Available Water Supply of the Las Vegas Ground-Water Basin Nevada

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1780

Prepared in cooperation with Nevada
Department of Conservation and
Natural Resources

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March 3, 1849

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By GLENN T. MALMBERG

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AVAILABLE WATER SUPPLY OF THE LAS VEGAS GROUND-WATER BASIN, NEVADA

By Glenn T. Malmberg

ABSTRACT

The Las Vegas ground-water basin as described in this report includes the southern part of Indian Spring Valley, Three Lakes Valley, the northern half of Ivanpah Valley, and Las Vegas Valley. These valleys in part are inferred to form a hydrologic unit that includes an area of about 3,000 square miles in the southern part of Clark County, Nev.

The valleys forming the Las Vegas ground-water basin are broad structural depressions surrounded by mountains. The climate of the region is arid, and precipitation in the basin lowlands rarely exceeds 5 inches per year. Drainage is interior except for occasional flood runoff and waste from the industrial plants at Henderson; the occasional flood runoff and waste flow through the Las Vegas Wash to Lake Mead. The mountain ranges are composed of indurated rocks that impede the movement of ground water from the basin and form the boundary of the ground-water reservoir.

The valley fill that forms the principal ground-water reservoir is composed of a thick sequence ranging from Miocene(?) through Recent in age. Most of the ground water is in a large leaky artesian system comprising four principal zones of aquifers—the deep, middle, and shallow zones of artesian aquifers and the near-surface zone of water-table aquifers. To facilitate quantitative analyses of recharge, discharge, and yield, the aquifers have been divided arbitrarily into an artesian system, which includes the three principal artesian aquifers, and the near-surface water-table system.

Natural recharge to the artesian system is from precipitation in the mountains within the drainage area of the basin. As ground water moves from areas of recharge toward areas of discharge in the lower parts of Las Vegas Valley, it becomes confined between relatively impermeable beds. Nearly impervious barriers caused by faulting of the valley fill impede the lateral movement of the ground water. Artesian pressure causes the water to leak upward along the faults into shallow aquifers.

The average annual natural recharge to the Las Vegas artesian system was estimated by the following methods: (1) Estimation of consumptive use by phreatophytes under natural conditions prior to ground-water development; (2) estimation of ground-water underflow to the Las Vegas area during a period of near-stability in the ground-water reservoir; and (3) study of the relationship between precipitation and recharge during periods of equilibrium in the ground-water reservoir. Estimates of the natural recharge based on these methods suggest that the average annual natural recharge to the basin is on the order of 25,000 acre-feet. The total draft on the artesian aquifers in 1955 was approximately 48,000 acre-feet, of which about 42,000 acre-feet was from wells and springs and about 6,000 acre-feet was from upward leakage. Therefore, overdraft on the artesian reservoir in 1955 was about 23,000 acre-feet.

Recharge to the near-surface reservoir in 1955 was derived from upward leakage from the underlying artesian aquifers and by infiltration of waste water. The total estimated recharge to the near-surface reservoir in 1955 was about 25,000 acre-feet. The draft on the near-surface reservoir in 1955 was about 25,000 acre-feet, of which about 24,000 acre-feet was discharged by phreatophytes and about 1,000 acre-feet was discharged by wells. During this study, the near-surface reservoir was in a state of approximate dynamic equilibrium.

The above data indicate that the overdraft on the entire Las Vegas ground-water basin in 1955 was approximately equal to the overdraft on the artesian aquifers—that is, about 23,000 acre-feet.

As the artesian heads continue to decline in Las Vegas Valley, the quantity of ground water lost through upward leakage and subsequent transpiration will decrease. Conditions of optimum development of the artesian system will be achieved when the artesian heads have been lowered to about 50 feet below land surface, because most of the upward leakage that is currently discharged by phreatophytes will have been eliminated. At the present rate of decline of the artesian head and with the present distribution and amount of withdrawals, the artesian head will be lowered sufficiently to prevent most natural discharge in the Las Vegas area in about 40 years and in the Paradise Valley area in about 75 years. The maximum sustained yield that can be developed from the artesian aquifers when the artesian head has been lowered below the root zone of phreatophytes will be limited to the approximate average annual natural recharge to the artesian system plus the amount of nonconsumptively used ground water and imported water which becomes available for reuse through downward leakage or artificial recharge.

The accumulated annual discharge from the Las Vegas artesian aquifers has exceeded the accumulated recharge since the development of the first successful well in 1906, and as a result the artesian pressure has declined almost uninterruptedly from year to year since that time. The artesian head in selected observation wells in the vicinity of Las Vegas and Paradise Valley declined about 30 feet between 1941 and 1956. During this time the approximate cumulative overdraft amounted to about 300,000 acre-feet. The amount of overdraft per foot of lowering of artesian head within the area of approximately 40 square miles represented by the observation wells during this period was about 10,000 acre-feet.

The chemical quality of the ground water in Las Vegas Valley is, in general, better in the northern than in the southern part of the valley. In the northern part of the valley, water from the shallow and middle zones of aquifers is of better quality than water in the deep zone of aquifers. As the ground water migrates southward into the Paradise Valley and the Whitney-Pittman areas, the water in the middle and shallow zones becomes more mineralized than the water in the deep zone of aquifers.

The lowering of artesian head in the Las Vegas area between 1935 and 1950 has caused about 180 millimeters of local land subsidence in the vicinity of the Bonanza Street underpass, where the sediments are predominantly clay and silt. In the western part of the valley, where the sediments are predominantly sand and gravel, subsidence during the same period of time was negligible.

INTRODUCTION

LOCATION OF THE AREA

The area described in this report covers about 3,000 square miles and includes Las Vegas Valley, the southern part of Indian Spring

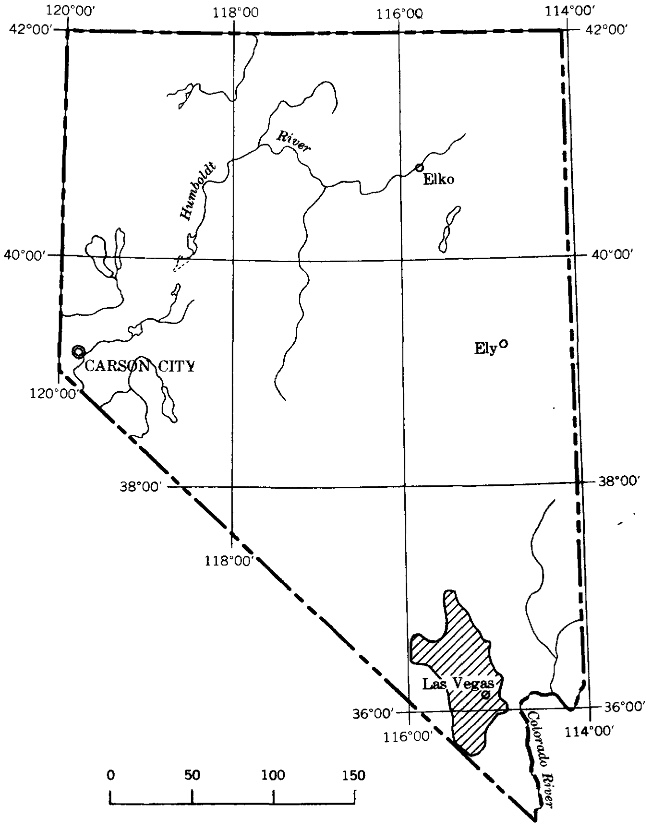

FIGURE 1.—Location of area.

Valley, Three Lakes Valley, and the northern part of Ivanpah Valley. Available data suggest that these valleys form a single hydrologic unit which, for purposes of this report, is termed the "Las Vegas groundwater basin," or simply the "Las Vegas basin."[1] Most of the Las Vegas basin is in Clark County, but small parts of the northern and the northwestern parts of the basin are in Lincoln and Nye Counties. (See fig. 1.)

This report describes an area more extensive than the area described in previous publications because of the inclusion of parts of Indian Spring and Ivanpah Valleys and all of Three Lakes Valley, for these

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[1] Hydrologic data from numerous deep test wells drilled in 1963 by the Atomic Energy Commission at the Nevada Test Site and in the vicinity of Indian Springs suggest that the circulation of ground water in the alluvial fill in Indian Spring and Three Lakes Valleys may be through the underlying Paleozoic carbonate rocks towards the Amargosa Desert. On the basis of the water-level altitude in some of the test wells, Winograd (1963, pl. 2) suggested that there may be a ground-water divide 15 miles east of Indian Springs that separates the ground-water reservoir in the alluvial fill in Indian Spring and Three Lakes Valleys from Las Vegas Valley.

valleys tentatively are considered tributary to the main ground-water reservoir in Las Vegas Valley.

PURPOSE AND SCOPE OF THE INVESTIGATION

This study of the hydrology of the Las Vegas basin is the second quantitative investigation of the area by the U.S. Geological Survey. The first investigation, made in cooperation with the State Engineer of Nevada began in July 1944 and included as its main objectives a study of the geology of the area and of the relation of the geology to the source and occurrence of ground water and an estimate of the recharge to Las Vegas and Indian Spring Valleys. These objectives were accomplished and reported, insofar as available data would permit, in a comprehensive report by Maxey and Jameson (1948). These authors estimated that the annual recharge to Las Vegas Valley is between 30,000 and 35,000 acre-feet and that the recharge to Indian Spring Valley, which was assumed to be separate from Las Vegas Valley, is about 4,700 acre-feet.

The purpose of this report is to refine the estimates of the average annual recharge to the Las Vegas ground-water reservoir by using additional data that have become available since the earlier report. Three methods of estimating the annual recharge to the ground-water reservoir are described, and these methods are applied to the Las Vegas basin for 1955 and for periods during the development of the ground-water reservoir. In general, the results agree reasonably well with those of Maxey and Jameson (1948) although they are somewhat lower.

Other objectives of this report include a study of the occurrence and availability of ground water in selected areas of the ground-water basin and the relationship between the average annual decline in ground-water levels and the annual overdraft. This report includes a review of the existing literature on ground-water conditions in the area, a review and analysis of existing hydrologic data, and discussions on the occurrence and movement of the ground water in the ground-water reservoir. The report also includes an analysis of the water budget, an estimate of the amount of upward leakage of ground water from deep aquifers to shallower aquifers, a discussion of land subsidence resulting from ground-water withdrawals, and an interpretation of the chemical quality of the ground water in the different aquifers at many places in the basin.

During the course of this study, considerable data were collected from wells in the Las Vegas basin but are not included in this report. Data were collected for 33 permit wells (wells drilled for purposes other than domestic use that are subject to appropriation according to provisions of the ground-water law of the State) and 54 selected domestic and test wells drilled during the period 1946–57. These data, which were collected to supplement the well data previously published by Maxey and Jameson (1948), are available for inspection in the Office of the State Engineer of Nevada and in the district office of the Water Resources Division of the U.S. Geological Survey, Carson City, Nev.

The fieldwork, begun in July 1954, consisted principally of inventorying the wells and collecting the data needed to calculate the amount of ground water discharged under natural and artificial conditions, establishing a network of observation wells throughout the valley for the purpose of observing and recording fluctuations of ground-water levels, making pumping tests, collecting water samples for chemical analysis, determining the elevation of measuring points in observation wells, and measuring the discharge from wells and springs.

This report was prepared by the U.S. Geological Survey under the supervision of O. J. Loeltz, district engineer in charge of ground-water investigations in Nevada.

PREVIOUS INVESTIGATIONS

Studies of the geology and hydrology of the Las Vegas area have resulted in several published and unpublished reports, some of which are included in the list of selected references.

The following summary of previous investigations is a chronological sketch of the publications from which data on the quantity and quality of ground water in the area were obtained during the preparation of this report.

The earliest hydrologic investigation of the Las Vegas area was made by Mendenhall (1909). His report summarized the water resources of southern Nevada and California. It briefly described the location of wells and springs and presented data on their yields and their quality of water. In 1912 the U.S. Geological Survey began a comprehensive ground-water survey of the entire State of Nevada to determine the possible development of ground-water supplies for irrigation. The first report resulting from these investigations, written by Everett Carpenter, was published as Water-Supply Paper 365 in 1915. The report included data on the quality and quantity of ground water in Las Vegas and Indian Spring Valleys and discussed the source and occurrence of ground water. From 1922 to 1936 the University of Nevada Agricultural Experiment Station, under the direction of George Hardman, made studies on the occurrence and utilization of ground water in Las Vegas Valley. Valuable data on the discharge of wells and springs and water-level measurements collected during these investigations are contained in several published reports that are included in the list of references.

In 1938, in response to a request by the State Engineer of Nevada, the U.S. Geological Survey made an investigation of underground leakage in Las Vegas Valley. This study, made by Penn Livingston and reported as Water-Supply Paper 849–D, pointed out that the aggregate leakage from the wells at that time was not enough to account for the serious decline in water levels in the valley.

The most intensive investigation of the ground-water resources of the Las Vegas and Indian Spring Valleys was made by G. B. Maxey, of the U.S. Geological Survey, and C. H. Jameson, of the Office of the State Engineer, during the period 1944–48. Various aspects of this study were published in Nevada Water Resources Bulletins 3, 4, 5, and 6. Bulletin 5 (Maxey and Jameson, 1948) contains all the data and results of the investigation. It summarizes many of the reports on the geology of the area and describes the stratigraphy and the water-bearing characteristics of the formations. It also includes estimates of recharge to and discharge from the ground-water reservoir and discusses the significance of water-level fluctuations.

Since 1948 several mimeographed reports pertaining to the hydrology of the Las Vegas basin have been prepared by the U.S. Bureau of Reclamation. These reports are included in the list of references at the end of this report.

WELL-NUMBERING SYSTEM

Wells listed in this report are numbered according to their location within the Federal system of land divisions and are identified by a local number used by the Office of the State Engineer. The number assigned to a well by the Geological Survey consists of three principal parts: (1) a capital S followed by the number of the township south of the Mount Diablo base line; (2) a slanted line followed by the number of the range east of the Mount Diablo meridian; and (3) a hyphen followed by the section number and letters that designate the 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 letter, the quarter-quarter-quarter section (10-acre tract). Finally, the wells in each 10-acre tract are numbered consecutively in the order in which they were recorded. For example, the first well recorded in the NE¼NW¼SW¼ sec. 1, T. 20 S., R. 61 E., would be numbered S20/61–1cba1 (fig. 2); the second well would be numbered S20/61–1cba2, and so forth. Where the 40-acre and 10-acre tracts are unknown, the numbering systems is modified to include only the designations for the sub-

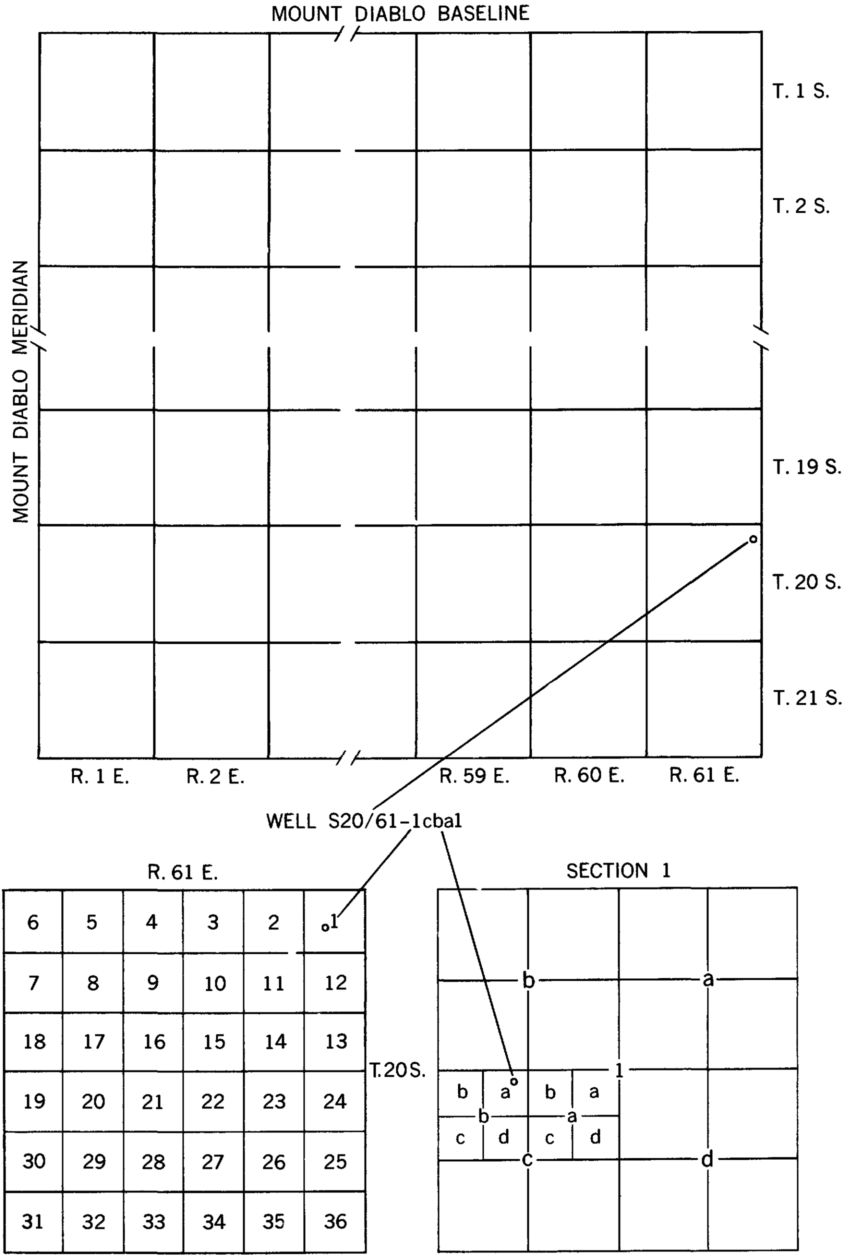

FIGURE 2.—Well-numbering system.

divisions of the section that are known. In this report the Geological Survey number is followed by the State Engineer's local field number in parentheses (where numbers have been assigned) to further identify the well. A typical well identification number as used in this report would be as follows: S20/60–36dbb1 (No. 18).

ACKNOWLEDGMENTS

Acknowledgment is made of the cooperation of owners of wells in supplying data and permitting the use of their wells in the course of this investigation. The author also wishes to thank the many Federal, State, and local governmental agencies for their cooperation. Especially helpful were personnel of the U.S. Bureau of Reclamation, the U.S. Weather Bureau, and the staffs of the Southern Nevada Power Co. and the Las Vegas Valley Water District.

GEOGRAPHY

The area described in this report includes approximately one-third of Clark County and small areas in Nye and Lincoln Counties, as shown on plate 1. The boundary of the irregularly shaped area was arbitrarily drawn along the drainage divides of mountains that border the principal valleys, along ground-water divides across the southern end of Indian Spring Valley, and through the central part of Ivanpah Valley. The area includes a series of structural depressions that have a combined length of about 110 miles and a maximum width of about 50 miles. The area lies between longitude 115°00′ and 116°00′ W. and latitude 35°30′ and 37°15′ N.

Las Vegas Valley, the largest of the four valleys included in the basin, trends southeast about 50 miles from Indian Springs to Las Vegas Wash. The northern part of the valley, which extends 30 miles from Indian Springs to Tule Spring, is irregularly shaped and relatively narrow; it ranges from 4 to 10 miles in width. South of Tule Spring the valley widens into a rectangular-shaped basin that is approximately 18 miles wide and 24 miles long. The cities of Las Vegas and North Las Vegas are in the center of this part of the valley, and it is within this area that the major development of ground water has taken place. There has also been substantial development of ground water in the area locally known as Paradise Valley, immediately south of Las Vegas.

Mountains surround the lowland areas of the Las Vegas ground-water basin. The southwestern side of the basin is bordered by the lofty Spring Mountains, which reach an elevation of nearly 12,000 feet. The northeastern side of the basin is bordered by several somewhat lower mountain ranges, chiefly by the Sheep and Las Vegas Ranges, and by Frenchman Mountain. The part of Indian

Spring Valley that forms the northern part of the basin is bordered by a series of spurs from the north-trending Pintwater and Desert Ranges and by the southern end of the Spotted Range. Black Mountain and parts of both the River Mountains and the McCullough Range are adjacent to the southern end of the basin.

Most of Las Vegas Valley is tributary to the Colorado River through Las Vegas Wash. However, drainage from the northern part of Las Vegas Valley and from Indian Spring Valley, Three Lakes Valley, and Ivanpah Valley ends in playas. The only perennial stream in the area is in Las Vegas Wash. The flow in the wash is composed principally of industrial waste water and sewage effluent but occasionally is in part flood runoff. The other washes carry surface water only during, and for short periods after, infrequent storms. Water from even the larger springs and from snowmelt in the mountains ordinarily disappears within short distances in the gravels of the drainage ways or is lost through evaporation and transpiration.

Indian Spring Valley is northwest of Las Vegas Valley and is separated from it by a low alluvial divide about 4 miles east of Indian Springs. It is a long narrow crescent-shaped valley about 6 miles wide and 36 miles long. It extends 12 miles eastward from near the Clark-Nye County line to Indian Springs, and thence northward approximately 24 miles to Quartz Spring. Only the southern part of Indian Spring Valley was included in the study area because water-level data and geologic information indicate that the north-trending limb of Indian Spring Valley is separated from the southern part of the valley by a ground-water barrier that seems to coincide with the axis of an anticline extending eastward from the southern end of the Spotted Range to the southern end of the Pintwater Range. Only the southern part of Indian Spring Valley, south of this flexure, seems to have hydraulic continuity with the Las Vegas ground-water reservoir.

Three Lakes Valley, which is east of Indian Spring Valley, is assumed to be in hydraulic continuity with the Las Vegas basin; however, there are only meager data to substantiate this assumption. Three Lakes Valley parallels the northern limb of Indian Spring Valley and is somewhat similar to it topographically. The valley is about 35 miles long and has three playas along its axis where surface drainage from the bordering mountains ends. The Pintwater and Desert Ranges border the valley on the west and on the east, respectively.

Ivanpah Valley is separated from the southern end of Las Vegas Valley by low hills underlain by limestone and by andesite or basalt flows. However, it is assumed that the northern part of the valley is hydraulically connected with Las Vegas Valley because the slope of the piezometric surface is northward toward Las Vegas Valley from a point near the California-Nevada boundary where there seems to be a ground-water divide (George Hardman, 1931, written commun.). Ivanpah Valley north of the California-Nevada boundary is roughly crescent shaped and is approximately 24 miles long and 6 miles wide. The valley extends northward from the California-Nevada boundary approximately 12 miles to Jean, Nev., and from there northeastward beyond Sheep Mountain toward Las Vegas Valley. There are two small playas in the northern part of the valley, and a third and larger playa is in the southern end of the valley near the State line. The valley is bordered by the Spring Mountains on the west, the McCullough Range on the east, and the southern end of the Bird Spring Range and a low range of unnamed hills on the north.

PHYSICAL FEATURES

The area described in this report lies within the Basin and Range physiographic province. The province is characterized by desert basins having interior drainage flanked by mountains that generally are sparsely covered with vegetation. The high mountains usually are dissected by deep ravines that open onto broad alluvial fans. Commonly, fans from adjoining canyons have coalesced and formed a continuous alluvial slope along the base of the mountain ranges. These slopes extend outward into the valleys, where they merge with the valley floor or extend across the valley toward the adjacent mountain ranges to form alluvial divides. Beyond the toes of the fans is the valley floor. The valley floors are usually flat and contain one or more playas where periodic runoff from storms accumulates and eventually evaporates.

MOUNTAINS

About half of the drainage area tributary to the Las Vegas ground-water basin consists of mountains. The mountains are composed largely of well-consolidated sedimentary rocks of Paleozoic and Mesozoic age that have been considerably deformed by folding and faulting. The generally rugged topography of the mountainous areas is characterized by sharp peaks and ridges, steep and precipitous slopes, and deep, steeply sloping canyons.

The highest peaks in the area are in the Spring Mountains along the western margin of Las Vegas and Ivanpah Valleys. The elevation of much of the range from Mount Stirling southward to Table Mountain, a distance of about 56 miles, is above 5,000 feet. Charleston Peak, the highest peak in the range, has an elevation of 11,918 feet.

Deep canyons have been incised into the eastern slope of the range. Most of these canyons follow fault zones or other areas of structural weakness. The canyons are narrow and have steep, precipitous slopes. In most places the canyon floors are mantled with highly permeable gravel deposits and rock debris, and consequently infiltration rates are high. Runoff infiltrates quickly into this permeable material to the underlying bedrock where part of it may seep into fractures or other secondary openings and part of it may move laterally beneath the floor of the canyons to the alluvial fans at the mouths of the canyons.

The main canyons on the eastern slope of the Spring Mountains are Lee, Kyle, and Red Rock Canyons and Cottonwood and Goodsprings Valleys.

The Pintwater, Desert, Sheep, and Las Vegas Ranges which border the northeastern part of the Las Vegas ground-water basin, are somewhat similar to the Spring Mountains; but they are lower and not as deeply dissected and commonly are more barren. Of the four ranges, only the Sheep Range reaches elevations of 8,000 feet or more. Sheep Peak, which is the highest peak in the range, has an elevation of 9,926 feet. Frenchman Mountain, east of Las Vegas, has an elevation of 4,054 feet; but the elevation drops rapidly toward Las Vegas Wash, where it is about 2,000 feet.

The River Mountains and the McCullough Range along the south side of Las Vegas Valley are rugged barren mountains whose highest peak is less than 4,000 feet above sea level. These mountain ranges differ from the other ranges in the area in that they are principally underlain by igneous and metamorphic rocks.

Except in the high parts of the Spring Mountains and the Sheep Range where precipitation is adequate to support plant life, the mountain ranges are barren of all but the hardiest type of desert vegetation.

ALLUVIAL FANS

In Las Vegas and Indian Spring Valleys, large fans have formed along the eastern and northern slopes of the Spring Mountains. The largest and most extensive fans, at the mouths of Kyle and Lee Canyons, head high in the Spring Mountains at elevations of about 9,000 feet and extend about 15 miles from the heads of the fans onto the basin lowlands. Smaller fans have formed at the mouths of Red Rock Canyon, Cottonwood Valley, and smaller canyons along the mountain front. Many of the fans have coalesced to form an extensive alluvial apron along the front of the Spring Mountains. The largest fans flank the highest mountains; accordingly, the fans along the eastern side of the basin are in general much smaller than those flanking the Spring Mountains. The largest fans on the east side of the basin are along the southern and western sides of the Las Vegas and Sheep Ranges.

The surfaces of fans near the upper limit of the alluvial apron ordinarily slope away from the mountains at angles of 4° to 6°. The upper limit of the alluvial apron is well defined in most places by the abrupt change in slope between the mountain front and the alluvial slope and by the difference in type of rock material, but the lower parts of the alluvial slopes commonly merge imperceptibly with the valley floor.

BASIN LOWLANDS

The lowland areas beyond the toes of the fans are commonly characterized by playas, or dry lakes. Most of the lowlands are well-defined flat areas which, for the most part, are barren of vegetation. The playa deposits are composed almost entirely of fine sand, silt, clay, and evaporite. Occasionally, runoff from desert storms, laden with sediment, accumulates in these playas, but most of the time they are dry and dusty.

In the Las Vegas basin, playas occur only in Indian Spring, Three Lakes, and Ivanpah Valleys. There are no playas in the main part of Las Vegas Valley. The area east of the city of Las Vegas between Nellis Air Force Base and Las Vegas Wash probably was a playa in the recent geologic past, although at the present time it drains eastward into the Colorado River.

Older lacustrine deposits that border the playas consist of light-colored calcareous silt and clay and contain vertebrate and invertebrate fossils of Pleistocene age. These lacustrine deposits are similar to the sediments currently being deposited in playas and, in general, are less than 50 feet thick. Where lacustrine deposits crop out in Las Vegas Valley, they have been eroded to a badland topography that is typified by a labyrinth of deep arroyos and narrow divides.

Sand dunes and other wind-built features are also present in the basin lowlands. Dunes are especially numerous in three widely scattered areas in Las Vegas Valley; the largest area is in Paradise Valley, south of the city of Las Vegas. Here the dune area extends from Warm Springs Ranch to Whitney, a distance of about 7 miles. In the vicinity of Sand Hill Road, the dune area has a maximum width of approximately 2 miles. Other large dune areas occur northeast of Lake Mead Military Base in the northeastern part of Las Vegas Valley and along the toe of the alluvial fan at the foot of the Sheep Range north of Corn Creek Springs.

Other prominent topographic features of the basin lowlands are the north-trending scarps that traverse the valley floor in the vicinity of Las Vegas. The longest scarp has a length of approximately 16 miles and forms an arc around the west side of the city of Las Vegas from the vicinity of the intersection of the Warm Springs Road and U.S. Highway 91 to a point about 3 miles north of the Craig Ranch in T. 19 S., R. 61 E. Several other, nearly parallel shorter scarps occur as far east as Grapevine Spring, about 1 mile west of the town of Whitney.

The scarps, which range from a few feet to nearly 100 feet in height, are believed by Maxey and Jameson (1948, p. 70) to have resulted from faulting of the sediments of the valley fill. These faults have a profound control on the occurrence and movement of ground water in the shallow aquifers of Las Vegas Valley and are discussed in some detail in a later section of this report.

CLIMATE

The climate of southern Nevada ranges from arid on the valley floor to semiarid in the mountains. The arid climate of the lowlands of the Las Vegas basin is characterized by low precipitation, low humidity, and wide extremes in daily temperature. The winters are relatively short and mild, and the summers, long and very hot. Most of the precipitation occurs during the winter months and in July and August. Precipitation in July and August commonly is from highly localized thunderstorms which typically are of high intensity and short duration, whereas precipitation during the winter usually is from regional storms of lower intensity and longer duration. Evaporation rates at lower elevations are extremely high and probably exceed 80 inches per year. Strong winds are common throughout the year but are prevalent during the spring.

Climatological data for stations listed in table 1 show that the precipitation at any station may vary widely from year to year. At the Las Vegas station, annual precipitation has varied from 0.60 inch to 8.63 inches and averages 4.56 inches for the period of record 1896–1955. Records of precipitation at other stations in the valley span a much shorter period of time and range between 0.55 inch and 5.66 inches at North Las Vegas, 0.76 inch and 10.72 inches at Nellis Air Force Base (formerly Las Vegas Airport), 0.56 inch and 5.55 inches at Las Vegas Airport (McCarran Field), 1.00 inch and 8.74 inches at the Desert Game Range, and 0.66 inch and 7.04 inches at Indian Springs. Figure 3 shows precipitation recorded at the Las Vegas Weather Bureau station from 1896 to 1899 and from 1908 to 1956. The cumulative departure from average was computed by algebraically adding the annual departures from the 52-year average precipitation of 4.56 inches.

TABLE 1.—*Annual precipitation, in inches, at stations in the Las Vegas basin*

[From records of U.S. Weather Bur.; no records available for 1900–07. Elevation, in feet, at each station shown in parentheses]

Year	Station					
	North Las Vegas (1,820)	Las Vegas (2,033 to 1947; 2,006 after 1947)	Nellis Air Force Base (formerly Las Vegas Airport) (1,876)	Las Vegas Airport (McCarran field) (2,162)	Desert Game Range (3,025)	Indian Springs (3,136)
1896	--------	3.24	--------	--------	--------	--------
1897	--------	5.35	--------	--------	--------	--------
1898	--------	1.64	--------	--------	--------	--------
1899	--------	2.03	--------	--------	--------	--------
1900–07	--------	--------	--------	--------	--------	--------
1908	--------	4.73	--------	--------	--------	--------
1909	--------	7.05	--------	--------	--------	--------
1910	--------	4.11	--------	--------	--------	--------
1911	--------	[1] 3.41	--------	--------	--------	--------
1912	--------	[1] 2.70	--------	--------	--------	--------
1913	--------	4.96	--------	--------	--------	--------
1914	--------	4.98	--------	--------	--------	--------
1915	--------	8.41	--------	--------	--------	--------
1916	--------	8.11	--------	--------	--------	--------
1917	--------	4.33	--------	--------	--------	--------
1918	--------	8.63	--------	--------	--------	--------
1919	--------	4.95	--------	--------	--------	--------
1920	--------	4.74	--------	--------	--------	--------
1921	--------	5.47	--------	--------	--------	--------
1922	--------	5.81	--------	--------	--------	--------
1923	--------	4.50	--------	--------	--------	--------
1924	--------	2.49	--------	--------	--------	--------
1925	--------	5.27	--------	--------	--------	--------
1926	--------	3.58	--------	--------	--------	--------
1927	--------	4.49	--------	--------	--------	--------
1928	--------	1.75	--------	--------	--------	--------
1929	--------	2.77	--------	--------	--------	--------
1930	--------	3.97	--------	--------	--------	--------
1931	--------	8.58	--------	--------	--------	--------
1932	--------	7.75	--------	--------	--------	--------
1933	--------	2.94	--------	--------	--------	--------
1934	--------	[1] 3.24	--------	--------	--------	--------
1935	--------	4.38	--------	--------	--------	--------
1936	--------	5.84	--------	--------	--------	--------
1937	--------	3.13	--------	--------	--------	--------
1938	--------	5.84	--------	--------	--------	--------
1939	--------	7.67	--------	--------	--------	4.58
1940	--------	4.93	5.36	--------	--------	3.28
1941	--------	8.40	10.72	--------	8.74	6.44
1942	--------	1.45	2.39	--------	1.83	1.19
1943	--------	5.66	4.24	--------	5.66	5.72
1944	--------	1.91	2.20	--------	3.26	2.20
1945	--------	4.34	5.28	--------	5.43	5.44
1946	--------	3.58	3.29	--------	4.33	3.64
1947	--------	2.65	--------	--------	--------	--------

See footnotes at end of table.

TABLE 1.—*Annual precipitation, in inches, at stations in the Las Vegas basin*—Con.

[From records of U.S. Weather Bur.; no records available for 1900–07. Elevation, in feet, at each station shown in parentheses]

Year	Station					
	North Las Vegas (1,820)	Las Vegas (2,033 to 1947; 2,006 after 1947)	Nellis Air Force Base (formerly Las Vegas Airport) (1,876)	Las Vegas Airport (McCarran field) (2,162)	Desert Game Range (3,025)	Indian Springs (3,136)
1948	--------	1.00	.76	--------	1.19	.74
1949	--------	6.88	4.42	--------	--------	7.04
1950	--------	2.05	2.34	--------	1.41	.66
1951	[2] 3.16	[2] 3.01	2.81	--------	4.21	1.95
1952	5.66	6.98	--------	5.55	6.54	3.26
1953	.55	.60	--------	.56	1.00	1.41
1954	4.75	[1] 4.75	--------	4.71	3.05	3.02
1955	3.75	5.98	--------	5.40	3.64	1.73
Average	3.57	4.56	3.93	4.05	3.87	3.27

[1] Estimated from nearby stations.

[2] Total for 11 months.

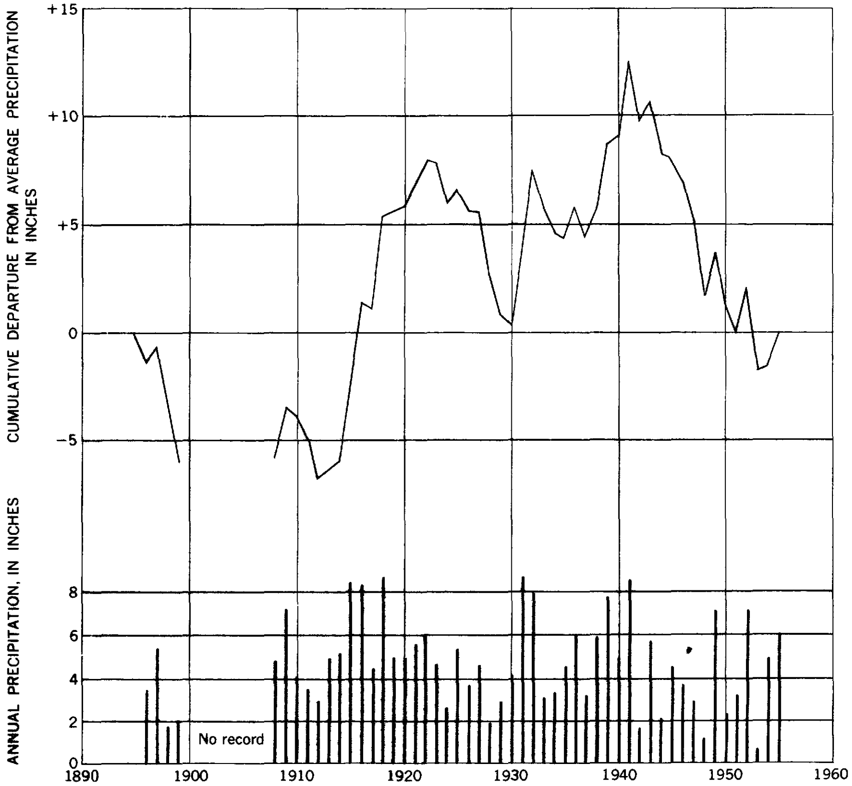

FIGURE 3.—Annual precipitation and cumulative departure from average precipitation at Las Vegas, Nev.

The average annual precipitation is greater in the mountain areas than in the adjacent valleys. In most places in the basin above 6,000 feet elevation, precipitation occurs in sufficient amounts to provide practically all the recharge to the ground-water reservoir. The amount of moisture recorded in four precipitation storage gages located at various altitudes in the Spring and Sheep Mountains and the departure from average annual precipitation for the period 1947–52 is shown in figure 4. The storage gages are visited twice a year, usually in June or July and in October or November. The annual precipitation for the four storage gages are based on monthly precipitation values prorated by the U.S. Weather Bureau. For comparison, precipitation recorded at Las Vegas is shown in the left half of figure 4.

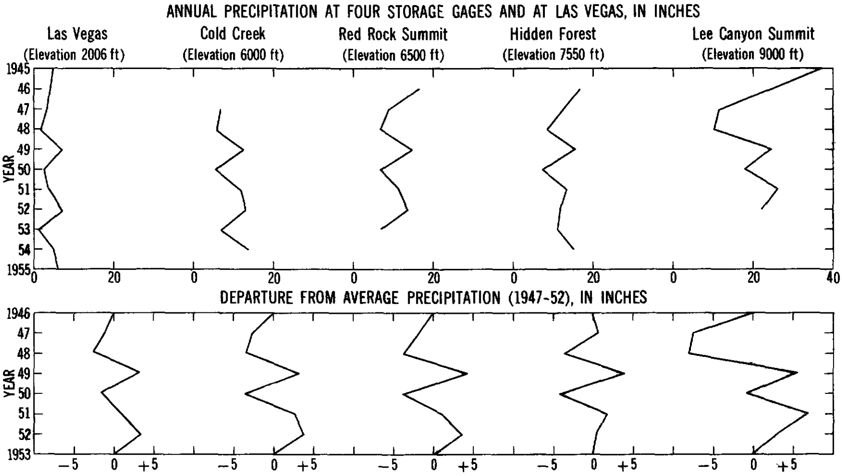

FIGURE 4.—Annual precipitation at four storage gages and at Las Vegas, and annual departure from 1947–52 average.

The amount of precipitation occurring as snow in the mountain areas surrounding the basin probably represents a substantial part of the water available for recharging the ground-water reservoir. The water content of the snow pack in each of four snow courses in the Spring Mountains is shown in table 2 as inches of water present as of approximately April 1 of each year. The table shows wide annual variations in the amount of water in the snow cover of each course.

TABLE 2.—*Snow-course data from four stations in the Spring Mountains*

[Record from the Nevada Cooperative Snow Surveys; figures give total water content of snow cover, in inches, as of approximately April 1 each year. Elevation, in feet, at each snow course shown in parentheses]

Year	Station			
	Rainbow Canyon (7,800)	Kyle Canyon (8,200)	Lee Canyon	
			No. 1 (8,300)	No. 2 (9,000)
1941	21.1	18.5	16.3	20.8
1942	11.0	9.5	12.6	15.2
1943	15.0	None	7.3	None
1944	11.2	11.2	7.7	7.7
1945	16.0	15.7	15.6	15.2
1946	7.7	8.3	7.7	9.7
1947	6.4	2.8	4.8	5.2
1948	12.6	10.5	9.4	8.0
1949	17.1	16.8	18.7	20.3
1950	9.4	5.1	3.9	4.8
1951	1.1	.5	.5	1.8
1952	31.0	26.4	20.4	23.0
1953	2.9	.6	0	.4
1954	18.8	14.7	14.3	14.8
1955	9.6	7.5	5.8	6.6

CULTURE

The cities of Las Vegas and North Las Vegas had a combined population of approximately 50,000 people in 1955. Las Vegas, the principal commercial center for Clark County and much of southern Nevada, has prospered over the past several decades from a brisk tourist trade.

Henderson, a city having a population of approximately 12,000, is 12 miles southeast of Las Vegas and is the principal industrial area in southern Nevada. The industrial complex at Henderson includes the various operations of Titanium Metals Corp., Stauffer Chemical Co., and U.S. Lime Products Co.

Indian Springs Air Force Base, about 45 miles northwest of Las Vegas, and both Nellis Air Force Base and the adjoining Lake Mead Military Base, about 7 miles northeast of Las Vegas, have bolstered the population and economy of Las Vegas valley. Las Vegas also serves as a field headquarters for operations at the Nevada Test Site of the Atomic Energy Commission, about 75 miles northwest of the city.

Other activities in the area include mining and, to a lesser degree, ranching. Active mines include the White Eagle and Blue Diamond gypsum mines, the limestone quarries at Sloan, and numerous gravel quarries throughout the valley. Ranching and farming are of minor significance. During the period of this investigation, approximately 2,125 acres was irrigated annually. With the exception of five ranches averaging about 265 acres each, the irrigated acreage consisted of small farms, some as small as 1 acre.

GEOLOGY

The geology of Las Vegas Valley and the surrounding mountains has been studied in considerable detail by several geologists, whose works are contained in several published and unpublished reports. The nature and occurrence of the rock formations discussed in this section is based on those reports.

For convenience of discussion, the rocks of the area are divided into two general groups on the basis of their hydrologic properties: the consolidated, relatively impervious rocks that crop out in the mountains and that underlie the valley fill deposits; and the unconsolidated permeable sediments of the valley fill. The approximate extent and areal distribution of these to groups of rocks is shown on plate 1. Outcrops of the consolidated rocks are limited in most places to isolated inliers and to the mountainous areas that form the impermeable barriers along the margins of the basin. The unconsolidated sediments are widespread throughout the central part of the basin, and because of their capacity for storing and trasmitting significant quantities of ground-water, they form the principal ground-water reservoir in the Las Vegas basin.

PREVIOUS GEOLOGIC INVESTIGATIONS

The geologic work of the early investigators throughout the Western United States generally covered wide areas and was usually a reconnaissance. The first brief description of the geology of southern Nevada appeared in a U.S. Geological Survey publication by Gilbert in 1875; in this report Gilbert described the geology of the Spring Mountains. Reports by Spurr (1901, 1903) described the geologic structure of Las Vegas Valley and the Spring Mountains.

Detailed geologic studies were begun by Longwell in 1921 and have been in progress since that time. Since 1927 various local aspects of the geology of the region have been discussed in publications by Glock (1929), Hazzard and Mason (1935), Hewett (1931, 1956), Hewett and others (1936), Hunt and others (1942), Longwell (1921, 1925, 1926, 1928, 1930, 1936, 1945, 1946, and 1952), Miller (1944), and Nolan (1929, 1943). A report on the water resources of Las Vegas Valley, published by Maxey and Jameson (1948), summarized much of the geologic work of the authors mentioned. Also, it included descriptions of the lithology, stratigraphy, and water-bearing character of the rocks, a discussion of the geologic structure and history, and geologic maps and sections. The reader is referred to this publication for a summary of the geology of the area.

ROCKS OF THE MOUNTAIN RANGES

OCCURRENCE AND DISTRIBUTION

The mountains that border the area described in this report are composed of consolidated sedimentary, metamorphoric, and igneous rocks ranging in age from Precambrian to Quaternary.

The rocks exposed in the Spring Mountains west of Las Vegas include a wide variety of consolidated sediments, as well as intrusive igneous rocks and lavas, that range from Cambrian to Recent in age. In the southern part of the Spring Mountain Range, the aggregate thickness of sedimentary rocks is about 13,000 feet. According to Hewett (1931, p. 9), about 8,500 feet of limestone, dolomite, sandstone, and shale of Paleozoic age are overlain by about 4,500 feet of sandstone, shale, conglomerate, and limestone of Mesozoic age. Toward the northern end of the range, the Paleozoic section thickens to about 33,000 feet. The basal part of the section is composed of about 12,000 feet of quartzite and shale of Early Cambrian age, most of which is missing or is not exposed in the Goodsprings area. The upper part of the Paleozoic section is composed mostly of calcareous rock.

Along the northern and eastern borders of the Las Vegas basin in the Spotted, Pintwater, Desert, Sheep, and Las Vegas Ranges, an aggregate thickness of approximately 20,000 feet of sedimentary rocks is exposed. About 7,800 feet of rocks ranging in age from Precambrian through Mesozoic is exposed at Frenchman Mountain about 6 miles east of Las Vegas.

The northern extremities of the River Mountains, which border Las Vegas Valley on the southeast, are composed of about 1,000 feet of lava flows of Tertiary and Quaternary age. The lavas are predominantly porphyritic latitic flows and flow breccias. Black Mountain, about 9 miles south of Henderson, comprises a series of andesitic and basaltic lava flows of late Tertiary and Quaternary age. South of Black Mountain in the McCullough Range, a complex of schist and gneiss of Precambrian age is exposed.

WATER-BEARING CHARACTER

In general, the consolidated rocks are dense and well indurated, but locally they are highly fractured and, therefore, may contain water in secondary interstices, such as joint and fracture systems or solution openings. Of the total aggregate thickness of about 33,000 feet of exposed sedimentary rocks in the mountain ranges surrounding the area, the Sultan limestone and Monte Cristo limestone of Devonian and Mississippian age, respectively, probably are the most permeable. Although these two formations are well consolidated, they are cavernous in part and probably are capable of transmitting significant quantities of ground water. Many small mountain springs issue from these formations, particularly where they are cut by faults or joints.

Limited quantities of ground water are also transmitted through the thin-bedded limestone at the base of the Moenkopi formation of Triassic age. Ground water has been developed at Goodsprings, Nev., from shallow wells penetrating this formation (Hewett, 1931, p. 7).

The igneous rocks in the drainage basin tributary to the Las Vegas ground-water basin in most places are impervious and commonly act as barriers to the movement of ground water. Movement of water through these rocks is confined largely to joint openings and other fractured zones or to scoriaceous zones between lava flows. Few springs issue from the igneous rocks, and only one well, S24/61–28bb1, is believed to have been developed in igneous rock.

The consolidated rocks are buried by a considerable thickness of saturated valley fill in most parts of the ground-water basin; therefore, there has been no attempt to develop a water supply from them. However, deep oil test wells in Las Vegas Valley have found water in the consolidated sedimentary rocks; this water locally is of poor chemical quality and under high artesian head. Although little is known about the occurrence and movement of ground water in the consolidated rocks beneath the valley fill, there is no evidence of ground-water discharge from Las Vegas Valley to adjacent areas by underflow. Therefore, in this report the consolidated rocks are considered to form a barrier to ground-water underflow from the basin.[2]

SEDIMENTS OF THE VALLEY FILL

TERTIARY DEPOSITS

MUDDY CREEK FORMATION

The oldest sediments of the valley fill consist principally of a thick sequence of beds of light-colored fine-grained sand, silt, and clay that is similar to the Muddy Creek formation of Pliocene(?) age (Maxey and Jameson, 1948, p. 55). Outcrops of the Muddy Creek formation occur in isolated outcrops in Las Vegas Valley and adjacent mountains, but they are small and show the character of only a small part of the stratigraphic section. The most reliable data on the character

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[2] Recent (1962–63) exploratory drilling by the Atomic Energy Commission in the vicinity of Indian Springs indicates that ground water contained in the highly fractured Paleozoic carbonate rocks underlying the southern part of Indian Spring Valley may be in hydraulic continuity with a regional ground-water system that drains toward the Amargosa Desert.

of the formation in Las Vegas Valley are the logs of deep wells that penetrate it. The logs show that the formation consists of sand, silt, clay, gravel, and evaporite.

Maxey and Jameson (1948, p. 69) stated that the materials constituting the Muddy Creek formation differ considerably from the overlying sand and gravel beds in that they are finer grained, better assorted, and more thinly and evenly bedded. Characteristically, the formation consists of thin sand lenses and some fine gravel interbedded with thick beds of clay. The sand and gravel lenses usually contain silt and clay and in places are cemented with calcareous material. Where the sediments crop out, the predominant colors range from buff to red. Well logs show that the formation also contains beds of brown, gray, and green sediments.

The Muddy Creek formation, or its equivalent, is believed to underlie almost all of Las Vegas Valley and the adjacent valleys. Widely distributed outcrops of the formation indicate that the beds probably extended over a much larger region in the past than at present. As Longwell (1928, p. 95) pointed out, the character of the sediments indicates that they probably were deposited in great basins having environmental conditions of deposition similar to those prevailing in the present-day playas.

The thickness of the Muddy Creek formation in Las Vegas Valley is not known with certainty and undoubtedly varies considerably from place to place. An oil test well east of Whitney, S21/62–22dd1, penetrated approximately 3,050 feet of sediments that resembled the Muddy Creek formation before entering the underlying bedrock. Another oil test well, S21/61–23ba1, penetrated bedrock at a depth of about 1,200 feet. Although no log of the alluvial material in this hole was kept, data from other wells in the vicinity suggest that the top of the Muddy Creek formation is at a depth of about 700 feet. The apparent thickness of the Muddy Creek formation at this location, therefore, is approximately 500 feet.

ALLUVIAL DEPOSITS OF PLIOCENE(?) AND PLEISTOCENE(?) AGE

Overlying the Muddy Creek formation are deposits of gravel, sand, silt, and clay that form the alluvial fans and aprons along the mountain fronts. According to Maxey and Jameson (1948, p. 58), these alluvial deposits lie unconformably on the Muddy Creek formation and are unconformably overlain by lacustrine deposits of Pleistocene age. These sediments were derived from the surrounding mountain areas and were transported to lower parts of the valley by rapidly fluctuating streams and intermittent flood runoff following the infrequent torrential rains. Where this unit has been penetrated by wells, the aggregate thickness is on the order of 500 to 1,000 feet.

The alluvial-fan deposits are of two general types: poorly sorted heterogeneous mixtures of boulders, gravel, sand, silt, and clay; and stringers of sorted gravel deposited in the drainages. The poorly sorted deposits, which make up the bulk of the fan deposits, occur in the interstream areas and are probably the result of erratic streamflow, sheet wash, or mudflows. They are relatively impermeable and, where saturated, yield water very slowly. They are commonly cemented with caliche into thick beds of conglomerate that are highly resistant to erosion. However, in many fresh exposures along roadcuts and in washes, the deposits are only poorly cemented and are virtually unconsolidated. The alluvium is coarsest at the apex of the fans, becomes progressively finer down gradient, and eventually grades into silt and clay.

Intrenched in the fans or alluvial aprons are drainage channels or arroyos formed by ephemeral streams and flood runoff. Commonly the main stream channels divide near the head of the fan into several distributaries that radiate from the mouths of the canyons. Moderately well sorted deposits of gravel accumulate in these washes and form highly permeable trains of gravel leading down the slope of the fan. Most of these gravel trains are incised in the heterogenous mixture of colluvial and alluvial material of the fans and are in a favorable position to receive recharge from the runoff and to transmit it to underlying parts of the valley fill. Characteristically, channel deposits are coarsest near the mouth of a canyon and become progressively finer grained away from the mountains. Where larger streams of greater permanence existed, clean gravel was deposited at points many miles from the mountains. As the fans were built up, the principal drainage ways shifted many times, and the abandoned channels eventually became covered with poorly sorted alluvium. As the fans grew, they became a thick mass of heterogenous sediments enclosing stringers of relatively clean gravel. The gravel trains not only absorb and transmit recharge to the main ground-water reservoir but also, yield water readily to wells in areas where they occur within the zone of saturation.

Near the toe of the fans in the lower parts of the valley, the coarser material gives way almost entirely to fine-grained sand, silt, and clay. Where gravel has been deposited in the lower parts of the valley, it is commonly interbedded with the fine-grained playa deposits or dispersed in them, and in most places the gravel is moderately stratified.

The playa deposits range from white or light yellow to red. Although data from driller's logs generally do not permit individual beds to be traced over wide areas, a layer of light-greenish-blue to dark-blue clay about 200 to 250 feet above the base of the alluvial deposits is commonly reported and can be used locally in the Las Vegas Valley as a stratigraphic marker bed. This unit ranges in thickness from 10 to 60 feet and has been found in wells drilled in an area extending from sec. 9, T. 19 S., R. 60 E., to Pittman, Nev.

PLEISTOCENE LAKE BEDS

Lake beds of Pleistocene age as much as 50 feet thick occur in widely separated areas in Las Vegas, Indian Spring, and Three Lakes Valleys. These deposits of fine-grained sand, silt, and clay lie unconformably on Pliocene and earlier Pleistocene sediments and in part are overlain by a veneer of Recent gravels. The deposits consist mostly of light-buff slightly calcareous fossiliferous material that has been considerably eroded. The lake beds that crop out in the Las Vegas basin are commonly cut by arroyos that breach the entire thickness of the deposits and expose the underlying older gravels.

RECENT ALLUVIUM

The surficial deposits of gravel, sand, silt, and clay that overlie the lake beds of Pleistocene age form a thin mantle over much of the valley floor. They include playa deposits in Indian Spring, Three Lakes, and Ivanpah Valleys and are composed principally of reworked material from the lake beds of Pleistocene age, the alluvium of Pliocene and Pleistocene ages, and the Muddy Creek formation. Deposits of Recent age also occur in the washes and as eolian deposits.

WATER-BEARING CHARACTER

The unconsolidated sediments of the valley fill form the principal ground-water reservoir in the Las Vegas basin, and in this report this reservoir is called the Las Vegas ground-water reservoir. The extent of the ground-water reservoir is shown on plate 1. It is the area outlined by the boundary between the bedrock and the alluvium. The sediments have a wide range of hydraulic properties due principally to lithologic differences inherent in alluvial deposits. Artesian conditions within the Las Vegas ground-water reservoir are due in part to confining layers of clay or other relatively impermeable material and in part to differences in permeability of the water-bearing materials themselves. Because of vertical and horizontal differences in permeability of the sediments, the hydraulic continuity of individual permeable zones and the intervening confining beds is relatively poor. Leakage between individual aquifers results in a nearly continuous hydraulic system.

Although beds of widespread areal extent in the valley fill of Las Vegas Valley are usually difficult to delineate, three rather indistinct zones of artesian aquifers—a shallow, a middle, and a deep zone—were described by Maxey and Jameson (1948, p. 81–82).

In addition to the three principal zones of artesian aquifers, there is a shallower zone of ground water in Las Vegas Valley that is locally termed "surface water" (Maxey and Jameson, 1948, p. 81). It is part unconfined but more commonly is under slight artesian pressure. In this report the aquifers containing the "surface water" are called the near-surface zone of aquifers or the near-surface reservoir.

The shallow and middle zones of the artesian aquifers, which are principally in the highly permeable alluvial deposits of Pliocene and Pleistocene age, are the most productive sources of ground water in Las Vegas Valley. The deep zone of artesian aquifers and the near-surface zone of aquifers are composed dominately of fine-grained deposits of low permeability, and except for development of domestic water supplies in the near-surface reservoir, these two aquifer zones have not been developed extensively.

The shallow zone of artesian aquifers lies between a depth of approximately 200 feet and the top of a blue clay layer that occurs at depths ranging from about 380 to 450 feet below the land surface (Maxey and Jameson, 1948, p. 81–82). Most of the wells finished in this zone tap water in several permeable sand and gravel lenses that interfinger with semiconfining layers of clay and silt. The permeable beds generally contain ground water under artesian pressure.

The middle zone of artesian aquifers underlies the blue clay layer mentioned above. Most wells developed in this zone tap water under sufficient artesian head to raise the static water level to within a few feet of land surface or, in some localities, considerably above land surface. Logs of wells developed in this zone show that the aquifers are extremely permeable in the vicinity of the Las Vegas Valley Water District well field, in secs. 30 and 31, T. 20 S., R. 61 E., but that in the area east and south of the field the sediments grade into fine-grained material of relatively low permeability.

The deep zone of aquifers includes all the aquifers below approximately 700 feet. Water is developed in this zone from thin lenses of fine-grained sand in the Muddy Creek formation. The sand and gravel lenses commonly contain much silt and clay and, consequently, do not yield water readily to wells. Where wells are developed in the deep zone, artesian pressure may initially cause the water to rise as much as 40 to 50 feet above the composite piezometric surface of the shallower zones. However, as the wells are developed and used the artesian head rapidly declines to the elevation of the regional composite piezometric surface.

The near-surface zone of aquifers is not well defined in areal extent or depth, and except where it occurs as the semiconfining deposits above the shallow artesian aquifers, it is difficult to delineate because it is not a distinct lithologic or hydrologic unit.

In the vicinity of Las Vegas and The Strip, the near-surface zone of aquifers occurs in the cofining beds overlying the shallow artesian aquifers and in these areas is about 200 feet thick. East of Las Vegas and The Strip, however, the lithology of the principal artesian aquifers changes from predominately coarse- to fine-grained material, and as a consequence, there are no distinct zones of artesian aquifers. East and southeast of Las Vegas, in the lower part of the basin, ground water occurs in a thick sequence of fine-grained sand, silt, and clay that for practical purposes is a single hydraulic unit. In most parts of this area, ground water is under some artesian pressure.

The near-surface aquifers in the Las Vegas and Paradise Valley areas is composed principally of playa, eolian, and channel deposits derived from the older rocks of the alluvial slopes and mountains. The channel deposits of sand and gravel in most places are permeable and locally contain small quantities of unconfined water. However, most of the ground water developed in the near-surface aquifers is from thin sand and gravel lenses in playa and other fine-grained valley-fill deposits. The permeability of most of the deposits in the near-surface reservoir is low, and consequently the yields of wells developed in this aquifer are sufficient only for domestic use.

Water in the near-surface reservoir usually occurs at depths ranging from a few feet to 40 or 50 feet below land surface. In many areas in Las Vegas Valley below an elevation of about 2,100 feet, the water is near enough to the surface to support the growth of phreatophytes.

GROUND-WATER HYDROLOGY

GENERAL PRINCIPLES

The principles of ground-water hydrology have been described in detail by Meinzer (1923 a, b), Tolman (1937), Wenzel (1942), and others. Only a brief discussion of the general principles of ground-water hydrology as they apply to the Las Vegas basin, therefore, is presented.

The main supply of ground water in the Las Vegas basin is in the porous alluvial deposits of the valley fill. Ground water contained in these deposits is chiefly derived from precipitation on the mountains within the drainage basin.

Ground water is generally considered to occur under either of two conditions: artesian (confined) or water table (unconfined). Artesian conditions occur if ground water in permeable material is confined under hydrostatic pressure by a relatively impervious material. When an artesian aquifer is tapped by a well, the water entering the well will rise above the bottom of the confining bed. The height of the column of water that extends above the zone of saturation and that can be supported by the hydrostatic pressure at a given point is called the artesian head. The imaginary surface that everywhere coincides with the static level of the water in the artesian aquifers defines a piezometric surface. Where the artesian head is great enough to cause a well to flow at the land surface, the well is known as a flowing artesian well.

Water-table conditions occur if the upper surface of the zone of saturation is not overlain by an impermeable barrier, and consequently recharge can enter the reservoir by direct downward infiltration. The upper surface of the zone of saturation is called the water table, and its position is marked by the water level in wells tapping the aquifer.

Artesian aquifers differ markedly from water-table aquifers. Artesian aquifers serve chiefly as conduits that transmit water from the intake area to outlets of natural or artificial discharge, whereas water-table aquifers function mostly as storage reservoirs. When ground water is discharged from water-table aquifers, the water table around the well is lowered and a hydraulic gradient is established toward the well from all directions. In response to the decline in head, the water released from storage is attributed partly to gravity drainage from the zone through which the water table moved and partly to compressibility of the water and aquifer material in the saturated zone. The volume of water thus released divided by the product of the area of aquifer surface over which the head change occurs and the component of head change normal to that surface is the storage coefficient (S) of the aquifer. Usually, the volume of water attributable to compressibility is a negligible proportion of the total volume of the water released and can be ignored. Therefore, the coefficient of storage for practical purposes may be considered equal to the specific yield.

When an artesian aquifer is tapped by a well and ground-water discharge begins, the piezometric surface around the well declines and a pressure gradient is established toward the discharging well. Some water is released from storage as a result of the decline in hydrostatic pressure, not by unwatering of a part of the formation but by compression of the aquifer and of the adjacent confining beds and by a slight expansion of the water itself. The results of these properties can also be expressed quantitatively as the coefficient of storage of the artesian aquifer, which is defined as the volume of water released from, or taken into, storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The storage coefficient for artesian aquifers is on the order of a thousandth of the coefficient of storage under water-table conditions. Until the artesian head declines below the bottom of the confining bed, the water in storage in the artesian aquifer remains virtually the same as under natural conditions, because there has been no drainage of the saturated sediments.

In the Las Vegas basin, ground water occurs in a large leaky artesian system under both confined and unconfined conditions. The principal features of the hydrology of the Las Vegas ground-water basin are shown in figure 5. All natural replenishment to the ground-water body is by infiltration of precipitation occurring principally in the Spring Mountains and in the Sheep Range. In the lower parts of the area below an elevation of about 6,000 feet, where the annual precipitation averages less than 5 inches a year, virtually all the precipitation evaporates or is transpired, and there is probably no direct natural recharge to the ground-water reservoir. At elevations above 6,000 feet, precipitation commonly occurs in sufficient quantities to permit some water to infiltrate through the alluvium to the zone of saturation. The main intake areas, or areas where the ground-water body is recharged by direct downward percolation of precipitation, are along the base of the mountains, particularly in the areas of the large alluvial fans at the mouths of the principal canyons. From the intake areas, ground water moves downward and laterally in the direction of the hydraulic gradient toward the principal area of discharge in the lower part of Las Vegas Valley. During the movement away from the intake areas, the ground water eventually becomes confined beneath layers of clay, caliche, or other relatively impervious beds.

Confining beds at various depths in the alluvium of Las Vegas Valley effectively separate the artisian aquifers into three principal hydrologic units, which Maxey and Jameson (1948, p. 81 and 82) called the deep, middle, and shallow zones of aquifers. These aquifers serve as the conduits through which virtually all the natural recharge is transmitted from the intake areas to the areas of natural or artificial discharge. Near the toe of the alluvial slopes in the vicinity of Las Vegas are a series of faults that truncate the three principal zones of artesian aquifers. These faults act both as ground-water barriers that impede the lateral movement of the ground water and as avenues for upward leakage of ground water from the artesian aquifers. Ground water leaking upward from the three principal artesian zones through the semiconfining beds and along the fault zones has saturated the confining layers of fine sand and silt and clay that overlie the shallow zone of artesian aquifers and has created a fourth major hydrologic unit that, in this report, is referred to as either the near-surface zone of aquifers or the near-surface reservoir (p. 23). Ground water in the near-surface reservoir occurs under both water-table and artesian conditions.

In Paradise Valley and in that part of the lower Las Vegas Valley which lies east of the fault that passes through the western part of the city of Las Vegas (pl. 8), ground water in the near-surface zone

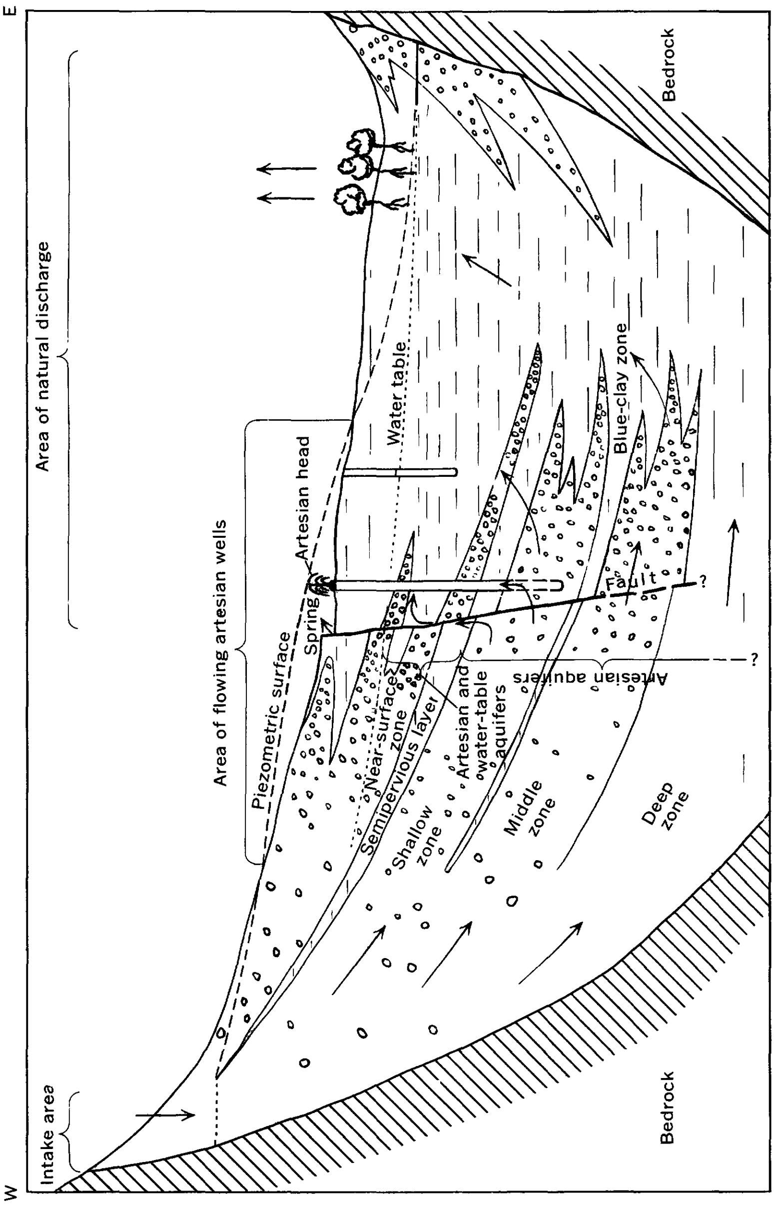

FIGURE 5.—Las Vegas Valley showing the principal zones of aquifers, direction of ground-water movement, and general geology of the valley fill.

of aquifers commonly is within a few feet of the land surface. These areas are the points of natural discharge of ground water from the artesian aquifers.

Early geologic and hydrologic studies by Carpenter (1915, p. 10) showed that Las Vegas Wash did not flow except during periods of flood. In subsequent studies by Hardman and Miller (1934, p. 23) and Maxey and Jameson (1948, p. 94), the authors concluded that there was no ground-water underflow from the Las Vegas basin. Therefore, it seems highly reasonable to conclude that, before the development of ground water in the Las Vegas basin, the hydrologic system represented by the replenishment of water in the intake area, the transmission of water through the aquifers, and the natural discharge by upward leakage and subsequent evapotranspiration was in dynamic equilibrium—that is, the natural discharge was equal to the average annual recharge at the intake area. Under natural conditions virtually all ground water in the near-surface zone of aquifers was supplied by ground water leaking upward from the artesian aquifers and by infiltration from artesian spring flow. After the development of artesian wells began in 1906, however, part of the water in the near-surface reservoir was supplied by infiltration from excess irrigation water, sewage effluent, and leaky wells. Since 1942 there has been some additional infiltration to the near-surface reservoir from water imported into the basin from Lake Mead.

The increase in discharge imposed on the artesian system by pumpage from wells since 1906 has been balanced by a decrease in natural discharge and a reduction in the amount of water stored in the ground-water reservoir. If pumping is to continue indefinitely, singly or combined, recharge to the sytem must increase or natural discharge decrease. If this adjustment is not made, the pumpage eventually must be decreased until it is equal to the net recharge, or water will be mined from the ground-water reservoir.

In the vicinity of the Las Vegas Valley Water District well field, the piezometric surface is estimated to have declined about 100 feet since development of wells in the area began. Declines of smaller magnitude have been observed in most other parts of Las Vegas Valley. As a result of this reduction in artesian pressure over a wide area in Las Vegas Valley, upward leakage has been greatly reduced. Despite the decrease in upward leakage the total amount of water in the near-surface reservoir has not changed significantly because of a corresponding increase in direct infiltration, principally from sewage effluent, industrial waste water, and excess irrigation water. Only part of the ground-water discharge in Las Vegas Valley is consumptively used. The remainder evaporates, runs off to Lake Mead, or infiltrates to the zone of saturation in the near-surface reservoir.

Some of the water that infiltrates to the zone of saturation becomes available for reuse and thus increases the total available supply in the basin. Because of the deterioration in the chemical quality that commonly results from recycling, however, subsequent use of the water may be limited. The total amount of ground water available on an annual basis is equal to the natural recharge that replenishes the three principal artesian zones plus the amount of water that is annually recycled to the near-surface reservoir and is recoverable through wells.

ARTESIAN WATER

AREA OF ARTESIAN FLOW

The area where flowing artesian wells could be developed in Las Vegas Valley was first outlined by Carpenter (1915). Subsequent maps showing areas of artesian flow were made by George Hardman (written commun., 1929) and by Maxey and Jameson (1948). Prior to the work of Maxey and Jameson, data were insufficient to outline accurately the area of artesian flow. The area of artesian flow in 1946 (Maxey and Jameson, 1948, pl. 2) was approximately 75 square miles in the vicinity of the city of Las Vegas and Paradise Valley and approximately 8 square miles in the vicinity of Tule Springs Ranch. From 1946 to 1955 the area of artesian flow (pl. 2) decreased to approximately 73 square miles in the vicinity of Las Vegas, and it diminished almost completely in the Tule Springs Ranch area. The most noticeable change in the area of artesian flow since 1946 has occurred between Bracken and Las Vegas, along U.S. Highways 91 and 466, where the west edge of the area of flowing wells has shifted as much as 3 miles eastward as a result of declining head.

PIEZOMETRIC SURFACE

The piezometric surface (p. 25) is generally illustrated on maps by contours that show the shape of the pressure surface in much the same way as topographic contours show topographic features. The piezometric surface is not a plane, as it has irregularities and variations of slope. Neither is it stationary, as it fluctuates with the hydrostatic pressure in the aquifer. The movement of ground water is from areas of higher head towards areas of lower head in a direction that is usually normal to the contours. In Las Vegas Valley there are several aquifers at different depths. Under natural conditions, these aquifers had different hydrostatic pressure. However, because of the common practice of gravel packing wells and installing perforated casing throughout most of the saturated deposits penetrated by wells, there has been significant leakage between the principal artesian zones and the pressures in the various aquifers have tended to become equalized.

Piezometric maps for Las Vegas Valley in February and in September 1955 (pls. 3, 4) were drawn on the basis of elevations of water levels in wells of varying depths and construction, and they represent a piezometric surface that shows the composite effect of pressures in all the aquifers tapped by the wells. The maps show that the piezometric surface slopes away from the surrounding mountains toward the basin lowlands and that virtually all ground-water flow is from the remote parts of the basin toward Las Vegas Valley. Although the piezometric surface is not shown for areas bordering Sunrise Mountain and Black Mountain, fragmentary water-level data in these areas indicate that the piezometric surface slopes away from these areas toward the central part of Las Vegas Valley also.

Flow lines (shown as arrows on pl. 3) show the general direction of movement of ground water in the artesian aquifers. In the vicinity of Las Vegas, the lateral movement of ground water in the artesian aquifers is from west to east. South of Las Vegas in the resort hotel area along U.S. Highways 91 and 466 (locally called "The Strip"), the lateral movement is toward the northeast. The gradient of the piezometric surface averages about 50 feet per mile but ranges from about 150 feet per mile in the area west of Whitney to about 12 feet per mile along the axis of the valley south of Nellis Air Force Base.

In the northern extremities of the ground-water reservoir (not shown on pls. 3, 4), George Hardman (written commun., 1931) indicated by a profile of the water surface that the piezometric surface slopes northward from the Spring Mountains toward the town of Indian Springs and thence eastward toward Las Vegas Valley. Water-level observations made by Carpenter (1915, pl. 1) indicate that ground water in the main north-south limb of Indian Spring Valley is separated from Las Vegas Valley by a ground-water barrier approximately 3 miles north of Indian Springs. Some underflow from the area south of the barrier may spill over the barrier, but on the basis of the water-table profile prepared by George Hardman (written commun., 1931) and the studies made by Hardman and Miller (1934, p. 23), the movement of the bulk of the water in this area is interpreted to be southeastward toward Las Vegas.

In the southern extremity of the Las Vegas ground-water basin, in Ivanpah Valley, George Hardman (written commun., 1931) also showed that there was a hydraulic gradient northward at about 8 feet per mile toward Las Vegas Valley from a ground-water divide in the vicinity of the Nevada-California State line. A profile of the gradient suggests that the probable avenue of discharge of ground water into Las Vegas Valley is through the low hills in the vicinity of the railroad siding at Erie, Nev.

FLUCTUATIONS OF ARTESIAN PRESSURE

Fluctuations of the piezometric surface over a prolonged period of time indicate changes in the amount of water in storage in the ground-water reservoir. The piezometric surface will rise during periods when recharge exceeds the draft and will decline during periods when the draft exceeds the recharge. The greatest fluctuations of the piezometric surface result from the artificial discharge of ground water.

When a pump discharges water from a well or an artesian well is permitted to flow, a hydraulic gradient is established toward the discharging well, and the piezometric surface assumes the shape of an inverted cone. Effects of withdrawals from artesian aquifers are principally pressure effects and are transmitted throughout the artesian aquifer almost instantaneously.

Minor fluctuations of the piezometric surface may result from changes in barometric pressure, earth tides, earthquakes, or temporary loading and unloading of the aquifer due to passing trains, trucks, or other heavy loads. These small changes in water levels, however, are of short duration and do not represent substantial changes in the amount of ground water in storage.

Fluctuations of the piezometric surface in Las Vegas Valley were determined by observing water levels in wells tapping the artesian system. Water-level measurements in many observation wells during the present investigation were continuations of measurements begun by Maxey in 1944 (Robinson and others, 1947). Continuous water-level changes in some wells were observed by means of automatic water-stage recorders or pressure gages. Water-level measurements of other wells were made at weekly, monthly, or quarterly intervals.

Prior to 1944, water-level measurements in a few wells were recorded by Carpenter (1915), George Hardman (written commun. 1929, 1931, 1936), and Livingston (1940). From 1938 to 1944, numerous measurements were made by C. H. Jameson (Robinson and others, 1947).

ANNUAL FLUCTUATIONS

Annual fluctuations of the piezometric surface result chiefly from discharge by wells and springs and by evapotranspiration. Fluctuations in response to changes in recharge commonly are masked by fluctuations resulting from ground-water withdrawals because the withdrawals are of much greater magnitude. Hydrographs of water levels in wells show that, during periods of above-average recharge, the annual range of fluctuation is less than that during periods of average or below-average recharge; conversely, the range of fluctuation is greater during periods of below-normal recharge. Hydrographs for three wells shown in figure 6 illustrate typical daily, seasonal, and annual fluctuations of the water surface in Las Vegas Valley.

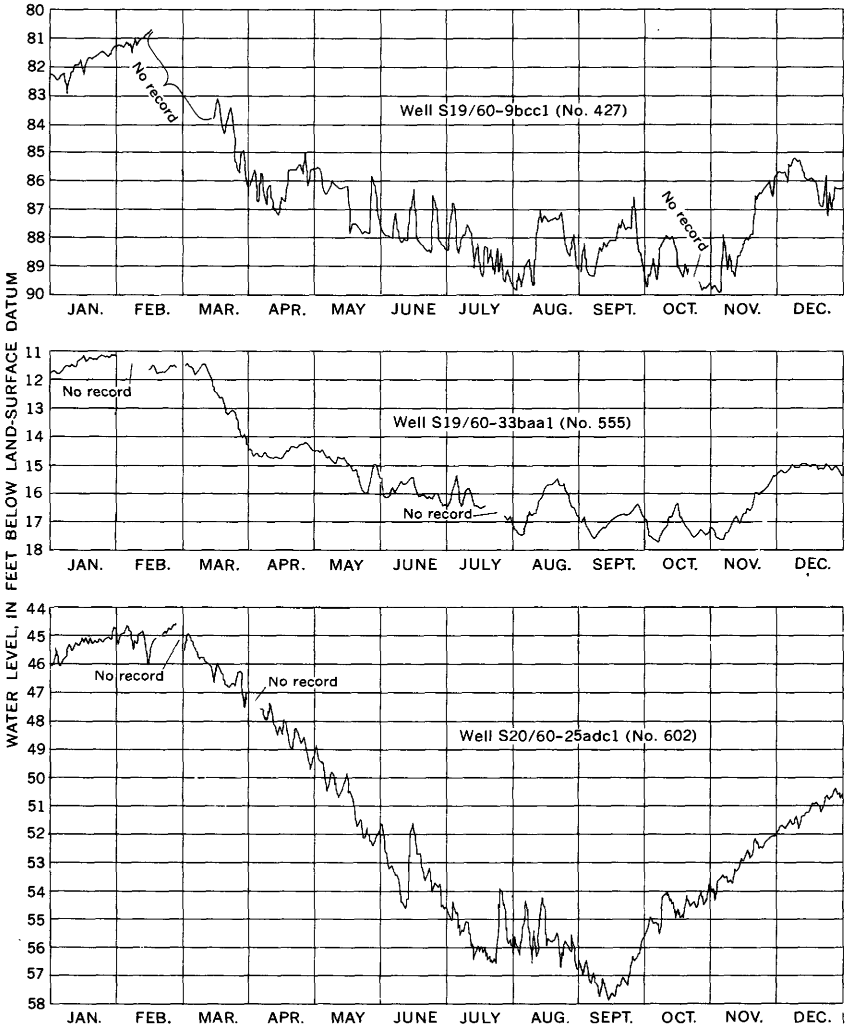

FIGURE 6.—Artesian wells S19/60-9bcc1 (No. 427), S19/60-33baa1 (No. 555), and S20/60-25adc1 (No. 602) showing water-level fluctuations for 1955.

Hydrographs show that water levels begin to decline during the latter part of February or in early March when the pregrowing season irrigation and lawn watering begins. Water levels continue to decline until about September when withdrawals for irrigation and lawn watering are reduced. Annual water-level fluctuations in 15 observation wells in the Las Vegas municipal area averaged 10.1 feet per year during the period 1941–55 and ranged from a minimum of about 3 feet to a maximum of about 13.6 feet. (See hydrograph showing average artesian head for selected wells in the Las Vegas area, fig. 8.) The annual fluctuations of water levels in some wells may be less than the average or several times greater, depending on the relative position of the wells with respect to centers of concentrated ground-water discharge.

The main centers of pumping in Las Vegas Valley are the Las Vegas Valley Water District well field, about 2 miles west of the municipal area, and The Strip area along U.S. Highways 91 and 466, approximately 2 miles south of Las Vegas. Pumping in the Las Vegas well field affects the water levels throughout the Las Vegas municipal area and much of the area to the northwest. The decline in head resulting from pumping in the well field between February 1955 and February 1956 is shown on plate 5. The figure shows that water levels near the areas of large withdrawals declined more than 5 feet.

Pumping of wells in the vicinity of The Strip has affected water levels underlying an area about 4 miles wide that extends from the city limits of Las Vegas southward about 10 miles. The area of pressure decline developed around this center of large ground-water withdrawals during the period February 1955 to February 1956 merged with that developed around the Las Vegas Valley Water District well field to the north. The maximum observed water-level change near the center of the area of sharp declines for this period was approximately 14 feet.

In addition to these two main centers of pumping, plate 5 shows several other areas where ground-water withdrawals produced local declines during the period between February 1955 and February 1956.

During the same period, water levels in wells rose in the area about 1½ miles northwest of Whitney and in the area between Whitney and Henderson. These anomalies are the result of local decreases in ground-water withdrawals.

LONG-TERM FLUCTUATIONS

Prior to 1944, only a few measurements of artesian pressures were made in flowing wells in Las Vegas Valley; practically all the measurements were of water levels in nonflowing wells. Between 1922 and 1936, however, personnel of the University of Nevada Agricultural Experiment Station, under the direction of George Hardman, measured and recorded the discharge from springs and flowing artesian wells in the valley. From these measurements, considerable information can be inferred about changes in artesian head. Tables showing the discharge of representative flowing wells during this period (Hardman, George, written commun., 1929, 1931, 1936) show that flows tended to decrease during the period 1922–37 except in the years 1933 and 1934, when the flows remained approximately the same or increased slightly. It is inferred that the artesian heads followed similar trends.

Water-level and flow measurements of wells and springs made prior to 1922, even though discontinuous and fragmentary, clearly show a gradual but steady lowering of the artesian head since the beginning of ground-water development. During the long period of declining water levels since 1906, available water-level data indicate only two periods when the downward trend was reversed—during 1933 and 1934 and again in 1941 and 1942. During these periods the water levels in some wells rose, and in others they leveled off or declined only slightly; the flow from most artesian wells remained about the same or increased slightly. The reversal of the downward trend of water levels during these periods resulted from above-average natural recharge to the artesian system. A detailed description of the effects of precipitation on water-level fluctuations is given in the section on estimates of recharge.

Heavy withdrawals in the Las Vegas Valley Water District well field and in The Strip area since 1944 have accelerated the lowering of water levels throughout most of the valley. Between February 1944 and February 1956, water levels in wells near the Las Vegas Valley Water District well field were lowered more than 40 feet, and in The Strip area, more than 50 feet. Plate 6 shows the magnitude and distribution of water-level changes during this 12-year period. The areas of head decline during this 12-year period approximately correspond to those of the 1-year period from February 1955 to February 1956 shown on plate 5.

Effects of pumping from the Las Vegas Valley Water District well field are shown in the hydrograph of well S20/60–36dbbl (No. 18) (fig. 8). A record of water-level changes in well 18 has been maintained sporadically since 1925 and is the longest single record of water-level changes in the valley. The well is 385 feet deep and is approximately 1½ miles west of the Las Vegas Valley Water District well field. Water levels in this well fluctuate in response to pumping from the well field. From June 1925, when the water level in the well was first recorded, to June 1955 the water level declined approximately 71 feet. The hydrograph shows an annual decline of the water level in the well throughout the period of observation except between February 1940 and February 1941, for which months the water levels were unchanged. The flattening of the hydrograph during this period reflects in part a slight decrease in the total withdrawals in 1940 and in part a corresponding increase in ground-water recharge.

Effects of pumping in The Strip area are shown in hydrograph of well S22/61–4bccl (No. 41) (fig. 7). Records of water-level fluctuations in this well have been maintained since 1939. Well 41 is about 4 miles south of the center of greatest ground-water withdrawal in The

Strip area. During the period of record the water level in this well declined approximately 15 feet. Near the center of greatest ground-water withdrawal, water levels have declined 75 feet or more.

To establish the average rate of water-level fluctuations in the area of greatest ground-water development, 15 representative wells were selected in and around the municipal areas of Las Vegas, North Las Vegas, and The Strip. Measurements of the water levels in these wells were obtained at 3-month intervals from 1941 to 1948. In 1948, measurements of 5 of the 15 original observation wells were suspended and measurements of 5 substitute wells were begun. In 1955 it became impossible to measure the water level in one of these wells, and since that time the average head has been computed for the remaining 14 wells.

The hydrograph of the average static water level in these wells for the period 1941–47 is shown at the top of figure 8. If the midpoints of the annual average water level in the wells are connected by a straight line, the resulting curve represents the trend of the water level throughout the major area of development in the valley. The trend of the average artesian water level has been downward except during 1942, when the artesian water level remained nearly unchanged from the preceding year. During the 15-year period from 1941 through 1955, the average artesian water level dropped about 30 feet in the area of approximately 40 square miles represented by these wells.

Large withdrawal of ground water in the urban area has caused a lowering of water levels in wells in the surrounding rural areas. Hydrographs of wells S19/60–27bdc1 (No. 554) and S19/60–33baa1 (No. 555) (fig. 7), approximately 7 miles north of Las Vegas, show a corresponding downward trend of the water levels. Similarly, the hydrographs of wells S22/61–9cbb1 (No. 42) and S22/61–4bcc1 (No. 41) (fig. 7), south of the area represented by the 15-well average, show a lowering of water levels from the summer of 1941 to the summer of 1955 ranging in magnitude from about 15 feet at well 41 to an inferred decline of about 11 feet at well 42.

RECHARGE

SOURCE

All recharge to the artesian aquifers is derived solely from precipitation occurring within the drainage area tributary to the Las Vegas ground-water basin. The amount of recharge in relation to precipitation is influenced by the topography; geology; vegetation; kind, time, intensity, duration, and distribution of precipitation; temperature; humidity; wind; and other factors.

In the lower parts of the valley, where precipitation averages less than 5 inches a year, the high temperature, low humidity, and wind are generally favorable for rapid evaporation. The average annual

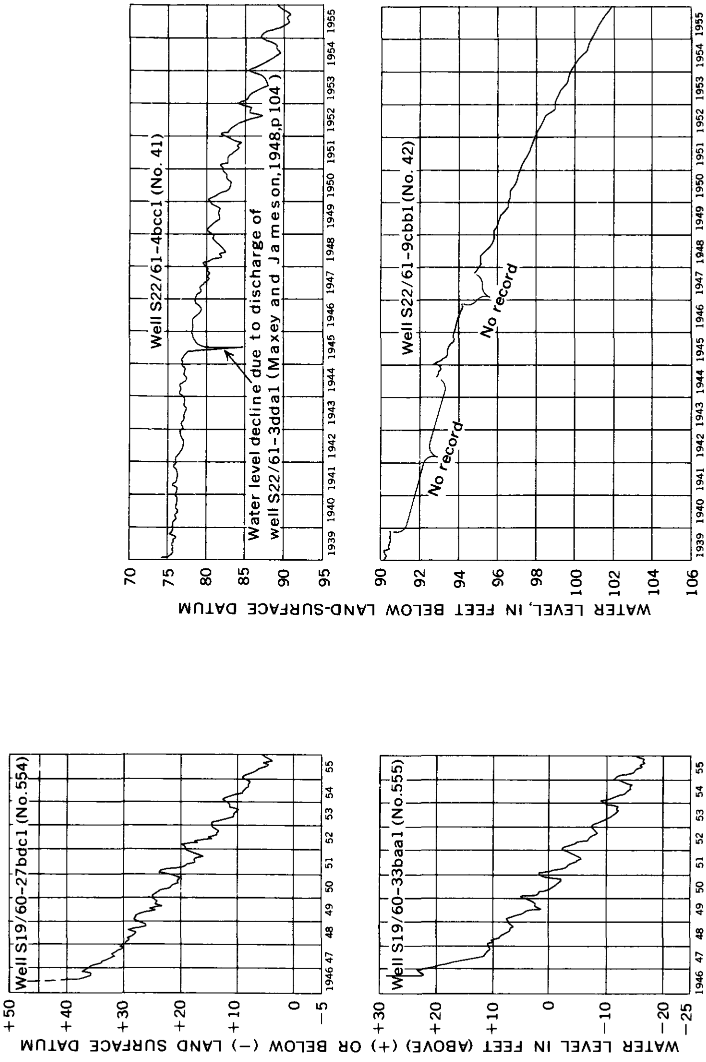

FIGURE 7.—Water-level fluctuations in remote parts of Las Vegas Valley.

potential evapotranspiration on the valley floor is considerably more than the average annual precipitation, and therefore, except for short periods following summer thunderstorms evapotranspiration exceeds precipitation. During periods when precipitation exceeds evapotranspiration, some water is temporarily available for recharge; however, because of the low permeability of the silt and clay deposits that underlie most of the valley floor and because of the short duration of the typical summer storm and the high rate of evaporation, deep penetration of precipitation probably is negligible. Most of the precipitation on the valley floor in excess of the evapotranspiration potential flows as surface water to the arroyos and is discharged from the basin through Las Vegas Wash, or it accumulates in playas and is subsequently evaporated. Most of the precipitation that infiltrates into the ground replenishes the soil moisture that supports the scanty desert vegetation.

Precipitation in the mountains within the drainage basin is greater than that in the lowlands, the temperature is lower, and the evaporation losses are less. Much of the precipitation in the mountains occurs as snow during the winter and as rain in the summer. The snow usually melts rather slowly during a period when transpiration is low and thus affords maximum opportunity for snowmelt to infiltrate directly into the soil. Because transpiration is low during the winter, most of the infiltration from melt water in excess of the soil-moisture requirements eventually drains to the zone of saturation. In contrast to the relatively slow runoff from melting snow, runoff from the rather frequent summer storms commonly occurs as small floods of brief duration. Storm runoff may percolate directly into the alluvial fill on the canyon floor, or it may flow as a stream onto the fans at the mouths of the canyons, where part of it eventually infiltrates to the zone of saturation. Precipitation, stream flow, and snowmelt infiltrate directly into the coarse alluvial material mantling the canyon floors and into the upper part of the alluvial fans; and this infiltration accounts for most of the natural recharge to the ground-water reservoir. An unknown amount of precipitation infiltrates directly or indirectly into the consolidated rocks along joints, bedding planes, solution and other secondary openings, although the general lack of water in most of the mines in the area suggests that the quantity may be insignificant (Hewett, 1931, p. 8; 1956, p. 14). Deep oil-test wells indicate that some of the consolidated rocks beneath Las Vegas Valley are saturated.

ESTIMATES OF RECHARGE

One of the primary objectives of the cooperative ground-water study of the Las Vegas area was to make an estimate of the average annual natural recharge to the artesian aquifers in the Las Vegas ground-water reservoir. Except for about 5,000 acre-feet of water that infiltrated to the near-surface reservoir from water imported from Lake Mead, all recharge to the Las Vegas basin in 1955 was originally derived from precipitation in the mountains within the drainage basin. An estimate of recharge to the artesian aquifers approximates the total amount of natural recharge to the ground-water basin. Estimates of recharge to the artesian aquifers cannot be made directly because of insufficient data. However, recharge can be approximated or inferred by quantitatively analyzing various components of the hydrologic cycle. The three principal components of the hydrologic cycle that have been analyzed with respect to estimating the natural recharge to the Las Vegas artesian system include (1) consumptive use of ground water by phreatophytes under natural conditions, (2) ground-water underflow from areas of recharge to areas of discharge during periods of approximate dynamic equilibrium in the ground-water reservoir, and (3) average annual recharge resulting from direct infiltration of precipitation and snowmelt. Estimates by any one of these methods may not be reliable because some of the computations may be based on inadaquate data. However, the estimates of recharge by all three methods are in reasonable agreement and therefore are considered to be reliable.

CONSUMPTIVE USE OF WATER BY PHREATOPHYTES UNDER NATURAL CONDITIONS

Natural recharge to the Las Vegas ground-water reservoir probably differed little under virgin conditions from what it is today or from what one might expect it to be in the foreseeable future unless precipitation can be increased by weather modification, evapotranspiration losses in the recharge area are reduced, or artificial-recharge projects are developed to salvage the waste water originating from either the ground-water reservoir or from water imported from Lake Mead. Under natural conditions the long-term average annual recharge equaled the long-term average annual discharge. Studies by Maxey and Jameson (1948) and others have shown that virtually no underflow leaves Las Vegas Valley through the Las Vegas Wash; therefore, under natural conditions the ground-water underflow ultimately leaked upward from the artesian aquifers to the near-surface reservoir, from which it was eventually discharged by evaporation and transporation. The increase in salinization of the soil in the area of evapotranspiration is periodically leached by flood runoff that discharges through Las Vegas Wash; this leaching prevents excessive accumulation of saline deposits typical of most closed basins. To the same extent that it is possible to determine the discharge from Las Vegas Valley prior to any significant development of ground water, it is, possible to infer the recharge for the same period of time.

A study of natural discharge of ground water prior to 1906 (p. 82) shows that the estimated annual discharge under natural conditions was on the order of 24,000 acre-feet. From this estimate it can be inferred that the average annual recharge to the Las Vegas ground-water basin is of similar magnitude.

GROUND-WATER UNDERFLOW

The amount of ground water underflow through a given section of an aquifer during a given length of time is dependent on the physical character of the aquifer materials through which the water moves and the hydraulic gradient. Underflow moves in the direction of the hydraulic gradient and is measured along a cross section of the saturated sediments normal to the direction of flow. Under natural conditions the direction of ground-water flow in the Las Vegas ground-water basin was from the surrounding mountains toward the area of natural discharge in the vicinity of Las Vegas. The hydraulic system was in a state of dynamic equilibrium, and therefore the annual underflow across any particular piezometric contour between the area of recharge and the area of natural discharge was approximately equal to the average annual replenishment to the ground-water reservoir.

Since the development of the first successful flowing well in 1906, however, the annual discharge from the artesian system has exceeded the annual recharge almost continuously and has resulted in the removal of some water from ground-water storage.

The principal area of ground-water development in the Las Vegas basin is in the area of natural discharge—and therefore, after the development of ground water began, the direction of underflow remained virtually unchanged. Underflow moving toward the discharge area, however, was increased by the amount of water released from storage upgradient from the point of discharge.

Draft on the artesian system caused water levels in the area of discharge to decline and thus caused a cone of depression in the piezometric surface. As long as the withdrawals were relatively small, the cone of depression probably remained small, and the amount of water released from storage as a result of the change in artesian head was small also. As draft on the ground-water reservoir in the Las Vegas area continued, the cone of depression expanded and, as early as 1939, when systematic measurements of water levels in the valley began, water levels had declined in wells as much as 9 miles from the principal center of pumping. (See fig. 17.)

Since 1906, when overdraft on the ground-water basin began, the underflow annually moving across any particular piezometric contour between the area of recharge and the area of discharge approximated the average annual rate of replenishment (recharge) to the artesian aquifers plus that portion of ground water released from storage that moves across the same contour. Ground-water underflow approximates recharge only during periods when the ground-water reservoir is in dynamic equilibrium. Therefore, if underflow is computed during a period when the ground-water reservoir is in equilibrium or near equilibrium and when virtually no ground water is released from storage, the computed value will approximate the recharge to the system. On the other hand, if underflow is computed during a period when water levels are declining, the computed value will be larger than the actual recharge to the system.

In the Las Vegas area, ground water moves eastward under a fairly uniform hydraulic gradient (pls. 3, 4, 7). Flowlines constructed normal to the contours converge toward the area east of Whitney and show that the direction of movement of the ground water is toward that area. Discharge in the remote areas of the reservoir is relatively small, and therefore the annual underflow into the Las Vegas area is equal to the average annual recharge to the basin plus the amount of water released from storage outside the Las Vegas area as a result of the draft on the system. Underflow to the Las Vegas area is computed across a section upgradient from the area of upward leakage and the principal area of discharge (shaded areas on pls. 3, 7) and includes virtually all the underflow in the confined and unconfined aquifers. The cross section through which underflow is computed is about 21 miles long and extends from the base of Sunrise Mountain on the east around the west side of Las Vegas to Black Mountain on the south. Because data are insufficient, computation of underflow across a single piezometric contour is not possible. Flowlines shown in the figures divide the 21-mile section into 12 irregular segments through which virtually all underflow to the Las Vegas area passes. By computing the underflow crossing each of the 12 segments along this section, the total underflow to the Las Vegas ground-water reservoir can be approximated. If ground-water underflow across this section is computed during a period when the water level throughout the entire ground-water reservoir is stabilized, the computed underflow will approximate the rate of recharge entering the artesian aquifers at that time. Unfortunately, during 1912 and 1955, the years for which underflow to the Las Vegas area is computed, there was an overdraft on the artesian system, and therefore underflow computed for these years undoubtedly is somewhat larger than it would have been had conditions of equilibrium prevailed.

The estimate of underflow moving through each vertical segment midway between two consecutive piezometric contours in each of the 12 map segments shown on plates 3 and 7 is based on the width of the segment, the average gradient of the piezometric surface across the segment, and the estimated transmissibility of the saturated sediments. The coefficients of transmissibility used in this study were determined by field methods described by Theis (1935), Cooper and Jacob (1946), and Jacob and Lohman (1952). Coefficients of transmissibility for the Las Vegas Valley are listed in table 3.

TABLE 3.—*Calculated constants for formations in Las Vegas Valley*

[Computed values of transmissibility and storage should be considered correct only to the general order of magnitude]

Date of test	Pumped well	Depth (ft)	Observation well	Depth (ft)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage
6-2-47	S19/60-27bdc1 (No. 554)	905			7,100	
6-2-47	33baa1 (No. 555)	1,008			18,100	
4-18-55	S19/62-36ccc1	1,036	S20/62-1bb1	1,247	1,600	0.000036
4-18-55	36ccc1	1,036			1,600	
4-20-55	36dbb1 (No. 696)	1,434			800	
4-21-55	36dcc1 (No. 695)	1,502			1,000	
5-26-55	S20/61-3adc3 (No. 418)	500			30,000	
5-27-55	3dab1 (No. 314)	242			40,000	
3-12-56	15abb1	1,700			3,200	
3-2-55	20cbc1 (No. 7)	278			9,500	
3-2-55	20cbc2 (No. 43)	318			4,000	
3-4-55	20dab1 (No. 549)	306			8,000	
3-1-55	29dbb1 (No. 380)	475			12,500	
2-18-46	31dac1 (No. 457)	940	S20/60-36dbb1 (No. 18)	385	240,000	.0008
2-20-46	31dac1 (No. 457)	940			240,000	
2-20-46	31dac1 (No. 457)	940	S20/61-31ada1 (No. 277)	801	280,000	
2-21-46	31dac1 (No. 457)	940	31dab1 (No. 399)	766	240,000	.00016
2-21-46	31dac1 (No. 457)	940	31ddc1 (No. 401)	1,250	310,000	.00023
1-24-46	36cca2 (No. 462)	500			1,300	
4-21-55	S20/62-1bbb1	1,247			800	
5-26-55	4add1 (No. 416)	800			4,800	
5-27-55	9abc1 (No. 676)	1,000			4,600	
5-25-55	9bcc1 (No. 681)	1,000			3,800	
3-2-55	S21/61-5caa1 (No. 25)	585			2,800	
6-25-52	16adb1 (No. 679)	450	S21/61-15cbb1 (No. 533)	925	24,000	.00007
2-10-55	20daa1 (No. 517)	920			4,000	
2-10-55	21abb1 (No. 537)	737			700	
3-1-55	23ccc1 (No. 694)	350			3,700	
2-10-55	27ccc1 (No. 38)	263			900	
2-10-55	29aaa1 (No. 534)	540			18,500	
2-15-57	29dba1	500			1,600	
2-11-55	S21/62-17ddc1 (No. 374)	540			200	
2-11-55	21cbc2 (No. 430)	500			2,500	
3-1-55	30dcb1 (No. 466)	400			900	
2-12-46	S22/61-3dda1 (No. 434)	335			125,000	
2-12-46	3dda1 (No. 434)	335	S22/61-4bcc1 (No. 41)	355	110,000	.00045
2-15-57	18aaa1 (No. 875)	398			2,400	
2-14-57	10cbc1	196			300	
10-13-54	16bcc1	200			3,200	

The coefficients of transmissibility shown in the table range from about 200 gpd per ft (gallons per day per foot) in wells developed in fine-grained or poorly sorted deposits to about 300,000 gpd per ft in wells developed in relatively clean, uniform, well-rounded sand and gravel. Although a few of the coefficients of transmissibility were determined at random locations in Las Vegas Valley, most of the determinations were made for wells along the 21-mile section upgradient from the principal discharge area and area of upward leakage.

A study of the distribution of the size of the coefficients of transmissibility shows that the coefficients usually decrease in the direction of the hydraulic gradient, the smallest values occurring east of the city of Las Vegas in the area between the sewage disposal plant and Whitney, Nev.

The coefficients of transmissibility computed along the perimeter of the principal area of discharge indicate that the transmissibility of the aquifers varies markedly within relatively short distances along the section through which the underflow is computed.

The two areas in the valley where the coefficients of transmissibility are particularly high are west of the city of Las Vegas, in the vicinity of the Las Vegas Valley Water District well field, and south of McCarran Airfield in the vicinity of Hidden Wells Ranch.

The wide range in the coefficients of transmissibility obtained from the pumping tests may be due in part to the fact that all the basic assumptions of uniform conditions required in the derivation of the coefficients are not met. (See Theis, 1935, p. 519–524.) However, the principal cause is the wide range in the sedimentary characteristics of the alluvium.

The irregular character of the sediments, together with the necessity of using closely spaced wells that penetrate only part of the saturated thickness of the sediments, leads to the conclusion that most of the computed values of transmissibility given in tables 3, 4, 5, and 6 should be considered correct only to a general order of magnitude. Under a uniform hydraulic gradient, the amount of underflow moving across any particular piezometric contour varies as the transmissibility of the alluvium varies. Therefore, rather than averaging the coefficients of transmissibility in the whole basin (table 3), which would have overgeneralized the geologic and hydraulic characteristics of the saturated sediments, the author arbitrarily divided the valley into 12 irregular segments on the basis of differences in transmissibility indicated by pumping tests, specific capacity of wells, and available geologic data. The computations of underflow discussed in the following sections are based on the coefficients of transmissibility of the deposits to the depth penetrated by the wells. Although the deposits below a depth of about 700 feet—the deep zone of aquifers (p. 24)—contain permeable beds capable of transmitting water, data currently available indicate that the transmissibility of the deeper beds is much lower than that of the overlying middle and shallow zones of aquifers. Except for an insignificant amount of ground water discharged from wells developed in the deep zone of aquifers, all discharge from the deep zone of aquifers is by upward leakage. Therefore, virtually all water moving through the deep zone of aquifers has to move upward across the bedding and through the confining clay layers to reach the depth range tapped by most wells or by phreatophytes. Consequently, underflow through the deposits below a depth of about 700 feet is assumed to be but a small fraction of the flow through the overlying zones of aquifers, and it probably is included in the final estimate by rounding the totals to the nearest 1,000 acre-feet.

The following calculations for underflow into the principal area of ground water development at Las Vegas are based on the best estimate of hydraulic conditions that prevailed in 1912 and 1955.

Application to past conditions.—For purposes of comparing underflow into Las Vegas Valley at some time in the historic past with the underflow in 1955, the values for the coefficient of the transmissibility determined from pumping tests made throughout the valley over the past several years (table 4) were applied to a piezometric map compiled from data for 30 wells in 1912 (Carpenter, 1915; Kearney, 1913; McWilliams, 1913). (See pl. 7.) Flow lines drawn normal to the contours of the piezometric surface divide Las Vegas Valley into 12 irregular segments as described on page 41.

The ground-water underflow across the 21-mile long section in 1912 was computed by a useful form of Darcy's law, which is often applied to ground-water hydraulics problems; this form of Darcy's law is expressed by the equation $Q=TIW$, where Q is the quantity of water discharged per unit time, T is the coefficient of transmissibility, I is the hydraulic gradient, and W is the width of the section through which the water moves measured normal to the direction of flow. Q may be expressed in gallons per day (gpd); T, in gallons per day per foot (gpd per ft); I, in feet per mile (ft per mi); and W, in miles.

The width, W, across which the water in each of the segments moves was obtained from the piezometric map (pl. 7) and is the average length of the two contours between the limiting flow lines for each of the 12 areas (shaded areas on pl. 7) for which coefficients of transmissibility have been computed or estimated. The hydraulic gradient, I, is the average hydraulic gradient in the segment.

The coefficients of transmissibility that are used for computing underflow to the Las Vegas area in 1912 are listed in table 4.

In map segments 3, 5, 7, 8, 10, 11, and 12 (pl. 7; table 4), the coefficients of transmissibility were determined from pumping tests on wells less than 700 feet deep. Therefore, in computing underflow across these segments, the largest coefficient in each segment is used so that some degree of compensation can be made for the effects of partial penetration.

In map segments 1, 2, 4, 6, and 9 (pl. 7; table 4), the T values were computed from pumping-test data for wells 700 feet or more deep that penetrate and tap the saturated sediments through which the

TABLE 4.—*Coefficients of transmissibility used for computing underflow into Las Vegas Valley in 1912*

[Estimates of transmissibility should be considered correct only to the general order of magnitude]

Map segment (pl. 7) (1)	Well and location (2)	Owner or local name (3)	Depth of well (ft) (4)	Coefficient of transmissibility (gpd per ft) (5)	Approximate coefficient of transmissibility in map segments (gpd per ft) (6)
1	S19/62-36ccc1	Lake Mead Base	1,036	1,600	[1] 1,100
	36dbb1 (No. 696)	do	1,434	800	
	S20/62-1bb1	do	1,247	800	
2	4add1 (No. 416)	Nellis Air Force Base	800	4,800	[1] 4,400
	9abc1 (No. 676)	do	1,000	4,600	
	9bcc1 (No. 681)	do	1,000	3,800	
3	S20/61-3abc3 (No. 418)	do	500	30,000	[2] 40,000
	3dab1 (No. 314)	do	242	40,000	
4	15abb1	City of North Las Vegas	1,700	3,200	3,200
5	20cbc1 (No. 7)	Oppedyk Estate	278	9,500	[2] 9,500
	20cbc2 (No. 43)	do	318	4,000	
6	31dac1 (No. 457)	Las Vegas Valley Water District.	940	240,000	[1] 265,000
	31ada1 (No. 277)	do	801	280,000	
	31dab1 (No. 399)	do	766	240,000	
	31ddc1 (No. 401)	do	1,250	310,000	
7	S21/61-5caa1 (No. 25)	Splane Estate	585	2,800	2,800
8	16adb1 (No. 679)	Desert Inn	450	24,000	24,000
9	20daa1 (No. 517)	A. F. Winter	920	4,000	4,000
10	27ccc1 (No. 38)	W. I. Jenison	263	900	[2] 18,500
	29aaa1 (No. 534)	Murray Woolman	540	18,500	
	29dba1	Lady Luck National Corp.	500	1,600	
11	S22/61-3dda1 (No. 434)	Henry Wick	335	125,000	125,000
12	16bcc	M. Roubert	200	3,200	3,200

[1] Average coefficient of transmissibility in map segment.
[2] Highest computed value of coefficient of transmissibility in map segment.

major part of the underflow into Las Vegas Valley moves. Where more than one *T* value is available for these segments, the average value is used.

Ground-water underflow to the Las Vegas area, based on the estimated hydraulic gradient in 1912, is shown in table 5. The sum of the computed values of ground-water underflow across the 12 map segments represents the bulk of the inflow into the Las Vegas area.

The areas bordering Frenchman Mountain and Black Mountain are relatively undeveloped, and consequently there are insufficient data on coefficients of transmissibility and hydraulic gradients to compute any underflow that may be contributed to the ground-water reservoir from these areas. Recharge from Frenchman and Black Mountains, however, is considered negligible and would not significantly affect the total computed value.

Ground water discharged in the more remote areas of the ground-water reservoir represents an additional amount of ground water that must be considered in making an estimate of the total recharge to the Las Vegas basin.

TABLE 5.—*Estimated underflow into Las Vegas Valley in 1912*

[Estimates of transmissibility should be considered correct only to the general order of magnitude]

Map segment (pl. 7)	Water-level contour interval used (pl. 7)	Average length of contours (miles) (*W*)	Approximate coefficient of transmissibility (gpd per ft) (*T*)	Average hydraulic gradient (ft per mi) (*I*)	Underflow (mgd) (*Q*)
1, 2					[1] 0. 41
3	1950–2000	0. 5	40, 000	38	. 76
4	1950–2000	2. 3	3, 200	73	. 42
5	2100–2150	1. 1	9, 500	35	. 37
6	2220–2230	2. 5	265, 000	15	10. 00
7	2150–2200	1. 7	2, 800	55	. 26
8	2100–2150	. 5	24, 000	42	. 50
9	2100–2150	. 8	4, 000	32	. 01
10	2100–2150	2. 3	18, 500	24	1. 02
11	2100–2150	1. 8	125, 000	19	4. 30
12	2100–2150	1. 7	3, 200	17	. 09
Total (rounded)					18

Approximate underflow into Las Vegas Valley in segments 1–12 acre-feet per day	55
Approximate ground-water discharge upgradient from segments 1–12 acre-feet per day	3
Approximate total underflow into Las Vegas Valley in 1912 do	58
Approximate total underflow into Las Vegas Valley in 1912 acre-feet per year (rounded)	21, 000

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[1] Underflow in 1912 into segments 1 and 2 of plate 7, estimated to be the same as inflow into segments 1 and 2 of plate 3 in 1955.

Ground water discharged upgradient from the areas of computed underflow for 1912 includes approximately 1.47 acre-feet per day from well S20/60–24adb1 (No. 2), 0.9 acre-foot per day from Tule Spring, and 0.6 acre-foor per day from Corn Creek Springs and Cottonwood Spring, or a total of approximately 3 acre-feet per day. Discharge from the above mentioned springs includes only the amount used by phreatophytes; the remainder of the spring flow is assumed to have returned to the ground-water reservoir and therefore is included in the computed value of underflow into Las Vegas Valley. Underflow to Las Vegas Valley (about 55 acre-feet per day) plus the amount of ground water discharged upgradient from the area of computed underflow (about 3 acre-feet per day) approximates the total daily underflow through the ground-water reservoir in 1912 (about 58 acre-feet per day). (See table 5.) Inasmuch as the rate of ground-water underflow probably was very nearly constant throughout the year, the approximate annual underflow to Las Vegas Valley in 1912 was computed to be about 21,000 acre-feet. Even at this early date in the development of ground water in the valley, however, artesian heads were declining in the Las Vegas area, signifying a depletion of ground-water storage. Consequently, the computed underflow of about 12,000 acre-feet for 1912 must be somewhat larger than the actual recharge to the ground-water reservoir.

Application to present conditions.—Ground-water underflow to the Las Vegas area in 1955 is computed in a manner similar to that described above and is based on the hydraulic conditions that existed in the ground-water reservoir at that time. Water levels in wells in the Las Vegas Valley fluctuate throughout the year, the highest stages generally occurring in February and the lowest stages, in September. (See figs. 6, 7, 8.) During these two periods, when the hydrographs peak and trough, there is a short period of relative stability. During the period when the hydrographs peak, ground water withdrawals in Las Vegas Valley are at a minimum, and that part of the underflow resulting from drainage of the sediments in the remote areas of the reservoir is at a minimum, so that the condition is most nearly approached in which the rate of underflow to the Las Vegas area is approximately equal to the average rate of recharge. Therefore, underflow to the Las Vegas area during February 1955 rather than during September 1955 was computed as an estimate of average annual recharge to the basin. Plate 3 shows the composite piezometric surface in the vicinity of Las Vegas in February 1955. The 21-mile-long section through which ground water underflow is computed is divided into 12 irregular segments similar to those described previously (p. 41). Values of the coefficient of transmissibility used for computed underflow into the valley in 1955 are the same as those used for computing inflow during 1912 (table 4). The ground-water underflow through a cross section of the aquifer between two consecutive piezometric contours in each map segment of the valley and the total ground-water underflow into Las Vegas Valley are shown in table 6.

As can be seen from table 6, approximately 61 acre-feet per day of ground-water underflow moved across the 12 map segments shown on plate 3 toward the Las Vegas area within the average depth tapped by the wells. Approximately 12 acre-feet of ground water per day was discharged in the remote areas of the reservoir. Therefore, the total underflow during February 1955 through the depth of sediments commonly tapped by wells in Las Vegas Valley was about 73 acre-feet per day, or about 15 acre-feet per day more than in 1912. The increase in underflow to the Las Vegas area in 1955 that is indicated by these computations is due to the increased hydraulic gradient in 1955.

If it can be assumed that recharge enters the aquifers at a uniform rate throughout the year and that underflow in February is approxi-

TABLE 6.—*Estimated underflow into Las Vegas Valley in February 1955*

[Estimates of transmissibility should be considered correct only to the general order of magnitude]

Map segment (pl. 3)	Water-level contour interval used (pl. 3)	Average length of contours miles) (*W*)	Approximate coefficient of transmissibility (gpd per ft) (*T*)	Average hydraulic gradient (ft per mi) (*I*)	Underflow (mgd) (*Q*)
1............	1750–1800	2. 25	1, 100	27	0. 07
2............	1750–1800	2. 5	4, 400	31	. 34
3............	1900–1950	. 6	40, 000	46	1. 10
4............	1950–2000	2. 6	3, 200	77	. 56
5............	2100–2150	1. 1	9, 500	50	. 52
6............	2155–2160	3. 25	265, 000	12	10. 50
7............	2100–2150	1. 7	2, 800	62	. 30
8............	2000–2050	. 5	24, 000	55	. 66
9............	2100–2150	. 8	4, 000	33	. 02
10...........	2100–2150	2. 3	18, 500	25	1. 06
11...........	2100–2150	1. 8	125, 000	21	4. 73
12...........	2100–2150	1. 7	3, 200	28	. 15
Total (rounded)	....	....	....	....	20

Approximate underflow into Las Vegas Valley in segments 1–12 acre-feet per day..	61
Approximate ground-water discharge in area outside segments 1–12.do..	12
Approximate total underflow into Las Vegas Valley in February 1955 acre-feet per day..	73
Approximate total underflow into Las Vegas Valley in 1955, based on an extrapolation of February underflow...acre-feet per year (rounded)..	27, 000

mately equal to the rate of accretion in the recharge area, then the recharge in 1955 was about 73 acre-feet per day, or approximately 27,000 acre-feet per year. Hydrographs for wells in the remote areas of the reservoir (fig. 7), however, show that the water levels in these areas in February 1955 were at a lower altitude than in February 1954, and therefore the ground-water reservoir had not reached dynamic equilibrium in the remote areas of the reservoir. Consequently, part of the computed underflow into the Las Vegas area in February 1955 was water released from storage up gradient from the 21-mile-long section. In so far as the computed underflow is a measure of the average annual natural recharge, then recharge to the Las Vegas ground-water basin probably is somewhat less than 27,000 acre-feet annually.

RECHARGE FROM PRECIPITATION

Recharge in the Las Vegas ground-water basin depends almost entirely on precipitation, and fluctuations in annual precipitation undoubtedly result in fluctuations in recharge. General considerations of the hydrologic regimen—particularly the rate of movement of ground-water through the sediments and the time lag of pressure heads—suggest that a measurable period of time should elapse between the time recharge occurs in the uplands and the time the recharge affects water levels in the central part of the basin. A preliminary estimate of this time lag in the Las Vegas area was made by Maxey and Jameson (1948, p. 102). A more quantitative approach to a similar problem in New Mexico was made by Hantush (1955), who applied a mathematical relationship between rainfall and recharge. This relationship was developed by Jacob (1944, p. 564) and is called the 3-year effective average rate of precipitation. Although the mathematical approach could not be applied to the Las Vegas area because of a shortage of data, several pieces of evidence, which are discussed in the following paragraphs, suggest that an empirically analogous, but not exactly similar, 3-year effective average-rate-of-precipitation relationship exists in the Las Vegas ground-water basin.

The 3-year effective average-rate-of-precipitation relationship in the Las Vegas basin was derived by trial and error, and the evidence documenting it is scanty; moreover, further information will undoubtedly refine or modify the equation suggested for the relationship. However, the 3-year effective average rate of rainfall suggested for the Las Vegas area is believed to be reasonably valid because the estimate of the average annual recharge based on this relationship is in general agreement with estimates of recharge computed from discharge under natural conditions and from inflow to the pumped area.

Records of precipitation, water-level fluctuation, and discharge were used to analyze the relationship between the amount of precipitation in the recharge area and the resulting ground-water recharge in the Las Vegas basin. Recharge can be estimated if records of precipitation and of ground-water discharge from the basin are available for a period when the ground-water body is in equilibrium—that is, when the average recharge equals the average discharge.

The Las Vegas precipitation record is used as a basis for comparing precipitation and recharge because it is the only long-term precipitation record in the valley and because variations in amounts of precipitation at the Las Vegas weather station are similar to those in the recharge area. The precipitation map of Nevada (Hardman and Mason, 1949, p. 10) and "Climatological Data, Nevada, Annual Summary 1960" show that the amount of precipitation varies principally with increase or decrease in altitude. Records of precipitation and departure-from-average curves for four storage gages in the mountains, although short and discontinuous, show a distinct correlation with the record of precipitation at Las Vegas (fig. 4). (See also, Maxey and Jameson, 1945, p. 30.) The 6-year period, 1947–52, is the only period common to the records from the gages in the mountains and the record at Las Vegas. Periods of above- or below-normal precipitation at Las Vegas generally correspond with those in the recharge area. Because of the relationship between weather stations in the recharge area and the Las Vegas weather station, the precipitation recorded at Las Vegas is used as an index in studying the effect of precipitation on water levels in wells and on the recharge to the ground-water reservoir.

In the Las Vegas area, Maxey and Jameson (1948, p. 102) compared a hydrograph of the mean monthly water level in 15 selected wells with a graph of precipitation and found that the effects of precipitation were noticeable 12 to 18 months after the precipitation fell. As a result of the present investigation, however, the comparison of precipitation with the average annual water-level fluctuations in the 15 selected wells and in individual wells indicated, first, that the maximum effect may occur as much as 2 years after above-average precipitation and, secondly, that the recharge effect on the developed part of Las Vegas Valley extends over several years. The extended period of the effect is due largely to the differences in thickness of unsaturated sediments in the recharge areas and to the irregularity of the distances of the recharge area from the developed area. The time lag is undoubtedly due more to the impedance of the transmission of pressure effects than to the actual movement of water.

The relationship of annual water-level fluctuation to changes in recharge in the Las Vegas basin can be shown in spite of incomplete records and the masking effects of increasing ground-water withdrawals since the 1940's. When the effects of withdrawal are minimal, the relationship of precipitation to water-level fluctuations can be shown by annual water-level measurements; on the other hand, when withdrawals result in a generally continuous decline of the water table, the relation of precipitation to recharge is suggested by seasonal variations in the amplitude of water-level fluctuations.

The lag in time and the duration of the recharge effect are illustrated by comparing the hydrograph of well S20/60–36dbb1 (No. 18) with precipitation and ground-water discharge during the period prior to 1942 when withdrawals were relatively uniform (fig. 8). Although records of water levels in most wells prior to 1940 are few and are usually discontinuous, the water level in well 18 has been measured periodically since 1925. Prior to 1941 the annual water-level fluctuations illustrated by the hydrograph reflect changes in the rate of water-level decline resulting from variations in recharge caused by precipitation. The hydrograph shows that the water level in well 18 has been generally declining since the well was drilled, except in the years 1933–35 and 1939–41, when the mean annual water level in the well remained virtually unchanged. A comparison of the hydrograph for this well for the period prior to 1941 with the record of precipitation at the index station at Las Vegas (fig. 8) and with the cumulative departure from average precipitation (fig. 3) shows that the water level in well 18 declined during 1931–32 despite the abnormally

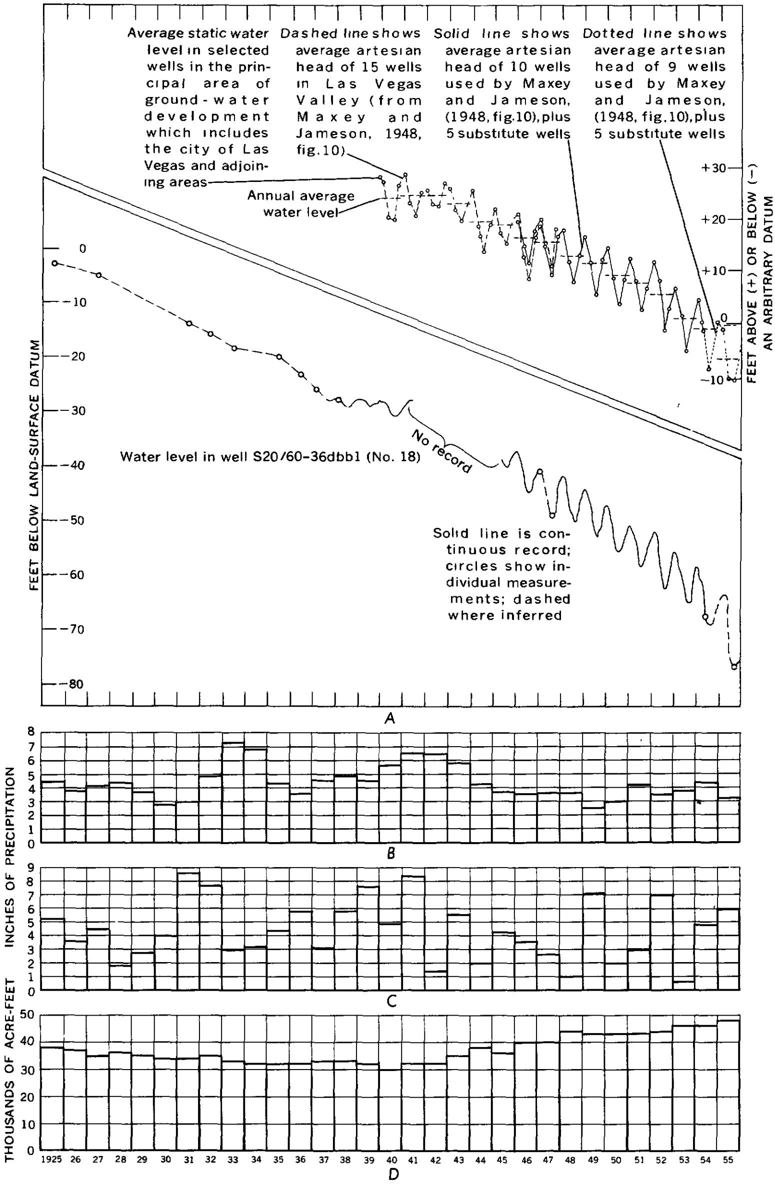

FIGURE 8.—Relation between discharge, recharge, precipitation, and changes in ground water levels in the Las Vegas ground-water basin. *A*, Changes in ground-water levels in basin. *B*, Three-year effective average rate of precipitation computed from annual precipitation at Las Vegas. *C*, Annual precipitation at Las Vegas. *D*, Ground-water discharge from basin.

large amount of precipitation that fell during those years. The relatively small decline in head suggested by the water-level measurements in July 1933 and July 1935 is not fully explained by the small decrease in discharge, and, further, the low precipitation during 1933 and 1935 should have caused an increase in the rate of decline. Therefore, the leveling off of the hydrograph during 1933–35 seems to be the result of recharge resulting from the above-average precipitation in 1931–32. A similar lag in time between precipitation and the corresponding effect on water levels in wells in the Las Vegas area occurred in 1938, and this apparently resulted from the above-average precipitation in the latter part of 1936. A straight line connecting the annual "lows" on the hydrograph of well 18 during 1937–40 shows that the anual low water level continued to decline through July of 1938 and did not begin to rise until the latter part of 1938. The maximum effects of the recharge presumably resulting from above-average precipitation in 1936 seem to begin in the last six months of 1938 and to continue into the first six months of 1939.

Unfortunately, no water-level measurements were made in well 18 between April 1941 and May 1945, a period during which the effects of the above-average precipitation of 1938–41 presumably would have affected water-level fluctuations in the well. Part of the effects of the above-average recharge resulting from the high precipitation in 1938–41 can be seen, however, by comparing the annual precipitation at Las Vegas with the average water level in 15 wells in the vicinity of Las Vegas (fig. 8). Although there are no water-level data for the 15 observation wells prior to 1940, part of the effects of the above-average precipitation during 1938–41 can be observed in the average water-level fluctuations through 1943. A comparison of the hydrograph for well 18 with the hydrograph for 15 selected wells shows that the water level in well 18 responds similarly to the annual average water level represented by the 15 selected wells. Therefore, it seems reasonable to assume that prior to 1940 the average water levels in the 15 wells were declining also.

The fact that the annual average water level did not change significantly during 1940–43 despite the increased discharge during those years suggests that the above average precipitation of 1938–41 may have effected an increase in recharge.

The annual increase in ground-water discharge since 1943, together with the below-average annual precipitation during most of the period 1943–55, resulted in a general decline in water levels in the observation wells that tends to conceal the effects of recharge during 1943–55. The effects of abnormally high or low recharge since 1943 generally are not apparent.

The major effects of the recharge in any one year seem to last over a period of about 3 years. The duration is not distinguishable during most of the periods of record, but it can be identified in the period between the summers of 1933 and 1935. The hydrograph of well 18 shows that after the heavy rains of 1931–32 the water-level decline that had been occurring was temporarily checked and that from 1933 to 1935 it remained checked despite the decrease in annual rainfall during 1933–35. Discharge in 1934–35 was about 1,000 acre-feet less than in 1933. Although a decrease in discharge would tend to reduce the rate of decline of water levels during 1934–35, the decreased rate of decline in head suggested by the hydrograph during those years is not commensurate with the relatively small decrease in discharge. Also, the natural discharge from artesian springs in Las Vegas Valley showed no decline in discharge from 1933–35 but showed a small decline in 1936. These observations suggest that the recharge of 1931–32 was carried over into 1935, and general considerations of the hydrologic regimen would suggest that such a carryover might be expected at other periods following heavy recharge. That part of the precipitation that becomes the recharge for any one year is called in this report the 3-year effective average rate of precipitation.

Effective average rate of precipitation (Hantush, 1955, p. 45) was originally defined by Jacob (1944, p. 564) as the "* * * rate of precipitation which, had it been maintained uninterruptedly throughout the past, would have produced the same water-table profile as actually existed at that particular time." An attempt to correlate the precipitation recorded at Las Vegas with the mean annual water-level fluctuations in wells in a manner analogous to the method used by Hantush (1955, p. 45–52) for the Roswell basin, New Mexico, was unsuccessful because the results obtained were not compatible with the existing hydrologic data. By substituting various values for the various components of the effective average rate of precipitation, it was found that the best correlation between the hydrologic and precipitation data was obtained by using the sum of one-fourth, one-half, and one-fourth of the annual precipitation recorded at Las Vegas for the 3 years preceding the year in question. For any one year this amount and proportional distribution of precipitation simulates the fluctuation of the water level and seems to be indicative of the amount of recharge that reaches the water table. The 3-year effective average rate of precipitation (R) for year (n) can be expressed as follows: $R_n = \frac{1}{4}R_{n-1} + \frac{1}{2}R_{n-2} + \frac{1}{4}R_{n-3}$, in which R_n is the annual precipitation for a particular year. Table 7 shows the average annual precipitation recorded at the Las Vegas station and the effective average rate of precipitation computed from the above relationship. The relationship between the 3-year effective average rate of precipitation and water-level fluctuations at Las Vegas is graphically illustrated in figure 8. Prior to 1943, ground-water discharge remained relatively uniform. During this period the graph of the 3-year effective average rate of precipitation is closely reflected by the hydrographs. The effects of increased ground-water discharge and deficient precipitation after 1943 has resulted in an annual water-level decline that conceals any apparent relationship.

TABLE 7.—*Annual precipitation and computed effective average rate of precipitation at Las Vegas, in inches*

[No records available for 1900–07]

Year	Precipitation	Effective average rate of precipitation[1] (R_n)
1896	3.24	
1897	5.35	
1898	1.64	
1899	2.03	
1900–1907		
1908	4.73	
1909	7.05	
1910	4.11	
1911	[2] 3.41	5.7
1912	[2] 2.70	4.6
1913	4.96	3.40
1914	4.98	3.49
1915	8.41	4.39
1916	8.11	5.83
1917	4.33	7.46
1918	8.63	7.23
1919	4.95	6.34
1920	4.74	6.63
1921	5.47	5.81
1922	5.81	4.98
1923	4.50	5.36
1924	2.49	5.39
1925	5.27	4.32
1926	3.58	3.67
1927	4.49	4.14
1928	1.75	4.22
1929	2.77	3.57
1930	3.97	2.65
1931	8.58	2.81
1932	7.75	4.78
1933	2.94	7.22
1934	3.24	6.74
1935	4.38	4.22
1936	5.84	3.44
1937	3.13	4.46
1938	5.84	4.79
1939	7.67	4.48
1940	4.93	5.62
1941	8.40	6.52
1942	1.45	6.48
1943	5.66	5.79
1944	1.91	4.23
1945	4.34	3.67
1946	3.58	3.44
1947	2.65	3.54
1948	1.00	3.53
1949	6.88	2.46
1950	2.05	2.88
1951	3.01	4.20
1952	6.98	3.49
1953	.60	3.75
1954	4.75	4.39
1955	5.98	3.22
1956		4.01

[1] Sum of one-fourth the precipitation of the preceding year, one-half the precipitation of the second year prior to the current year, and one-fourth the precipitation of the third year prior to the current year.

[2] Estimated from nearby weather stations.

During a period when there has been no net change in ground water in storage, the ground-water system is in dynamic equilibrium, and the ground-water inflow is proportional to the effective average rate of precipitation and is equal to the outflow according to the following relationship adapted from Hantush (1955, p. 45):

$$Q = CR_n = P + D,$$

where Q is equal to inflow into the reservoir, in acre-feet per year, which during conditions of equilibrium is equal to recharge; C is equal to a constant for the basin, in terms of acre-feet per inch of average rainfall; R_n is equal to the effective average rate of precipitation, in inches per year; P is equal to the amount of artificial ground-water withdrawals, in acre-feet per year; and D is equal to the natural discharge, in acre-feet per year. When the ground-water system is in equilibrium, the ratio $\frac{P+D}{R_n}$ provides a reasonable value for C, the amount of recharge per inch of the 3-year effective average rate of precipitation. This formula, then, can be used to determine the annual recharge and the average annual recharge for the period of record.

The available records on discharge from artesian springs and flowing wells and on water-level fluctuations in wells indicate that during 1933–34 and 1941–42 the Las Vegas ground-water reservoir was in approximate equilibrium. The total ground-water discharge from the valley for 1933 was about 33,000 acre-feet, and for 1934, 1941, and 1942 the discharge was estimated to be about 32,000 acre-feet (table 9). The effective average rate of precipitation computed for the Las Vegas weather station for these years was 7.33, 6.74, 6.52, and 6.48 inches, respectively. By substituting these values into the equation above, one derives a constant which, when multiplied by the effective average rate of precipitation at the Las Vegas station, will be the approximate amount of recharge entering the valley for that year. If the equation is applied to the data for 1933, 1934, 1941, and 1944, the value obtained for C for each successive year is computed to be 4,570, 4,748, 4,908, and 4,938 acre-feet of recharge per inch of precipitation at Las Vegas. The above computations suggest that for each inch of effective average rate of precipitation recorded at the Las Vegas station there is about 4,800 acre-feet of recharge to the ground-water reservoir. From the above relationship it then becomes possible by substituting the proper values into the equation to determine the approximate amount of recharge, in acre-feet, during any year for which the effective average rate of precipitation can be computed. Figure 9 shows the approximate recharge annually replenishing the ground-water reservoir based on the above relations. The natural recharge to the Las Vegas ground-water reservoir suggested by these computations ranges from about 12,000 to 37,000 acre-feet annually. The rigid use of the method for calculating recharge for any one year is subject to considerable error because even years having the same total rainfall will have differences in the amount of infiltration due to variation in storm intensities, in soil moisture at the beginning and during the rainy season, and in related characteristics. However, over a series of years these errors will tend to balance each other.

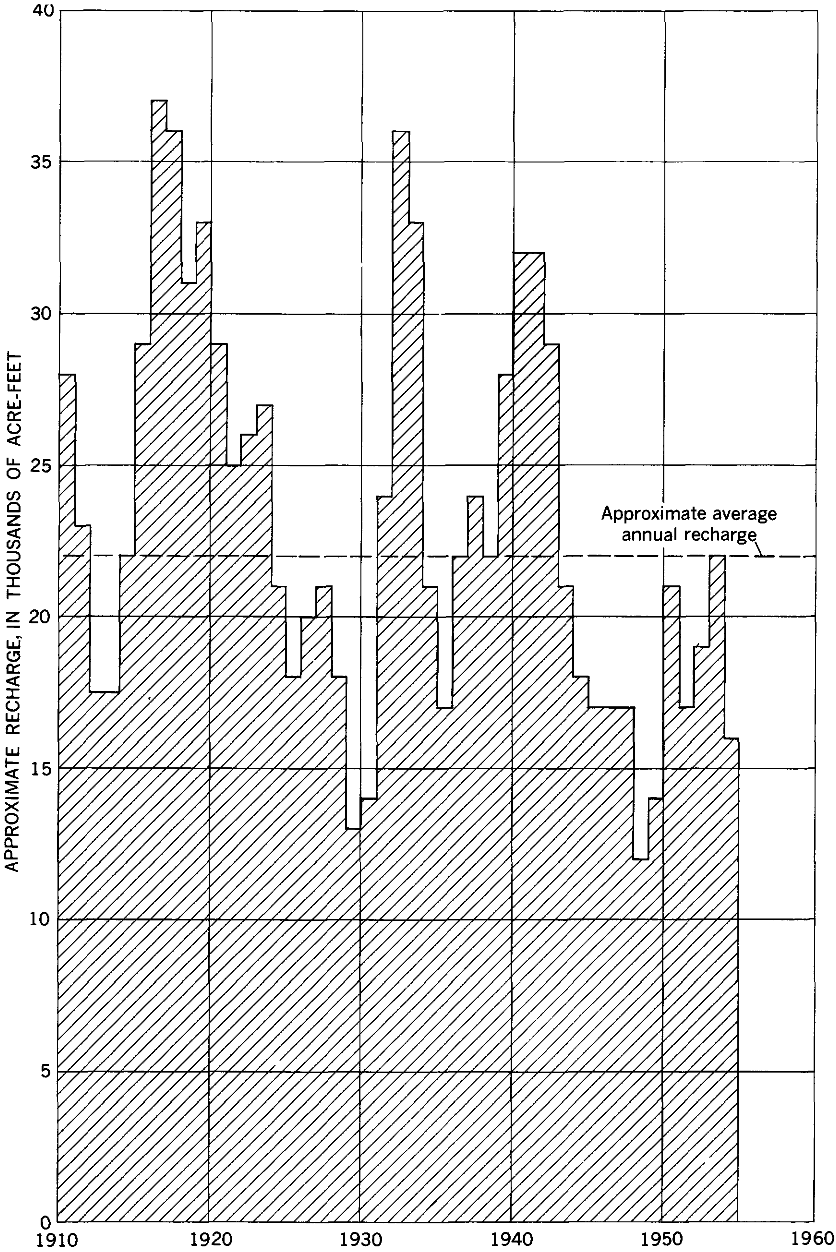

FIGURE 9.—Estimated annual natural recharge from precipitation to the three principal zones of artesian aquifers.

The average annual recharge for the period of record can be estimated by assuming that the long-term annual rate of precipitation for the index station at Las Vegas is equal to the sum of the yearly effective average rate of precipitation divided by the number of years of record. Consequently, the average annual recharge to the Las Vegas ground-water basin, based on the period of available precipitation records, can be computed by multiplying the average annual rate of precipitation at the Las Vegas station (4.56 inches for the 50-year period of record) by C (4,800 acre-feet of recharge per inch of effective average rate of precipitation). The result is approximately 22,000 acre-feet, which is in close agreement with estimates of the average annual recharge derived by methods previously described.

SUMMARY OF RECHARGE ESTIMATES

The three methods of estimating the natural recharge to the Las Vegas ground-water basin indicate that the average annual natural recharge is about 25,000 acre-feet.

The first method of estimating the average annual recharge to the Las Vegas basin under natural conditions is an indirect method and is based on the assumption that the average annual recharge to the basin is in dynamic equilibrium with the average annual discharge from the basin. It is inferred from estimates of discharge under natural conditions that the average annual recharge to the ground-water basin is about 24,000 acre-feet per year.

The second method of estimating average annual recharge to the Las Vegas basin is based on computations of ground-water underflow and yields only rough estimates because during 1912 and 1955, the only years for which data are available to compute underflow, part of the underflow was derived from water released from storage in the more remote areas of the ground-water reservoir. Therefore, the underflow of about 21,000 and 27,000 acre-feet computed for 1912 and 1955, respectively, is probably somewhat larger than the annual recharge to the ground-water reservoir during those years.

The chief value of the calculations by the first two methods is that they place an upper limit on the amount of natural recharge to the ground-water basin during those years.

The third method of estimating the average annual recharge to the basin is based on the relationship between water-level fluctuations in the ground-water reservoir and precipitation. This method indicates that the average annual recharge to the ground-water basin is on the order of 22,000 acre-feet.

The close agreement of the results obtained by the three different methods suggests that the average annual recharge to the Las Vegas ground-water reservoir is about 25,000 acre-feet, or about 10,000 to

15,000 acre-feet per year less than the estimates made by Maxey and Jameson (1948, p. 108).

Maxey and Jameson estimated that the average annual natural recharge to Las Vegas Valley probably is between 30,000 and 35,000 acre-feet and that the recharge to Indian Spring Valley which they considered to be a separate hydrologic unit, is about 4,700 acre-feet. These estimates were based on the relationship between recharge and precipitation and were adapted from studies in other regions having physical characteristics somewhat similar to those of Las Vegas Valley. The estimates were obtained by multiplying the area within selected altitude zones in the recharge area by the amount of precipitation that occurred in each of these zones and that was estimated to reach the ground-water body. The estimate of recharge to the northern part of Las Vegas Valley was supported by the computations of ground-water underflow through a cross section of the valley fill between the Tule Springs Ranch and the base of La Madre Mountain. Maxey and Jameson computed that the underflow through this section is about 24,000 acre-feet per year. This estimate agrees favorably with their estimated recharge for that particular part of the basin. However, because of the inadequate hydrologic data on which the computation was based, Maxey and Jameson (1948, p. 106) recognized that the actual figure might be considerably more or less than the computed value.

The estimates of recharge to the Las Vegas basin discussed in this report are in part based on methods that incorporate many hydrologic data that have become available since the earlier estimate was made, and, therefore, the proposed revision of the estimated average annual recharge from 30,000–35,000 acre-feet to about 25,000 acre-feet seems justified.

DISCHARGE

Ground water is discharged from the artesian aquifers naturally and artificially. Natural discharge of ground water from the deep aquifers in Las Vegas Valley is by springs and seeps and upward leadage to the near-surface reservoir. There is no evidence of appreciable underflow from the valley. Ground water is artificially discharged from the deep aquifers by means of flowing or pumped artesian wells.

NATURAL DISCHARGE

Under natural conditions the sedimentary deposits beneath the floor of the valley were saturated with ground water to within a few tens of feet of the land surface, and for all practical purposes the average annual discharge was equal to the average annual replenishment. Practically all ground-water discharge in the basin at that time was by spring discharge and upward leakage and subsequent evapotranspiration by native vegetation in the area east of the Las Vegas Springs and in Paradise Valley. Although the hydraulic gradient southeast of Las Vegas is toward Las Vegas Wash, it is highly unlikely that there is any significant ground-water discharge from the east side of the basin by subsurface underflow. Precambrian granite along the base of Frenchman Mountain and highly impermeable conglomerate, sandstone, shale, and volcanic rocks beneath Las Vegas Wash and the region to the south prevents most subsurface outflow. In the area west of Las Vegas Wash, ground water in the valley fill and in the underlying bedrock probably leaks upward to the near-surface reservoir and is discharged by evapotranspiration.

Overdraft of the Las Vegas artesian reservoir since 1906 has caused a lowering of artesian pressures and a consequent decrease in spring flow and upward leakage. However, much water is still being discharged by natural processes. The major part of the natural discharge from the artesian aquifers leaks upward through the semiconfining beds to recharge the near-surface ground-water reservoir. An estimate of the amount of discharge by upward leakage is discussed on pages 78–92.

SPRINGS

Las Vegas, Kyle, Stewart, Corn Creek, Stevens and Grapevine Springs (pl. 1) discharge ground water that leaks upward from the artesian aquifers. The decline in artesian head that has accompanied the ground-water development in Las Vegas Valley has resulted in the reduction of the flow of most springs in the valley and has caused many of the smaller springs in the valley to dry up. Consequently, discharge of ground water from artesian springs in Las Vegas Valley has dwindled from approximately 6,400 acre-feet per year in 1906 to approximately 1,400 acre-feet per year in 1955. (See tables 8, 9.)

The principal artesian springs and seep areas are along the base of the north-south fault scarps that pass through the central part of Las Vegas Valley (p. 12).

Where permeable aquifers have been faulted against impermeable beds, the lateral movement of the ground water is impeded, and therefore the water moves upward by artesian pressure through the semiconfining beds and through the fault zones. Part of this water recharges the near-surface reservoir, and part of it reaches the land surface as seeps or spring flow.

All the discharge from the Las Vegas Springs is used to supplement the Las Vegas municipal water supply. Approximately half the flow from Corn Creek Springs is consumptively used for domestic purposes and irrigation. The water not consumptively used infiltrates to the ground-water reservoir or is evaporated. Most of the discharge from the smaller springs in the valley is consumed by phreatophytes. Because virtually all the spring discharge in Las Vegas Valley is used

TABLE 8.—*Discharge of springs and drains, in acre-feet, in the Las Vegas ground-water basin*

[See pl. 1 for location]

Year	Springs in Las Vegas Valley							Springs in the remote areas of the ground-water basin					Spring and drains in Las Vegas Valley			Total (rounded)
	Las Vegas Springs S20/61-30ddc S20/61-30ddd S20/61-31aab	Tule Spring S19/60-9cd	Kyle Spring S20/61-15dc	Corn Creek Springs S17/59-34ab	Stevens or Mesquite Springs S21/62-31dac	Grapevine Springs S21/62-29db	Subtotal (rounded)	Indian Spring S16/56-16b1	Cottonwood Spring S22/59-7db	Sandstone Spring S22/58-3cb	Red Rock Canyon Springs S21 and 22/58	Subtotal (rounded)	Stewart Spring and drain S20/61-27dac	Charleston drain and ditch [1]	Subtotal (rounded)	
1946	1,800	400	650	240	42	38	3,200	700	360	230	96	1,400	10	0	10	4,600
1947	1,700	380	590	200	42	38	3,000	700	360	230	96	1,400	10	0	10	4,300
1948	1,700	320	530	200	42	38	2,800	700	360	230	96	1,400	10	0	10	4,200
1949	1,600	260	460	200	42	38	2,600	700	360	230	96	1,400	10	500	500	4,500
1950	1,500	200	400	200	42	38	2,400	700	360	230	96	1,400	10	500	500	4,300
1951	1,400	160	340	200	42	38	2,200	700	360	230	96	1,400	10	500	500	4,100
1952	1,300	100	280	200	42	38	2,000	700	360	230	96	1,400	10	500	500	3,900
1953	1,200	60	220	200	42	38	1,800	700	360	230	96	1,400	10	500	500	3,700
1954	1,100	0	140	200	42	38	1,500	700	360	230	96	1,400	[2] 107	500	600	3,500
1955	1,000	0	90	200	42	38	1,400	700	360	230	96	1,400	107	500	600	3,400

[1] Discharge from the Charleston Boulevard drain flows in an open ditch from the SW¼ sec. 36, T. 20 S., R. 61 E., diagonally across sec. 36 to the ditch carrying the effluent from the Las Vegas sewage disposal plant. The drainpipe parallels Charleston Boulevard from the vicinity of the Union Pacific Railroad and was constructed to lower the water level in the area of upward leakage east of the Las Vegas Valley Water District well field.

[2] In 1954 a concrete drainpipe was buried adjacent to Stewart Spring, and the entire spring area was covered by fill. Elimination of phreatophyte discharge and the interception of some additional upward leakage along the fault scarp by the drainage tile caused the increased discharge.

consumptively or is evaporated, the discharge by springs shown on the left side of table 8 represents a draft on the artesian system.

In addition to the artesian springs in Las Vegas Valley, there are several gravity springs in the intake areas of the artesian system in the remote areas of the ground-water reservoir. These include Indian Spring in Indian Spring Valley; Cottonwood Spring at Blue Diamond; Sandstone Spring, 4 miles northwest of Blue Diamond; and several smaller springs south of Red Rock Canyon that include Oak Creek, Pine Creek, First Creek, Wheeler Camp, and Mormon Green Springs—included under the heading of Red Rock Canyon Springs in table 8. Indian and Sandstone Springs have been developed principally for irrigation, and Cottonwood Spring has been developed as the main water supply for the mine and townsite at Blue Diamond. Approximately 450 acre-feet of spring discharge from Indian Spring was used consumptively during 1955. The remainder of the spring flow is assumed to have returned to the ground-water reservoir. Most of the discharge from the springs in the Red Rock Canyon area is consumed by native vegetation. Except for a small amount of spring discharge that may infiltrate down to the main ground-water reservoir, spring discharge in the remote areas of the ground-water basin is consumptively used or is evaporated and, consequently, represents a draft on the ground-water body.

A few large springs and many small springs are in the mountains bordering Las Vegas Valley; water from these springs is principally used for watering cattle. The flow of many of the mountain springs percolates into the ground within short distances from the points of discharge and, probably, recharges the main ground-water reservoir eventually.

SEEPS AND DRAINS

Along most of the scarps in the vicinity of Las Vegas, small springs and ground-water seeps discharge ground water leaking upward from the artesian system. In general, the ground-water discharge from these areas cannot be measured by direct methods, but, on the basis of the density and species of phreatophytes that grow along the scarps, ground-water discharge by evapotranspiration in these areas is estimated to be small.

Two exceptions to the above generalities are Stewart Spring and its drain in the SE¼ sec. 27, T. 20 S., R. 61 E., and the Charleston Boulevard drain, which is buried below Charleston Boulevard and extends from the Union Pacific Railroad track in the SE¼ sec. 33, T. 20 S., R. 61 E., to the SW¼ sec. 36, T. 20 S., R. 61 E.

Stewart Spring originally issued from a seep area covered by dense vegetation near the base of a large scarp. Prior to 1954, discharge from the spring was about 10 acre-feet per year. As a result of the realinement of 5th Street in the vicinity of the spring in 1954, a drainpipe was buried adjacent to the spring, and the entire area was covered by fill. Water which previously was consumed by phreatophytes and could not be measured, was collected and discharged through the drain. Thus, the apparent increase in discharge shown in table 8 actually indicates that before 1954 about 100 acre-feet was consumed by phreatophytes annually.

The Charleston Boulevard drain is a buried drain that was constructed principally to lower the ground-water level in the vicinity of the intersection of Caarleston Boulevard and the Union Pacific Railroad tracks. This area is near the center of what once was a principal area of natural discharge. Prior to the construction of the drain, much of the ground water leaking upward through the confining layers and along the fault scarp from which the Las Vegas Springs issue was transpired by lush stands of saltgrass and other native grasses that grew in the area. Since the construction of the drain, however, almost all natural discharge by phreatophytes in the area of the drain has been eliminated. Estimates of the discharge from the Charleston Boulevard drain are shown in table 8.

ARTIFICIAL DISCHARGE

The principal means of recovery of water from the three main artesian aquifers in the Las Vegas ground-water reservoir is by pumping from wells. After the completion of the first successful artesian well in 1906 by the Las Vegas Artesian Water Syndicate, development of ground water progressed rapidly, and by 1912 the pumpage had reached approximately 15,000 acre-feet annually. The pumpage from wells remained fairly constant until aobut 1943 when it began to increase again. By 1955 it had reached approximately 40,000 acre-feet annually. (See table 9.)

The largest withdrawal of ground water is from the Las Vegas Valley Water District well field immediately west of the city of Las Vegas. Other areas of large withdrawals are in the vicinity of the city of North Las Vegas, The Strip area, Nellis Air Force Base, and irrigated areas north and south of Las Vegas.

Most of the farms and rural housing developments are supplied by water from wells generally not more than 100 feet deep that tap the near-surface aquifers. The majority of the domestic wells are up the hydraulic gradient from the principal areas of infiltration of waste water from the Las Vegas sewage disposal plant, and, therefore, the bulk of the ground water pumped from shallow wells is water that has leaked upward from the artesian system. Therefore, in this report, ground water pumped from shallow wells is considered as a draft on the artesian system and is included in the estimates of upward leakage in table 9.

TABLE 9.—*Estimated net draft, in acre-feet, on the artesian aquifers of the Las Vegas ground-water basin*

Year	Spring and drain discharge				Well discharge [3]				Total discharge from springs, drains, and wells	Approximate upward leakage		Total [5] (rounded to nearest 1000 acre-feet)
	Springs in Las Vegas Valley	Springs in the remote areas of ground-water basin [1]	Spring and drains in Las Vegas Valley	Total [2]	Las Vegas Valley	Indian Spring Valley	Red Rock Canyon area	Total [3]		Discharge by phreatophytes (from fig. 14)	Discharge by shallow wells [4]	
1906	6,400	1,100		7,500	0			0	7,500	17,600		25,000
1912	5,300	1,100		6,400	15,200			15,200	21,600	16,100		38,000
1924	5,100	1,100		6,200	17,300			17,300	23,500	12,900		36,000
1925	5,000	1,100		6,100	19,300			19,300	25,400	12,600		38,000
1926	5,000	1,100		6,100	18,400			18,400	24,500	12,400		37,000
1927	4,800	1,100		5,900	17,300			17,300	23,200	12,100		35,000
1928	4,200	1,100		5,300	18,600			18,600	23,900	11,800		36,000
1929	4,100	1,100		5,200	18,500			18,500	23,700	11,600		35,000
1930	4,200	1,100		5,300	17,300			17,300	22,600	11,300		34,000
1931	4,200	1,100		5,300	17,500			17,500	22,800	11,000		34,000
1932	4,100	1,100		5,200	19,200			19,200	24,400	10,800		35,000
1933	4,100	1,100		5,200	17,500			17,500	22,700	10,500		33,000
1934	4,100	1,100		5,200	16,700			16,700	21,900	10,200		32,000
1935	4,100	1,100		5,200	17,100			17,100	22,300	10,000		32,000
1936	4,000	1,100		5,100	17,400			17,400	22,500	9,700		32,000
1937	4,100	1,100		5,200	17,800			17,800	23,000	9,500		33,000
1938	4,100	1,100		5,200	18,200			18,200	23,400	9,200		33,000
1939	3,800	1,100		4,900	17,900			17,900	22,800	8,900		32,000
1940	3,700	1,100		4,800	16,900			16,900	21,700	8,700		30,000
1941	3,400	1,100		4,500	18,700			18,700	23,200	8,300		32,000
1942	3,000	1,100		4,100	19,000	10		19,600	23,700	8,100		32,000
1943	3,300	1,100		4,400	22,100	650		22,800	27,200	7,800		35,000
1944	3,000	1,100		4,100	25,300	650		26,000	30,100	7,600		38,000
1945	3,100	1,100		4,200	23,900	650		24,600	28,800	7,300		36,000
1946	3,200	1,100		4,300	28,500	10		28,500	32,800	7,100		40,000
1947	3,000	1,100		4,100	29,000	40		29,000	33,100	6,800		40,000
1948	2,800	1,100		3,900	[6] 32,800	60		32,900	36,800	6,500	140	44,000
1949	2,600	1,100	500	4,200	[6] 32,600	90		32,700	36,900	6,300	150	43,000
1950	2,400	1,100	500	4,000	[6] 32,400	110		32,500	36,200	6,000	160	43,000
1951	2,200	1,100	500	3,800	[6] 32,800	140		32,900	36,700	5,700	200	43,000
1952	2,000	1,100	500	3,600	[6] 34,300	170		34,500	38,100	5,500	310	44,000
1953	1,800	1,100	500	3,400	[6] 36,200	190	0	36,400	39,800	5,200	620	46,000
1954	1,500	1,100	600	3,200	[6] 36,800	220	40	37,000	40,200	4,900	880	46,000
1955	1,400	1,100	600	3,100	[6] 38,600	200	40	38,800	41,900	4,600	1,100	48,000

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[1] Adjusted so as not to include spring discharge that infiltrates down to the main ground-water body.

[2] Includes only spring and drain discharge that is a draft on the artesian system. Does not include discharge that returns to the ground-water body.

[3] Includes only discharge from wells developed in the three principal artesian aquifers and in the intake areas.

[4] Discharge by shallow wells is assumed to be supplied principally by upward leakage.

[5] Total discharge shown in this column does not include phreatophyte discharge of recycled ground water.

[6] Adjusted to eliminate pumpage from shallow wells.

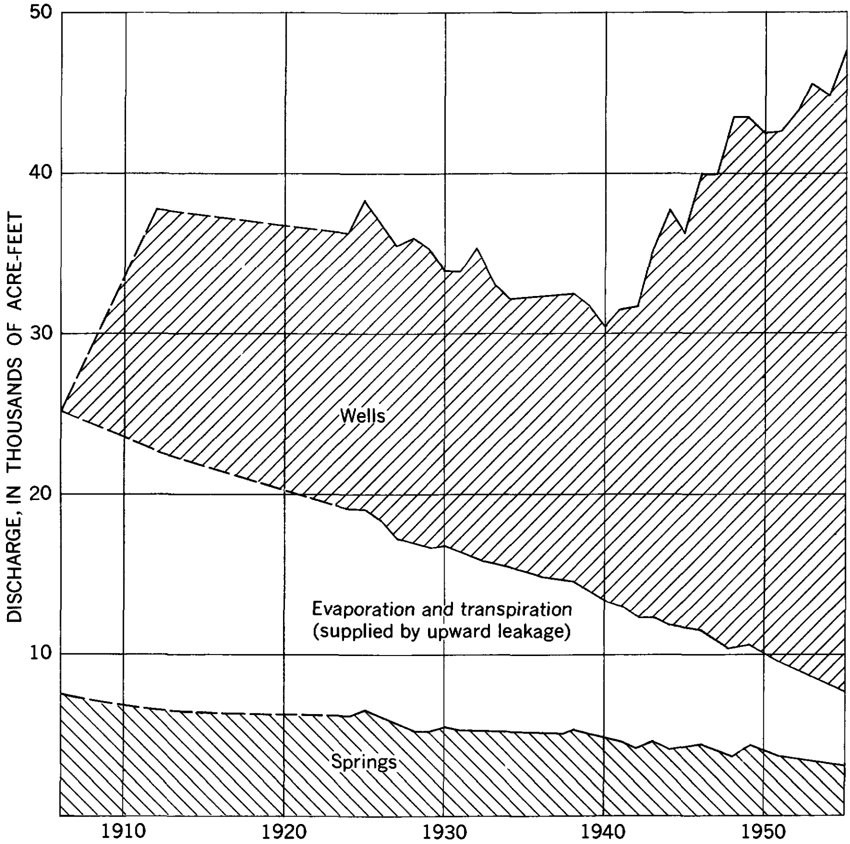

FIGURE 10.—Approximate draft on the artesian system resulting from natural and artificial discharge, and the relative magnitude of the principal discharge components.

Figure 10 shows the approximate amount of ground water discharged naturally and artificially from the artesian system during the period of development of the Las Vegas ground-water basin.

NET DRAFT ON THE ARTESIAN AQUIFERS

The estimated net draft on the artesian aquifers from wells and springs and by upward leakage to the unconfined aquifers is shown in table 9. The estimated annual discharges by wells and springs in Las Vegas Valley for 1906 and 1912 and for the 23-year period 1924–46 were taken from Maxey and Jameson (1948, p. 94–95). The estimates of the annual discharge from wells and springs in Las Vegas Valley for the 9 years 1947–55 were prepared jointly by the Las Vegas Artesian Well Supervisor and members of the Nevada District Ground Water Branch office of the U.S. Geological Survey. The estimates of upward leakage were determined indirectly from computations of phreatophyte discharge discussed on pages 73–82. (See fig. 14.) Also shown are data on ground-water withdrawals in the more remote areas of the ground-water reservoir for the years 1906 and 1912 and for the 32-year period 1924–55.

The yearly draft on the artesian aquifers is estimated to have increased from about 25,000 acre-feet in 1906 to about 48,000 acre-feet in 1955. From 1912 to 1945 the annual discharge from the artesian aquifers remained at a relatively uniform level that ranged between 32,000 and 38,000 acre-feet. After 1945, annual discharge increased steadily due to the rapid growth of the Las Vegas area. Most of the increase in ground-water withdrawals during this 10-year period resulted from increased municipal withdrawals by Las Vegas and North Las Vegas and also from increased withdrawals at the resort hotels and other commercial establishments that were constructed along The Strip.

NEAR-SURFACE WATER

Within the area roughly encompassed by the 2,100-foot land-surface contour, ground water in the near-surface reservoir in most places occurs at depths of less than 50 feet (pl. 8) in beds of fine sand, silt, or clay. In most places these beds have low permeability and yield only small quantities of water to wells.

Ground water in the near-surface reservoir occurs under confined and unconfined conditions. Small artesian heads may develop in the near-surface reservoir if ground water becomes confined beneath deposits of caliche or other semiconfining beds as it moves laterally toward lower elevations. Upward leakage from the deep artesian aquifers through semiconfining layers to the near-surface reservoir also gives rise to slight variations in water levels in wells. In areas of upward leakage the static water level is generally higher in deeper wells than in shallower wells in the same vicinity.

The upper surface of the near-surface ground water, based on water-level measurements from 41 shallow wells, is shown on plate 8.

The water table in the near-surface reservoir is not a plane surface but has irregularities that are roughly comparable to those of the land surface. The water table does not remain stationary but fluctuates in a pattern similar to that of the piezometric surface in the deeper artesian aquifers; generally, however, the amplitude of the fluctuations of the water table is much smaller. Plate 8 shows that the slope of the water table varies considerably in different parts of the valley, ranging from about 7 feet per mile in the vicinity of the Las Vegas Valley District well field to about 140 feet per mile in the vicinity of the fault passing through the east-central part of Las Vegas.

WATER-LEVEL FLUCTUATIONS

The water-table surface rises when the recharge to the shallow aquifers exceeds the discharge and declines when the discharge exceeds the recharge. Fluctuations of the water table represent changes in the amount of ground water in storage.

Under natural conditions virtually all recharge to the near-surface reservoir was by upward leakage from the artesian aquifers and all discharge from it was by evapotranspiration. During that time recharge balanced discharge and conditions of equilibrium generally prevailed. Since the development of artesian wells and the subsequent lowering of artesian head, recharge to the near-surface system from upward leakage has been diminishing. However, coincident with the development of artesian wells, natural recharge to the near-surface system by upward leakage has been supplemented by leakage from artesian wells and by infiltration of waste water. Although local changes in storage have occurred, the total amount of ground water in storage in the near-surface reservoir probably has not changed significantly from what it was under natural conditions.

Water levels in wells tapping the near-surface ground-water reservoir have been declining in the area of Las Vegas Valley west of T. 62 E. Ground water in the near-surface reservoir in the area west of T. 62 E. is recharged principally by upward leakage from the artesian aquifers, and, consequently, the water-table fluctuations in that area commonly reflect the changes in artesian head. (See fig. 11.) The hydrographs show both seasonal and long-term changes

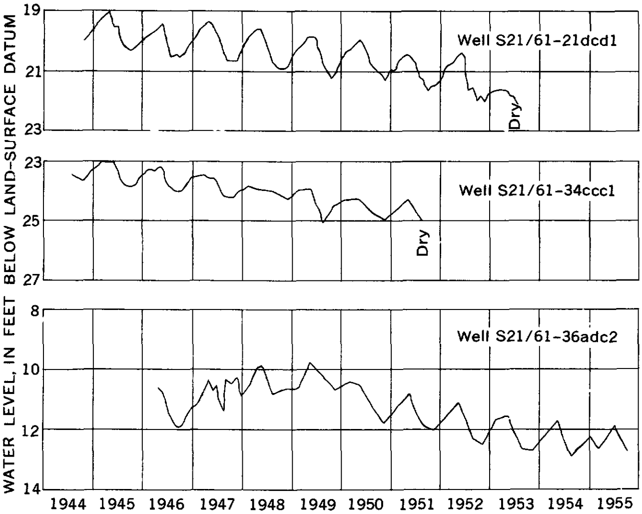

FIGURE 11.—Seasonal and long-term water-level fluctuations in wells in the near-surface ground-water reservoir in the western part of Las Vegas Valley.

in water levels in the near-surface system. The water level is generally highest in April or May and lowest in September or October and thus, closely reflects the period of heavy draft on the artesian system.

In contrast, in the lower areas of Las Vegas Valley east of T. 61 E., the water-table has been rising because of increased recharge from infiltration of waste water. A hydrograph of test well S20/62-33ccc1 (fig. 12) shows annual and long-term water-level fluctuations in the near-surface ground-water reservoir in the eastern part of Las Vegas Valley since 1945. Annual water-level fluctuations in this area are influenced by excessive recharge and by seasonal variations in discharge resulting from transpiration. After the growing season ends in September or October, transpiration stops, and the altitude of the water-table surface begins to rise. The rise generally continues through the winter until the following spring, when the growing season begins. During the period from about April or May until September or October, transpiration causes the water level to decline.

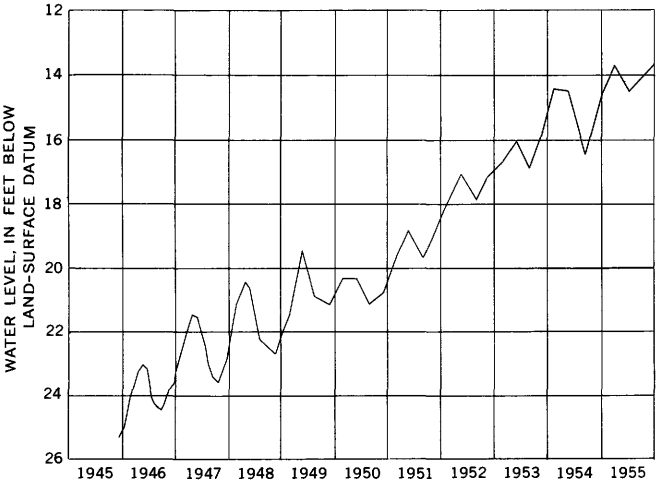

Figure 12.—Seasonal and long-term water-level fluctuations of well S20/62-33ccc1 in the near-surface ground-water reservoir in the eastern part of Las Vegas Valley.

Figure 12 shows that, during the period of record, 1945–55, the water level in the near-surface zone of aquifers in the area southeast of the sewage disposal plant rose about 11.5 feet. Rises in water level of lesser magnitude have been noted locally in many areas adjacent to irrigated plots.

RECHARGE

Recharge to the near-surface ground-water reservoir is by upward leakage from the artesian aquifers, infiltration from sewage-disposal plants and industrial waste ponds, infiltration of irrigation water, and leakage from artesian wells. Recharge to the shallow aquifers from industrial waste at Henderson is from water imported into the basin from the Colorado River. Except for the recharge derived from upward leakage and from infiltration from the industrial waste at Henderson, most of the water currently recharging the near-surface aquifer is ground water originally withdrawn from the artesian aquifers. Infiltration of imported water to the near-surface reservoir adds significantly to the total available supply of ground water in the basin. However, ground water in the near-surface reservoir has not been extensively developed because it is inferior in chemical quality to water from the artesian aquifers.

The shallow ground water underlying much of the city of Las Vegas is partly the result of upward leakage in the vicinity of Las Vegas Springs. Recharge from upward leakage to the near-surface aquifers in this area is dependent on the amount and distribution of withdrawals from the artesian aquifers, faulting of the valley sediments, and the lithologic character of the sediments. Areas of potential upward leakage are shown on plate 2. The upward leakage to the near-surface aquifers varies considerably from one area to another depending on differences in head between the artesian aquifers and the near-surface aquifers and on the permeability and thickness of the semiconfining deposits.

The recharge to the near-surface reservoir by upward leakage was not measured directly but was computed indirectly from data on evapotranspiration, infiltration, and precipitation. In 1955, recharge to the near-surface reservoir by upward leakage from the artesian aquifers was estimated to be about 6,000 acre-feet. (See table 9.)

East of Las Vegas, sewage effluent and infiltration of irrigation water contribute to the near-surface reservoir. Effluent from the sewage treatment plant in sec. 25, T. 20 S., R. 61 E., flows southeastward in an open unlined ditch toward Las Vegas Wash. Water levels in most shallow wells in this area have been rising progressively as a result of infiltration of sewage effluent. Water levels have risen most in the irrigated areas adjacent to the discharge ditch where the effluent is diverted for irrigation. Spreading of the effluent on the irrigated fields has resulted in increased infiltration to the near-surface reservoir and has caused the water table to rise. The most notable rise has occurred on the Winterwood Ranch, about 3.5 miles southeast of the treatment plant, where 350 acres of alfalfa are irrigated with sewage effluent. The water level in observation well S20/62–33ccc1, which is near the irrigated acreage, rose approximately 11.5 feet during the 10-year period between December 1945 and December 1955. During the spring of 1956 it became necessary to construct drainage ditches at the ranch to prevent a further rise of the water table.

During the winter, when irrigation requirements and phreatophyte consumption are at a minimum, the sewage effluent is permitted to flow to waste in the desert south of the Winterwood Ranch. Part of this effluent reaches Las Vegas Wash and, eventually, Lake Mead. During the winter, areas in the lower parts of the valley east of Whitney are inundated by effluent, and large quantities of water go into storage in the shallow aquifers. During the following growing season the water is withdrawn from storage by evapotranspiration; as a result the mean annual water level in this area has remained fairly stable from year to year throughout the period of observation.

Seepage from industrial waste water percolating into the near-surface reservoir from the settling and evaporation basins north and east of Henderson has caused water levels in much of the Pittman area to rise to within a foot or two of land surface. The high water table has caused many drainage and construction problems, particularly in laying municipal water and sewer mains. All the water presently recharging the shallow aquifers in the Henderson-Pittman area is being discharged by evapotranspiration or as effluent seepage to Las Vegas Wash.

Inefficient irrigation and excessive watering of lawns also add to the recharge of the shallow aquifers. Water levels in shallow wells in the vicinity of a golf course of one of the large resort hotels south of Las Vegas have risen approximately 3.5 feet since 1945 as a result of seepage losses from small artificial lakes and excess irrigation. Also, excessive watering of lawns in Las Vegas and Henderson have locally contributed substantial amounts of water to the near-surface reservoir.

Water from uncontrolled flowing artesian wells and leaky wells also recharges the shallow aquifers. However, legal provisions for the plugging and repairing of abandoned or leaky wells are minimizing this source of recharge.

Recharge to the shallow aquifers by precipitation is negligible. Precipitation stations in and near Las Vegas show that the average annual precipitation throughout the lower parts of Las Vegas Valley is less than 5 inches. Because of the arid climate, practically all the precipitation is lost by evaporation and transpiration and generally does not directly contribute to the recharge of the shallow aquifers. However, precipitation on phreatophyte areas indirectly affects the amount of water in storage in the near-surface reservoir by supplying part of the water needed by the phreatophytes—water that would otherwise be obtained from the ground-water reservoir.

ESTIMATE OF RECHARGE

In 1955, approximately 10,500 acre-feet of effluent was discharged by the Las Vegas sewage disposal plant. Approximately 1 mile southeast of the treatment plant, the Charleston drain, which discharges approximately 500 acre-feet per year, joins the open drain from the plant. Winterwood Ranch and five smaller ranches divert approximately 5,100 acre-feet per year of the flow for the irrigation of 525 acres. On the basis of crop consumption, one-half of this diversion is assumed to be beneficially used or evaporated, and the other half is assumed to infiltrate to the near-surface reservoir. Part of the remaining 5,900 acre-feet of water that is not diverted infiltrates to the near-surface reservoir, and part reaches Las Vegas Wash, where it is joined by waste flow from Basic Management, Inc., and from the Henderson sewage disposal plant; from Las Vegas Wash it flows into Lake Mead.[3] During March, April, and May, and during the last 15 days of September, approximately half the effluent from the Las Vegas disposal plant and the flow of Charleston drain are diverted for irrigation. During June, July, August, and the first half of September, the entire flow is diverted. During the winter months part of the sewage effluent from the Las Vegas disposal plant flows to Las Vegas Wash, where it combines with industrial waste water flowing to Lake Mead.

The surface flow in Las Vegas Wash ranges from 1 to 9 cfs throughout the year (U.S. Bur. Reclamation, 1955, p. 128). As monthly records of flow in Las Vegas Wash are not available, it is assumed that the maximum discharge into Lake Mead of 9 cfs occurs during January and February when irrigation requirements and use by phreatophytes are at a minimum.

No sewage effluent from the Las Vegas plant or flow from the Charleston drain reaches Las Vegas Wash from June through October. During this time the flow of approximately 1 cfs is solely from industrial waste and from the Henderson sewage plant. If it is assumed that the flow of Las Vegas Wash gradually increases from about 1 cfs in October to about 9 cfs in January and February and then decreases to about 1 cfs in March, the estimated runoff in Las Vegas Wash, by months, would be approximately as shown in figure 13. The contributions of runoff in the wash for January and February are assumed to be proportional to the average daily consumption at Basic Management, Inc., and to the average daily discharge of the disposal plants.

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[3] In 1956, Clark County constructed a sewage disposal plant in section 15, T. 21 S., R. 62 E.; and in the following year, a new Las Vegas municipal sewage disposal plant was constructed in section 10, T. 21 S., R. 62 E., about a mile north of the Clark County plant. Since March of 1957, all sewage effluent from Las Vegas and North Las Vegas has been piped to the new plant near the head of Las Vegas Wash; and since that time, much of the treated effluent, which is discharged into the Wash, flows to Lake Mead.

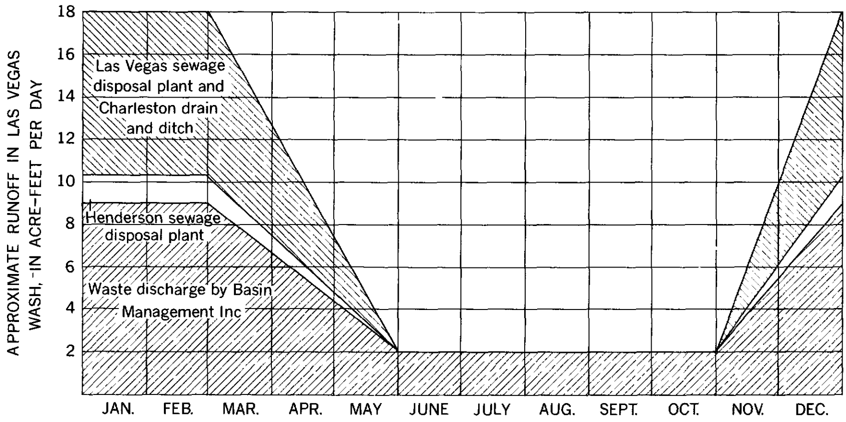

FIGURE 13.—Estimated runoff in Las Vegas Wash in 1955, and approximate amounts from various sources

Of the combined discharge of about 11,000 acre-feet during 1955 from the Las Vegas sewage disposal plant and the Charleston drainage ditch, approximately 1,000 acre-feet was discharged to Lake Mead, as is shown in figure 13. Of the remaining 10,000 acre-feet of effluent, about 3,000 acre-feet was beneficially used for irrigation (p. 70), and the remaining 7,000 acre-feet of effluent infiltrated to the near-surface aquifers. In addition to the infiltration of water from the Las Vegas sewage plant and the Charleston drainage ditch, the shallow aquifers are recharged from septic-tank effluent and from irrigation losses from privately owned wells and springs. Estimates of recharge to the near-surface aquifer by infiltration from these sources are only approximate and are based on estimates of consumptive and nonconsumptive use of water discharged from all wells and springs in the ground-water basin.

The estimated recharge to the near-surface system from infiltration of water derived from wells and springs for the different areas of the basin is shown in table 10. The table shows that recharge of the shallow aquifers by infiltration of water originating within the basin in 1955 was about 14,000 acre-feet.

In addition to the recharge resulting from recycling of ground water, some recharge to the near-surface system is from water imported from Lake Mead. Since 1942, when Lake Mead water was imported into the basin to supply the municipal and industrial demands at Henderson, there has been some recharge to the near-surface reservoir by sewage effluent from the municipal disposal plant and by waste water from the industries at Henderson. It is estimated that, during 1955, virtually all the recharge to the near-surface groundwater reservoir from these sources was discharged by phreatophytes

TABLE 10.—*Approximate recharge, in acre-feet, to the near-surface reservoir in Las Vegas basin from infiltration of waste water from wells and springs, 1955*

[Estimates of infiltration in this table should not be considered accurate beyond two significant figures]

Subarea [1]	Source of recharge	
	Infiltration of waste water from wells	Infiltration of water from springs and drains [2]
1	70	0
2	1, 000	0
3	700	0
4	1, 000	[3] 90
5	1, 000	0
6	7, 300	[4] 600
7	300	0
8	300	0
9	30	0
10	200	0
11	1, 400	[5] 80
12	30	0
Corn Creek Springs	0	120
Indian Springs Air Force Base	100	0
Indian Springs	0	90
Town of Indian Springs	13	0
Red Rock Canyon Springs	0	100
Blue Diamond Townsite	50	0
Total (rounded)	[6] 13, 000	1, 000

[1] Subareas 1-12 are map units in Las Vegas Valley as subdivided by flow lines shown on plate 3.

[2] Spring discharge includes only that which returns to the shallow-water zone and ultimately support phreatophyte growth.

[3] Kyle Springs.

[4] Stewart Spring and drain and Charleson Boulevard drain.

[5] Stevens and Grapevine Springs.

[6] Does not include return flow of approximately 5,000 acre-feet from the Henderson disposal plant or industrial waste from the plants at Henderson.

in the Las Vagas Wash area. Recharge to the near-surface reservoir from imported water was estimated to have been about 5,000 acre-feet in 1955. (See table 14.)

The three principal sources of recharge to the near-surface system in 1955 included approximately 6,000 acre-feet from upward leakage, 14,000 acre-feet from infiltration resulting from recycling of spring and well discharge, and about 5,000 acre-feet from infiltration of nonconsumptive waste water originally imported from Lake Mead. Thus the total recharge to the near-surface ground-water reservoir from these three sources in 1955 was about 25,000 acre-feet. (See table 18.)

DISCHARGE

EVAPORATION

Discharge of ground water by evaporation from the near-surface aquifers occurs where the water table is near the land surface. The most extensive area underlain by ground water at shallow depth is an area in the vicinity of Whitney, where the water level is within a few feet of the land surface. Although ground-water discharge from the area is principally by transpiration by phreatophytes, undoubtedly some ground water is also lost by direct evaporation from the soil.

Other small areas where ground water evaporates are along fault scarps where water under artesian pressure comes to the land surface as seeps. Although most of this upward leakage is consumed by phreatophytes, some water also evaporates. Generally, however, discharge of ground water by evaporation in the Las Vagas area is considered nominal because areas in the basin where water levels are near the land surface are small. Draft on the ground-water reservoir by evaporation is probably small enough to be obscured in the rounding of the computed value of the consumptive use by phreatophytes.

TRANSPIRATION BY PHREATOPHYTES

Phreatophytes obtain their water supply from the zone of saturation. The depth from which they are capable of extracting water varies with the plant species. Generally, the roots of grasses do not extend more than a few feet below the land surface; however, the roots of other plant species, such as alfalfa and mesquite, have been known to extend to depths of about 50 feet to reach the water table (Meinzer, 1927, p.74–77).

In Las Vegas Valley the spring discharge and upward leakage from the artesian aquifers that support the growth of phreatophytes have been diminishing at a relatively uniform rate since development of the ground-water reservoir began in 1906. Despite this reduction in spring discharge and upward leakage, the areas of phreatophytes have not declined materially except in areas cleared for agricultural use or urban development. The decreased amount of water available to phreatophytes from spring discharge and upward leakage from the artesian system has been compensated for by recharge to the near-surface aquifers from infiltration of irrigation water, sewage effluent, water from leaky artesian wells, and water imported from Lake Mead. A quantitative analysis of water consumption by phreatophytes in Las Vegas Valley is presented in the following paragraphs.

PHREATOPHYTE AREAS

Phreatophytes in Las Vegas Valley include mesquite, saltgrass, sacaton, arrowweed, baccharis, willows, cottonwood, greasewood, tule, and marsh grass. Of these, mesquite and saltgrass predominante. The areal extent and density of saltgrass, mesquite, and cottonwood were mapped in an area of 17,650 acres (pl. 9). The total area covered by each species was then converted to an equivalent area of 100-percent areal density (Gatewood and others, 1950, p. 25)

These computations indicated that, in the central part of the ground-water basin, there was the equivalent of approximately 2,800 acres of saltgrass, 4,500 acres of mesquite, 800 acres of tule and marsh grass, and 25 acres of cottonwood, or a total of approximately 8,000 acres of phreatophytes at 100-percent areal density.

The smallest of the three main areas of phreatophytes in the Las Vegas basin is in Las Vegas Wash, where approximately 800 acres of marsh grass, saltgrass, tule, and mesquite has 100-percent density. Phreatophytes in this area are supported entirely by recharge to the shallow aquifers by the effluent from the sewage treatment plant at Henderson, industrial waste water from the plants of Basic Management, Inc., at Henderson, and precipitation.

The second largest area of phreatophytes, in Paradise Valley south of the city of Las Vegas, includes an equivalent of 1,300 acres having 100-percent density of saltgrass and 1,400 acres of mesquite and cottonwood.

The largest area of phreatophytes in the Las Vegas ground-water basin is in the vicinity of the cities of Las Vegas and North Las Vegas. Approximately 2,100 acres having an equivalent 100-percent areal density of mesquite and 1,400 acres of saltgrass and sacaton were mapped in 1955.

Isolated areas of phreatophytes occur in areas of lesser areal extent in the vicinity of the Craig and Corn Creek Springs Ranches, Indian Springs, Cactus Spring, and Red Rock Canyon. The combined area of phreatophytes reduced to 100-percent areal density at these scattered locations is about 1,000 acres.

CONSUMPTIVE USE OF WATER BY PHREATOPHYTES

The quantity of water consumed by phreatophytes in Las Vegas Valley was estimated by following the method, described by Blaney and Criddle (1945), in which consumptive use for various plants is computed from commonly collected weather data on precipitation, monthly temperature, frost-free period, and percent of daytime hours. The consumptive use varies with temperature, daytime hours, and availability of water, as well as with type and density of plants and depth to water (Blaney and Criddle, 1945; Blaney, 1952). A monthly consumptive-use factor is obtained by multiplying the mean monthly temperature, in degrees Fahrenheit, by the monthly percent of daytime hours of the year. (See table 11.) Where actual consumptive use has been determined by tank and plot experiments, it is equal to the consumptive-use factor multiplied by a coefficient which varies with the type of plants. Expressed mathematically, $U=KF$, where U equals consumptive use, in inches K equals an empirical coefficient determined for each type of plant for a growing season; and F equals the sum of the monthly consumptive-use factor (F')

for the growing period. The monthly consumptive-use factor is obtained as follows: multiply the mean monthly temperatures (t) by the monthly percent (p) of daytime hours for the growing period and divide by 100. Consumptive-use factors for Las Vegas Valley computed from data for the Las Vegas weather station are shown in table 11.

TABLE 11.—*Consumptive-use factor at Las Vegas, Nev.*

[Data from Las Vegas weather station, elevation 2,033 ft. Frost-free period, 239 days, from Mar. 22, 1955 to Nov. 16, 1955]

Month	t	p	F' [1]	F [2]
January	45.1	6.99	3.15	----------
February	50.4	6.86	3.46	----------
March	56.5	8.35	4.72	1.37
April	64.3	8.85	5.69	5.69
May	71.9	9.81	7.05	7.05
June	80.0	9.83	7.86	7.86
July	86.3	9.99	8.62	8.62
August	84.5	9.40	7.94	7.94
September	77.2	8.36	6.45	6.45
October	65.9	7.85	5.17	5.17
November	53.8	6.92	3.72	1.98
December	46.4	6.79	3.14	----------
Total or average	65.2	100.0	66.97	52.13

[1] F'=monthly consumptive-use factor=$\frac{t \times p}{100}$.

[2] F=monthly consumptive-use factor for frost-free period.

Blaney and Criddle (1945, p. 8) found that there is a definite consistency in the value of K for each type of vegetation if ample water is available for plant growth; they also found that the value of K depends on the plant type and not on the geographic location. Values of K for the various types of phreatophytes found in Las Vegas Valley are listed in table 12.

TABLE 12.—*Consumptive-use coefficients for phredtophytes*

	K
Tule	[1] 1.50
Cottonwood and willow (large trees)	[2] 1.30
Cottonwood	[1] 1.25
Small willow	[2] 1.00
Saltgrass and sacaton	[2] .80
Mesquite	[1] .75

[1] Blaney and Harris (1952).

[2] Blaney (1952, fig. 1).

Rates of consumptive use of water by phreatophytes, as determined by Blaney and Harris (1952) from measurements of evapotranspiration under controlled conditions, are shown in table 13. These rates are based on the assumption that a water supply ample for the water requirements on the plants is available from precipitation and ground water. In this report it is assumed that the precipitation on phreatophytes during the growing season reduces the draft on ground water by an amount that is equal to the amount of precipitation. For most perennial crops, such as native hay, and for saltgrass, growth starts before the last killing frost in spring and continues after the first

TABLE 13.—*Estimated rates of consumptive use of water by phreatophytes in the Las Vegas basin under optimum conditions*

Plant type	Growing period (1955)	Sum of consumptive-use factor (*F*)	Coefficient (*K*)	Consumptive use, in inches per year (*U*)
Tule	March 3–November 16	52.13	1.50	78
Cottonwood and willow	do	52.13	1.30	68
Cottonwood	do	52.13	1.25	65
Small willow	do	52.13	1.00	52
Saltgrass and sacaton	do	52.13	.80	42
Mesquite	do	52.13	.75	40
Mesquite in Red Rock Canyon area [1]	April 15–November 1 [2]	45.9	.75	34

[1] Altitude of Red Rock Canyon area is approximately 2,000 ft higher than principal phreatophyte areas in Las Vegas Valley; therefore, the growing period is shorter in the Red Rock Canyon area than in the valley. The growing season at Red Rock is assumed to be similar to that at Beatty, Nev.

[2] Approximate.

killing frost in the fall. In this study, the additional draft resulting from transpiration losses during the prefrost and postfrost periods was not computed because the quantity of water involved was assumed to be offset by the reduction in transpiration during the summer months resulting from the increased depth to the water table. The rate of consumptive use of about 42 inches per year for saltgrass (table 13) assumes optimum growing conditions and a depth to water ranging from half a foot to 2 feet. Studies by Young and Blaney (1942, p. 129) involving determination of consumptive use of water by saltgrass show a straight-line relationship between depth to the water table and the amount of water consumed. Computations of consumptive use by saltgrass in Las Vegas Valley for the period prior to 1912 (tables 16, 17) are based on the assumptions that the average depth of the water table was 1 to 3 feet and that there was a corresponding consumptive use of about 36 inches of water per year. The change in rate of use for saltgrass and sacaton from 36 inches of water for the years prior to 1912 to 30 inches in 1955 (table 14) was made to compensate for the declining water levels in the near-surface aquifers during this period (p. 66). The drop in the water table resulted from the reduction in artesian head and subsequent decrease in upward leakage from the artesian system during this span of time. The upper part of table 14 lists the areas of the principal phreatophytes, by species of plants, in terms of equivalent 100-percent areal density in the Las Vegas basin in 1955. The lower part of the table shows the approximate consumptive use by phreatophytes and the approximate amount of water from various sources supplying this demand. The total annual water requirement by phreatophytes is computed by multiplying the phreatophyte acreage having an equivalent 100-percent areal density by the consumptive use of each species of plant. The table shows that total consumptive use of water by phreatophytes in 1955 was about 22,000 acre-feet, but this total excludes the consumptive use by phreatophytes in Las Vegas Wash. The 5,000 acre-feet of infiltration from the Henderson area and the 800 acres of phreatophytes which it supports does not affect the net draft on the artesian aquifers because most of the water transpired by these plants is imported from outside the basin.

Precipitation on the phreatophyte areas during the growing season in 1955 was 3.82 inches in Las Vegas Valley and about 12 inches in Red Rock Canyon. Precipitation on phreatophytes during the growing season contributes part of the water required by the plant and in this report is subtracted from the total consumptive use requirements in computing the draft on the ground-water reservoir resulting from transpiration. Precipitation on the phreatophyte areas is computed by multiplying the equivalent acreage of phreatophytes at 100-percent areal density by the precipitation during the growing period.

In the principal phreatophyte areas, approximately 3,000 acre-feet of the water transpired by phreatophytes was supplied directly by precipitation and about 19,000 acre-feet was derived from the ground water reservoir. (See table 14.)

Table 14.—*Equivalent acreage of phreatophytes, at 100-percent areal density, and consumptive use of water by phreatophytes in the Las Vegas ground-water basin, 1955*

[Estimates of phreatophyte acreage and consumptive use should not be considered accurate beyond two significant figures]

	Mesquite	Mesquite	Saltgrass	Tule and marsh grass	Cotton-wood	Totals (rounded)
Area, in acres						
Las Vegas Valley	----------	4,060	2,800	800	25	----------
Corn Creek Springs [1]	----------	170	----------	----------	----------	----------
Indian Springs [1]	----------	30	----------	----------	----------	----------
Cactus Spring [1]	----------	15	----------	----------	----------	----------
Red Rock Canyon [1]	200	----------	----------	----------	----------	----------
Total (rounded)	200	4,300	2,800	800	25	----------
Consumptive use, in acre-feet						
1. Total (acreage times consumptive-use rate)	(200×2.8) 560	(4300×3.3) 14,000	(2800×2.5) 7,000	(800×6.5) 5,200	(25×5.4) 135	22,000
2. Supplied from precipitation	200	1,400	900	[2] 260	8	3,000
3. Supplied from the ground-water reservoir, infiltration of cycled water, and springs (1)−(2)	360	12,600	6,100	----------	127	[3] 19,000
4. Supplied from waste water from the industrial plants at Henderson, which obtain water supplies from the Colorado River	----------	----------	----------	[2] 5,000	----------	----------

[1] Areas not shown on plate 9.

[2] The 800 acres of tule and marsh grass are in Las Vegas Wash. Phreatophytes in Las Vegas Wash derive their entire water supply from effluent from the Henderson disposal plant and from industrial waste water. Water from these sources was originally imported from Lake Mead; therefore, transpiration losses in this area do not affect the net draft on the Las Vegas ground-water basin. Not included in totals.

[3] Consumptive use derived from ground water.

UPWARD LEAKAGE

Upward leakage of ground water from the artesian aquifers to the near-surface reservoir is a major part of the natural discharge from the deep aquifers and a major part of the recharge to the near-surface aquifers. Because upward leakage cannot be estimated directly, it has been computed indirectly from data on evapotranspiration, infiltration, and precipitation. Although the computations are based on limited data and are subject to large error, they indicate the order of magnitude and are useful in showing the reduction in upward leakage resulting from the lowering of the artesian pressure. Ground water under artesian pressure leaks upward into shallow aquifers along fault zones, through semiconfining beds, and from leaky wells. A map (pl. 2) of Las Vegas Valley shows the area where the composite piezometric surface of the three principal artesian aquifers is above the water table in the near-surface aquifers. Within this area, discharge may occur from the artesian aquifers to the near-surface reservoir.

In the preceding section, computations were presented showing that approximately 22,000 acre-foot of water was consumed by phreatophytes occurring largely in the area of upward leakage. Of this amount, approximately 3,000 acre-feet was supplied directly from precipitation; thus a balance of about 19,000 acre-feet was derived from the near-surface ground-water reservoir. Table 10 shows that the estimated recharge to the near-surface reservoir by infiltration was approximately 14,000 acre-feet during 1955. As there was no appreciable change in ground water in storage in the near-surface reservoir during 1955 (p. 66), it is reasonable to assume that the additional 5,000 acre-feet of water required to sustain the phreatophyte growth was supplied by upward leakage from the artesian aquifers. An analysis of upward leakage supporting phreatophytes in various areas in Las Vegas Valley in 1955 is shown in table 15.

Upward leakage is a function of artesian head and ordinarily varies directly with the artesian head. Significant changes in artesian heads have occurred principally in the Las Vegas area, so it is within this area that significant changes in upward leakage have occurred. The following discussion on changes in upward leakage, therefore, is limited to the Las Vegas Valley.

To estimate the average change in upward leakage to the near-surface reservoir resulting from declining artesian head, estimates of recharge to and discharge from the near-surface reservoir were made for the years 1906, 1912, and 1955. Natural discharge from the near-surface reservoir for 1906 and 1912 was estimated on the basis of the areal distribution and estimated consumptive use of phreatophytes shown on plates 10 and 11. The distribution and areal

TABLE 15.—*Estimated upward leakage in the Las Vegas basin, 1955*

[Estimates should not be considered accurate beyond two significant figures]

Subareas[1]	Total consumptive use by phreatophytes, in acre-feet	Source of water, in acre-feet			
		Precipitation[2]	Return flow from wells (from table 10)	Springs and drainage ditches[3] (from table 10)	Upward leakage[4] (2) minus (3, 4, 5)
(1)	(2)	(3)	(4)	(5)	(6)
1			70	0	−100
2	1,900	200	1,000	0	
3			730	0	
4			960	90	[5] −280
5			1,000	0	
6	11,600	1,240	7,300	610	
7			310	0	
8			340	0	
9			30	0	
10	580	60	180	0	340
11	6,000	680	1,400	80	3,840
12	390	40	30	0	320
Corn Creek Springs	560	50	0	120	390
Indian Springs	100	10	133	90	−133
Cactus Spring	50	5	0	0	45
Red Rock Canyon	560	200	50	100	210
Totals (rounded)	[6] 22,000	[7] 3,000	13,000	1,000	5,000

[1] Subareas 1–12 are map units in Las Vegas Valley as subdivided by flowlines shown on plate 3.

[2] Based on estimate of 12 inches of rainfall for Red Rock Canyon and 3.82 inches (0.32 ft) of rainfall in other areas during growing season in 1955; computed for areas of 100-percent density.

[3] Spring discharge includes only the amount of spring discharge that infiltrates to the shallow water zone and ultimately supports phreatophyte growth.

[4] Includes upward leakage used by phreatophytes only. An additional 1,100 acre-feet of upward leakage is assumed to be discharged by wells tapping the near-surface reservoir.

[5] Much of the return flow from wells in areas 4–9 is discharged through the municipal disposal plant and is returned to near-surface aquifer in the southeastern part of Las Vegas Valley and therefore undoubtedly supplies a part of the consumptive use required by phreatophytes in areas 10–12.

[6] Does not include consumptive use of approximately 5,000 acre-feet by phreatophytes in Las Vegas Wash, which is derived from water imported into the basin from the Colorado River.

[7] Does not include precipitation on phreatophyte area in Las Vegas Wash (approx. 260 acre-feet).

density of phreatophytes shown on plates 10 and 11 were estimated partly from areal photographs of the Las Vegas Valley made in 1943, when the valley was nearly undeveloped, and partly from maps and early documents, including field notes of O. E. Meinzer and Everett Carpenter of the U.S. Geological Survey, who studied the area in 1912–13.

The consumptive use by phreatophytes for 1906 and 1912 shown in tables 16 and 17 is based on the estimated areal density and distribution as described on pages 74–77. Table 16 shows that the estimated consumptive use by phreatophytes in 1906 was about 30,000 acre-feet, of which approximately 3,000 acre-feet was supplied by precipitation; 8,000 acre-feet, by spring discharge; and about 19,000 acre-feet, by upward leakage from the artesian aquifers.

TABLE 16.—*Estimated equivalent acreage of phreatophytes, of 100-percent areal density, and consumptive use of water by phreatophytes in the Las Vegas ground-water basin, 1906*

[Estimates of phreatophyte acreage and consumptive use should not be considered accurate beyond two significant figures]

	Mesquite	Mesquite	Saltgrass and sacaton	Mesquite, cottonwood, and willows	Tule, marsh grass, and willows	Totals (rounded)
Area, in acres						
Las Vegas Valley		3,300	5,200	140		
Corn Creek Springs		40		18		
Tule Springs					10	
Indian Springs		30		80	5	
Cactus Spring		15				
Red Rock Canyon	200					
Totals (rounded)	200	3,400	5,200	240	15	
Consumptive use in acre-feet						
1. Total (acreage times consumptive use)	(200×2.8) 560	(3400×3.3) 11,000	(5200×3.0) 15,600	(240×5.4) 1,300	(15×6.5) 100	30,000
2. Supplied from precipitation[1]	200	1,000	1,500	70	30	3,000
3. Supplied from springs						8,000
4. Supplied from upward leakage (1)−(2)−(3)						19,000

[1] Based on estimate of 12 inches of rainfall for Red Rock Canyon and 3.5 inches (0.29 ft) of average rainfall for the growing season in other areas.

TABLE 17.—*Estimated equivalent acreage of phreatophytes, of 100-percent areal density, and consumptive use of water by phreatophytes in the Las Vegas ground-water basin, 1912*

[Estimates of phreatophyte acreage and consumptive use should not be considered accurate beyond two significant figures]

	Mesquite	Mesquite	Saltgrass and sacaton	Mesquite, cottonwood, and willows	Tule, marsh grass, and willows	Totals (rounded)
Area, in acres						
Las Vegas Valley		3,100	4,800	140		
Corn Creek Springs		40		18		
Tule Springs					10	
Indian Springs		30		80	5	
Cactus Spring		15				
Red Rock Canyon	200					
Totals (rounded)	200	3,200	4,800	240	15	
Consumptive use, in acre-feet						
1. Total (acreage times consumptive use)	(200×2.8) 560	(3200×3.3) 11,000	(4800×3.0) 14,000	(240×5.4) 1,300	(15×6.5) 100	27,000
2. Supplied from precipitation[1]	200	900	1,400	70	4	3,000
3. Supplied from infiltration water from wells[2] and spriugs						9,000
4. Supplied from upward leakage (1)−(2)−(3)						15,000

[1] Based on estimate of 12 inches of rainfall for Red Rock Canyon and 3.5 inches (0.29 ft) of average rainfall for the growing season in other areas.

[2] Estimates of infiltration supporting phreatophytes in 1912 include approximately 8,600 acre-feet from wells and 1,400 acre-feet from springs. Estimated gross infiltration is reduced by 1,000 acre-feet, the estimated discharge of Las Vegas Wash (Hardman and Miller, 1934, p. 28).

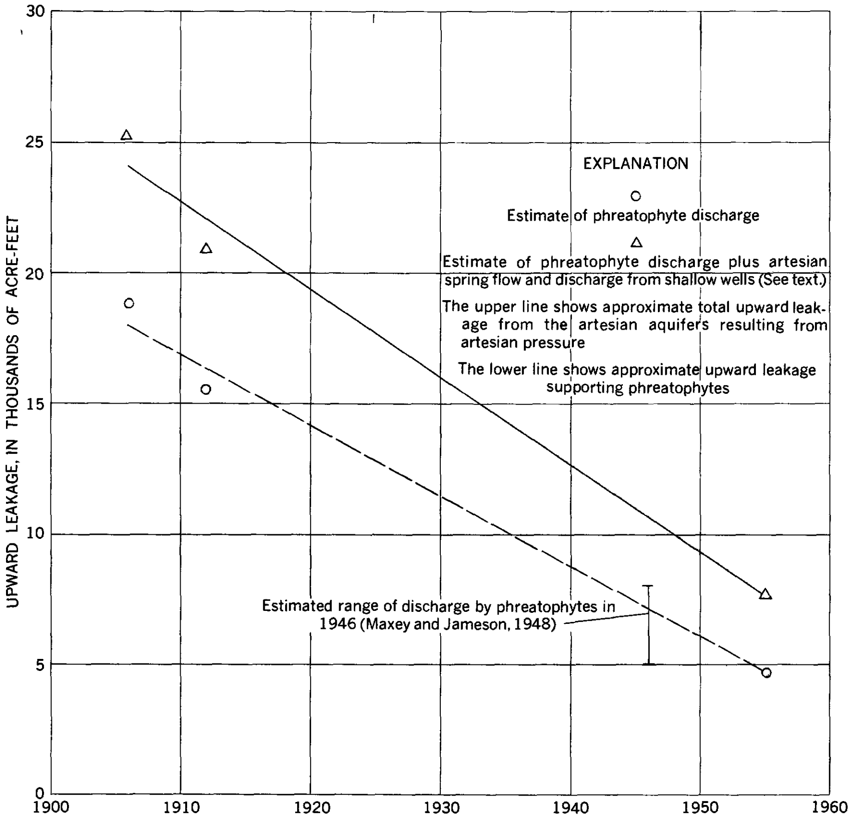

FIGURE 14.—Approximate decrease in upward leakage in the Las Vegas area resulting from reduction of artesian head.

Table 17 shows that the amount of ground water consumed by phreatophytes in 1912 was about 27,000 acre-feet, of which about 3,000 acre-feet was supplied by precipitation; 9,000 acre-feet, by infiltration from wells and springs; and about 15,000 acre-feet, by upward leakage from the artesian aquifers.

The values for the computed rates of upward leakage for 1906, 1912, and 1955 (tables 15, 16, 17) are plotted against time on plain coordinate paper (lower line, fig. 14), and a straight line is drawn between the value for 1955 and a point about midway between the computed values for 1906 and 1912. The values suggested by the lower line are assumed to be the best estimates of the part of upward leakage supporting phreatophyte growth and are the values that were used in compiling the total ground-water discharge from the Las Vegas artesian aquifers. (See table 9.) The values range from about 18,000 acre-feet of upward leakage consumptively used by phreatophytes in 1906 to about 5,000 acre-feet in 1955. The annual decrease in upward leakage consumptively used by phreatophytes suggested by the lower line is the result of declining artesian head and the consequent decrease in upward leakage.

The lower line of figure 14 shows that the approximate amount of upward leakage supporting phreatophytes in 1946 was about 7,000 acre-feet. This amount agrees favorably with the estimate of phreatophyte discharge of about 5,000 to 8,000 acre-feet made by Maxey and Jameson (1948, p. 86) for that year.

The upper line in figure 14 shows the approximate decrease in the total upward leakage in Las Vegas Valley. The discharge by artesian springs and shallow wells that tap the near-surface reservoir may also be considered as upward leakage, in that the ground water discharged by these processes is supplied largely by water leaking upward under artesian pressure. (See p. 59, 62.) Therefore, to establish an estimate of the total upward leakage, the discharge from shallow wells and artesian springs was added to the upward leakage supporting phreatophytes. In 1906 and 1912 there was virtually no discharge by wells tapping the near-surface reservoir; therefore, the values represented by the points on the upper line were obtained merely by adding the discharge of the artesian springs in Las Vegas Valley for those years (table 9) to the values represented by the points on the lower line. The value for the point on the upper line for 1955 was computed by adding the discharge from artesian springs and from the Charleston Boulevard and Stewart drains (table 9) and the estimated discharge by wells developed in the near-surface reservoir (table 9) to the upward leakage consumed by phreatophytes. A straight line drawn between the value for 1955 and a point midway between the values computed for 1906 and 1912, similar to that described above, indicates that the total annual upward leakage in Las Vegas Valley decreased from about 24,000 acre-feet in 1906 to about 8,000 acre-feet in 1955. The array of errors that may be included in this derivation of upward leakage is broad, and therefore the results should be regarded as approximations that are subject to gross error.

ARTIFICIAL DISCHARGE

Estimates of well discharge from the near-surface reservoir totaled about 1,100 acre-feet in 1955.

The principal withdrawals from the near-surface reservoir are made within a radius of 3 to 5 miles from Las Vegas, where the greatest concentration of shallow wells has been drilled. The largest concentrations of ground-water withdrawals from shallow domestic wells are east of the city of North Las Vegas and in Paradise Valley.

SUMMARY OF DISCHARGE FROM THE NEAR-SURFACE RESERVOIR

The discharge from the near-surface reservoir in 1955 was principally by phreatophytes and from shallow wells. Evaporation may account for a small part of the discharge from the near-surface reservoir, but, the amount is considered insignificant. Therefore, the total discharge from the near-surface reservoir is approximately equal to the sum of the transpiration losses and the water discharged by shallow wells. The discharge of ground water by phreatophytes was about 19,000 acre-feet. In addition, phreatophytes in the Las Vegas Wash area consumed about 5,000 acre-feet, which was supplied by infiltration of water imported from the Colorado River; this consumption made the total discharge by phreatophytes about 24,000 acre-feet. Approximately 1,100 acre-feet of ground water was discharged by shallow wells in 1955, making the total draft on the near-surface reservoir about 25,000 acre-feet. However, about 5,000 acre-feet discharged by the phreatophytes and all the discharge from shallow wells is presumed to be ground water that has leaked upward from the artesian aquifer. Thus, about 6,000 acre-feet of discharge from the near-surface reservoir has been previously accounted for in the estimates of discharge from the artesian aquifer (p. 62) and must be subtracted from the apparent total discharge from the near-surface reservoir. Therefore, the total discharge from the near-surface reservoir, exclusivie of upward leakage, was about 20,000 acre-feet in 1955.

SUMMARY OF TOTAL DISCHARGE IN THE LAS VEGAS BASIN

The total discharge from the Las Vegas ground-water basin includes the discharge from both the artesian and the near-surface reservoirs. In 1955 the draft from the artesian reservoir in the Las Vegas basin is estimated to have been about 48,000 acre-feet, and the net draft from the near-surface reservoir is estimated to have been about 20,000 acre-feet. Thus, the total draft on the Las Vegas ground-water basin in 1955 was about 70,000 acre-feet.

WATER BUDGET IN 1955

The hydrologic regimen in the Las Vegas ground-water basin in 1955 is summarized in a water budget that attempts to account for all water recharged into or discharged from the basin. The following table (table 18) shows that the recharge to the artesian reservoir is solely from precipitation and that the discharge is by springs, wells, and upward leakage. It further shows that the recharge to the near-surface reservoir was from infiltration of water originally derived from the artesian aquifers, infiltration of water imported from the Colorado River, and upward leakage from the artesian aquifers; discharge from the near-surface reservoir was by evapotranspiration and shallow wells.

TABLE 18.—*Generalized water budget for the Las Vegas ground-water basin for 1955*

[Amounts of recharge and discharge should be considered correct only to the general order of magnitude]

	Acre-feet	
Artesian system		
Estimated average annual recharge		25,000
Estimated discharge:		
Wells and springs	42,000	
Upward leakage	6,000	
Total (rounded)		48,000
Net draft on storage		23,000
Near-surface system		
Recharge:		
Infiltration from wells and springs	14,000	
Upward leakage	6,000	
Infiltration of water imported from Lake Mead	5,000	
Total (rounded)		25,000
Discharge:		
Phreatophytes	24,000	
Shallow wells	1,000	
Total (rounded)		25,000
Net draft on storage		0
Net draft on Las Vegas ground-water basin		23,000

From table 18 it is evident that the discharge from the artesian reservoir in 1955 exceeded the estimated average annual natural recharge to the reservoir by about 23,000 acre-feet. It is further evident that there was no overdraft on the near-surface reservoir. Thus, the overdraft on the entire Las Vegas ground-water basin was approximately equal to the overdraft on the artesian reservoir. The overdraft was supplied almost entirely by water from storage in the artesian system and thereby caused declines of water levels and artesian head.

RELATION BETWEEN RESERVOIR STORAGE AND WATER-LEVEL FLUCTUATION

Removal of water from storage as a result of ground-water development in the Las Vegas basin has caused a change from artesian to water-table conditions in many areas. As was pointed out on page 26 the amount of water released from storage per unit lowering of head under artesian conditions is only a very small fraction of the amount of water released from storage per unit lowering of head under water-table conditions. Thus, the amount of water released from storage in the Las Vegas ground-water basin per unit change in water level in wells has not been and probably never will be constant because of the continual changes in the reservoir as conditions change from artesian to water-table as a result of the lowering of water levels below confining beds.

To relate the change in storage of the Las Vegas reservoir to the annual decline in artesian head through 1955, it is necessary to know the average water level in wells throughout the reservoir and the amount of recharge to and discharge from the reservoir during the same period of time. (See fig. 15.)

Figures 15*A* and *B* show the relationship between the estimated annual discharge from the artesian aquifers and the estimated annual recharge to them. The estimated annual discharge shown in figure 15*A* is taken from table 9, and the estimated annual recharge is taken from figure 9. Annual recharge for 1906–10 is assumed to be the average of 22,000 acre-feet per year (fig. 9). The discrepancy between the estimated recharge and discharge for 1906 may be due to errors inherent in the estimates and does not affect materially the significance of figures 15*A* and *B*.

Figure 15*B* shows the cumulative discharge and recharge. The figure shows that the cumulative annual discharge has exceeded the cumulative annual recharge since the development of the first successful well in 1906. If the average annual recharge of 30,000 to 35,000 acre-feet per year, as estimated by Maxey and Jameson (1948, p. 108, 119), is used for computing cumulative recharge to Las Vegas Valley for the 50-year period 1906–55, the cumulative recharge would be approximately equal to the estimated cumulative discharge during that time, and, therefore, it would appear that either Maxeys and Jameson's estimates of recharge were too high or their estimates of discharge were too low.

Changes in the average annual water level in the 15 observation wells in the vicinity of the city of Las Vegas and Paradise Valley were used as a measure of the average water-level change throughout the developed part of the reservoir from 1941–55. Unfortunately, the data are insufficient to determine the average change in water levels in remote areas of the reservoir, and, therefore, the computed value for the amount of water derived from storage per foot of change in water level is principally representative of the developed part of the reservoir.

Figure 15*C* shows the relation between average change in artesian head of 15 observation wells in Las Vegas Valley and the estimated cumulative overdraft. During the period of record from 1941–55, the total change in the average head for the 15 wells was 30.37 feet, and the estimated overdraft was approximately 300,000 acre-feet. Thus, during this period the average change in storage for each foot of lowering of the mean annual artesian head in the 15 observation wells

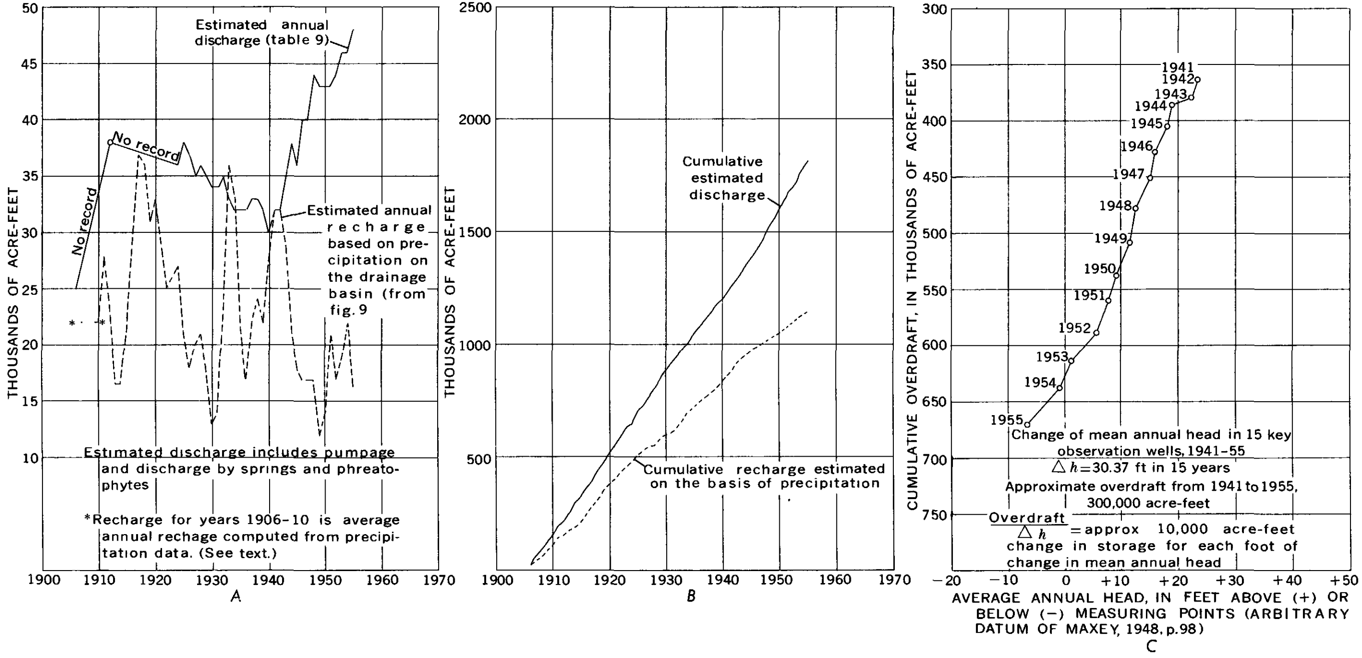

FIGURE 15.—Relation between recharge, discharge, and artesian head in the Las Vegas ground-water reservoir. *A*, Comparison of estimated annual recharge and discharge. *B*, Comparison of estimated cumulative recharge and discharge. *C*, Relation between cumulative overdraft and the average change in artesian head of 15 wells in and near the city of Las Vegas.

was approximately 10,000 acre-feet. The amount of ground water released from storage per unit change in head will increase as the hydraulic regimen changes from artesian to water-table conditions.

EFFECTS OF GROUND-WATER DEVELOPMENT

Although the ground-water reservoir in the Las Vegas basin is a continuous hydrologic unit, different sections of the reservoir react to development in somewhat different ways. In planning for development of the maximum sustained yield, these differences should be considered.

Although water levels in wells in Las Vegas Valley have declined as a result of overdraft of the ground-water reservoir, a further decline in water levels may be desirable in areas where the artesian head is still sufficient to cause upward leakage. If the artesian head were lowered to approximately 50 feet below the land surface, practically all upward leakage would be diverted to wells and beneficial use. Diverting upward leakage away from phreatophytes probably will not materially reduce the phreatophyte acreage, however, except in areas where the phreatophytes are entirely dependent on upward leakage for survival. In 1955, most of the phreatophytes in the basin were supported by infiltration of waste water, and unless they are deprived of this source of water, their acreage in the basin will remain virtually unchanged.

There are two main areas of upward leakage in the Las Vegas basin. The largest of these areas underlies the city of Las Vegas and extends eastward from the base of a fault scarp near the Las Vegas Valley Water District well field to the lower part of the valley about 3 miles east of the city. The second area of upward leakage is in Paradise Valley, approximately 5 miles south of the city of Las Vegas, and forms a zone about 1½ miles wide and 7 miles long that extends northeastward from a point about half a mile east of the Warm Springs Ranch.

In the Las Vegas area, ground-water movement is influenced principally by two north-trending faults; one is approximately 2 miles west of the city in the vicinity of the Las Vegas Valley Water District well field, and the other passes through the east-central part of the city approximately parallel to 15th Street. These faults are normal to the hydraulic gradient and act as partial barriers to the lateral movement of water in the artesian aquifers but permit upward leakage of the confined water. Ground water under artesian pressure migrates upward along the fault zones and then laterally into the shallow-water reservoir; this migration causes high water levels in and east of Las Vegas. If withdrawals from the artesian aquifers in the various parts of the ground-water reservoir were properly controlled, the artesian head could be lowered to prevent this upward leakage.

Ground water in the near-surface ground-water reservoir beneath the city of Las Vegas is virtually unused for beneficial purposes, and, as of 1955, it was discharged principally by evapotranspiration. The Las Vegas Valley Water District well field is favorably located for intercepting and salvaging the major part of the upward leakage in the Las Vegas municipal area and could be used as an effective means of controlling shallow water levels beneath Las Vegas.

Future decline of water levels has been estimated on the assumption that ground-water withdrawals will continue at about the 1955 rate and that future increases in demand will be met by importation of water from Lake Mead. If the rate of withdrawal from the artesian aquifers remains at about the 1955 rate, and if the water levels continue to decline at about the same rate as in the past, the piezometric surface in the vicinity of the well field would be lowered to approximately 50 feet below the orifice of Las Vegas Springs by 1967. Water-level records indicate that the artesian head in the vicinity of the Las Vegas well field has declined progressively at a fairly uniform rate of from 4 to 6 feet per year, whereas the altitude of the water table in the near-surface system in the same area has declined about 1 foot per year. The shallow-water level probably will decline at a slower rate than the artesian head because the lower permeability of the shallow aquifers (p. 25) will retard their rate of drainage. The rate at which the two water surfaces will decline when the artesian head declines to the same altitude as the water table is not known.

Immediately east of Las Vegas, however, the rate of decline of the artesian head has been about half that in the well field. For example, well 20/61–36bbb1 (No. 393) declined an average of about 2 feet per year during the period 1952–57. The artesian head in 1955 in well 393 was 28 feet above the land surface. At the present rate of decline, the artesian head will require about 40 years to decline to about 50 feet below land surface.

If the ratio between the rate of lowering of the artesian head in the Las Vegas Valley Water District wells and the rate of lowering of artesian head in wells in the eastern part of the valley is the same in the future as it was in the past, it will be necessary to lower the piezometric surface at the well field to a much greater depth than that described above to prevent natural losses that result from upward leakage in the eastern part of the valley. Lowering of water levels in the eastern part of the valley to reduce upward leakage could be effected by a redistribution of artesian withdrawals in the vicinity of the fault scarp passing through the east-central part of the city of Las Vegas.

Throughout much of the Paradise Valley area, the near-surface water stands within a few feet of the land surface. The few wells that tap the near-surface aquifers utilize only insignificant quantities of the available ground water. Virtually all the replenishment to this reservoir is lost by natural discharge. Upward leakage to the near-surface aquifers in this area will diminish as a result of reductions in artesian heads, and phreatophyte areas will recede and thus make additional water available for beneficial use. The largest area of natural discharge in Paradise Valley is in the eastern part of the valley and is centered in the vicinity of sec. 31, T. 21 S., R. 62 E. Ground-water movement in this area is influenced by a north-trending fault approximately half a mile east of Sand Hill Road. This fault extends from Whitney Mesa to about half a mile south of the intersection of U.S. Highway 93 and Sand Hill Road and is normal to the hydraulic gradient in the area. It apparently acts as a ground-water barrier that permits water under artesian pressure to migrate upward to the near-surface aquifers.

Much of the water presently leaks upward from the artesian aquifers into the near-surface aquifers and is lost by evapotranspiration; this water could be salvaged if the artesian head were lowered below the root zone of the phreatophytes. The average decline in artesian head throughout the area of upward leakage in Paradise Valley has been approximately 15 feet since 1944, but many wells still flowed in 1955. In the vicinity of Sand Hill Road, the artesian pressure in 1955 still was sufficient to raise water 50 feet or more above the land surface. If the present distribution of wells, withdrawals, and recharge remain about the same, and if the artesian head continues to decline at approximately the same rate as in the past few years, the artesian head in the area of Sand Hill Road will be lowered to about 50 feet below the land surface in about 75 years. Lowering of water levels in this area could best be achieved by a controlled redistribution of artesian withdrawals along Sand Hill Road in sec. 31, T. 21 S., R. 61 E.

If the rate of decline of artesian head changes, the dates by which the piezometric surface will have been lowered to the desired elevation in the different areas of Las Vegas Valley will be either retarded or advanced, depending on whether the change in rate of decline is reduced or accelerated. The average rate of decline of the artesian head in the Las Vegas area since 1943 (see fig. 8) probably has been accelerated owing to the decreased precipitation and subsequent reduction in recharge during this period. If precipitation and recharge return to normal or above normal within the immediate future, the average rate of decline of the artesian head will probably be reduced, and the time when the artesian heads will be lowered to 50 feet below land surface may have to be projected.

Approximately 90 percent of all upward leakage in the Las Vegas ground-water basin occurs near Las Vegas and in Paradise Valley. The remaining areas where upward leakage occurs are too scattered and insignificant to warrant special ground-water development to salvage the losses.

When the piezometric surface throughout the Las Vegas and Paradise Valley areas has been lowered to a depth where most upward leakage is salvaged, pumpage from the ground-water basin should be reduced to the average annual natural recharge to the basin plus the amount of infiltration that would become available through recycling. Otherwise, the water level will continue to decline. Data are not available to permit speculation on the quantity of water that may infiltrate to the zone of saturation and become available for reuse when artesian heads have been lowered sufficiently to permit downward percolation. Reduction of artesian head also may impair the quality of ground water locally by increasing the infiltration of sewage effluent and other waste water.

MAXIMUM DEVELOPMENT ON PERENNIAL-YIELD BASIS

Unless phreatophytes are eradicated or water-spreading or other types of artificial recharge techniques are used for returning effluent or other large quantities of waste water to the deeper aquifers, the amount of infiltration of waste water to the deeper aquifers probably will be small. Therefore, a conservative estimate of the perennial yield that can be obtained from the principal artesian reservoir is the average annual natural recharge of approximately 25,000 acre-feet.

The maximum perennial yield that can be developed from the near-surface reservoir depends on the recharge to the reservoir and deterioration in quality with use. Lowering the head in the artesian aquifers to 50 feet below land surface will progressively diminish the upward leakage recharging the near-surface reservoir. A large part of the perennial yield from the near-surface reservoir will be discharged by phreatophytes so long as nonconsumptive water is permitted to flow to waste. If importations of water from the Colorado River are substantially increased in the future, infiltration will increase, and thus the potential perennial yield will also increase.

QUALITY OF THE GROUND WATER

Most of the chemical analyses of water samples from wells and springs throughout the Las Vegas basin have been published wholly or in part in previous publications. However, because some of the analyses have been published in part only, all data currently available on the chemical quality of ground water in the Las Vegas basin are presented in tables 19 and 20. The following summary and interpretations of the chemical character of ground water in Las Vegas Valley are based in part on the published works of Carpenter (1915), Hardman and Miller (1934), and Maxey and Jameson (1948).

As the ground water moves from areas of recharge toward areas of discharge, it dissolves minerals from the sediments and rocks through which it moves. The type of material through which the water moves, the length of time the water is in contact with the material, the distance the water travels from the point of recharge, and the water temperature are some of the factors that determine the type and amount of chemical constituents in ground water. Because of the varied nature and distribution of the sediments and rocks in the Las Vegas basin, the chemical character of the ground water often changes markedly as it moves through the reservoir.

There are four areas in Las Vegas Valley in which the chemical character of the ground water is distinctively different. These areas include the Las Vegas–Tule Springs area in the north; Paradise Valley in the south; the Whitney-Pittman area, about 7 miles southeast of Las Vegas; and the area in the vicinity of Lake Mead Base about 9 miles northeast of Las Vegas. The average content of the various chemical constituents and the average temperature of the ground water in the shallow, middle, and deep zones of aquifers are given in table 21.

TABLE 19.—*Chemical analyses of water from wells in the Las Vegas ground-water basin*

Agency making analysis:

1. Miller, M. R., Univ. Nevada Agr. Expt. Sta.; or, Adams, W. B., Public Service Div., Univ. Nevada, Dept. Food and Drugs.
2. Hardman and Miller (1934, p. 24–29).
3. Carpenter (1915, table facing p. 30).
4. U.S. Geological Survey.
5. Nevada Soil and Water Testing Laboratory, College of Agriculture, Univ. Nevada.

[Analyses are in parts per million, except as otherwise indicated]

State Engineer's well No.	Location	Depth	Date collected	Temperature (°F)	Agency making analysis	Silica (SiO_2)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions										Boron (B)	Solids		Hardness as $CaCO_3$		Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Classification for irrigation
							Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium (Na) and potassium (K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)		Total	Dissolved (residue on evaporation at 180°C)	Calcium and magnesium	Noncarbonate				
----	S16/56-5dd1	600	6-20-42	----	1	25	87 4.34	23 1.89	---- ----	6.0 .26	---- ----	239 3.92	98 2.04	20 .56	---- ----	---- ----	----	340	----	312	----	----	----	----	----
----	9bb2	50	3-18-42	----	1	22	86 4.29	20 1.64	---- ----	42 1.83	---- ----	329 5.39	95 1.98	14 .39	---- ----	---- ----	----	415	----	297	----	----	----	----	----
428	S19/60-9abb1	631	9-13-45	----	1	----	38 1.90	28 2.31	---- ----	5 .28	---- ----	240 3.93	22 .45	3.9 .11	---- ----	---- ----	0.07	338	----	211	----	0.2	407	----	C_2-S_1
429	9cda1	612	10-23-44	70	1	----	46 2.29	26 2.14	---- ----	4 .174	---- ----	250 4.10	19 .4	5 .14	---- ----	---- ----	----	350	----	221	----	----	----	----	----
----	21ccc1	8	9-13-45	----	1	----	55 2.74	29 2.38	---- ----	3 .130	---- ----	274 4.49	31 .64	2.8 .08	---- ----	---- ----	----	394	----	256	----	.1	467	----	C_2-S_1
449	23bbc1	560	10-25-44	70	1	----	46 2.29	26 2.14	---- ----	4 .17	---- ----	250 4.10	19 .4	5 .14	---- ----	---- ----	----	350	----	222	----	.1	442	----	C_2-S_1
384	27aab1	605	10-23-44	70	1	----	44 2.18	27 2.20	---- ----	8.9 .39	---- ----	247 4.05	23 .47	8.8 .25	---- ----	---- ----	.0	358	----	219	----	.3	420	----	C_2-S_1
----	S19/62-36ccc1[1]	1,036	4-19-55	82	4	40	41 2.04	23 1.89	90 3.92	---- ----	8.1 ----	187 3.07	172 3.58	48 1.35	1.5 .08	1.9 .04	----	----	518	197	44	2.8	786	7.4	C_3-S_1
696	36dbb1	1,434	4-21-55	84	4	81	106 5.29	75 6.16	86 3.74	---- ----	11 ----	142 2.33	549 11.42	43 1.21	1.9 .1	9.9 .16	----	----	1,030	573	456	1.6	1,330	7.4	C_3-S_1
695	36dcc1	1,502	3- 5-55	80	4	77	190 9.48	170 14.13	102 4.44	---- ----	9.5 ----	134 2.20	1,150 23.92	55 1.55	1.8 .1	1.6 .03	----	----	1,810	1,180	1,070	1.3	2,180	7.6	C_3-S_1
2	S20/60-24adb1	385	9-14-12	----	1, 2	7	52 2.59	3 .25	---- ----	43 1.87	---- ----	235 3.85	34 .71	4 .11	---- ----	---- ----	----	251	----	141	----	----	----	----	----
314	S20/61-3dab1	242	5- 1-41	71	1	13	54 2.69	15 1.23	---- ----	24 1.04	---- ----	237 3.89	45 .94	7 .2	---- ----	---- ----	----	245	----	196	----	----	----	----	----
	3dab1	300	10-16-56	74	4	16	48 2.39	23 1.89	6 .27	---- ----	1.1 ----	232 3.8	34 .71	4.9 .14	.2 .01	1.5 .02	----	----	249	242	26	.2	421	7.6	C_2-S_1

318	4add1	850	10-12-31	71	2	17	12 .6	19 1.56	----	71 3.09	----	220 3.61	72 1.50	7.1 2.02	----	----	----	200	----	108	----	----	----	----	----
468	13adc1	930	1-24-47	74	4	----	54 2.70	32 2.63	----	20 .87	----	205 3.36	129 2.68	3.2 .09	.5 .03	1 .02	----	----	341	266	98	.5	551	----	C_2–S_1
89	14ddd1	402	do	72	4	----	46 2.30	27 2.22	----	.9 .04	----	226 3.71	35 .73	3.5 .1	.4 .02	.8 .01	----	----	225	226	41	.0	424	----	C_2–S_1
----	15ab1	1,700	4-20-56	82	4	40	14 .7	11 .91	139 6.05	----	43	284 4.66	114 2.37	8 .23	.9 .05	.3 .01	.52	----	484	80	0	6.7	721	7.5	C_2–S_2
208	16bdb1	386	1-21-47	69	4	----	44 2.20	23 1.89	----	2.8 .12	----	212 3.48	27 .56	4.8 .14	.4 .02	1.4 .02	----	----	208	204	31	.1	382	----	C_2–S_1
505	18bcc1	412	2-16-45	----	1	----	46 2.30	26 2.14	----	12 .51	----	212 3.47	30 .63	5.3 .15	----	----	----	352	----	222	----	.3	434	----	C_2–S_1
5	19abd1	260	10-23-44	70	1	----	49 2.49	26 2.09	----	4.8 .21	----	238 3.90	32 .67	7.1 .20	----	----	.01	357	----	228	----	.1	428	----	C_2–S_1
354	19ddc1	354	----	70	1	----	48 2.38	26 2.09	----	8.7 .38	----	242 3.97	34 .71	6 .17	----	----	----	364	----	224	----	.3	432	----	C_2–S_1
166	20cac1	347	9-15-34	70	1	9	44 2.19	14 1.15	----	33 1.43	----	237 3.88	30 .62	10 .28	----	----	----	240	----	167	----	----	----	----	----
7	20cbc1	278	10-18-44	71	1	----	49 2.45	26 2.09	----	5.9 .26	----	242 3.95	33 .68	6.2 .17	----	----	.01	361	----	227	----	.2	427	----	C_2–S_1
360	20cdc1	325	do	71	1	----	49 2.47	26 2.12	----	4.6 .2	----	238 3.9	36 .74	5.3 .15	----	----	----	359	----	230	----	.1	428	----	C_2–S_1
----	21	125	7-21-52	----	5	----	164 8.2	----	----	190 8.28	----	242.7 3.98	417 8.68	136 3.82	----	----	.34	1,190	----	----	----	----	1,700	----	----
213	27adb1	----	----	----	1	18	78 3.89	21 1.73	----	9 .39	----	249 4.08	61 1.27	22 .62	----	----	----	323	----	281	----	----	----	----	----
276	27cdd1	357	6-14-35	----	1	37	57 2.84	9 .74	----	33 1.43	----	232 3.81	22 .46	28 .79	----	----	----	335	----	179	----	----	----	----	----
12	28cbd1	660	1-19-45	74	1	----	43 2.15	23 1.85	----	10 .44	----	221 3.62	31 .65	6 .17	----	----	.06	334	----	200	----	.2	402	----	C_2–S_1
403	28cda1[2]	440	10-25-44	76	1	----	38 1.90	22 1.82	----	10 .44	----	210 3.45	27 .56	5 .15	----	----	.02	312	----	185	----	.3	375	----	C_2–S_1
403	28cda1[3]	690	do	76	1	----	38 1.92	24 1.78	----	11 .51	----	192 3.15	33 .69	6 .17	----	----	.02	310	----	193	----	.4	384	----	C_2–S_1
199	28dac1[2]	640	1-19-45	----	1	----	46 2.30	22 1.76	----	6.7 .29	----	171 2.80	24 .51	11 .31	----	----	.15	280	----	203	----	.2	335	----	C_2–S_1
199	28dac1[3]	805	do	----	1	----	40 2.02	22 1.80	----	9.2 .4	----	210 3.45	30 .62	5.3 .15	----	----	----	317	----	192	----	.3	408	----	C_2–S_1
83	29cbc2	600	2- 5-32	75	2	17	64 3.19	20 1.64	----	7.9 .34	----	233 3.82	58 1.21	5.5 .16	----	----	----	235	----	242	----	.2	557	----	C_2–S_1
81	29cbb1	375	do	72	----	13	36 1.78	22 1.82	----	5.1 .22	----	180.6 2.96	32 6.68	7.1 2	----	----	----	190	----	----	----	.2	404	----	C_2–S_1
77	29ccc1	----	10- 2-42	----	1	10	60 2.99	19 1.56	----	11 .48	----	220 3.61	45 .94	13 .36	----	----	----	265	----	228	----	----	----	----	----
380	29dbb1	475	10-18-44	72	1	----	48 2.42	25 2.04	----	5.7 .25	----	236 3.87	33 .69	5.3 .15	----	----	----	354	----	224	----	.2	429	----	C_2–S_1
52	29dca1	664	10-24-44	74	1	----	46 2.31	25 2.01	----	6.2 .27	----	227 3.72	32 .67	7.1 .20	----	----	----	343	----	216	----	.2	423	----	C_2–S_1
109	30bb1	350	3-27-31	72	2	18	51 2.54	24 1.97	----	7.6 3.31	----	249 4.08	38 .79	Tr.	----	----	----	246	----	227	----	----	----	----	----

See footnotes at end of table.

TABLE 19.—*Chemical analyses of water from wells in the Las Vegas ground-water basin*—Continued

State Engineer's well No.	Location	Depth	Date collected	Temperature (°F)	Agency making analysis	Silica (SiO_2)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions										Boron (B)	Solids		Hardness as $CaCO_3$		Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Classification for irrigation
							Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium (Na) and potassium (K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)		Total	Dissolved (residue on evaporation at 180°C)	Calcium and magnesium	Noncarbonate				
367	S20/61-31aad2	500	11- 2-51	----	4	14	50 2.50	26 2.14	---- ----	---- ----	---- ----	238 3.90	43 .89	3.5 .09	.2 .01	2.1 .03	----	----	----	232	37	----	430	7.7	----
457	31dac1	940	5-16-52	76	4	14	48 2.40	25 2.06	8 .35	---- ----	3.6 .09	222 3.64	51 1.06	6.5 .18	.2 .01	1 .02	.10	----	267	222	41	.2	447	7.4	C_2-S_1
390	32acb2	660	2-16-45	77	1	----	46 2.31	25 2.09	---- ----	11 .49	---- ----	235 3.85	40 .84	7.1 .2	---- ----	---- ----	.06	365	----	220	----	.3	441	----	C_2-S_1
205	33cca1[3]	200	----	71	1	----	46 2.30	28 2.28	---- ----	9.2 .4	---- ----	233 3.82	44 .91	8.8 .25	---- ----	---- ----	.02	369	----	229	----	.3	447	----	C_2-S_1
205	33cca1[3]	400	----	72	1	----	47 2.35	26 2.14	---- ----	12 .53	---- ----	233 3.82	46 .95	8.8 .25	---- ----	---- ----	.18	373	----	225	----	.4	446	----	C_2-S_1
206	33cca2	226	2-21-38	----	1	22	84 4.19	Tr. ----	---- ----	32 1.39	---- ----	270 4.43	47 .98	7 .2	---- ----	---- ----	----	280	----	210	----	----	----	----	----
15	33ccb2	425	----	----	1	----	49 2.47	13 1.06	---- ----	26 1.13	---- ----	231 3.80	25 .52	7.8 .22	---- ----	---- ----	----	357	----	177	----	.9	423	----	C_2-S_1
47	34adc1	354	1-19-45	69	1	----	28 1.42	19 1.55	---- ----	11 .48	---- ----	162 2.65	26 .55	8.8 .25	---- ----	---- ----	.07	255	----	148	----	.4	326	----	C_2-S_1
159	34bcb1	----	6-14-41	----	1	25	84 4.19	25 2.05	---- ----	50 2.17	---- ----	305 5	144 2.99	16 .45	---- ----	---- ----	----	460	----	312	----	----	----	----	----
363	35cbb2	460	9-14-45	----	1	----	31 1.56	22 1.76	---- ----	4 .16	---- ----	162 2.66	32 .65	6 .17	---- ----	---- ----	.02	256	----	166	----	.1	339	----	C_2-S_1
368	35ddc2	418	---do---	----	1	----	39 1.96	26 2.14	---- ----	5 .2	---- ----	206 3.38	40 .83	3.2 .09	---- ----	---- ----	.01	319	----	205	----	.1	377	----	C_2-S_1
393	36bbb1	325	1-19-45	69	1	----	44 2.20	26 2.12	---- ----	10 .45	---- ----	233 3.82	36 .75	7.1 .2	---- ----	---- ----	.06	356	----	216	----	.3	424	----	C_2-S_1
831	S20/62-3dab1	504	10-16-56	74	4	18	46 2.29	23 1.89	7 .32	---- ----	1.8 ----	232 3.8	32 .67	4.5 .13	.2 .01	1.1 .02	----	----	248	230	20	.2	413	7.8	C_2-S_1
416	4add1	800	5- 5-41	71	1	15	60 2.99	17 1.40	---- ----	15 .65	---- ----	244 4.00	34 .71	12 .34	---- ----	---- ----	----	255	----	220	----	----	----	----	----
----	1bbc1[4]	1,247	3- 2-55	77	4	70	47 2.34	43 3.53	46 2	---- ----	4.5 .12	198 3.25	171 3.56	39 1.1	1.3 .07	2 .03	----	----	522	294	132	1.2	748	7.6	C_2-S_1
416	4add1	790	10-17-56	77	4	27	43 2.15	23 1.89	18 .78	---- ----	3.8 .1	252 4.13	25 .52	5.8 .63	.5 .03	2.4 .04	----	----	272	201	0	.6	440	7.8	C_2-S_1
676	9abc1	1,000	---do---	78	4	36	39 1.95	19 1.56	91 3.96	---- ----	7.1 .18	228 3.74	162 3.37	18 .51	1.3 .07	.7 .01	----	----	486	176	0	3	728	8.0	C_2-S_1

681	9bcc1	1,000	do	77	4	57	38 1.90	25 2.05	49 2.13	------	5.8 .15	256 4.2	88 1.83	8.6 .24	1 .05	.9 .02	----	------	399	199	0	1.5	575	7.7	C_2-S_1
444	19bbb1	289	12-17-45	----	1	51	25 1.25	10 .82	------	56 2.44	----	204 3.34	35 .73	15 .42	----	----	----	294	------	102	------	------	------	----	------
442	19cab1	200	do	----	1	30	39 1.95	15 1.23	------	84 3.65	----	221 3.62	110 2.29	32 .90	----	----	----	408	------	159	------	------	------	----	------
----	30	132	10-27-52	----	5	----	162 8.1	------	------	175 7.62	----	218 3.58	451 9.38	75 ------	----	----	.34	1,050	------	------	------	3.8	1,500	----	------
84	S21/61-1cdc1	------	1-21-47	70	4	----	49 2.45	26 2.14	------	3.9 .17	----	223 3.66	47 .98	3.5 .10	.2 .01	1.3 .02	----	------	241	230	47	.1	428	----	C_2-S_1
51	2cbb1	1,120	1-19-45	83	1	----	32 1.62	18 1.45	------	50 2.17	----	152 2.50	124 2.57	6.2 .17	----	----	.07	382	------	154	------	1.8	508	----	C_2-S_1
238	3abb2[2]	------	9-14-45	70	1	----	45 2.24	26 2.09	------	4.1 .18	----	218 3.58	41 .85	2.8 .08	----	----	.01	337	------	219	------	.1	423	----	C_2-S_1
238	3abb2[3]	807	do	----	2,3	----	40 2	23 1.89	------	5.5 .02	----	199 3.26	39 .81	3.2 .09	----	----	.25	310	------	196	------	.0	398	----	C_2-S_1
172	3bcc2	800	10-10-35	72	1	22	51 2.54	13 1.07	------	26 1.13	----	210 3.44	50 1.04	10 .28	----	----	----	225	------	181	------	------	------	----	------
386	4aad1	793	1-19-45	74	1	----	41 2.07	23 1.89	------	17 .76	----	223 3.65	37 .77	9.6 .27	----	----	.07	351	------	197	------	.5	418	----	C_2-S_1
48	4baa1	381	do	72	1	----	31 1.57	27 2.19	------	29 1.27	----	236 3.87	46 .96	7.1 .20	----	----	.02	376	------	188	------	1	448	----	C_2-S_1
347	4dac1	810	5-19-41	----	1	12	60 2.99	18 1.48	------	2 .09	----	220 3.61	32 .67	10 .28	----	----	----	228	------	224	------	------	------	----	------
420	4dac2	650	10-25-44	70	1	----	36 1.82	26 2.17	------	10 .43	----	174 2.85	42 .87	5 .15	----	----	.01	309	------	197	------	.3	404	----	C_2-S_1
88	4ddb1	400	10- 9-45	----	1	20	60 2.99	17 1.40	------	2 .09	----	195 3.20	44 .92	10 .28	----	----	----	265	------	220	------	------	------	----	------
21	6acc1	394	7- 6-47	72	4	----	54 2.69	29 2.38	------	11 .48	----	231 3.79	74 1.54	5 .14	.2 .01	3.5 .06	----	------	290	254	64	.4	501	----	C_2-S_1
155	7acc1[2]	------	3-15-45	72	1	----	49 2.43	28 2.28	------	7.1 .31	----	232 3.80	51 1.07	5.3 .15	----	----	----	372	------	236	------	.3	458	----	C_2-S_1
155	7acc1[3]	355	do	72	1	----	48 2.41	27 2.23	------	10 .44	----	232 3.80	52 1.08	7.1 .20	----	----	.02	376	------	232	------	.3	458	----	C_2-S_1
377	9acd1	550	10-17-44	72	1	----	45 2.25	24 1.98	------	11 .48	----	223 3.65	39 .81	8.8 .25	----	----	.04	350	------	212	------	.3	424	----	C_2-S_1
757	10cda1	931	4-13-53	----	5	----	143 7.12	------	------	521 22.64	----	95 1.56	1,050 21.93	210 5.93	----	----	.25	2,100	------	------	------	12	3,000	----	C_2-S_1
292	13bdb1	260	1-21-47	72	4	----	60 2.99	29 2.39	------	10 .44	----	227 3.72	71 1.48	2.5 .07	.6 .03	2.9 .05	----	------	278	268	82	.3	485	----	C_2-S_1
478	15bcc1	892	1-23-47	76	4	----	47 2.35	25 2.06	------	4.1 .18	----	211 3.46	47 .98	3.8 .11	.4 .02	1.4 .02	----	------	233	220	48	.1	420	----	C_2-S_1
30	18dbd1	300	9-10-30	----	2	16	68 3.39	32 2.63	------	12 .52	----	243 3.98	109 2.27	10 .28	----	----	----	329	------	301	------	------	------	----	------
123	21bbb1	325	10-17-44	70	1	----	40 2	24 1.93	------	9.2 .4	----	204 3.35	40 .83	5.3 .15	----	----	.05	322	------	197	------	.3	399	----	C_2-S_1
117	22ccc1	500	1- 6-47	72	4	----	65 3.24	32 2.63	------	7.8 .34	----	227 3.72	106 2.20	7 .2	.1 .01	4.3 .07	----	------	334	294	108	.2	560	----	C_2-S_1
126	23ccb1	------	1-23-47	----	4	----	72 3.59	37 3.04	------	15 .65	----	216 3.54	165 3.43	8.8 .25	.3 .02	1.4 .02	----	------	406	332	156	.4	657	7.9	C_2-S_1

See footnotes at end of table.

TABLE 19.—*Chemical analyses of water from wells in the Las Vegas ground-water basin*—Continued

State Engineer's well No.	Location	Depth	Date collected	Temperature (°F)	Agency making analysis	Silica (SiO_2)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions										Boron (B)	Solids		Hardness as $CaCO_3$		Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Classification for irrigation
							Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium (Na) and potassium (K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)		Total	Dissolved (residue on evaporation at 180°C)	Calcium and magnesium	Noncarbonate				
149	S21/61-25cab1	------	1-20-47	74	4	----	139 6.94	51 4.19	------	7.4 .32	----	218 3.58	357 7.43	14 .40	.4 .02	2.3 .04	-----	------	678	556	378	.1	1,000	----	C_3-S_1
35	27cbb1	400	9-18-12	----	2,3	21	85 4.24	31 2.55	------	10 .44	----	210 3.44	165 3.43	10 .28	----	----	-----	430	------	340	------	------	------	----	--------
38	27cc1	263	10-17-44	75	1	----	61 3.07	31 2.58	------	20 .88	----	253 4.53	101 2.11	11 .30	----	----	-----	478	------	282	------	.5	544	----	C_2-S_1
53	28bcc1	176	3-6-43	----	1	35	72 3.59	21 1.73	------	18 .78	----	220 3.61	116 2.41	3 .09	----	----	-----	400	------	266	------	------	------	----	--------
93	29dda1	260	10-17-44	70	1	----	67 3.33	34 2.78	------	7.3 .32	----	227 3.72	118 2.46	8.8 .25	----	----	.11	462	------	306	------	.2	574	----	C_2-S_1
39	33bac1	224	10-27-30	79	1	19	81 4.04	25 2.05	------	31 1.35	----	245 4.02	148 3.08	12 .34	----	----	-----	410	------	304	------	------	------	----	--------
37	34abc1	246	1-6-47	74	4	----	64 3.19	30 2.47	------	11 .48	----	223 3.66	107 2.22	6 .17	.3 .02	3.9 .06	-----	------	332	283	100	.3	564	----	C_2-S_1
125	35dcc1 [2]	300	8-5-27	----	1	----	151 7.53	52 4.27	------	35 1.52	----	219 3.59	418 2.69	38 1.07	----	----	-----	912	------	590	------	------	------	----	--------
125	35dcc1 [3]	485	do	----	1	----	116 5.79	39 3.20	------	42 1.83	----	168 2.75	358 7.45	22 .62	----	----	-----	745	------	451	------	------	------	----	--------
484	36adc1	------	1-20-47	----	4	----	137 6.84	56 4.61	------	22 .96	----	205 3.36	392 8.15	29 .82	.4 .02	2.4 .04	-----	------	740	572	404	.4	1,520	----	C_3-S_1
339	S21/62-3bac1	546	12-24-12	----	2,3	15	500 24.95	150 12.33	------	1,510 65.64	----	51 .84	4,010 83.37	658 18.55	----	----	-----	7,360	------	1,870	------	------	------	----	--------
337	4aaa2	180	4-19-29	----	2	----	142 7.08	94 7.73	------	120 5.22	----	254 4.16	681 14.16	60 1.69	----	----	-----	1,310	------	741	------	------	------	----	--------
374	17ddc1	540	3-18-42	----	1	74	228 11.38	68 5.59	------	678 29.49	----	154 2.52	1,600 33.26	378 10.66	----	----	-----	3,110	------	849	------	------	------	----	--------
130	19acd1	------	1-23-47	77	4	----	42 2.10	22 1.81	------	14 .61	----	194 3.18	55 1.14	5.2 .15	.4 .02	1.3 .02	-----	------	841	196	36	.4	419	----	C_2-S_1
833	19cdd1	114	5-20-57	----	5	----	123 6.13	37 3.01	------	53 2.29	----	217 3.56	357 7.42	16 .45	----	----	-----	744	------	------	------	1.1	1,025	----	C_3-S_1
407	20ddd1	458	12-21-42	76	1	46	66 3.29	20 1.64	------	25 1.09	----	144 2.36	134 2.79	15 .42	----	----	-----	371	------	247	------	.7	118	----	C_1-S_1

295	21ddd1	------	7-13-42	----	1	48	246 12.27	98 8.05	------ ------	765 33.28	---- ----	78 1.28	2,250 46.84	192 5.41	---- ----	---- ----	-----	3,710	------	1,020	------	------	------	----	--------
342	27bcb1	525	do	----	1	37	148 7.38	46 3.78	------ ------	511 22.23	---- ----	81 1.33	1,360 28.20	136 3.83	---- ----	---- ----	-----	2,360	------	559	------	------	------	----	--------
355	27bcd1	450	do	----	1	48	240 11.98	120 9.78	------ ------	544 23.66	---- ----	107 1.75	1,680 34.90	308 8.68	---- ----	---- ----	-----	3,050	------	1,090	------	------	------	----	--------
296	27cba1	420	do	----	1	37	158 7.88	45 3.70	------ ------	504 21.92	---- ----	81 1.33	1,370 28.54	128 3.61	---- ----	---- ----	-----	2,390	------	580	------	------	------	----	--------
491	27ccc1	375	9-27-46	----	2	82	610 30.44	360 29.43	------ ------	805 35.02	---- ----	204 3.35	2,860 59.38	1,140 32.15	---- ----	---- ----	-----	6,380	------	2,990	------	------	------	----	--------
293	28aad1	420	7-13-42	----	1	35	162 8.08	63 5.18	------ ------	573 24.92	---- ----	81 1.33	1,600 33.28	161 4.54	---- ----	---- ----	-----	2,820	------	663	------	------	------	----	--------
297	28acd1	18	9-20-12	----	3	71	295 14.72	160 13.48	------ ------	297 12.92	---- ----	197 3.23	1,230 25.65	417 11.76	---- ----	---- ----	-----	2,830	------	1,410	------	------	------	----	--------
294	28ada1	570	7-13-42	----	1	70	282 14.07	190 15.45	------ ------	474 20.62	---- ----	181 2.97	1,640 34.13	460 12.97	---- ----	---- ----	-----	3,250	------	1,480	------	------	------	----	--------
301	29bcc1	------	8- 4-42	----	1	22	64 3.19	34 2.79	------ ------	11 .48	---- ----	181 2.97	147 3.06	16 .45	---- ----	---- ----	-----	420	------	299	------	------	------	----	--------
133	29ccb1	700	7-13-42	----	1	36	79 3.94	39 3.21	------ ------	33 1.44	---- ----	195 3.20	232 4.83	20 .56	---- ----	---- ----	-----	580	------	357	------	------	------	8.2	--------
133	29ccb1	1,165	3- 8-45	----	1	----	80 3.99	46 4.30	------ ------	21 1.08	---- ----	206 3.31	240 4.99	11 .68	---- ----	---- ----	.21	603	------	357	------	.5	783	----	C_3–S_1
134	29ccc1	404	7-14-42	----	1	25	110 5.49	50 4.11	------ ------	29 1.26	---- ----	215 3.53	327 6.80	20 .56	---- ----	---- ----	-----	715	------	480	------	------	------	----	--------
128	30dbb1	390	8- 4-42	77	1	12	110 5.49	42 3.45	------ ------	18 .78	---- ----	160 2.62	315 6.55	20 .56	---- ----	---- ----	-----	602	------	447	------	------	------	----	--------
466	30dcb1	400	1-20-47	74	4	----	106 5.29	47 3.87	------ ------	29 1.22	---- ----	232 3.81	295 6.14	13 .37	---- .4	---- 1.8	-----	------	606	458	268	.6	890	----	C_3–S_1
----	30d	140	10-21-57	----	5	----	460 22.96	------ ------	------ ------	19 .84	---- ----	202.4 3.32	820 17.06	121 3.42	.02 ----	.03 ----	-----	1,670	------	------	------	------	------	----	--------
132	31bdc2	600	7-13-42	74	3	21	147 7.33	50 4.11	------ ------	.8 .35	---- ----	158 2.59	392 8.15	37 1.04	---- ----	---- ----	-----	805	------	572	------	------	------	----	--------
----	S21/63-30cbb	500	3- 4-25	----	2	58	282 14.07	170 14.14	------ ------	500 21.75	---- ----	165 2.71	1,270 26.48	737 20.78	---- ----	---- ----	-----	3,300	------	------	------	------	------	----	--------
272	S22/61-1bcb4	------	9-17-12	----	2, 3	36	193 9.63	73 6	------ ------	104 4.52	---- ----	191 3.13	587 12,21	168 4.74	---- ----	---- ----	-----	1,380	------	782	------	------	------	----	--------
62	1bdb1	------	9-25-30	----	2	34	229 11.43	94 7.73	------ ------	128 5.57	---- ----	182 2.98	901 18.74	107 3.02	---- ----	---- ----	-----	1,550	------	959	------	------	------	----	--------
57	1dac1	209	7-13-42	----	2, 3	25	177 8.83	56 4.60	------ ------	44 1.91	---- ----	207 3.39	448 9.32	94 2.65	---- ----	---- ----	-----	1,020	------	672	------	------	------	----	--------
226	2aba1	200	10-17-44	76	1	----	134 6.71	57 4.64	------ ------	2.3 .10	---- ----	198 7.34	353 7.35	30 .85	---- ----	---- ----	.17	775	------	568	------	.2	1,090	----	C_3–S_1
122	3acc1	------	7- 3-41	----	1	----	148 7.38	40 3.29	------ ------	55 2.39	---- ----	207 3.39	452 9.40	10 .28	---- ----	---- ----	-----	882	------	534	------	------	------	----	--------
121	3caa1	395	do	84	1	21	150 7.48	44 3.62	------ ------	40 1.74	---- ----	171 2.80	453 9.42	22 .62	---- ----	---- ----	-----	863	------	555	------	------	------	----	--------
434	3dda1	335	6-15-45	84	1	----	158 7.88	53 4.37	------ ------	.7 .31	---- ----	176 2.88	441 9.17	.5 .01	---- ----	---- ----	.45	838	------	613	------	.1	1,138	----	C_3S_1
69	10bda1	305	9-18-12	90	2, 3	30	155 7.73	50 4.11	------ ------	15 .65	---- ----	205 3.36	405 8.42	35 .99	---- ----	---- ----	-----	857	------	592	------	------	------	----	--------

See footnotes at end of table.

TABLE 19.—*Chemical analyses of water from wells in the Las Vegas ground-water basin*—Continued

State Engineer's well No.	Location	Depth	Date collected	Temperature (°F)	Agency making analysis	Silica (SiO_2)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions										Boron (B)	Solids		Hardness as $CaCO_3$		Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Classification for irrigation
							Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium (Na) and potassium (K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)		Total	Dissolved (residue on evaporation at 180°C)	Calcium and magnesium	Noncarbonate				
352	S22/61-11bac2	175	3-28-45	----	1	----	140 7.02	52 4.30	------	25 1.08	----	202 3.31	4.04 8.40	24 .68	----	----	.29	848	------	566	------	.5	1,069	----	C_3-S_1
261	11bac3	------	9-17-12	----	2, 3	35	177 8.83	56 4.60	------	47 2.04	----	215 3.53	483 10.05	67 1.89	----	----	----	1,040	------	672	------	------	------	----	--------
266	12bbb1	------	10-17-44	82	2	----	120 9.38	51 4.19	------	102 4.44	----	329 5.39	326 6.78	205 5.78	----	----	----	851	------	------	------	1.1	1,001	----	C_3-S_1
----	16a1	65	-26	----	1	37	188 5.98	51 4.17	------	58 2.50	----	157 2.57	414 8.61	52 1.46	----	----	.21	1,100	------	508	------	------	------	----	--------
350	S22/62-1cba1	465	7-13-42	75	1	62	210 10.48	50 4.11	------	253 11	----	117 192	753 15.66	284 8.01	----	----	----	1,800	------	730	------	------	------	----	--------
494	1cbc1	1,135	3-15-45	91	1	----	106 5.30	20 1.66	------	436 18.9	----	84 1.38	1,030 21.4	112 3.16	----	----	1.6	1,790	------	347	------	10.2	2,480	----	C_4-S_3
----	1cbc2 [5]	------	do	----	1	----	120 6.00	31 2.56	------	536 23.3	----	323 5.30	932 19.4	254 7.16	----	----	3.1	2,200	------	427	------	11.3	2,770	----	C_4-S_3
495	1cbd1	850	7-13-42	----	1	63	76 3.79	9 .74	------	743 32.32	----	160 2.62	1,300 26.96	256 7.22	----	----	----	2,560	------	227	------	------	------	----	--------
431	1ccc1	300	9-24-45	----	1	----	174 8.7	85 6.93	------	378 16.45	----	102 1.68	513 10.67	700 19.74	----	----	1.3	1,950	------	782	------	5.9	3,160	----	C_4-S_2
382	9dcc1	180	11- 9-42	----	1	35	98 4.89	56 4.60	------	124 5.39	----	176 2.89	279 5.80	218 6.15	----	----	----	943	------	475	------	------	------	----	--------
----	12aac1	200	5-23-45	----	1	80	81 4.04	29 2.38	------	189 8.22	----	134 2.20	390 8.11	154 4.36	----	----	----	1,010	------	321	------	------	------	8.1	--------
----	S20/61- [6]	------	10- 2-42	----	1	10	60 2.99	19 1.56	------	11 .48	----	220 3.61	45 .94	13 .36	----	----	----	265	------	228	------	------	------	----	--------
----	S20/61- [7]	------	-27	----	1	12	58 2.89	25 2.05	------	17 .74	----	259 4.25	48 .99	18 .50	----	----	----	291	------	248	------	------	------	----	--------

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[1] Lake Mead Base well 4.

[2] Shallow flow.

[3] Deep flow.

[4] Lake Mead Base well 3.

[5] Dug well.

[6] Composite sample of wells and springs of city supply.

[7] Composite sample of Las Vegas springs and well S20/61-29ccc1.

TABLE 20.—*Chemical analyses of water from springs in the Las Vegas ground-water basin*

[Analyses are in parts per million, except as otherwise indicated]

No. and location	Name	Date collected	Temperature (°F)	Agency making analysis [1]	Silica (SiO_2)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions								Solids		Total hardness (as $CaCO_3$)	Specific conductance (micromhos at 25° C)
						Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Total	Dissolved (residue on evaporation at 189° C)		
S16/56-16b1	Indian Springs	12-15-12	78	1	17	0.16 .57	48 2.39	15 1.23	31 1.35	239 3.92	28 .58	5 .14	0.00 ------	330	------	181	------
S17/59-34a1	Corn Creek Spring	12- 8-12	------	2	18	.03 .01	54 2.69	28 2.30	17 .74	292 4.79	26 .54	12 .34	4 .06	287	------	250	------
S19/60-9c1	Tule Springs	4-20-29	70	3	------	------ ------	52 2.59	28 2.30	2 .08	255 4.18	27 .56	9 .24	------ ------	207	------	------	------
21ccc	Stillwell Spring	9-13-45	------	?	------	------ ------	55 2.77	29 2.35	2.3 .1	275 4.50	31 .64	3 .08	------ ------	------	------	------	467
S20/61-15dc1	Kyle Spring	9-16-12	76	2	8	.01 .03	53 2.64	27 2.22	26 1.13	251 4.12	33 .69	55 1.55	2 .03	258	------	243	------
30ddc1 30ddd1 31aab1	Las Vegas Springs	9-23-12	73	2	13	Tr. ------	56 2.79	23 1.89	17 .74	239 3.92	43 .89	2 .06	6. .1	267	------	234	------
31aab1	Las Vegas Big Springs	11- 2-51	62	4	13	------ ------	51 2.55	25 2.06	------ ------	238 3.90	37 .77	3 .08	2 .02	------	------	230	424
S21/62-20bc	Unnamed spring	8-17-42	------	1	45	Tr. ------	66 3.29	30 2.47	23 1	183 3.01	158 3.29	18 .51	------ ------	477	------	288	------
20bc	do	do	------	1	30	Tr. ------	108 5.39	47 3.86	32 1.39	205 3.36	320 6.66	22 .62	------ ------	664	------	463	------
29db1	Grapevine Spring	12-24-12	------	2	55	.3 .01	275 13.72	130 10.69	99 4.31	239 3.92	959 19.95	172 4.85	.3 .05	2,010	------	1,220	------
29dbb	do	7- 8-46	------	4	50	Tr. ------	377 18.81	130 10.28	365 15.88	237 3.89	1,610 33.43	270 7.16	------ ------	------	3,140	1,460	------
S22/59-7c1	Cottonwood Spring	9-18-12	------	2	19	.40 .01	102 5.09	43 3.53	46 2.01	290 4.76	146 3.04	11 .31	.5 .72	563	------	431	------

[1] See headnote, table 19.

TABLE 21.—*Average concentration of chemical constituents, in parts per million, and temperature of ground water in four areas in Las Vegas Valley*

Zone of aquifers	Number of samples	Dissolved solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and potassium (K) as sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Temperature (°F)
Las Vegas-Tule Springs Area										
Shallow	34	[1] 318	[2] 22	[1] 49	[3] 22	[1] 18	229	[1] 44	[3] 9	[4] 71
Middle	17	[5] 318	[6] 18	48	25	7	226	37	7	[7] 72.7
Deep	16	[8] 323	[9] 27	41	[8] 21	[8] 39	214	[8] 69	[8] 8	[10] 76
Paradise Valley Area										
Shallow	21	696	27	125	[11] 40	28	203	[11] 273	35	[10] 77
Middle	2	570	[12] 21	106	41	8.0	192	249	22	73
Deep	2	592	[12] 36	80	42	27	200	236	16	--------
Whitney-Pittman and Lake Mead Base Areas										
Shallow	11	[13] 2,070	[14] 55	[13] 218	106	352	156	1,080	[13] 231	[12] 75
Middle	5	[15] 3,000	51	288	125	[15] 541	126	1,980	474	--------
Deep	7	[16] 1,260	[6] 66	92	55	223	159	658	81	[6] 81

[1] Average of 33 samples.
[2] Average of 14 samples.
[3] Average of 32 samples.
[4] Average of 19 samples.
[5] Average of 16 samples.
[6] Average of 5 samples.
[7] Average of 13 samples.
[8] Average of 15 samples.
[9] Average of 9 samples.
[10] Average of 12 samples.
[11] Average of 20 samples.
[12] One sample.
[13] Average of 10 samples.
[14] Average of 8 samples.
[15] Average of 4 samples.
[16] Average of 7 samples.

Table 21 shows that ground water in the Las Vegas-Tule Springs area contains less dissolved solids than does water from wells and springs elsewhere in the valley. Water from wells and springs along the eastern margin of the valley in the Whitney-Pittman area and in the vicinity of Lake Mead Base are similar and usually have more dissolved solids than does water from other parts of the valley. Water from wells in most places in Paradise Valley contains greater quantities of dissolved solids than does water from wells in Las Vegas Valley north of Las Vegas, but it contains smaller amounts of dissolved solids than does water from wells and springs in the southeastern part of Las Vegas Valley in the Whitney-Pittman area. Ordinarily, the dissolved-solids content increases from the northern and western margins of the valley to the eastern and southern parts of the valley.

Many of the aquifers in the northern part of the valley are composed of coarse sand and gravel through which water is readily transmitted. Ground water in this area is closer to the source of recharge and has had less opportunity to dissolve minerals from the rocks than has ground water farther south and east. In the southern part of the valley, the rocks are composed principally of fine sand, silt, and clay that contain much gypsiferous material. Ground water is not readily transmitted through these beds, and the water is farther from the source of recharge. Consequently, the water has been in contact with the valley-fill deposits longer and thus has had a greater opportunity to become highly mineralized. The high content of sulfate in the ground water in the Whitney-Pittman and Lake Mead Base areas results from the solution of gypsum as the water passes through the sedimentary deposits.

The deep aquifers, although relatively impervious, are composed principally of clay, silt, and fine-grained sand of the Muddy Creek formation. Water from these aquifers usually contains less calcium and magnesium than does water from the shallower aquifers.

The character of water from aquifers at different depths differs principally in concentration of dissolved solids and in temperature. Water from the deeper aquifers contains less dissolved solids, has a smaller concentration of calcium and magnesium, and has a greater concentration of silica than does water from either the middle or the shallow zone in the same area. The higher dissolved-solids content in water from the middle and shallow zones results in part from the higher solubility of the calcareous material in the aquifers in those zones and in part from the solution of minerals from the semiconfining beds as the water leaks upward from deep to shallow aquifers. An exchange of minerals in solution with ions adsorbed on the surface of clay and silt particles also affects the relative amounts of the various chemical constituents. Cations adsorbed on clay or silt particles can interchange freely with cations in solution; the proportion of the various cations in the exchange process is related to their concentrations.

The average concentration of chemical constituents shown in table 21 does not show the extremes in the dissolved-solids content found in the ground water. Lenses of gypsum and other evaporites may cause local increases in the concentration of the chemical constituents of the ground water. Water from wells developed in these local mineralized areas may contain as much as seven or eight times more dissolved solids than does water from nearby wells of similar depth and construction. Table 21 was prepared to show the chemical quality of water in various areas of the basin—that is, the quality that most nearly typifies water in the particular area— and, therefore, in the computation of the average values listed in the table, the analyses of the extremes have been omitted. Analyses of water from several wells having unusually high concentrations of dissolved minerals are listed in table 19.

TEMPERATURE

Differences in the temperature of water from aquifers at different depths have been noted in Las Vegas Valley. In general, water from the shallow zone of artesian aquifers in the vicinity of Las Vegas is 1°F cooler than water from the middle zone of aquifers and about 5°F cooler than water from the deep zone. The few analyses from the Paradise Valley area indicate that the water from the shallow zone of aquifers in that area is about 4°F warmer than the water from the middle zone of aquifers. Because of the limited data, however, the indicated difference probably is not a representative average. In the Whitney-Pittman area, water from the shallow zone of aquifers usually is about 6°F cooler than water from the deep zone of aquifers.

Ground water normally increases in temperature with increasing depth. Furthermore, the temperature of ground water may be raised by heat from intrusive volcanic rocks, heat of friction resulting from faulting, heat resulting from exothermic chemical reactions, and heat from other sources. The recent development of wells on the west side of Paradise Valley has revealed an area where ground-water temperatures are abnormally high. Wells in the vicinity of the intersection of U.S. Highway 91 and the Blue Diamond road tap thermal water at shallow depths. Well S22/61–16bcc1, drilled for domestic use, obtained water having a temperature of 106°F from a depth of 200 feet. About half a mile south of this well, ground water having the same temperature is pumped from well S22/61–21bb, which is 460 feet deep. Northeastward from these wells in the direction of movement of ground water, water temperatures gradually decrease, probably as a result of the mixing of the water with cooler water. Because of the limited number of wells in the area, data presently available are inadequate to determine the cause of the high water temperature or to determine the extent of the area where thermal water may be tapped.

DISSOLVED-SOLIDS CONTENT

The dissolved-solids content of water is obtained by weighing the residue remaining from the evaporation at 180°C of a given volume of water and by expressing the weight of the residue as parts per million (ppm). Because a large proportion of the inorganic salts in water are ionized, a relationship exists between the specific conductance of the solution and the dissolved-solids content. This relationship has lead to the practice of measuring the specific electrical conductance of the solution as an indication of the concentration of dissolved solids. The specific conductance is expressed in micromhos per centimeter at 25°C. A rough approximation of the dissolved-solids content, expressed in parts per million, can be obtained by multiplying the specific conductance, as defined, by 0.7.

A fair relationship also exists between the specific conductance and the sum of the cations and anions in solution. The sum of the anions or cations in solution, expressed in equivalent parts per million, can be approximated by dividing the specific conductance by 100.

The most common constituents in ground water include the common cations calcium, magnesium, and sodium, and the anions bicarbonate, sulfate, and chloride. Constituents that generally occur in minor amounts include potassium, carbonate, nitrate, silica, fluoride, and boron. Other constituents may be present in low concentrations but usually are not determined in routine analyses.

SOURCE AND SIGNIFICANCE OF DISSOLVED SOLIDS

Table 22 lists the principal dissolved constituents in ground water in the Las Vegas basin and their probable source, range in concentration, and significance.

The average water user commonly is more interested in the hardness than in most of the other chemical characteristics, except when unusually high concentrations of one or more of the dissolved constituents impart undesirable characteristics. Hardness is associated with the amount of soap required to make suds and the amount of insoluble scale that forms when water is heated. Most of the effect observed with soap results from the presence of calcium and magnesium; iron, manganese, and certain other substances, however, also contribute to hardness. Carbonate hardness—sometimes called temporary hardness—normally is caused by dissolved calcium and magnesium bicarbonate. Carbonate hardness can be eliminated by heating the water, but scale is deposited in the process. Noncarbonate hardness—sometimes called permanent hardness—can be removed only by chemical treatment of the water.

In evaluating the suitability of water for irrigation, it is desirable to evaluate the relative concentration of sodium in solution so that proper management may be affected. Sodium, like other cations, reacts with certain clay minerals, and this reaction results in a change of both the physical and chemical character of the soil. If a soil containing exchangeable calcium and magnesium ions is irrigated with water containing a high percentage of sodium ions, the calcium and magnesium of the soil will tend to be replaced by the sodium and thus will impair the soil's tilth and permeability. For this reason, the sodium concentration in water is one of the most significant criteria for judging the suitability of a water for irrigation. The sodium, or

TABLE 22.—*Principal dissolved chemical constituents in ground water in the Las Vegas basin*

Constituent	Major source	Occurrence (ppm)		Significance
		Minimum	Maximum	
Silica (SiO_2)	Silicate minerals, in practically all rocks.	7	82	Does not affect water for domestic or irrigation use. Water containing more than 1 ppm silica is undesirable for use in high temperature boilers or in turbines because of scale that forms in pipes.
Calcium (Ca).	Calcareous rocks, such as limestone, dolomite, gypsum, and basic igneous rocks.	12	460	Compounds of calcium and magnesium cause most of the hardness and scale-forming properties of water. No fixed limits have been set for the maximum hardness acceptable in water for domestic use. If hardness is in excess of 100 to 150 ppm, treatment to reduce hardness is desirable.
Magnesium (Mg).	Principally from dolomite	3	358	Significance of magnesium is similar to that of calcium except that magnesium is more soluble. Water containing concentrations in excess of 125 ppm is not recommended for domestic use.
Sodium (Na) and Potassium (K).	Feldspars, evaporites, industrial brines, and sewage.	.7	1510	Concentrations in excess of 50 ppm may necessitate careful operation of steam boilers to prevent foaming. High percent-sodium value necessitates special irrigation practices.
Bicarbonate (HCO_3) and Carbonate (CO_3).	Solvent action of carbon dioxide in water on carbonate rocks.	51	329	Carbonates of calcium and magnesium are fairly insoluble and are readily deposited upon release of carbon dioxide gas resulting from boiling or evaporation. Water containing more than 2.5 milliequivalents per liter of residual sodium carbonate is unfit for irrigation.
Sulfate (SO_4).	Igneous and sedimentary rocks, particularly deposits of gypsum or sodium sulfate, and industrial wastes.	22	4010	Water containing concentrations in excess of 250 ppm are not suitable for domestic use. Calcium and magnesium sulfate form hard scale.
Chloride (Cl).	Evaporites, sedimentary rocks of marine origin, natural and artificial brines, and sewage.	.5	1140	Recommended concentrations are not to exceed 250 ppm in drinking-water supplies subject to Federal regulations. High concentrations impart salty taste and may be corrosive to some metals.
Fluoride (F).	Complex fluoride-bearing minerals in igneous and metamorphic rocks, and fluorite in sedimentary rocks.	.1	1.9	Excessive amounts cause mottling of enamel of children's teeth. Water containing concentrations in excess of 1.6 ppm is not suitable for domestic use. Based on the annual average maximum daily air temperature at Las Vegas, the concentration should not average more than 0.8 ppm.
Nitrate (NO_3).	Oxidation product of organic matter, leaching of caliche and nitrate fertilizers, sewage, and nitrate-bearing minerals in igneous rocks.	0	9.9	Values higher than the local average may suggest pollution. Concentrations in excess of 45 ppm may cause methemoglobinemia ("blue baby") of infants.
Boron (B)	Solution of minerals such as tourmaline in igneous rocks, and solution of borax and other saline deposits.	.01	3.1	Toxic to most vegetation in concentrations in excess of 3.75 ppm.

alkali, hazard is determined by the sodium-adsorption-ratio (SAR), which may be expressed as

$$SAR=\frac{Na^{+1}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}},$$

where the ions are given in equivalents per million or in milliequivalents per liter.[4] The alkali hazard is determined by the absolute and relative concentrations of the cations. If the concentration and proportion of sodium is high, the alkali hazard is high; conversely, if calcium and magnesium predominate, the alkali hazard is low.

In irrigated areas or in areas where the water supporting plant growth is derived from upward leakage, water within the root zone may become more mineralized without a change in the relative percentage of soluble sodium. The SAR, however, increases in proportion to the square root of the total concentration. Thus, if the concentration is doubled, the SAR increases by a factor of 1.41.

In addition to determining the SAR, it is desirable to know the specific conductance of the water in order to classify waters for irrigation. (See discussion under "Dissolved-solids content.") Wilcox (1948, p. 80) has constructed a graph for classifying irrigation water on the basis of the electrical conductivity (specific conductance) and the SAR.

The four classes of water based on conductivity described below are taken in part from Wilcox (1948, p. 79):

1. Low-salinity water (C1) can be used to irrigate most crops on most soils, and it is rather unlikely that soil salinity will develop. Some leaching may be required in soils of extremely low permeability.
2. Medium-salinity water (C2) can be used if moderate leaching occurs. Plants of moderate salt tolerance usually can be grown without special practices for salinity control.
3. High-salinity water (C3) cannot be used on soils of low permeability, and special management for salinity control may be required. Only plants having good salinity tolerance should be planted.
4. Very high salinity water (C4) is not suitable for irrigation except in very permeable soils where adequate water is available to provide considerable leaching.

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[4] Milliequivalents per liter are numerically identical to equivalents per million if the specific gravity of the solution is 1.

The four classes of water with respect to the sodium-absorption-ratio are described as follows:

1. Low-sodium water (S1) can be used for irrigation of most soils and on all but the most sodium-sensitive crops with little danger of buildup of exchangeable sodium.
2. Medium-sodium water (S2) can be used on coarse-textured or organic soils of good permeability but will produce a high sodium hazard in fine-textured soils that have poor leaching conditions.
3. High-sodium water (S3) will produce harmful amounts of exchangeable sodium in most soils unless an abundance of gypsum is present. Chemical additives may be required to replace the exchangeable sodium.
4. Very high sodium water (S4) is unsatisfactory for irrigation except where it has low or perhaps medium salinity and where the soil to be irrigated contains an abundance of calcium.

Irrigation of calcareous soils will tend to reduce the sodium hazard and should be considered in the use of C1–S3 and C1–S4 waters. Waters of the classes C1–S3, C1–S4, and C2–S4 can be improved by adding gypsum if calcareous soils having high pH values or noncalcareous soils are being irrigated. Periodic addition of gypsum to waters of the types C2–S3 and C3–S2 may also be beneficial.

SUBSIDENCE OF THE LAND SURFACE

The land surface in the vicinity of the city of Las Vegas has subsided in part as the result of a reduction in artesian pressures brought about by large ground-water withdrawals and in part by a localized downward warping of the earth's surface as a result of the additional load imposed by Lake Mead (Carder and Small, 1948, p. 767–771; Smith and others, 1960, p. 33–38).

Precise releveling of a network of bench marks by the U.S. Coast and Geodetic Survey in Las Vegas Valley indicates that a maximum subsidence of approximately 13.5 inches (349.9 millimeters) occurred between 1935 and 1950 near the Bonanza Street underpass at bench mark L169 (pls. 12, 13).[5] This network of levels was established in the Hoover Dam area in 1935 for the purpose of observing the expected deformation of the earth's surface resulting from the increased load of the impounded water of Lake Mead. The network of bench marks is 715 miles long (Smith and others 1960, p. 31). That part of the network in Las Vegas Valley consists of a northwest-southeast line approximately parallel to U.S. Highway 95 from the vicinity of Corn Creek Springs to Pittman, and a northeast-southwest line

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[5] Unadjusted levels of part of the Hoover Dam level network surveyed during May to July 1963 by the U.S. Coast and Geodetic Survey indicate that the total subsidence of bench mark L169 during 1935–63 has increased to about 752 millimeters or approximately 2.5 feet (Malmberg, 1963).

paralleling the Union Pacific Railroad tracks from Apex to Arden, Nev. A northwest-southeast line traverses the northeastern part of the valley from a point on the Union Pacific Railroad approximately 2½ miles northeast of Nellis Air Force Base to the Boulder Wash gage on the shore of Lake Mead.

Elevations were established in 1935, 1940–41, and, for a third time, in 1949–50. The changes in elevation occurring between 1935 and 1940–41 and 1949–50 have been published in their entirety by Smith and others (1960, pl. 3).

Maps showing the shape of the cone of subsidence in Las Vegas Valley (pls. 12, 13) were prepared from these published data. Although a large amount of extrapolation was necessary and the location of the lines connecting points of equal change of the land surface is only approximate, the maps show the approximate extent and magnitude of the subsidence. Unfortunately, the level lines did not cross the area where the greatest withdrawals of ground water have occurred, principally to the west of the city of Las Vegas; therefore, the extrapolation in this area may be incorrect.

The principal cause of the localized subsidence in the Las Vegas area is believed to be compaction of fine-grained deposits interbedded with the water-bearing sand and gravel. Meinzer and Hard (1925, p. 90–93) pointed out that part of the weight of the overburden in an artesian system is supported by the hydraulic pressure. As the artesian head is reduced by ground-water withdrawals, a pressure differential is established between the fine-grained materials and the sand strata, and this differential causes water to move into the sand strata. Thus, a reduction in artesian head increases the effective load on the skeletal structure of the aquifer and causes compaction of the sediments and a consequent subsidence of the land surface. In the studies by Tolman and Poland (1940, p. 32) in the Santa Clara Valley, Calif., it was pointed out that virtually no subsidence was observed in areas underlain by more than 40 percent of sand and gravel and that subsidence was in most places restricted to areas underlain by clay.

A comparison of the areas of subsidence in Las Vegas Valley (pls. 12, 13) with areas in which artesian heads have declined (pl. 6) shows that the area of maximum land subsidence is about 2½ miles east of the Las Vegas Valley Water District well field and about 5 miles northeast of the center of greatest decline of artesian heads along "The Strip." In a homogeneous aquifer it would be expected that the land subsidence would be greatest near the centers of greatest head decline. An examination of logs of wells in the Las Vegas Valley Water District well field shows that the percentage of clay and silt is smaller in these wells than in wells drilled farther east. For example, the log of the

Las Vegas Valley Water District well S20/61–31ddc1 (No. 401), which is 1,250 feet deep, shows approximately 470 feet, or approximately 38 percent, of clay (Maxey and Jameson, 1948, App. 1, p. 96); the log of well S20/61–35cbb1 (No. 233), which is 795 feet deep and is near the center of greatest land subsidence, shows approximately 625 feet, or 79 percent, of silt and clay (Maxey and Jameson, 1948, App. 1, p. 101). Inasmuch as subsidence is more pronounced for a given lowering of artesian head in areas underlain by sediments predominantly composed of clay and silt rather than of sand and gravel, it is understandable that the reduction in artesian head resulting from groundwater withdrawals in the Las Vegas Valley Water District well field has caused a greater subsidence east of the city well field where clay and silt in the water-bearing deposits predominate.

Smith and others (1960, pl. 4) constructed profiles along the lines of levels showing the change in elevation of the land surface between 1935 and 1940–41 and between 1935 and 1949–50. These profiles show the land subsidence resulting from regional tilting caused by downward warping of the earth's surface in the vicinity of Lake Mead. The profiles also show a regional tilting of the general land surface in the Las Vegas Valley toward the southeast. In the vicinity of Las Vegas, however, the effects of land subsidence resulting from regional tilting have been modified by additional subsidence resulting from a reduction in artesian pressure. The profiles shown in figure 16 have been taken in part from Smith and others (1960, pl. 4) and have been modified to show the effects of land subsidence resulting from regional tilting and the effects of subsidence resulting from reduction in artesian head.

To determine the effects of land subsidence resulting from the reduction in artesian head, it is necessary to remove the effects of regional tilting from the total amount of land subsidence. Figure 16 shows that during the intervals between 1935 and 1940–41 and between 1935 and 1949–50, the land subsidence in the vicinity of bench mark A166 resulting from regional tilting was about 20 mm (millimeters) and 100 mm, respectively. By subtracting 20 mm and 100 mm from the total land subsidence for the respective time intervals, the maximum subsidence resulting from a reduction in artesian head was about 70 mm during the short interval of time and about 180 mm during the longer interval.

During the period 1935–50 the change in artesian head in well S20/61–19adb1 (No. 5) was approximately 32 feet (fig. 17). During the same period of time, bench mark P169, which is about 100 feet from the well, subsided about 5 mm in response to the change in artesian head (profile *A–A′*, fig. 16). Thus, in the vicinity of well 5, the ratio between land subsidence resulting from a reduction in

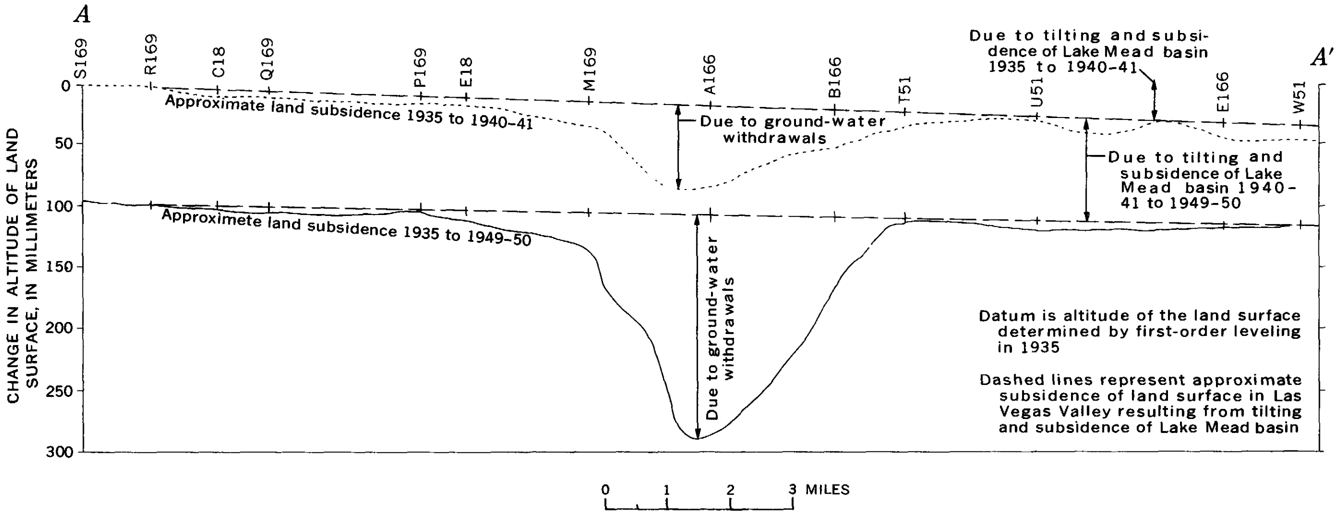

Figure 16.—Regional tilting and subsidence across Las Vegas Valley resulting from the filling of Lake Mead, and localized land subsidence resulting from ground-water withdrawals.

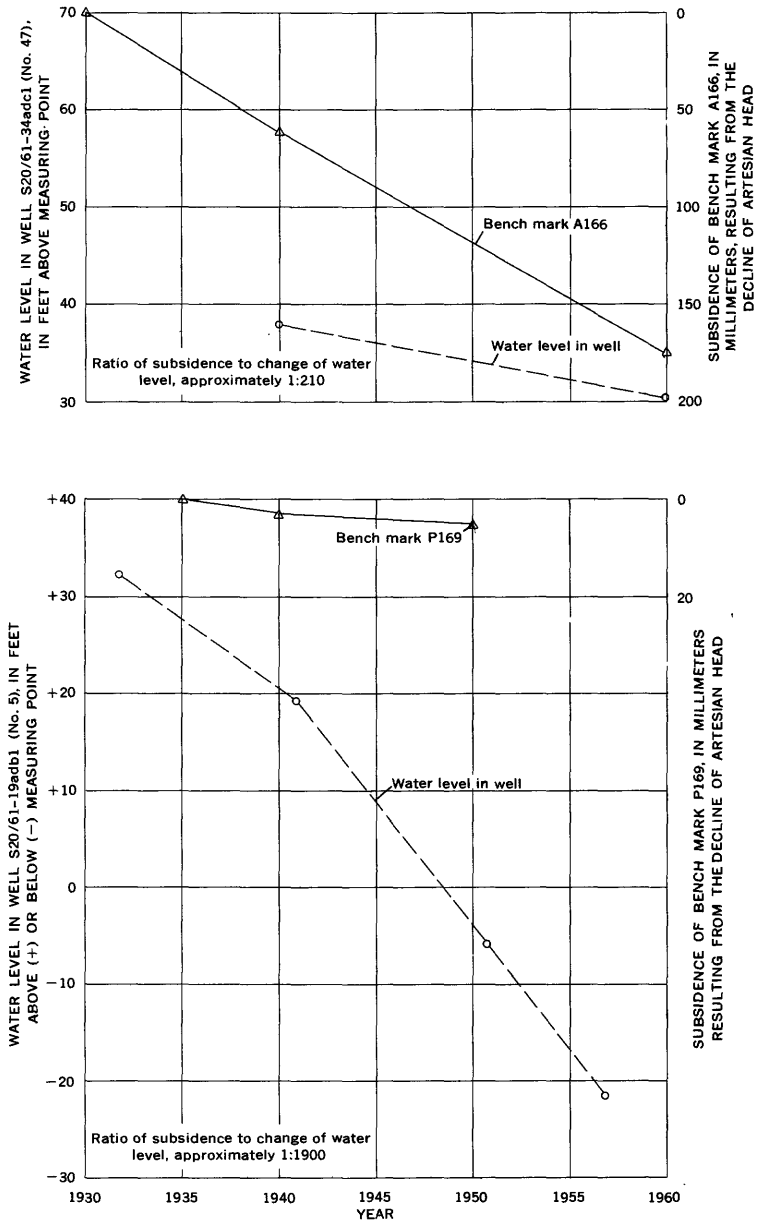

Figure 17.—Change in piezometric surface at well S20/61-19adb1 (No. 5) and S20/61-34adc1 (No. 47) and concurrent subsidence of bench mark P169 and A166 respectively.

artesian pressure and the decline in artesian head is about 1:1,900. Near the center of greatest subsidence, where the water-bearing deposits are composed predominantly of fine-grained sediments, there is substantially more subsidence of the land surface in response to changes in artesian head. From 1940 to 1950 the artesian head in well S20/61–34adc1 (No. 47) declined about 7½ feet. During this same 10-year period, bench mark A166, which is about 2,500 feet east of the well, subsided about 110 mm in response to the reduction in artesian head. Thus it is indicated that for each 10 feet of decline in artesian pressure in the vicinity of well 47 there will be approximately 147 mm (about half a foot) subsidence of the land surface at bench mark A166.

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