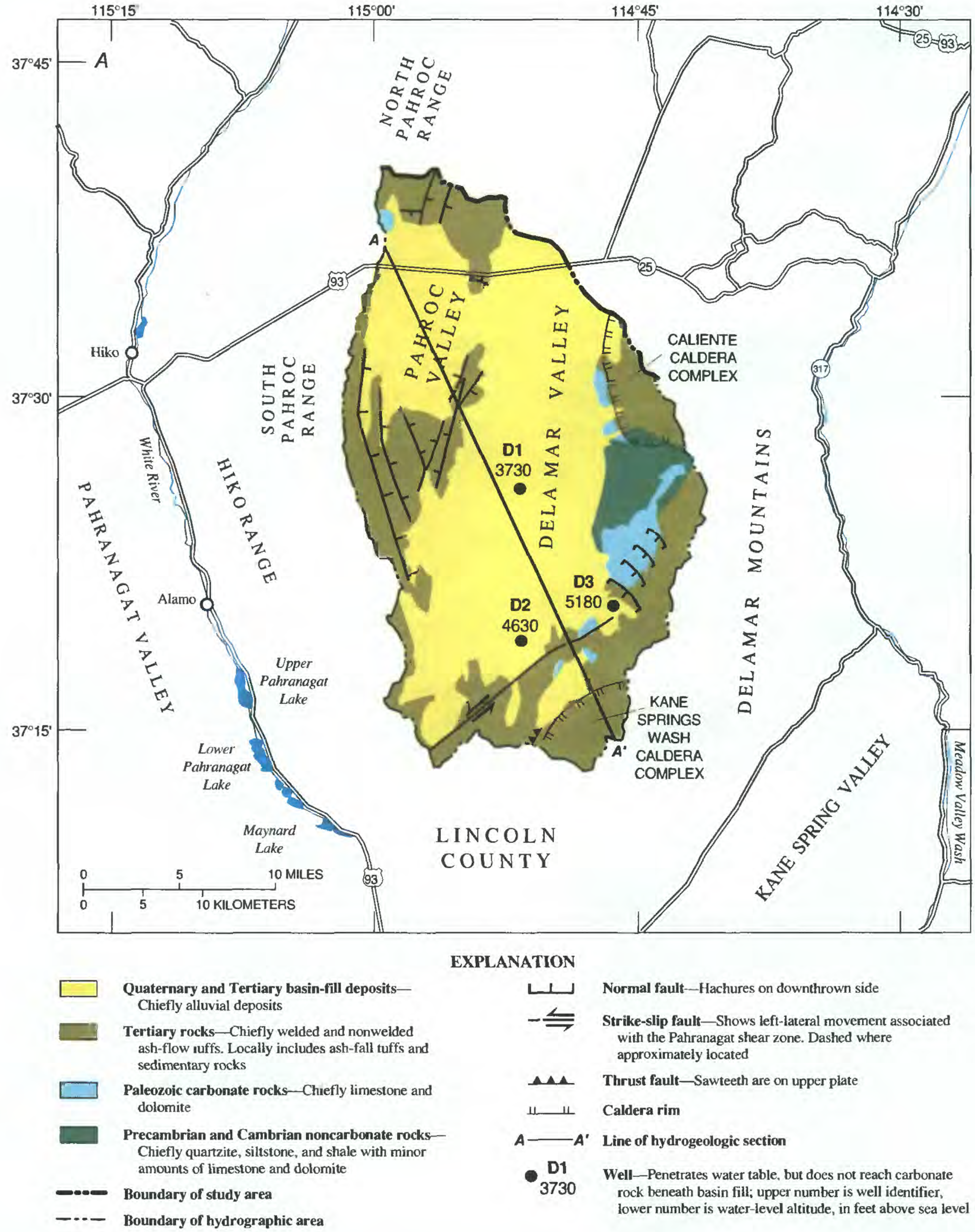


Figure 6. Hydrogeologic map and generalized section through Delamar Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, and water levels in basin fill which are considered equivalent to water levels in carbonate rocks in adjacent valleys (structural geology from 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).

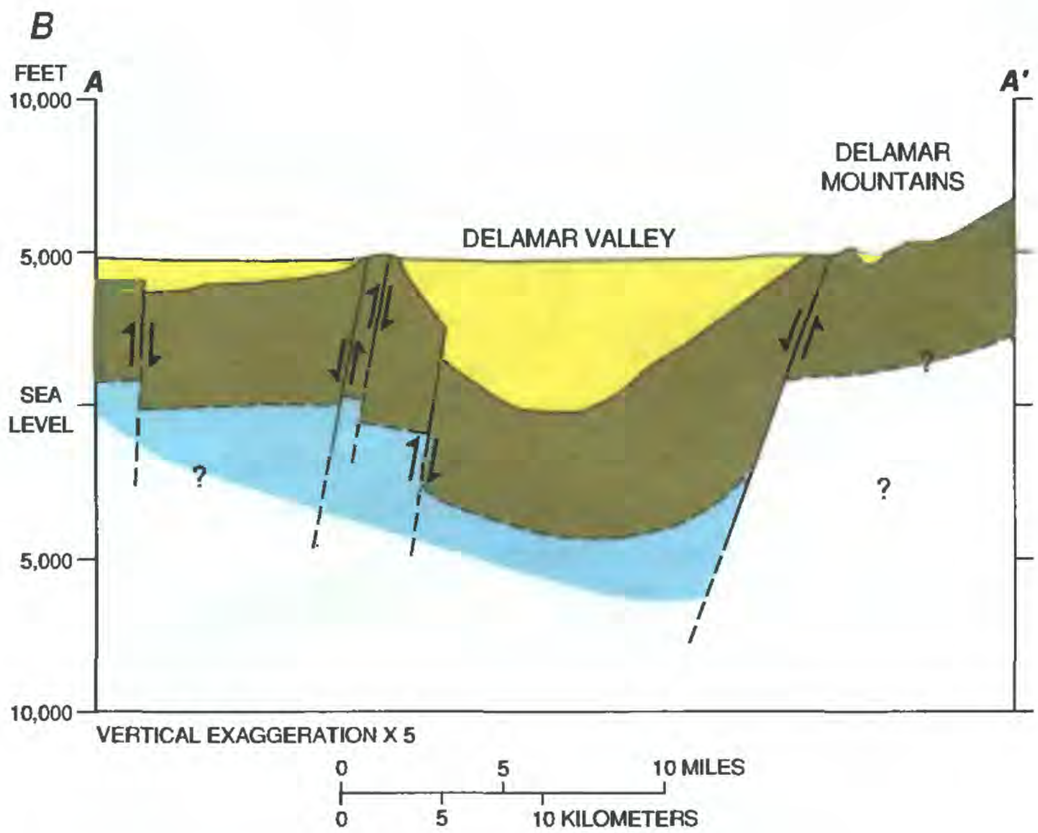


Figure 6. Continued.

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.

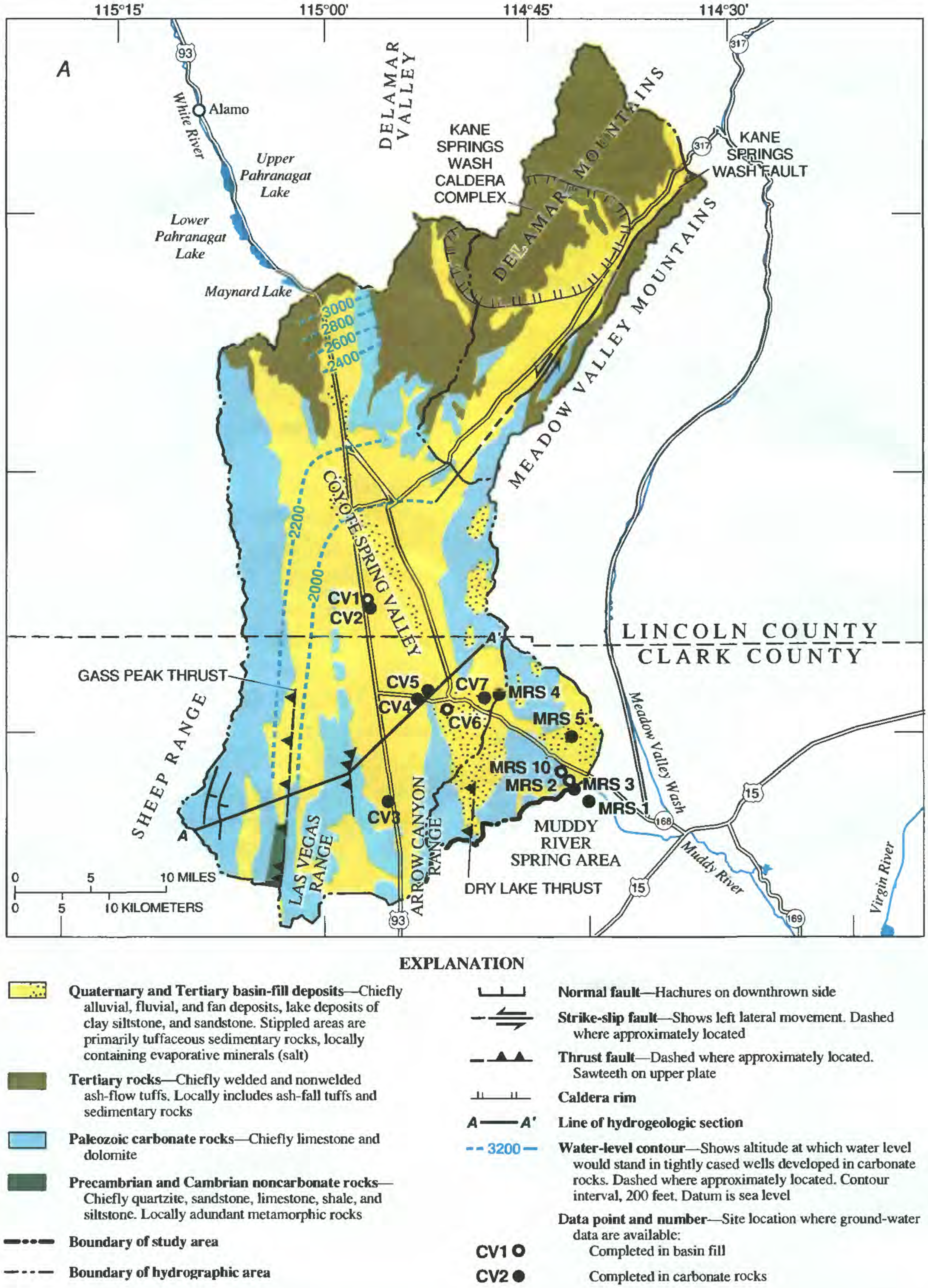


Figure 7. Hydrogeologic map of Coyote Spring Valley, Kane Springs Valley, and Muddy River Springs area and generalized hydrogeologic section through southern Coyote Spring Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, 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).

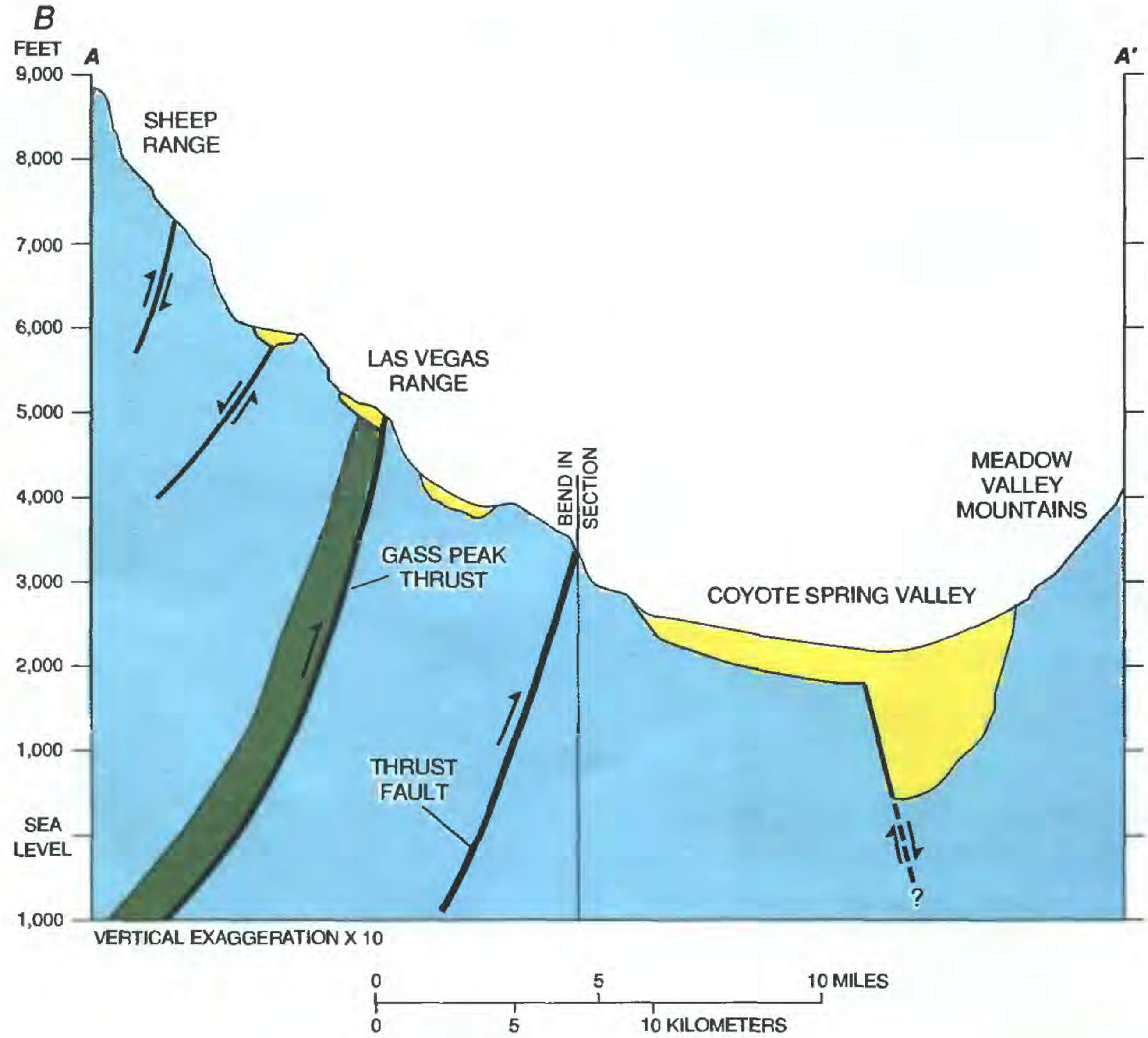


Figure 7. Continued.

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.

Table 6. Recharge and discharge estimates for Coyote Spring Valley, Kane Springs Valley, and Muddy River Springs Area

[Symbols: --, no data; <, less than; >, greater than]

Component of recharge or discharge	Quantity (acre-feet per year)		
	Coyote Spring Valley	Kane Springs Valley	Muddy River Springs area
Recharge			
Precipitation in adjacent mountain blocks			
Eakin (1964)	2,100	500	0
Welch and Thomas (1984)	4,000	500	0
Kirk (1987)	2,700	1,000	0
Subsurface inflow			
Eakin (1966)	35,000	0	37,000
Welch and Thomas (1984)	24,000 [a]	0	36,000 [c]
Kirk (1987)	26,800 [b]	0	34,000 [d]
Discharge			
Evapotranspiration from phreatophytes and bare soils			
Eakin (1964)	<200	<200	0
Springs issuing from carbonate rocks			
Eakin and Moore (1964)	<200	<200	36,000 [e]
Pumpage from basin fill or carbonate rocks			
Eakin (1964)	0	0	3,000
Whipple [f]	<300	--	--
Subsurface outflow			
Eakin (1966)	37,000 [g]	500 [h]	<200
Welch and Thomas (1984)	28,000	500	0
Kirk (1987)	29,500	1,000	0
Total recharge (rounded)	26,000-39,000	500-1,000	34,000-37,000
Total discharge (rounded)	>28,000-37,000	>500-1,000	36,000-39,000

[a] Includes 5,000 acre-feet per year from Dry Lake Valley, 2,000 acre-feet per year from Delamar and Kane Springs Valleys, and 17,000 acre-feet per year from Pahranagat Valley.

[b] Includes 16,500 acre-feet per year from Pahranagat Valley, 9,300 acre-feet per year from Dry Lake and Delamar Valleys, and 1,000 acre-feet per year from Kane Springs Valley.

[c] Includes 8,000 acre-feet per year from Meadow Valley Wash.

[d] Includes 4,500 acre-feet per year from Meadow Valley Wash.

[e] 33,700 acre-feet per year leaves as streamflow to the Muddy River. Some diurnal and seasonal fluctuations in discharge occur due to local evapotranspiration.

[f] J. Whipple, Moapa Water District, oral commun., 1988.

[g] Subsurface outflow to Muddy River Springs area.

[h] Subsurface outflow to Coyote Spring Valley.

Table 7. *Information on wells completed in and springs issuing from carbonate rocks and basin fill in Coyote Spring Valley and Muddy River Springs area*

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987.
Abbreviations and symbols: D, domestic; I, irrigation; O, observation; --, no data; ~, approximate]

Number (fig. 7)	Source	Name	Depth to water (feet below land surface)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Use
CV1	well	VF1 [a]	543	230	--	O
CV2	well	VF2	604	470	33.8	O
CV3	well	CSV3	587	380	41.1	O
CV4	well	MX4 [b]	350	480	33.8	O
CV5	well	MX5	349	470	35.5	O
CV6	well	CSV1[a]	344	320	15.5	O
CV7	well	MX6	457	560	33.3	D
MRS1	springs[c]	Muddy River[d]	0	610	32.2	I
MRS2	well	EH-4[a]	--	~600	23.88	O
MRS3	well	EH-5	--	~600	28.88	O
MRS4	well	CSV2	391	590	27.2	O

[a] Well penetrates basin fill, but water level may reflect that of carbonate rocks below.

[b] Pump-test data at well CV4 indicate specific yield of 14 percent, with transmissivity of 1 million feet squared per day (Ertec, 1981).

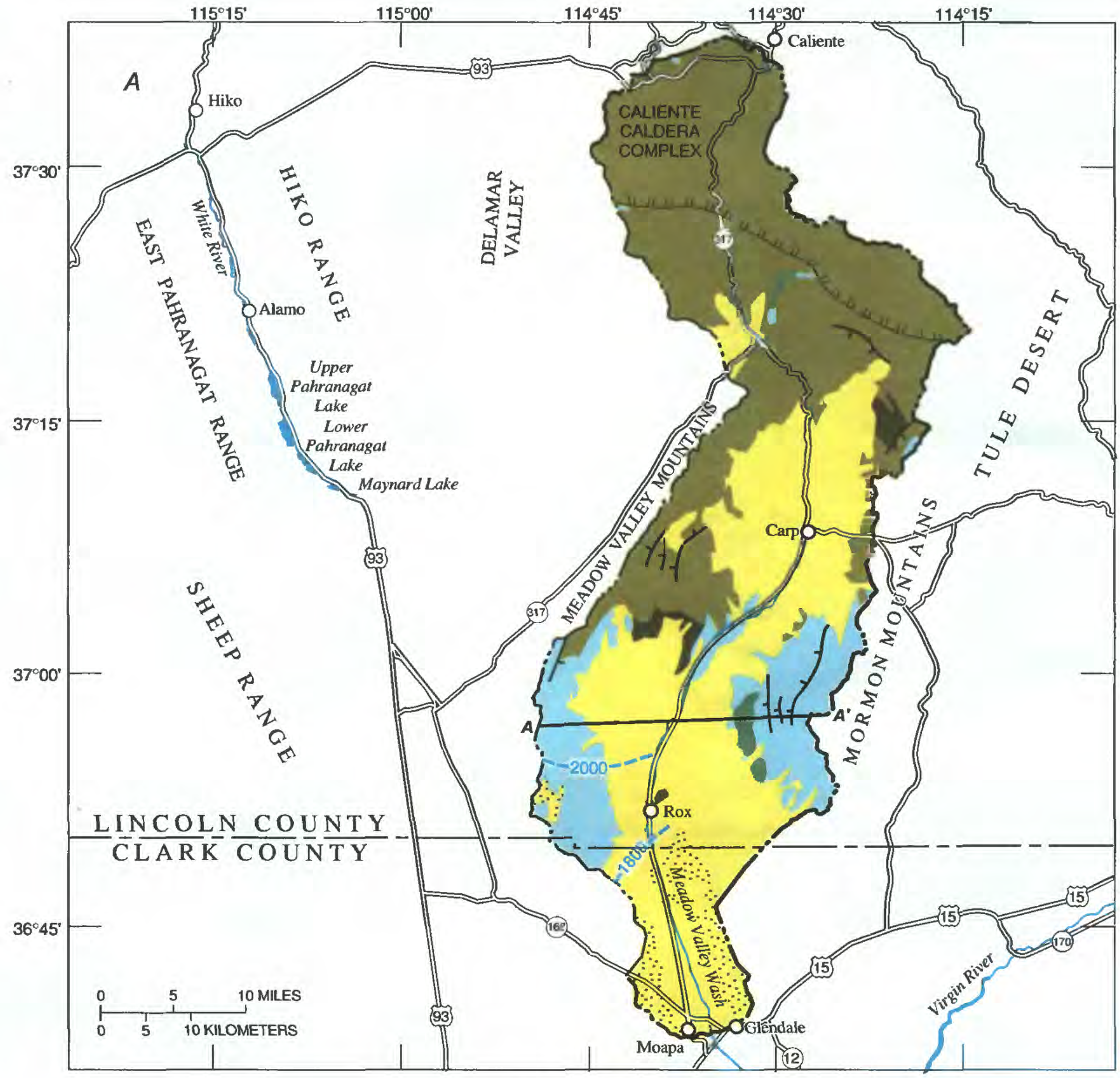
[c] Combined flow of several springs.

[d] Discharges 36,000 acre-ft/yr.

Meadow Valley Wash was incised through volcanic rocks in the northern part of the area and primarily through basin-fill deposits in the southern part of the area. The wash trends southward to the Muddy River (fig. 8), which drains into the Colorado River to the southeast. The wash south of about 37°N latitude is ephemeral due to pumping, evapotranspiration, and infiltration along its course.

Geology

The lower Meadow Valley Wash area has undergone an extremely complex geologic history that has only recently begun to be understood (Wernicke and others, 1985; Axen and others, 1987; G.J. Axen, Harvard University, written commun., 1988; Axen and others, 1988a; Axen and others 1988b). In general, the northern part of the Lower Meadow Valley Wash area consists predominantly of volcanic rocks, mostly tuffs, many of which erupted from the large Caliente caldera complex (Ekren and others, 1977) during the early Miocene. The total thickness of volcanic rocks in the caldera complex is unknown, but is believed to be at least several thousand feet. In the southern one-half of the area, exposed rocks are chiefly Paleozoic carbonates. The thickness of carbonate rocks may increase westward toward the miogeocline where much thicker deposits of carbonate rocks were deposited during the Paleozoic. Hence, the Meadow Valley Mountains may represent a much thicker sequence of carbonate rock than the Mormon Mountains. Thicknesses of carbonate rocks are generally only 1,000-3,000 ft in the



EXPLANATION

- **Quaternary and Tertiary basin-fill deposits**—Chiefly alluvial, fluvial, and fan deposits, lake deposits of clay siltstone, and sandstone. Stippled areas are primarily tuffaceous sedimentary rocks, locally containing evaporative minerals (salt)
- **Tertiary rocks**—Chiefly welded and nonwelded ash-flow tuffs. Locally includes ash-fall tuffs and sedimentary rocks
- **Upper Paleozoic carbonate rocks**—Chiefly siltstone, claystone, and cherty limestone, with sparse conglomerate and gypsum
- **Paleozoic carbonate rocks**—Chiefly limestone and dolomite
- **Precambrian and Tertiary basin-fill deposits**—Chiefly quartzite, sandstone, limestone, shale, and siltstone. Locally abundant metamorphic rocks
- **Boundary of study area**
- **Boundary of hydrographic area**
- **Caldera rim**
- **Normal fault**—Hachures on downthrown side
- *A*——*A'* **Line of hydrogeologic section**
- --1800— **Water-level contour**—Shows altitude at which water level would stand in tightly cased wells developed in carbonate rocks. Dashed where approximately located. Contour interval, 200 feet. Datum is sea level

Figure 8. Hydrogeologic map and generalized section through Lower Meadow Valley Wash. *A*, Hydrographic area showing rock units and major structural features (structural geology from Ekren and others, 1977; Wernicke and others, 1985; Axen and others, 1987; and G.J. Axen, Harvard University, written commun., 1988; hydrogeology from Thomas and others, 1986; Emme, 1986). *B*, Generalized hydrogeologic section through the Lower Meadow Valley Wash (geology from P.L. Guth, Harvard University, written commun., 1988).

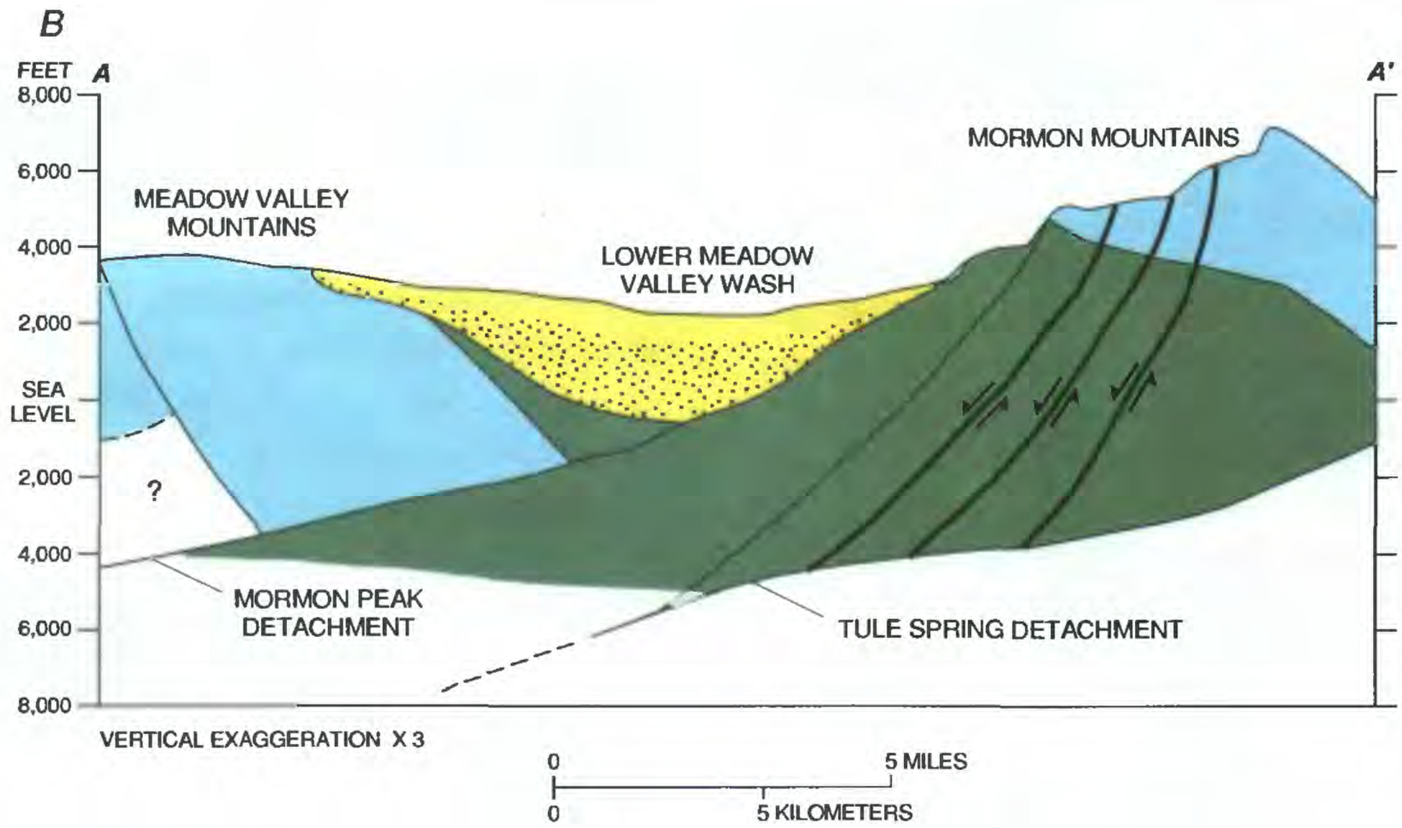


Figure 8. Continued.

Mormon Mountains and perhaps 5,000-6,000 ft in the Meadow Valley Mountains (fig. 8). Paleozoic rocks may be absent beneath much of the valley. A thick wedge of Tertiary deposits and Mesozoic sedimentary rocks occupies the basin between the ranges. Tertiary deposits thicken southward and may exceed 4,000 ft in the extreme southern part of the area (B.F. Lyles, Desert Research Institute, oral commun., 1988). Mesozoic sedimentary rocks containing evaporites may be abundant beneath the north-central part of the area (D.L. Schmidt, U.S. Geological Survey, oral commun., 1988) and may influence the quality of ground water. In the western part of the Mormon Mountains, exposures of Precambrian and Cambrian noncarbonate rocks, comprised mainly of quartzite, conglomerate and other clastic, and metamorphic rocks, are common. These rocks of low permeability probably act as a barrier to ground-water flow. These rocks become more predominant with depth, as schematically shown in figure 8.

Evidence for eastward thrusting and thickening of the Paleozoic section has been found in the Mormon Mountains (Wernicke and others, 1985). Later, in middle Tertiary time, extreme extension between the Mormon and Meadow Valley Mountains (fig. 8) has resulted in a highly complex, highly broken, faulted, and thin sequence of Paleozoic rocks overlying Cambrian clastic and Precambrian basement rocks in the Mormon Mountains (fig. 8). These highly broken carbonate rocks probably represent a large aquifer system where located below the water table. Extension greatly thinned the area between the Mormon and Meadow Valley Mountains (5-16 mi of extension likely, Wernicke and others, 1985). Thick sequences of Tertiary deposits overlie Mesozoic to Precambrian rocks beneath the basin between these ranges. Extension in this area probably postdates active volcanism in the northern part of the hydrographic area (Axen and others, 1987; Axen and others, 1988a); hence, many of the volcanic rocks are probably highly fractured and may transmit a significant amount of water locally. Extensional boundaries concomitant with stable or less extended areas often represent flow-system boundaries as well (Dettinger, 1987).

Hydrology

Recharge from surrounding mountain ranges, namely the Clover and Delamar Mountains to the north and the Mormon Mountains to the east, is estimated to be 1,300 acre-ft/yr (Rush, 1964). Recharge in the Meadow Valley Mountains (estimated by the Maxey-Eakin method to be about 1,000 acre-ft/yr) probably flows southward beneath the range to the Muddy River Springs area, and does not likely contribute significantly to the Lower Meadow Valley Wash hydrographic area. Additional water from surface flow within Meadow Valley Wash and subsurface inflow from areas to the north probably contribute most of the ground water in Meadow Valley Wash. Surface-water flow in Meadow Valley Wash south of Caliente averages about 8,800 acre-ft/yr (Frisbie and others, 1985). However, Rush (1964) concluded that the total surface-water contribution to ground-water flow in the wash is considerably less because pumping (water primarily from the river) and evapotranspiration account for an estimated 6,000 acre-ft/yr of this total. The amount of subsurface inflow from the north has not been estimated, but Emme (1986) suggests that the amount may be negligible on the basis of the isotopic and geochemical composition of ground water north of the area. The presumed absence of subsurface inflow may be attributed to the thick volcanic section in the northern part of the area.

No wells penetrate carbonate rocks in the area; consequently, water levels within the carbonate rocks are not known. Water levels within the basin fill are shallow throughout much of the area, but correlation between these water levels and those within the carbonate rocks is difficult to postulate—particularly in the southern part of the area where late Tertiary sediments are thick and may confine the water within the carbonate rocks. Perhaps only in the southwesternmost part of the area are basin-fill water levels representative of water levels in the underlying carbonate rocks.

Ground-water flow within the Lower Meadow Valley Wash area is generally from north to south in either the shallow alluvium or in Paleozoic carbonate rocks at depth along the west side of the valley (fig. 8) because the Tertiary and Mesozoic deposits have low permeability. Rush (1964) estimated that between 4,400 and 8,000 acre-ft/yr of ground water may leave the area as subsurface outflow near Glendale at the southernmost part of the valley (fig. 8). The amount of discharge surpasses the amount of estimated recharge; hence, the additional source of recharge to the area must be either (1) recharge from the volcanic rocks in the northern part of the hydrographic area, (2) surface water that infiltrates into the basin fill, or (3) subsurface inflow from outside the immediate hydrographic area boundary. The first of these three sources is the most plausible because, as stated earlier, the volcanic rocks may be highly fractured and may allow more infiltration of precipitation than previously thought. Subsurface inflow may also contribute additional ground water to the area (Prudic and others, 1993). Further studies are needed to accurately describe the quantity and origin of ground water recharged to and discharged from the area.

The structural geology of the area is such that two distinct flow systems may be present. The main flow system probably extends from the Clover and Delamar Mountains in the north to the south-southwest beneath the Meadow Valley Mountains where the carbonate rock section is thickest. J.M. Thomas (U.S. Geological Survey, oral commun., 1988) suggests that discharge from the Lower Meadow Valley Wash area supports spring discharge in the Muddy River Springs area (figs. 7 and 8). Ancient spring mounds (areas where springs once discharged) in the eastern Meadow Valley Mountains (D.L. Schmidt, U.S. Geological Survey, written commun., 1988) indicate that abundant ground water flowed during late Tertiary time beneath the Meadow Valley Mountains. This may indicate that the main flow path today is similarly located.

A second flow system within the area may be a narrow zone extending southward from the Mormon Mountains (Dettinger, 1987). Because Precambrian crystalline rock as well as Cambrian clastic rocks, Mesozoic sedimentary rocks, and upper Tertiary sediments occupy much of the area between the western Mormon Mountains and the Meadow Valley Mountains (fig. 8), it is unlikely that flow from these two areas mixes beneath the central part of the valley. Instead, recharge from the Mormon Mountains may feed Rogers and Blue Point Springs farther to the south (M.D. Dettinger, U.S. Geological Survey, oral commun., 1988).

The total quantity of storage in the carbonate rocks of the Lower Meadow Valley Wash area has been estimated, on the basis of the assumptions described earlier in this report, to be about 2.7 million acre-ft. This estimate is likely to be high as the thickness of saturated carbonate rock is limited beneath the Mormon Mountains. Local storage (within the basin fill) is limited to areas adjacent to the Meadow Valley Mountains (pl. 1) and has been estimated to be about 0.7 million acre-ft. This local storage reservoir is probably continuous with the carbonate-rock reservoir beneath the Coyote Spring Valley hydrographic area located to the west of the Meadow Valley Mountains.

Potential for Ground-Water Development

Parts of the Lower Meadow Valley Wash area may be favorable sites for development; however, further study is needed to accurately describe the hydrology of the area because no wells penetrate the underlying carbonate rocks. Geologic sections (G.J. Axen, Harvard University, written commun., 1988) indicate that the carbonate rocks along the western side of the valley (east of the Meadow Valley Mountains) are several thousand feet thick and relatively shallow beneath the basin fill (pl. 1). However, this is a questionable site for development until further investigations are made because of the uncertainty about the depth to water, the quantity of water, and the effects of development on discharge at Muddy River Springs.

The eastern part of the area, where carbonate rocks are known to be present, is not easily accessible except in the extreme south because Precambrian rocks are exposed in the western part of the Mormon Mountains, and the amount of flow is probably not more than several thousand acre-ft/yr. Thus, this area is also a questionable site for developing carbonate-rock aquifers.

Development potential in the northern part of the area is highly uncertain because a thick section of volcanic tuff covers most of the area and the thickness and distribution of carbonate rocks underlying the volcanic rock is uncertain, especially in the area of the caldera complex. Another disadvantage in developing the northern part of the area is that a thick sequence of evaporite-bearing Mesozoic sedimentary rocks intervenes at least in places between the volcanic rocks and the Paleozoic carbonate rocks (D.L. Schmidt, U.S. Geological Survey, written commun., 1988).

Hidden and Garnet Valleys

Hydrographic Setting

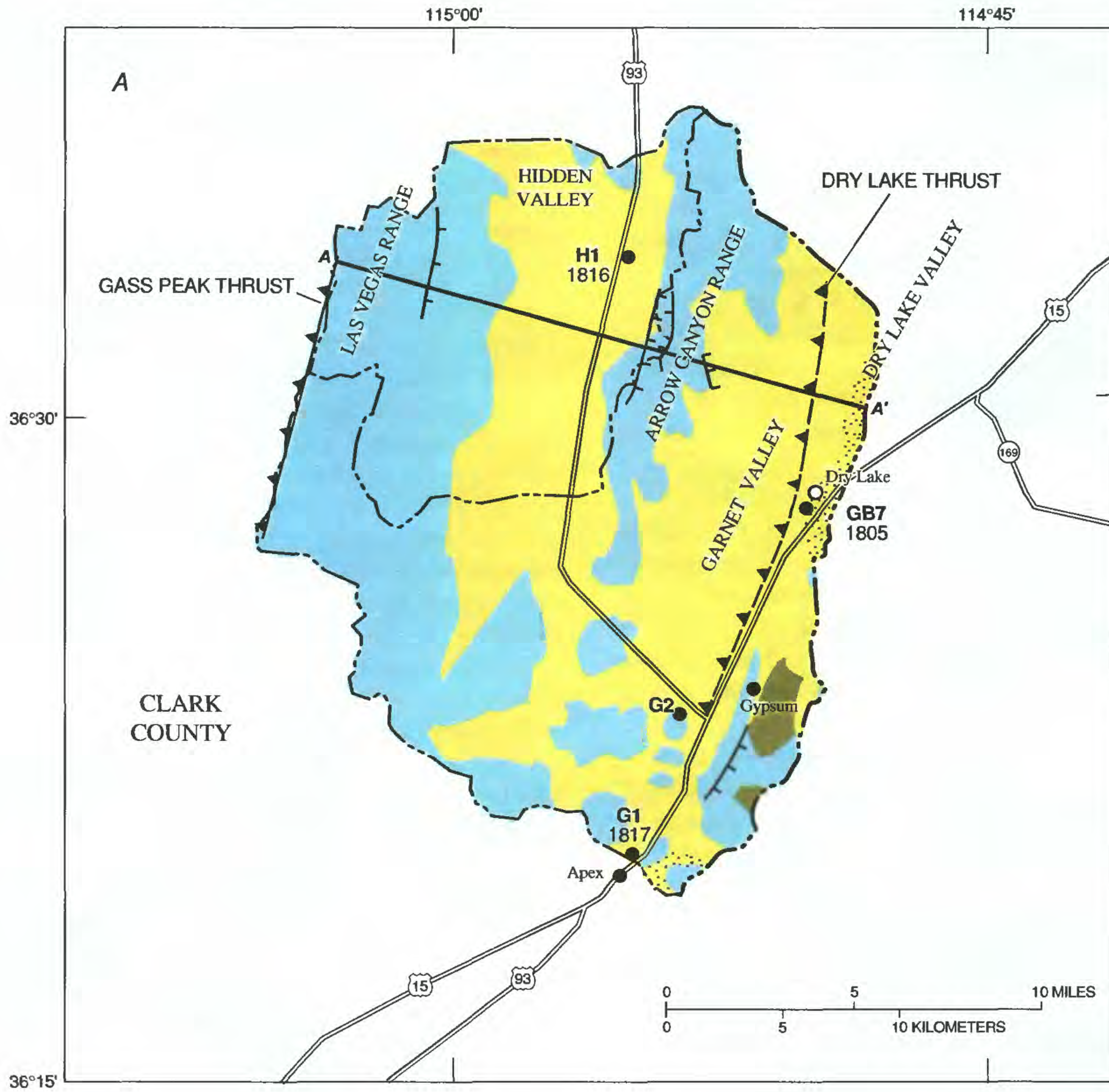
The Hidden and Garnet Valley hydrographic areas are the two smallest areas discussed in this report (fig. 9). Hidden Valley occupies only 80 mi^2, whereas Garnet Valley (more commonly referred to as Dry Lake Valley, but distinct from the earlier mentioned Dry Lake Valley north of Delamar Valley) encompasses about 156 mi^2. Both valleys are topographically closed and are bordered by small mountains or basin-fill topographic divides. Surface drainage in both valleys terminates in dry playas near the center of each valley (fig. 9). Hidden Valley is uninhabited, whereas the small community of Dry Lake in Garnet Valley is supported by a railroad that crosses the southeastern part of the valley. Lime and gypsum plants are also located along the railroad in southwestern Garnet Valley.

Geology

The Hidden and Garnet Valley areas are composed of mainly Paleozoic carbonate rock, both in the ranges surrounding the areas and beneath the valleys (fig. 9). Perhaps the thickest known section of carbonate rock in southern Nevada is beneath the Arrow Canyon Range where about 17,000 ft of limestone and dolomite were measured during exploration drilling (G2, fig. 9). Evaporite-bearing Mesozoic sedimentary rocks are exposed in the southern part of Garnet Valley, and these rocks may be present in between the basin fill and carbonate rocks beneath the valley. Quaternary and Tertiary basin fill may reach a thickness of 4,500 ft in Garnet Valley (D.L. Berger, U.S. Geological Survey, oral commun., 1988), whereas the basin fill in Hidden Valley is generally less than 500 ft thick and directly overlies carbonate rock (fig. 9). The Tertiary deposits, like the Mesozoic rocks, contain evaporites (mainly gypsum).

Compressional tectonics have had a dramatic impact on the area as evidenced by the thick carbonate-rock section that may contain three thrust sheets, according to drillers' logs. Of the three possible thrusts, only the Dry Lake thrust fault is exposed and can be inferred at depth (fig. 9). This fault is a potential barrier to ground water flowing out of Garnet Valley to the east. The Gass Peak thrust, which does not directly affect the area, is exposed along the western edge of the Hidden Valley hydrographic area and probably represents a hydrologic barrier because Precambrian and Cambrian clastic rocks lie between the carbonate rocks beneath Hidden Valley and carbonate rocks in areas to the west.

Extensional tectonics have not had a significant impact on the geology of the Hidden and Garnet Valley hydrographic areas, according to Wernicke and others (1984), because much of the Paleozoic section has retained its subhorizontal structure between the Gass Peak thrust fault to the west and the range-front fault on the west side of the Arrow Canyon Range to the east (fig. 9). The range-front fault zone contains prominent



EXPLANATION

Quaternary and Tertiary basin-fill deposits—Chiefly alluvial and fluvial sandstone, lakebed clay, siltstone and conglomerate. Stippled areas include gypsiferous sandstone and gypsum

Upper Paleozoic carbonate rocks—Chiefly siltstone, sandstone, cherty limestone, shale, and gypsum

Paleozoic carbonate rocks—Chiefly limestone and dolomite

Boundary of study area

Boundary of hydrographic area

Normal fault—Hachures on downthrown side

Thrust fault—Dashed where approximately located. Sawteeth on upper plate

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

G1 ● 1817 **Well**—Completed in carbonate rocks. Upper number is well identifier; lower number is water-level altitude, in feet above sea level

Figure 9. Hydrogeologic map and generalized section through Hidden and Garnet Valleys. *A*, Hydrographic areas showing hydrogeologic rock units, major structural features, and wells completed in carbonate rocks (structural geology from D.L. Schmidt, written commun., 1988; D.L. Schmidt and G. Dixon, written commun., 1987; Langenheim, 1988; and Anderson and Jenkins, 1970; hydrogeology from Thomas and others, 1986). *B*, Generalized hydrogeologic section through Hidden and Garnet Valleys (geology from D.L. Schmidt, U.S. Geological Survey, written commun., 1988; Langenheim, 1988; Anderson and Jenkins, 1970; Hedlund and others, U.S. Geological Survey, written commun., 1966).

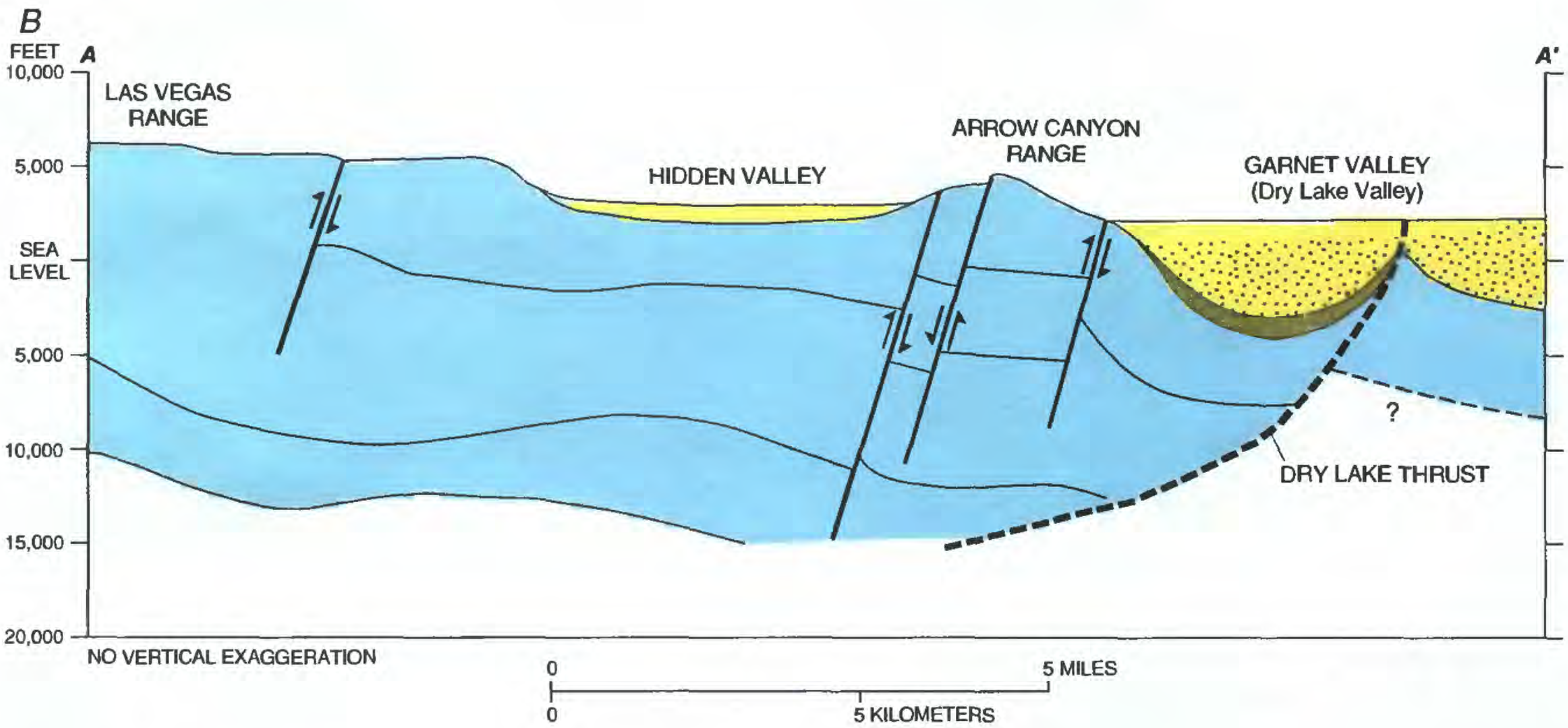


Figure 9. Continued.

vertical faults with vertical displacements of thousands of feet (Langenheim, 1988) and may compartmentalize ground-water flow locally. East of the range-front fault zone in the Arrow Canyon Range, Paleozoic carbonate rocks form a syncline (Anderson and Jenkins, 1970), as shown in figure 9.

Hydrology

Recharge to and discharge from Hidden and Garnet Valleys is small. Rush (1968a) estimated that 800 acre-ft/yr may recharge this area from local ranges; most of the recharge originates in the Las Vegas Range. A small amount of subsurface inflow from Coyote Spring Valley to the north may also enter the area. Discharge is either by subsurface outflow or pumping near the community of Dry Lake and at the lime and gypsum plants near Apex in southern Garnet Valley (fig. 9). Water levels are too deep for evapotranspiration of ground water or spring discharge. In Hidden Valley, depth to water is generally 800-900 ft below land surface. In Garnet Valley the altitude of the land surface is about 700 ft less than Hidden Valley; consequently, the depth to water is only 200-300 ft below the valley floor. At the town of Dry Lake, most wells penetrate the carbonate-rock aquifers because the Quaternary and Tertiary basin-fill deposits and Mesozoic sedimentary rocks are thin or not present at the margins of the valley (fig. 9).

Water-level gradients in the Hidden-Garnet Valley area are extremely flat (water-table altitude is approximately 1,800 ft above sea level in both areas; fig. 9). Geochemical and isotopic data from wells completed in carbonate rocks in the valleys (table 8) suggest that the area is both chemically and isotopically homogeneous (J.M. Thomas, U.S. Geological Survey, oral commun., 1988). Isotopic data also suggest that the water in this area is probably from the White River ground-water flow system with possibly some recharge from the Sheep Range or, more likely, the Las Vegas Range. Generally, ground-water flow into the area is negligible. Thus, the area probably represents the extreme southern end of the White River flow system, but is not dynamically connected to it because virtually all the ground-water flow in the White River system is discharged north of these valleys in the Muddy River Springs area. A small amount of ground water flows southeast from Hidden to Garnet Valley and a similarly small amount flows eastward from Garnet Valley beneath California Wash (Rush, 1968a).

Table 8. Information on wells completed in carbonate rocks in Hidden and Garnet Valleys

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations and symbol: D, domestic; I, industrial; O, observation; --, no data]

Number (fig. 9)	Name	Depth to water (feet below land surface)	Depth to carbonate rocks (feet below land surface)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Use
H1	SHV-1	833	250	470	23.8	O
G1	APEX	660	1,050	1,000	31.1	I
G2	Grace Petroleum	--	1,040	1,000	26.6	O
GB-7	Dry Lake Valley	260	532	960	28.8	D

The quantity of ground-water storage in carbonate aquifers beneath Hidden and Garnet Valleys is limited because of the small size of the area. Total storage in the two hydrographic areas, on the basis of assumptions discussed earlier in this report, is estimated to be about 2.8 million acre-ft. Local storage (within the basin fill) in the two areas represents about 1.4 million acre-ft, or about one-half of the total storage. This total falls within the range reported by Rush (1968a), who estimated that between 1,500 and 5,000 acre-ft/ft of water is stored in the carbonate rocks directly beneath the valley floors. Although the criteria for estimating storage uses a 2,000-ft thickness, there is potentially eight times this amount of saturated carbonate rocks beneath the area; hence, the actual quantity of ground-water storage may be much greater than presented here. The carbonate rocks constituting the storage reservoir of the area probably are hydrologically connected with the carbonate rocks beneath Coyote Spring Valley to the north. Continuity with carbonate rocks beneath Las Vegas Valley to the southwest may be restricted by the presence of the Las Vegas Valley shear zone, and water-level data suggest that a hydrologic divide is present between Las Vegas and Garnet Valleys (Thomas and others, 1986).

Potential for Ground-Water Development

Virtually all of the ground water that would be removed during development would come from storage within the carbonate rocks because only a small amount of water replenishes the aquifer in the area. Furthermore, development would initially not have significant impact on discharge to surrounding areas. Structural boundaries such as the Gass Peak thrust fault to the west, the possibility of rather shallow clastic rock to the north, and the Las Vegas Valley shear zone to the south also may favor development of the area and may limit the effects of ground-water withdrawal on nearby areas. Sites most suited for development are in east Hidden Valley where the depth to carbonate rock and water quality meet established criteria (pl. 1). How structural boundaries may aid in limiting effects of development is not known, but Hidden Valley probably represents a more favorable site for development than most other hydrographic areas in southern Nevada even though water levels are quite deep.

The factors that make Hidden Valley a favorable site also contribute to its disadvantage as a potential site. Almost all water pumped from the region would come from storage that is not readily replenishable. It could take thousands of years for these aquifers to be replenished if they are significantly developed. Long-term pumping would be limited due to the small area, although the thickness of the saturated carbonate-rock section is substantial (more than 10,000 ft). Ground-water quality is somewhat lower than in many other carbonate-rock settings in the study area because sulfate is at high concentrations in wells tapping carbonate rocks owing to the presence of evaporites in the thick Tertiary basin fill and Mesozoic sedimentary rocks in the Garnet Valley area.

Las Vegas Valley

Hydrographic Setting

Las Vegas Valley is the largest hydrographic area described in this report, covering 1,564 mi^2 in east-central Clark County (fig. 10). Metropolitan Las Vegas occupies much of the valley lowlands and is surrounded by long, gently sloping, piedmont surfaces that separate the lowlands from the mountain ranges (Bell, 1981). These piedmont surfaces, sometimes referred to as coalescing alluvial fans, reach lengths of 10 mi west of the city, but are generally about 2-5 mi long in much of the valley. The valley slopes gently to the east and southeast and is drained by Las Vegas Wash, which discharges into Lake Mead. Las Vegas Wash was ephemeral, but has become perennial as a result of urban-induced discharges, especially treated effluent.

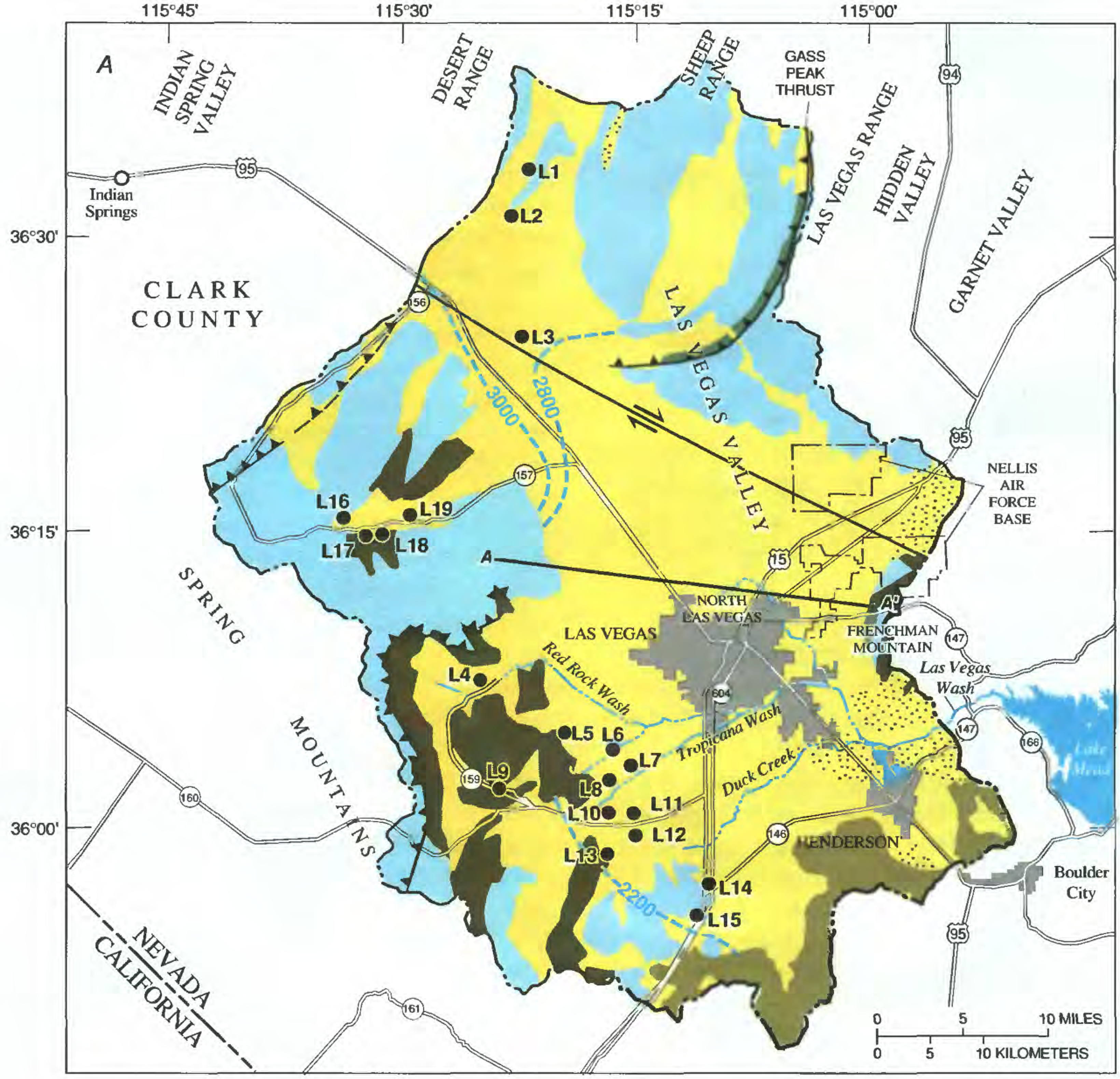
Las Vegas Valley, the population center of the entire study area, had approximately 630,000 residents as of 1987, living in three principal communities—Las Vegas, North Las Vegas, and Henderson. The Las Vegas area was probably first inhabited by settlers because of springs in the area. During the mid-1800's, the area was settled by Mormon missionaries and after 1905 became a community supported by railroads that ran through the area. During and after World War II, gaming and tourism began to thrive, accompanied by an increasing population. Las Vegas and vicinity remains one of the fastest growing areas in the country and has undergone a 3,000-percent increase in population since 1946 when the area had only 21,000 residents (Maxey and Jameson, 1948). Today, Las Vegas is not only a major tourist attraction but also is one of the world's largest convention centers. In addition, Nellis Air Force Base is in the east part of the valley (pl. 1).

The rapid growth of metropolitan Las Vegas has led to an overdraft of aquifers, resulting in depleted ground-water storage and locally severe land-subsidence problems (Bell, 1981; Harrill, 1976). Water imported from Lake Mead surpassed that obtained from pumping in 1975. In 1990, imported surface water represented approximately 75 percent of the total consumptive use in the valley; this figure is likely to increase as water demands increase.

Geology

The Las Vegas Valley hydrographic area contains all five hydrogeologic rock units defined in this study. Precambrian and Cambrian noncarbonate rocks are exposed along the Gass Peak thrust fault and extend at depth along the fault plane. A small wedge of these noncarbonate rocks is also exposed in Frenchman Mountain east of Las Vegas (fig. 10). Paleozoic carbonate rocks are the most prevalent unit in the mountainous areas because most of the ranges north of the valley contain thick sections of limestone and dolomite. The carbonate-rock section in the Sheep Range contains up to 26,000 ft of Paleozoic and Mesozoic rocks (Longwell and others, 1965). It is not known to what depth carbonate rocks extend beneath the Spring Mountains, but carbonate rocks beneath the western part of the valley are at least several thousand feet thick (fig. 10). Upper Paleozoic and Mesozoic sedimentary rocks are widespread in the western part of the area and may also be thousands of feet thick. Although these sedimentary rocks may locally contain a significant amount of limestone, they also contain abundant evaporite deposits. Tertiary volcanic rocks are limited, in general, to the southern part of the area. They predominate in the southeastern part of Las Vegas Valley, where thicknesses of basaltic and andesitic flows may reach 17,000 ft (Anderson, 1971), and directly overlie mostly Precambrian rock (Smith and others, 1987b); hence, these volcanic rocks mark the southern extent of the carbonate-rock province. Quaternary and Tertiary basin fill has accumulated to thicknesses of as much as 5,000 ft in the center of the valley beneath Las Vegas (Plume, 1989; fig. 10). A second thick section of Quaternary and Tertiary basin fill is in the northern part of the area between the Sheep and Desert Ranges (fig. 10), where as much as 2,500 ft of these deposits may have accumulated (Guth, 1981).

Recent studies report both compressional and extensional tectonic deformation in the vicinity of Las Vegas Valley. The geology and structure of the Desert, Sheep, Las Vegas, and Arrow Canyon Ranges north of the valley are discussed by Guth (1987), Wernicke and others (1984), Guth (1981), and D.L. Schmidt (U.S. Geological Survey, written commun., 1987); of the Spring Mountains to the west by Axen (1984), Wernicke and others (1982), Burchfiel and others (1974), and Wright and Troxel (1973); and of the area



EXPLANATION

Quaternary and Tertiary basin-fill—Chiefly alluvial, tuffaceous sedimentary rocks, lake deposits, sandstone and siltstone. Stippled pattern represents Muddy Creek or Horse Spring Formations that include evaporite deposits, particularly gypsum

Tertiary rocks—Chiefly andesite and basalt flows with locally significant rhyolite flows and intusive rocks

Upper Paleozoic and Mesozoic sedimentary rocks—Chiefly siltstone, sandstone, limestone, and gypsum with sparse dolomite, shale, and conglomerate

Paleozoic carbonate rocks—Chiefly limestone and dolomite

Precambrian and Cambrian noncarbonate rocks—Chiefly quartzite and clastic rocks, with minor amounts of metamorphic rocks

Boundary of study area

Boundary of hydrographic area

Strike-slip fault—Shows right-lateral movement associated with Las Vegas Valley Shear Zone

Thrust fault—Dashed where approximately located. Sawteeth on upper plate

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

2800 **Water-level contour**—Shows altitude at which water level would stand in tightly cased wells developed in carbonate rocks. Contour interval, 200 feet. Datum is sea level

● L2 **Well**—Completed in carbonate rocks. Number is well identifier

Figure 10. Hydrogeologic map and generalized section through Las Vegas Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, and water levels in the carbonate rocks (structural geology from Burchfiel and others, 1974; Plume, 1989; hydrogeology from Thomas and others, 1986; Harrill, 1976; Morgan and Dettinger, 1994). *B*, Generalized hydrogeologic section through Las Vegas Valley (geology from Plume, 1989).

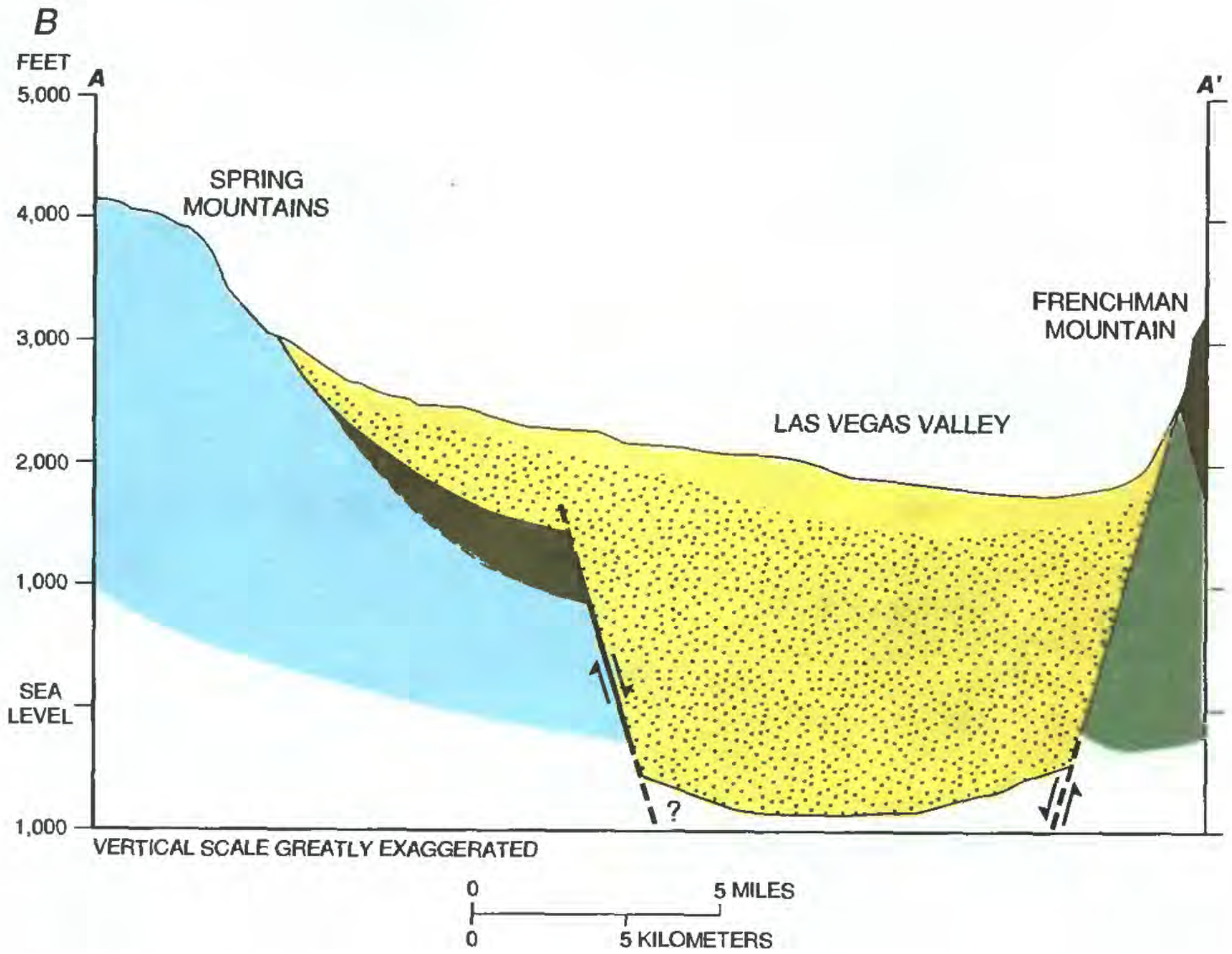


Figure 10. Continued.

to the south and east by Smith and others (1987a, b) and Anderson (1971). Together, these reports, among many others, characterize the geology and tectonic deformation of the carbonate-rock province in the vicinity of the Las Vegas Valley hydrographic area.

Numerous thrust faults in the Spring Mountains suggest that compressional tectonic deformation was extensive in the western part of the area. The Gass Peak thrust is the most prominent thrust in the northern part of the area, where compression was great and little extension occurred (Wernicke and others, 1982). Extension was significant in the northwest part of the area—west of the Sheep Range where a deep extensional basin formed as a result of faulting associated with stretching of the crust (Guth and others, 1988; Guth, 1981). This extensional basin may represent an isolated aquifer system separate from the aquifer system beneath the floor of Las Vegas Valley (Dettinger, 1987). Extension was much less severe south of the Las Vegas Valley shear zone—a vertical fault boundary and ground-water flow barrier having about 45 mi of lateral displacement in response to differential rates of extension on either side (Fleck, 1970; Wernicke and others, 1982). The shear zone produced the bowl-shaped trough beneath Las Vegas Valley, which is bounded to the east and west by steeply dipping faults (fig. 10) and to the north by the Las Vegas Valley shear zone. This large trough, filled with Tertiary and Quaternary sediments, contains the major aquifers beneath Las Vegas Valley.

Hydrology

Recharge to Las Vegas Valley is by precipitation in the adjacent ranges, particularly the Spring Mountains to the west. Recharge totals about 30,000 acre-ft/yr, although the estimated amount differs somewhat from author to author (table 9). Recharge from precipitation, however, is not adequate to meet the growing demand for water by metropolitan Las Vegas. Furthermore, little or no subsurface inflow from surrounding hydrographic areas has been reported. Consequently, the percentage of imported water from Lake Mead has continued to increase over the past several decades (table 9) while the natural ground-water discharge in the valley has decreased. Heavy pumping from the basin-fill aquifers within the valley has dried up the springs that once flowed naturally. Natural evapotranspiration has also diminished greatly in the western part of the valley, although evapotranspiration rates remain high in the southeast part of the valley north of Henderson. Ground-water withdrawals

Table 9. Recharge and discharge estimates for Las Vegas Valley

[Symbols: --, no data; >, greater than]

Component of recharge or discharge	Year for which estimate was made	Quantity (acre-feet per year)
Recharge		
Precipitation primarily in Spring Mountains		
Maxey and Jameson (1948)	1944	30,000-35,000
Malmberg (1965)	1955	25,000
Harrill (1976)	1972	30,000
Morgan and Dettinger (1994)	1981	32,000
Imported surface water from Lake Mead		
Maxey and Jameson (1948)	1944	0
Malmberg (1965)	1955	5,000
Harrill (1976)	1972	75,000
Morgan and Dettinger (1994)	1981	>112,000
Discharge		
Evapotranspiration from phreatophytes and bare soils		
Maxey and Jameson (1948)	1944	5,000-8,000
Malmberg (1965)	1955	24,000
Harrill (1976)	1972	--
Morgan and Dettinger (1994)	1981	10,000
Springs issuing from basin fill		
Maxey and Jameson (1948)	1944	6,000
Malmberg (1965)	1955	2,000
Harrill (1976)	1972	minor
Morgan and Dettinger (1994)	1981	0
Pumpage from basin fill		
Maxey and Jameson (1948)	1944	15,000
Malmberg (1965)	1955	39,000
Harrill (1976)	1972	63,000
Morgan and Dettinger (1994)	1981	71,000
Subsurface outflow and leakage to washes		
Maxey and Jameson (1948)	1944	0
Malmberg (1965)	1955	0
Harrill (1976)	1972	1,200
Morgan and Dettinger (1994)	1981	12,000

by pumping are the main source of discharge from the aquifers beneath the valley as even leakage to washes results from return flow of pumped or imported water (table 9).

Water-level data from wells drilled into carbonate rocks are restricted to the northwestern and southwestern parts of the valley (fig. 10, table 10), and indicate a southeastward and eastward flow of ground water. A possible exception to this flow pattern occurs in the northwest part of the area where recent drilling indicates that ground-water flow may be northwestward. The thick sequence of basin-fill sediments in the central part of the valley makes it difficult to determine whether or not the basin fill and carbonate rocks are hydraulically connected. The chemical and isotopic composition of several springs in Las Vegas Valley indicates that ground water discharges from the carbonate-rock aquifer through the basin-fill deposits in some areas, particularly in the west and west-central parts of the valley (J.M. Thomas, U.S. Geological Survey, written commun., 1989). Conversely, water levels in the basin fill may not reflect water levels in the carbonate rocks in the central and eastern parts of

Table 10. Information on Corn Creek Spring (discharge, 200 acre-feet per year) and selected wells completed in carbonate rocks in Las Vegas Valley

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987; and Lyles, 1987a. Abbreviations and symbol: D, domestic; I, irrigation; N, not used; NA, not applicable; O, observation; Z, other; --, no data]

Number (fig. 10)	Source	Name	Total depth (feet)	Depth to water (feet below land surface)	Depth to carbonate rocks (feet below land surface)	Use
L1	well	Cow Camp	1,403	1,334	350	O
L2	well	SBH No. 1	694	581	60	O
L3	spring	Corn Creek	NA	0	NA	D,I
L4	well	none	158	149	153	D
L5	oil well	BD No. 1	6,220	--	0	O
L6	well	none	778	302	765	D
L7	well	none	600	530	545	D
L8	well	none	905	650	650	D
L9	well	none	570	230	200	D
L10	well	none	835	437	500	D
L11	oil well	LOG No. 1	6,800	--	750	O
L12	well	none	500	426	350	D
L13	well	none	385	--	225	D
L14	well	none	755	345	500	D
L15	well	none	670	520	589	D
L16	well	MaryJane	261	219	210	N
L17	well	Mt Charleston	377	272	240	Z
L18	well	Kramer	290	213	250	N
L19	well	Kingston	650	458	280	N

the valley. This may be especially true in areas of heavy pumping because local flow directions may be toward major well fields. In the western part of the valley, however, the thickness of basin-fill deposits is less than 1,500 ft (fig. 10, pl. 1). Plume (1989) suggests that ground water may flow from carbonate rocks to the basin fill. Weaver (1982) analyzed the chemistry of water from pumped wells in west-central Las Vegas Valley and concluded that some of the pumped water originated from carbonate rocks beneath the basin fill. Lyles (1987b) also suggested that deeper ground water from carbonate rocks mixes with shallow basin-fill water along the Las Vegas Valley shear zone in the northwest part of the valley. The geometry and extent of this hydraulic connection in the structurally deeper parts of the basin is not known.

Continual pumping of the basin-fill aquifers has significantly depleted ground-water storage of the basin-fill aquifer in the west-central part of the valley (Harrill, 1976; Morgan and Dettinger, 1994). Storage depletion within the basin fill was estimated to be nearly 1.5 million acre-ft/yr as of 1983 (Morgan and Dettinger, 1994; earlier estimates were reported by Malmberg, 1965, and Harrill, 1976). Ground-water overdraft has led to water-level declines of as much as 5 ft/yr at some localities in the western part of the valley. Land subsidence caused by overdraft of the basin-fill aquifers was between 0.6 and 1.0 ft from 1972 to 1981 (Morgan and Dettinger, 1994). Bell (1981) reported a maximum land subsidence of between 2.5 and 3.0 ft from 1963 to 1980.

In 1987, the Las Vegas Valley Water District initiated an artificial recharge program (Katzer and Brothers, 1989; Brothers and Katzer, 1990) that, as of 1995, has recharged over 100,000 acre-ft into the ground-water system (Zikmund and Cole, 1996). This recharge has reduced the net pumpage in the west and northwest parts of the valley and has slowed, and locally may have reversed, the decline of ground-water levels.

Although water levels in basin-fill aquifers have been drawn down by development, ground-water storage within the carbonate rocks of the Las Vegas Valley hydrographic area has probably not been greatly affected by pumping and the amount of storage within these rocks may be large. Total storage in carbonate rocks, on the basis of assumptions described earlier in this report, is estimated to be about 14 million acre-ft, whereas local storage (beneath the basin-fill areas) is estimated to be about 9 million acre-ft. The area north of the Las Vegas Valley shear zone and west of the Gass Peak thrust fault may represent a storage reservoir different from that beneath the city of Las Vegas south of the shear zone (M.D. Dettinger, U.S. Geological Survey, oral commun., 1988).

Potential for Ground-Water Development

Too few data are available for the carbonate rocks beneath Las Vegas Valley to adequately evaluate the potential for development from these rocks. However, the limited quantity of recharge to the Las Vegas hydrographic area indicates that ground-water development from the carbonate rocks in the area would possibly result in either a direct decline in water levels in the basin-fill aquifers, or a storage depletion within the carbonate rocks, or both.

The criteria used to evaluate potential development sites are met in the southwestern third of the valley (pl. 1). Because the carbonate rocks in this area probably have a close hydraulic connection with the basin fill, development would likely affect water levels within the basin-fill aquifers.

Water quality within the carbonate rocks varies both laterally and with depth. Several wells in the southwest part of the valley intersected zones of saline water. Ground-water quality generally decreases toward the southeast along the flowpath because evaporite minerals are common in the fine-grained Tertiary basin fill. In the southwest part of the valley, the Mesozoic sedimentary rocks also contain evaporites. In the carbonate rocks, no water-quality pattern can be identified; hence, the area of average or high ground-water quality, shown on plate 1, was limited to the northwest part of the valley where the quality of the ground water is known.

Overall, development of the carbonate-rock aquifers in Las Vegas Valley is constrained by limited recharge and a high probability that any development in areas meeting proposed criteria would have immediate effects on currently used basin-fill aquifers.

Tikaboo Valley

Hydrographic Setting

The Tikaboo Valley hydrographic area in southwestern Lincoln County consists of a northern part encompassing Tikaboo Valley (627 mi^2), and a southern part encompassing Desert Valley (380 mi^2; fig. 11). The area is topographically closed, with surface drainage mostly in a southward direction to Desert Lake playa along a gradient of 51 ft/mi. Drainage from Tikaboo Valley enters Desert Valley through a narrow divide between exposures of carbonate rock that separate the two valleys. Much of the central and southern part of the Tikaboo Valley hydrographic area is part of the Nellis Bombing Range and the Desert National Wildlife Range (pl. 1); hence, much of the area is restricted to public access and is off limits for development. Consequently, little or no hydrologic data exist for the Tikaboo Valley area.

Geology

The oldest rocks exposed in the area are Precambrian and Cambrian clastic rocks in the extreme northwestern corner of the area (fig. 11). Otherwise, the area is predominately composed of Paleozoic carbonate rocks that are exposed in the Pahranagat, Sheep, and Desert Ranges, where stratigraphic thicknesses of as much as 20,000 ft have been reported by Guth (1981) for the Sheep Range and by Dolgoff (1963) for the Pahranagat Range. The thickness of carbonate rock in the Desert Range, however, is probably only several thousand feet (Guth, 1981). Tertiary deposits composed primarily of welded and nonwelded tuffs and rhyolite and andesite flows are predominately in the northern half of the area, especially the Groom Range (fig. 11). Geophysical studies indicate that the basin beneath Tikaboo Valley contains more than 5,000 ft of Quaternary and Tertiary basin-fill deposits and Tertiary volcanic rocks overlying Paleozoic carbonate rocks (Bedsun, 1980). In Desert Valley, thicknesses of Quaternary and Tertiary basin-fill deposits are more than 3,000 ft in the vicinity of Desert Lake playa where there are few or no Tertiary volcanic rocks present (H.A. Pierce, U.S. Geological Survey, written commun., 1988).

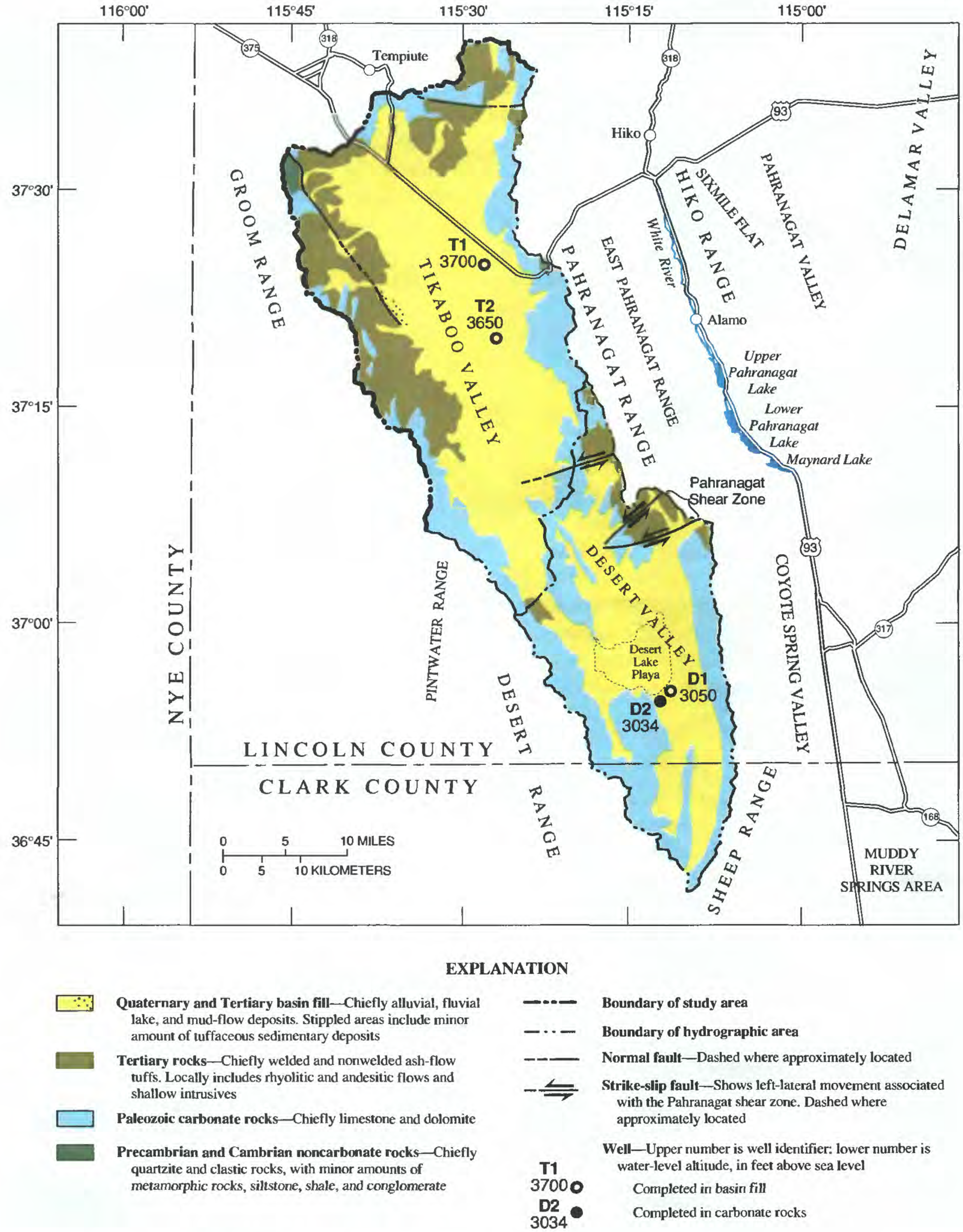


Figure 11. Hydrogeologic map of Tikaboo Valley (modified from Plume and Carlton, 1988).

Mesozoic thrust faults in both the Pahranagat Range and the eastern part of the Sheep Range (figs. 7 and 10) indicate that the Paleozoic section (both carbonate and clastic rocks) was thickened during the Mesozoic era when compressional forces were active. Evidence for extreme extension during the Tertiary period (large-scale thinning of the Paleozoic rocks) has been reported by Wernicke and others (1984) and Guth (1981) along the western margin of the Sheep Range and the area to the west (Desert Valley and Desert Range). The extent to which this large-scale "pulling-apart" has affected the Tikaboo Valley area in the north is not known. The Pahranagat shear zone, which has differential rates of extension between the two areas, divides the known highly extended area to the south from the Tikaboo Valley area to the north (fig. 11). Large extension west of Tikaboo Valley appears likely, however, as structures in the Groom Range are similar to structures in the Desert Range (Humphrey, 1945). Tikaboo Valley represents a structurally deep basin similar to Desert Valley and is characteristic of extended terranes. Therefore, carbonate-rock aquifers within the study area are likely to be either extremely thin or located at great depths beneath the valleys such that most ground-water flow would be through basin-fill deposits.

Hydrology

Empirical techniques (Maxey-Eakin method; Eakin and Maxey, 1951) used to estimate recharge in the mountains of the hydrographic area indicate that 2,600 acre-ft/yr recharges Tikaboo Valley mostly from the Pahranagat Range, and that 3,400 acre-ft/yr recharges Desert Valley, mostly from the Sheep Range. Estimated recharge to Desert Valley may be high because most of the recharge to the Sheep Range is believed to flow eastward to Coyote Spring Valley (J. M. Thomas, U.S. Geological Survey, oral commun., 1988). Ground-water recharge is discharged solely by subsurface outflow because neither springs nor evapotranspiration discharge ground water from the Tikaboo Valley hydrographic area.

Only one well is completed in carbonate rock and three wells in the basin fill (two of which are dry) for the entire hydrographic area (table 11). The depth to water in the carbonate well and nearby basin-fill well is about 160-220 ft below land surface near the southeastern edge of Desert Lake playa (fig. 11). Basin-fill water levels in Tikaboo Valley are greater than 750 ft below the valley floor (Winograd and Thordarson, 1975, pl. 1).

Ground-water flow within the carbonate rocks is difficult to estimate. In addition to the 6,000 acre-ft/yr of local recharge, Winograd and Thordarson (1975) estimated that as much as 6,000 acre-ft/yr of ground water flows beneath the Tikaboo Valley hydrographic area from Pahranagat Valley toward Ash Meadows near Death Valley (pl. 1). If this is an accurate estimate, a probable route for ground-water flow in the carbonate-rock aquifers is southwestward parallel to the Pahranagat shear zone between the Groom and Desert Ranges and across the north end of the Pintwater Range. The ground-water gradient is large from Pahranagat Valley to Frenchman Flat (pl. 1) and similar to the gradient across the Pahranagat shear zone between Pahranagat Valley and Coyote Spring Valley (fig. 11; pl. 1) and the gradient in the basin-fill deposits

Table 11. Information on observation wells in Tikaboo Valley

[Data modified from J.M. Thomas, U.S. Geological Survey, written commun., 1987. Symbols: >, greater than; --, no data]

Number (fig. 11)	Name	Depth to water (feet below land surface)	Depth to carbonate rocks (feet below land surface)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
T1	none	dry	--	--	--
T2	none	dry	--	--	--
D1	DDL-1	160	>160	300	18.8
D2	DDL-2	216	6	--	--

southwest of the Groom Range. Therefore, because of the large hydraulic gradient and presence of carbonate rocks along this proposed flow path, ground water in the carbonate-rock aquifers beneath the Tikaboo Valley area is believed to flow westward toward Ash Meadows (pl. 1; Winograd and Thordarson, 1975, p. 85-90; Winograd and Pearson, 1976; Winograd and Friedman, 1972).

Prudic and others (1993) suggested, on the basis of conceptual simulations, that a ground-water divide occurs west of Tikaboo Valley, and flow in the valley is north to south rather than east to west as proposed by Winograd and Thordarson (1975). Therefore, much additional information is needed to determine the flow direction beneath Tikaboo Valley.

Estimates of ground-water storage in the Tikaboo hydrographic area are based on the assumptions described earlier in this report. Because the thickness and extent of carbonate rocks beneath Tikaboo Valley are unknown, a satisfactory estimate cannot be made. Nonetheless, a total storage for the area has been estimated to be 5.3 million acre-ft. This large value reflects the large area of the two valleys and the high percentage of carbonate-rock-dominated mountains. Local storage (beneath the basin fill) is considerably less than the total storage. A local storage value of 1.8 million acre-ft has been estimated for the southern part of the area. No estimate was made for the northern part of the area because depths to carbonate rocks are assumed to be too deep to incorporate into the storage estimates.

Potential for Ground-Water Development

The current geologic and hydrologic data preclude determination of the overall potential for development. The hydraulic connectivity throughout the carbonate rocks at depth beneath the Tikaboo Valley area is not known, but may not be sufficient if the area has been highly extended. The thickness of carbonate rocks beneath Tikaboo Valley (northern one-half of the hydrographic area) is not known and the depth to carbonate rocks may be prohibitive to future development except possibly near the margins of the valley. In the southern one-half of the area (Desert Valley), however, high permeabilities may prevail in the vicinity of the Pahranagat shear zone (Winograd and Thordarson, 1975, p. 92). The few available water-level measurements (160-220 ft below land surface) may not reflect the general depth to water throughout Desert Valley (especially to the north). Water quality within carbonate rocks beneath Tikaboo Valley is probably high on the basis of the quality of adjacent areas.

Three Lakes Valley

Hydrographic Setting

Three Lakes Valley is divided into two distinct hydrographic areas—a northern area covering 298 mi^2 in northwestern Clark and southern Lincoln Counties, and a southern area covering 311 mi^2 in northwestern Clark County (fig. 12). Although these two hydrographic areas belong to different drainage systems, according to Rush (1974), they are not hydrologically distinct and are therefore discussed as a single hydrographic area. The northern and southern parts of Three Lakes Valley each contain a playa which represents the terminus of surface drainage from surrounding ranges; the southern playa is about 500 ft lower in altitude than the northern playa. A major highway (U.S. Highway 95) connecting Las Vegas with the northern part of the state crosses the southern part of the area (fig. 12). All of the hydrographic area north of the highway is part of the Nellis Bombing Range (pl. 1) and is currently restricted. Consequently, available data and understanding of the geology and hydrology of the area are greatly limited. Most of the hydrographic area is also part of the Desert National Wildlife Range (pl. 1) where development is limited. A maximum security penitentiary is located in southern Three Lakes Valley.

Geology

Ranges made up of Paleozoic carbonate rock encompass most of the Three Lakes Valley hydrographic area. The thickness of carbonate rocks in the Desert Range is several thousand feet (Guth, 1981) and in the northern part of the area decreases westward to the center of the valley where few or no carbonate rocks are at depth (fig. 12; P.L. Guth, Harvard University, written commun., 1988). A thick section of carbonate rocks extends beneath the Pintwater Range and beneath most of the western and probably southern parts of the area. Precambrian and Cambrian noncarbonate rocks are exposed in the Desert Range and extend beneath the eastern one-half of the valley, probably to great depths (fig. 12). Tertiary volcanic rocks are not abundant in the area (Ekren and others,

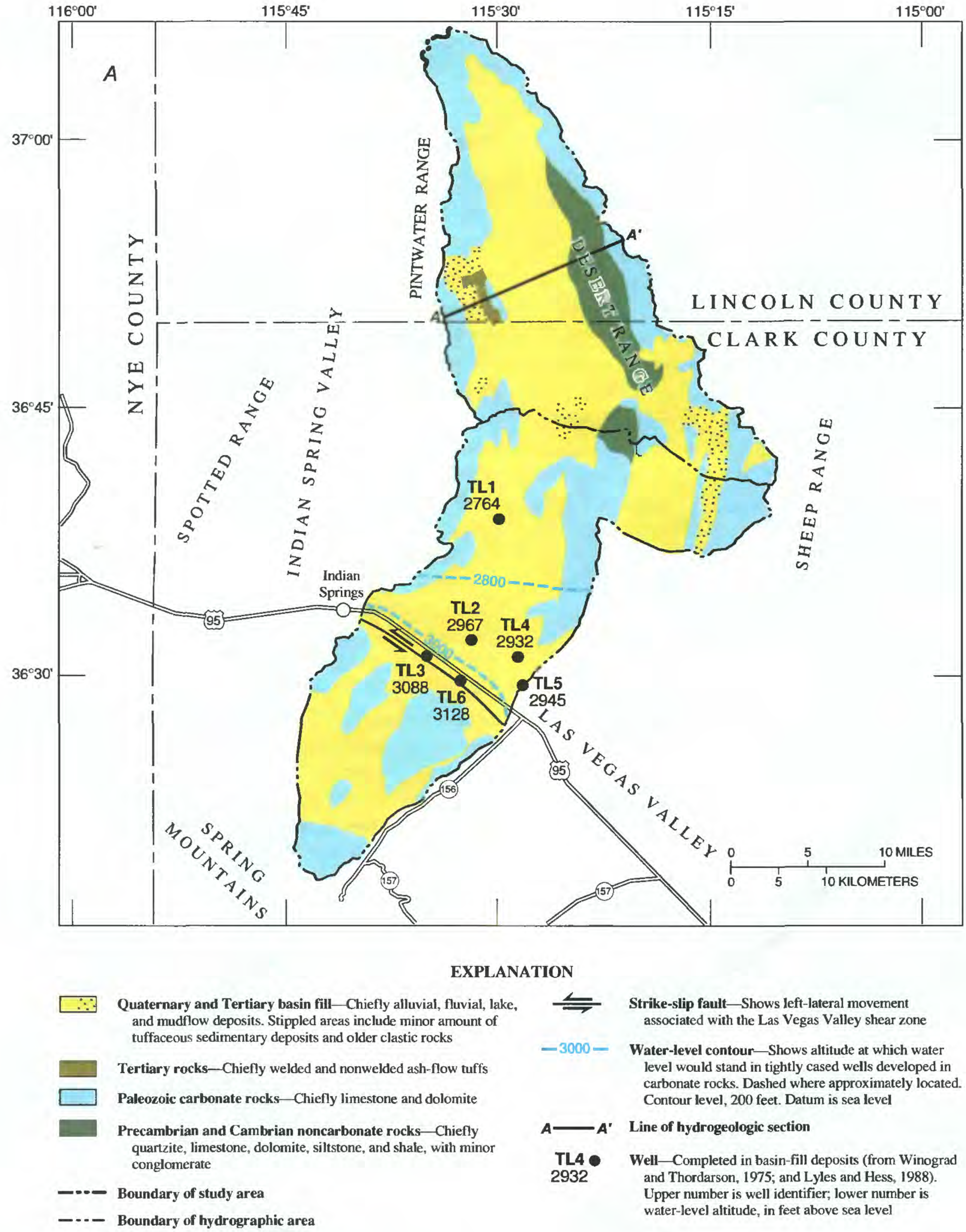


Figure 12. Hydrogeologic map of the northern and southern Three Lakes Valley areas and generalized hydrogeologic section through northern Three Lakes Valley. *A*, Hydrographic areas showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, and wells completed in basin-fill deposits (structural geology from Longwell and others, 1965; Tschanz and Pampeyan, 1970; Ekren and others, 1977; Wernicke and other, 1984; Guth, 1987; and P.L. Guth, Harvard University, written commun., 1988; hydrogeology from Thomas and others, 1986, and Lyles and Hess, 1988). *B*, Generalized hydrogeologic section through the northern part of the Three Lakes Valley (geology from Longwell and others, 1965; Tschanz and Pampeyan, 1970; Ekren and others, 1977; Guth, 1981; Wernicke and others, 1984; Guth, 1987; and P.L. Guth, Harvard University, written commun., 1988).

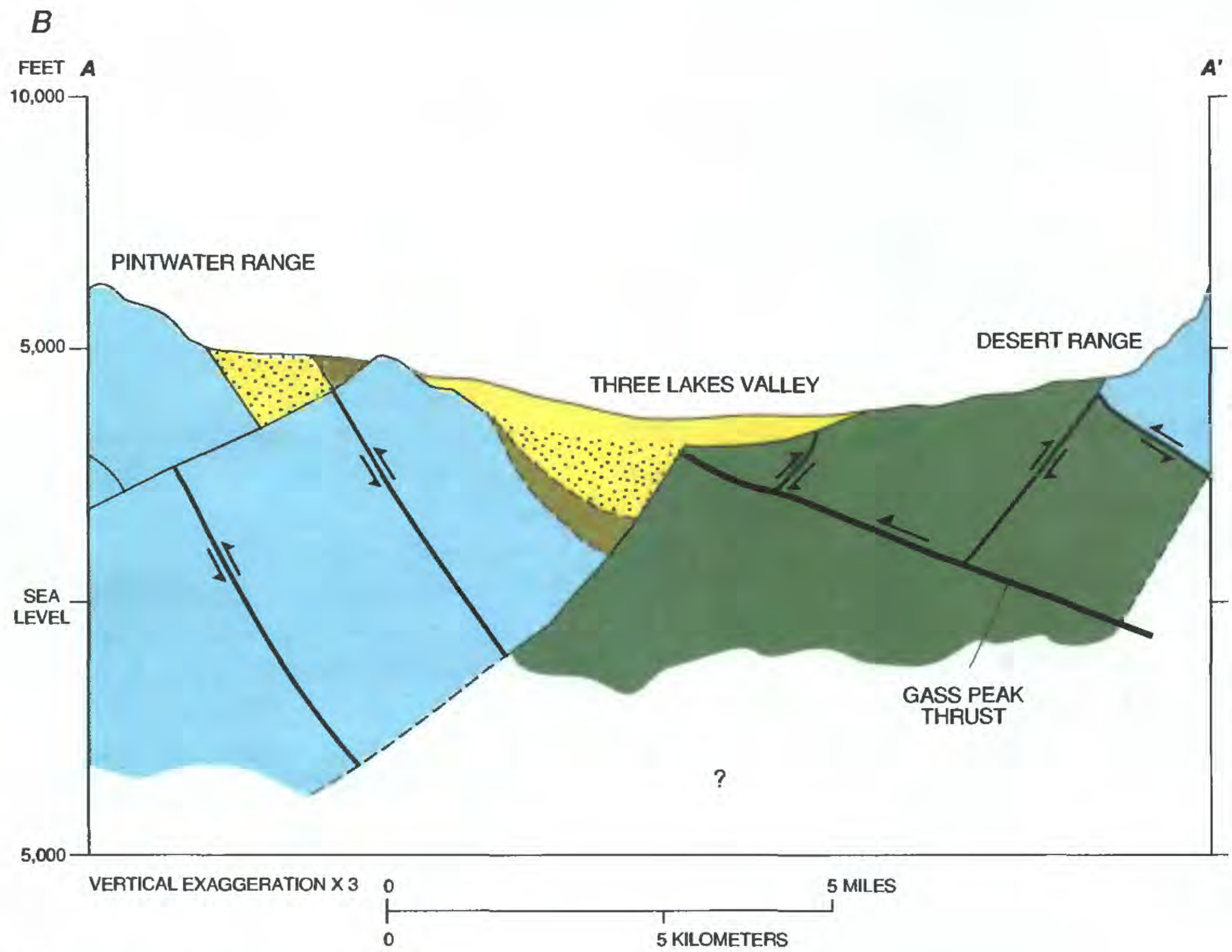


Figure 12. Continued.

1977), but may underlie the basin-fill deposits in the northern part of the area. Quaternary and Tertiary basin-fill deposits overlie Precambrian and Cambrian noncarbonate rocks west of the Desert Range, and Paleozoic carbonate or Tertiary volcanic rocks elsewhere. Basin-fill thicknesses generally range from 1,000 ft in the south to more than 3,000 ft in the northwest (P. L. Guth, Harvard University, written commun., 1988; D.H. Schaefer, U.S. Geological Survey, oral commun., 1988).

The Three Lakes Valley area was probably greatly thickened during Mesozoic time by compressional deformation because major thrust faults are exposed in the Sheep and Pintwater Ranges. Late Tertiary extension greatly thinned the area west of the Sheep Range resulting in faulting, tilting, rotation, and breakage of large rock masses. This extension also initiated movement along older thrust faults (Guth, 1988; Guth, 1987; Wernicke and others, 1984; Guth, 1981). Extensional thinning and subsequent erosion has exposed the large area of Cambrian clastic rocks (Precambrian and Cambrian noncarbonate rock unit) in the central Desert Range (fig. 12). In the Pintwater Range, extensional faulting has rotated a thick section of carbonate rock into the subsurface that has been preserved. This same fault probably greatly deepened the basin and consequently thickened the basin-fill deposits in the western one-half of Three Lakes Valley. Erosion removed most of the Tertiary volcanic rocks, although volcanism was probably not significant in the area (Guth, 1987; fig. 12).

The Las Vegas Valley shear zone, possibly representing the boundary between two regions with differential Tertiary extension (Wernicke and others, 1984) extends northwestward across the southern part of the area. The depth and characteristics of this fault zone beneath the basin fill are not known.

Hydrology

About 75 percent of the estimated 8,000 acre-ft/yr of mountain-block recharge in the Three Lakes Valley hydrographic area is supplied by precipitation on the Spring Mountains in the southern part of the area (Rush, 1970). Additional recharge as subsurface inflow from Pahranagat Valley (6,000 acre-ft/yr; Winograd and Friedman, 1972) and Tikaboo Valley (6,000 acre-ft/yr; Rush, 1970) may flow through the northern part of Three Lakes Valley westward into the Indian Springs Valley hydrographic area.

The estimated amount of inflow from Tikaboo Valley may be excessive because most of the recharge to Tikaboo Valley (Rush, 1970) originates in the Sheep Range. J.M. Thomas (U.S. Geological Survey, oral commun., 1988) suggests that most of, if not all, the recharge in the Sheep Range flows east toward the Muddy River Springs area. No regional springs or evapotranspiration of regional ground water are thought to occur in Three Lakes Valley because water levels are assumed to be deep throughout the area, as indicated by depths to water of 100 to 200 ft in southern Three Lakes Valley. Therefore, discharge from the area is inferred to be exclusively by subsurface outflow. The precise direction of subsurface flow beneath the valley, however, is not known because there are no water-level data for the carbonate rocks beneath the basin fill. Only six wells intercept the basin-fill aquifer in the southern part of the valley (table 12). No water-level data are available for the northern part of the valley.

If basin-fill water levels reflect water levels in the carbonate rocks at depth, the general direction of flow, according to Thomas and others (1986), is northward toward the northern part of the area and then probably west toward Ash Meadows. A ground-water divide may lie along the southern part of the valley, which may cause some recharge in southern Three Lakes Valley from the Spring Mountains to flow southeastward toward Las Vegas Valley (Lyles, 1987b). Recent drilling (Lyles and Hess, 1988) in Three Lakes Valley (Wells TL4 and TL5, fig. 12) and in nearby Las Vegas Valley suggests that a northward component of flow may be prevalent near the highway in the southeast part of the area. However, further drilling is necessary because interpretations of regional flow gradients are based on water levels in the basin-fill deposits and not on water levels in the deeper carbonate rocks.

The amount of ground-water storage beneath Three Lakes Valley is difficult to estimate without knowing the vertical extent of carbonate rocks in the area. However, based on assumptions used in this report for estimating storage, the total ground-water storage in the Three Lakes Valley hydrographic area is 6.0 million acre-ft. About 4.3 million acre-ft of the total is present in the southern part of the area. Local storage is somewhat limited and is confined to areas adjacent to the Pintwater Range (pl. 1). An estimated 3.5 million acre-ft of local storage is available in the area, most of which is in the southern half of Three Lakes Valley.

Potential for Ground-Water Development

Potential for development of the Three Lakes Valley area is uncertain due to the absence of available data on the thickness and extent of carbonate rocks and water levels beneath the valley. Much of the valley is currently part of a military reservation, making access for the public difficult in areas north of the highway. The southern part of Three Lakes Valley may have a potential for development because water levels generally are shallow and basin-fill deposits are thin (about 200 ft thick). Carbonate-rock aquifers in the southern part of the area also may be laterally continuous with

Table 12. Information on wells completed in basin fill in Three Lakes Valley

[Data modified from J.M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations and symbol: D, domestic; O, observation; --, no data]

Number (fig. 12)	Name	Depth to water (feet below land surface)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Use
TL1	none	301	--	--	O
TL2	none	54	--	--	O
TL3	Point Bravo	118	200	25	O
TL4	Old Dry	125	200	22.7	O
TL5	Divide	131	200	20.5	O
TL6	Prison	222	200	22.7	D

carbonate-rock aquifers beneath northwestern Las Vegas Valley, although the extent of carbonate rocks beneath the southern Desert Range is uncertain. Further exploration of the area would be beneficial to help determine the direction of deep flow and to provide information on the extent of carbonate rocks beneath the basin fill. If the Las Vegas Valley shear zone is a barrier to ground-water flow, the part of Three Lakes Valley north of the shear zone may have potential for development because the effects of pumping would be limited to areas north of the zone. However, areas to the west (Indian Springs Valley) may be adversely affected by development if a significant amount of water is withdrawn from the valley. If ground water flows toward Ash Meadows (pl. 1), spring discharge in Ash Meadows would eventually decline, although hundreds or thousands of years may pass before spring flows decline.

Indian Springs Valley

Hydrographic Setting

The Indian Springs hydrographic area occupies 655 mi^2 in northwestern Clark, southwestern Lincoln, and southeastern Nye Counties (fig. 13). All the area, except for a small part that extends into Nye County, is part of the Desert National Wildlife Range. The northern two-thirds of the area (generally north of U.S. Highway 95) is part of the Nellis Bombing Range (pl. 1) and is closed to the public; hence, hydrogeologic information in this part of the valley is extremely limited.

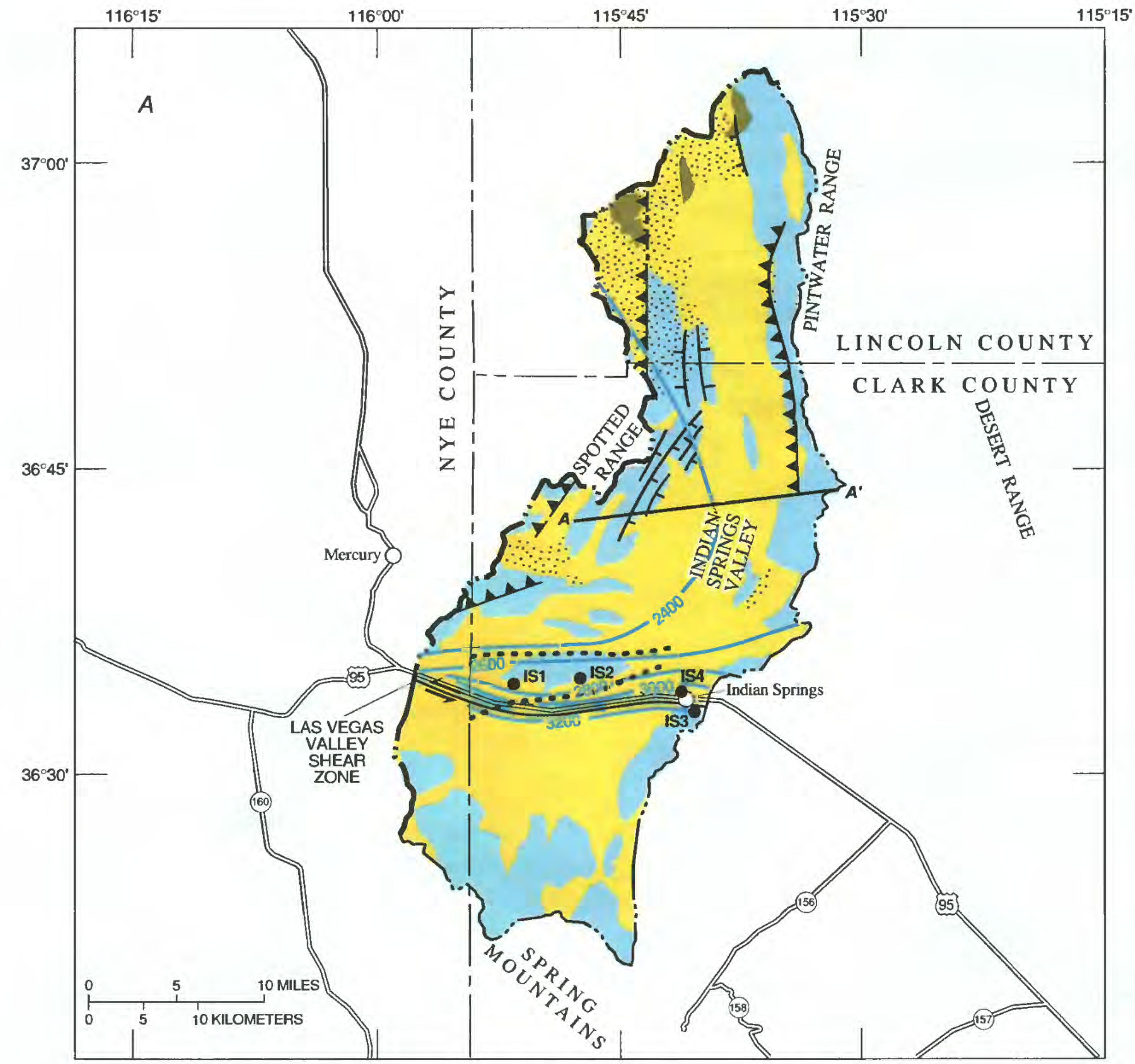
Surface drainage is northward from the Spring Mountains in the south, eastward from the Spotted Range to the west, and westward from the Pintwater Range to the east, and converges at a playa in the center of the valley. Except for several perennial reaches in and adjacent to the Spring Mountains, no streams in the area are perennial. Surface water occurs only during torrential storms or spring snowmelt (Maxey and Robinson, 1947). Most of the runoff rapidly infiltrates the highly fractured carbonate rocks of the Spring Mountains, Spotted and Pintwater Ranges, and the coarse basin-fill deposits of the alluvial fans adjacent to these ranges so that surface runoff rarely reaches the valley floor.

Indian Springs Air Force Base is located near the small community of Indian Springs (population 900) along U.S. Highway 95, which is the major highway connecting Las Vegas with the northern part of Nevada.

Geology

The ranges encompassing Indian Springs Valley consist primarily of Paleozoic carbonate rocks. These rocks extend to depths of more than 5,000 ft in the ranges and beneath the valley (P. L. Guth, Harvard University, written commun., 1988; fig. 13). A locally significant clastic-rock section within the Paleozoic carbonate unit is exposed in the Spotted Range and may restrict ground-water flow, particularly to the west of the Spotted Range (shown as stippled pattern in the Paleozoic carbonate-rock unit in fig. 13) where the clastic section thickens abruptly. Precambrian and Cambrian clastic rocks brought to the surface during thrusting are exposed in the Spring Mountains to the south and may extend to depths of thousands of feet. Tertiary volcanic rocks, mainly tuffs, crop out in the extreme northern part of the area, but their effect on ground-water flow is negligible. Quaternary and Tertiary basin-fill deposits are generally less than 500 ft thick, although south of the playa their thickness may increase to as much as 1,000 ft (D.H. Schaefer, U.S. Geological Survey, oral commun., 1988; fig. 13).

No detailed studies have thoroughly described the structural geology in the Indian Springs Valley hydrographic area; however, several regional studies have included the area (Guth, 1988; Guth, 1987; Wernicke and others, 1984; Barnes and others, 1982; Longwell and others, 1965). Thickening of the Paleozoic carbonate section resulting from Mesozoic compressional forces has occurred in the Spring Mountains (Burchfiel and others, 1974; Axen, 1984), and in the Spotted and Pintwater Ranges (Guth, 1988; see thrust faults in fig. 13). Tertiary extensional deformation resulted in extensive faulting and thinning of the carbonate-rock section (Guth, 1987), but the section remained fairly thick in the Indian Springs Valley area (P. L. Guth, Harvard University, written commun., 1988); it is possible that the carbonate rocks beneath the valley may have retained their subhorizontal position (fig. 13). In the Spotted Range west of Indian Springs Valley, extensional forces have produced highly broken west-dipping fault blocks (Guth, 1988).



EXPLANATION

Quaternary and Tertiary basin-fill deposits—Chiefly alluvial, fluvial, lake, and mud-flow deposits. Stippled areas include minor amount of tuffaceous sedimentary deposits and older clastic rocks

Tertiary rocks—Chiefly welded and nonwelded ash-flow tuffs

Paleozoic carbonate rocks—Chiefly limestone and dolomite, with locally thick sequences of clastic rocks including shale, sandstone, and conglomerate. Stippled areas include clastic unit comprised primarily of argillite, quartzite, and conglomerate

Boundary of study area

Boundary of hydrographic area

Normal fault—Hachures on downthrown side

Strike-slip fault—Shows left-lateral movement associated with the Las Vegas shear zone

Thrust fault—Dashed where approximately located. Sawteeth on upper plate

3000 **Water-level contour**—Shows altitude at which water level would stand in tightly cased wells developed in carbonate rocks. Dashed where approximately located. Contour interval, 200 feet. Datum is sea level

Inferred ground-water barrier—As postulated by Winograd and Thordarson (1968, 1975)

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

IS4 **Well or spring**—Completed in or discharging from carbonate rocks. Number is well or spring identifier

Figure 13. Hydrogeologic map of Indian Springs Valley and generalized section through northern Indian Springs Valley. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, wells completed in carbonate rocks, and springs issuing from carbonate rocks (structural geology from Longwell and others, 1965; Winograd and Thordarson, 1968; Tschanz and Pampeyan, 1970; Wernicke and others, 1984; Barnes and others, 1982; hydrogeology from Winograd and Thordarson, 1975, and Thomas and others, 1986). *B*, Generalized hydrogeologic section through northern Indian Springs Valley (geology from Anderson and Jenkins, 1970; Guth, 1987; P.L. Guth, Harvard University, written commun., 1988).

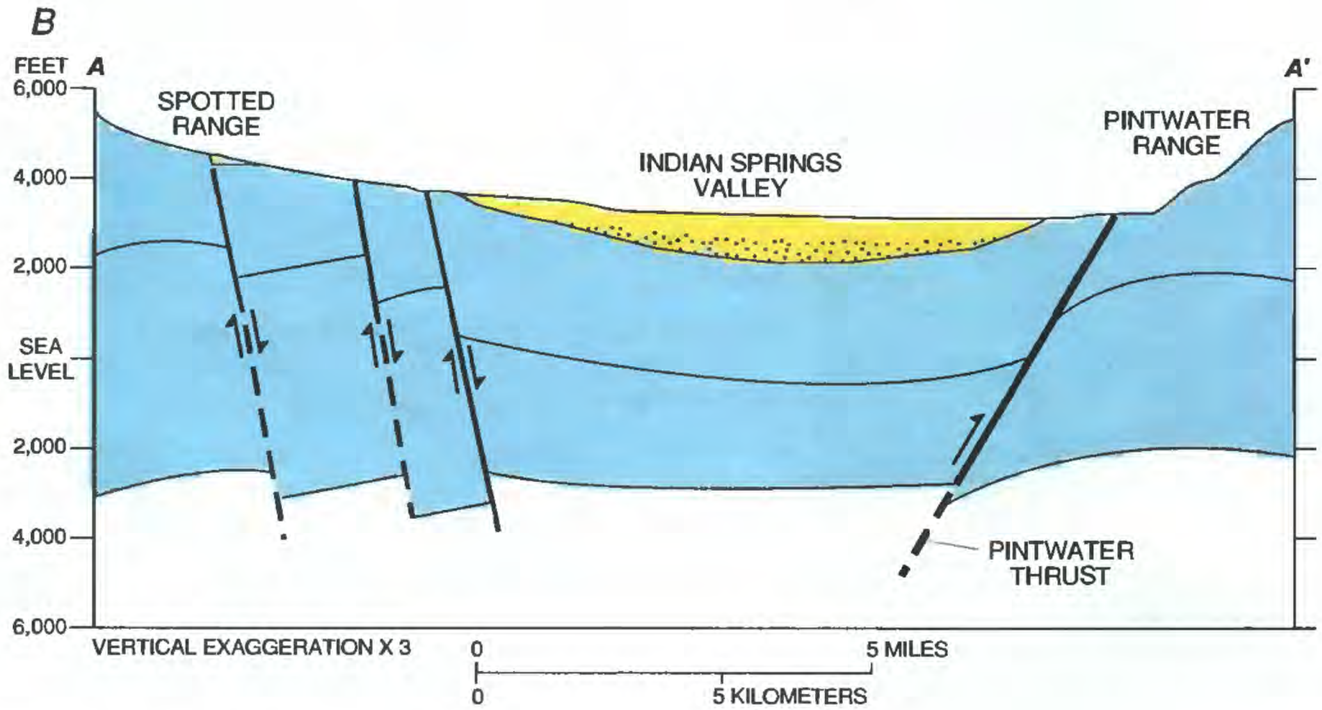


Figure 13. Continued.

The Las Vegas Valley shear zone, which nearly parallels the highway (fig. 13), marks the boundary between two regions of differential Tertiary extension (Wernicke and others, 1984). Correlation of stratigraphic and structural features across the shear zone indicates displacements ranging from 24 to 40 mi (Longwell, 1974; Stewart, 1967; Burchfiel, 1965). Winograd and Thordarson (1968, 1975) suggest that fault gouge (finely crushed rock) along the shear zone may act as a barrier to ground-water flow (see next section).

Hydrology

Nearly all the estimated 10,000 acre-ft/yr of recharge derived from precipitation in Indian Springs Valley originates in the Spring Mountains (Rush, 1970; fig. 13). Near the community of Indian Springs, ground water is discharged from springs and by evapotranspiration. This discharge is small (5 percent) in comparison with the estimated subsurface outflow. Ground water originating as recharge in the Spring Mountains flowing beneath Indian Springs Valley may supply more than 50 percent of the spring discharge at Ash Meadows in the Amargosa Desert (J.M. Thomas, U.S. Geological Survey, oral commun., 1988).

Water levels decrease abruptly from the Spring Mountains toward the playa in the center of the valley. Water levels south of the highway near Indian Springs are generally less than 100 ft below land surface, but they decrease to a depth greater than 800 ft north of the highway toward the playa (fig. 13). Winograd and Thordarson (1968, 1975) suggested that two ground-water barriers are responsible for the lowering of water levels to the north; these authors believe that the barriers create a step-like, water-level pattern. The southernmost ground-water barrier almost coincides with the inferred position of the Las Vegas Valley shear zone (Longwell and others, 1965). The northern barrier may result from shallow Cambrian and Precambrian clastic rocks penetrating into the aquifer from below. Winograd and Thordarson (1968) suspect these barriers are responsible for the location of Indian Springs (IS3, fig. 13; table 13) located just south of the Las Vegas Valley shear zone. Between the two inferred barriers, according to these observers, is a gentle westward-trending hydraulic gradient. The two inferred ground-water flow barriers may not be significant in the carbonate-rock aquifers, but may merely reflect the steep hydraulic gradient in the Spring Mountains recharge area (Lyles, 1987b; and J.M. Thomas, U.S. Geological Survey, oral commun., 1988). More water-level data are needed to accurately determine flow directions in this part of Indian Springs Valley. Meanwhile, no water-level data are available for the northern part of the valley (fig. 13, table 13).

Table 13. Information on wells completed in and a spring issuing from carbonate rocks in Indian Springs Valley

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations and symbols: D, domestic; O, observation; --, no data; <, less than]

Number (fig. 13)	Source	Name	Depth to water (feet below land surface)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Use
IS1	well	none	840	<500	--	O
IS2	well	none	740	<500	25.5	O
IS3	spring [a]	Indian	0	200	25	D
IS4	well	none	75	<500	--	O

[a] Discharges 645 acre-ft/yr

The quantity of subsurface inflow from Three Lakes Valley to the east and from Emigrant Valley to the north is not known. Estimates have been reported to be 22,000 acre-ft/yr, and probably include underflow originating from Pahranagat Valley (Scott and others, 1971). Coupled with the 10,000 acre-ft/yr recharging the valley from precipitation, the total quantity of subsurface outflow toward Ash Meadows (pl. 1) is estimated to be 32,000 acre-ft/yr. This quantity appears too large on the basis of discharge measurements at Ash Meadows and is based on the assumption that all water from the Sheep Range flows toward Ash Meadows. If all, or most, recharge in the Sheep Range flows eastward, then the total outflow from Indian Springs Valley would be on the order of 21,000 acre-ft/yr. Ground-water flow through carbonate rocks is expected to flow northward from the Spring Mountains and then westward toward Ash Meadows. Exactly where beneath Indian Springs Valley this change of direction may occur is not known, although the scant water-level data indicate that this westward flow may begin in southern Indian Springs Valley (fig. 13).

The quantity of ground water stored in carbonate rocks within the Indian Springs hydrographic area has been estimated, on the basis of assumptions described earlier in this report, to be about 7 million acre-ft. Local storage (within the basin fill) represents an estimated 4.1 million acre-ft, or about 58 percent of the total storage.

Potential for Ground-Water Development

Water-level data indicate that the best area for development is south of the highway (south of the Las Vegas Valley shear zone) in the Indian Springs area where water levels are generally less than 100 ft below land surface and where the basin fill is relatively thin. As reported earlier, an estimated 10,000 acre-ft/yr may flow from the Spring Mountains northward then westward toward Ash Meadows. Development in this area could have dramatic short-term effects on wells at the Indian Springs Air Force Base and on discharge from Indian Springs. However, it could take several hundred years for the effect of pumping in this area to cause significant declines in spring discharge at Ash Meadows and the water level at Devils Hole where the environmentally protected Pupfish live. The area north of U.S. Highway 95 is restricted to public access, so even if this area proved to be a potential site for development on the basis of the criteria described in this report, it would be difficult to gain access for further data collection and development.

Amargosa Desert

Hydrographic Setting

The Amargosa Desert hydrographic area occupies about 896 mi^2 in western Nye County, Nevada, and 468 mi^2 in eastern Inyo County, California (fig. 14). The area is part of the much larger Death Valley drainage basin (Walker and Eakin, 1963;

Winograd and Thordarson, 1975). Because of its proximity to the Nevada Test Site (northeast of Amargosa Desert) and its prominent regional springs and Devils Hole, the hydrogeology of Ash Meadows in south-central Amargosa Desert has been investigated extensively during the past few decades (Eakin and others, 1963; Winograd and Eakin, 1965; Winograd and Friedman, 1972; Winograd and Thordarson, 1975; Winograd and Pearson, 1976; Claassen, 1983; and Kilroy, 1991).

The hydrographic area is surrounded by mountain ranges, the most prominent being the Funeral Mountains to the west. Part of the northeastern boundary through Lathrop Wells is not bounded by mountains and is arbitrarily drawn along U.S. Highway 95 (fig. 14). Intermittent surface water drains to the Amargosa River, which flows southeastward through the central part of the area. The Amargosa River enters the northwestern part of the area at Beatty where the altitude is about 5,000 ft. The river leaves the area south of Death Valley Junction where its altitude is 1,900 ft. Surface water entering the Amargosa River mostly infiltrates into the basin fill; hence, the river is dry along most of its course, except during rain storms. Amargosa Flat and Alkali Flat are two prominent playas occupying the southeast and southern parts of the area, respectively (fig. 14).

Few people live in the area. A large farm, located in the north-central part of the area, supports farmers and ranchers who have attempted to grow various crops including alfalfa and pistachios, but declining water levels caused by extensive irrigation have disrupted production. Devils Hole, a national monument where an endangered species of Pupfish are protected, is located in Ash Meadows in the south-central part of the area (A5, fig. 14). Consequently, pumpage has been greatly reduced in the Ash Meadows area in an effort to preserve the Pupfish habitat.

Geology

Precambrian and Cambrian noncarbonate rocks are widespread and abundant. The northern Funeral Mountains consist primarily of metamorphic rocks that likely extend to significant depths and act as a barrier to ground-water flow. Precambrian and Cambrian quartzites and clastic rocks are common in Bare Mountain in the northern part of the area and in the Montgomery Mountains along the eastern border of the area. In the Montgomery Mountains, 3,000 ft of quartzite of low permeability overlies Paleozoic carbonate rocks (Burchfiel and others, 1983a). More than 16,000 ft of Paleozoic carbonate rocks crop out in the Specter Range in the northeastern part of the area (Burchfiel, 1965). Carbonate rocks are also common in the Montgomery Mountains, but are not as thick as exposed sections in the Specter Range (Burchfiel and others, 1983a, fig. 3), and in the southern Funeral Mountains. The thickness and extent of carbonate rocks beneath Amargosa Desert is not known, but they probably are limited mostly to the southeastern part of the area. Several thousand feet of Tertiary volcanic rocks comprised chiefly of tuffs are exposed in the Bullfrog Hills in the northern part of the area. Thick sequences of basalt, andesite, and rhyolite constitute the Greenwater Range in the southwestern part of the area. Thicknesses of Quaternary and Tertiary basin fill vary greatly within the Amargosa Desert. In the northern part of the area, the basin-fill deposits may be as thick as 2,300-3,500 ft (Healey and Miller, 1971), but they thin to about 1,400 ft toward the central part of the area southwest of Lathrop Wells (fig. 14). In Amargosa Flat and southwest of Ash Meadows, basin-fill thicknesses may exceed 5,000 ft locally (fig. 14), and generally are at least 3,500 ft. In the extreme southwest part of the area, the thickness of basin fill generally ranges from 2,000 to 3,500 ft.

Within the Amargosa Desert hydrographic area, compressional deformation has produced at least three thrust faults (fig. 14) and has thickened the upper Precambrian and Paleozoic sections beneath Amargosa Flat in the northeastern part of the area (Winograd and Thordarson, 1975, p. 75). The lateral extent of the carbonate rocks beneath the southern part of Amargosa Desert extending northwest to the center of the desert is not known because extreme extension may have removed the thick Paleozoic carbonate section except beneath Amargosa Flat. Greenhaus and Zablocki (1982) suggest, on the basis of geophysical data, that Paleozoic carbonate or Precambrian clastic rocks underlie much of southern Amargosa Desert, where Tertiary volcanic rocks are generally sparse or not present. Figure 14 shows a thin section of Paleozoic rock at depth southwest of Alkali Flat, but more information is needed to adequately describe the hydrogeologic rock units at depth.

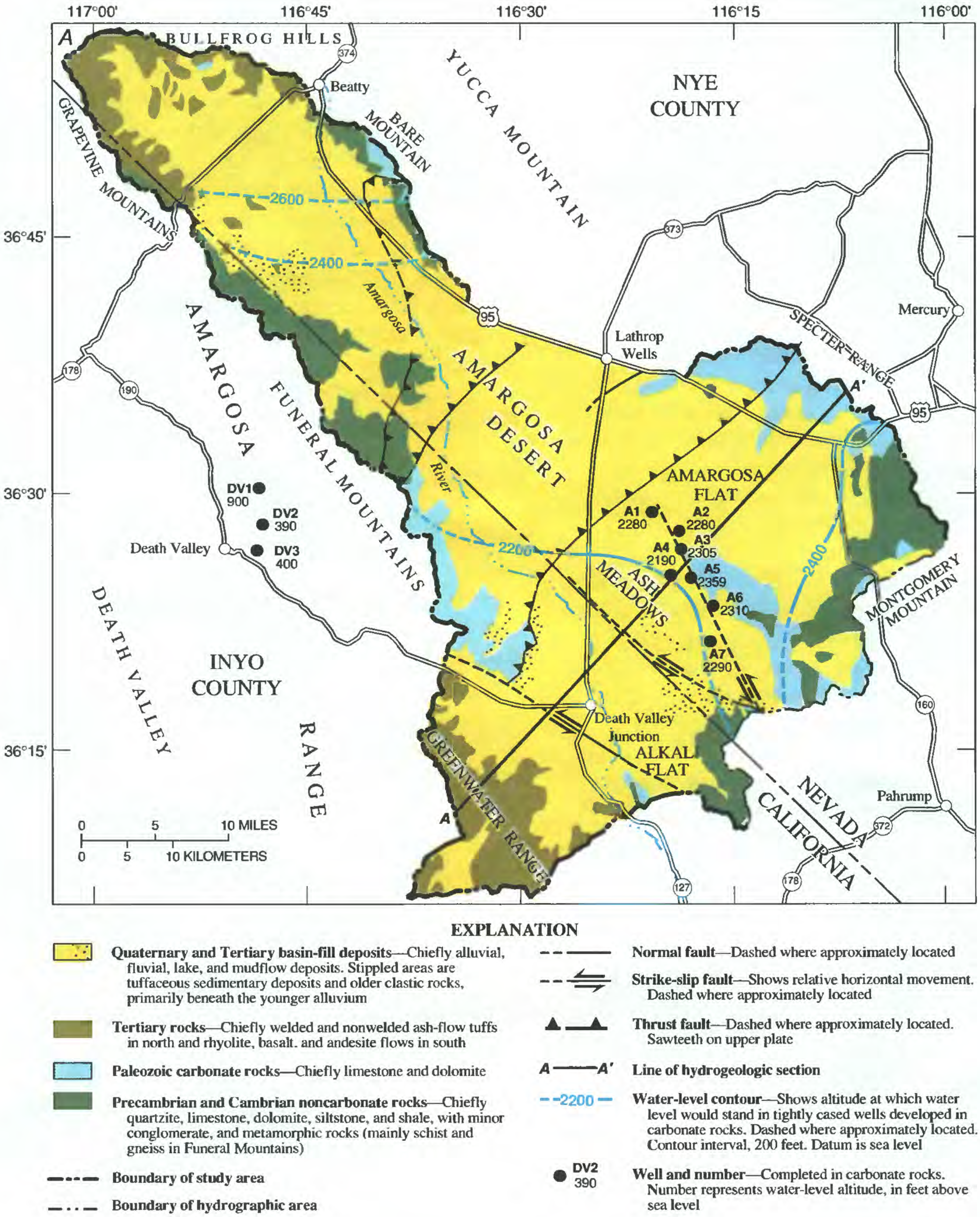


Figure 14. Hydrogeologic map and generalized section through Amargosa Desert. *A*, Hydrographic area showing hydrogeologic rock units, major structural features, and water levels in the carbonate rocks (structural geology from Winograd and Thordarson, 1975; Carr and Monsen, 1988; Burchfiel and others 1983a; Wernicke and others, 1988b; hydrogeology from Thomas and others, 1986, and Kilroy, 1991). *B*, Generalized hydrogeologic section through the Amargosa Desert (geology from Winograd and Thordarson, 1975, and Wright and Troxel, 1967).

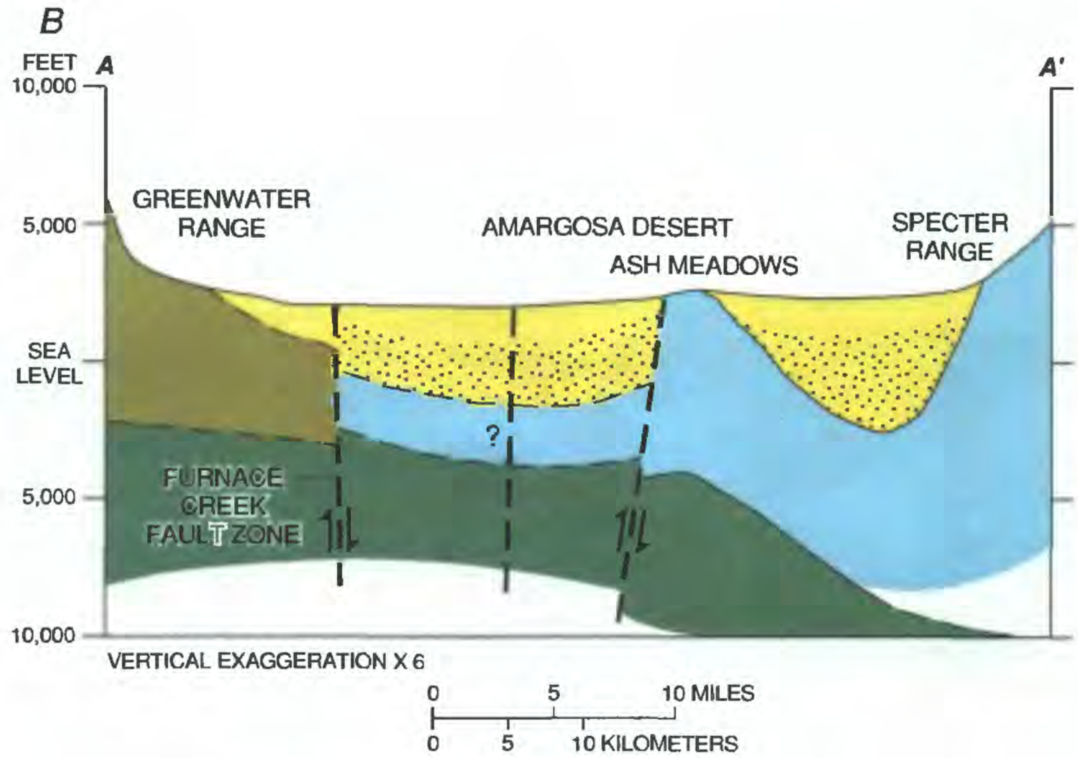


Figure 14. Continued.

Extensional faults are found throughout the area. Large Late Tertiary faults are exposed at Bare Mountain in the northwestern part of the area where a westward-trending highly extended area has been mapped on the west side of the mountain (Carr and Monsen, 1988; Robinson, 1985). Extreme thinning of the Paleozoic carbonate rocks in the Bull Frog Hills has all but eliminated the carbonate-rock section so that thick, Late Tertiary volcanic rocks mostly overlie Precambrian basement rock (Maldonado, 1988). Other important extensional faults are in the south and south-central Amargosa Desert where strike-slip and normal faults may have juxtaposed carbonate rocks against low-permeability clastic rocks or basin-fill deposits, perhaps greatly affecting the hydrogeology of the area. Most of the faults are buried by basin fill and their significance is not well understood. However, a high-angle normal fault trending north-northwest through the springs in Ash Meadows strongly suggests juxtaposition of highly permeable Paleozoic carbonate rocks against low-permeability Tertiary basin-fill deposits because many springs emerge from either carbonate rocks or basin fill along a line coinciding with this fault. Figure 14 shows the inferred geologic section through this fault at Ash Meadows.

Hydrology

Numerous hydrologic investigations of south-central Nevada have focused, at least in part, on the Amargosa Desert and particularly Ash Meadows (Eakin and others, 1963; Walker and Eakin, 1963; Winograd and Friedman, 1972; Naff and others, 1974; Winograd and Thordarson, 1975; Winograd and Pearson, 1976; Waddell, 1982; Claassen, 1983; Waddell and others, 1984; and Czarnecki, 1985). Recharge from infiltration of precipitation in surrounding mountain blocks is probably small (Walker and Eakin, 1963) compared with water that enters the area as subsurface inflow (Winograd and Friedman, 1972; Winograd and Thordarson, 1975; Waddell, 1982; Claassen, 1983) primarily through thick sequences of carbonate rocks beneath the Specter Range (table 14). Subsurface inflow from carbonate rocks in this area supports springflow at Ash Meadows and at Death Valley (fig. 14, table 14) and may exceed 21,000 acre-ft/yr. The ground water entering Amargosa Desert through the Specter Range is not local, but originates from several distant sources. According to Winograd and Friedman (1972) and Winograd and Thordarson (1975), sources of recharge include the Spring Mountains, the Sheep Range, and Pahranagat Valley nearly 100 mi to the northeast of Ash Meadows. J.M. Thomas and M.D. Dettinger (U.S. Geological Survey,

Table 14. Recharge and discharge estimates for Amargosa Desert

[Symbol: <, less than]

Component of recharge or discharge	Quantity (acre-feet per year)
Recharge	
Precipitation in adjacent mountain blocks (Walker and Eakin, 1963)	1,200
Subsurface inflow from:	
Spring Mountains and Jackass Flats beneath Specter Range (Walker and Eakin, 1963)	19,000
Spring Mountains, Sheep Range, and Pahranagat Valley (Winograd and Thordarson, 1975)	21,000
Spring Mountains, Sheep Range, Pahranagat Valley, Jackass Flats, and Oasis Valley (Waddell and others, 1984)	34,000
Discharge	
Evapotranspiration from phreatophytes, bare soils, and springs issuing from carbonate rocks for:	
Ash Meadows and Alkali Flat (Walker and Eakin, 1963)	24,000
Ash Meadows (Winograd and Thordarson, (1975)	17,000
Pumpage for:	
1962 (Walker and Eakin, 1963)	3,000
1985 (Kilroy, 1991)	10,000
Subsurface outflow to Death Valley	
Walker and Eakin (1963)	<3,000
Winograd and Thordarson (1975)	4,000-5,000
Waddell and others (1984)	5,000
Total recharge (rounded)	20,000-35,000
Total discharge (rounded)	21,000-27,000

oral commun., 1988) exclude the Sheep Range as a source of water for the springs in Ash Meadows on the basis of recent geologic, hydrologic, and geochemical evidence that indicates eastward flow from the Sheep Range. Additional recharge from Oasis Valley to the northwest and Jackass Flats to the northeast enters the area primarily through basin-fill deposits and possibly welded-tuff aquifers of the Nevada Test Site. The amount of recharge or subsurface flow from these sources may be large (Walker and Eakin, 1963; Waddell and others, 1984; table 14).

Ground water within the hydrographic area, as already mentioned, discharges primarily as springflow along a northwest-trending line of springs in Ash Meadows (fig. 14). The location and emergence of these springs is believed to be related to the high-angle normal fault that coincides with the line of springs (fig. 14, table 15). Evapotranspiration in Ash Meadows probably results from spring discharge and local subsurface flow from carbonate rocks rather than from inflow through basin-fill deposits north of Ash Meadows (Winograd and Thordarson, 1975; Claassen, 1983). Farther south, in Alkali Flat, evapotranspiration may be significant because of shallow water levels (Waddell and others, 1984). Some throughflow beneath Amargosa Desert through carbonate rocks or basin fill toward Death Valley is likely because springs in Death Valley (fig. 14) have similar geochemical and isotopic characteristics to springs emerging at Ash Meadows. Furthermore, discharge of these Death Valley springs near the terminus of carbonate rocks exposed in the southern Funeral Mountains strongly indicates regional flow through carbonate rocks.

Water-level data indicate that ground-water flow within basin-fill deposits is generally northwest to southeast along the course of the Amargosa River in the northern part of the area, but southwestward in the southern part of the area. Similar ground-water flow directions are inferred in carbonate rocks at depth in the southern part of the area. Overall, the depth to water is generally shallow throughout the Amargosa Desert except in the extreme northern and southwestern parts of the hydrographic area where depths to water may reach 500 ft or more (Kilroy, 1991).

Ground-water storage within the carbonate rocks beneath the Amargosa Desert has been estimated at about 3.6 million acre-ft, according to the assumptions outlined in this report. Local ground-water storage (within basin fill) has been estimated at 2.3 million acre-ft.

Potential for Ground-Water Development

Amargosa Desert is an unlikely site for potential development of carbonate-rock aquifers for two reasons. First is the U.S. Supreme Court's mandate that pumping in the vicinity of Ash Meadows be greatly reduced to protect the Pupfish habitat in Devils Hole, which greatly reduces, if not excludes, the potential area where carbonate rocks can be practically and economically penetrated. Pumping anywhere upgradient from or in the vicinity of the springs would eventually affect water levels in the area, particularly at Devils Hole (A5, fig. 14). Second, the absence of hydrogeologic data in areas downgradient of Ash Meadows precludes comprehensive evaluation of

Table 15. Information on major springs issuing from carbonate rocks in Amargosa Desert and adjacent parts of Death Valley

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations and symbol: D, domestic; U, unused; <, less than]

Number (fig. 14)	Name	Discharge (acre-feet per year)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)	Use
A1	Fairbanks	2,900	420	27.2	U
A2	Rogers	1,200	<500	27.7	U
A3	Longstreet	1,700	<500	27.2	U
A4	Crystal Pool	4,700	450	31.1	U
A5	Devils Hole	0	430	32.7	U
A6	Point-of-Rock	2,500	<500	32.7	U
A7	Big	1,700	490	27.2	U
DV1	Nevares	260	630	33.8	D
DV2	Texas	360	610	32.7	D
DV3	Travertine	490	660	33.8	D

development potential. Although evidence suggests that carbonate rocks may underlie the basin fill in this area, the depth to and thickness of the carbonate-rock sequences and the quantity of flow are not known. Winograd and Thordarson (1975) suggest that the quantity of flow beneath the area is equivalent to the quantity of spring discharge at Death Valley (between 4,000 and 5,000 acre-ft/yr). Therefore, development in this area would probably affect spring discharge at Death Valley, which is used for domestic purposes.

In the northwestern half of the Amargosa Desert area, the presence of carbonate rocks at depth is unknown. Further study of this area is needed to make even a reconnaissance appraisal of development potential.

Pahrump Valley

Hydrographic Setting

The Pahrump Valley hydrographic area encompasses about 1,050 mi^2 in Nye and Clark Counties in southern Nevada, and Inyo County in southeastern California (fig. 15). Approximately 80 percent of the area is in Nevada. Pahrump Valley is a topographically closed basin with surface drainage generally from northeast to southwest (Malmberg, 1967). The Spring Mountains on the northeast side of the area are the source of recharge for the valley and greatly influence the direction and magnitude of ground-water flow throughout the area. Large alluvial fans, extending southwestward from the Spring Mountains, have a surface gradient of between 200 and 400 ft/mi. Historically, two major springs discharged near the foot of the fans until pumping for irrigation eventually lowered the water table to where the springs no longer flow (Harrill, 1986). More recently, water levels have slightly risen as a result of decreased pumping in the vicinity of the springs. The southwestern part of the valley is gently sloping with typical gradients of 15 to 30 ft/mi in a southwest direction. The Pahrump area is one of the chief areas for growing alfalfa, cotton, and grains in southern Nevada, and is currently being developed for residential purposes. The town of Pahrump is the major community in the area. All water for domestic and irrigation purposes is obtained from wells; no perennial streams flow in Pahrump Valley.

Geology

The Spring Mountains, the largest range in southern Nevada, are composed largely of thick sections of Paleozoic carbonate rocks and contain locally interlayered units of Precambrian and Cambrian noncarbonate rocks. Paleozoic carbonate rocks are also widespread in the Nopah Range to the west and may exceed 10,000 ft in thickness (Burchfiel and others, 1983a,

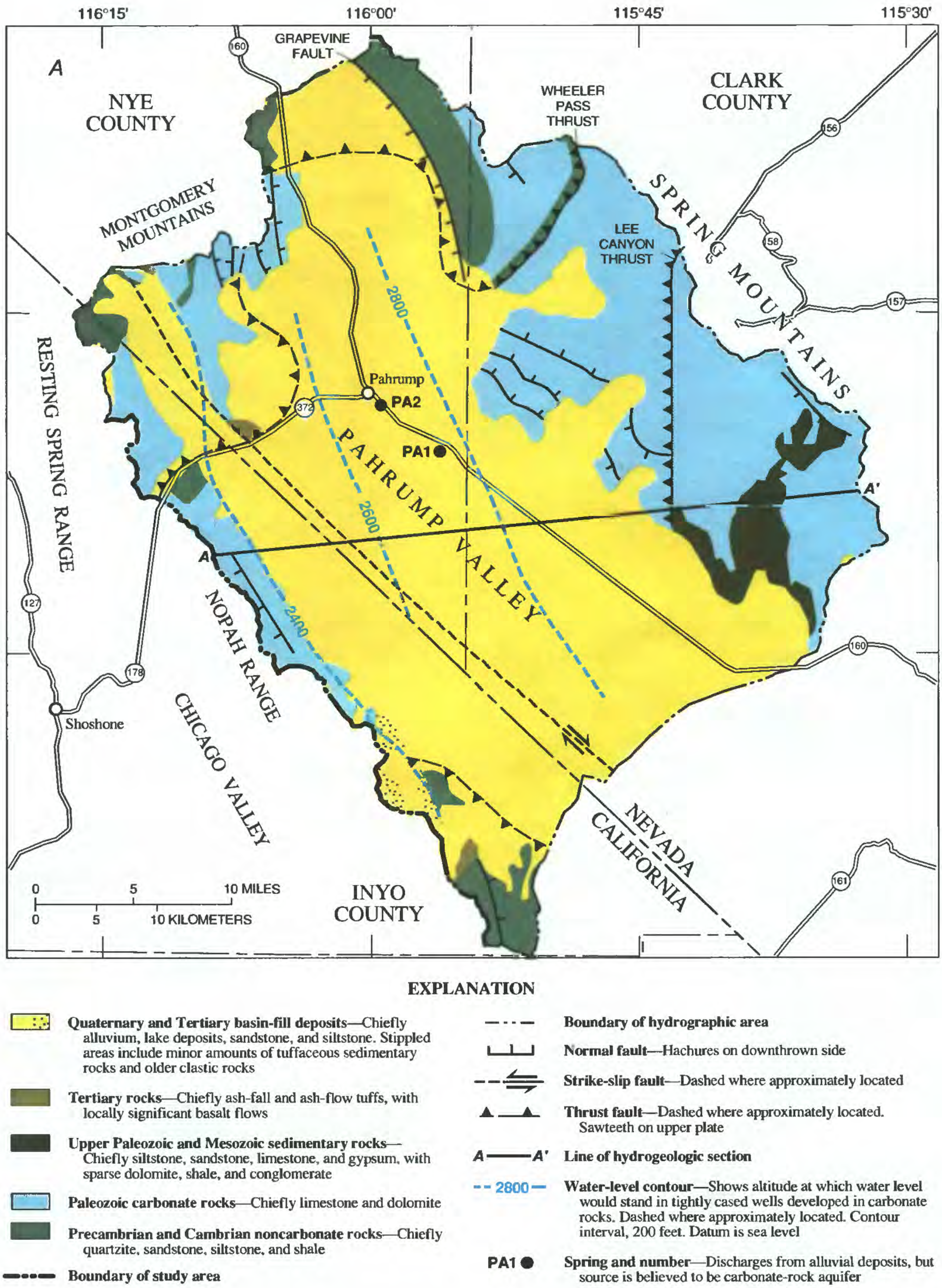


Figure 15. Hydrogeologic map and generalized section through Pahrump Valley. *A,* Hydrographic area showing hydrogeologic rock units, major structural features, water levels in the carbonate rocks, and springs discharging (or previously discharging) from carbonate rocks (structural geology from Cornwall, 1972; Burchfiel and others, 1974; Wright and others, 1981; Wernicke and others, 1988b; hydrogeology from Thomas and others, 1986, and Harrill, 1986). *B,* Generalized hydrogeologic section through Pahrump Valley (geology from Malmberg, 1967; Burchfiel and others, 1974; Wright and others, 1981; and Harrill, 1986).

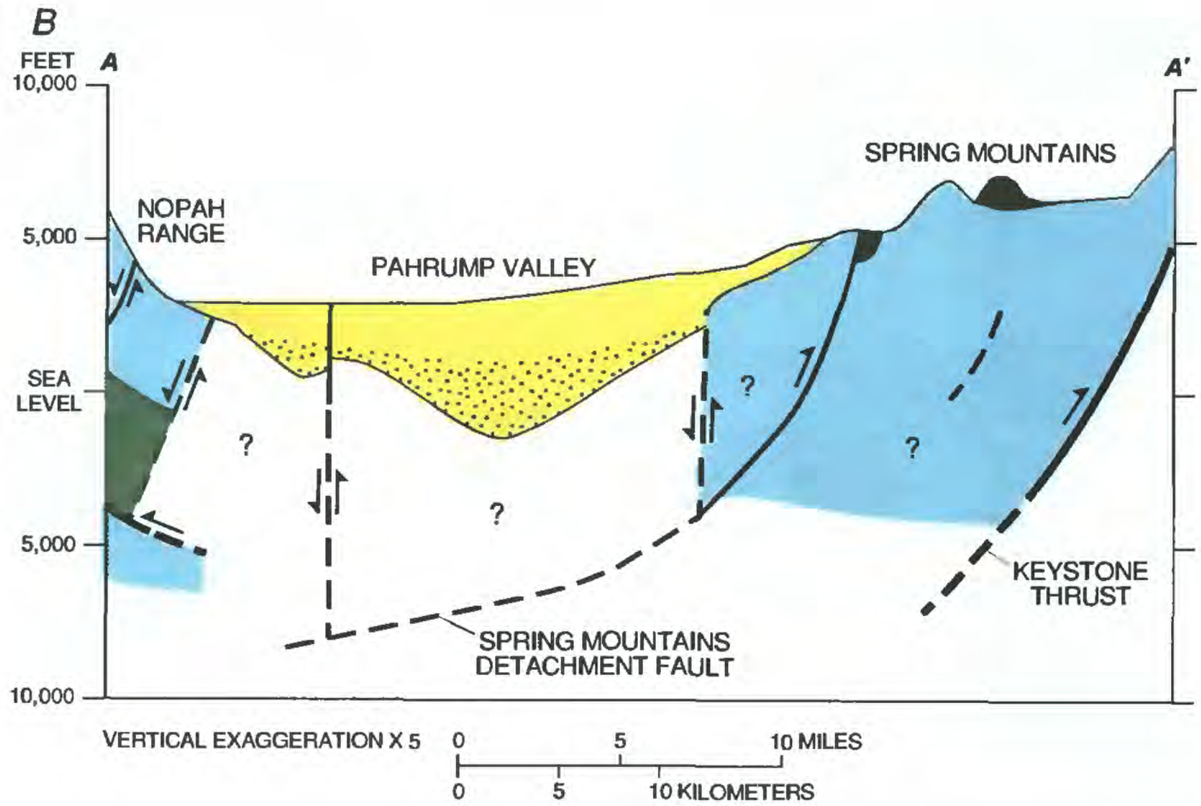


Figure 15. Continued.

fig. 3). Precambrian and Cambrian noncarbonate rocks are prevalent in the northern part of the Spring Mountains, in the Montgomery Mountains, and in the Kingston Range (fig. 15). Thicknesses of this unit generally exceed 3,000 ft (Burchfiel and others, 1983b; Burchfiel and others, 1974). A thick wedge of Mesozoic sedimentary rocks is exposed in the Spring Mountains in the eastern part of the area (fig. 15). Quaternary and Tertiary basin-fill deposits are thin near the margins of the valley, but may exceed 4,000 ft near the center of the valley (Harrill, 1986). Because no wells penetrate the rocks underlying the basin fill, the hydrologic rock units beneath the valley are not known.

Widespread evidence of compressional tectonics can be seen in the Spring Mountains where thick sequences of Paleozoic carbonate rocks and Cambrian and Precambrian clastic rocks have been thickened by thrusting. The westernmost thrust fault in the Pahrump Valley area, the Wheeler Pass thrust, brought a thick sequence of Precambrian clastic rocks over much of the younger Paleozoic carbonate rocks. Pahrump Valley and the Resting Springs Range to the southwest are results of extreme extensional deformation, which has resulted in high-angle block and normal faulting as the area was "pulled apart" (Burchfiel and others, 1983b; fig. 15). The geology beneath Pahrump Valley is probably highly complex. It is not known whether thick sequences of Precambrian and Cambrian clastic rocks were transported eastward (beneath the valley) during thrusting, or whether Paleozoic carbonate rocks or older clastic rocks still remain after being greatly extended.

Hydrology

Pahrump Valley is recharged almost exclusively from the infiltration of precipitation atop the abundantly exposed carbonate rocks of Spring Mountains, the largest area of recharge in southern Nevada. Malmberg (1967) estimated that about 22,000 acre-ft/yr is recharged to Pahrump Valley from the Spring Mountains, whereas Harrill (1986) estimated that as much as 37,000 acre-ft/yr may recharge the valley, on the basis of computer simulations. Of the 37,000 acre-ft/yr estimated by Harrill, approximately 18,000 acre-ft/yr recharges the carbonate rocks at depth while the remaining 19,000 acre-ft/yr recharges the basin fill. Prior to extensive pumping for irrigation, ground water within Pahrump Valley was discharged by evapotranspiration, springs (Manse and Bennets Springs, fig. 15, table 17), and subsurface outflow. Table 16 shows the natural recharge and discharge estimates (prior to pumping) made by previous investigators.

Table 16. Recharge and discharge estimates for Pahrump Valley prior to development

Component of recharge or discharge	Quantity (acre-feet per year)
Recharge	
Precipitation in Spring Mountains	
Malmberg (1967)	22,000
Harrill (1986)[a]	37,000
Recirculated discharge from Manse and Bennet Springs	
Harrill (1986)[a]	4,600
Discharge	
Evapotranspiration from phreatophytes	
Malmberg (1967)	10,000[b]
Harrill (1986)	14,000[c]
Springs issuing from carbonate rocks and basin fill	
Maxey and Jameson (1948)	9,700
Subsurface outflow to Shoshone, Tecopa, and possibly Death Valley	
Malmberg (1967)	12,000[d]
Harrill (1986)	18,000
Total recharge (rounded)	22,000-42,000
Total discharge (rounded)	22,000-42,000

[a] Results from simulation of steady-state ground-water flow model. Amount of spring discharge recirculated back into flow model.

[b] Represents spring discharge consumed by evapotranspiration.

[c] Does not include direct evapotranspiration of 5,200 acre-feet per year of spring discharge not recirculated back to ground water.

[d] Represents 2,000 acre-feet per year through the basin fill and 10,000 acre-feet per year through carbonate rocks.

Water levels in the basin fill were within 50 ft of land surface in much of the valley prior to development. Several wells near the springs had artesian flow caused by high water pressures at depth. Subsequently, water-level declines of 100 ft have been measured for 60 years following the onset of pumping (Harrill, 1986). Water levels have recovered on the order of 5 to 10 ft since the mid-1970's because of decreased pumping. Most wells within the valley, however, are shallow because the water levels are shallow. The deepest wells extend to about 1,000 ft below land surface, but are still well within the basin fill, which may be as thick as 4,000 ft. No water-level data are available for carbonate rocks beneath Pahrump Valley.

The hydrologic character of Pahrump Valley shows evidence of structural influences at depth. Prior to development of the valley, both Manse and Bennets Springs issued from the base of the large alluvial fans sloping up to the Spring Mountains. These springs originate from ground water in carbonate rocks, on the basis of geochemistry (J.M. Thomas, U.S. Geological Survey, oral commun., 1988), but evidence suggests that ground-water circulation is relatively shallow because the temperature of the springs is less than 27°C (table 17). The present location of the springs may be the result of extensional faults that have juxtaposed highly permeable Paleozoic carbonate rocks with Tertiary basin fill of low permeability near where the springs discharge (fig. 15), or more simply due to the break in slope at the toe of the alluvial fans. As pumping began and water levels declined within the valley, these springs dried up because of the shallow source of ground-water flow and the close hydraulic connection between the carbonate rocks and adjacent basin fill.

Table 17. Information on springs assumed to be fed by carbonate-rock aquifer and used for irrigation in Pahrump Valley [a]

[Data modified from James M. Thomas, U.S. Geological Survey, written commun., 1987.]

Number (fig. 15)	Name	Discharge [b] (acre-feet per year)	Dissolved solids (milligrams per liter)	Temperature (degrees Celsius)
PA1	Manse	4,400	230	22
PA2	Bennets	5,400	240	25

[a] Water-quality data were obtained from wells adjacent to springs before pumping began.

[b] Discharge rate prior to development.

Spring discharge at Shoshone and Tecopa (south of Shoshone) southwest of the Resting Spring Range (fig. 15 and pl. 1) originates from recharge to the carbonate rocks within the Spring Mountains. Model simulations by Harrill (1986) indicate that pumping centers in Pahrump Valley have little short-term influence on spring discharge or evapotranspiration at Shoshone and Tecopa; rather, pumping tends to extract stored water in the basin fill or perhaps the shallow underlying carbonate rocks. How long-term pumping in Pahrump Valley would affect discharge at Shoshone and Tecopa depends (1) on the difference in altitude between water in the wells at the pumping center and the water level at the downgradient discharge areas, which is currently about 1,000 ft below the altitude of the pumping wells, and (2) on the amount of flow the pumping wells could capture. Furthermore, the influence of possible low-permeability clastic rocks beneath Pahrump Valley on long-term pumping and downgradient discharge is not known.

Because much of the Pahrump Valley area has exposed carbonate rocks, the estimated ground-water storage within the area is quite high. About 10 million acre-ft of storage has been estimated for the area, according to the assumptions outlined in this report; of this total, about 6.7 million acre-ft represents local storage (within the basin fill). Both total (carbonate rock and basin-fill storage) and local storage estimates may be high if extension has thinned or moved the carbonate rocks from beneath Pahrump Valley.

Potential for Ground-Water Development

Pahrump Valley has many positive attributes that make it a potential site for future development: shallow water levels, potentially thick sequences of carbonate rocks at depth, high water quality (pl. 1), and, most importantly, a source of water (10,000-18,000 acre-ft/yr) that under natural conditions leaves the valley. However, much of the valley is filled with thick basin-fill deposits and the underflow leaving the basin may be prohibitively deep (greater than 2,500 ft), especially if Precambrian clastic rocks overlie Paleozoic carbonate-rock aquifers as a result of thrust faulting. Conversely, basin-fill deposits may be hydraulically connected to the underlying carbonate rocks so that development of the basin-fill aquifers may capture deeper carbonate-rock ground-water flow. The possibility of deep flow paths beneath the valley is supported by the temperature of discharging water at Tecopa (108°F) and Shoshone (92°F) Springs, southwest of and downgradient from Pahrump Valley. The possibility of deep flow also is supported by the estimated age of the water (approximately 16,000 years, according to corrected carbon-14 ages; J.M. Thomas, U.S. Geological Survey, written commun., 1990) discharging at Shoshone Spring; the water is believed to flow beneath Pahrump Valley from the Spring Mountains.

If most of the throughflow beneath Pahrump Valley is recharged through carbonate rocks in the Spring Mountains, then development on the alluvial fans adjacent to the Spring Mountains, and perhaps southeast of the currently active pumping areas, may be feasible. The thickness of basin fill is not excessive on the fans (fig. 15) and carbonate rocks may be thick. In addition, ground-water quality does not seem to be impaired by the presence of Mesozoic sedimentary rocks in the Pahrump Valley area (fig. 15), although further study is needed to verify this conclusion.

Mesquite and Ivanpah Valleys

Hydrographic Setting

Two hydrographic areas, Mesquite Valley and Ivanpah Valley, are combined in this report into a composite area because both areas are small in size. Mesquite Valley occupies 456 mi^2; 236 mi^2 are in extreme southern Nevada and 220 mi^2 are in the southeastern part of California (fig. 16). Ivanpah Valley is located across the southern Spring Mountains to the east of Mesquite Valley and occupies 235 mi^2. Both valleys have ephemeral streams that originate in the Spring Mountains to the north, which rapidly evaporate or infiltrate into the basin fill before reaching the lower parts of the valleys. In Mesquite Valley, surface drainage is southeastward toward Mesquite Lake, a dry playa fringed by vigorously growing phreatophytes. In Ivanpah Valley, surface drainage is generally southward toward Roach Lake, a dry playa. In addition to the Spring Mountains, the Kingston and Clark Ranges encompass Mesquite Valley. The McCullough Range borders Ivanpah Valley to the east (fig. 16).

Mesquite Valley is sparsely populated with isolated farms and ranches located along the lower parts of the valley. Some livestock grazing is also associated with ranching but, for the most part, Mesquite Valley does not have a local economy. Interstate 15 connecting Los Angeles and Las Vegas bisects Ivanpah Valley. The high volume of traffic has led to the recent buildup of gaming facilities at Jean and at the State line. Gaming and tourism represent the major part of the economy in Ivanpah Valley, which supports about 200 residents who live primarily in Jean and Goodsprings (fig. 16), but the transient tourist population is much larger (and growing) and the demand for domestic water is likewise increasing.

Geology

The southern Spring Mountains, separating Mesquite and Ivanpah Valleys, contain more than 10,000 ft of Paleozoic carbonate rocks (fig. 16), but the carbonate rocks thin to about 2,000 ft in the Clark Mountains south of the Spring Mountains (Burchfiel and Davis, 1971; Burchfiel, 1988). In general, the carbonate rocks become thicker relative to Precambrian and Cambrian noncarbonate rocks toward the east. To the west, in the Kingston Range, Precambrian crystalline and Cambrian clastic rocks are the thickest and most abundant of the exposed hydrologic units (fig. 16). In the eastern part of the area, Precambrian and Cambrian non-carbonate rocks, composed primarily of granitic and metamorphic rocks, predominate in the McCullough Range, representing the southeast boundary of the carbonate-rock province. Small exposures of Tertiary volcanic rocks are found in the southern Spring Mountains and in the McCullough Range. A larger volcanic area is in the Kingston Range to the west where Tertiary granitic rocks form the central core of the range. Mesozoic sedimentary rocks have only limited exposure in the area, yet they may be more extensive at depth beneath the overthrusted Paleozoic carbonate rocks (fig. 16). Quaternary and Tertiary basin-fill deposits form an extremely thick basin in Mesquite Valley where geophysical (gravity) studies indicate as much as 10,000 ft of basin fill may overlie Paleozoic carbonate rocks (MIT Field Geophysics Course, 1985). In Ivanpah Valley, basin fill is generally several thousand feet thick (Bates, 1967) and overlies primarily carbonate rocks (Glancy, 1968; fig. 16).

The Mesquite-Ivanpah area marks the southeasternmost extent of the Cordilleran miogeosyncline (Hewett, 1956). In the southern Spring Mountains, three separate episodes of thrust faulting are recognized that greatly thickened the carbonate-rock section in this area (Carr, 1983). Farther to the south in the Clark Mountains, Burchfiel and Davis (1971) and Burchfiel (1988) recognized three distinct episodes of thrusting as well. The amount of Tertiary extension is still uncertain. Extreme extension occurred in the Kingston Range to the west (McMackin, 1988; Burchfiel and others, 1983b) and in the McCullough Range to the east (Smith and others, 1986). Evidence favors significant extension within the area because of the extremely deep basin beneath Mesquite Valley, and the presence of abundant low-angle faults superimposed on thrust faults in Ivanpah Valley (Burchfiel and Davis, 1988; fig. 16).

Hydrology

Mesquite and Ivanpah Vallêys receive virtually all their recharge from the southern Spring Mountains. Of the 1,500 acre-ft/yr estimated to recharge Mesquite Valley from precipitation on the adjacent ranges, 1,400 acre-ft/yr originates from the Spring Mountains (Glancy, 1968). In Ivanpah Valley, all 700 acre-ft/yr recharging the valley from precipitation originates in the Spring Mountains (Glancy, 1968). Mesquite Valley may receive an additional estimated 700 acre-ft/yr of underflow from the carbonate-rock aquifers beneath Pahrump Valley to the northwest (Glancy, 1968). Ivanpah Valley may receive an additional 800 acre-ft/yr of subsurface inflow from California through both carbonate rocks and basin fill, according to Glancy (1968).

Discharge from the area is generally by evapotranspiration or subsurface outflow. In Mesquite Valley, virtually all of the recharge entering the valley is discharged as evapotranspiration from phreatophytes surrounding Mesquite Lake playa. Some minor quantities of ground water may be lost to irrigation. Increased pumping in Ivanpah Valley may capture much of the subsurface outflow inferred by Glancy (1968) to be flowing toward Las Vegas Valley to the northeast. The growing tourist industry will lead to an estimated increase in ground-water pumping that will be currently twice the estimated recharge to the valley (Katzer and others, 1988).

Water levels within the carbonate rocks beneath Mesquite and Ivanpah Valleys are unknown in most areas as only a few wells penetrate the thick basin-fill cover in these areas. Basin-fill water levels in Mesquite Valley are generally less than 100 ft below land surface and decrease to less than 30 ft near the playa. Because of the thick basin-fill cover, it is not known whether water levels in the carbonate rocks are similar, but large differences are probably unlikely. The depth to water generally increases to the northeast. In Ivanpah Valley, basin-fill water levels are generally greater than 100 ft below land surface and may deepen to more than 500 ft. One well in the center of the valley that penetrates carbonate rocks has a water level greater than 800 ft below land surface (well I1; fig. 16, table 18). The inferred direction of ground-water flow (Glancy, 1968) is northward toward Las Vegas Valley from Ivanpah Valley. In Mesquite Valley, deep ground-water flow directions are not known except for possible flow from Pahrump to Mesquite Valley. The shallow flow within the basin fill is toward the playa in the southeastern part of the valley.

Ground-water quality in the basin fill is generally poor because evaporite minerals are common in these deposits. Within the carbonate rocks at depth, however, water quality probably improves significantly (Katzer and others, 1988). Evidence for this is based on data from wells penetrating basin fill near recharge areas where only a thin basin-fill cover exists. At these sites, water quality is greatly improved in comparison to wells where thick basin-fill deposits are known to be present, especially areas far from sources of recharge in the Spring Mountains.

Ground-water storage within the Mesquite and Ivanpah hydrographic areas is estimated to be about 3.4 and 2.4 million acre-ft, respectively, based on assumptions discussed earlier in this report. Most storage within these areas is local storage (beneath basin fill). In Mesquite Valley, local storage has been estimated to be 2.1 million acre-ft, or 62 percent of the total storage; in Ivanpah Valley, local storage has been estimated to be 1.7 million acre-ft, or 71 percent of the total storage.

Potential for Ground-Water Development

Little recharge from precipitation occurs within the area; hence any development of the carbonate-rock aquifers must depend heavily upon storage reservoirs within the carbonate rocks. Because the basin fill in both valleys is thick (pl. 1), and because poor-quality ground water is commonly associated with these areas, particularly in Ivanpah Valley, development would have to be confined to areas near the Spring Mountains where basin fill is not thick and water quality may be generally satisfactory. Also, because the carbonate-rock section in the Spring Mountains is thick, the quantity of available ground water from storage is probably significant. Development in northern Mesquite Valley may capture ground water consumed by phreatophytes around Mesquite Lake, although this is a small quantity (2,200 acre-ft/yr, according to Glancy, 1968).

Long-term effects of development are difficult to evaluate. In Ivanpah Valley, intensive pumping may lower water levels below most domestic wells as the hydraulic connection is probably good between basin fill and the underlying carbonate rocks. Difficulty in obtaining ground water of good quality in most parts of Ivanpah Valley, thus, may limit development (table 18). Further information is needed to accurately assess the long-term effects of development in this area.

SUMMARY AND CONCLUSIONS

The geology and hydrology of selected hydrographic areas in southern Nevada was summarized and each area was assessed for its potential for development of the carbonate-rock aquifers underlying the valley floor. Geologic and hydrologic information for each site was compiled and used to evaluate potential

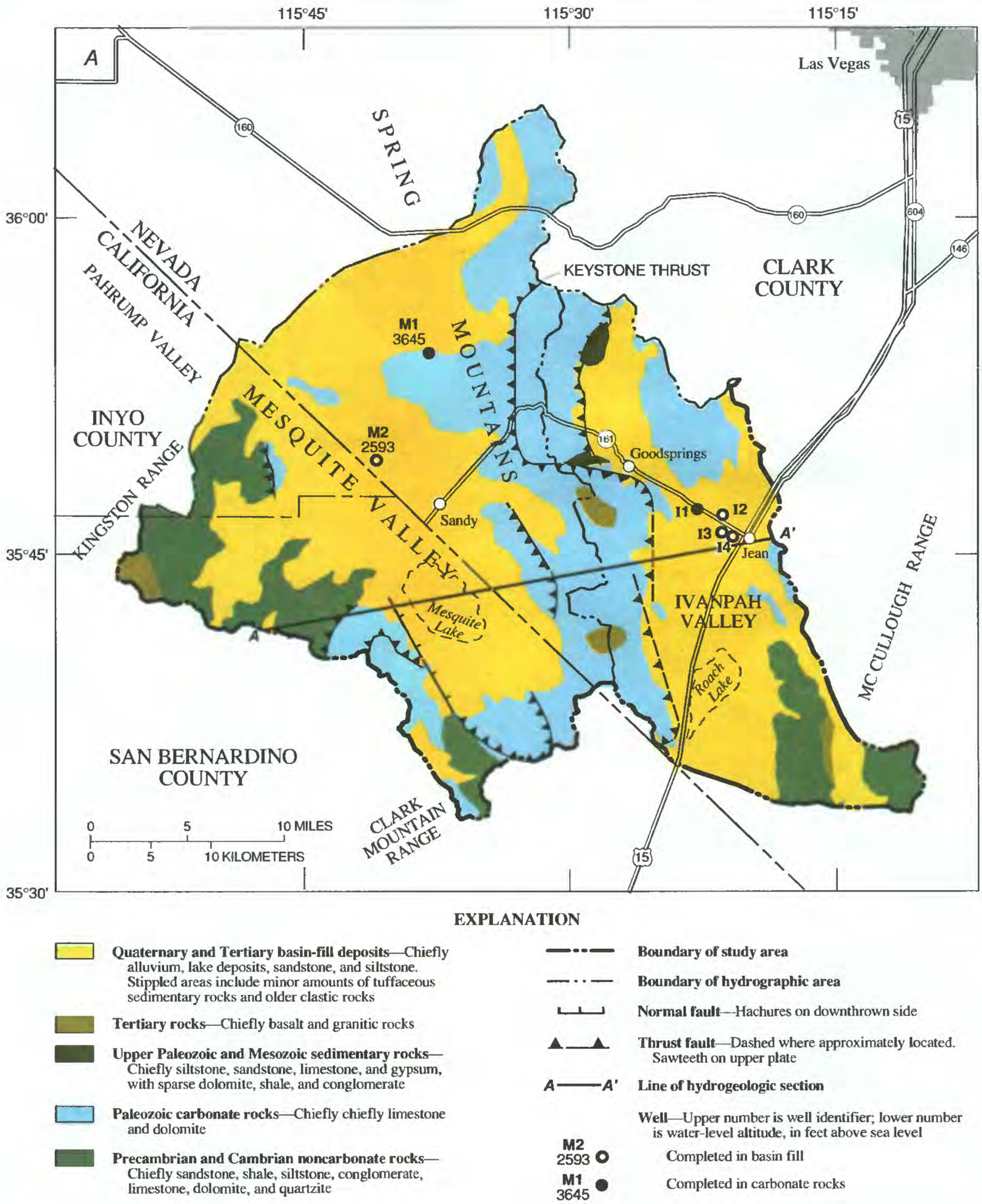


Figure 16. Hydrogeologic map and generalized section through Mesquite and Ivanpah Valleys. *A*, Hydrographic areas showing hydrogeologic rock units, major structural features, and points where ground-water data are available from carbonate rocks (structural geology from Longwell and others, 1965; Burchfiel and Davis, 1971; Carr, 1983; MIT field geophysics course, 1985; Burchfiel and Davis, 1988; and McMackin, 1988; hydrogeology from Thomas and others, 1986). *B*, Generalized hydrogeologic section through Mesquite and Ivanpah Valleys (geology from Burchfiel and others, 1974; Burchfiel and Davis, 1971; Carr, 1983; MIT field geophysics course, 1985; and Burchfiel, 1988).

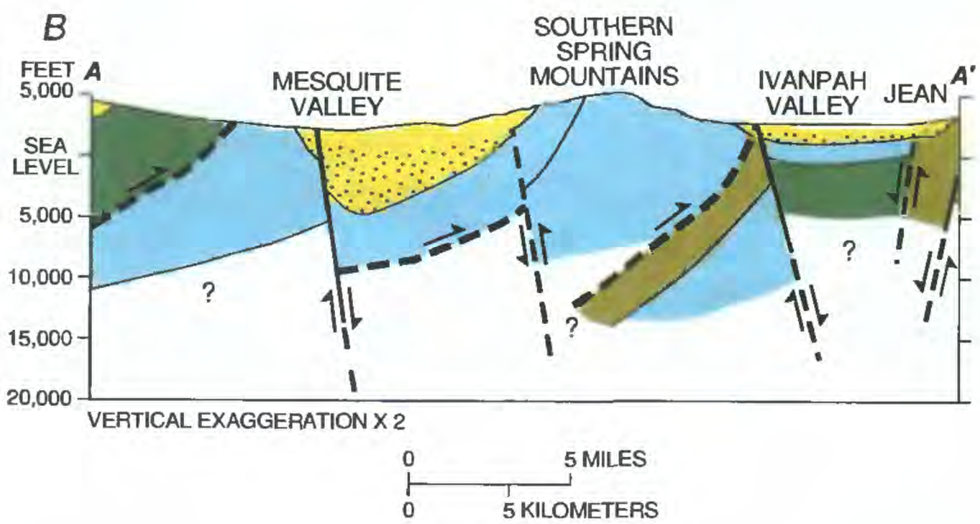


Figure 16. Continued.

Table 18. Information on wells completed in carbonate rocks and basin fill in Mesquite Valley and Ivanpah Valley

[Data modified from J.M. Thomas, U.S. Geological Survey, written commun., 1987. Abbreviations and symbols: D, domestic; M, municipal; O, observation; --, no data; <, less than; >, greater than]

Number (fig. 16)	Name	Total depth (feet)	Depth to water (feet below land surface)	Depth to carbonate rocks (feet below land surface)	Dissolved solids (milligrams per liter)	Use
M1	none	800	355	33	<500	D
M2	none	925	62	>925	--	D
I1	A3-1	939	840	909	920	O
I2	A3-9	800	630	>800	800	O
I3	A3-11	785	585	>785	350	O
I4	Gold Strike	1,281	570	>1,281	620	M

areas for development on the basis of three major criteria: (1) depth to water, (2) depth to and thickness of carbonate rocks, and (3) water quality. Other factors, such as short and long-term effects of development and accessibility, were also taken into consideration.

Geologic data indicate that much of the central part of southern Nevada is underlain by thick sequences of carbonate rock, although overall thicknesses may be highly variable locally. Less desirable areas for potential ground-water development include those where little or no carbonate rock is present at depth; such areas include Lower Meadow Valley Wash, northern Three Lakes Valley, northern Amargosa Desert, and possibly eastern Las Vegas Valley. In these areas, structural patterns indicate that clastic and crystalline rock of Precambrian age underlie the unconsolidated deposits. Other factors that limit the potential for development include areas where the carbonate rock is present, but where there are less than 2,000 ft of carbonate rock in the uppermost 5,000 ft of depth; examples of such areas include southern Amargosa Desert, central Mesquite and Pahrump Valleys, Delamar Valley, Garnet Valley, Three Lakes Valley, and possibly Tikaboo Valley. These areas generally possess trough-like basins filled with thick sedimentary deposits of Quaternary and Tertiary age. Several areas contain at least 2,000 ft of carbonate rocks in the uppermost 5,000 ft of rock and overlapping sediments, but they are not potential areas for development because the depth to carbonate rocks is greater than 1,500 ft; examples of such areas include parts of Ivanpah Valley, western Pahranagat Valley, and west-central Las Vegas Valley. Many of the remaining areas may provide favorable sites for development of the carbonate-rock aquifers on the basis of geologic data, assuming that the carbonate rocks are well enough fractured to allow adequate ground-water flow. The potentially favorable areas include eastern Pahranagat and Coyote Spring Valleys, southernmost Delamar Valley, eastern Lower Meadow Valley Wash, Hidden Valley, northwest Las Vegas Valley, southern Indian Springs Valley, northern Mesquite Valley, and eastern Pahrump Valley.

The extent of favorable areas for ground-water development is further limited when available hydrologic data are used to assess potential areas. For example, hydraulic continuity of carbonate-rock aquifers from area to area, particularly if regional springs are present, indicates that development of one area may affect the quantity of flow or spring discharge in an adjacent area. Examples of such areas include eastern Pahranagat Valley, southern Delamar Valley, and Coyote Spring Valley, which are all part of the White River ground-water flow system terminating at the Muddy River Springs area. Development in any one of these areas may eventually affect spring discharge. Similarly, development in southern Indian Springs Valley may eventually affect discharge at springs in Ash Meadows because a large amount of ground water flows from the Spring Mountains beneath Indian Springs Valley to Ash Meadows. Further limitations caused by conditions of poor water quality in the easternmost part of the area must also be considered in selecting potential sites. These areas include Lower Meadow Valley Wash, eastern Las Vegas Valley, and Ivanpah Valley.

Favorable areas for ground-water development that meet the three major criteria are further classified as one of two types: (1) areas that have plentiful, but underdeveloped ground water, and (2) areas that have isolated ground-water storage reservoirs. Northern Mesquite Valley is a favorable area on the basis of the first classification. It has an adequate supply of recharge (Spring Mountains) and a large amount of the recharge is lost to phreatophytes within the hydrographic area. Eastern Pahrump Valley may also be a favorable area based on the first classification; however, existing development in basin-fill deposits in the western part of the valley has already created a basin-wide overdraft. This condition needs to be taken into consideration when evaluating any additional development because development in the carbonate rocks may affect water levels in overlying basin-fill deposits, if the two are hydraulically well connected.

Potential favorable areas, on the basis of the second classification, include northwest Las Vegas Valley and southern Tikaboo Valley, because of potential ground-water flow barriers in the Desert and Sheep Ranges formed by thick sequences of Precambrian and Cambrian clastic rock, and along the Las Vegas Valley shear zone. These barriers may compartmentalize flow in carbonate-rock aquifers and inhibit the undesirable effects of aquifer development. The extremely thick carbonate-rock aquifers beneath Hidden and Garnet Valleys may represent potential areas for development. The carbonate-rock aquifers may be compartmentalized by hydraulic barriers to the west in the Sheep Range, because of thick sequences of Precambrian and Cambrian clastic rock, and by the Las Vegas Valley shear zone to the south; these features may reduce undesirable effects of development. However, a possible hydraulic connection between aquifers in Hidden and Garnet Valleys and Coyote Spring Valley to the north should be considered because of the possible effect on discharge at Muddy River Springs. Development in areas bounded by flow barriers and not significantly recharged by adjacent ranges, such as Hidden and Garnet Valleys, provides a one-time source of ground water. Thousands of years may be required for these aquifers to be replenished if they are extensively developed.

More information is needed to adequately evaluate the potential for ground-water development within each of the hydrographic areas. The area-by-area evaluations described herein are only preliminary, but provide information relevant to the selection of sites for further detailed assessment.

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GLOSSARY

The definitions presented in this glossary have been modified from Bates and Jackson (1987), Fiero (1986), and Lohman and others (1972).

Accretion—process by which the continents increased in size by addition of an island arc—a chain of islands margined by a deep trench and a deep sea basin.

Anticline—a fold in rocks in which the strata dip outward from both sides, away from the axis. An anticline is convex.

Aquifer—a permeable geologic unit that can transmit significant quantities of water.

Block fault—a high-angle normal fault in which a block is downfaulted relative to adjacent blocks.

Broken terrane—region of severe extension, characterized by imbricate faults (domino-style faulting), rotated blocks, and gravity slides (slumping of large rock masses under the influence of gravity).

Clastic rocks—consolidated sedimentary rocks (such as sandstone and shale) composed of transported fragments of older rock.

Compressional tectonics—mountain-building process resulting from collision of two crustal plates and characterized by large low-angle faults (thrust faults) causing a thickening of the crust.

Confining unit—a body of relatively impermeable material stratigraphically adjacent to one or more aquifers.

Detachment—a low-angle normal fault that usually comprises the lower boundary of an extensional rock mass.

Dry playa—a flat-lying dry lakebed located within a desert basin representing the terminus of drainage from surrounding areas.

Evaporite—a salt-rich sedimentary deposit resulting from evaporation of saline water.

Extensional tectonics—large scale spreading or "pulling-apart" of the Earth's crust, resulting in areas of broken terrane and thinning of the crust.

Fracture porosity—the fraction of the total porosity that results from fractures, joints, and solution cavities; also called secondary porosity.

Ground-water storage—the volume of water that a unit volume of aquifer releases under a unit decline in water level. In confined aquifers, storage represents the quantity of water released due to compaction of the aquifer and expansion of the water. In unconfined aquifers, the quantity of storage also includes the water obtained from gravity drainage of the aquifer.

Hydraulic gradient—the change in water level over a specified distance along a flow path.

Interstitial porosity—a ratio representing the volume of voids within the matrix of the porous medium to the total volume of porous medium.

Island arc—a chain of volcanic islands separated from the continental margin by a deep submarine trench.

Miogeocline—a large linear trough that subsided deeply over a long period of time during which thick deposits of sedimentary rocks accumulated.

Permeability—the ability of a porous medium (aquifer) to transmit water.

Piedmont—the sloping area transitional between the valley lowlands and the mountain block.

Potentiometric surface—a surface that represents the static hydraulic head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells within a specific aquifer or stratum.

Shear zone—a strike-slip fault or series of faults (faulting that represents lateral movement) in which the rocks along the fault have been sheared or crushed.

Specific yield—a ratio of the volume of water a porous medium yields by gravity, after being saturated, to the total volume of porous medium. The value is usually given as a percentage.

Stable terrane—large rock mass that has been only slightly or moderately extended relative to adjacent rock mass; characterized by thick, coherent sequences of rock.

Syncline—a fold in rocks in which the strata dip inward from both sides toward the axis. A syncline is concave.

Thrust fault—a low-angle (less than 45°) fault in which the mass of rock above the fault plane has moved upward relative to the mass of rock beneath the fault plane.

Thrust sheet—a rock mass or sequence of rock units that have been moved over another rock mass or sequence of rock units during the process of thrusting and resulting in a thickening of the crust.

Total porosity—a ratio representing the volume of voids (includes primary and secondary porosity—that is, interstitial porosity, fractures, and solution cavities) to the total volume of porous medium.

Unconformity—a surface of erosion that separates two rock sequences of different ages.

Water table—the ground-water surface in unconfined aquifers (under atmospheric pressure).