Hydrology of the Valley-Fill and Carbonate-Rock Reservoirs Pahrump Valley Nevada-California

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1832

Prepared in cooperation with the
Nevada Department of Conservation
and Natural Resources

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By GLENN T. MALMBERG

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HYDROLOGY OF THE VALLEY-FILL AND CARBONATE-ROCK RESERVOIRS, PAHRUMP VALLEY, NEVADA-CALIFORNIA

By GLENN T. MALMBERG

ABSTRACT

This is the second appraisal of the water supply of Pahrump Valley, made 15 years after the first cooperative study. In the first report the average recharge was estimated to be 23,000 acre-feet per year, only 1,000 acre-feet more than the estimate made in this report. All this recharge was considered to be available for development. Because of the difficulty in salvaging the subsurface outflow from the deep carbonate-rock reservoir, this report concludes that the perennial yield may be only 12,000 acre-feet.

In 1875, Bennetts and Manse Springs reportedly discharged a total of nearly 10,000 acre-feet of water from the valley-fill reservoir. After the construction of several flowing wells in 1910, the spring discharge began to decline. In the mid-1940's many irrigation wells were drilled, and large-capacity pumps were installed. During the 4-year period of this study (1959–62), the net pumping draft averaged about 25,000 acre-feet per year, or about twice the estimated yield. In 1962 Bennetts Spring was dry, and the discharge from Manse Spring was only 1,400 acre-feet.

During the period February 1959–February 1962, pumping caused an estimated storage depletion of 45,000 acre-feet, or 15,000 acre-feet per year. If the overdraft is maintained, depletion of stored water will continue and pumping costs will increase. Water levels in the vicinity of the Pahrump, Manse, and Fowler Ranches declined more than 10 feet in response to the pumping during this period, and they can be expected to continue to decline at the projected rate of more than 3 feet per year.

The chemical quality of the pumped water has been satisfactory for irrigation and domestic use. Recycling of water pumped for irrigation, however, could result in deterioration of the water quality with time.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The Pahrump Valley drainage basin discussed in this report includes about 1,050 square miles in Clark and Nye Counties, southern Nevada, and Inyo and San Bernardino Counties, southeastern California (fig. 1). Approximately 200 square miles, or about 20 percent

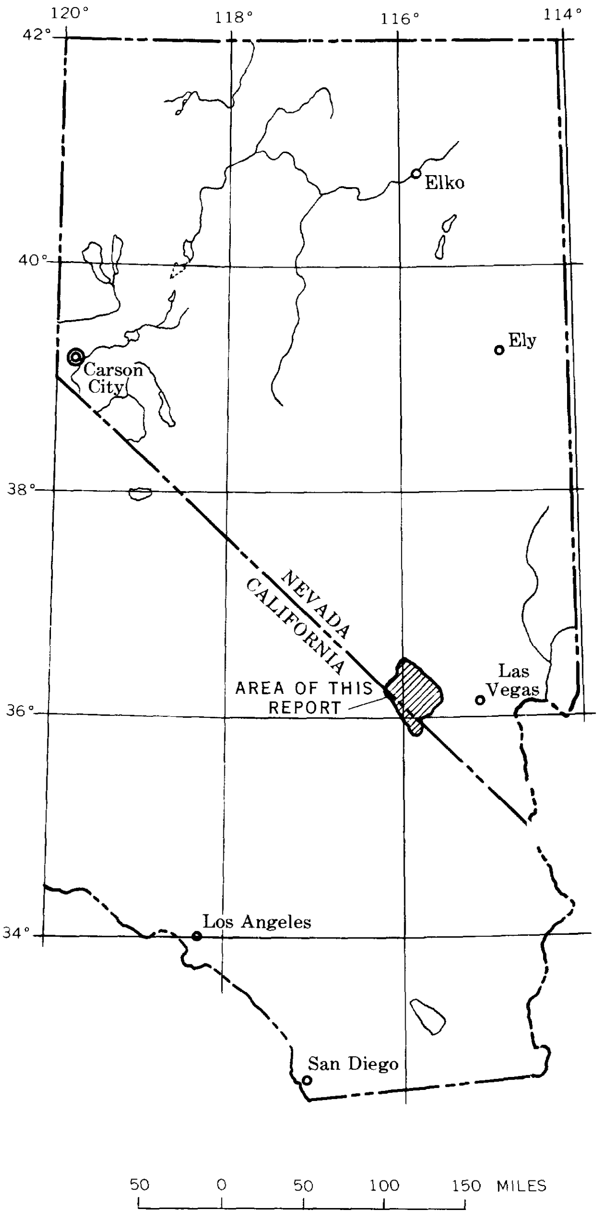

Figure 1.—Area in Nevada and southern California described in this report.

of the total drainage area, is in California. Pahrump Valley lies approximately between lats 35°45′ and 36°30′ N. and longs 115°30′ and 116°15′ W. It is east of Death Valley and the southern part of the Amargosa Desert, and west of Las Vegas Valley. The area extends from Johnnie, Nev., southeastward approximately 42 miles to a point about 14 miles south of Hidden Hills Ranch; it is about 30 miles wide and extends from the crest of the Nopah, the Kingston, and the northern part of the Resting Spring Ranges, on the southwest, to the crest of the Spring Mountains, on the northeast.

PURPOSE AND SCOPE OF THE INVESTIGATION

This is the second hydrologic investigation of Pahrump Valley made by the U.S. Geological Survey under a cooperative program with the Nevada Department of Conservation and Natural Resources. Results of the first cooperative investigation are given in a report by Maxey and Jameson (1948), in which the geology and hydrology are briefly described and an estimate of recharge to and discharge from Pahrump Valley are given.

The second investigation was initiated at the request of the Nevada State Engineer and was prompted by inhabitants of the valley who are concerned with the accelerated rate of water-level decline in wells and the decrease in the yields of springs. The probability of overdevelopment of ground water in the valley and the evidence that Pahrump Valley is not a hydraulically closed basin, as it had previously been described, emphasized the need for a reevaluation of the occurrence and availability of the ground-water supply of the valley. This reevaluation is consistent with the objectives of the long-range cooperative program (Shamberger, 1962, p. 14) for the orderly study of the water resources of Nevada; the long-range program provides for additional detailed studies of areas where moderate to substantial development has occurred and where records are available as a result of a long-continuing inventory.

The purpose of the investigation was to (a) describe the ground-water hydrology of the valley, with special emphasis on the occurrence, movement, and chemical character of ground water in the valley-fill reservoir and in the underlying carbonate-rock reservoir; (b) estimate the perennial yield of the basin; and (c) determine the extent of the overdraft. Early in the investigation it was found that subsurface outflow from the valley occurs through the carbonate rocks to adjacent areas. Owing to a lack of data to define the subsurface outflow and points of discharge, only a cursory study was made of this critical factor in the water supply of Pahrump Valley.

The field investigation was made in 1959, and analysis of the resultant data continued through 1962. The field study included a brief study of the geology of the area as related to the occurrence of ground water, an inventory of ground-water pumpage, the collection and analysis of water samples, and a limited number of determinations of the hydraulic characteristics of the saturated part of the valley fill. Thirteen test wells were drilled in December 1959 to augment the data in the undeveloped areas along the southwest margin of the valley and to establish a network of wells so that fluctuations of ground-water levels could be observed. The fieldwork was done by the author, assisted by C. P. Zones and Philip Cohen.

PREVIOUS INVESTIGATIONS

Several reports were published as a result of the previous hydrologic and geologic studies of parts of Pahrump Valley; reports used in the preparation of this report are included in the list of selected references.

One of the first investigations of the water resources of the area was made by Mendenhall (1909), who made a reconnaissance of the water resources of southwestern Nevada and southeastern California. His report describes the wells and springs and gives data on their yields and on the chemical quality of the water. Data on springs and wells in the valley are listed in other publications, but the information commonly is not quantitative.

Waring (1921) studied the water resources of Pahrump Valley somewhat more intensively than did Mendenhall. Waring's report includes data on the quantity and quality of the ground water from springs and wells in Pahrump Valley and discusses the source and occurrence of ground water.

During 1922–36 the University of Nevada Agricultural Experiment Station at Las Vegas, under the direction of George Hardman, studied the occurrence and utilization of ground water in Las Vegas and Pahrump Valleys (Hardman, 1934, 1949). Valuable data on well and spring discharges, water-level measurements, and chemical quality of water were obtained during those studies and are contained in several reports, some of which were published and are listed in "Selected References."

In 1944 a reappraisal of the ground-water resources of Pahrump Valley was made by G. B. Maxey, U.S. Geological Survey, and C. H. Jameson of the Nevada State Engineer's office (Maxey and Jameson, 1948). Results of that investigation were published in Nevada Water Resources Bulletin 5, which contains all data and results of the study of Pahrump Valley up to that time. The report summarizes the early history and development of ground water, describes ground-water occurrence and quality, and includes estimates of recharge to, and discharge from, the ground-water reservoir. Additional data are contained in two other reports (Robinson and others, 1947; Maxey and Robinson, 1947).

In January and February 1953 several electrical-resistivity depth profiles were made by the U.S. Geological Survey near the springs in Ash Meadows and in the dry lake in Stewart Valley. These profiles were made in an effort to obtain information on the source of water issuing from springs in Ash Meadows. Results of the studies were inconclusive.

WELL-NUMBERING SYSTEM

In this report the numbering of well locations is based on the rectangular system for the division of public lands. The study area encompasses the southeast quadrant of the Mount Diablo base line and meridian, California, and the northeast quadrant of the San Bernardino base line and meridian, California. In this report the numbers assigned to wells in the Nevada part of the area consists of three principal parts: first, a capital S followed by the number of the township south of the Mount Diablo base line; second, a slash followed by a number designating the range east of the Mount Diablo meridian; and third, a hyphen followed by the section number and a series of letters used to designate the well location within the section. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quadrants. The first letter designates the quarter section; the second letter, the quarter-quarter section; and the third—where it was possible to make a determination—the quarter-quarter-quarter section. Where there is more than one well within a quarter-quarter-quarter section, the wells are consecutively numbered according to the order in which they were recorded. For example, the first well recorded in the NE¼NE¼NE¼ sec. 25, T. 21 S., R. 53 E., is numbered S21/53–25aaa1 (fig. 2), the second well recorded is numbered S21/53–25aaa2, and so forth. Where the 40-acre and 10-acre tracts are unknown, the numbering system is modified to include only the designations for the subdivisions of the sections that are known. All wells in Pahrump Valley west of the boundary between Nevada and California are numbered in this report according to their location in relation to the San Bernardino base line and meridian line by a method similar to that just described. The only modification of the number is that a capital letter N precedes the township number (such as N24/8–26bac), which indicates that the township is north of the San Bernardino base line. It thus enables the reader to distinguish wells in California from those in Nevada.

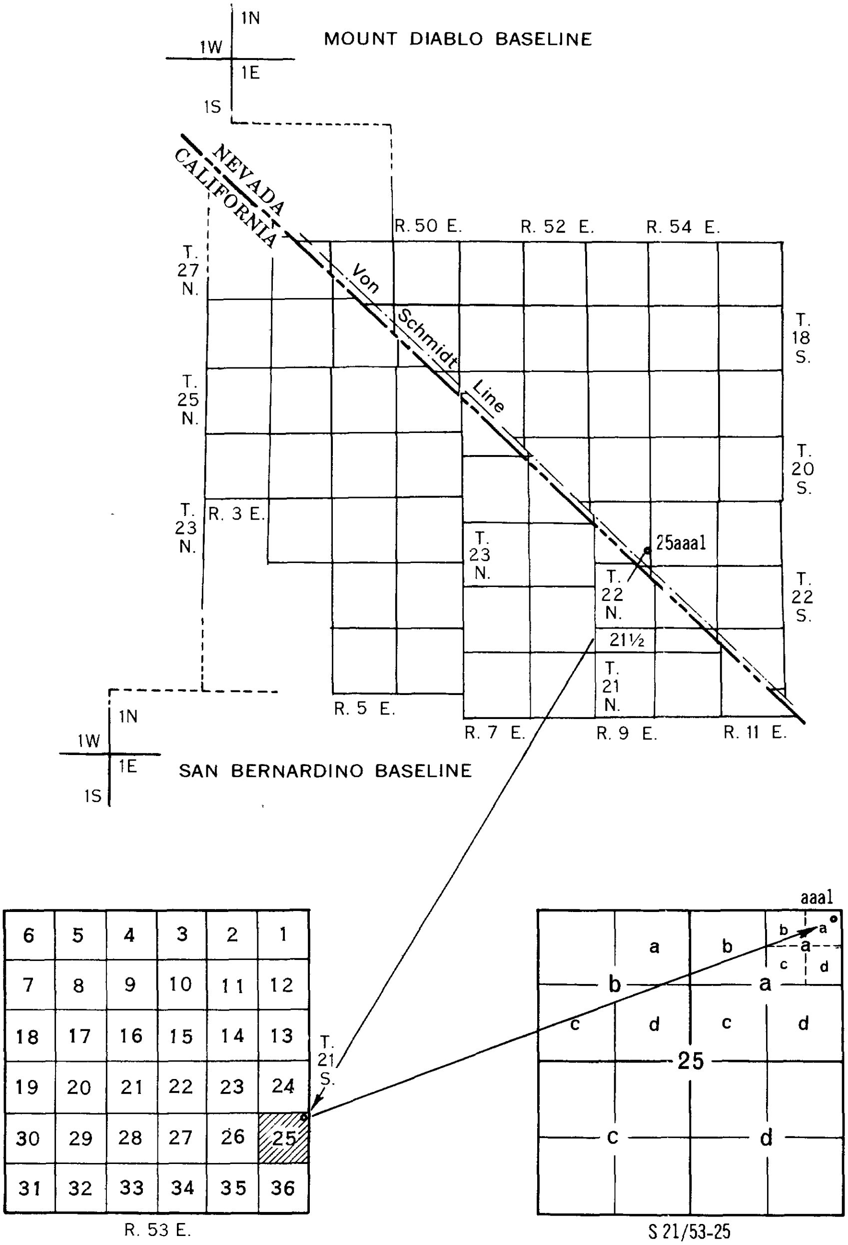

FIGURE 2.—Well-numbering system.

ACKNOWLEDGMENTS

Acknowledgement is made of the cooperation of residents of the valley in supplying data and permitting the use of their wells in the course of this investigation. The author is grateful for the wholehearted assistance received from Federal, State, and local governmental agencies. Most of the drillers' logs and other pertinent data on well construction used in this investigation were furnished by the Nevada State Engineer. Some of the data on chemical analyses of water were furnished by the California Department of Water Resources. Water-level records and estimates of annual pumpage were obtained from the Las Vegas Artesian Well Supervisor.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Pahrump Valley is a structural depression bordered by high mountains. On the northeast the valley is bounded by the Spring Mountains, which have a maximum altitude of approximately 12,000 feet, and on the southwest by the parallel Nopah, Kingston, and Resting Spring Ranges, which have a maximum altitude of 6,000 feet (pl. 1). The crest of a series of unnamed fault-block mountains forms a topographic divide that separates Pahrump Valley on the southwest from the Amargosa Desert. The southeast boundary of the valley is the crest of the unnamed hills that form a topographic divide between Pahrump Valley and Mesquite Valley.

Approximately 5 miles east of the Resting Spring Range, an unnamed bedrock spur about 10 miles long forms a low range of mountains that extend southeastward into Pahrump Valley from the northwest edge of the study area. This bedrock spur becomes progressively lower in altitude toward the southeast, and near the intersection of Nevada Highway 52 and the State border, it plunges beneath the alluvium of the valley floor. The small valley between the bedrock spur and the Resting Spring Range on the southwest is known as Stewart Valley. Stewart Valley is hydraulically continuous with Pahrump Valley to the southeast and is included in the Pahrump Valley drainage basin (pl. 1).

Pahrump Valley is a topographically closed basin from which there is no surface-water flow. Because of the aridity of the region (p. 10), no perennial streams exist in the area, except for short distances below the springs. Even the water from larger springs and from snowmelt in the mountains ordinarily seeps into the gravel of the drainage ways within short distances or is lost by evaporation and transpiration. Storms, though infrequent, cause the other washes to carry surface water for only short periods of time.

Runoff from precipitation within the basin ends in one of two playas, or "dry lakes," that lie at the base of the Resting Spring and Nopah Ranges on the southwest side of the valley. The northwesternmost playa, in Stewart Valley, is the larger of the two, is somewhat irregularly shaped, and has an area of about 6½ square miles. At an altitude of about 2,457 feet, it occupies the lowest part of the study area. The second playa, about 13 miles southeast of Stewart Valley, is about 3½ miles long and 2 miles wide and is about 60 feet higher in altitude than the playa in Stewart Valley. The two playas are separated by a low drainage divide that historically has precluded flow of surface water northwestward to Stewart Valley.

Runoff from most of the Pahrump drainage basin southeast of the Manse Ranch flows into the Pahrump Valley playa, and runoff northwest of the ranch flows to the playa in Stewart Valley. Water ponding in the playas ordinarily evaporates within a few days or weeks.

West of the community of Pahrump the valley floor is broad and flat and appears to have been an ancient playa or lake bottom. The valley floor slopes gently upward to the toe of the Pahrump fan and has an average gradient of about 15 feet per mile. Erosion has dissected it only slightly. Isolated spring mounds and sand dunes occur on this part of the valley floor. Because of the moderately low gradient, the stream channels are poorly integrated and shallow. Consequently, storm runoff reaching this part of the valley generally spreads over a broad area and collects in shallow depressions, from which it is eventually discharged by evaporation and transpiration.

The topography of the valley floor near Hidden Hills Ranch is one of sharp contrasts, characterized in part by badlands. Between the northeast edge of the playa and the Manse Ranch, the valley floor slopes upward about 30 feet per mile. Locally the gradient is much steeper, however, owing to a northwest-trending range of low rounded hills and a series of fault scarps 1½–6 miles northeast of the playa. The hills and the scarps are breached in several places by deep southwest-trending arroyos, the largest of which, about 50 feet deep, are near Hidden Hills Ranch, Stump Spring, and Browns Spring. Locally buttes have formed as the result of erosion.

The southwest side of the Spring Mountains is characterized by large alluvial fans that head high in the canyons leading from Mount Charleston. The most prominent of these alluvial fans have formed at the mouths of Wheeler, Wallace, Carpenter, and Trout Canyons and have coalesced to form two major fans called the Pahrump and Manse fans, which were named for the large ranches established near their toes. The Pahrump and Manse fans extend far into the valley and are among the most notable topographic features of the area. The slopes of the fans become progressively steeper toward the mountains and range in gradient from about 200 feet per mile near the ranches to about 400 feet per mile near the heads of the fans. Fan-head trenching is especially conspicuous in the Pahrump and Manse fans, where arroyos have been entrenched 100 feet or more into the fan deposits, as shown in figure 3. The large fans have coalesced with smaller fans at the mouths of smaller canyons to form an extensive alluvial apron along the front of the mountain range.

The topography along the southwest side of Pahrump Valley differs markedly from that on the northeast. Southwest of the two playas the alluvial fans rise abruptly to the base of the Nopah and Resting Spring Ranges, the slope being as much as 500–600 feet per mile.

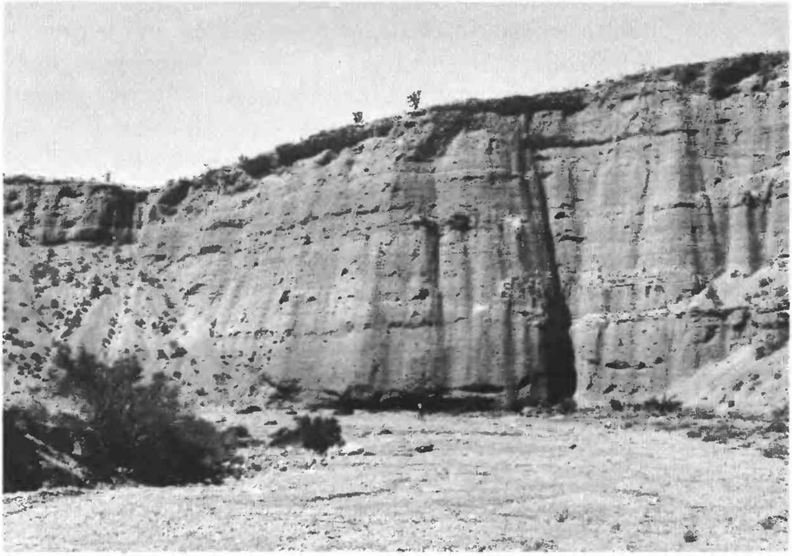

Figure 3.—Upper part of the Pahrump fan in Wheeler Wash. The wash has been incised to a depth of more than 100 feet below the surface of the alluvial fan, and the underlying bedrock is exposed.

CULTURE

The small settlement of Pahrump—the only community in the area—is in the north-central part of the valley, at the intersection of Nevada Highways 52 and 16. Pahrump is the local supply center for ranches, and during the summer of 1959 a cotton gin was constructed there to process the cotton grown in the valley. A consolidated public elementary school is available to the school-age residents in the valley.

Pahrump Valley is one of the most productive farming districts in southern Nevada. Agriculture, the principal occupation in the valley, is dependent wholly on irrigation from ground water. During 1961 approximately 6,500 acres was irrigated. Because the climate is arid and the daytime temperatures are extremely high, only cotton, alfalfa, small grains, and native grasses can generally be grown. Except for a dairy herd and a few range cattle maintained at the Manse Ranch, the raising of livestock has been limited by the sparseness of native vegetation suitable for browsing.

CLIMATE

The climate of southern Nevada ranges from arid to semiarid. Pahrump Valley is arid, characterized by small amounts of precipitation, low humidity, and wide extremes in daily temperatures. Winters are short and mild, and the summers, long and very hot.

The precipitation occurs mainly during the winter, and it generally increases in abundance with altitude. Winter storms are commonly regional in nature, whereas summer storms ordinarily occur as very localized thunderstorms in the mountains. At the lower altitudes evaporation rates are extremely high, probably exceeding 100 inches per year. Strong winds are common throughout the year but are more prevalent in the spring than in the other seasons.

Climatological data have been obtained intermittently at Pahrump Ranch since 1914. Table 1 shows the approximate precipitation for the 14 years during which observations were made and indicates that the annual precipitation for those years ranged from 1.88 to 7.26 inches and averaged about 4 inches.

In 1945 two precipitation storage gages were installed at Roberts Ranch and Bedrock Summit on the west slope of the Spring Mountains. The amount of precipitation recorded at these stations is graphically illustrated in figure 4.

TABLE 1.—*Annual precipitation at Pahrump Ranch*

[NR, no record. From records of the U.S. Weather Bureau]

Year	*Inches*	*Year*	*Inches*
1914	[1] 4.90	1948	NR
1915–19	NR	1949	5.73
1920	7.26	1950	1.88
1921	[2] 5.87	1951–58	NR
1922	5.58	1959	[3] 3.58
1923	[2] 4.49	1960	4.77
1924	2.20	1961	[3] 2.43
1925–44	NR	1962	2.46
1945	4.57		
1946	NR	Average	4.18
1947	2.80		

[1] 3 months of the year estimated from monthly averages.
[2] 1 month of the year estimated from monthly averages.
[3] Values listed as estimates.

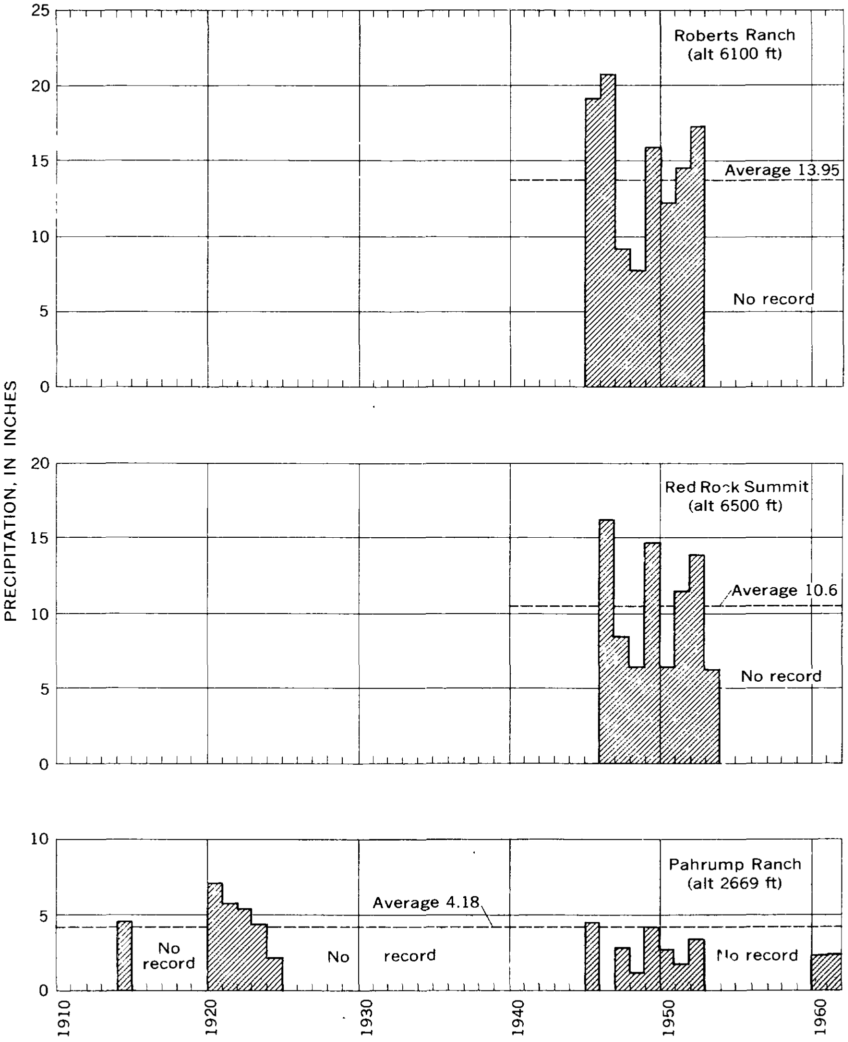

FIGURE 4.—Annual precipitation at three stations in Pahrump Valley.

Records of two snow courses in the Spring Mountains—one in Clark Canyon and the other at Trough Springs—are listed in table 2; the snow-course data indicate a wide annual variation in the amount of water contained in the snow cover.

TABLE 2.—*Snow-course data for two stations in the Spring Mountains, 1945–62*

[NR, no record. Snow and water data given in inches. Record from the Nevada Cooperative Snow Surveys]

Year	Clark Canyon Station (Alt 9,000 ft)						Trough Springs Station (Alt 8,500 ft)					
	February–March			March–April			February–March			March–April		
	Date	Snow	Water	Date	Snow	Water	Date	Snow	Water	Date	Snow	Water
1945	NR	NR	NR	Mar. 28	46.3	14.3	NR	NR	NR	NR	NR	NR
1946	Mar. 2	16.4	4.9	Apr. 1	28.8	8.3	Feb. 27	14.3	4.3	Mar. 29	20.6	6.8
1947	Mar. 6	24.8	7.6	Mar. 27	15.4	5.2	Feb. 28	13.9	4.9	Mar. 26	3.2	1.6
1948	Feb. 26	23.4	7.2	Mar. 29	27.7	8.1	Feb. 25	20.0	6.2	Mar. 30	21.0	7.2
1949	Mar. 4	48.4	13.5	Apr. 1	61.6	18.0	Mar. 4	46.4	11.5	Apr. 3	51.8	14.3
1950	Mar. 1	14.5	4.9	Mar. 30	9.4	3.9	Feb. 27	9.9	3.1	Apr. 2	1.9	0.9
1951	Feb. 27	16.8	2.8	Mar. 29	6.2	1.5	Feb. 28	13.3	2.9	Mar. 30	2.7	0.5
1952	Feb. 24	36.6	11.8	Mar. 25	59.8	18.7	Feb. 25	38.6	13.5	Mar. 31	49.5	17.4
1953	Feb. 26	10.7	3.1	Mar. 29	1.1	0.3	Feb. 28	3.9	1.2	Mar. 28	0	0
1954	Feb. 24	23.3	8.5	Apr. 1	34.5	12.8	Feb. 25	20.1	7.0	Apr. 2	29.2	11.0
1955	Feb. 27	26	7.9	Mar. 30	19	6.2	Mar. 1	23	7.6	Mar. 28	10	3.9
1956	Feb. 25	13	3.8	Mar. 29	2	0.8	Feb. 29	9	2.9	Mar. 30	Trace	Trace
1957	Feb. 28	11	4.6	Mar. 26	8	3.7	Feb. 26	7	2.3	Mar. 28	4	1.2
1958	Feb. 23	24	7.0	Mar. 29	40	11.6	Feb. 23	18	6.6	Mar. 31	29	9.9
1959	Mar. 1	21	5.4	Mar. 29	9	4.7	Feb. 28	16	4.6	Mar. 27	5	2.2
1960	Feb. 26	37	11.1	Mar. 27	22	7.9	Feb. 27	33	10.1	Mar. 26	17	6.0
1961	Feb. 25	10	2.8	Mar. 29	15	3.1	Feb. 25	7	2.0	Mar. 29	7	1.9
1962	Feb. 28	41	12.6	Mar. 29	41	13.7	Feb. 28	34	10.6	Mar. 27	30	10.9
Average	----------	------	7.0	----------	------	7.9	----------	------	5.9	----------	------	5.6

GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTER

The geology of many of the mountains bordering Pahrump Valley is described in detail in several published reports, the most pertinent of which are listed in "Selected References." The generalized description of rocks in the mountains, as given in this report, is based mainly on a review of those publications. The geology of the sedimentary deposits of the valley fill was studied and mapped by the author during the course of this investigation.

For purposes of this report the rocks of the area are divided into two very generalized groups. The division is based mainly on the water-bearing character and the relative stratigraphic position of the rocks with respect to the occurrence and movement of ground water: the consolidated rocks that form the mountain ranges and underlie the valley fill, and the unconsolidated and partially consolidated sedimentary deposits of the valley fill. Table 3 shows the principal rock units and their stratigraphic relationships, lithologic character, and water-bearing properties. Plate 1 shows the areal distribution of the lithologic units listed in table 3.

TABLE 3.—*Geologic units of Pahrump Valley*

System	Series	Lithologic unit	Member	Lithology and occurrence	Water-bearing properties
Quaternary	Pleistocene and Recent	Younger fan deposits	Younger alluvial-fan deposits	Unconsolidated alluvial-fan deposits and mudflow debris, consisting of boulders, gravel, sand, silt, and clay derived from older alluvial fans and local exposures of consolidated rock; occur locally as stringers and lenses of relatively clean sand and gravel that partly mantle the alluvial apron along the mountain fronts. A veneer covers the pediment in the area east of Hidden Hills Ranch. Heterogeneity of the material decreases away from the mountains; material grades laterally into finer grained and better sorted younger alluvium.	Lies mainly above the zone of saturation; however, where it dips beneath the valley floor into the zone of saturation, stringers and lenses of relatively clean well-sorted gravel readily yield water to wells.
			Channel deposits	Unconsolidated fairly well sorted gravel, sand and silt in the principal arroyos draining the major watershed areas. Particle size decreases and sorting and rounding generally increase away from mountain fronts.	Highly permeable material occurring mainly above the zone of saturation in the recharge area. Outcrops provide ready access for ground-water recharge from snow melt and storm runoff. Where buried within the alluvial fans, deposits transmit water from areas of recharge to the valley fill. Deposits yield large quantities of water when tapped by wells in the zone of saturation.
		Younger surficial deposits	Younger alluvium	Unconsolidated moderately well sorted sand, silt, and clay and minor amounts of gravel derived mostly from medial and older lacustrine deposits and from alluvial fans. Extensively exposed on the valley floor.	Moderate to low permeability generally limits productivity of wells to small yields.
			Playa deposits	Unconsolidated clay, silt, and fine sand. The surface of the playa in Stewart Valley is loosely compacted and flocculated clay, whereas the surface of the playa in the west-central part of the valley is hard and compact.	Where saturated, the permeability of these deposits is very low; consequently, they will not readily yield water to wells. The chemical quality of the ground water beneath the playa in Stewart Valley is generally unfit for most uses.

TABLE 3.—*Geologic units of Pahrump Valley*—Continued

System	Series	Lithologic unit	Member	Lithology and occurrence	Water-bearing properties
Quaternary—Con.	Pleistocene and Recent—Con.	Younger surficial deposits—Con.	Dune sand	Unconsolidated sand, silt, and clay derived mainly from younger alluvium and older and medial lacustrine deposits. Dunes are commonly stabilized by vegetation.	Lies above the zone of saturation. Downward percolation and subsequent ground-water recharge from precipitation are limited because of the low permeability of the material.
			Sinter	Calcareous siliceous spring mounds derived form the conspicuous mounds along the fault in the central part of the valley.	Limited areal extent and low degree of permeability render the deposit unimportant as an aquifer.
Tertiary and Quaternary	Pliocene and early Pleistocene	Medial fanglomerate		Unconsolidated to cemented alluvial fan deposits and mudflow debris composed of boulders, sand, silt, and clay; contains stringers and lenses of relatively clean well sorted sand and gravel. Crops out adjacent to consolidated rock along the Spring Mountains and dips toward the center of the valley beneath the younger alluvial-fan deposits.	The generally poor sorting and partial cementation limit the water bearing zones to buried gravel trains in the higher areas of the alluvial fans. Zones are also limited to lenses of fairly well-sorted and rounded sand and gravel in the lower areas of the fans. Where the deposits lie in the zone of saturation, highly permeable lenses of gravel and sand readily yield water to wells and are the most productive aquifers in the valley.
		Medial lacustrine deposits		Calcareous clay and silt. Occur as shore-line deposits along the base of the Pahrump and Manse fans.	Unconsolidated to partly consolidated clay and silt and minor amounts of sand that occur mainly above the zone of saturation.
		Older lacustrine deposits		Predominantly clay and silt; minor amounts of fine sand and mudflow debris; a few beds of caliche; faulted and gently warped. Principal exposures occur on the upthrown fault block along the longitudinal axis of the valley.	Mostly unconsolidated to indurated fine-grained material that has low permeability. Where saturated, thin beds of fine-grained sand may yield moderate amounts of water to wells.
		Older fanglomerate		Poorly consolidated to unconsolidated alluvial-fan and mudflow debris consisting of poorly-sorted boulders, gravel, sand, silt, and clay. The debris, derived mainly from Kingston Mountain, is of igneous, metamorphic and sedimentary origin. Outcrops are present only in the southern half of the valley. The unit is faulted and highly dissected.	Lies largely above the zone of saturation and is not known to be penetrated by wells. Heterogeneity of the material suggests that its permeability is low.

TABLE 3.—*Geologic units of Pahrump Valley*—Continued

System	Series	Lithologic unit	Member	Lithology and occurrence	Water-bearing properties
Tertiary	Miocene or Pliocene	Tuff		White and light-yellow to light-green beds of thinly laminated tuff; extensively faulted and folded. Exposed at the base of the upthrown fault block along the Nevada-California border.	Consolidated and partly to highly indurated; has very low permeability. Where saturated, it would yield virtually no water to wells.
Precambrian to Tertiary(?)		Sedimentary, metamorphic, and igneous rocks		Basement complex; forms the confines of the alluvial basin; composed of: Precambrian gneiss, granite, and sedimentary rock; Paleozoic limestone, dolomite, and quartzite; Mesozoic clastic and granitic rocks; and Tertiary tuff, some volcanic flows, and fresh-water limestone.	Highly indurated rock having limited primary porosity. The intensive faulting and crushing and subsequent solution of the carbonate rocks have resulted in the formation of local and regional zones of high permeability. Inferences drawn from the existing data suggest that highly fractured and altered carbonate rocks transmit approximately half of the estimated average annual recharge to adjacent areas. Rocks not tapped by wells.

CONSOLIDATED ROCKS

GENERAL FEATURES

The consolidated rocks that crop out in Pahrump Valley are several thousand feet thick and are made up predominantly of dense highly indurated crystalline, metamorphic, and sedimentary rocks. The sedimentary rocks include a thick sequence of beds composed mainly of calcareous and clastic material; they are widespread throughout eastern and southern Nevada and adjacent areas of Utah and California. In this region the consolidated rocks have been intensely folded, faulted, and deeply dissected by erosion. Consequently, they form a rugged surface of high relief. Sedimentary rocks of Paleozoic age and, to a lesser extent, sedimentary and igneous rocks of Mesozoic and Tertiary age occur beneath the intermontane basins and form most of the mountain ranges that border the basins. Beneath the floor of most of the alluvium-filled valleys the consolidated rocks occur at depths of as much as several thousand feet.

The lithologic units forming the consolidated-rock group differ widely in lithology. In the study area they consist principally of limestone, dolomite, sandstone, shale, and quartzite and lesser amounts of intrusive igneous rocks, tuff, breccia, and volcanic flows. In aggregate, the units range in thickness from about 13,000 feet (Hewett, 1931,

p. 9), in the southern part of the Spring Mountains, to about 33,000 feet (Nolan, 1929, p. 465), at the north end of the range.

The Spring Mountains, south of Charleston Peak, are composed of about 8,500 feet of dominantly fossiliferous limestone and dolomite of Paleozoic age (Hewett, 1931, p. 9, 10) overlain by approximately 4,500 feet of largely sandstone, shale, and conglomerate of Mesozoic age. North of Charleston Peak the Paleozoic section thickens, and near Mount Sterling the exposed rocks consist of about 12,000 feet of quartzite and shale of Cambrian age (Nolan, 1929, p. 461–465) overlain by about 21,000 feet of dominantly carbonate rocks of marine origin.

In the Kingston Range, bordering Pahrump Valley on the southwest, about 5,400 feet of metamorphic and sedimentary rocks of Precambrian age is exposed. The Precambrian rocks are overlain by about 2,000 feet of carbonate rocks of Paleozoic age which have been intruded by monzonite porphyry and related intrusive rocks of Late Cretaceous to late Tertiary age. The carbonate rocks, in turn, are overlain by an unmeasured thickness of unconsolidated deposits consisting of sand, gravel, bentonite, and ash of Cenozoic age (Hewett, 1948, p. 196–200). In the Nopah and Resting Spring Ranges, about 7,000 feet of Precambrian metamorphic, igneous, and sedimentary rocks is overlain by about 22,900 feet of Paleozoic rocks (Hazzard, 1937, p. 289). The base of the Paleozoic section is composed of about 14,800 feet of dominantly clastic rock of Cambrian age. Most of the overlying strata in the Paleozoic section are carbonate rocks. Lava flows of probable Tertiary age lie unconformably on rocks of Paleozoic age in the Resting Spring Range but are absent from the Nopah Range. Isolated exposures of highly indurated fresh-water limestone, tuff, and flows of Tertiary (?) age on the north and northeast flanks of the Kingston Range are included with the basement complex on plate 1.

In the Spring Mountains, normal faults having relative displacements of several thousand feet and a series of north-trending thrust faults have caused intense local fracturing of the rocks and the superposition of rocks of older geologic age on younger ones. The regional structural deformation that created the mountains also formed the large structural depression in the consolidated rocks that underlie Pahrump Valley. More than a thousand feet of erosional debris from the adjacent highland areas has accumulated in this depression and now covers most of the underlying bedrock. Consequently, the geologic and topographic features that resulted from the structural activity are buried and are not known. Because of the structural origin of the basin, however, the relief on the buried bedrock surface probably varies markedly within short distances.

WATER-BEARING CHARACTER

The consolidated rocks differ widely in hydraulic properties; most are dense and well indurated and possess little primary permeability. Some of the rocks, however, are capable of absorbing, storing, and transmitting water owing to intensive fracturing and chemical weathering. The crystalline and clastic units contain some water in fractures and joints, although the fractures are generally tight and, therefore, do not readily transmit water.

The carbonate-rock units, on the other hand, principally those of Paleozoic age, contain fractures and solution channels and are locally moderately to highly permeable. They constitute a major reservoir system that underlies most of southern Nevada, and ground water is thereby transmitted beneath topographic divides from one valley to another. In this report the complex carbonate rocks, as related to the hydrology of the valley, are referred to simply as the carbonate-rock reservoir. This reservoir was not recognized in the study made 20 years ago by Maxey and Jameson (1948, p. 116), who stated that the consolidated rocks were impermeable.

Test drilling at several locations at the Nevada Test Site, about 25 miles north of Pahrump Valley, has shown that locally the carbonate-rock aquifer is capable of transmitting large quantities of ground water. Coefficients of transmissibility, computed from pumping-test data for wells tapping this aquifer, range from 400 to 900,000 gpd per ft (gallons per day per foot) (Winograd, 1963, p. 29). The coefficient of transmissibility is defined as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a 1-foot-wide vertical strip of the aquifer that extends the full saturated height of the aquifer, under a hydraulic gradient of 100 percent (Theis 1935). The test drilling also showed that the Precambrian crystalline and sedimentary rocks and Paleozoic clastic formations have low permeability. These rocks contain little water and generally function as barriers that impede ground-water movement.

Hundreds of feet of core from numerous widely spaced wells at the Nevada Test Site indicate that the permeability of the carbonate-rock aquifer at depth is probably due principally to fractures rather than to solution channels. The presence of numerous caves and large springs in carbonate rocks that crop out throughout the southern and eastern parts of the State, and the occurrence of open fractures in the carbonate rocks at depths of several thousand feet suggest, however, that solution by percolating ground water is also a significant factor in the transmission of ground water. Devils Hole, near Ash Meadows, is an example of a solution opening in Paleozoic carbonate rocks.

VALLEY FILL

Thick semiconsolidated to unconsolidated continental deposits of fluvial and lacustrine origin have accumulated in Pahrump Valley and form the principal ground-water reservoir. The continental deposits are of Tertiary and Quaternary age and are composed mainly of detrital material; they underlie an area of about 650 square miles in the central part of the valley. Thickness of the valley fill is unknown; although several wells have been drilled to depths of about 1,000 feet, none have penetrated bedrock.

The valley fill consists principally of alluvial material derived from older consolidated rocks in the surrounding mountains and is interbedded with some tuff and chemical precipitates. The oldest recognized sedimentary deposits of the valley fill are composed of an unknown thickness of partially consolidated and highly indurated tuff of Tertiary age. Overlying the tuff is a succession of unconsolidated material consisting of alluvial-fan and lacustrine deposits ranging in age from late(?) Tertiary to Quaternary. Six major units are recognized in this succession of deposits; they are: Older fanglomerate, older lacustrine deposits, medial lacustrine deposits, medial fanglomerate, younger surficial deposits, and younger fan deposits.

The older deposits have been uplifted by faulting and gentle folding and subsequently have been exposed by erosion. Northeast of the fault that approximately parallels the California-Nevada border (pl. 1), erosion of the upthrown fault block has exposed approximately 1,000 feet of the upper part of the valley fill.

The valley-fill deposits are grouped into two very generalized types. On the basis of their lithologic and and hydrologic character as determined from exposures and lithologic logs, the types are (1) the coarse-grained alluvial-fan deposits of low to high permeability along the margin of the valley, and (2) the uniformly fine-grained lacustrine and playa deposits of low permeability in the central part of the valley.

COARSE-GRAINED DEPOSITS

The coarse-grained deposits of the valley fill crop out in an area of about 300 square miles along the perimeter of the valley and in isolated exposures on the crests of a range of low hills along the Nevada-California border. The coarse-grained deposits, composed principally of sand, gravel, and boulders, were derived from adjacent mountains. The material was deposited mainly in alluvial fans and aprons that form thick wedges of gravel along the edge of the valley. These deposits are the older and the medial fanglomerate of Pliocene and early Pleistocene age and the younger fan deposits of Pleistocene and

Recent age. Those alluvial-fan deposits that had been raised above the adjacent alluvial surfaces by faulting or upwarping and then dissected by erosion were mapped as older and medial fanglomerate. Alluvial-fan deposits that are unaltered by deformation and erosion and are sites of active deposition were mapped as younger fan deposits. Coarse-grained channel deposits in the major arroyos were also included in the younger fan deposits.

The most extensive outcrop area of coarse-grained deposits is in the alluvial apron along the east side of Pahrump Valley, adjacent to the Spring Mountains. Exposures are widest at the reentrant valleys that drain onto the Pahrump and Manse fans. The outcrop is approximately 12 miles wide on the Pahrump fan, but elsewhere along the northeast side of the valley it averages about 7 miles wide. Less extensive areas of alluvial-fan deposits are exposed along the southwest side of Pahrump Valley, where the average width of the outcrop is less than 3 miles.

Most material in the alluvial fans and aprons is poorly bedded, and locally it is moderately to highly indurated by calcareous cement. The beds dip away from the mountain fronts toward the central part of the valley.

The coarsest, most angular, and least sorted material occurs near the heads of the alluvial slopes at the mountain front. Farther away from the mountains the dip of the beds decreases, and the material becomes smaller, slightly more rounded, and better sorted. Along the lower margins of the fans, these deposits interfinger with and grade laterally into contemporaneous lacustrine or playa deposits. Well logs of some of the deeper wells drilled near the toes of the fans along the northeast side of the valley show that beds of sand, gravel, and boulders interfinger with playa or lacustrine strata. Although marked differences in lithology between typical fan deposits and typical lacustrine or playa deposits are common, the lateral change in lithology is generally gradational through a zone of several miles.

Faulting, upwarping, and subsequent erosion of the alluvial-fan deposits have resulted in the formation of drainage channels, or arroyos, that have been deeply entrenched in the heads of the alluvial fans. Characteristically, the bed material in these channels is coarsest near the mouths of the canyons and becomes progressively finer grained downslope. In the larger stream channels, stringers of relatively clean gravel and sand have been transported to points many miles from the mountains.

WATER-BEARING CHARACTER

The coarse-grained valley-fill deposits form the most productive water-bearing material in the area. For purposes of this report, the older and the medial fanglomerates and the younger fan deposits along the mountain fronts, as shown on plate 1, are regarded as a single hydrogeologic unit. The high degree of cementation of the alluvial deposits in the walls of the arroyos near the heads of the alluvial fans indicates that the bulk of the coarse-grained material in the upper part of the alluvial apron has low permeability and porosity. Stringers of relatively clean uncemented gravel in the existing channels and in those buried within the alluvial-fan deposits, however, are highly permeable and readily transmit water. Most runoff from the watershed that reaches the alluvial fans percolates into the gravel deposits. Following cloudbursts, only rarely does runoff from the mountains reach the valley floor.

Because of the wide variation in lithology of the alluvial-fan deposits, the hydraulic characteristics vary greatly within short distances; and predictions of the water-bearing properties in undeveloped areas are, therefore, somewhat speculative. Wells drilled along the toes of the fans, however, usually penetrate highly permeable lenses or stringers of sand and gravel that are capable of yielding large quantities of water. The specific capacities of 20 wells drilled along the toes of Pahrump and Manse fans range from about 5 to 185 gpm (gallons per minute) per foot of drawdown. The specific capacity of a well is defined as the rate of yield per unit of drawdown and is generally expressed as gallons per minute per foot of drawdown (Wenzel, 1942, p. 151).

Water-bearing lenses of sand and gravel in the alluvial-fan deposits are generally irregular in thickness and in areal extent and commonly cannot be traced as individual beds from well to well. These alluvial-fan deposits are overlain locally by layers of caliche or other comparatively impermeable material, or they interfinger with lacustrine or playa deposits; therefore they may contain ground water under confined or artesian pressure. In early stages of agricultural development of the valley, many high-capacity flowing wells were developed in these deposits.

Southwest of the alluvial apron the thickness and the number of highly permeable layers of sand and gravel decrease, and the amount of silt and clay increases. Consequently, the yields of wells commonly decrease farther away from the fans.

No attempt has been made to develop wells in the coarse-grained deposits along the base of the Nopah and Resting Spring Ranges on the southwest side of Pahrump Valley. The water-bearing character of the deposits in this area, therefore, generally is not known. Because the alluvial fans are small and the transport distance of the alluvial-fan material is short, however, the materials probably are more angular, less well sorted, and less permeable than correlative material on the northeast side of the valley.

FINE-GRAINED DEPOSITS

The deposits that crop out in an area of about 350 square miles in the central part of Pahrump Valley are composed principally of silt, clay, and fine-grained sand and some tuff and precipitates. These fine-grained deposits include four principal lithologic units (table 3; pl. 1): (1) tuff of Miocene or Pliocene age, (2) older and (3) medial lacustrine deposits of Pliocene and early Pleistocene age, and (4) younger surficial deposits of Pleistocene and Recent age, which include younger alluvium, playa deposits, dune sand, and sinter.

The beds of tuff and overlying older lacustrine deposits are exposed in the central part of the valley, where they have been uplifted and faulted and subsequently exposed by erosion. The fault is approximately parallel to the boundary between Nevada and California and extends from the south edge of the study area about 23 miles along the trough of the valley. The deposits northeast of the fault are now stratigraphically higher than those on the southwest side, and the beds adjacent to the fault on the northeast are tilted at angles of as much as 15°. Along the east margin of the fine-grained deposits, the medial and older lacustrine deposits are slightly tilted and bowed upward. Erosion has planed off the surface of the upthrown fault block, exposing approximately 1,000 feet of the uppermost beds of the fine-grained deposits.

Exposed in the banks of arroyos near Hidden Hills Ranch (pl. 1) is about 200 feet of thin-bedded to massive tuff that is overlain by about 800 feet of thin to massive beds predominantly of silt and clay. The silt and clay are interbedded locally with layers of caliche, laminations of fine-grained sand, and thin beds of fanglomerate. Most of the material is erosional debris transported from the alluvial fans and weathered material eroded from older Tertiary deposits. Some of the strata containing mud cracks, ripple marks, and crossbedding are interbedded with uniform layers of clay and silt, which suggests that they probably were deposited in a basin that was occupied alternately by playas and by lakes. The thickness of the lacustrine deposits generally is unknown and may vary considerably from one area to another, owing to the irregularity of the surfaces of the tuff and bedrock on which the deposits lie unconformably.

Logs of wells drilled in the fine-grained deposits in the northern part of the valley west of Pahrump (pl. 1) indicate a gross overall lithology similar to that exposed near Hidden Hills Ranch. Data are insufficient at this time, however, to indicate whether individual beds extend as continuous stratigraphic units beneath the entire valley floor.

WATER-BEARING CHARACTER

The predominance of clay throughout the fine-grained deposits generally causes them to be poor aquifers. In the upper 800 feet of the exposed material in the walls of the dry wash passing through Hidden Hills Ranch, the only beds that would be capable of transmitting small amounts of ground water are thin beds of fine sand. The tuff in the lower 200 feet of exposed material has low porosity and low permeability and generally tends to retard the movement of ground water.

Several attempts have been made to develop ground water from the fine-grained deposits near Hidden Hills Ranch, in the adjacent area to the southwest, and in the area west of Pahrump. Several wells have been drilled in these areas to depths of 800 feet or more, and well N22/10–26 (not shown on pl. 1), 2½ miles southwest of Stump Spring, was reportedly drilled to a depth of 1,351 feet. This well, though never completed, is the deepest known in the valley, and the driller reported that it was dry. The driller's log shows that, except for minor amounts of sand, silt, and cemented gravel, the entire drilled thickness was clay.

Of the wells in the vicinity of Hidden Hills Ranch for which pumping data are available, none have a specific capacity greater than 1 gpm per foot of drawdown. In the area between the toes of the Manse and Pahrump fans and the California-Nevada boundary, approximately 50 wells of various depths have been developed in fine-grained deposits. The highest specific capacity in any of the 10 wells tested in this group was only about 5 gpm per foot of drawdown.

GROUND-WATER HYDROLOGY

RESERVOIR SYSTEMS

Ground water in Pahrump Valley occurs in two principal reservoirs: the valley fill and the carbonate rocks. The valley-fill reservoir is coextensive with the area shown as fine-grained and coarse-grained deposits on plate 1. The carbonate-rock reservoir underlies the valley fill and extends laterally into the adjacent hills and mountains. Because no wells penetrate both systems, the hydraulic continuity and magnitude of interflow between them these systems is poorly understood.

Figure 5 is a diagrammatic cross section of Pahrump Valley showing, the probable general relation between the valley-fill and carbonate-rock reservoirs. If the tuff in the lower part of the valley fill is widespread, as is suggested by the diagrammatic section, the hydraulic continuity between the two systems beneath the valley floor

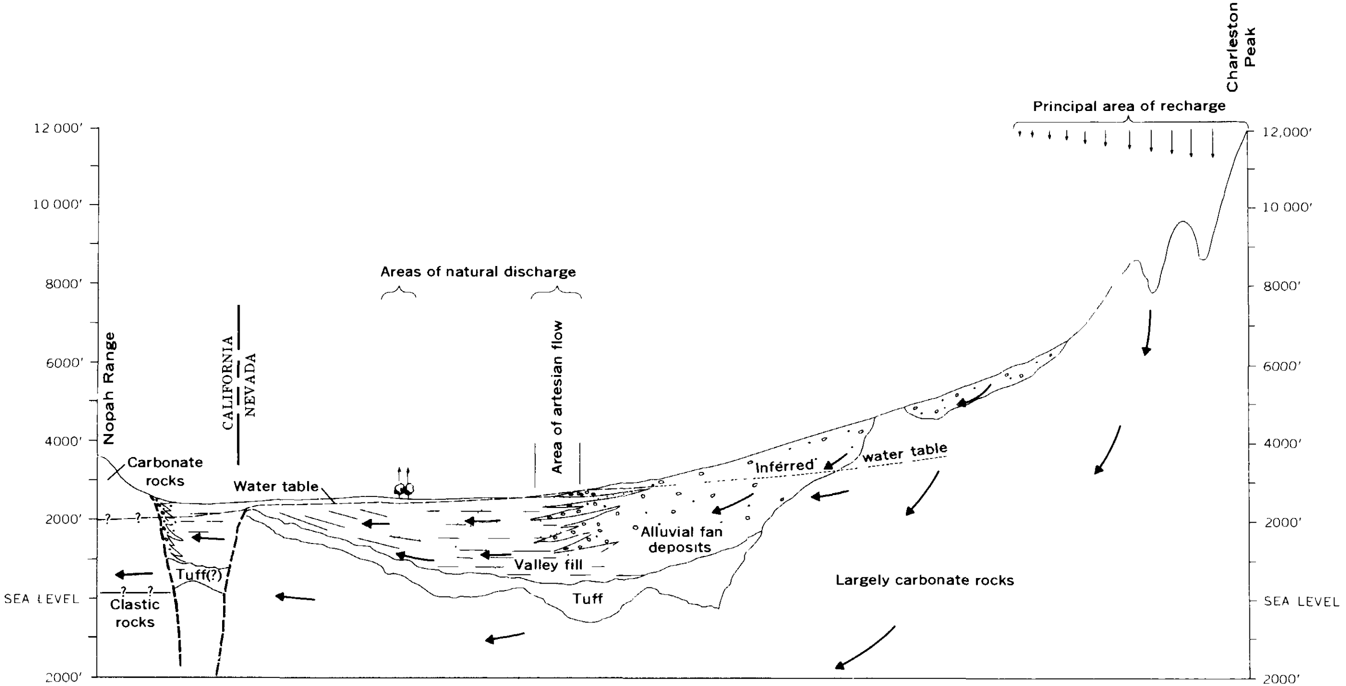

FIGURE 5.—Principal topographic, geologic, and hydrologic features of Pahrump Valley, as shown in section from Charleston Peak to the Nopah Range.

would be poor; nonetheless, the lateral continuity may be reasonably good. Thus, beneath the valley floor the two ground-water reservoirs are considered to function mainly as independent flow systems, although interflow almost certainly occurs laterally along the contact between them.

CARBONATE-ROCK RESERVOIR

The carbonate-rock reservoir crops out in the Spring Mountains, underlies the valley fill of Pahrump Valley, and extends southwestward through the Nopah and Resting Spring Ranges into California and Chicago Valleys (pl. 1; fig. 5). Except for a small wedge of carbonate rocks north of Stewart Valley, the reservoir is terminated by structural deformation along the northwest side of Pahrump Valley, where quartzite and other poorly permeable rocks crop out. The reservoir probably extends southeastward to Mesquite Valley.

The carbonate-rock reservoir, which may have a maximum thickness of at least 20,000 feet locally, is inferred by the author to be hydraulically continuous beneath the area just described. Continuity in the carbonate-rocks reservoir probably is achieved principally through extensive fractures and to a small degree by localized solution channels. Ground water in the reservoir is mainly unconfined in the mountainous areas where the carbonate rocks crop out and receive recharge; at depth it is confined beneath the tuff in Pahrump Valley. No wells tap the carbonate-rock reservoir; hence, the head distribution is not known.

VALLEY-FILL RESERVOIR

On the northeast, northwest, and southwest, the valley-fill reservoir is terminated by consolidated rocks, but on the southeast it is generally continuous with the valley-fill reservoir in Mesquite Valley (pls. 1, 2). The southeast edge of the reservoir is arbitrarily regarded to be at the surface divide between Pahrump and Mesquite Valleys. The total area in Pahrump Valley is about 650 square miles. The bottom of the reservoir is the contact between the older lacustrine deposits and the older fanglomerate and the underlying tuff. In most places the saturated thickness of the reservoir probably exceeds 1,000 feet.

The principal aquifers in the valley-fill reservoir are the coarse-grained deposits which underlie Pahrump and Manse fans and which southwestward interfinger with the fine-grained deposits (pl. 1). Similarly, aquifers probably occur along the southwest side of the valley, where only a few wells have been drilled.

Confined ground water occurs along the toes of Pahrump and Manse fans in a narrow band about 2 miles wide and 13 miles long. Prior to extensive ground-water development, two large springs—Bennetts (Pahrump) and Manse Springs—discharged nearly 10,000 acre-feet per year of water in this area. By 1962 Bennetts Spring was dry and Manse Spring discharged only a third of its original flow (table 6). The area of artesian flow had decreased to only several square miles (pl. 2).

SOURCE AND MOVEMENT OF GROUND WATER

Plate 2 shows that in 1962 the movement of ground water in the valley-fill reservoir was southwestward across the valley; this indicates that the principal recharge area is in the Spring Mountains. Similarly, the direction of flow in the carbonate-rock reservoir is presumed to be southwestward (fig. 5). Although the configuration of the water-level contours in the valley fill has been substantially modified by pumping along the toes of Pahrump and Manse fans, the overall slope of the flow net in the rest of the valley has not been greatly altered by pumping.

The contours also show that near the southwest side of the valley the ground water moves into the Nopah and Resting Spring Ranges, thus demonstrating a hydraulic continuity between the valley-fill and carbonate-rock reservoirs in this part of the valley. In 1962 the depth to water in wells along the southwest side of the valley ranged from 21 feet, in Stewart Valley, to more than 200 feet, at the base of the Kingston Range. Except in Stewart Valley, there was little possibility of water being lost through evapotranspiration. Most ground water reaching this part of the valley is transmitted from Pahrump Valley southwestward through the mountains to California and Chicago Valleys.

Along the southeast side of the valley, ground-water flow is generally parallel to the arbitrary boundary between Pahrump and Mesquite Valleys (pls. 1, 2). Any extensive ground-water development near the boundary would change the flow net and, hence, necessitate a corresponding change in position of the present arbitrary boundary between the two valleys.

At the northwest edge of the valley-fill reservior, the water-level contours are generally normal to the consolidated rocks and, therefore, do not indicate any water movement into them. The small wedge of carbonate rocks north of Stewart Valley provides a potential avenue of flow northwestward to the springs in Ash Meadows—Last Chance, Bole, Big, and Jack Rabbit Springs, which issue at depth from carbonate rocks. Although the head differential is favorable for the potential northwestward flow of ground water in the carbonate-rock reservoir, the water-level contours in the valley fill do not indicate this possibility, nor does the quality of water in the two areas support this thesis. Nevertheless, until the head distribution in the carbonate rocks in Pahrump and Stewart Valleys and in the intervening area to the northwest is known, the possibility of northwestward flow to the springs must remain unresolved.

RECHARGE

Maxey and Jameson (1948, p. 117) estimated that the long-term average recharge to Pahrump Valley is about 23,000 acre-feet per year. This estimate was based on the assumption that 25 percent of the precipitation at altitudes above 8,500 feet, 20 percent of the precipitation at altitudes between 6,500 and 8,500 feet, and little precipitation below the 6,500-foot level reach the ground-water reservoirs; virtually all recharge occurs in the Spring Mountains. Maxey and Jameson's estimate of recharge is in close accord with that described next, which was determined by use of a similar technique.

A method described by Eakin and others (1951, p. 26, 27) is used to reappraise the estimated recharge to Pahrump Valley. This method is also based on the assumption that a fixed percentage of a given average annual rate of precipitation ultimately recharges the ground-water reservoirs. More altitude zones are used, however, to correspond more closely to the amounts of precipitation, which ranges from about 4 inches on the valley floor (alt, about 2,600 ft), to about 28 inches in the higher parts of the Spring Mountains (alt, 11,000 ft).

The altitude zones and the estimated average annual precipitation and recharge in these zones are given in table 4, which shows that ordinarily no recharge occurs in the zones where precipitation is less than 8 inches per year. The estimated average annual precipitation in the entire area is about 420,000 acre-feet, and the estimated average annual recharge from this precipitation is 22,000 acre-feet, or only about 5 percent of the total precipitation. This estimate of recharge is 1,000 acre-feet less than that made by Maxey and Jameson (1948).

TABLE 4.—*Estimated average annual precipitation and ground-water recharge in Pahrump Valley*

Precipitation zone (ft)	Area (acres)	Estimated annual precipitation			Estimated recharge	
		Range (in.)	Average (ft)	Average (acre-ft)	Assumed percentage of precipitation	Acre-feet per year
Above 8,000	29,500	>20	1.75	51,600	20	10,300
7,000–8,000	30,200	15–20	1.46	44,100	15	6,600
6,000–7,000	48,600	12–15	1.12	54,400	7	3,800
5,000–6,000	51,100	8–12	.83	42,400	3	1,300
Below 5,000	454,000	<8	.50	227,000	0	
Total (rounded)	613,000			420,000		[1] 22,100

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[1] Except for several hundred acre-feet of recharge in the Nopah and Resting Spring Ranges, virtually all the estimated recharge occurs in the Spring Mountains.

The recharge, as estimated by this method, may occur in three ways: by direct infiltration of rainfall in areas that are generally higher than 5,000 feet, by seepage loss from streams in the mountains and in the valley, and by lateral movement from the carbonate-rock reservoir, as well as from fractures in the other consolidated rocks to the valley-fill reservoir. Because there are many unknown factors in the spatial distribution both of recharge to and of interflow between ground-water reservoirs, no direct estimates of recharge to each of the two reservoirs could be made. In the section "Discharge," however, the probable division of the total average annual recharge is computed indirectly to be about 12,000 acre-feet to the valley-fill reservoir and about 10,000 acre-feet to the carbonate-rock reservoir.

DISCHARGE

Ground-water discharge from Pahrump Valley occurs by pumping from wells, by evapotranspiration, through springs, and by subsurface outflow principally to areas southwest of the valley. Prior to the construction and use of large-capacity wells in about 1912, virtually all the discharge was by natural processes. By 1962, pumpage constituted about 60 percent of the total discharge from the valley.

In this section of the report, estimates of discharge are made for natural conditions and for the 4-year period 1959–62; some discharge records that date back discontinuously to 1875 are also presented (table 6). For the valley-fill reservoir, direct estimates are made for the several elements of discharge; but for the carbonate-rock reservoir, only an indirect estimate of discharge by subsurface outflow can be made from the present data.

VALLEY-FILL RESERVOIR

SPRINGS

Before large-scale withdrawals from wells began, ground water under artesian pressure issued from two large springs in the valley fill near the toes of Pahrump and Manse fans. Bennetts Spring (Pahrump Spring), originally the larger of the two, is approximately a quarter of a mile south of the community of Pahrump (pl. 1). Manse Spring is about 6 miles southeast, near the headquarters of the Manse Ranch.

During the initial phases of ground-water development in the valley, diversions from the large springs provided virtually all water for irrigation. Subsequently, ground-water development from wells tapping the valley-fill reservoir has caused a reduction of artesian pressure and a continual decline of the spring discharge. The artesian head in the vicinity of the two large springs was sufficiently lowered by 1959 to cause Bennetts Spring to become dry and the flow from the Manse Spring to decrease to about a third of the original flow. The total discharge from these two springs has dwindled from nearly 10,000 acre-feet per year under natural conditions to about 1,400 acre-feet per year in 1962 (table 6).

Several small springs issue from the scarps that transect the valley fill in the southern part of Pahrump Valley. These include Stump Spring, southeast of Hidden Hills Ranch, Brown's Spring, and several other unnamed springs and seeps northwest of the ranch headquarters (pl. 1). The combined discharge of these small springs probably does not exceed 50 acre-feet per year (table 6, col. 4). Their flow in 1962 had not been affected by ground-water development.

The term "net spring discharge" is used to describe that part of the total spring discharge that is permanently removed from the valley-fill reservoir by evapotranspiration downstream from the spring orifices. The total spring discharge less the net spring discharge is the amount that returns to ground water in the valley-fill reservoir. As described in the following section of this report, under natural conditions approximately 7,000 acre-feet of the total spring discharge of nearly 10,000 acre-feet per year (table 6) was consumed by evapotranspiration. Thus, in approximate terms, the net spring discharge prior to pumping averaged about 7,000 acre-feet per year, and the amount that returned to ground water averaged about 3,000 acre-feet per year.

During the period 1959-62, the total spring discharge averaged only about 1,600 acre-feet per year and was almost wholly from Manse Spring. Approximately one-third of the anual flow of Manse Spring occurred in the nongrowing season—from about November 10 to March 15. During this 4-month period, most spring discharge percolated into the ground and returned to the ground-water reservoir. Accordingly, the net spring discharge in the period 1959-62 probably averaged about 1,000 acre-feet per year.

EVAPOTRANSPIRATION

Evaporation from bare soil and transpiration by phreatophytes occur along stream channels downstream from the springs, along drainage ditches that convey tail-waste from irrigated areas, around the playa in Stewart Valley, and locally in the lowlands west of the community of Pahrump. The areal extent of phreatophytes in 1961 is shown on plate 3. Areal photographs made in 1952 show that the distribution of phreatophytes was about the same in 1952 as in 1961. Phreatophyte areas formerly supported by spring flow under natural conditions were receiving irrigation tail waste in 1961 from irrigated areas through the same channels that originally carried the spring flow. Consequently the phreatophyte areas and the amount of water probably used by them have not been appreciably altered from the natural state.

The principal phreatophytes include mesquite, saltgrass, saltbrush, saltcedar, and cottonwood. The areas, estimated rates of use, and estimated evapotranspiration from areas of phreatophytes are shown in table 5. The estimated use also includes the evaporation from bare soil in and near the areas of phreatophytes. Table 5 shows that the estimated annual evapotranspiration from spring discharge and irrigation tail-waste was about 7,000 acre-feet and that from areas of shallow ground water, about 3,300 acre-feet.

TABLE 5.—*Estimated annual evapotranspiration in Pahrump Valley*

Phreatophytes	Phreatophyte area (acres)	Rate of use [1] (ft)	Evapotranspiration [2] (acre-ft)
From spring discharge and irrigation tail-waste:			
Mesquite	1, 600	3. 3	5, 300
Saltgrass and saltbrush	450	3. 0	1, 400
Saltcedar	35	6. 0	200
Cottonwood	10	5. 5	50
Subtotal (rounded)	2, 100	--------	7, 000
From ground water in the valley-fill reservoir:			
Mesquite	1, 000	3. 3	3, 300
Total (rounded)	3, 100	--------	10, 000

[1] Modified to reflect climatic and hydrologic conditions in Pahrump Valley: mesquite (Robinson, 1958, p. 38), saltgrass (Young and Blaney, 1942, p. 129), saltcedar (Gatewood and others, 1950, p. 150–152), and cottonwood (Blaney and Harris, 1952).

[2] Includes evaporation from bare soil in and near phreatophyte areas.

SUBSURFACE OUTFLOW

The water-level contours (pl. 2) show that ground water in the valley-fill reservoir moves southwestward into the carbonate-rock reservoir in the Nopah and Resting Spring Ranges. The outflow from the valley-fill reservoir can be estimated by use of a form of Darcy's law:

$$Q=0.00112\ TIL,$$

in which Q is the discharge, in acre-feet per year; T is the coefficient of transmissibility, in gallons per day per foot; I is the hydraulic gradient, in feet per mile; and L is the width, in miles, of the cross section through which outflow occurs (Ferris and others, 1962, p. 73). The factor 0.00112 is used to convert gallons per day to acre-feet per year.

The logs of wells in the southwestern part of the valley show that the valley fill is dominantly clay and silt; hence, the coefficient of transmissibility probably is low and may be only about 1,000–5,000 gallons per day per foot. The hydraulic gradient averages about 20 feet per mile along the 35-mile length of the valley trough. Thus, by substituting these values in the above equation, this preliminary estimate of outflow is computed to be about 2,000 acre-feet per year. Because little historic change in hydraulic gradient has occurred in this part of the valley, the subsurface outflow remained nearly constant through 1962. The pumping in an area 5–10 miles northeast of the valley trough and in the southern part of the valley may eventually reduce the hydraulic gradient and thereby proportionately reduce the outflow.

PUMPAGE

Practically all discharge of ground water by pumping and by flow from artesian wells occurs along the toes of Manse and Pahrump fans on the northeast side of the valley floor. After the first successful flowing artesian wells were drilled in 1910, the number of new wells drilled and the annual discharge increased slowly until the mid-1940's. At that time many wells were drilled and large-capacity pumps were installed. From the mid-1940's through 1962 the annual discharge from wells increased from an estimated 10,000 acre-feet to about 28,000 acre-feet. During the period 1959–62 the discharge averaged about 26,000 acre-feet per year. Discharge from wells in 1962 was about three times that from springs in 1875.

Table 6 lists the discharge from wells and springs for all years for which records or estimates are available. Figure 6 shows the areal distribution and approximate magnitude of well and spring discharge in 1961. Figure 6 shows that the largest areas of well and spring discharge are centered around the Fowler and Manse Ranches, where the discharge was about 5,700 and 6,200 acre-feet, respectively.

As described in "Storage capacity" of this report, approximately 1,000 acre-feet of irrigation water infiltrated the valley-fill reservoir each year during the period 1959–62. The net pumping draft, or the amount of ground water permanently removed from the reservoir by pumping, therefore, was about 25,000 acre-feet per year for that period. Moreover, an estimated 7,000 acre-feet per year of the pumped water ran off as tail-waste and, as previously mentioned, was consumed by evapotranspiration. These estimates suggest that approximately 18,000 acre-feet, or 70 percent, of the annual pumpage during this period was consumptively used for the irrigation of about 6,500 acres of crops—that is, about 2.8 acre-feet per irrigated acre.

TABLE 6.—*Approximate discharge, in acre-feet, from springs and wells in Pahrump Valley, 1875–1962*

[Discharge measurements from records of the Nevada State Engineer, except as indicated]

Year	Springs [1]			Wells	Total	Remarks
	Manse	Bennetts	Other			
1875	[2] 4,300	[2] 5,400	----------	0	[2] 9,700	
1877	[3] 4,300	----------	----------	0	----------	
1910	----------	----------	----------	0	----------	First well drilled in Pahrump Valley.
1913	----------	----------	----------	[4] 500	----------	Combined flow from 3 wells.
1916	[5] 2,300	[5] 3,400	----------	[5] 4,300	[5] 10,000	28 wells in valley; 15 flowing.
1927	[6] 1,900	[6] 1,600	----------	[6] 4,600	[6] 9,000	
1937	2,200	4,100	----------	3,300	9,600	
1939	2,200	3,200	----------	3,500	8,900	
1940	2,200	2,600	----------	2,200	7,000	
1943	----------	4,100	----------	----------	----------	Bennetts Spring cleaned and deepened.
1946	2,200	----------	----------	16,300	18,500	Flow from Bennetts Spring included in estimate of well discharge.
1947	1,500	----------	----------	15,500	17,000	Do.
1948	2,000	----------	----------	16,000	18,000	Do.
1949	1,900	----------	----------	19,100	21,000	Do.
1950	1,900	----------	----------	13,100	15.000	Do.
1951	1,900	----------	----------	16,100	18,000	39 wells in use.
1952	----------	----------	----------	----------	----------	No inventory made.
1953	1,800	----------	----------	26,200	28,000	39 wells in use.
1954	1,900	----------	----------	25,100	27,000	Do.
1955	1,800	----------	----------	27,200	29,000	Do.
1956	1,700	2,000	----------	23,300	27,000	
1957	1,800	2,000	----------	21,300	25,000	
1958	1,700	1,400	----------	22,900	26,000	
1959	1,800	0	[7] 50	24,200	26,000	
1960	1,700	0	----------	25,300	27,000	
1961	1,500	0	----------	28,500	30,000	
1962	1,400	0	----------	27,600	29,000	

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[1] Flow from springs estimated on the basis of one or more measurements a year.
[2] Maxey and Jameson (1948, p. 10).
[3] Maxey and Jameson (1948, p. 78).
[4] Clark County Review, Feb. 22, 1913.
[5] Waring, G. A. (1921, p. 61–66).
[6] George Hardman (written commun., 1935).
[7] Estimated by author. The discharge has probably remained constant during historic period.

Pumpage for domestic and other uses probably was only a few hundred acre-feet per year for the period 1959–62. This amount of pumpage is so small that it is within the limits of error of the estimated pumpage for irrigation. Therefore, the discharge from wells (table 6) is considered to be the total pumpage in Pahrump Valley.

CARBONATE-ROCK RESERVOIR

Virtually all discharge of ground water from the carbonate-rock reservoir in Pahrump Valley is by subsurface outflow beneath topographic divides to Chicago and California Valleys and possibly to Ash Meadows (pl. 2). A minor amount of discharge may occur in the vicinity of Sixmile Spring, where several seeps are present adjacent to carbonate-rock outcrops (pl. 1). Sixmile Spring apparently has never flowed; Waring (1921) described it as water standing about 6 feet below the surface in a low sandy mound. In 1962 the water was at about the same level, and standing about 10 feet above the regional water level in the valley fill; the higher head may be due to the flow system in the carbonate-rock reservoir.

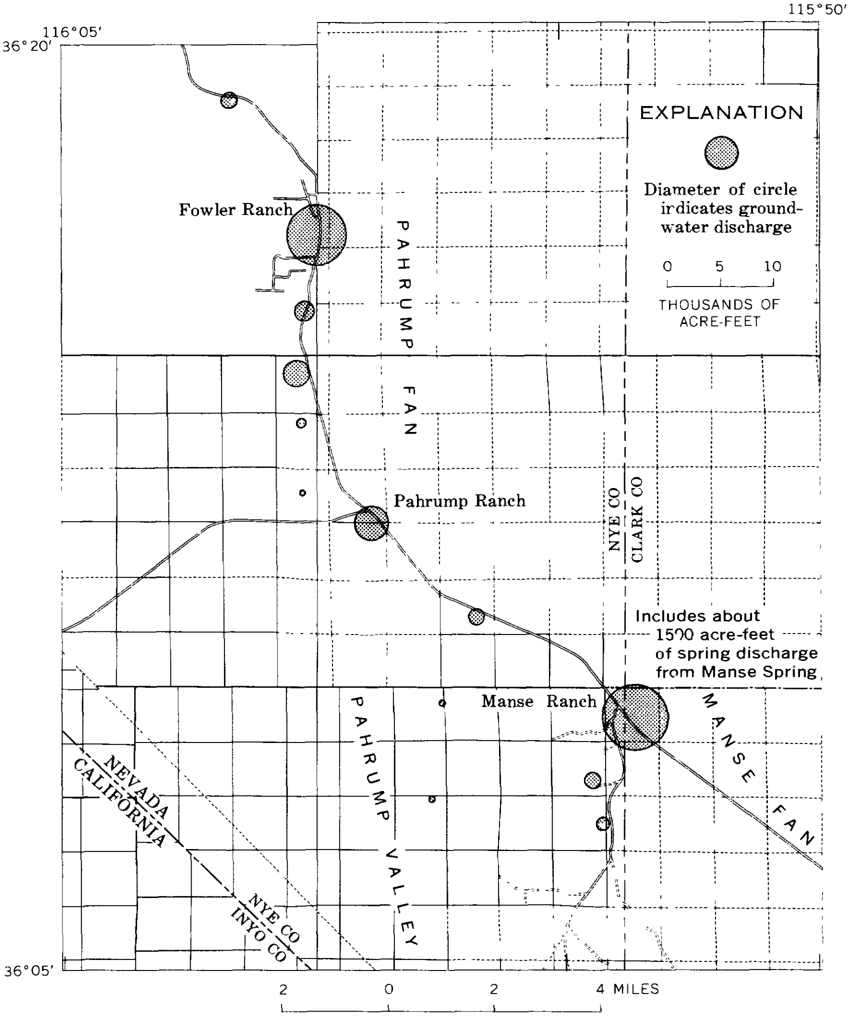

FIGURE 6.—Approximate area and magnitude of ground-water discharge from springs and wells in Pahrump Valley in 1961.

A crude estimate of the average annual subsurface outflow is indirectly computed as the difference between the total recharge (22,000 acre-ft, table 4) and the natural discharge from the valley-fill reservoir by evapotranspiration (about 10,000 acre-ft, table 5), or about 12,000 acre-feet. Of this annual outflow from the carbonate-rock reservoir, approximately 2,000 acre-feet is supplied from the valley-fill reservoir along the southwest side of the valley (p. 30); the rest, 10,000 acre-feet, is supplied by flow at depth from the recharge area in the Spring Mountains (fig. 5). These crude estimates suggest in turn that the division of total recharge between the two reservoirs is 12,000 acre-feet to the valley-fill reservoir and 10,000 acre-feet to the carbonate-rock reservoir.

The ultimate disposition of all the estimated 12,000 acre-feet of subsurface outflow to adjacent valleys was not resolved during this study. The geologic controls suggest that most of the outflow moves southwestward through a thick section of carbonate rocks beneath the Nopah and Resting Spring Ranges; part may move northwestward through a thin section of carbonate rocks or along major fault zones to the springs at Ash Meadows. Most springflow at Ash Meadows, however, probably is derived from sources to the north (I. J. Winograd, U.S. Geol. Survey, oral commun., 1965).

In Chicago Valley, the phreatophytes (pl. 3), covering an area of about 600 acres, probably discharge about 2,000 acre-feet per year—far more than the local recharge. Tecopah Springs, at the southwest end of California Valley (pl. 3), and other springs may have a combined total discharge of 1,000–2,000 acre-feet per year. But even if all this discharge of 3,000–4,000 acre-feet per year were supplied from Pahrump Valley and none were supplied from local sources—which is not true—it would account for only about a fourth of the estimated subsurface outflow from Pahrump Valley.

GROUND WATER IN STORAGE

STORAGE CAPACITY

The valley-fill reservoir in Pahrump Valley contains a large amount of ground water that is moving slowly from areas of recharge to points of discharge. The amount stored, or in transient storage, in the reservoir is many times the average annual recharge and represents water accumulated during several hundred years. The amount of water contained in a selected volume of the valley-fill reservoir is computed by multiplying the volume of saturated material by the specific yield of the material. As defined by Meinzer (1923, p. 28), specific yield is the ratio of (1) the volume of water which the material, after being saturated, will yield by gravity to (2) the volume of the material. This ratio is stated as a percentage.

An estimated specific yield of 15 percent is assigned for determinations in this report because no tests were made to ascertain the specific yield of the valley-fill deposits in Pahrump Valley. Studies made in other areas show that the specific yield of valley fill commonly ranges from 7 to 20 percent. (For example, see Davis and others, 1959, p. 206–211, 242–253; and Thomasson and others, 1960, p. 283–286, 292.)

To show that a large amount of ground water probably is stored in the valley-fill reservoir in Pahrump Valley, an estimate is made for the upper 100 feet of saturated material. The reservoir area is about 650 square miles, or about 400,000 acres; the selected saturated zone is 100 feet thick; and the assigned specific yield is 15 percent. The estimated ground water in storage is the product of these three values, or about 6 million acre-feet—that is, the water in storage in each foot of saturated material is about 60,000 acre-feet, which is equivalent to about 5 years of recharge to the valley-fill reservoir.

DEPLETION OF GROUND WATER IN STORAGE

Changes in the amount of ground water in storage are indicated by water-level fluctuations and occur chiefly in response to changes in the rates of recharge and discharge. Pumping from wells commonly places a large stress on a ground-water system and, if prolonged or intense, generally results in a marked decline in water levels and a corresponding decrease in stored water.

Development of ground water in the valley-fill reservoir was started in the vicinity of Manse and Bennetts Springs. Since about 1948 the water level in well S21/54–10aac, near Manse Spring, and in well S20/53–24caa, near Bennetts Springs, has been declining because of pumping (fig. 7). In these two areas, pumping had caused water levels to lower more than 25 feet by 1962. Hydrographs of wells N24/8–26bac and S19/53–32aaa, which are farther from heavy-pumping areas, show only minor changes in water level during the period of ground-water development (fig. 7).

Plate 4 shows the net change in water levels for the 3-year period February 1959–February 1962. Areas in which water levels have declined 5 feet or more are around major centers of pumping and total about 13,000 acres; areas having less than 5 feet of water-level decline are ill-defined but probably total at least four times as much acreage. The total volume of deposits dewatered during the 3-year period was about 300,000 acre-feet. Determined with the assigned specific yield of 15 percent, this total volume indicates a probable storage depletion of roughly 45,000 acre-feet, or about 15,000 acre-feet per year.

INCREASE OF GROUND WATER IN STORAGE

Infiltration of irrigation water along diversion ditches and in irrigated areas during the period 1959–62 caused water levels to rise 1–2 feet each year in three areas southwest of the principal irrigated areas (pl. 4). The estimated total return flow in these areas, as represented by the net increase in storage, is the product of (1) the area of about 7,000 acres, (2) the average water-level rise of about 0.8 foot, and (3) the assigned specific yield of 15 percent, or a net increase of approximately 1,000 acre-feet. Areas of water-level rise generally dissipate

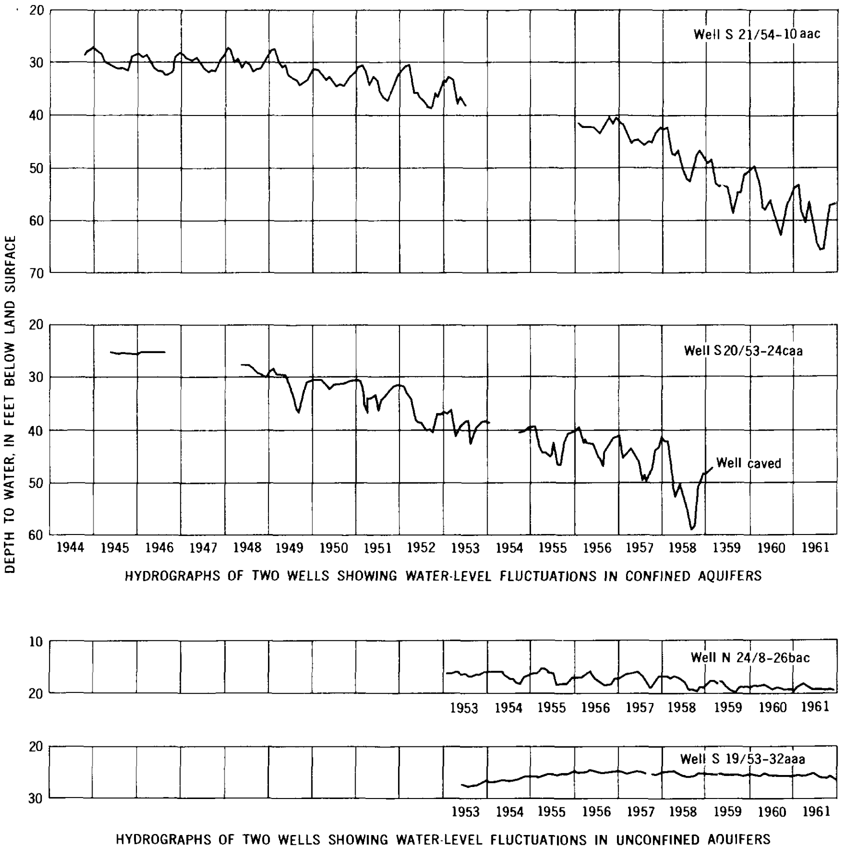

FIGURE 7.—Water-level fluctuations in selected wells tapping the valley-fill reservoir in Pahrump Valley.

after each successive year's irrigation season; hence, the computed return-flow value of about 1,000 acre-feet mainly indicates the annual increment of return flow, or recycled water.

WATER BUDGET

The water budget for Pahrump Valley brings together and compares the estimated elements of recharge and discharge and the changes in amount of ground water in storage for natural conditions and for the 4-year period 1959–62. This analysis includes the carbonate-rock and valley-fill reservoirs and shows the magnitude of the errors involved in the estimates made in the preceding sections of this report. These estimates are summarized in table 7 and show the marked change that has occurred in the ground-water regimen of the valley-fill reservoir from conditions prior to ground-water development to conditions of moderately large withdrawals in the period 1959–62.

TABLE 7.—*Water-budget analysis, in acre-feet per year, for Pahrump Valley*

[Boldface numbers indicate steps in analysis]

Budget item	Natural conditions			Conditions in 1959–62		
	Carbonate-rock reservoir	Valley-fill reservoir	Total	Carbonate-rock reservoir	Valley-fill reservoir	Total
Recharge (**1**)						
Precipitation (table 4)	[1] 10,000	[2] 12,000	22,000	[1] 10,000	[2] 12,000	22,000
Discharge:						
Springs:						
Total (p. 28, 31)	Minor	(10,000)		Minor	(1,600)	
Return to storage (p. 28)		(−3,000)			(−600)	
Net discharge (p. 28)	Minor	[3] 7,000	7,000	Minor	[4] 1,000	[4] 1,000
Evapotranspiration:						
Shallow ground water (table 5)	Minor	3,300	3,300	Minor	3,300	3,300
Subsurface outflow (p. 30, 32)	10,000	2,000	12,000	10,000	2,000	12,000
Pumpage:						
Total (table 5)	0	0	0	0	(26,000)	
Return to storage (p. 34)					(−1,000)	
Net pumping draft (p. 30)					[4] 25,000	[4] 25,000
Total (**2**)	10,000	12,000	22,000	10,000	31,000	41,000
Difference (**3**) = (1−2)	0	0	0	0	−19,000	−19,000
Storage depletion (**4**)	0	0	0	0	−15,000	−15,000
Difference between methods (3−4)	0	0	0	0	[5] 4,000	[5] 4,000

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[1] Computed by difference: total recharge less recharge to valley-fill reservoir.

[2] Assumed equal to total discharge under natural conditions from the valley-fill reservoir.

[3] Total amount was consumed by evapotranspiration (p. 29).

[4] Of the 26,000 acre-feet of net spring discharge and net pumping draft, about 7,000 acre-feet was consumed by evapotranspiration of irrigation tail waste.

[5] Average for 3-year periodFebruary 1959–February 1962.

Pumping from the valley-fill reservoir probably has not yet intercepted any of the subsurface outflow from the valley. Table 7 shows that the annual outflow of 10,000 acre-feet from the carbonate-rock reservoir and the outflow of 2,000 acre-feet from the valley-fill reservoirs to the carbonate-rock reservoir have therefore remained constant. For two reasons, moreover, the water budget for the carbonate-rock reservoir balances: (1) it is assumed that no change in storage has occurred; and (2) the estimates of recharge and discharge, which were determined by difference, were assumed to be equal. Similarly, the water budget for natural conditions in the valley-fill reservoir balances.

During the period 1959–62 the estimated total annual discharge from the valley-fill reservoir increased from about 12,000 acre-feet under natural conditions to approximately 31,000 acre-feet—nearly a threefold increase (table 7). As a result the estimated annual natural discharge has been reduced from 12,000 acre-feet to 6,000 acre-feet, and the ground water in storage has been depleted at an estimated average rate of 15,000 acre-feet per year.

The water-budget analysis for the period 1959–62 also shows a discrepancy of 4,000 acre-feet per year in the difference between the estimated recharge and discharge and the estimated storage depletion. This imbalance shows a magnitude of error of about 25 percent in the several estimates of recharge, discharge, and storage change. Except for the estimates of pumpage and storage depletion, the estimates of other budget items are too small to affect the imbalance. One probable source of error is the estimated return to storage of irrigation water, which seems low—only 4 percent of the pumpage. In other areas the return commonly ranges from 25 to 40 percent of the total pumpage (Thomasson and others, 1960). The estimated storage depletion of 15,000 acre-feet per year may also be considerably in error, owing principally to the poor control of area and thickness in determining the volume of deposits dewatered in the areas of pumping.

PERENNIAL YIELD

The perennial yield of a ground-water reservoir may be defined as the maximum amount of water of usable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time. If the perennial yield is continually exceeded, water levels will decline until the ground-water reservoir is depleted of water of usable quality or until the pumping lifts become uneconomical to maintain. Perennial yield cannot exceed the natural recharge to an area indefinitely; it is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use.

Before pumping began, the natural discharge from Pahrump Valley comprised about 10,000 acre-feet per year from the carbonate-rock reservoir and about 12,000 acre-feet per year from the valley-fill reservoir (table 7). During the period 1959–62, when pumpage averaged about 26,000 acre-feet per year, natural discharge from the valley-fill reservoir was about 6,000 acre-feet per year less than before pumping began, but probably little or no decrease had occurred in the discharge from the carbonate-rock reservoir. To estimate the maximum amount of natural discharge that can be salvaged, the future cause-and-effect relation between pumping and natural discharge must be evaluated. The following estimates and assumptions are made to ascertain this relation:

1. The 1962 areal pattern of pumping on the Nevada side of Pahrump Valley will probably not change appreciably in the near future, but pumpage may increase. As a result, Manse Spring probably will stop flowing, and evapotranspiration from areas of shallow ground water west of Pahrump will markedly decrease (pl. 3). The total additional salvage of natural discharge may ultimately be as much as 4,000 acre-feet per year.
2. Pumping on the California side and near the south end of Pahrump Valley may markedly increase. From February 1959 to February 1962 (pl. 3), pumping lowered water levels in this area about 4 feet. Large withdrawals will reduce the ground-water outflow from the valley-fill reservoir to the carbonate-rock reservoir possibly as much as 50 percent, or about 1,000 acre-feet per year. No other development on the California side seems feasible or imminent as of 1962.
3. At the 1962 rate or at a higher rate, prolonged pumping from the valley-fill reservoir will probably somewhat reduce subsurface outflow from the carbonate-rock reservoir to adjacent valleys. Until both the cause-and-effect relation of the future pumping regimen and the subsurface outflow from the carbonate-rock reservoir can be more thoroughly evaluated, the salvable outflow from the carbonate-rock reservoir is assumed to be only 1,000 acre-feet per year.
4. The carbonate-rock reservoir probably occurs at a depth of more than a thousand feet beneath most of Pahrump Valley. Future drilling of deep wells in an attempt to tap water in fracture zones in the carbonate rocks seems only a remote possibility. Accordingly, the possibility of salvaging outflow from this reservoir by pumping also seems remote at this time.

Based on these estimates and assumptions, the maximum amount of natural discharge that can be salvaged probably is not more than 12,000 acre-feet per year, which is 6,000 acre-feet per year more than the yearly amount salvaged during the period 1959–62.

In summary, the maximum salvable discharge comprises the following (annual estimates):

1. All net spring discharge, which was originally 7,000 acre-feet;
2. Possibly as much as 3,000 acre-feet of evapotranspiration in areas of shallow ground water;
3. About 1,000 acre-feet of subsurface outflow from the valley-fill reservoir;
4. Possibly 1,000 acre-feet of outflow from the carbonate-rock reservoir to adjacent valleys (table 7).

Thus, the estimated perennial yield of Pahrump Valley also probably does not exceed 12,000 acre-feet. This means that about 10,000 acre-feet per year of subsurface outflow probably is not salvable and that, ultimately, any net pumping draft in excess of 12,000 acre-feet per year will be supplied from ground water in storage.

OVERDRAFT

Overdraft may be defined as the amount by which the net pumping draft exceeds the perennial yield. During the period 1959–62 the estimated net pumping draft averaged 25,000 acre-feet per year (table 7), or approximately twice the estimated perennial yield of 12,000 acre-feet. Annual overdraft in Pahrump Valley during this period thus averaged about 13,000 acre-feet. Even if the net pumping draft was somewhat smaller than that estimated (p. 37), it still would have exceeded the estimated yield.

Table 6 shows that pumpage increased during the last several years of record. As long as annual pumpage continues to increase, overdraft also will continue to increase. Over the long term this deficiency will be supplied almost wholly from ground water in storage in the valley-fill reservoir. This depletion in turn will be manifested, principally in the areas of large withdrawals, by the continued downward trend of water levels, as shown in figure 7, and by increased pumping lifts.

Continued overdraft and the accompanying increase in pumping lifts will clearly result in an increase in pumping costs. The electrical energy required to lift water from a well to the point of discharge commonly is 2 kilowatt-hours per acre-foot per foot of lift. For example, using this energy factor, 200 kilowatt-hours would be required to lift 1 acre-foot of water from a pumping level 100 feet below the discharge point. If the pumping lift should double in the future, the kilowatt-hours per acre-foot would also double, provided that the well and pumping plant efficiencies were to remain nearly the same.

CHEMICAL QUALITY OF WATER

Chemical analyses made by several agencies are available for water from 43 wells and 5 springs in Pahrump Valley and vicinity. Of these analyses, 18 are "complete" analyses and 30 are "partial" analyses (specific conductance, chloride, hardness, and pH). Water-temperature data are also available for most of the sampling points. Representative chemical analyses are shown in table 8, and the range in chemical quality of all "complete" analyses is shown in table 9. Plate 5 shows the chemical quality of water and its variation from one part of the valley to another.

The scope of this section is limited to brief presentations of the variations in water quality and of the suitability of the water for irrigation use. A brief analysis is made of the geothermal gradient in the valley-fill reservoir.

VARIATIONS IN QUALITY

Along the northeast side of Pahrump Valley most ground water in the valley-fill reservoir is of calcium-magnesium bicarbonate type (pl. 5), indicating the abundance of carbonate rocks in the Spring Mountains, where most recharge occurs. The dissolved-solids content of the ground water increases as the water moves southwestward across the valley. Most of the water analyzed, however, was from shallow wells, and its quality may not be indicative of the quality of water in the deeper aquifers. Most analyses of water sampled in the vicinity of the Nevada-California boundary showed an increase in magnesium concentration in relation to calcium; consequently, magnesium is the predominant cation in solution. Northeast of the boundary the total dissolved-solids content is generally less than 300 ppm (parts per million).

Analyses of ground water sampled along the southwest side of the valley showed a wide variation in quality. In Stewart Valley the water generally has a high sodium content, and locally high contents of magnesium, sulfate, and chloride. The total dissolved-solids content ranges from about 520 ppm (well N24/8–6dcd) to about 40,000 ppm (well N25/7–25ccc, not shown on pl. 5). At the north edge of the playa in Pahrump Valley, the water (well N22/9–5abc) is high in magnesium, sodium, sulfate, and total dissolved-solids content. Elsewhere on the California side of Pahrump Valley, the water is generally of magnesium bicarbonate type, having a total dissolved-solids content of less than 500 ppm.

TABLE 8.—*Chemical analyses of typical irrigation water in Pahrump Valley*

[Constituents in parts per million, except as indicated. CO_3 not present. Analyses by U.S. Geol. Survey, except as indicated]

Selected wells	Depth of well (ft)	Date of collection	Temperature (° F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	pH	Specific conductance (micromhos at 25°C)
S19/52-36bdd	389	4-29-59	69.5	26	30	22	13	2.2	199	22	5.0	0.2	1.5	0.06	220	165	7.8	360
S19/53-9bbc	746	4-24-59	73	21	46	26	28	4.0	280	36	12	.3	2.4	.14	314	222	7.8	524
S19/53-21aaa	595	4-29-59	72.5	20	47	28	7.5	1.6	269	20	6.0	.1	2.0	.04	264	232	7.9	447
S20/53-3cda	662	4-29-59	79.5	17	50	22	6.9	2.2	242	26	3.8	.2	1.7	.5	249	215	8.1	431
S20/53-20bba	902	5-22-59	--------	23	62	60	11	2.7	257	176	17	.3	2.4	.06	481	400	7.4	719
S21/54-16ada	795	2-10-55	74	16	53	22	7.1	.8	224	47	3.0	.5	.6	--------	260	223	7.8	428
S21/54-21bca	1,050	5-28-53	--------	20	36	24	9.2	1.5	186	48	2.8	.2	.9	.02	234	188	7.7	403
S22/54-24dcc [1]	680	5-10-57	--------	20	69	26	6.9	.4	281	55	6.0	.4	.5	0	324	--------	8.0	518

[1] Analysis by California Department of Water Resources.

TABLE 9.—*Summary of chemical quality of ground water in Pahrump Valley*

[Constituents in parts per million except as indicated]

	Maximum	Minimum	Median	Number of determinations
Silica (SiO^2)	90	3. 6	20	26
Iron (Fe):				
Total	3. 0	. 00	0. 10	17
Dissolved	1. 4	. 00	. 01	6
Calcium (Ca)	264	5. 6	43	40
Magnesium (Mg)	594	8. 3	29	40
Sodium (Na)	13, 000	5. 8	23	40
Potassium (K)	1, 980	. 3	3. 1	40
Bicarbonate (HCO_3)	1, 450	125	238	40
Carbonate (CO_4)	57	0	0	40
Sulfate (SO_4)	8, 830	14	55	40
Chloride (Cl)	15, 700	2. 0	16	40
Fluoride (F)	1. 4	. 1	. 3	28
Nitrate (NO_3)	42	0	1. 5	27
Boron (B)	54	. 00	. 07	37
Dissolved solids (calculated)	40, 600	220	301	30
Hardness as $CaCO_3$:				
Total	3, 100	54	223	38
Noncarbonate	2, 780	0	17	29
Specific conductance (micromhos at 25°C)	50, 300	348	515	30
pH	9. 3	7. 4	7. 9	36
Percent sodium	83	5	18	31

Water in Sixmile Spring is of calcium bicarbonate type and is, therefore, different from the types of water in nearby wells which tap the valley-fill reservoir (pl. 5). The spring-water type suggests that it is derived from the carbonate-rock reservoir.

SUITABILITY OF THE WATER FOR IRRIGATION

Most water users in Pahrump Valley are interested in the suitability of the water for irrigation, because the economy of the valley is dependent almost wholly on irrigation agriculture. Table 9 briefly summarizes the range of principal chemical constituents in the ground water, listing the maximum, minimum, and the median values for each constituent and the number of samples on which these values are based. Several characteristic properties of the water are also listed; these include dissolved solids, hardness, specific conductance, pH, and percent sodium (the ratio of sodium ions to the total number of cations in solution). Table 8 shows the chemical character of the ground water in eight selected wells in and adjacent to the principal areas of pumpage. Of the factors shown in this table, the most critical with respect to the suitability of water for irrigation are the dissolved-solids content and the concentration of toxic elements, such as boron. Other factors, such as soil type and composition, climate, and methods of water application also affect the suitability of water for irrigation.

Extensive irrigation in the poorly drained central part of Pahrump Valley may cause an eventual rise in the water table that will result in water logging and drainage problems. To maintain irrigation on a permanent basis in these areas, construction of drainage ditches may be required to control the depth of the water table and to prevent an excessive increase in dissolved-mineral constituents in the soil and in the underlying ground water.

Recirculation, or reuse, of water also tends to increase the dissolved-solids content. As water levels along the base of the Manse and Pahrump fans continue to decline, recirculation of irrigation water probably will increase because of the accompanying decrease in ground-water movement away from the pumped area. The recirculation of water through several cycles of irrigation in the same area will tend to increase the concentration of dissolved solids.

The ground water in most of Pahrump Valley is of moderate salinity and is low in sodium content. Water that is low in sodium content can be used successfully for irrigation of nearly all soils. After a small amount of leaching, the soil in the principal irrigated areas and at the south end of the valley is satisfactory for irrigation.

TEMPERATURE

The temperature of ground water is closely related to the temperature of the aquifer in which the water occurs. Therefore, insofar as the temperature of the water is in equilibrium with that of the aquifer, an increase in water temperature with depth probably is indicative of the geothermal gradient in the area. Residual heat from metamorphism, from crushing and shearing during faulting, or from underlying bodies of hot igneous rock may cause local anomalous temperatures both areally and at depth. Difference in thermal conductivity of different rock types may also result in different geothermal gradients in the same area.

The regional geothermal gradient is controlled by the transfer of heat from great depths within the earth toward the land surface. Hence, if the regional geothermal gradient is not altered by localized thermal activity, the temperature of the ground and of the water it contains will increase with depth. If the rate of temperature change with depth is known, the temperature of water being discharged from a well or spring may indicate the depth from which the water is coming. Although variations in the heat-flow pattern within the zone of saturation may result from many causes, the heat from the interior of the earth probably is fairly constant throughout the study area.

Near-surface temperatures approximate the mean annual air temperature, but they may vary slightly in response to exposure or to environmental changes caused by the activity of man.

The mean annual air temperature in Pahrump Valley is approximately 65°F, and the temperature of ground water from wells and springs in the valley area should equal or exceed that amount. In figure 8, 65 measurements of ground-water temperature are plotted against the depth of the well from which the water was discharged. Temperatures were measured at the point of discharge and possibly are somewhat lower than the water temperature in the principal aquifer supplying water to the well. The average temperature gradient for the area, as shown by the approximate curve of best fit in figure 8, is about 1°F for each 85 feet in depth.

Figure 8 is useful in estimating the approximate depth of the source of water. For example, the water temperature of Bennetts and Manse Springs averages about 75° and 76°F, respectively. This temperature is about 10°–11° warmer than the temperature of the shallowest water in the zone of saturation, which is at mean annual air temperature. This suggests that if the water from Bennetts Spring originated from a single water-bearing zone, the depth of the zone would be about 850 feet. Also, water discharged at the Manse Spring probably would originate from a depth of about 900 feet. If the spring discharge is a mixture of water derived from different depths, however, its temperature would be a composite of the temperatures of all the contributing aquifers, and the computed depths of 850–900 feet, therefore, would represent average depths.

SUMMARY AND CONCLUSIONS

This second appraisal of the ground-water resources of Pahrump Valley has revealed the existence of two reservoir systems—one in the valley fill, which has been extensively developed for irrigation, and the other in the underlying carbonate rocks, which is undeveloped. Of the estimated total average annual recharge of 22,000 acre-feet, approximately 12,000 acre-feet is believed to leave the valley by subsurface outflow through the carbonate rocks to adjacent areas. Pumping from the valley-fill reservoir in the future may salvage only 2,000 acre-feet per year of this outflow. This possibility suggests in turn that the salvable discharge may be only 12,000 acre-feet per year, or that the perennial yield of the valley may be limited to this amount of water over a long period of time.

The net pumping draft in the 4-year period 1959–62 averaged about 25,000 acre-feet per year, which is about twice the estimated perennial yield, or an overdraft of about 13,000 acre-feet per year. Over the long term the overdraft will be supplied from ground water stored in the valley-fill reservoir. This will result in declining water levels, increased pumping lifts, and, hence, increased pumping costs.

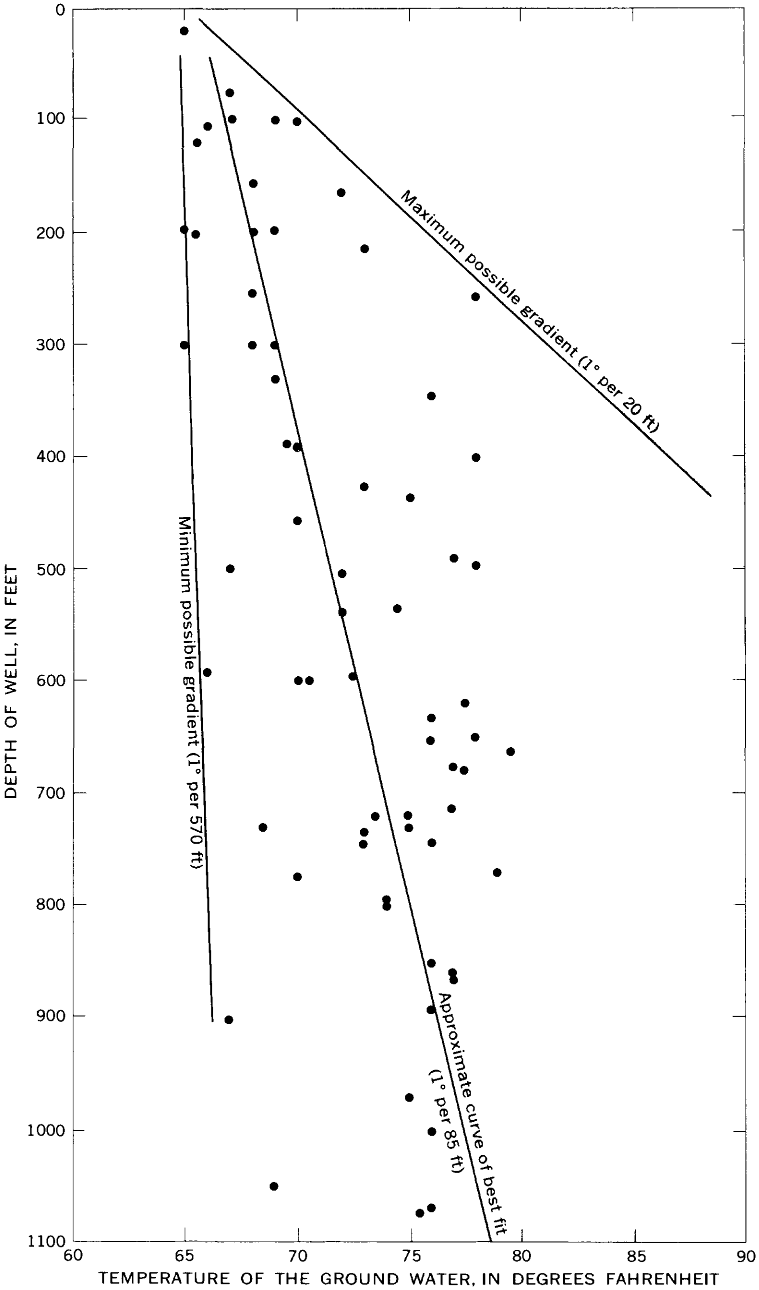

FIGURE 8.—Approximate geothermal gradient in Pahrump Valley.

Still unresolved is the ultimate disposition of the subsurface outflow from Pahrump Valley. This second investigation suggests that most of the outflow is southwestward through the Nopah and Resting Springs Ranges to discharge points in California, and that part may move northwestward to discharge at the springs in Ash Meadows. A direct determination of the magnitude and direction of the outflow, however, would require costly exploratory drilling. Even if the magnitude of the outflow could be determined, the amount that could be salvaged by pumping in Pahrump Valley probably would be small.

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GEOLOGICAL SURVEY

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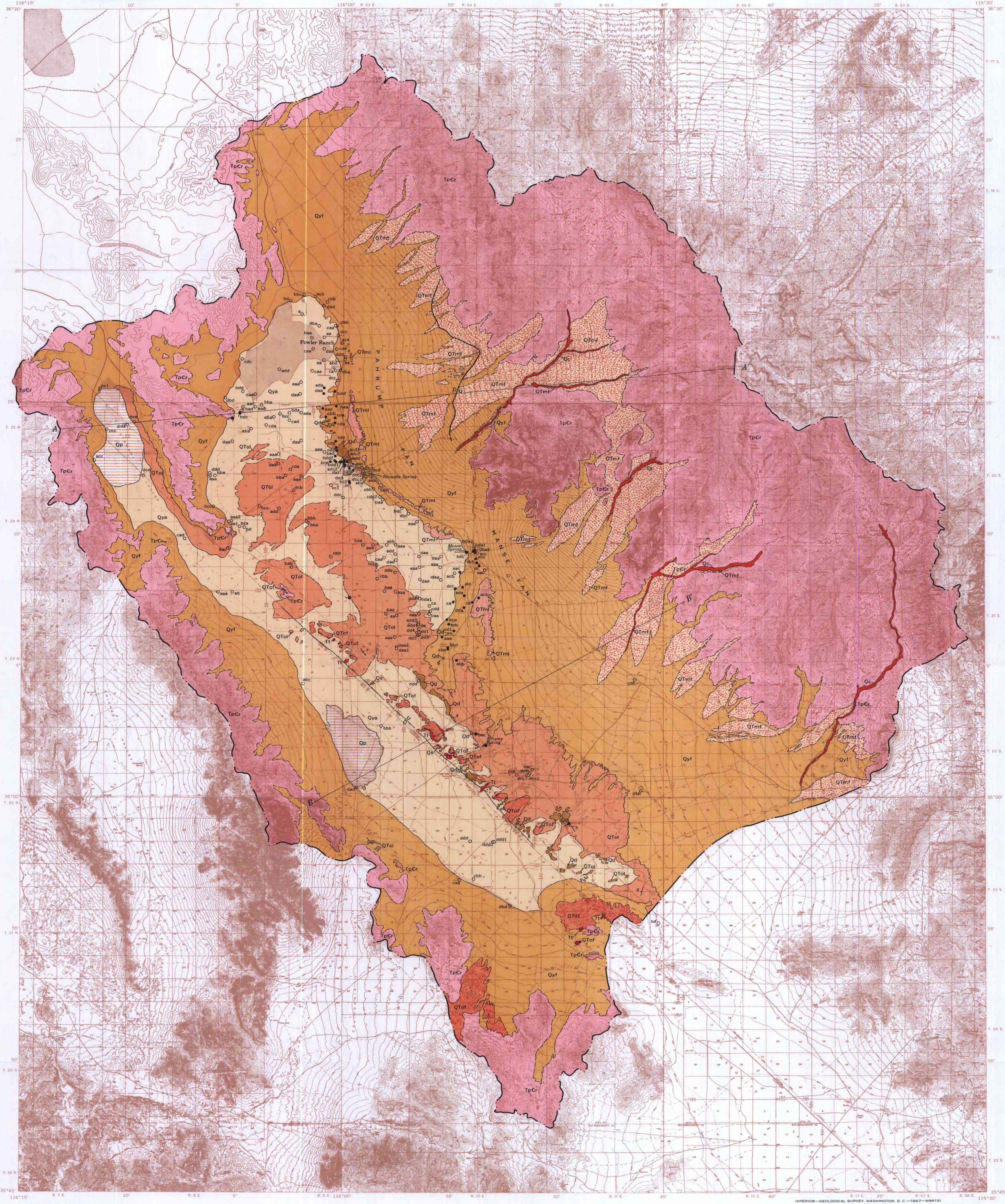
AND NATURAL RESOURCES

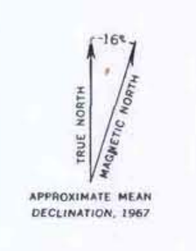
WATER SUPPLY PAPER 1832
PLATE 1



Base from U.S. Geological Survey quadrangles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1967—W66131

Geology of valley fill by G. T. Malmberg, 1963



APPROXIMATE MEAN DECLINATION, 1967

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 40, 80 AND 200 FEET
SUPPLEMENTAL CONTOUR INTERVALS 20 AND 40 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

DEPOSITS OF THE VALLEY FILL

FINE-GRAINED DEPOSITS | **COARSE-GRAINED DEPOSITS**

Pleistocene and Recent — QUATERNARY

Qya | Qp | Qd | Qs

Younger surficial deposits

Qya, *younger alluvium: gravel, sand, silt, and clay derived principally from older lacustrine and alluvial-fan deposits; forms a veneer on older sedimentary deposits and lies largely above the zone of saturation*

Qp, *playa deposits: silt and clay; yield virtually no water to wells; depth to ground water beneath both playa surfaces more than 10 feet*

Qd, *dune sand: sand, silt, and clay; commonly stabilized by vegetation; lies above the zone of saturation*

Qs, *sinter: calcareous and siliceous; forms conspicuous mounds adjacent to fault in central part of valley*

Qyf | Qc

Younger fan deposits

Qyf, *younger alluvial-fan deposits: gravel, sand, silt, and clay derived from older alluvial fans and consolidated rock in adjacent mountains; form alluvial fans and aprons along base of mountains; heterogeneity decreases with altitude; lie largely above zone of saturation but where saturated, stringers of highly permeable sand and gravel yield water readily to wells*

Qc, *channel deposits: gravel, sand, and silt in major stream channels; confined to arroyos on alluvial fans; highly permeable; where saturated they yield water readily to wells. Outcrop areas form principal areas of ground-water recharge*

UNCONFORMITY

Pliocene and Lower Pleistocene — TERTIARY AND QUATERNARY

QTml

Medial lacustrine deposits

Silt and clay, highly calcareous; form a prominent bench along east side of valley. Bench lies above the zone of saturation; lies conformably on older lacustrine deposits

QTol

Older lacustrine deposits

Clay, silt, sand, and minor amounts of gravel; in part cemented by caliche; faulted and dissected. Saturated beneath the water table but generally does not yield large quantities of water to wells

QTmf

Medial fanglomerate

Gravel, sand, silt, and clay, in part cemented; faulted and dissected; contains stringers and lenses of highly permeable sand and gravel. Where saturated may yield large quantities of water to wells. Grades laterally into medial and older lacustrine deposits

QTof

Older fanglomerate

Boulders, gravel, sand, silt, and clay. Composed of igneous, metamorphic, and sedimentary rocks; faulted and dissected. Not known to occur at depth, but if saturated it probably would yield only limited amounts of water to wells. Interfingers with lower part of older lacustrine deposits

UNCONFORMITY

Miocene or Pliocene — TERTIARY

Tt

Tuff

Includes thin to massive beds of tuff; highly faulted and folded; where saturated would yield limited amounts of water to wells

UNCONFORMITY

CONSOLIDATED ROCKS

PRECAMBRIAN TO TERTIARY(?)

TpCr

Sedimentary, metamorphic and igneous rocks

Highly indurated; intensely faulted and folded. Carbonate rocks absorb and transmit a large part of annual recharge from precipitation, and probably form a hydrologic system that in part is separated from the ground-water system in the alluvial fill

Contact
Dashed where approximately located

U
D
Fault
Dashed where approximately located; dotted where concealed.
D, *downthrown side;* U, *upthrown side*

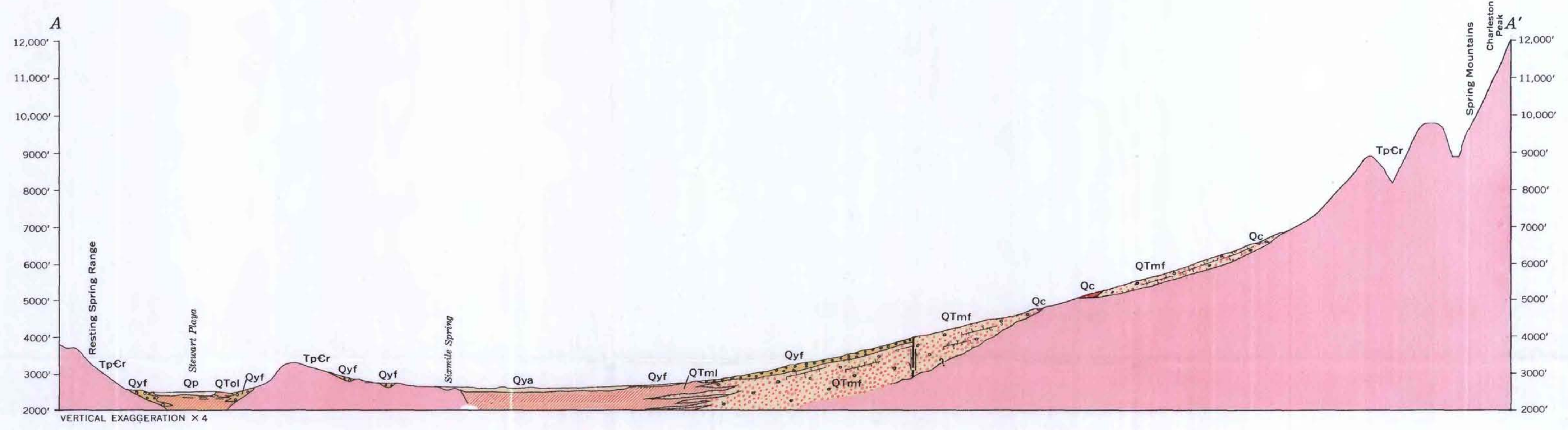
Basin boundary

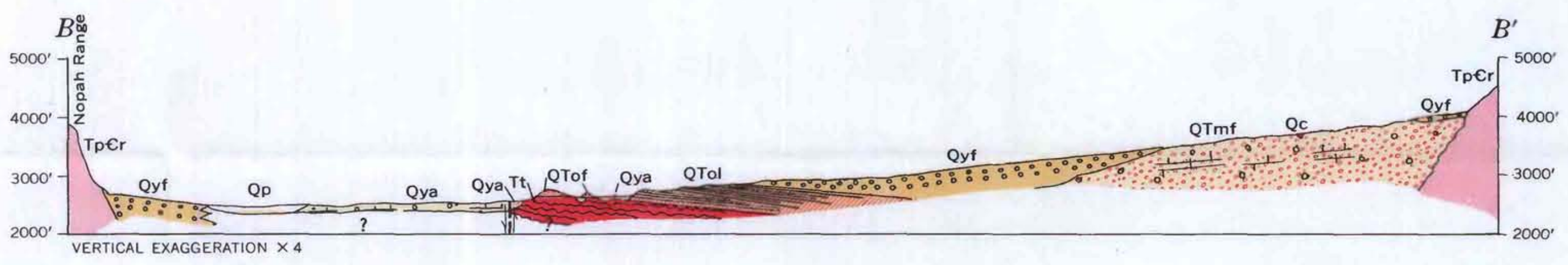
○ baa
Well and identification number

● acd1
Flowing well and identification number

bdc
Spring and identification number

5
Strike and dip of beds





GEOLOGIC MAP AND SECTIONS OF PAHRUMP VALLEY, NEVADA-CALIFORNIA, SHOWING THE LOCATION OF SELECTED WELLS AND SPRINGS

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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NEVADA DEPARTMENT OF CONSERVATION
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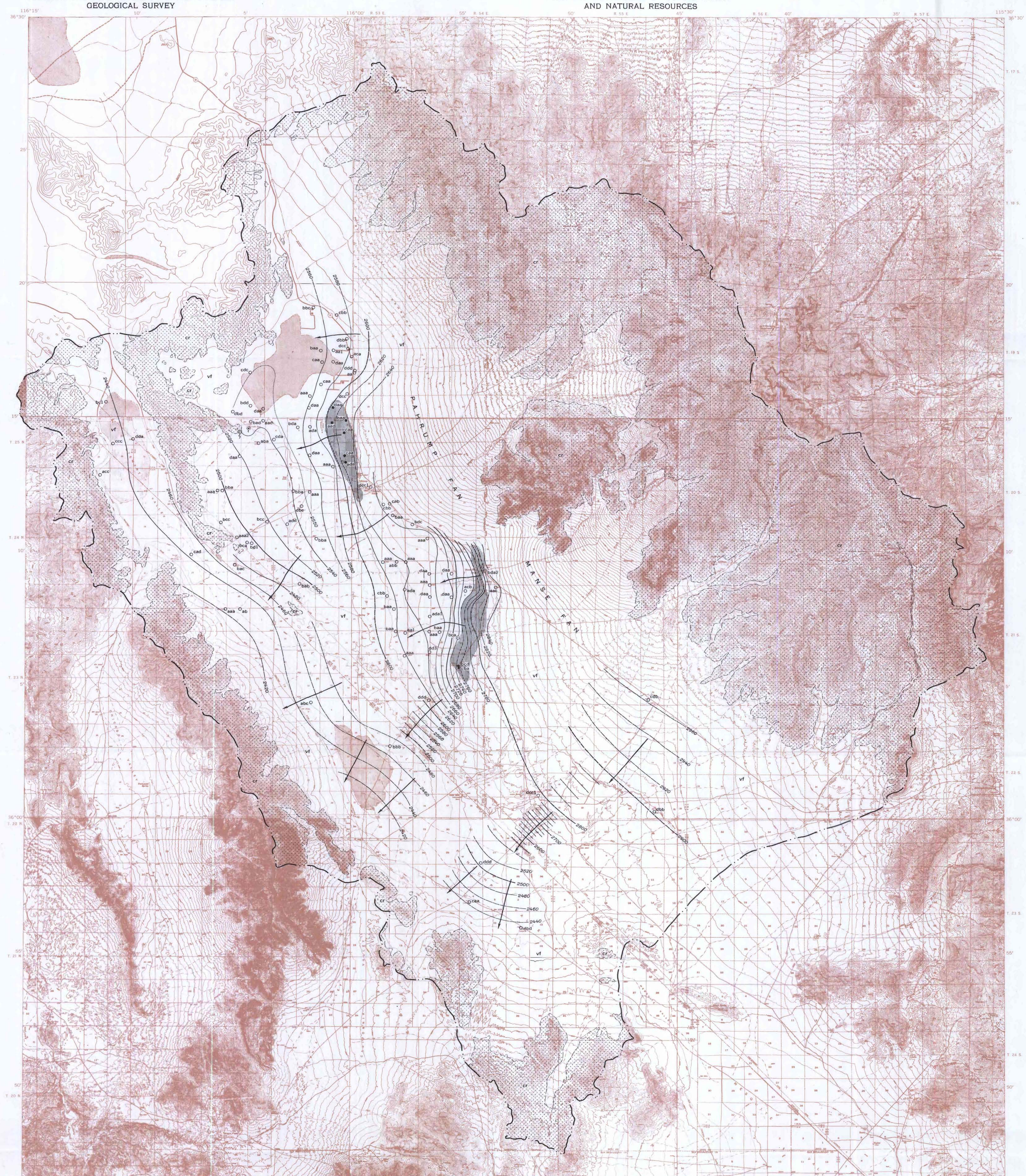
WATER SUPPLY PAPER 1832
PLATE 2



Base from U.S. Geological Survey quadrangles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1967—W66131

EXPLANATION

vf

Valley fill

cr

Consolidated rocks

Area of artesian flow in February 1962

Approximate contact between valley fill and consolidated rocks

2800

Water-level contour, February 1962
Dashed where approximate; contour interval 20 feet; dotted lines are 10-foot contours. Datum is mean sea level

Direction of ground-water flow

Basin boundary

○aac ●cba

Well in which water-level measurement was made; solid circle indicates flowing well

⊙bca

Well in which water level declined below land surface during 1959–62

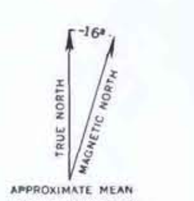
⊙~

Spring that flowed in 1959 but was dry in 1962

●~

Spring

MAP OF PAHRUMP VALLEY, NEVADA-CALIFORNIA, SHOWING WATER-LEVEL CONTOURS IN THE VALLEY-FILL RESERVOIR IN FEBRUARY 1962



APPROXIMATE MEAN DECLINATION, 1967

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 40, 80, AND 200 FEET
SUPPLEMENTAL CONTOUR INTERVALS 20 AND 40 FEET
DATUM IS MEAN SEA LEVEL

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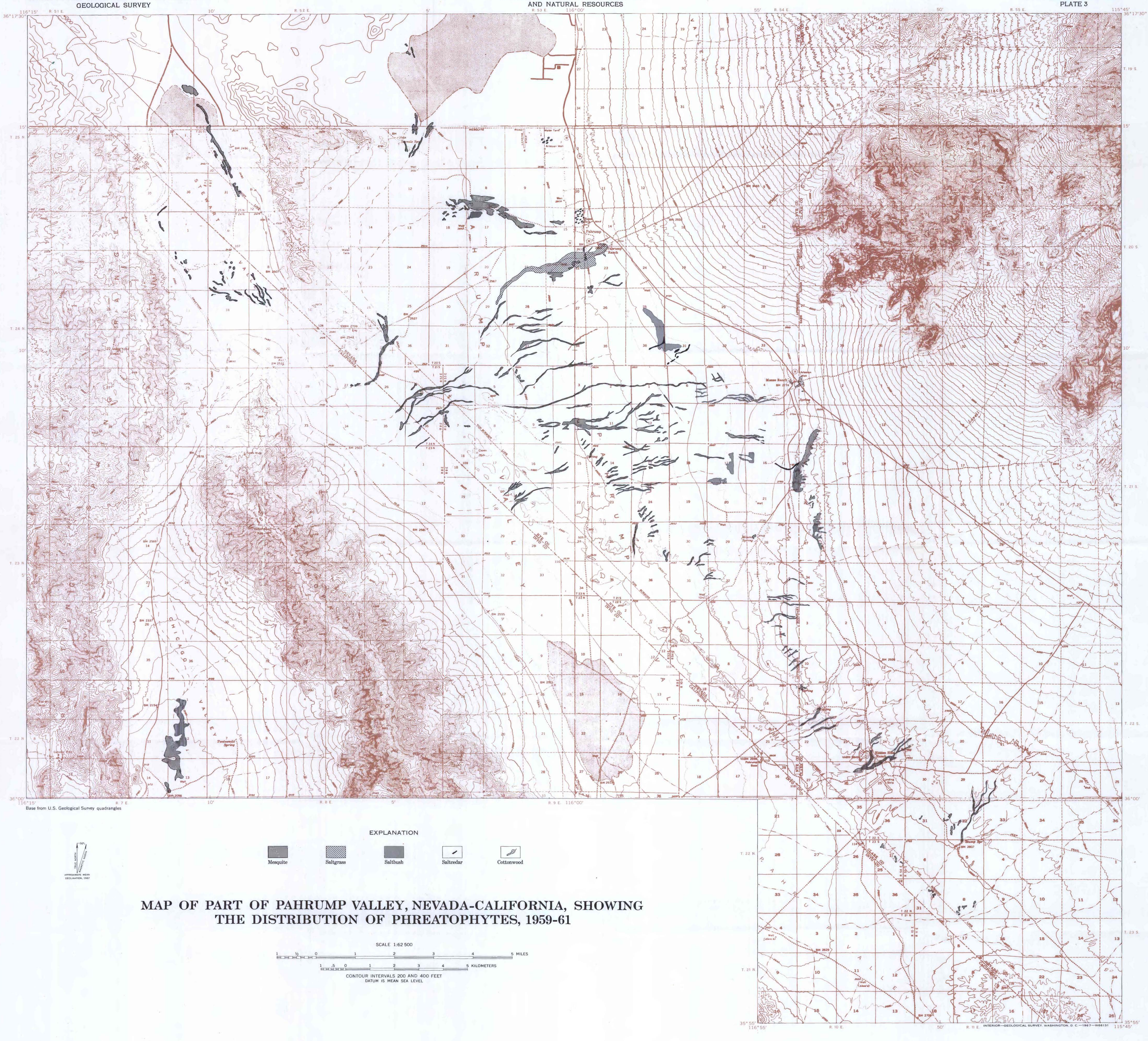
WATER SUPPLY PAPER 1832
PLATE 3



Base from U.S. Geological Survey quadrangles

EXPLANATION

▥ Mesquite

▧ Saltgrass

■ Saltbush

Saltcedar

Cottonwood

MAP OF PART OF PAHRUMP VALLEY, NEVADA-CALIFORNIA, SHOWING THE DISTRIBUTION OF PHREATOPHYTES, 1959-61

SCALE 1:62 500

1 ½ 0 1 2 3 4 5 MILES

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVALS 200 AND 400 FEET
DATUM IS MEAN SEA LEVEL

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AND NATURAL RESOURCES

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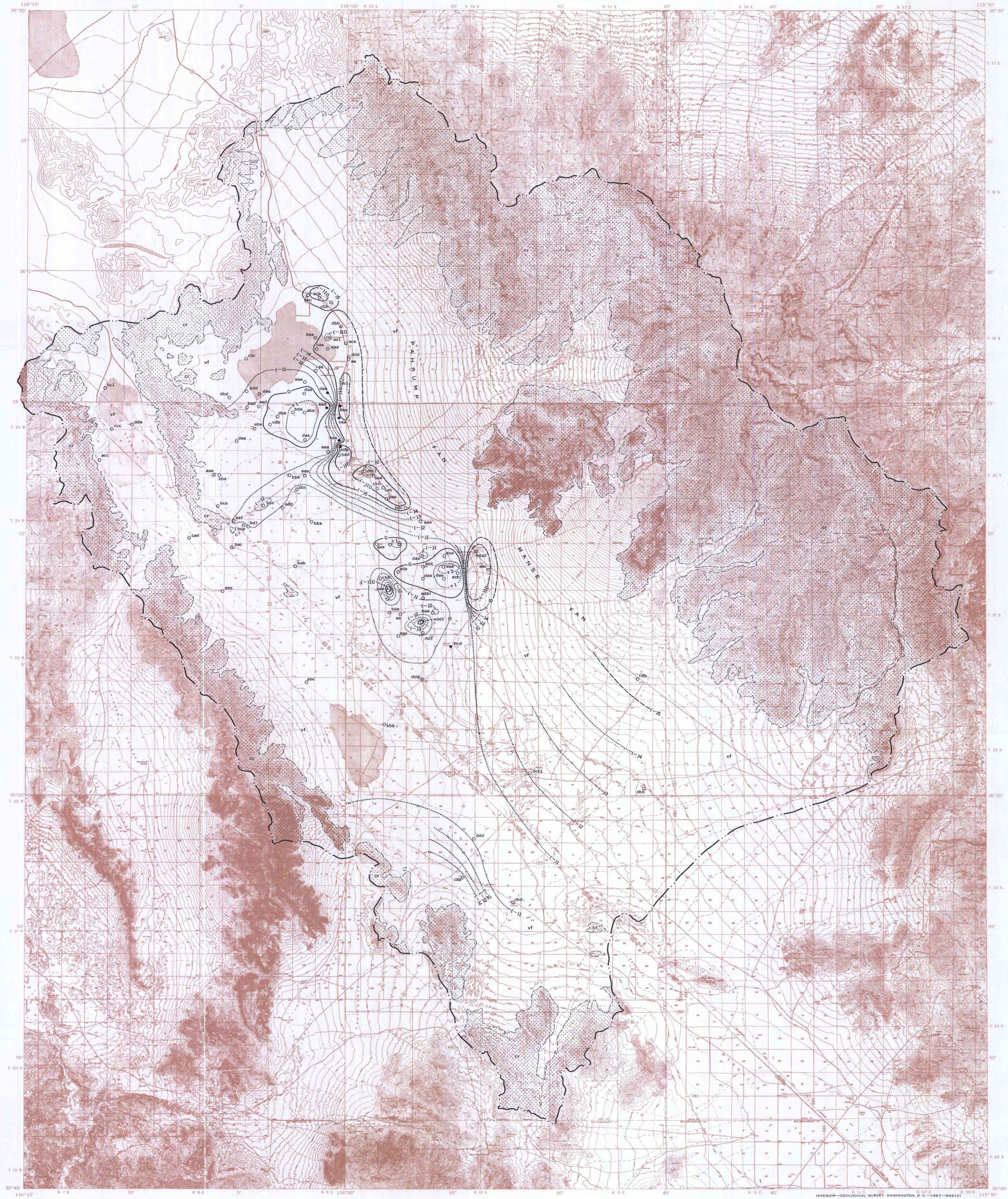
PLATE 4



Base from U.S. Geological Survey quadrangles

MAP OF PAHRUMP VALLEY, NEVADA-CALIFORNIA, SHOWING NET CHANGE IN WATER LEVEL IN THE VALLEY-FILL RESERVOIR BETWEEN FEBRUARY 1959 AND FEBRUARY 1962

16°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN
DECLINATION, 1967

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 40, 80 AND 200 FEET
SUPPLEMENTAL CONTOUR INTERVALS 20 AND 40 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

vf

Valley fill

cr

Consolidated rocks

— — — — — —

Approximate contact between valley fill and consolidated rocks

——— (−)5 — — — ·····

Line of equal change of water level, February 1959 - February 1962
Dashed where approximate; interval 5 feet; dotted line represents 1-foot interval

——— · · ———

Boundary basin

○aac

Nonflowing well used as a control point

●bcd

Flowing well used as a control point

⊙bda2

Well in which water level declines below land surface during 1959-62

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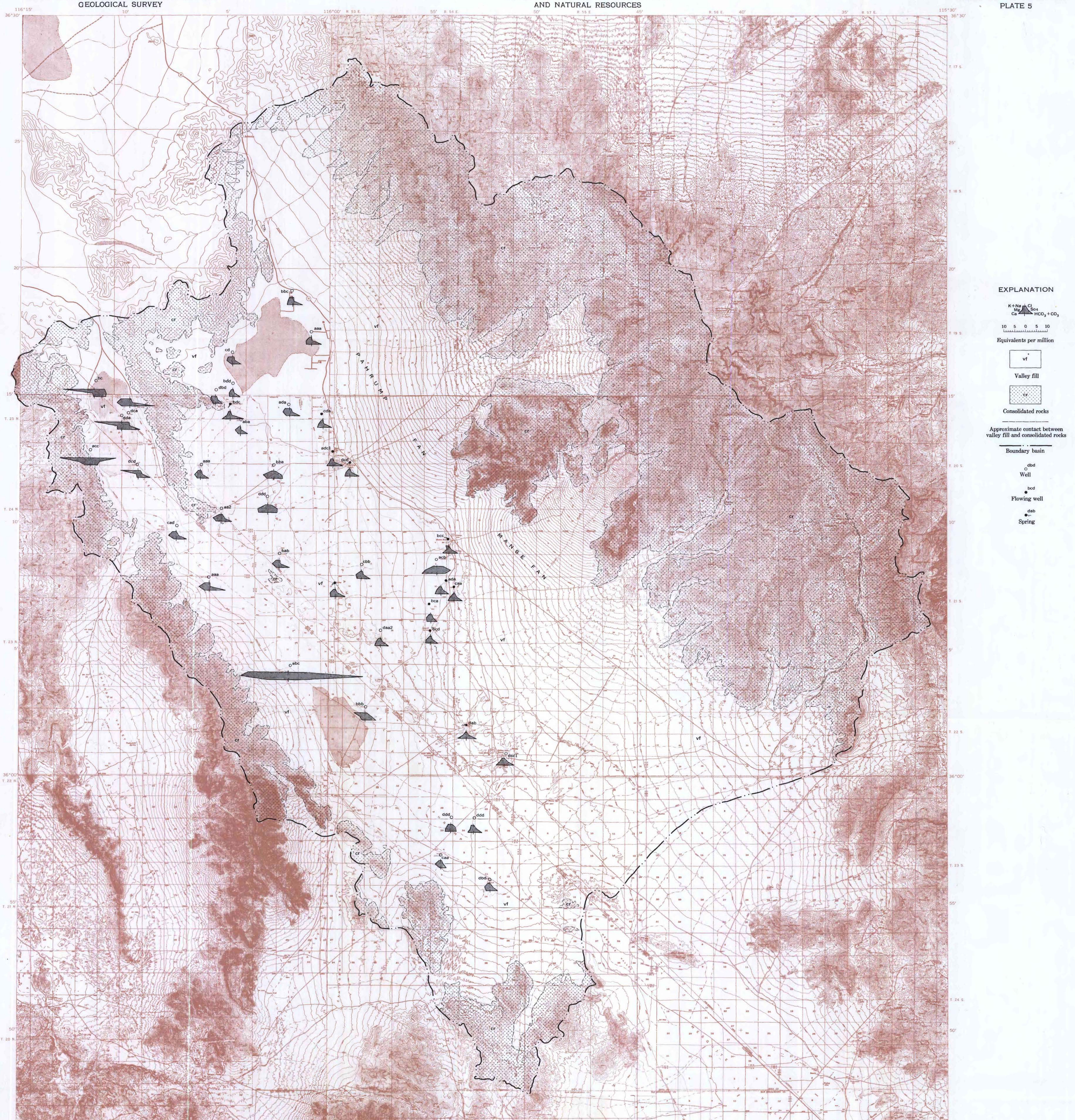
WATER SUPPLY PAPER 1832
PLATE 5



Base from U.S. Geological Survey quadrangles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1967—W66131

MAP SHOWING VARIATIONS IN PRINCIPAL CHEMICAL CONSTITUENTS OF GROUND WATER IN PAHRUMP VALLEY, NEVADA-CALIFORNIA

16°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1967

SCALE 1:125 000
2 0 2 4 6 8 10 MILES
2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 40, 80, AND 200 FEET
SUPPLEMENTAL CONTOUR INTERVALS 20 AND 40 FEET
DATUM IS MEAN SEA LEVEL