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OFFICE OF THE STATE ENGINEER

WATER RESOURCES BULLETIN No. 5

Geology and Water Resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye Counties, Nevada

By
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UNITED STATES DEPARTMENT OF THE INTERIOR
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TABLE OF CONTENTS

APPENDIX I

(Water Resources Bulletin No. 4)

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(Water Resources Bulletin No. 4)

FOREWORD

This report is the seventh in the series of Nevada Water Resources Bulletins, four of them dealing with ground water in Las Vegas Valley. It sets forth the results of a comprehensive and detailed geologic and hydrologic investigation in Las Vegas, Pahrump, and Indian Spring Valleys, in Clark and Nye Counties, Nevada. The report was prepared by the U. S. Department of the Interior, Geological Survey, in cooperation with the State Engineer.

A cooperative arrangement for a study of the ground-water resources in Las Vegas Valley was begun in July 1944 as the result of an agreement between the Director of the Geological Survey and the State Engineer of Nevada. The program for the State is under the supervision of Hugh A. Shamberger, Assistant State Engineer, and for the Geological Survey, under the direction of Thomas W. Robinson, District Engineer in Nevada for the Ground Water Division.

Prior to the present cooperative arrangement, a cooperative study was made of the underground leakage from artesian wells in the vicinity of Las Vegas. The findings of this investigation by Penn Livingston of the Ground Water Division, Geological Survey, are set forth in U. S. Geological Survey Water Supply Paper 849-D. As the result of the present cooperative arrangement the following reports on the ground water of the area have been prepared. The first, entitled "Progress report on the ground-water resources of the Las Vegas Artesian Basin, Nevada," was published in 1945. This was followed by "Water levels and artesian pressure in wells in Las Vegas Valley and in other valleys in Nevada, 1913–1945," Water Resources Bulletin No. 3 published in 1947; "Well data in Las Vegas and Indian Spring Valleys, Nevada," Water Resources Bulletin No. 4 published in 1946; "Ground water in Las Vegas, Pahrump, and Indian Spring Valleys, Nevada" (A summary), published in 1947, and the present report.

ALFRED MERRITT SMITH,
State Engineer.

June 28, 1948.

ABSTRACT

Las Vegas, Pahrump, and Indian Spring Valleys are situated in Clark and Nye Counties in southwestern Nevada. The city of Las Vegas, in the south-central part of Las Vegas Valley, is the chief commercial center for the three valleys. The Union Pacific Railroad and U. S. Highway 91, which pass through the southern part of Las Vegas Valley and the city of Las Vegas, are the main transportation routes to Los Angeles, California, about 300 miles south, and to Salt Lake City, Utah, about 450 miles north of Las Vegas. The population of Las Vegas Valley is chiefly dependent for its livelihood upon a resort and tourist trade, a limited chemical and mining industry, and the railroad. The people of Pahrump Valley are chiefly farmers and ranchers and the few people in Indian Spring Valley depend for their livelihood upon the tourist trade and the operation of one large ranch. The climate of the area is arid, for the average annual precipitation in the valleys is less than 10 inches, and there are no perennial surface streams. The water supply for the valleys is obtained from springs and wells, except at the town of Henderson in Las Vegas Valley, where a pumping station and pipe line supply water from Lake Mead.

A rapid increase in population in Las Vegas Valley, beginning in 1941, caused an apparently critical water shortage there, and in Pahrump Valley increased agricultural development resulted in further exploitation of ground-water supplies. The purpose of the study upon which this report is based was to determine the occurrence, source, and amount of ground water available in the three valleys.

The three valleys lie near the southwestern boundary of the Great Basin. They are bounded by high, rugged mountain masses with precipitous slopes which abut against relatively gently sloping alluvial aprons. The highest and largest mountains are the Spring Mountain and Sheep Ranges. The alluvial aprons usually terminate at their lower ends in playas. Remnants of the alluvial aprons extend far up the mountain canyons and, in many places, blanket the mountain slopes to elevations as high as 9,000 feet. In part of Pliocene and Pleistocene time, during and immediately following deposition of the sediments of the aprons, the mountains bounding the three valleys were probably buried deeply in alluvial materials which have since been partially removed by erosion.

The alluvial slopes are being eroded at the present time, although in some places they are sites of deposition. Sediments are being deposited in the lower parts of all the valleys. The mountains are everywhere being eroded.

Drainage in Pahrump and Indian Spring Valleys is interior, to playas that occupy the lowest portion of each valley. In effect, drainage in most of Las Vegas Valley is likewise interior, although if appreciable surface runoff occurred the water would drain to the Colorado River through Las Vegas Wash in the extreme southeastern part of the valley.

The rocks exposed in the area range in age from pre-Cambrian to Recent. Generally the older rocks of pre-Cambrian, Paleozoic, Mesozoic, and early Tertiary age form the mountains, and the rocks of Miocene (?), Pliocene, Pleistocene, and Recent age form the relatively unconsolidated materials within the valleys. Of the older rocks only the Sultan limestone of late (?) Devonian age and the Monte Cristo limestone of early and middle Mississippian age are important water-bearing formations, and usually they occur above the regional ground-water level. The other older rocks are relatively impermeable and are not important aquifers. They impede ground-water movement and act as barriers to form the boundaries of the ground-water reservoirs. The Esmeralda (?) formation of late Miocene (?) age and the Muddy Creek formation of Pliocene (?) age are thick deposits of chiefly fine-grained alluvial materials with a few thin sand and gravel lenses. They crop out in five widely separated localities in Las Vegas Valley and probably are present in the valley fill beneath the younger sediments in three valleys. These beds are not important as aquifers at the present time. Deeper drilling in the valleys may produce wells of moderate yield in the sand and gravel lenses in the sediments of the Esmeralda (?) and Muddy Creek formations. However, water from them may be highly mineralized.

The upper 700 to 1,000 feet of sediments in the valleys are the older alluvial deposits of gravel, sand, silt, and clay, chiefly of Pliocene (?) and Pleistocene (?) age. They are probably underlain by the Muddy Creek and Esmeralda (?) formations, and in some places they are overlain by a thin veneer of Recent playa and eolian sediments. These Pliocene (?) and Pleistocene (?) alluvial deposits form the alluvial apron and are typical alluvial-fan deposits. The upper part of the alluvial apron consists chiefly of gravel and sand beds, some of which grade into silt and clay toward the lower parts of the valley; others extend persistently toward the axes of the valleys and interfinger with the silt and clay beds. These persistent gravel layers are believed to represent periods when the streams had relatively great carrying power, probably periods of more humid climate. The silt and clay beds are inferred to represent periods when the streams had smaller carrying power, during times of aridity. The alluvial-fan materials are generally coarser and the deposits are much thicker and topographically higher in the valleys opposite the larger canyons in the mountains. In the valleys opposite the smaller canyons and along the mountain slopes, they consist chiefly of fine materials and are thinner and topographically lower. Numerous logs of the alluvial materials have been recorded from wells drilled in the southern part of Las Vegas Valley and in the central part of Pahrump Valley. They show that clay, sandy and silty clay, and caliche make up by far the largest part of the valley deposits near the lower ends of the alluvial fans. Layers of gravel and sand ranging from 1 to 20 feet in thickness occur infrequently there. The logs also show that these layers of gravel and sand are lenticular and thin rapidly toward the central parts of the valleys. Probably most of the gravel and sand lenses are limited in horizontal extent and are more or less imperfectly interconnected.

Most of the ground water used in the three valleys is obtained from wells and springs and is supplied by the gravel and sand lenses of the valley fill. In the Las Vegas Valley more than three-fourths of the wells draw water from aquifers ranging from 250 to 450 feet below land surface, designated as the Shallow Zone of aquifers. This zone is separated from the underlying Middle Zone of aquifers, which range from 500 to 700 feet in depth, by a persistent 10- to 50-foot-thick blue clay layer. Several wells of large yield draw water from aquifers in the Middle Zone. A few wells drilled to depths of more than 700 feet have encountered thin water-bearing beds as deep as 1,225 feet. All the water-bearing beds below 700 feet are included in the Deep Zone of aquifers. In Pahrump Valley confined water is encountered in wells at depths ranging from 165 feet to more than 900 feet. In Indian Spring Valley confined water has been found at depths ranging from 400 to 600 feet.

Ground water also occurs in the three valleys at shallow depths (100 feet or less). In parts of the valleys this water is under slight artesian pressure, in other parts of the valleys it occurs under water-table conditions. This water is referred to in this report as the "near-surface" water.

Playa and lacustrine deposits of Pleistocene age occur in the lower parts of the three valleys. These beds consist of superficial deposits of relatively impermeable silt and clay which are rarely thicker than 50 feet.

The playa, eolian, and wash deposits of Recent age consist chiefly of unconsolidated gravel, sand, silt, and clay. The deposits are usually less than 100 feet thick. They are only locally significant as aquifers. In the vicinity of Indian Springs and in the southeast part of Las Vegas Valley water, used chiefly for domestic purposes, is withdrawn from occasional thin gravel and sand lenses occurring in Recent deposits.

Outstanding geologic structural events include block faulting, which occurred previous to late Mesozoic time, and overthrusting and folding during Mesozoic and during early Tertiary and Quaternary time. Minor faulting and folding were probably synchronous with and related to both the overthrusting and the block faulting. Evidence that major faults and other large-scale structural activities displaced the older alluvial deposits was not observed anywhere in the three valleys. Small normal faults of probable Recent and late Pleistocene age were observed in the older alluvial deposits and in the Muddy Creek formation in Las Vegas Valley. These faults are probably a result of differential compaction in the younger relatively unconsolidated sediments, and probably do not cut the older bedrock, as do faults of Recent age in adjacent regions.

Movements of ground water in Las Vegas Valley are significantly affected by these faults. They act as partial barriers that impede the movement of water through the various aquifers. Moderately permeable beds in the valley fill were probably offset against less permeable beds, thus partly or wholly damming the flow of water through the permeable beds. Some of the ground water thus impeded moves upward along the fault zones and issues as springs near the traces of the faults. The location and origin of Kyle, Stevens, and Las Vegas Springs near the foot of the fault scarps in Las Vegas Valley are apparently a result of such faulting. The older structures in the indurated bedrock of the mountains also affect the movement of ground water. Most fault zones are cemented and generally form ground-water dams. Where the attitude and permeability of the rock strata are favorable, the water is brought to the surface as springs. When joints occur in soluble formations, they generally transmit large quantities of water.

The only source of ground water for the three valleys is precipitation on the higher areas of the Spring and Sheep Mountains. However, only a small part of the precipitation recharges the alluvial-fan and valley-fill materials that compose the ground-water reservoirs. The rest of the water from precipitation on the area is lost by evaporation and transpiration. The water that reaches the ground-water reservoirs is ultimately discharged through springs and wells and by evaporation and transpiration.

Estimates based on the available precipitation data, and checked with information from all available geologic and hydrologic data, show that the annual recharge of the ground-water reservoir in Las Vegas Valley is between 30,000 and 35,000 acre-feet.

The total annual discharge from the ground-water reservoirs in Las Vegas Valley probably never exceeded 35,000 acre-feet until 1946. Water levels have declined in the valley. They may be expected to continue to decline until the cones of depression in the piezometric or pressure-indicating surface, caused by withdrawal of water from wells and springs, have grown sufficiently to intercept the amount of recharge necessary to balance the total withdrawals of ground water. Locally, much of the excessive decline of water levels in Las Vegas Valley has been a result of local overdevelopment caused by close spacing and heavy pumping of wells. However, the available data indicate that ground water probably is now being pumped from storage; that is, more water is being taken from the reservoirs than is entering them from the recharge areas, and that therefore part of the water-level decline has resulted from overpumping. Thus, continued withdrawal of substantially more than 35,000 acre-feet of ground water annually will result in continued, and possibly increasing, decline of the water level and in overdevelopment of the ground-water supply in Las Vegas Valley.

Of the total discharge of ground water in Las Vegas Valley probably 5,000 to 8,000 acre-feet, or 12 to 15 percent, is lost by evaporation and transpiration. Also, it is estimated that possibly 15 percent of the total discharge is wasted through lack of conservation, mostly within the city of Las Vegas. It appears that at least half the water thus lost can be utilized by further development of wells in the near-surface reservoir and by increased, more efficient conservation of supplies now obtained from the Shallow, Middle, and Deep Zones of aquifers.

In Pahrump Valley approximately 23,000 acre-feet of water is annually available for recharge, and about 17,000 acre-feet is annually discharged from wells and springs. Water levels have declined during the short period of record and they may be expected to decline until the cones of depression have grown sufficiently to intercept the amount of recharge necessary to balance the total withdrawals of ground water. However, some ground water is available for additional development in Pahrump Valley.

Although sufficient data are not available to show whether there is a substantial unused supply in Indian Spring Valley, it appears that some additional ground water is available there also.

The chemical character of the ground water in Las Vegas Valley differs considerably from place to place. In general the quality is better in the vicinity of the city of Las Vegas than it is toward the lowest part of the valley to the south. The ground water in the vicinity of the city of Las Vegas is suitable and is used for both domestic and irrigation purposes. However, in the south part of the valley the water is not suitable for either domestic or irrigation use.

In Pahrump Valley the best water is found along the east side and poorer water in the central part. Although the water in the central part of the valley has a higher concentration of dissolved solids than that from the east side, it is suitable for domestic use and safe for irrigation.

PLATE 3—Well (S-21-54) 3cad1. Manse Ranch, Pahrump Valley, Nevada. Flowing 3,450 gallons per minute in February 1941

GEOLOGY AND WATER RESOURCES OF LAS VEGAS, PAHRUMP, AND INDIAN SPRING VALLEYS, CLARK AND NYE COUNTIES, NEVADA

By G. B. MAXEY and C. H. JAMESON

INTRODUCTION

LOCATION AND GENERAL FEATURES

The area described in this report covers about 3,100 square miles in the arid country of southwestern Nevada, in Clark and Nye Counties (see fig. 1). As is shown on plates 1 and 2, it comprises most of the drainage areas of Las Vegas, Pahrump, and Indian Spring Valleys. The chief communities are Las Vegas, North Las Vegas, and Henderson. The estimated population of these communities in 1946 was: Las Vegas 21,000, North Las Vegas 3,500, and Henderson 6,000. The first and last-named cities are, respectively, the second and third largest cities in Nevada (Reno is first). Las Vegas is the county seat of Clark County, a division point on the Union Pacific Railroad, and the main commercial center for Clark County and most of Southern Nye County. Las Vegas also is a lively pleasure resort and has a large tourist trade. A small chemical industry, which started with the construction of the Basic Magnesium Project at the beginning of World War II, is situated in Henderson. Agricultural activity in the area is mostly confined to Pahrump Valley, but there are a few scattered ranches in Las Vegas Valley. The people of Pahrump Valley depend partly upon nearby Shoshone, California, as a commercial point because adequate roads and other transportation facilities to Las Vegas are lacking. The few people who live in Indian Spring Valley depend upon the tourist trade and the operation of one large ranch for their livelihood.

TRANSPORTATION

The main line of the Union Pacific Railroad between Salt Lake City, Utah, and Los Angeles, California, crosses the southeast corner of the area and passes through Las Vegas. U. S. Highway 91 follows approximately the same route. Las Vegas is about 450 miles southwest of Salt Lake City and 300 miles northeast of Los Angeles. U. S. Highway 95 enters Las Vegas Valley in the south and traverses the central part of the valley northward through

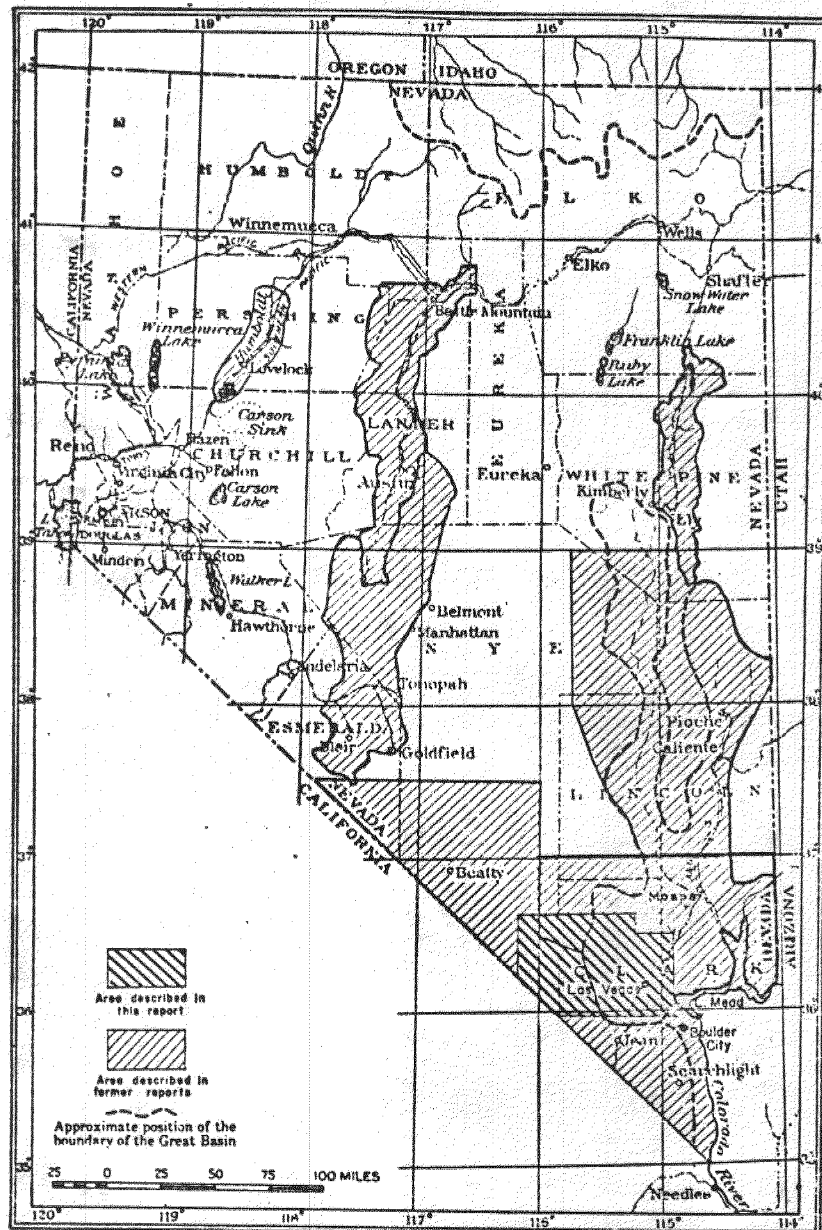


FIGURE 1—Map of Nevada showing areas covered by previous ground-water reports in Nevada and by the present report.

Las Vegas to Indian Springs, thence northwesterly to the cities in northern Nevada. An unimproved road, Nevada State Highway 16 (the "Johnnie Road"), traverses the central part of Pahrump Valley and connects with U. S. Highway 95 about 20 miles west of Indian Springs. Nevada State Highway 52 enters Pahrump Valley from the west, connecting the valley with Shoshone, California, and the West Coast. Many secondary roads and trails within the area have also been built. Thus, most parts of the area are readily accessible by automobile.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of the study upon which this report is based was to determine the sources and amount of ground water available to Las Vegas, Pahrump, and Indian Spring Valleys. This investigation was recommended by the State Engineer in part because of the danger of overdevelopment of the ground-water supplies in the area, and also to assist him in administration of the Nevada ground-water law and adjudication of rights to the use of ground water.

The investigation includes a study of the geology of the area in relation to the occurrence of ground water, a ground-water inventory for a 3-year period, and a determination of the chemical character of the water. The study necessarily involved collection of the existing records for past years relating to the various phases of the ground-water conditions in the three valleys. In addition, much time was spent in study of the relation of precipitation, runoff, and recharge to the occurrence of ground water. The field work was done by G. B. Maxey, who began an intensive study in July 1944. He was assisted in the ground-water studies by C. H. Jameson, Artesian Well Supervisor for Las Vegas and Pahrump Artesian Basins. The investigation was under the general supervision of O. E. Meinzer, Geologist in Charge, Division of Ground Water, U. S. Geological Survey, and T. W. Robinson, District Engineer, Ground Water Division for Nevada since June 1945. From July 1944 to June 1945 general supervision of the investigation was afforded by P. E. Dennis, Geologist in Charge of Ground-Water Investigations in Utah and Nevada during that period. Competent assistance was rendered by W. M. Clay, J. C. Fredericks, D. A. Phoenix, O. J. Loeltz, and Z. E. Bell.

The first seven sections of the present report—that is, those entitled Introduction, Climate, Vegetation and Soils, Physiography, Geology and Water-Bearing Characteristics of the Rock Formations, Springs and Streams, and Occurrence of Ground

Water—describe conditions in the area as a unit. The last three sections describe the detailed ground-water conditions in, respectively, Las Vegas, Pahrump, and Indian Spring Valleys. Preparation of the report, especially those sections dealing with the geology and the occurrence of ground water, was largely by Mr. Maxey. Mr. Jameson collected and compiled many of the data on water-level fluctuation, pumpage, and artesian flow. Mr. Robinson rendered valuable assistance in preparation of the report.

HISTORICAL SKETCH AND WATER-SUPPLY DEVELOPMENT

The large springs in Las Vegas, Pahrump, and Indian Spring Valleys were used as watering places by the aborigines long before the coming of the white man. The variety and abundance of discarded stone weapons and other artifacts, and evidences of primitive camp sites in the vicinity of these springs, indicate human utilization of ground water even before the coming of the Basket Makers and, later, the Paiute and Shoshone tribes. The springs were known by the Spaniards as early as 1770. Probably they were watering places for the Spaniards and other travelers before the Fremont[1] party stopped there in 1844, the first recorded visit of white men to Las Vegas Valley. Other early visitors and users of the springs were Jefferson Hunt, a Mormon missionary, who camped near Las Vegas Springs in 1847, and E. F. Beale and G. H. Heap,[2] who crossed Pahrump Valley, the Spring Mountains, and Las Vegas Valley in 1852, following the early trail past Las Vegas Springs and over Mountain Springs Pass.

By 1855 the existence of water in Las Vegas Valley was well-known and Brigham Young had assigned missionaries under the leadership of William Bringhurst to colonize and develop the valley. A community was built up at the Las Vegas Spring site and development of the land and water for producing agricultural crops was well under way by 1856. In 1857, because of troubles with the U. S. Government, the outlying missions of the Mormon Church were recalled by Brigham Young, and the Las Vegas mission was abandoned.

Further use of the ground water for agricultural purposes was made by O. D. Gass, and the Stewart and Kyle Ranches, from 1857 until the present time. The Stewart Ranch was purchased in 1903, during the construction of the San Pedro, Los Angeles,

[1]Fremont, J. C., Report of the exploring expedition to the Rocky Mountains, 1842–43–44. Washington, 1845.

[2]Beale, E. F., and Heap, G. H., Central route to the Pacific, pp. 101–108. 1854.

and Salt Lake Railroad, for a townsite, now the city of Las Vegas. In 1905, only small amounts of ground water were being used in the sparsely settled area, mostly by settlers whose ranches were way-stations on the southern route from Salt Lake City to the West Coast.

In 1905 the San Pedro, Los Angeles, and Salt Lake Railroad, now the Union Pacific Railroad, was completed and Las Vegas was selected as a division point, mainly because of its excellent water supply. A subsidiary of the railroad company, the Las Vegas Land and Water Company, built the townsite to attract workers and settlers to Las Vegas Valley. This was the beginning of the present city of Las Vegas. Most of the water used for the townsite came from the Las Vegas and Kyle Springs. Only a few shallow wells had been dug and there were no flowing wells. Las Vegas Spring was reported to flow approximately 3,000 gallons a minute, and Kyle Spring flowed approximately 300 gallons a minute. One deep well in which water stood approximately 65 feet below land surface was drilled, probably in 1905, by the Las Vegas and Tonopah Railroad Company for domestic supplies and construction at its Corn Creek station.

Late in 1905 the Vegas Artesian Water Syndicate was organized by residents of Las Vegas to prove by test-well drilling the existence of artesian water in Las Vegas Valley. The wells drilled by this organization were to be sold with adjacent areas of ground to responsible farmers to start agricultural development in the valley. The first flowing artesian well (S-20-61) 21abb1, in Las Vegas Valley was drilled by this organization in the spring of 1907, in the NW¼ NW¼ NE¼ sec. 21, T. 20 S., R. 61 E. At the present time it is owned by C. Gratz. Artesian aquifers were encountered at 176, 225, 260 and 293 feet below the surface, and a total flow of approximately 20 gallons a minute was reported. Following this successful venture, the Syndicate drilled two more artesian wells in 1907 and 1908. Several individuals also drilled wells during this period. In 1911, when Carpenter[3] made his study of ground water in Las Vegas Valley, he found that approximately 100 deep wells had been drilled, of which about 75 were flowing wells. Also, there were about 25 shallow wells, making a total of 125 wells in the valley at that time. Most of the water from the deep wells was being used for irrigation and about five ranches had become well established. About 1910 application of

[3]Carpenter, Everett. Ground water in southeastern Nevada: U. S. Geol. Survey Water-Supply Paper 365, pp. 39–40, 1915.

the Carey Act, enacted in 1894 by the U. S. Congress, further stimulated well drilling. Numerous organizations were formed to drill wells and make other improvements as required to obtain title to land under the provisions of this Act. In 1914 the South Nevada Land and Development Company, an organization backed by local and British capital, drilled several deep wells northwest of Las Vegas and, following this but before 1924, individuals drilled about 20 more deep wells.

During this early period of well drilling, flowing wells were not capped and water from them was wasted. This was undoubtedly due in large part to the belief of the residents that the valley was underlain by an inexhaustible supply of artesian water and that restricting the free flow from wells was a needless, expensive chore. However, as early as 1911, State Engineer W. M. Kearney[4] suggested that the artesian wells should be capped and that the water should be used "with economy instead of the lavish wasteful manner which has prevailed in the past." Carpenter[5] stated that allowing the water to run freely from the wells, and improper methods of casing the wells, had led to much waste of water and had diminished or completely stopped the natural flow of many wells. Although there are no recorded flow measurements between 1912 and 1924, it is known from many reports that the flow of individual wells had diminished and continued to diminish. The total yield from artesian wells and springs was approximately the same in 1924 as in 1912, notwithstanding the fact that more than 20 wells had been drilled during the period. Also, the flow of Las Vegas Spring had diminished from about 7 cubic feet per second in 1905 to about 4.5 cubic feet per second in 1924.

The population of the city of Las Vegas according to the 1910 census was 800, and probably a total of 1,000 people resided in all Las Vegas Valley. According to the 1920 census the city of Las Vegas had 2,304 people and the population of the valley was about 2,500. Most of these people were employed by the railroad and by various commercial concerns, and only a few were engaged in agricultural occupations. It is estimated that between 1910 and 1924 about 22,400 acre-feet of water a year was flowing from the artesian wells and springs. Of this total about 2,240 acre-feet of water a year was used for the municipal water supply and approximately 10,000 acre-feet a year was used for agricultural

[4]Kearney, W. M., in an article in the Las Vegas Age, Nov. 4, 1911.
[5]Carpenter, Everett, op. cit., pp. 40–41.

purposes. Thus, nearly half the water which issued from the ground-water reservoir was wasted throughout the period.

Between 1922 and 1936 the State Agricultural Experiment Station, under the immediate direction of George Hardman, made several studies of the wells in Las Vegas Valley to develop ground-water supplies for irrigation. Many measurements, pumping tests, and reconnaissance studies of the recharge areas were made. Hardman recognized early in the course of his studies that the artesian aquifers were recharged by precipitation on the neighboring mountain ranges. He stressed in his reports that the recharge was limited and that conservation of ground water should be practiced. He also pointed out the advisability of making a more detailed investigation of the water resources.

The most important industry in the Las Vegas Valley during the period 1922 to 1936 was the railroad division shop at Las Vegas. There were also a few farms and ranches. The population of the valley had increased to approximately 6,000. Hardman pointed out that any future development in the valley with an accompanying increase in population would be largely dependent upon the amount of water available from wells and springs, and that increased withdrawal of water from the aquifers would cause continued lowering of water levels and decreased yields of individual wells and springs. Beginning in 1930, and for several years thereafter, the population of the valley increased as a result of a growing tourist trade and the construction of Hoover Dam. Because of the demand for more water, wells were drilled and Hardman's prediction became fulfilled. For example, the flow of Las Vegas Springs, which was 4.5 cubic feet per second in 1924, diminished to about 3.75 cubic feet per second in 1936, and to only about 2.5 cubic feet per second early in 1944. Also, the head declined and flows decreased in all wells in the valley, particularly in the vicinity of the city of Las Vegas.

Following the completion of Hoover Dam, the construction of Army camps and training centers began, and later the Basic Magnesium Project was built and put into operation. These activities resulted in a large increase in the population and a consequent increase in the amount of water used. Continued declines of water levels and decreased yields of individual wells were noted. Since 1941 the largest supplies of water, which had previously been obtained from the free flow of artesian wells, have been pumped. The State Engineer's office has been actively interested in the ground-water resources of the State since 1938, and has been instrumental in having a law for the regulation of ground-water appropriation and use, written and passed in the State Legislature. Under this law the Las Vegas Artesian Basin

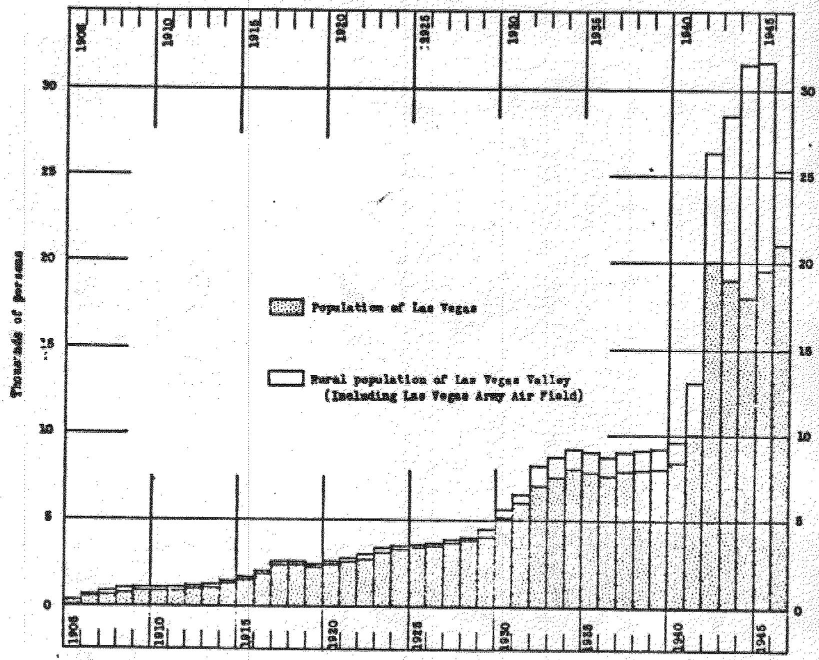
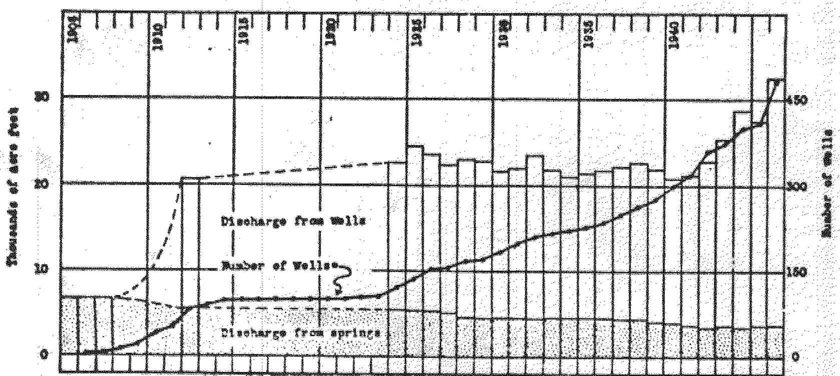


FIGURE 2—Population of Las Vegas Valley (Henderson and Basic Magnesium Project excluded).



* Includes only wells for which drilling dates are available

FIGURE 3—Total discharge from wells and springs and number of wells drilled in Las Vegas Valley, 1905–1946.

was designated, an Artesian Well Supervisor employed, and active steps taken to insure proper utilization and conservation of ground water.

Figures 2, 3, 4, and 5 illustrate the growth in population, the increase in the discharge of water and in the number of wells since 1907, and the general decline of water levels and flows of the ground water in Las Vegas Valley since about 1920, thus supplementing the above description. In the last 25 years the demand for water for domestic and cooling purposes has increased tremendously. More than 24,000,000 gallons of water a day (approximately 27,000 acre-feet a year) was used in Las Vegas Valley in 1945, and about 28,000,000 gallons a day (31,700 acre-feet a year) in 1946. Slightly more than one-fourth of this total is used by the city of Las Vegas. Probably not more than 2,500,000 gallons a day (about 2,800 acre-feet a year) was wasted in 1946 as a result of leaky casings and wells left flowing during

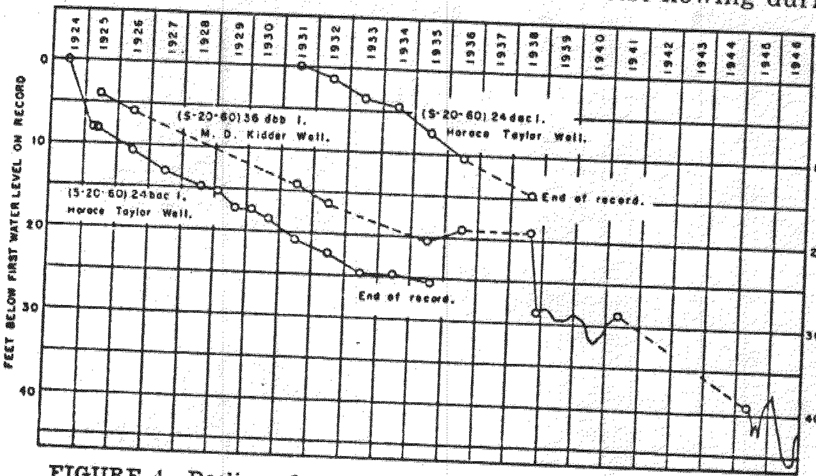


FIGURE 4—Decline of water levels in three wells in Las Vegas Valley, 1924–1946.

the nonuse period. In 1945 approximately 5,000,000 gallons of water a day (5,600 acre-feet a year) was used for agriculture, and nearly 16,000 acre-feet was used by establishments and domiciles not supplied by the city water system for domestic, industrial, railroad, and cooling purposes.

In 1942 a pipe line was constructed from Lake Mead to the Basic Magnesium Project, and for the first time Colorado River water was pumped into Las Vegas Valley. Thus, the town of Henderson and the industries in the Basic Magnesium Project did not use ground water throughout the war years and are still supplied by water pumped from Lake Mead.

In Pahrump Valley the first recorded organized attempt by white men to use ground water for irrigation was made by the Bennetts in 1875 at the present site of Pahrump Ranch. Joseph

Yount and Harsha White utilized spring water for irrigation at the Manse Ranch in 1877. Crops were grown successfully at both ranches. Bennetts Springs were reported to flow about 7½ cubic feet per second, and Manse Springs reportedly flowed approximately 6 cubic feet per second at about that time.

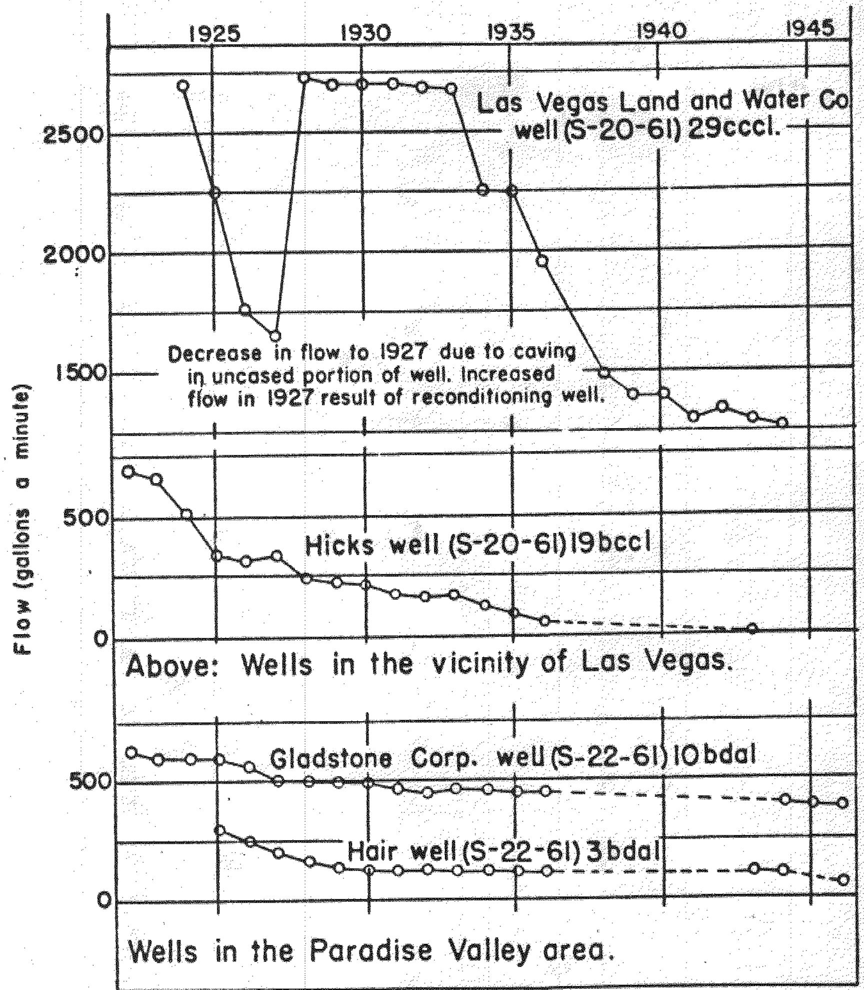


FIGURE 5—Decline in discharge of representative flowing wells in Las Vegas Valley, 1922–1946.

The first reported attempt to obtain artesian water from wells in Pahrump Valley was in 1910 when the Pahrump Valley Land and Irrigation Company drilled a well on the Pahrump Ranch in order to obtain more land under the Carey Act. This attempt was unsuccessful. In the spring of 1913 F. A. Buol drilled four wells just north of the Pahrump Ranch, and three of them encountered artesian water that flowed at the land surface. In 1916 Waring[6] reported 28 wells in Pahrump Valley. Of these wells, 15 were flowing, 7 were more than 150 feet deep but were nonflowing, and 6 were shallow nonflowing wells. Waring also measured the flow of Bennetts Springs (the two large springs), which he reported as 4.73 cubic feet per second, and the flow of Manse Springs, which he reported as 3.23 cubic feet per second.[7] He also measured the flows of many of the wells and other springs. From these measurements, and other reported measurements made at about the same time, it is estimated that approximately 12.5 cubic feet of water per second was flowing from artesian wells and springs in Pahrump Valley between 1915 and 1936. It is estimated that during this period not more than 1,000 acres of land were ever under cultivation at one time, and that probably no more than two-thirds of the total flow of water was ever put to beneficial use. Thus about 4.0 cubic feet of water per second was wasted.

Records of the development of ground water in Indian Spring Valley are few, although Indian Springs provided water for irrigation from the late nineties to the present time. The first attempts to secure water from wells for irrigation were made about 1910 and were unsuccessful. In the early twenties several shallow wells were dug and drilled for water for domestic supplies and many of these wells are still being used. In 1942, when the Indian Springs subbase of Las Vegas Army Air Field was built, two deep wells were drilled which encountered artesian water, but the head was not sufficient to force the water to the land surface. Pumps were installed and from 1943 to 1945 these two wells were heavily used. At the present time (1946) little water is used at the subbase. Mesquite Spring and one well about 4 miles west of Indian Springs are used for domestic and cooling purposes.

During the last 10 years several wells have been drilled in the vicinity of Manse and Bennetts Springs. Nearly all these wells yield large quantities of water (see pl. 3), and nearly 500 acres more land has been put under cultivation on the Manse and Pahrump Ranches. Recent exploratory drilling north of the Pahrump Ranch has so far developed no flowing wells of large yield. If good irrigation wells are developed here a large acreage of land

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[6] Waring, G. A., Ground water in Pahrump, Mesquite and Ivanpah Valleys, Nevada and California: U. S. Geol. Survey Water-Supply Paper 450-C, pp. 76-79, 1921.

[7] Op. cit., p. 63.

will undoubtedly be cultivated. However, this acreage would be limited by the amount of ground water available.

PREVIOUS WORK AND BIBLIOGRAPHY

The general geologic and hydrologic features of the area were first described by Gilbert in 1875, and by Spurr in 1901 and 1903. Reconnaissance studies of the ground-water resources by the Geological Survey were made by Mendenhall in 1909, by Carpenter in 1915, and by Waring in 1921. A study of the occurrence and methods of utilization of ground water in Las Vegas was conducted by the Nevada State Agricultural Experiment Station under the immediate direction of George Hardman from 1922 to 1936. Results of this study were published, in part, in 1928 and 1934 and are contained in several unpublished manuscripts, two of which are listed below. In 1938 a survey of leaky wells in the area was made by the Geological Survey in cooperation with the Office of the State Engineer, the city of Las Vegas, and the Las Vegas Land and Water Company. A general geologic study of the area by C. R. Longwell has been in progress since 1921 and has not yet been completed. During the last 20 years papers on various features of the geology of the area have been prepared by Longwell, Nolan, Glock, Hewett, Hazzard and Mason, Hunt and others, and Miller. References to all reports mentioned above are listed in the following bibliography and proper credit by footnote is given when reports are referred to in the text.

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ACKNOWLEDGMENTS

Only 80 square miles of the area covered by the present report has been described in published geologic reports. The geology of most of the remainder of the area is the subject of a study by Professor Chester Longwell of Yale University, which is not yet ready for publication. Professor Longwell kindly allowed the use of his areal geologic map and offered many valuable suggestions based on his experience in mapping the Las Vegas quadrangle. Because Professor Longwell's work was not complete, many details have been generalized and some modifications have been made in compiling plate 1 of this report. The senior author assumes all responsibility for any errors or misinterpretations which may result from these modifications and trusts that they will not be attributed to Mr. Longwell. Also, he expresses at this time deep appreciation and gratitude for the valuable and generous assistance rendered by Mr. Longwell.

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Wholehearted cooperation of the officials of the city of Las Vegas and of Clark County, and of the Office of the State Engineer of Nevada, is hereby acknowledged. The staffs of the officers of the State Highway Engineer and the Colorado River Commission contributed much data that assisted materially in the progress of the work.

The writers are also grateful to the Las Vegas Land and Water

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The writers are also grateful to members of the Geological Survey who reviewed the manuscript and offered valuable suggestions and constructive criticism.

CLIMATE

Below the altitude of 6,000 feet Las Vegas, Pahrump, and Indian Spring Valleys are arid to semiarid, as the average annual precipitation is less than 10 inches. The rain falls chiefly during the winter months and in July and August. The relative humidity is low, evaporation is rapid, the percentage of sunshine is high, and the daily and seasonal range in temperature is unusually wide. Strong winds are common throughout the year and are especially prevalent during the spring. At higher altitudes in the surrounding mountain ranges the climate is less arid, as precipitation increases rapidly with elevation and storms are more frequent and of greater duration.

Over a 36-year period the average length of the frost-free period at Las Vegas has been 241 days. Generally the first killing frost in the fall occurs in the second week of November, and the latest killing frost in the spring occurs in March. However, in the fall and winter of 1942–1943 there was no killing frost, the only such occurrence on record, and in 1941 the latest spring frost occurred on January 20, the earliest of record. Thus, the growing season at Las Vegas is long. Although few data are available concerning the growing season in Pahrump Valley, it is believed to be of approximately the same duration as that in Las Vegas Valley. The growing season in Indian Spring Valley is probably somewhat shorter than in the other two valleys because Indian Spring Valley is considerably higher. Short records at Kyle Canyon Ranger Station (altitude 7,165 feet) indicate that killing frosts occur there in the latter parts of June and September, giving a frost-free period of only about 3 months.

METEOROLOGICAL RECORDS

Long-period records of precipitation obtained by the U.S. Weather Bureau at Las Vegas, and fragmentary records from other precipitation stations in Las Vegas, Pahrump, and Indian Spring Valleys, are available. In late 1944 the U. S. Weather Bureau, the Nevada Cooperative Snow Surveys, and the U. S. Forest Service cooperated with the Geological Survey in placing five snow-storage gages in the Spring and Sheep Mountains, and a rain gage at Pahrump. Also, two snow-survey courses were established by the Nevada Cooperative Snow Surveys.

The records show that the average annual precipitation at the lower altitudes in the area (1,870 to 3,150 feet) is less than 6 inches. The average annual precipitation at Las Vegas, according to the 42-year record, was 4.62 inches. The average annual precipitation at four other stations, where the record of each is less than 10 years, is: Las Vegas Airport, 4.26 inches; Desert Game Range, 4.99 inches; Indian Springs, 5.77 inches; Pahrump, 5.02 inches, and Kyle Canyon Ranger Station, 19.79 inches. All available precipitation records are summarized in the tables that follow and in figure 6. Except for the stations at Boulder City and Clay City the locations of all weather stations listed in the tables are shown on plate 2.

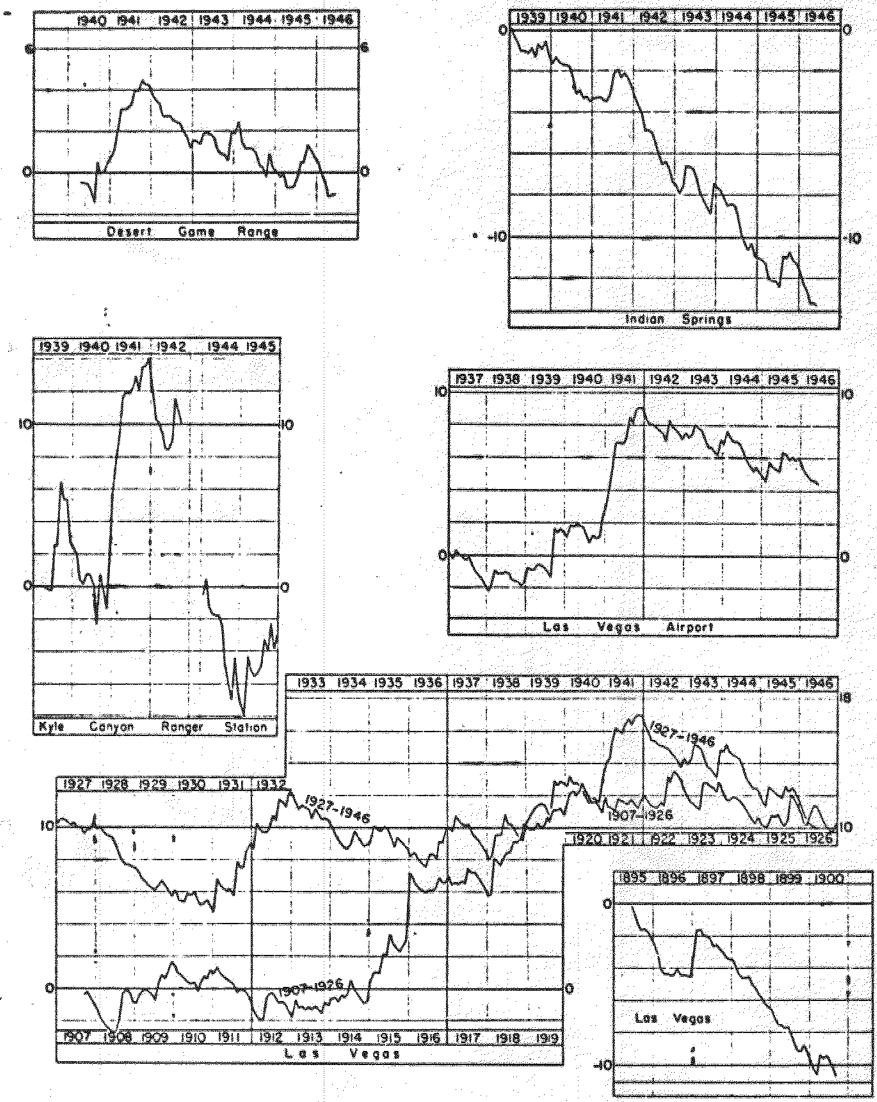

FIGURE 6—Cumulative departure, in inches, from normal precipitation at several precipitation stations in Las Vegas, Pahrump, and Indian Spring Valleys.

Annual Precipitation, in Inches, at 12 Stations in or near Las Vegas, Pahrump, and Indian Spring Valleys

(Data from Records of U. S. Weather Bureau)

Station	Las Vegas Airport	Las Vegas	Desert Game Range	Hidden Forest	Indian Springs	Cold Creek	Lee Canyon	Kyle Canyon Ranger Station	Boulder City	Roberts Ranch	Red Rock	Pahrump
No. on plate 2	1	2	3	4	5	6	7	8	–	10	11	12
Altitude (feet above sea level)	1,876	2,033	3,025	7,845	3,136	6,100	9,000	7,165	2,525	6,110	6,610	2,185
1896	—	3.24										
1897	—	5.35										
1898	—	1.64										
1899	—	2.03										
1908	—	4.73										
1909	—	7.05										
1910	—	4.11										
1911	—	3.41*										
1912	—	2.70*										
1913	—	4.96										
1914	—	4.98	—	—	—	—	—	—	—	—	—	4.90†
1915	—	8.41										
1916	—	8.11										
1917	—	4.33										
1918	—	8.63										
1919	—	4.95										
1920	—	4.74	—	—	—	—	—	—	—	—	—	7.26
1921	—	5.47	—	—	—	—	—	—	—	—	—	5.87‡
1922	—	5.81	—	—	—	—	—	—	—	—	—	5.58
1923	—	4.50	—	—	—	—	—	—	—	—	—	4.49‡
1924	—	2.49	—	—	—	—	—	—	—	—	—	2.20
1925	—	5.27										
1926	—	3.58										
1927	—	4.49										
1928	—	1.75										
1929	—	2.77										
1930	—	3.97										
1931	—	8.58										
1932	—	7.75	—	—	—	—	—	—	4.37			
1933	—	2.94	—	—	—	—	—	—	3.44			
1934	—	—	—	—	—	—	—	—	—			
1935	—	4.38	—	—	—	—	—	—	5.83			
1936	—	5.84	—	—	—	—	—	—	6.54			
1937	—	3.13	—	—	—	—	—	—	3.07			
1938	—	5.84	—	—	—	—	—	—	5.63			
1939	—	7.67	—	—	4.58	—	—	—	8.03			
1940	5.36	4.93	—	—	3.28	—	—	19.32	7.56			
1941	10.72	8.40	8.74	—	6.44	—	—	31.73	10.52			
1942	2.39	1.45	1.83	—	1.19	—	—	—	2.86			
1943	4.24	5.66	5.66	—	5.72	—	—	—	6.79			
1944	2.20	1.91	3.26	—	2.20	—	—	13.30	3.94			
1945	5.28	4.34	5.43	—	5.44	11.40†	28.81	21.33	6.88	13.08†	15.40	4.57
1946	3.29	3.58	4.33	15.0§	3.61	—	—	—	5.18	15.20	16.53	

*Estimated from surrounding stations.
†Three months of the year's record estimated from nearby stations.
‡One month of the year's record estimated from nearby stations.
§Two months of the year's record estimated from nearby stations.

Snow-Course Data From Six Stations in the Spring Mountain Range

(Record from the Nevada Cooperative Snow Surveys)

Station and location	Elevation	Water Content of Snow Cover, in Inches 1941	1942	1943	1944	1945	1946	6-yr. mean
Rainbow Canyon—T. 19 S.; R. 57 E.; sec. 31	7800	21.3	11.0	15.0	10.4	16.0	7.7	13.6
Kyle Canyon—T. 19 S.; R. 56 E.; sec. 26	8200	18.5	9.5	——	11.2	15.7	8.3	12.6
Lower Lee Canyon No. 1; T. 19 S.; R. 56 E.; sec. 10	8300	16.3	11.3	7.3	7.6	15.6	7.7	11.0
Upper Lee Canyon No. 2; T. 19 S.; R. 56 E.; sec. 9	9000	20.8	15.2	——	7.7	15.2	9.7	13.7
Trough Springs—T. 18 S.; R. 55 E.; sec. 23	8500	——	——	——	——	——	4.5	
Clark Canyon—T. 19 S.; R. 56 E.; sec. 8	9000	——	——	——	——	——	8.3	

Station and location	Percent of 6-Year Mean 1941	1942	1943	1944	1945	1946
Rainbow Canyon—T. 19 S.; R. 57 E.; sec. 31	156.2	80.9	110.2	76.6	117.8	56.6
Kyle Canyon—T. 19 S.; R. 56 E.; sec. 26	146.6	75.2	——	88.9	124.2	65.9
Lower Lee Canyon No. 1—T. 19 S.; R. 56 E.; sec. 10	148.2	102.7	66.2	69.1	141.9	70.0
Upper Lee Canyon No. 2—T. 19 S.; R. 56 E.; sec. 9	152.1	110.7	——	56.3	111.0	70.8
Trough Springs—T. 18 S.; R. 55 E.; sec. 23	——	——	——	——	——	——
Clark Canyon—T. 19 S.; R. 56 E.; sec. 8	——	——	——	——	——	——

Normal Monthly and Annual Precipitation, in Inches, at Eight Stations in or Near Las Vegas, Pahrump, and Indian Spring Valleys
(Data from Records of U. S. Weather Bureau)

Station	No. on plate 2	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Length of record, years
Las Vegas Airport	1	0.62	0.41	0.34	0.26	0.18	0.14	0.53	0.53	0.33	0.58	0.22	0.42	4.26	10
Las Vegas	2	.52	.59	.43	.23	.19	.15	.54	.60	.37	.28	.31	.41	4.62	42
Desert Game Range*	3	.50	.57	.80	.75	.02	.05	.21	.63	.03	.52	.30	.61	4.99	7
Indian Springs†	5	.50	.66	.52	.82	.05	.09	.48	.91	.37	.37	.34	.66	5.77	8
Kyle Canyon Ranger Station*	8	1.93	3.53	2.07	1.55	.55	.06	.61	2.53	.86	1.38	1.74	2.98	19.79	7
Pahrump	12	.78	.57	.61	.39	.30	.20	.26	.38	.26	.28	.05	.94	5.02	8
Boulder City	—	.76	.81	.63	.43	.15	.04	.55	.45	.66	.55	.20	.63	5.86	15
Clay City‡	—	.16	.54	.34	.15	.24	.00	.00	.58	.00	.52	.19	.04	2.76	4

*Based on 5-year average. †Based on 7-year average. ‡Based on 4-year average.

Normal Monthly and Annual Air Temperature, in Degrees Fahrenheit, for Six Stations in or near Las Vegas and Indian Spring Valleys
(Data from Records of U. S. Weather Bureau)

Station	No. on plate 2	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Las Vegas Airport	1	42.2	47.9	53.8	61.6	70.5	80.6	87.1	84.8	75.4	63.7	51.3	43.4	63.6
Las Vegas	2	45.0	50.4	56.8	64.2	71.5	80.4	86.4	84.8	77.0	65.8	53.8	46.2	65.2
Indian Springs*	5	41.1	42.9	50.4	58.5	68.1	75.4	82.7	81.1	71.8	60.2	46.9	40.9	59.9
Kyle Canyon Ranger Station†	8	29.6	29.8	36.7	40.9	50.2	57.2	65.7	63.1	55.4	46.6	36.4	32.4	45.3
Boulder City	..	45.6	49.0	56.9	65.0	74.1	82.8	89.5	87.5	80.7	68.8	55.7	47.7	66.3
Clay City‡	..	41.6	47.3	51.4	58.7	67.6	75.5	85.0	82.5	74.5	62.3	50.9	42.7	61.8

*Based on 7-year-average. †Based on 5-year average. ‡Based on 4-year average.

Average Monthly Evaporation, in Inches, at Three Stations in or near Las Vegas, Pahrump, and Indian Spring Valleys
(Data from Records of U. S. Weather Bureau)

Boulder City, Nevada (1935–1946) Altitude 2,525

No. of years*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
10–12	3.56	4.29	7.58	11.18	15.26	17.69	17.22	15.32	11.93	8.00	4.87	3.27	118.59

Clay City, Nevada (1926–1930) Altitude 2,185

No. of years*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1–4	5.31	4.89	7.27	10.72	16.06	19.50	20.80	21.07	15.13	9.41	6.87	5.00	141.58

Pahrump, Nevada (1914–1925) Altitude 2,667

No. of years*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
3–5	2.18	2.97	5.69	5.96	10.44	11.62	12.46	10.66	8.12	5.25	2.57	2.12	80.03

*Greatest and least number of years for any one month.

VEGETATION AND SOILS

The lowlands of Las Vegas and Pahrump Valleys are covered with a sparse to dense growth of vegetation. This vegetation may be classified largely as phreatophytes. Phreatophytes are plants that habitually grow where they can send their roots down to the water table or to the overlying capillary fringe and thus obtain a permanent water supply. Altogether seven species of plants known to be phreatophytes were observed. The most common were mesquite (*Prosopis velutina* and *Prosopis juliflora*), salt grass (*Distichlis spicata*), greasewood (*Sarcobatus vermiculatus*), and rabbit brush (*Chrysothamnus graveolens*). The three other species, usually localized in small areas, were pickleweed or iodine bush (*Allenrolfa occidentales*), saltbrush or quail brush (*Atriplex lentiformis*), and arrowweed (*Pluchea sericea*).

In other parts of the lowlands, and on the alluvial slopes where the "near-surface" water, or water table, is a considerable depth below the surface, creosote bush (*Covillea tridentata*) is by far the predominant plant and is associated with white bur-sage (*Franseria sp.*) and other less common species, such as saltbrush (*Atriplex sp.*), little rabbit brush (*Chrysothamnus stenophyllus*), sacaton (*Sporobolus wrighti*), and other southern desert shrubs and grasses. From the middle parts of the alluvial fans to the foothills the giant yucca or Joshua tree (*Yucca brevifolia*) and Spanish bayonet (*Yucca mohavensis*) abound, whereas creosote bush becomes scarce and blackbrush (*Coleogyne ramosissima*) becomes the prevalent small shrub. Many small cacti grow in this zone also. Above the lower foothills at elevations ranging from about 4,500 feet to the tops of the highest mountains, juniper (*Juniperus utahensis* and *Juniperus scopulorum*) and pinon pine (*Pinus monophylla*) grow, forming wooded areas over most of the higher slopes and ridges. Ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), and some foxtail pine (*Pinus aristata*) grow in the deeply shaded canyons and on north-facing slopes and ridges of the Spring and Sheep Mountain Ranges above an altitude of 7,000 feet. The undergrowth at this elevation is quite similar to undergrowth in other subalpine climates elsewhere in western United States.

The water table is only a short distance below the land surface where phreatophytes thrive. Here large quantities of water are discharged by the processes of soil evaporation and plant transpiration. Soil evaporation occurs when the capillary fringe extends to the land surface, and plant transpiration when the capillary fringe is within the reach of the roots of the plants. Generally the loss by transpiration is not large when the depth to the water table is greater than 20 feet.

In Las Vegas and Pahrump Valleys appreciable quantities of water are lost as the result of these processes (see p. 165). In the higher places, particularly in the mountains, the plant-cover undoubtedly increases the infiltration capacity of the drainage basin, and in this manner makes more water available for ground-water storage.

The soils in Las Vegas Valley were studied and reported upon by Carpenter and Youngs[8] in 1926, and the following discussion and most of plate 5, a map showing land classification and alkali concentration in part of the valley, are based on that report.

The soils of the valley are derived mainly from limestone and dolomite rocks with admixtures of materials derived from shale, sandstone, basalt, and other igneous rocks. The older soils of the alluvial fan have been modified to a large degree by weathering and accumulation of lime in the subsoils, with the result that a caliche hardpan underlies a large part of it. In places highly gypsiferous, subsoils have given rise to soils of the Bracken and Reeves series.[9] These soils consist of gypsiferous clay loam, generally with a high concentration of gypsum 1 foot to 3 feet below the surface. These types, together with other soils of a porous gravelly character, cover most of the area mapped on plate 5 as soils of limited and low agricultural value. Well-weathered old valley-filling soils having compact subsoils belong to the Spring, Arden, and Pond series[10], and make up most of the area mapped as soils with compact subsoils well-adapted to agriculture. Soils of recent deposition and slightly weathered soils with poorly compacted subsoils are referred to the Land of Gila series[11] and are considered the best soils in the valley. They make up, in large part, those mapped as soils with permeable subsoils well adapted to agriculture.

As Carpenter and Youngs have pointed out, "In the Las Vegas area there are three factors that have limiting effects on profitable agricultural development, and disregard of any of them could result in complete failure. Without water for irrigation, the

[8]Carpenter, E. J., and Youngs, F. O., Soil survey of the Las Vegas area, Nevada: U. S. Dept. Agr., Bur. Chemistry and Soils, Soil Survey Report No. 8, ser. 1923, 1928.

[9]Carpenter, E. J., and Youngs, F. O., op. cit., pp. 221–223.

[10]Idem., pp. 226–232.

[11]Idem., pp. 232–239.

profitable production of crops is impossible * * *. Of equal importance with water supply are the factors of alkali concentration and character and depth of soil. Other factors involved in the selection of a farm include location with respect to market, air drainage, and character of crop to be grown." In the foregoing paragraphs and on plate 5 the character and depth of soils have been briefly outlined, and alkali concentrations are also mapped.

In 1935 E. R. Fogarty of the Bureau of Reclamation made a detailed study of land classification in Las Vegas Valley below the 2,000-foot contour.[12] In this study 76,800 acres of land were classified, of which 10,174 acres were found suitable for irrigation. The standards used as a guide for classification of the lands were based upon soil character, depth, texture, alkali concentration, topography, and drainage conditions. Three classes of land were recorded:

Class 1—Irrigable.

Class 2—Irrigable (land with deficiencies in either soil, topography, or drainage).

Class 6—Nonirrigable (land which failed to meet the minimum requirements for Class 2, either in soil, topography, drainage, or a combination of such deficiencies).

The lands classified by Fogarty are shown on plate 5, on which Fogarty's classification is superimposed on the work by Carpenter and Youngs. The total of Class 1 land was determined to be 2,654.4 acres; of Class 2 land, 7,519.6 acres. All the Class 1 land is situated in secs. 1, 2, 12, and 13, T. 20 S., R. 61 E., and in secs. 1, 2, 11, 18, and 19, T. 20 S., R. 62 E. The Class 2 land is widely scattered and constitutes 74 percent of the irrigable land in Las Vegas Valley. The largest contiguous parcels of Class 2 land lie northeast of Las Vegas in T. 20 S., R. 62 E., and extend into adjacent townships.

The results of these two studies show that the largest tracts of land most suitable for agriculture are northeast and east of Las Vegas. Only small isolated tracts of arable land occur in other parts of the valley.

There are no published reports of soil studies in the north part of Las Vegas Valley and in Indian Spring and Pahrump Valleys. Parts of these valleys contain soils apparently similar to those in the south part of Las Vegas Valley. In Pahrump Valley an

[12] Kerr, John N., Report on Las Vegas pumping projects, Nevada; U. S. Bur. Reclamation mimeographed report, pp. 23–38, 1936.

area of about 11,000 acres lying along the west side of the "Johnnie" road, from a few miles south of the Manse Ranch to about 6 miles north of Pahrump, is apparently good agricultural land, and large tracts of it have been tilled successfully for many years.

PHYSIOGRAPHY

Las Vegas Valley is a northwest-trending trough bounded on the west by the lofty Spring Mountains, and on the northeast by the south parts of the north-south trending Pintwater, Desert, Sheep, and Las Vegas Ranges. The east part of the valley is bordered by Frenchman Mountain, locally called Sunrise Mountain, and a low range of unnamed hills extending southward to Las Vegas Wash, which drains southeasterly from Las Vegas Valley into the Colorado River. The River Mountains and the north extremity of the McCullough Range bound the south end of the valley.

Pahrump Valley lies at the west foot of the Spring Mountains. It is bounded on the north and west by a group of low-lying unnamed ridges that intersect the Spring Mountains in the vicinity of Johnnie and trend southward. The southern tip of these ridges and hills partially separate Pahrump Valley from Stewart Valley, a low-lying basin which receives drainage from the northern part of Pahrump Valley.

Indian Spring Valley is a crescent-shaped basin which trends north-south along the west foot of the Pintwater Range, then turns sharply west between the north end of the Spring Mountains and the Spotted Range, which bounds the north and west sides of the valley. Indian Spring Valley is separated from the north end of Las Vegas Valley by a low alluvial divide about 4 miles east of Indian Springs.

Thus, the area described in this report contains three topographically low basins with smooth gentle alluvial slopes, bounded by relatively high steeply sloping mountain ranges which trend north-south. These features are typical of the Great Basin section of the Basin and Range physiographic province. The poorly defined boundary between the Great Basin and the Sonoran Desert sections passes across the southern tip of Nevada near the south end of Pahrump Valley, Charleston Peak, and the north end of Las Vegas Valley. The northern boundary of the Mexican Highland section is formed by the Colorado River.[13] Therefore,

[13] Fenneman, N. M., and others, Physical division of the United States: Assoc. Am. Geographers Annals, vol. 6, pp. 19–98, map, 1927.

the area is partly within two sections of the Basin and Range province and is adjacent to a third section. However, the dominant physiographic features are, as Nolan[14] has stated, those of the Great Basin.

Most of Las Vegas Valley is tributary, through Las Vegas Wash, to the Colorado River. However, the northern part of Las Vegas Valley at the mouth of the Three Lakes Valley reentrant is an enclosed basin and is separated from the south part by a low alluvial divide. Drainage in Indian Spring Valley ends in a playa about 10 miles north of Indian Springs. The north part of Pahrump Valley drains westward into Stewart Valley, and the south part drains into a playa at the base of the Nopah Range about 12 miles southwest of the Manse Ranch. No perennial streams occur within the area and the intermittent streams have no regular seasonal flow. Surface water runs in washes only during, and for a short period following, infrequent and violent storms. Streams of water from even the larger springs and runoff from melting snows in the mountains disappear into the gravels or are dissipated by evaporation over short distances. Thus, most of the erosion at the present time occurs sporadically and violently, and conditions apparently are favorable for continued growth of alluvial fans and gradual filling of the present basins.

The area may be divided into three local physiographic provinces, one comprising the mountains, one the alluvial apron, and the third the basin lowlands. The mountains, having a relief of several thousand feet, consist largely of bare, well-consolidated sedimentary rocks. They are places of erosion where streams have cut and are continuing to cut deep ravines and canyons.

The alluvial apron has much less relief and the slopes are more gentle and regular than those in the mountains. It has been, in the geologically recent past, a place of deposition and still is in some localities. However, over most of the area the alluvial apron has been and is being eroded, and is considerably dissected. It consists of coarse, angular to poorly rounded, poorly assorted debris, which has been transported from the closely adjacent mountains.

The basin lowlands are underlain by fine-grained playa, lacustrine wash, and eolian materials deposited at the toe of the alluvial apron. The relief is low and the surface of the basins is smooth and apparently level in comparison to the alluvial apron and the mountains. The basins are sites of deposition and are

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[14] Nolan, T. B., The Basin and Range province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 1017-D, p. 142, 1943.

gradually becoming filled. Even in the south part of Las Vegas Valley, where there is opportunity for materials to be transported through Las Vegas Wash, little erosion is taking place, and large quantities of fine material are deposited by floods during and following torrential storms.

MOUNTAINS

The Spring Mountains (pl. 1) occupy almost 1,000 square miles, approximately one-third of the area covered by this report. They trend northwesterly across it from the center of the south boundary to the northwest corner. They are a persistently high mountain mass, the crest of which is more than 7,500 feet above sea level from Potosi Mountain in the south to a point north of Mt. Stirling, a distance of more than 45 miles. A considerable part of the central section of the range in the vicinity of Charleston Peak and The Mummy, a long, high ridge east and north of Charleston Peak, is over 10,000 feet in altitude. Charleston Peak, the highest point in the range and one of the highest peaks in Nevada, reaches an altitude of 11,910 feet, which is about 9,700 feet above Las Vegas and more than 10,300 feet above the floor of Las Vegas Wash (see pl. 1). The width of the mountain mass ranges from about 5 miles in the southern part of the area to more than 25 miles in the central part of the range.

The main canyons on the east side of the range from north to south are: Lee Canyon, which drains north and northeasterly from Mt. Charleston and The Mummy; Deer Creek Canyon, which drains most of the east side of The Mummy; Kyle Canyon, which drains the south side of The Mummy, the east side of Charleston Peak and Ridge, and the north side of La Madre Mountain; Red Rock Canyon, which drains the south side of La Madre Mountain and the north part of Sharktooth Ridge; and Cottonwood Valley, which drains most of the east slope of the Spring Mountains south of Red Rock Canyon. On the west side of the range from north to south the main canyons are: Wheeler Canyon and its tributary Clark Canyon, which drain most of the Spring Mountains north of Charleston Peak and south of Wheeler Spring in sec. 20, T. 18 S., R. 55 E.; Carpenter Canyon, which drains the southeast side of Charleston Peak; Trout Canyon, which drains the south side of the peak and the west side of Charleston Ridge; and Lovell Canyon, which drains Sexton Ridge, the east side of the southward extension of Charleston Ridge, and the west side of Sharktooth Ridge. Most of the main canyons are formed along fault zones or areas of weakness caused by structural movements.

Many of the smaller washes and canyons also, are cut along faults and are topographic expressions of structural processes affecting the rocks. The general topography of the mountain region is rugged and is characterized by sharp peaks and ridges, steep and precipitous slopes, and deep, steeply sloping canyons.

The Spring Mountains are composed of Paleozoic and Mesozoic well-consolidated sedimentary rock masses of complex structure, which rise abruptly out of the alluvial apron. Conclusive evidence of the cause of elevation of the range has not yet been observed, and any statement concerning the methods of elevation must necessarily be general or based upon considerable speculation. Field evidence and observation to date indicate that the present elevation of the range must be, in part at least, the result of regional faulting accompanied or followed by extensive erosion of Las Vegas Valley.

The southern extremities of the Pintwater, Desert, Sheep, and Las Vegas Ranges are rugged, abruptly rising mountain masses partly buried by the alluvium. They are generally similar to the Spring Mountains except that they are lower and smaller. Of the four ranges only the Sheep Mountains reach an altitude over 8,000 feet. They all trend more or less east-west at the extreme southern ends, but within a few miles the trend swings sharply north. The Desert and Pintwater Ranges are only about 6 miles wide in the vicinity of Las Vegas Valley. The Sheep and Las Vegas Ranges are from 8 to 10 miles wide. Frenchman Mountain (Sunrise Mountain) east of Las Vegas reaches an altitude of about 4,000 feet, and the southward-extending ridge drops off rapidly toward the vicinity of Las Vegas Wash, where it is only about 2,500 feet above sea level. Likewise, the River Mountains and the McCullough Range are rugged low-lying masses. They differ from the other mountains in the area because they are formed of igneous rocks, largely of Tertiary age.

The mountains are flanked on all sides by the alluvial apron, which is composed of rock waste eroded from the mountains and deposited on the mountain flanks and in the valleys. Small remnants of such alluvial materials, now being eroded, are present in the mountains at altitudes as high as 9,500 feet. Three erosion terraces cut in the gravels are conspicuous in Kyle Canyon and can be recognized in other canyons in the range. They indicate at least three periods of erosion of the alluvial apron since the oldest alluvial materials were deposited. Therefore, during parts of Tertiary and Quaternary time the mountains must have been buried deeply in alluvial materials, which have been partially removed by subsequent erosion. The presence of the gravel deposits in all the major canyons high up in the mountains is a factor of paramount importance to the water supply of Las Vegas, Pahrump, and Indian Spring Valleys. The gravels are highly permeable and water enters them readily, with the result that no perennial streams exist in the mountains. Water from precipitation in the mountains enters the ground-water reservoirs directly and there is little or no surface runoff. This water then moves laterally into the lower-lying parts of the alluvial apron.

The central and northern parts of the Spring Mountains form the most important watershed in the area. More than three-fourths of the ground water used in Las Vegas, Pahrump, and Indian Spring Valleys originates in this watershed. The south part of the Spring Mountains, south of La Madre Mountain, and the Sheep Range also contribute small quantities of water to the ground-water reservoir.

ALLUVIAL APRON AND THE BASIN LOWLANDS

The boundary between the main alluvial apron and the mountains is conspicuously marked by an abrupt change in slope and rock material (see pl. 4A). It averages about 4,500 feet in altitude. However, the maximum altitude of the boundary is nearly 9,500 feet in the vicinity of Charleston Peak near the heads of Kyle, Lee, and Clark Canyons. The minimum altitude of this boundary on the land surface is about 1,600 feet in the vicinity of Las Vegas Wash. The boundary of the alluvial apron and the basin lowlands is obscure, for the change in slope and in the characteristics of the materials is gradual. In places the alluvial apron on one side of a valley joins the alluvial apron on the other side, and the typical basin lowland is absent. Only in localities where there are playa lakes or lacustrine deposits is the boundary well-marked by a change, both of slope and of the character of the sediments. The basin lowlands are nearly all sites of deposition, whereas the alluvial apron is now being dissected by erosion, especially near its upper margin. The boundary between the alluvial apron and the basin lowlands is never more than about 3,100 feet in altitude and is about 1,600 feet in altitude at its lowest point in Las Vegas Wash. The altitude of the boundary averages about 2,500 feet.

The materials that make up the alluvial apron are poorly assorted alluvial gravels, sand, silt, clay, and caliche, the coarser materials being in marked predominance. Near the mountains in

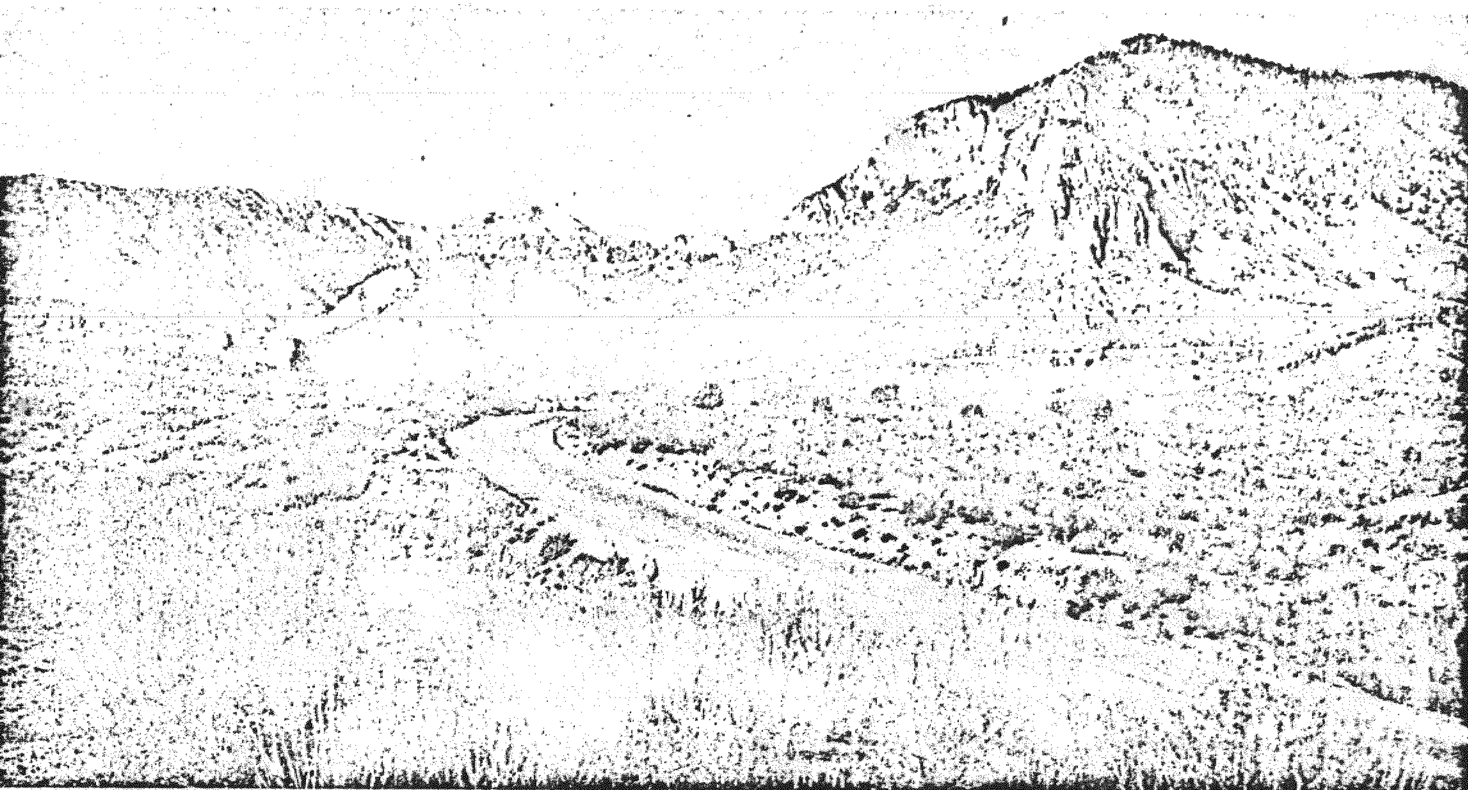

PLATE 4A—Kyle Canyon, Spring Mountain Range, about 25 miles northwest of Las Vegas. The distant peak, left of center, is Mt. Charleston. The foreground is a Pleistocene terrace cut on the older alluvial gravels.

the upper part of the alluvial apron, the materials are especially coarse, angular, and poorly assorted and dip away from the mountains at angles of 12° to 18° (see pl. 4B). Lower down on the alluvial apron the materials are not so coarse, are more rounded and better sorted, and dip at lower angles. The surface of the alluvial apron is cut by many drainage channels or washes of varying depth and width and, although from a distance it appears to be smooth, it has considerable relief. The "grain" of the topography of the alluvial apron is roughly normal to the mountains and the axes of the basins. The washes are generally

PLATE 4B—Section of the upper part of the alluvial apron in Kyle Canyon, showing coarse character and steep dip of the gravels.

dry and only during infrequent storms are they filled with water. However, little vegetation grows on the alluvial apron and it is poorly protected from erosion. When large storms occur, the washes are rapidly filled with swift torrents which cut deeply into the beds of the washes and transport large volumes of gravel, sand, and finer materials down the apron. After such storms, the detail of the drainage pattern of the alluvial apron is noticeably changed as a result of the channel shifting and rapid erosion which accompany the torrential flooding. Generally the desert storms follow a narrow path across the country or are localized over small areas, and washes which are filled with water in one part of the apron may be running only a small stream or be completely dry a few miles down the slope. Thus, the carrying power of the streams decreases rapidly, and the coarser materials are seldom carried far down the slopes. Mostly fine materials are deposited near the lower margin of the alluvial apron and in the basin lowlands.

The alluvial apron is made up of numerous coalescing fans which head high up in the mountains. The largest fans are always opposite the higher mountain masses at the mouths of the larger canyons and the smaller fans are opposite the mouths of the lower, smaller canyons. In Las Vegas Valley three high alluvial fans project far out into the valley from the mouths of Lee and Deer Creek Canyons, Kyle Canyon, and Red Rock Canyon. These fans are separated by low-lying interfan and small alluvial fan areas, and the lowest part of the valley swings sinuously out around the toes of the large fans and back toward the mountains in the interfan areas. In the north part of the valley the Lee-Deer Creek Canyon fan extends across the valley and joins the alluvial apron on the east side, forming an alluvial drainage divide, above which is the small playa lake at the mouth of Three Lakes Valley. Similarly, the Kyle Canyon fan extends far out into the valley and forms an alluvial dam which has been cut through by headward erosion of channels in the recent geologic past.

In Pahrump Valley similar conditions exist. The Pahrump and Manse fans (see pl. 1) at the mouths of Wheeler and Trout Canyons, respectively, are large, high fans extending far out into the basin and are separated by a low-lying interfan area. The character of the alluvial apron is of great significance to the occurrence of ground water because the larger alluvial fans contain the most productive and widespread sand and gravel aquifers.

The basin lowlands are sites of deposition. Generally fine sand, silt, and clay make up the surface deposits of the lowland and this surface is generally level. In Las Vegas Valley there are three such depositional areas. One of these is the playa at the mouth of Three Lakes Valley. Another is that part of the Las Vegas Valley southeast of the drainage divide formed by the Lee-Deer Creek fan, north of the Kyle fan and west of Corn Creek Ranch. The other is southeast of Las Vegas, from U. S. Highway 91 to Las Vegas Wash. The two latter areas were probably playas in the recent geologic past, although at the present time they drain southward into the Colorado River. The central part of Indian Spring Valley is a playa lake and there are playa lakes in the southwest and north parts of Pahrump Valley. Deposits of ancient lakes are present in the central parts of all three valleys (see pl. 1). These lakes left deposits of silt and clay, but no lake-shore features were observed and it is believed that the lakes were probably shallow and more or less ephemeral—similar to but larger than the present playa lakes.

Sand dunes and other wind-built features are present in several localities in the basin lowlands. They are particularly numerous in Las Vegas Valley north of Stevens and Mesquite Springs, between Whitney and the city of Las Vegas, a few miles north of the city, and northward in a long, wide arc from Corn Creek Ranch. Few of these dunes are active. Most of them are mounds of fine sediment built up around plants, generally mesquite trees, and are covered with a thick growth of mesquite. These mounds are prominent features in the vicinity of springs where ample water is available for plant growth. Some of the mounds have covered the vegetation growing around springs and have buried the springs as well, thus forming spring mound or knoll springs. Such spring mounds are common north and east of the Las Vegas Land and Water Company reservoir west of the city. Corn Creek and Tule Springs in Las Vegas Valley, Cottonwood and Mound Springs in Pahrump Valley, and Mesquite (Cactus) Spring in Indian Spring Valley are all typical knoll springs.

Many scarps are to be found in the south part of Las Vegas Valley in the vicinity of the city of Las Vegas and west of Whitney. They occur on the lower part of the alluvial apron and approximately along the boundary of the alluvial apron and the basin lowlands. They range from a few feet to nearly 150 feet high and are conspicuous topographic features. (See pl. 1.) All the larger springs and many small springs in the vicinity of Las Vegas, North Las Vegas, and Whitney issue from the ground near the base of these scarps.

The origin of some of the scarps is probably by differential compaction (see pp. 69–71), and undoubtedly they have been accentuated by erosion. In the north part of Las Vegas Valley, in the vicinity of Tule Springs and in Indian Spring and Pahrump Valleys, small erosional scarps have been formed in the soft, easily eroded Pleistocene lake beds.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCK FORMATIONS

PURPOSE AND SCOPE OF GEOLOGIC STUDIES

The geologic studies, which formed one phase of the investigation, were necessary for a basic understanding and interpretation of the ground-water conditions. The rocks of the area may be divided according to their hydrologic properties into two general groups: (1) the consolidated, relatively impervious rocks that form the mountains, and (2) the unconsolidated permeable sediments that make up the alluvial apron and underlie the valley floor. The ground-water reservoir, from which is withdrawn practically all of the ground water used, is composed of the unconsolidated sediments and is bounded by the relatively impervious consolidated docks. Consequently the geologic studies of the consolidated rocks in the mountains were largely of a reconnaissance nature, while detailed studies were reserved for the unconsolidated sediments of the valleys, with special attention to their water-bearing properties.

The geologic structure of the area has undergone modification in the relatively recent geologic past and has affected the occurrence and circulation of ground water. Considerable study, therefore, was made of the geologic structure, especially that of the sediments making up the ground-water reservoir.

The geologic information pertaining to the older rock formations and structures is based largely on studies by previous workers in the area (see Acknowledgments, pp. 15, 16.

GENERAL RELATIONS

Consolidated sedimentary and igneous rocks of Paleozoic, Mesozoic, and Tertiary age form the mountains adjacent to Las Vegas, Pahrump, and Indian Spring Valleys. Unconsolidated sedimentary rocks of Tertiary and Quaternary age form the alluvial apron and the valley floor. Pre-Cambrian rocks occur at only one place, near the base of Frenchman Mountain. No rocks of Cretaceous age are exposed in the area. Periods of time which are not represented by rocks were either periods of emergence, when no sediments were deposited in the area, or of deposition of sediments which were removed by later erosion or were buried by younger sediments. Block faulting occurred before last Mesozoic time, overthrusting occurred during Mesozoic and early Tertiary time, and block faulting again occurred during the Tertiary and Quaternary periods. Minor faulting and folding probably were synchronous with and related to both the overthrusting and block faulting.

Although the rocks are divided into many formations, several of these formations may be grouped together on the basis of the similarity of their water-bearing properties. This grouping has resulted in nine units. The sequence, physical character, and water-bearing properties of the units are summarized in the table that follows, in which are given the symbols used for the units shown on the geologic map, plate 1.

Generalized Stratigraphic Section in Las Vegas, Pahrump, and Indian Spring Valleys

Geologic age			Formation	Thickness within the area shown on plate 1 (feet)	Character and extent	Water-bearing properties
Cenozoic	Quaternary	Recent	Younger alluvial deposits (Valley fill and playa deposits) Qyal.	0 to unknown	Playa, eolian, and wash deposits locally derived from older rocks of the alluvial slopes and mountains; clean sand and gravel in washes on alluvial slopes in mountains, silty sand in dunes, and silty clay with little fine-grained sand and few sandy or gravelly lenses in playas and valley fill.	Wash deposits of sand and gravel are permeable and locally contain small quantities of unconfined ground water of good quality. Thin sand and gravel lenses of low permeability form aquifers in silty clay of playa and valley-fill deposits, and are the chief source of ground water east of U. S. Highway 91 and south of the Union Pacific R. R. in Las Vegas Valley, and in the central and western parts of Pahrump Valley. Feasibility for irrigation limited by low permeability; good for domestic and stock use where quality is suitable.
			—Unconformity—			
		Pleistocene	Lake and playa deposits Ql.	0 to 5 ±	Lacustrine and playa deposits of silt and silty clay, which crop out in the central parts of the valleys.	Thin, limited distribution and low permeability.
			—Unconformity (?)—			
	Late Tertiary(?) and Quaternary		Basalt series. Included in QTv.	(?)	Andesitic and basalt lava flows and associated deposits, which crop out near south margin of Las Vegas Valley.	Probably impermeable; act as a barrier to movement of ground water out of Las Vegas Valley.
			—Unconformity (?)—			

Cenozoic	Late Tertiary(?) and Quaternary(?)	Pliocene(?) and Pleistocene(?)	Older alluvial deposits QToa.	0 to unknown	Gravel, sand, silt, and clay forming the alluvial apron and much of the valley fill. Head of alluvial apron consists chiefly of gravel and sand deposits which grade into and interfinger with silt and clay deposits in the valleys.	Permeable beds are the layers of gravel and sand which finger between relatively impermeable beds of silt and clay. Permeable beds yield confined water and are the most important and practicable source of ground water in the valleys. Wells which bottom in this formation yield large quantities of water of good quality along the west side of Las Vegas Valley, the east side of Pahrump Valley, and the south side of Indian Spring Valley. Yields from wells drilled into this formation near the axes of the valleys yield smaller amounts of water of poorer quality. The gravel lenses in this formation are the source of the water which flows from Las Vegas, Tule, Manse Ranch, and Bennetts Springs, and probably much of the water from Indian Spring.

Unconformity

GENERALIZED STRATIGRAPHIC SECTION—*Continued*

Geologic age			Formation	Thickness within the area shown on plate 1 (feet)	Character and extent	Water-bearing properties
Cenozoic	Cretaceous to late (?) Tertiary	Miocene (?) and Pliocene (?)	Muddy Creek and Esmeralda(?) formations. Tme.	0–80	Lacustrine and playa deposits locally derived from older rocks in the area. Consist largely of silt and clay with a few thin lenses of sandstone and pebble conglomerate. Muddy Creek formation contains salt and gypsum beds in areas adjacent to Las Vegas Valley. Esmeralda (?) formation contains much volcanic ash. Gently folded locally and broken by block faults but not involved in thrust faulting.	Lenses of sandstone and conglomerate may be moderately permeable and may yield small quantities of water to a few deep flowing wells in Las Vegas Valley. Further drilling into these lenses may result in wells with larger yields. However, highly mineralized water may be encountered.
			-Unconformity-			
			Lavas of the River Mountains. Included in QTv.	0–1000	Porphyritic and latitic lava and flow breccia with glassy groundmass. Broken by numerous block faults but not involved in thrusting. Exposures limited to extreme southeast border of Las Vegas Valley and adjacent areas.	Forms a relatively impermeable barrier to ground-water movement southward out of Las Vegas Valley.
			-Unconformity(?)-			
		Eocene(?) to Miocene(?)	Black Canyon group of Ransome. Included in QTv.	(?)	Complex assemblage of andesitic lava flows, volcanic breccias, and related deposits. Probably unexposed in the area but crop out in Las Vegas Wash area closely adjacent. Cut by block faults and involved in thrusting.	May form impermeable barrier to movement of ground water southward and out of Las Vegas Valley.
			-Unconformity-			

Era	Period	Epoch	Formation	Thickness (feet)	Description	Water-bearing properties
Cenozoic	Cretaceous to Late Tertiary	Cretaceous to Miocene(?)	Horse Spring formation and Overton fanglomerate. Included in TKJTR.	(?)	Limestone, magnesite, clay, and sandstone deposits generally finer-grained and more indurated than the Muddy Creek formation. Locally intensely folded and cut by normal faults. Cut by thrust faults in adjacent areas. Unexposed in this area but possibly present as valley fill underlying more recently deposited sediments in Las Vegas Valley. Overton fanglomerate consists of well-indurated sandstone and fanglomerate.	Probably impermeable and unimportant as an aquifer.
			—Unconformity—			
Mesozoic	Jurassic(?)	Upper Jurassic(?)	Aztec sandstone. Included in TKJTR.	2400 +	Buff, white, and red medium- to fine-grained massive, cross-bedded sandstone involved in both block faulting and thrust faulting. Locally well-developed joint systems are present. Crops out in south-central part of area.	Well-consolidated and generally impermeable, but transmits limited quantities of water where it is extensively jointed.
			—Unconformity(?)—			
Mesozoic	Triassic	Upper Triassic	Chinle formation. Included in TKJTR.	700 ±	Red, pink, and lavender silty and shaly cross-bedded, thin-bedded sandstone.	Generally impermeable and forms a barrier to ground-water movement southward and out of Las Vegas Valley.
		Upper Triassic	Shinarump conglomerate. Included in TKJTR.	50–80	Light-gray and tan medium-grained thin-bedded to massive, well-consolidated sandstone with a few thin to thick beds of granule and pebble conglomerate.	Generally impermeable and well-consolidated but transmits limited quantities of water where extensively jointed.
			—Unconformity—			
		Lower Triassic	Moenkopi formation. Included in TKJTR.	1000–1500	Consists of a lower unit of reddish gypsiferous, sandy shale overlain by nearly 700 feet of buff sandy thin-bedded limestone, in turn overlain by about 500 feet of red shale, sandstone, and sandy shale.	Generally impermeable barrier to ground-water movement.
			—Unconformity—			

GENERALIZED STRATIGRAPHIC SECTION—*Continued*

Geologic age			Formation	Thickness within the area shown on plate 1 (feet)	Character and extent	Water-bearing properties
Paleozoic	"Late Paleozoic" PCksb	Permian	Kaibab limestone.	0–700	Gray massive to thin-bedded fossiliferous, cherty limestone with a few thin interbedded layers of buff medium-grained sandstone. Locally faulted and jointed.	Generally impermeable and above the regional ground-water level. Small quantities of ground water transmitted through rocks where they are extensively faulted and jointed. Springs, generally with small flow, occur in the mountainous area in these rocks where they are much faulted and jointed, and where other conditions are favorable. Generally these rocks act as a barrier to movement of ground water.
			Supai formation.	1100 +	Red beds composed of sandstone, shale, and some gypsum, all well-consolidated.	
Paleozoic	Mississippian (upper) and Pennsylvanian		Bird Spring formation.	2500–5200 +	Gray thick- to thin-bedded limestone interbedded with dolomite. Many sandy and silty buff to tan beds interbedded with limestone near base of the formation. Crops out over an extensive area in south and central part of area. Thickens much from south to north.	
Unconformity(?)						
"Middle Paleozoic" CDms	Mississippian (lower and middle)		Monte Cristo limestone.	800–1000	Light- to dark-gray massive to thin-bedded, moderately cavernous fossiliferous limestone. Formation contains sandy beds and is less cavernous in north part of area.	Generally above the regional ground-water level. Much water transmitted through solution channels along faults and joints. Many springs emerge from these formations in the mountains.
	Devonian (middle and upper)		Sultan limestone.	600 +	Light- to dark-gray massive to thin-bedded, moderately cavernous limestone.	

Paleozoic	"Early Paleozoic" D-C	Cambrian to Devonian (lower)	Limestone, shale, sandstone, and quartzite. (See text and fig. 7)	3000–18,000	Well-consolidated limestone and dolomite beds overlying shale, sandstone, and quartzite. The latter beds are very thin or not present in the south part of the area, but thicken northward. Much faulted and folded. (Includes pre-Cambrian gneiss in small area at base of Frenchman Mountain.)	Generally impermeable and above the regional ground-water level. Barrier to ground-water movement.

STRATIGRAPHY

PRE-CAMBRIAN ROCKS

A few small outcrops of reddish granite gneiss, unconformably overlain by hard dark-brown sandstone and green shale (Bright Angel shale), occur in a small area at the base of Frenchman Mountain. This gneiss has been assigned to the Archean by Longwell and Hewett,[15] and is the oldest known rock that crops out in the area.

These few outcrops have been mapped with the "Early Paleozoic" rocks on plate 1.

PALEOZOIC ROCKS

Rocks of Paleozoic age crop out in the mountains. For the purpose of the present report these rocks are arbitrarily divided on the basis of their water-bearing character into three groups designated "Early Paleozoic," "Middle Paleozoic," and "Late Paleozoic" rocks. Formations of Cambrian, Ordovician, Silurian, and Lower Devonian age are grouped together and whenever any or all of them appear they are designated "Early Paleozoic" rocks. As indicated above, the "Early Paleozoic" on the map also includes pre-Cambrian rocks at the base of Frenchman Mountain. Formations of Middle and Upper (?) Devonian age and the lower and middle parts of the Mississippian series are designated "Middle Paleozoic" rocks; and formations of the upper part of the Mississippian, the Pennsylvanian, and the Permian are referred to as "Late Paleozoic" rocks. The "Middle Paleozoic" rocks are important as water-bearing formations. The "Early" and "Late Paleozoic" rocks are not good aquifers and are important only as barriers to ground-water movements.

"EARLY PALEOZOIC" ROCKS

Outcrops of "Early Paleozoic" rocks are widely distributed throughout the area covered by this report. In the north and west parts of the area they underlie a preponderant part of the surface and are parts of huge thrust sheets that have moved over rocks deposited during later geologic time. Also, these formations are more numerous and thicker than they are in the south and east parts of the area, where unconformities exist in the lower part of the geologic section. Geologic sections showing the approximate thickness, type of rock, and geologic age of the various formations in and adjacent to the area are shown in figure 7.

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[15]Longwell, C. R., and Hewett, D. F., Geology of the region near Arden, Clark County, Nevada, with reference to possible occurrence of oil and gas: U. S. Geol. Survey (manuscript report on file).

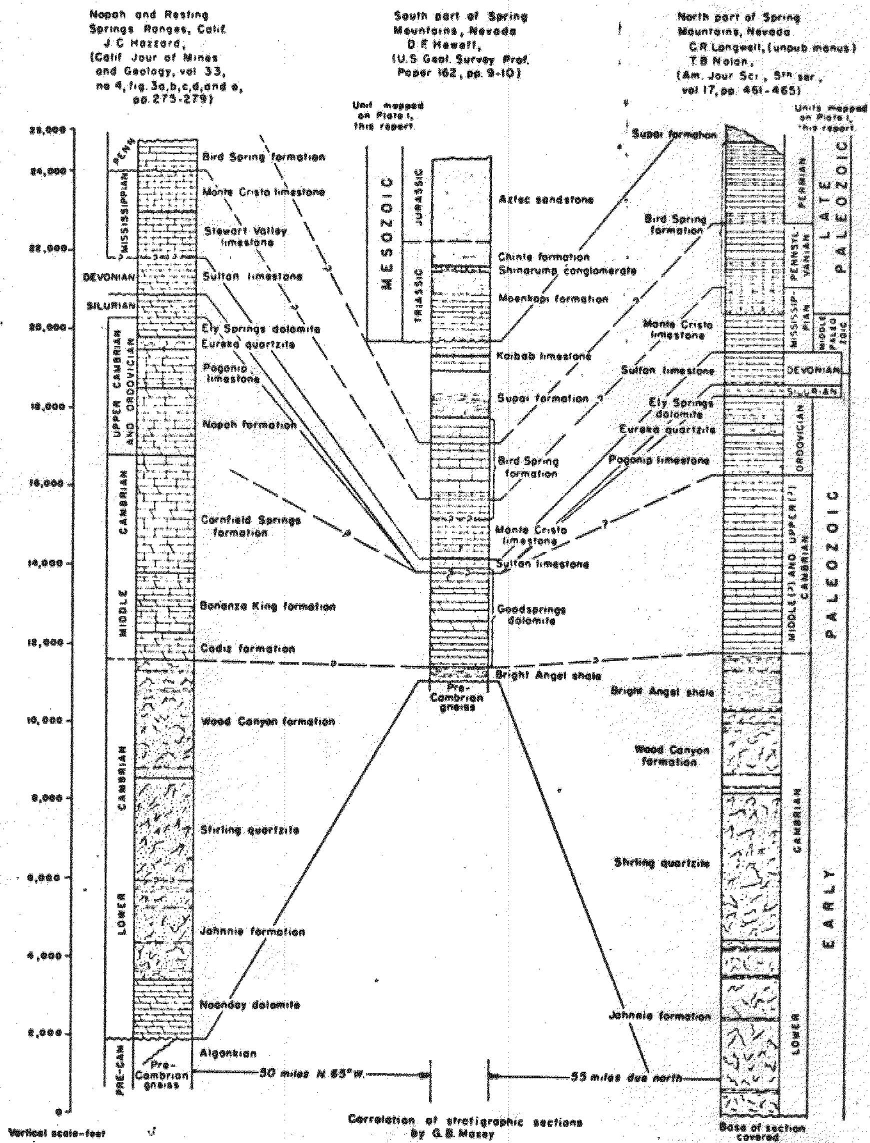

FIGURE 7—Diagrammatic correlation of stratigraphic columns in the Nopah and Resting Springs Ranges, California, and the Spring Mountains.

Nolan[16] has described the rocks of the lowest part of the geologic section in the vicinity of Johnnie, Nevada. These rocks include the Lower Cambrian Johnnie formation, more than 4,500 feet of grayish-green fine-grained quartzite, locally cross-bedded, and interbedded with layers of greenish shale and a little cream-colored dolomite; the Lower Cambrian Stirling quartzite, nearly 3,200 feet of pink and gray thick-bedded coarse-grained quartzite interbedded with reddish- or purplish-brown shaly cross-bedded quartzite; the Wood Canyon formation, 2,100 feet of brown micaceous shaly sandstone, dark quartzite, and sandy shale, with a few gray sandy limestone beds near the top; and the Bright Angel shale, 1,500 feet of greenish shale with minor amounts of white and reddish quartzite and much thin-bedded dark-gray limestone with shale partings, interbedded with the greenish shale layers toward the top of the formation. Fossils were found in the top of the Wood Canyon formation which were indicative of its Lower Cambrian age. Fossils found by Nolan in the Bright Angel shale are reportedly of Middle Cambrian age. The formations just described crop out near Johnnie and along the west side of Pahrump Valley, in the north part of the Spring Mountains, and in the Desert, Sheep, and Las Vegas Ranges.

Overlying the Bright Angel shale in the location just mentioned is about 7,000 feet of limestone and dolomite with a few interbedded shale and quartzite layers. Longwell[17] has divided these rocks into five formations. Three of the formations, the Pogonip limestone,[18] the Eureka quartzite,[19] and the Ely Springs dolomite,[20] all of Ordovician age, have been described and named in other regions. Of the two other formations, (1) a great thickness of limestone and dolomite overlying the Bright Angel shale and underlying the Pogonip limestone, has been tentatively assigned to the Middle and Upper Cambrian by Longwell and by others;[21] and (2) about 500 feet of dolomite and limestone overlying the Ely Springs dolomite and underlying the Sultan lime-

[16]Nolan, T. B., Notes on the stratigraphy and structure of the Spring Mountain Range: Am. Jour. Sci., 5th ser., vol. 17, pp. 460–465, 1929.

[17]Longwell, C. R., Geology of the Las Vegas quadrangle: U. S. Geol. Survey (manuscript report on file).

[18]Hague, Arnold, U. S. Geol. Survey 3d Ann. Rept., pp. 253–263, 1883.

[19]Westgate, L. G., and Knopf, A., Geology and ore deposits of the Pioche district, Nevada: U. S. Geol. Survey Prof. Paper 171, pp. 7, 15, 1932.

[20]Idem.

[21]Longwell, C. R., op. cit.; Mason, J. F., Longwell, C. R., and Hazzard, J. C., Sequence of Cambrian faunas in the southern Great Basin (abstract): Geol. Soc. America Proc., p. 366, 1936; Mason, J. F., Cambrian faunal succession in Nevada and California: Jour. Paleontology, vol. 12, pp. 287–297, 1938.

stone of Devonian age, has been assigned to the Silurian system.[22]

At the base of Frenchman Mountain and in the south part of the Spring Mountains the "Early Paleozoic" rocks consist of two formations, the Bright Angel shale and the Goodsprings dolomite. Here the Bright Angel shale crops out in only one limited locality, at the west base of Frenchman Mountain. It consists of a basal reddish dark-brown medium- to coarse-grained sandstone overlain by about 400 feet of micaceous green shale interbedded with a few thin layers of brown, mottled medium-crystalline dolomite. The total thickness of the formation is 525 feet. It rests unconformably upon reddish granite gneiss of pre-Cambrian age, and is conformably overlain by the Goodsprings dolomite which has been described in detail by Hewett.[23]

To the east of the southern part of the Goodsprings quadrangle a complete section of the Goodsprings dolomite, exposed on the southeast end of Sheep Mountain east of Jean, as measured by Hewett, was 2,500 feet thick. The thickness of the formation as measured by Longwell[24] on Frenchman Mountain is 2,000 feet.

The Frenchman Mountain section is the only location within the area covered by the present report where the total thickness of the formation is known to be exposed. The Goodsprings dolomite consists of gray crystalline thin-bedded mottled magnesium limestone layers interbedded with light-gray crystalline thick-bedded dolomite and some layers of dark-gray dolomite. Fossils collected by Hewett[25] indicate that the beds assigned to the Goodsprings may have been deposited during "Upper Cambrian, through Ordovician and Silurian, and possibly into the Devonian." According to Longwell[26] it is possible to identify beds in the Goodsprings dolomite exposed in the vicinity of Red Rock and La Madre Mountain that were probably contemporaneous with beds of Cambrian, Ordovician, and Silurian age that crop out in the northern part of the area. Thus, there is considerable northward thickening of the "Early Paleozoic" rocks.

Studies by Hazzard and Mason[27] of the faunal and stratigraphic relationships of the Goodsprings dolomite underlying Cambrian

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[22] Longwell, C. R., op. cit.

[23] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, pp. 11–13, 1931.

[24] Longwell, C. R., and Hewett, D. F., Geology of the region near Arden, Clark County, Nevada, with reference to possible occurrence of oil and gas: U. S. Geol. Survey (manuscript report on file).

[25] Hewett, D. F., op. cit., pp. 12–13.

[26] Longwell, C. R., personal communication, Dec. 1945.

[27] Hazzard, J. C., and Mason, J. F., "Goodsprings dolomite" of Nevada, and its faunas (abstract): Geol. Soc. America Proc. for 1935, p. 378, 1936.

formations in the Sheep Mountain section east of Jean, Nevada, have disclosed that the beds referred by Hewett to the Bright Angel shale are probably Lower Cambrian. Also, the lower 425 feet of beds included in the Goodsprings dolomite by Hewett has been tentatively referred by Hazzard and Mason to their Middle Cambrian Cadiz formation.[28] The upper 1,600 feet included in the Goodsprings by Hewett at Sheep Mountain and 460 feet of beds exposed near the Lincoln Mine in the Goodsprings quadrangle have been referred to their Bonanza King formation,[29] and an overlying 650 feet of dolomite has been referred to their Middle Cambrian Cornfield Springs formation.[30] Thus nearly all of the Goodsprings dolomite in the south part of the area is probably referable to the Middle Cambrian, and only 100 feet of dolomite beds at the top of the Goodsprings, separated from the beds of Cambrian age by an unconformity,[31] are of Devonian age. Beds of Upper Cambrian, Ordovician, and Silurian age are not present, at least in the vicinity of Goodsprings. It is probable then that some of the tremendous thickness of the "Early Paleozoic" beds in the north part of the area is represented in the south part by unconformities and is not altogether a result of northward thickening in the beds.

Water-Bearing Properties. In general the "Early Paleozoic" rocks are quartzite, well-indurated shale, noncavernous limestone, and dolomite which are relatively impermeable. Indeed, in some places ground water percolating through overlying permeable beds is brought to the surface along the upper contact of the "Early Paleozoic" rocks. Few springs occur except where the rocks have been brecciated or badly broken by faulting and other structural movements. Thus, the important hydrologic function of the "Early Paleozoic" rocks is as a barrier to ground-water movement from one basin to the other, or from the basins to the outside, rather than as an aquifer to transmit or store ground water.

"MIDDLE PALEOZOIC" ROCKS

The rocks classed in this report as "Middle Paleozoic" consist of two formations, the Sultan limestone and the Monte Cristo limestone, both of which were named and described in the report on the Goodsprings quadrangle by Hewett.[32] The rocks are widely distributed throughout the area and have outcrop attitudes similar

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[28]Hazzard, J. C., Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Jour. Mines and Geology, vol. 33, No. 4, Oct. 1937, pp. 314–316, 1938.

[29]Hazzard, J. C., op. cit., pp. 316–318.

[30]Hazzard, J. C., op. cit., pp. 318–320.

[31]Hazzard, J. C., and Mason, J. F., op. cit., p. 378.

to those of the "Early Paleozoic" rocks. However, the "Middle Paleozoic" rocks are much thinner and therefore do not crop out in as large an area. Also, the Monte Cristo limestone is not everywhere present in the northern part of the area because it has been removed by erosion.

The Sultan limestone consists of a lower layer of dark-colored dolomitic limestone overlain by light-gray massive to platy limestone of porcelain-like texture. The light-gray limestone is moderately cavernous in many parts of the area. The formation is nearly 600 feet thick in the southern part of the area. However, like the underlying "Early Paleozoic" rocks, it thickens to the north. Fossils found in the Sultan limestone were reported to be of late Middle Devonian or early upper Devonian age.[33]

The Monte Cristo limestone consists of 800 to 1,000 feet of massive, light-gray to dark-gray finely crystalline limestone, overlain by massive light gray porcelain-texture cherty limestone, in turn overlain by a massive almost white coarsely crystalline dolomite, which underlies massive fossiliferous dark gray limestone. All the limestones are moderately cavernous in the southern part of the area. The formation thickens northward and some beds are sandy and less cavernous in the north part of the area. This condition is apparent in outcrops of limestone in the hills south of Indian Springs and along the west flank of the Sheep Range. Fossils found in the Monte Cristo limestone indicate that it is of early and middle Mississippian age.[34]

Water-Bearing Properties. Although the "Middle Paleozoic" rocks are well-consolidated, they are moderately cavernous, particularly in the south and central parts of the Spring Mountains, and they are capable of transmitting large quantities of water. In many places in the mountains, springs issue where the rocks are cut by faults and joints, and at the lower contact of these rocks where they are exposed above the relatively impermeable "Early" and "Late Paleozoic" beds. Much of the area of outcrop of "Middle Paleozoic" rocks is far above the regional groundwater level. However, these rocks serve to store and transmit water to the alluvial fan with which they are in contact in many places. In the valleys they probably occur at great depths, where their geologic and hydrologic character is unknown. Development of water at such depths is believed to be not economically feasible.

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[32]Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, pp. 13–21, 1931.

[33]Hewett, D. F., op. cit., pp. 15–16.

[34]Hewett, D. F., op. cit., pp. 18–19.

"LATE PALEOZOIC" ROCKS

The "Late Paleozoic" rocks consist of the Bird Spring, Supai, and Kaibab formations. The Bird Spring formation was named and described by Hewett.[35] It was further described and its age was discussed by Longwell and Dunbar.[36] The Supai formation and Kaibab limestone were named and described near Grand Canyon in northern Arizona. Both formations are widely distributed in the southwest part of the United States.

The Bird Spring formation is a thick series of limestone, dolomite, shale, and silty sandstone which crops out in large areas of the Spring Mountains, the Las Vegas Range, and the Bird Spring Range. The formation is about 2,500 feet thick in the Bird Spring Range and on Frenchman Mountain. It thickens and changes in character considerably to the north. On the north side of La Madre Mountain, in the central part of the area, it is more than 5,200 feet thick and possibly becomes even thicker farther north.

The Bird Spring formation is divided into five members, one of which was named the Indian Springs member by Longwell and Dunbar. The basal member apparently is conformable with the Monte Cristo limestone north of La Madre Mountain. Hewett[37] suggests that it is unconformable with the Monte Cristo limestone in the vicinity of Goodsprings. The member is made up of tan and yellow shaly and sandy beds interbedded with light- to dark-gray fine- to medium-crystalline limestone. It is 400 to 600 feet thick in the south part of the area. Northward it apparently thickens and changes considerably in character. Near Indian Springs it is 700 feet thick. This member yielded many fossils which indicate an upper Mississippian or Chester age.

The Indian Springs member of Longwell and Dunbar is overlain by about 800 feet of alternating layers of resistant medium- to thick-bedded gray limestone and thin shaly, slightly sandy yellowish limestone. These beds are overlain by about 800 feet of thick-bedded limestone and dolomite, which form prominent cliffs. Fossils collected by Longwell and Dunbar[38] indicate that these beds are of Pennsylvanian age.

The cliff-forming member is succeeded by distinctive nonresistant slope-forming beds of platy limestone and gray, yellow, and orange calcareous shale. They range in thickness from 1,200 to 1,500 feet, and form the top of Charleston Peak.

[35] Hewett, D. F., op. cit., pp. 21–30.

[36] Longwell, C. R., and Dunbar, C. O., Problems of Pennsylvanian-Permian boundary in southern Nevada: Am. Assoc. Petroleum Geologists Bull., vol. 20, No. 9, 1936.

[37] Op. cit., p. 22.

[38] Op. cit., p. 1207.

The uppermost member of the Bird Spring formation is a series of ledge-forming thick-bedded limestone and dolomite layers, with a few interbedded units of shaly and platy limestone which weather to slopes. This member is about 1,500 feet thick. The upper two members of the Bird Spring formation yield fossils which indicate a probable lower Permian age.[39]

The Supai formation consists of a basal member of gray calcareous shale interbedded with thin-bedded limestone, about 100 feet thick. Overlying the basal member is approximately 1,000 feet of typical red beds composed of sandstone, shale, and a few gypsum layers. Generally the red sandstones and shales give way to buff-colored sandstones near the top of the formation. Outcrops are widely distributed over the south part of the Spring Mountains. The formation is 1,000 to 1,100 feet thick. It also crops out in the hills south of Frenchman Mountain, where it reaches about the same thickness. In the area covered by this report the evidence for identification of the Supai formation is its lithologic character and stratigraphic position. However, the formation so identified must be of Permian age because it is overlain and underlain by rocks which were deposited during the Permian period.

The Kaibab limestone crops out usually in the same places as the conformably underlying Supai formation. It ranges in thickness from a feather edge to about 700 feet. This range in thickness is largely the result of widespread erosion during a period of emergence following the deposition of the formation. Where the formation is thickest it characteristically consists of a basal member, containing about 225 feet of gray massive fossiliferous limestone, with a few thin cherty layers of dolomite. These beds are succeeded by a middle member consisting of 30 to 80 feet of pale yellowish-brown and red medium-grained sandstone with a few interbedded zones of sandy shale. The sandstone interval is overlain by an upper member of gray massive cherty limestone with some interbedded fossiliferous layers of limestone and a few thin light-gray dolomite units. The upper member is about 300 feet thick. The lowest beds in the formation are apparently conformable with the upper part of the Supai formation. Fossils collected from the Kaibab limestone are of Permian age.[40]

Water-Bearing Properties. The foregoing description shows that the "Late Paleozoic" rocks consist of well-consolidated limestone, dolomite, sandstone, and shale. None of the rocks are cavernous, and therefore they are essentially impermeable and

[39] Longwell, C. R., and Dunbar, C. O., op. cit., p. 1207.
[40] Hewett, D. F., op. cit., pp. 31, 32.

do not transmit appreciable quantities of ground water, except where they are broken by structural movements and are much faulted, jointed, and brecciated. Like the "Early Paleozoic" rocks, the chief hydrologic function of these rocks is to act as a barrier to ground-water movement, and not as an aquifer or reservoir to transmit and store ground water.

MESOZOIC ROCKS

Rocks of Mesozoic age crop out south of the Spring Mountains and near Frenchman Mountain. They consist of four formations, three of which are widely distributed throughout the southwestern part of the United States and have been studied and described in many localities. These are the Moenkopi, Shinarump, and Chinle formations. The other formation, the Aztec sandstone, was named and described by Hewett[41] in his report on the Goodsprings quadrangle and is tentatively correlated with the Navajo sandstone of Jurassic age which occurs in Utah and Arizona. Rocks of Cretaceous age are not exposed in the area covered by this report, but they crop out in the Muddy Mountains about 50 miles east of the city of Las Vegas. Here early Upper Cretaceous ferns were found in beds referred to the basal part of the Overton fanglomerate of Tertiary age.[42]

In the south part of the Spring Mountains and near Frenchman Mountain the Moenkopi formation is 1,000 to 1,500 feet thick. A lower unit, about 150 feet thick, of red shale, generally gypsiferous, with a conglomerate of varying thickness and character, forms the basal member of the formation. Locally the conglomerate is absent. In some places it consists of well-rounded pebbles and gray cross-bedded sandstone, and in other places the pebbles are angular and tightly cemented in a calcium carbonate matrix. The middle unit of the formation consists of buff-colored sandy platy fossiliferous limestone and dolomite beds, which are separated by thin layers of greenish-gray shale. This member is 600 to 700 feet thick. It is succeeded by the upper member of the formation, which consists of interbedded layers of red shale, sandstone, red sandy shale, and a few gypsiferous beds. The Moenkopi formation is everywhere classed as Lower Triassic. It commonly rests disconformably upon the Kaibab limestone or older formations, and is probably disconformable with the overlying Shinarump conglomerate.

The Shinarump conglomerate consists of 50 to 80 feet of thin-

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[41] Op. cit., p. 35.

[42] Hewett, D. F., and others. Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, pp. 121–122. 1936.

bedded to massive light-gray and tan medium-grained sandstone that contains thin beds of granule and pebble conglomerate and some petrified wood. The pebbles in the conglomerate are well-rounded, and are composed largely of red, white, and purple quartzite. The beds weather to low rough dark-brown outcrops. South of Frenchman Mountain, the Shinarump conglomerate contains large pebble and boulder conglomerate, all the pebbles and boulders being well-rounded but much larger than is characteristic of the formation elsewhere in Nevada, and also in Utah. The age of the formation is classified at present by the Geological Survey as Upper(?) Triassic.[43]

The Chinle formation consists of cross-bedded, red, silty and shaly sandstones with a few interbedded layers of white and red sandy limestone and sandstone. It apparently is conformable with the underlying Shinarump conglomerate and the overlying Aztec sandstone. The Chinle is nearly 700 feet thick in the area covered by this report,[44] and is classified by the Geological Survey as being of Upper Triassic Age.

The Aztec sandstone consists of over 2,400 feet of massive, buff, tan, white, and red, medium- to fine-grained, cross-bedded, mottled sandstone. Wherever it crops out it forms imposing colorful cliffs and bluffs. The top of the formation is not exposed in the area. It is suggested by Hewett[45] that the formation is probably of Jurassic age.

Water-Bearing Properties. The Chinle and Moenkopi formations are impervious but they localize many small springs along contacts with other formations when the attitude of the beds and topography is favorable. Also these two formations act as barriers to movement of ground water out of Las Vegas Valley in the vicinity of Las Vegas Wash. The Aztec sandstone and Shinarump conglomerate are the only two Mesozoic formations capable of transmitting even small quantities of ground water. In most places they are well-consolidated and impermeable and transmit water only where they are faulted and jointed.

CENOZOIC ROCKS

The rocks of Cenozoic age fall into two classes, (1) older well-consolidated and tilted formations and much igneous flow rock, all definitely deformed by earth movements subsequent to their deposition, and (2) younger, poorly consolidated, relatively undeformed beds of gravel, sand, silt, and clay, and a few basalt flows.

There are only five known outcrops of the older rocks and these

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[43] Hewett, D. F., op. cit., p. 34.
[44] Hewett, D. F., op. cit., p. 34.
[45] Op. cit., p. 35.

occur in limited and widely separated localities in the area. However, the older formations crop out in adjacent regions and many may be present in the valley fill. For the most part they have been buried by the younger alluvial sediments which form the major part of the surficial valley fill and alluvial apron. The older sedimentary formations are divided on plate 1 into two groups, designated, respectively, TKJTR and Tme. The igneous rocks are mapped together with the younger basalt flows and are designated QTv on plate 1.

The younger sediments of Cenozoic age are mapped as older alluvial deposits of Pliocene(?) and Pleistocene(?) age, lake and playa deposits of Pleistocene age, and younger alluvial deposits of Recent age. Wash deposits of Recent alluvium in the mountains and on the alluvial apron are not differentiated from the Pliocene(?) and Pleistocene(?) alluvial deposits because they are small, very thin, and only locally important as a source of ground water. The only deposits of Recent age differentiated on plate 1 are the valley fill and playa deposits in Indian Spring, Three Lake, and Las Vegas Valleys, designated Qyal on the map.

CRETACEOUS TO MIDDLE (?) TERTIARY ROCKS—UNEXPOSED FORMATIONS

Overton Fanglomerate and Horse Spring Formation. Longwell[46] has reported a thick section of Tertiary sediments that occurs in the Muddy Mountains several miles east of Las Vegas Valley. This section of Tertiary sediments has been further described by Hunt[47] in his report on geology in the vicinity of the Las Vegas Wash.

In summary, the section described by Longwell includes three formations: the Overton fanglomerate (which is now considered to be Cretaceous in part); the Horse Spring formation, which consists of limestone, magnesite, clay, and sand; and the Muddy Creek formation, which is largely composed of intermontane clay, silt, sand, and conglomerate deposits with some interbedded salt and gypsum. The Overton fanglomerate ranges from 20 to 3,500 feet in thickness, the Horse Spring formation ranges from 1,000 to 2,700 feet in thickness, and the Muddy Creek formation ranges from a feather edge to about 2,000 feet, making an aggregate maximum thickness of about 8,000 feet of these sediments in the Muddy Mountains. The Overton fanglomerate rests unconformably upon beds of early Upper Cretaceous age (see p. 50) and on

[46] Longwell, C. R., Geology of the Muddy Mountains, Nevada: U. S. Geol. Survey Bull. 798, pp. 68–96. 1928.

[47] Hunt, C. B., Reconnaissance geology of part of the Colorado River basin below Grand Canyon: U. S. Geol. Survey (manuscript report on file).

all other older sediments. It is apparently conformable with the beds of the Horse Spring formation. Its relation to the rocks of Ransome's Black Canyon group is unknown. Both the Overton fanglomerate and the Horse Spring formation occupy roughly the same outcrop area and were involved in similar structural movements: folding, thrust faulting, and block faulting. They are overlain by or interbedded with the middle-Tertiary(?) volcanics (lavas of the River Mountains). The Horse Spring formation may be the same age as the Artillery formation that crops out in the vicinity of Needles, Arizona, and which contains plant fossils assigned to the lower Eocene.[48]

According to Hunt, beds of considerable thickness of both the Horse Spring and the Muddy Creek formations are present in the vicinity of Las Vegas Wash and the Schumaker Gypsum Company claims, immediately east of Las Vegas Valley, but the Overton fanglomerate is not exposed.

In Las Vegas Valley the only part of these thick, widespread Tertiary deposits exposed at the surface is about 80 feet of the Muddy Creek formation (see page 55). However, it is possible that the lower part of the valley fill is made up of beds referable to the Horse Spring formation and Overton fanglomerate. At present sufficient evidence is not available to establish the presence of these formations in the basal part of the valley fill.

Black Canyon Group of Ransome. According to Longwell,[49] Ransome described a complex assemblage of andesitic lava flows, volcanic breccias, and related deposits, and called them the Black Canyon group in his report giving the results of geologic studies around the Black Canyon dam site. Although the stratigraphic relationship of these rocks with the Horse Spring formation is unknown, they are unconformably overlain and intruded by lavas of the River Mountains and have been involved in folding, thrust faulting, and block faulting.[50] Rocks of Ransome's Black Canyon group crop out near Las Vegas Valley but are not present in Pahrump and Indian Spring Valleys. Consideration of them and their stratigraphic relationships is important in the interpretation of the geologic history of Las Vegas Valley.

EXPOSED FORMATIONS

Lavas of the River Mountains. The northern extremities of the River Mountains and the McCullough Range that border Las

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[48] op. cit.

[49] Longwell, C. R., Geology of the Boulder Reservoir floor, Arizona-Nevada: Geol. Soc. America Bull., vol. 47, p. 1417, 1936.

[50] Hunt, C. B., op. cit.

Vegas Valley on the southeast, east of U. S. Highway 91 and south of Las Vegas Wash, are composed of igneous flow rocks of Tertiary and Quaternary age. These volcanic rocks have been described by Hale; Jones; Hewett and Webber; Hunt, McKelvye, and Wiese; Longwell; and Hunt.[51] The following paragraph is a brief summary of the former descriptions of the Tertiary igneous formations, modified slightly by observations of the senior author, who made a study of the rocks in the vicinity of Las Vegas Wash and Railroad Pass.

The lavas of the River Mountains are porphyritic, latitic lava flows and flow breccias, with a more or less glassy groundmass, and containing some felsitic lava, white vitrophyre, and dense stony glasses. The River Mountains are composed, in large part, of these rocks. In some places the rocks have been altered, especially near the prominent faults. In the River Mountains about 1,000 feet of the lavas is exposed. However, they may be much thicker. The sequence of flows and flow breccias probably thins southward and westward. No outcrops of it have been observed south of Lake Mead or very far west of the River Mountains; however, in the latter places it may be concealed by younger rocks. Northeast of Las Vegas Wash the lavas are overlain unconformably by the Muddy Creek formation. North of Las Vegas Wash, dikes and irregular masses associated with the lava flows are intruded into the sandstone and shaly siltstone of the Chinle formation. Although the upper part of the lavas is known to be younger than the Horse Spring formation, the relationship of the two formations is not completely known. According to Hunt,[52] lavas of the River Mountains are strikingly similar to and probably correlative with the Needles volcanics and the eruptives in the Artillery Mountain region,[53] which are exposed about 150 miles south and east of Las Vegas Valley.

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[51]Hale, F. A., Jr., Manganese deposits of Clark County, Nevada: Eng. and Min. Jour., vol. 105, pp. 775–777, 1918; Jones, E. L., Jr., Deposits of manganese ore in Nevada: U. S. Geol. Survey Bull. 710, p. 222, 1920; Hewett, D. F., and Webber, B. N., Bedded deposits of manganese oxides near Las Vegas, Nevada: Univ. of Nevada Bull., vol. 25, No. 6, pp. 5–17, 1931; Hunt, C. B., McKelvey, V. E., and Wiese, J. H., The Three Kids manganese district, Clark County, Nevada: U. S. Geol. Survey Bull. 936-L pp. 300–302, 1942; Longwell, C. R., Geology of the Boulder Reservoir floor, Arizona-Nevada: Geol. Soc. America Bull., vol. 47, pp. 1417–1419; Hunt, C. B., Reconnaissance geology of part of the Colorado River basin below Grand Canyon: U. S. Geol. Survey (manuscript report on file).

[52]Hunt, C. B., op. cit.

[53]Lasky, S. G., and Webber, B. N., Artillery Mountains Manganese District, Mohave County, Arizona: Arizona Bur. Mines Bull. 145, pp. 133–139, 1938; Geology and manganese deposits in the Artillery Mountains: U. S. Geol. Survey Bull. (in preparation).

On plate 1, all the igneous rocks, that is, the Black Canyon group of Ransome, the lavas of the River Mountains, and the late Tertiary(?) and Quaternary(?) basalt series (see p. 58), are mapped as one unit because their water-bearing properties are similar. Moreover, they act as a barrier to movement of ground water from the valley fill south and east out of Las Vegas Valley.

Esmeralda(?) and Muddy Creek Formations. Outcrops of silty, sandy, tuffaceous light-colored beds occur on the north side of the Las Vegas Range in a locality just north of Gass Peak and 7 to 10 miles east of Corn Creek Ranch. Similar beds crop out in places in the Sheep and Spotted Ranges. These beds are relatively well consolidated, gently folded or tilted, and have been cut by normal faults. The beds lie unconformably on rocks of Paleozoic age. The structural and stratigraphic relationships of these beds are similar to those of the Muddy Creek formation, and although they may be older than the Muddy Creek they are probably younger than the Horse Spring formation. It is probable that these beds are synchronous with rocks belonging to the Esmeralda formation,[54] whose lithology and structural relationships are similar and which crop out in Nye County, Nevada, near Ash Meadows—localities not far from Indian Spring and Pahrump Valleys. Lack of diagnostic fossils in beds of probable early and middle Tertiary age in this area preclude more accurate correlation at the present time.

Beds assigned to the Muddy Creek formation crop out 1 to 2 miles west of Whitney, Nevada. At that location they consist of nearly 80 feet of medium- to thick-bedded siltstone in layers 1 to 5 feet thick, interbedded with thin, sandy and pebbly layers of siltstone. Most of the beds are well-consolidated and some are tightly cemented with caliche. The beds are essentially horizontal although they are locally distorted into low, gentle, undulating folds, and they are cut near the south border of the outcrop by small normal faults. The upper surface of the beds is partially covered by a thin (1 to 10 feet) veneer of later alluvial sediments. The alluvium is eroded in many places by small washes and the silty beds are undoubtedly present everywhere in the outcrop area mapped on plate 1. At nearby localities the Muddy Creek formation is overlain unconformably by the late Tertiary(?) and Quaternary basalt series. The base of the Muddy Creek beds in adjacent regions rests unconformably upon the older Tertiary formations and upon formations of Mesozoic and

[54]Turner, H. W., U. S. Geol. Survey 21st Ann. Report, pt. 2, pp. 197–208, 1900; Ball, S. H., A geological reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, pp. 32–34, 1907.

Paleozoic age. Like the underlying lavas of the River Mountains, the beds of the Muddy Creek formation are not broken by thrust faults but are block faulted. The lithologic, stratigraphic, and structural relationships of these beds are similar to those of the Muddy Creek formation in other places as described by Longwell and Hunt.[55] Further, large areas of outcrop of the Muddy Creek formation exist in the vicinity of Las Vegas Wash, only a few miles east of Whitney. Therefore, the siltstone beds near Whitney are tentatively correlated with the Muddy Creek formation.

Fossils found in the Muddy Creek formation by Stock[56] and the structural and stratigraphic relationships of the beds indicate that they are possibly of Miocene or early Pliocene age.

The several widely distributed outcrops of rocks of approximate Miocene age indicate that these beds probably extended over a much larger region in the past than they do at the present time, and that they have been nearly all removed by erosion or covered by later alluvial deposits. Undoubtedly a large part of the valley fill consists of Muddy Creek and related deposits, particularly in Las Vegas Valley. The beds were probably deposited in great basins whose topography and geographic position rougly coincided with that of present-day basins. Much of the material in these formations resembles playa-lake deposits. However, as Longwell[57] has pointed out in his description of the Muddy Creek formation in the vicinity of the Muddy Mountains, "a playa of the extent represented by these intermontane deposits demands long bajada slopes adjacent, and the coarse sediments to be expected on such slopes are exposed very sparingly. In fact, except near the base of the series, the silt and fine sand extend without interruption to the slopes of high (mountain) masses * * * These relations * * * suggest deposition in a lake somewhat deeper than the ordinary playa." Longwell goes on to explain that the level of these lakes must have oscillated considerably but that for no extended time could there have been playa-lake and alluvial-fan deposition similar to that which existed later and which seems to exist at the present time. This description fits closely the conditions which must have been necessary to produce such widespread, uniformly deposited materials, and agrees with Hunt's statement[58] that the Muddy Creek formation in the vicinity of Las Vegas Wash seems to have been deposited under "very quiet, lacustrine conditions."

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[55] Longwell, C. R., op. cit., pp. 90–96; Hunt, C. B., op. cit.

[56] Stock, Chester, Later Cenozoic mammalian remains from the Meadow Valley Region, southeastern Nevada: Geol. Soc. America Bull., vol. 32, p. 146, 1921.

[57] Op. cit., (Geology of the Muddy Mountains, Nevada), pp. 95–96.

[58] Hunt, C. B., personal communication.

Water-Bearing Properties. The Overton fanglomerate and the Horse Spring formation consist of well-consolidated and tightly cemented gravels, sand, silt, clay, and limestone. If they are present in the valley they are probably impermeable and will not transmit large quantities of ground water.

Exposed rocks assigned to the Muddy Creek and Esmeralda(?) formations consist largely of fine-grained materials which are relatively impermeable and probably will not transmit much water. However, it is possible that in some places the fine-grained sediments are interbedded with sand and gravel tongues and lenses capable of transmitting appreciable quantities of water. Therefore, at least part of the early(?) and middle(?) Tertiary deposits may act as aquifers. A more detailed discussion of possible aquifers in the Muddy Creek formation is presented on page 68. The water-bearing properties of the Tertiary volcanic rocks have been discussed on page 55.

PLIOCENE (?) AND PLEISTOCENE (?) ALLUVIAL DEPOSITS

Exposed deposits of gravel, sand, silt, and clay, which form the alluvial apron and much of the valley fill, are much larger in extent than any other geological formation in Las Vegas, Pahrump, and Indian Spring Valleys. The contact of these deposits with the older, consolidated and highly deformed rocks composing the mountainous sections of the area is at an average altitude of about 4,500 feet. The minimum altitude of the alluvial deposits is about 1,500 feet in the vicinity of Las Vegas Wash. The maximum altitude in the vicinity of Charleston Peak and the heads of Kyle, Clark, and Lee Canyons is about 9,000 feet. Thus the bulk of these deposits is confined to the valleys and canyons and, by analogy, they form a "sea" in which numerous high "islands" of the older rocks occur.

The deposits range in thickness from a feather edge to several hundred feet, or even more. Near the mountains and the top of the alluvial apron where several exposures have been examined, they consist largely of massive beds of coarse, well-rounded to angular, poorly assorted gravel with some silt and sand, all of local derivation, which dip away from the mountains at angles of 12° to 18°. In many places the beds are well-cemented with caliche near the surfaces of the exposures, but in fresh exposures along road cuts and washes the beds were observed to be poorly cemented and essentially unconsolidated. Several of the well-cemented beds extend laterally for several miles. Lower down on the alluvial apron the beds become more silty and sandy and dip at lower angles. In this lower part of the alluvial apron the coarser materials finger out and are interbedded with thick deposits of silt and clay. The age of these alluvial materials is indicated only by their lithologic characteristics, stratigraphic position, and structural relationships, because no diagnostic fossils have been found in them. The deposits lie unconformably upon beds of the Muddy Creek formation and are unconformably overlain by lacustrine deposits of known Pleistocene age. The beds have not been involved in thrust-faulting or widespread folding, and were observed to be cut by normal faults in only one locality. Detailed descriptions of the physical characteristics and water-bearing properties of these beds are to be found in the section dealing with well logs of the valley fill. It is important to emphasize that the Pliocene(?) and Pleistocene(?) alluvial deposits contain the most productive aquifers and form the ground-water reservoir for nearly all the water used in Las Vegas, Pahrump, and Indian Spring Valleys.

LATE TERTIARY (?) AND QUATERNARY BASALT SERIES

This group of rocks is composed of andesitic and basalt lava flows and associated deposits, which overlie and are younger than the Muddy Creek formation and either overlie or are interbedded with the Pliocene(?) and Pleistocene(?) alluvial deposits in the vicinity of Las Vegas Wash. Most of the basalts are probably of late Pliocene age although some are probably younger. On plate 1 these rocks are mapped in the same unit (QTv) with the lavas of the River Mountains and the Black Canyon group of Ransome because their water-bearing properties are similar and because the rocks crop out only in a few places.

PLEISTOCENE LAKE BEDS

The deposits described in this report as Pleistocene lake beds crop out in the northern and central parts and in one place in the southern part of Las Vegas Valley, in the central part of Pahrump Valley, and in the central and eastern parts of Indian Spring Valley (see pl. 1). They range from a feather edge to probably not more than 50 feet in thickness and are approximately horizontal. In all the exposures examined the materials consist of light-colored somewhat calcareous, fossiliferous massive silt and clay beds, which lie unconformably upon the Pliocene(?) and Pleistocene(?) alluvial deposits. In general they are capped by a thin veneer of alluvium which, for the most part, has been removed in washes and other channels. This veneer is only 1 to 5 feet thick. The materials are weak, and thus great quantities of them have been removed by erosion.

Remnants of the deposits indicate that there were at least five different basins in the three valleys which were occupied by lakes during the Pleistocene epoch. The highest basin was in Indian Spring Valley, where the lake level reached an altitude of nearly 3,500 feet above sea level. In another basin, in Pahrump Valley, the maximum altitude of the water was between 2,800 and 2,900 feet. In Las Vegas Valley, at the mouth of Three Lakes Valley, the lake level stood at about 3,100 feet, and farther south, in the vicinity of Corn Creek Ranch, the level was about 3,000 feet. Southward, in the vicinity of Tule Springs, Las Vegas, and Warm Springs Ranch, remnants of the lake deposits indicate that the level of the water was about 2,600 feet above sea level. Although an intensive search was made for shore lines and other lake-cut or lake-built features, none were observed. This would indicate that the lakes probably were ephemeral, existing for only a short period of time. It is possible that the lakes were of the playa type and were at no time very deep. Invertebrate fossils collected from the lake deposits yield some evidence as to the nature and age of the lakes. The following statement by Frank C. Baker, Curator of the Museum of Natural History at the University of Illinois, to Professor C. R. Longwell, is quoted:

> The fresh water fauna would indicate a small lake into which the two species of land shells were washed. Such conditions prevail in this region at the present time, only the lakes are now mere pools which dry up more or less in the dry season. I think the deposit may be safely referred to the Pleistocene * * *. Some of the species listed * * * live in swampy places or ephemeral pools * * *. Others are known to live in larger lakes more or less permanent * * *. I may say that the two groups of species indicated * * * live in the same place, the mud-loving species along the shore or in sheltered places and the others in the more open part of the lake.

The following fossils collected by Professor Longwell from deposits near Corn Creek Ranch were identified by Mr. Baker:

FOSSIL	HABITAT
Valvatata humeralis californica Pils. Young.	Fresh water.
Physa virginia Gould. Young.	
Gyraulus similaris F. C. Baker	Fresh water.
Gyraulus vermicularis hendersoni (Walker)	Swampy places and ephemeral pools.
Stagnicola bulimoides techella (Hald.) Immature.	Swampy places and ephemeral pools.
Pisidium. Several species	Fresh water.
Fossaria species undet., possibly new	Swampy places and ephemeral pools.
Pupilla muscorum (Linn.) Spire of a shell	Land.
Succinea oregonesis gabbi Tryon? Immature.	

In addition to the above fossils, the remains of several vertebrates,[59] among them mammoths, camels, and horses, have been found and indicate the Pleistocene age of the lakes.

The lake beds consist of fine-grained relatively impermeable materials and are superficial deposits. As such they are unimportant either as aquifers or confining beds or as barriers to ground-water movement.

RECENT ALLUVIUM

The materials here described as Recent alluvium consist largely of surficial deposits of gravel, sand, silt, and clay and are present over large parts of three localities. They appear as playa-lake deposits in Indian Spring and Three Lake Valleys. The materials in the central part of the valley east and southeast of the city of Las Vegas are reworked silt and clay from the Muddy Creek formation, the Pliocene(?) and Pleistocene(?) alluvial deposits, and the Pleistocene lake beds. They vary from a feather edge to several feet in thickness. They are described in greater detail on pages 66–72. Other deposits of Recent alluvium occur as wash deposits, which range in thickness from a feather edge to about 50 feet, and form a thin veneer on the Pleistocene lake beds and the Pliocene(?) and Pleistocene(?) alluvial deposits. These deposits are not mapped in this report. Also, eolian deposits of Recent age occur in the larger valleys.

[59] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 157, 1903; Longwell, C. R., personal communication.

The water-bearing properties of the Recent alluvium are described in the general stratigraphic table.

GEOLOGIC STRUCTURE

The geologic structure within the area covered by this report is exceedingly complex, and the scope of this investigation limited study of the structure to its effect on ground-water conditions. Therefore, the following paragraphs describe only the general features of the structure and their relation to ground-water movements. Features of geologic structure are not mapped on plate 1 except as shown by the shape of the outcrops.

In the Spotted, Pintwater, Desert, and Sheep Ranges the "Early" and "Middle Paleozoic" rocks are folded in a huge anticline, the axis of which runs east along the south side of the Spotted Range to the south end of the Pintwater Range, where it turns abruptly and runs north along the east side of the latter range for several miles (see pl. 1). The anticline pitches to the north. The east limb is truncated by a huge thrust fault, the trace of which crops out along the west and north sides of the Las Vegas Range. The west limb is similarly broken by a thrust in the Spotted Range, which does not appear on plate 1. The anticline is broken also by at least two other thrusts of lesser magnitude and by numerous normal faults, some of which dip at very low angles. The low-angle normal faults in the Desert Range have been described in detail and their origin discussed by Longwell.[60] The thrust faults generally strike north-south but tend to swing west near the south ends of the ranges. The thrust planes of most of these faults dip west. Most of the major normal faults strike north, and several of them are probably responsible for the elevation of the ranges above the valleys in the north part of the area.

The most dominant structures in the Spring Mountains are a series of enormous thrust faults, some of which have been named and described by former workers. The most northern, or Johnnie, thrust was named and described by Nolan.[61] It occurs in the mountains a few miles east of Johnnie, Nevada, where great thicknesses of the Stirling quartzite and younger formations have been thrust over quartzite of the Johnnie formation. The trace of another thrust, the Wheeler Pass fault, crops out about 10

[60] Longwell, C. R., Low-angle normal faults in the Basin and Range province: Am. Geophys. Union Trans., vol. 26, pt. 1, pp. 107–118, 1945.

[61] Nolan, T. B., Notes on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 461–472, 1929.

miles southeast of the Johnnie thrust in a small wash east of Horse Springs. The trace extends east of the Spring Mountains where it is buried by gravels and alluvium in the vicinity of Willow Spring. The upper plate of this thrust consists of "Early" and "Middle Paleozoic" strata which have been thrust over rocks of "Late Paleozoic" age. The stratigraphic displacement of the Wheeler Pass thrust ranges from 13,000 to 15,000 feet, according to Nolan. Detailed descriptions and discussions of these two thrusts are given by Nolan and Longwell.[62]

The trace of the Lee Canyon thrust fault[63] crops out in the vicinity of Lee Canyon where it strikes northeast. Northeast from Lee Canyon the thrust trace retains this strike; southwest from the head of Lee Canyon the trace swings abruptly south, continuing in this direction to a point about 1 mile south of the Red Rock road where it is covered by the alluvial apron. The upper plate of the fault consists of "Early Paleozoic" rocks which have been thrust over "Middle" and "Late Paleozoic" strata. About 2 miles south of the Lee Canyon thrust trace, another thrust crops out on the east side of the mountains. Southward, two smaller thrusts occur in the vicinity of The Mummy and Kyle Canyon. On the south slopes of La Madre Mountain, rocks of "Early Paleozoic" age have been thrust over the Aztec sandstone and other Mesozoic strata. This thrust fault, the trace of which trends east-west near La Madre Mountain and swings sharply south where the latter joins the main Spring Mountain Range, was named the Keystone thrust by Hewett.[64] Its general character and structural relationships in the Goodsprings quadrangle were discussed by him and it has been described by Glock and Longwell[65] farther north in the vicinity of La Madre Mountain. The average dip of the Keystone thrust is 8° west, and the fault has a stratigraphic displacement exceeding 12,000 feet. Several other thrust faults occur farther south in the Goodsprings quadrangle and have been described in detail by Hewett.[66] Also, numerous small thrust faults occur in other parts of the area.

In addition to thrust faulting, block faulting has occurred in

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[62] Op. cit., 465–471: Longwell, C. R., The mechanics of orogeny: Am. Jour. Sci., vol. 243-A, Daly Volume, pp. 420–423, 1945.

[63] Longwell, C. R., Structural studies in southern Nevada and western Arizona: Geol. Soc. America Bull., vol. 37, p. 566, 1926.

[64] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, p. 48, 1931.

[65] Glock, W. S., Geology of the east-central part of the Spring Mountain Range, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 335–337, 1927; Longwell, C. R., op. cit., pp. 564–566.

[66] Hewett, D. F., op. cit., pp. 48–51.

the Spring Mountains and also on Frenchman Mountain. In general, the block faults strike northwest, although several trend north and a few trend east. In most places where the thrust faults are intersected by block faults, the traces of the thrusts are offset. However, in a few places normal-fault traces do not seem to extend across the thrust planes, crop out on only one side of the thrust, and therefore are offset by the thrust fault. Block faulting is probably responsible for much of the present elevation of the Spring Mountains; however, thrusting and folding must also have contributed much to this end.

Numerous minor faults occur, particularly in the vicinity of the outcrops of the thrust faults, and probably major folds also exist which further detailed study may disclose. The older, well-consolidated rocks are cut by two main systems of joints. However, the attitude and the degree of development of joints in the rocks depends largely upon local structural conditions and the character of the rocks. Where the rocks are much disturbed by faulting and folding, the joint systems are well-developed. Where the rocks are relatively undisturbed, joints may be poorly developed and relatively scarce.

Tear faults occur with much horizontal displacement. Hewett[67] has mapped several faults having considerable horizontal displacement in the Goodsprings quadrangle and has described the faults briefly in his report. Also, Longwell mapped a large tear fault which passes into a thrust fault in the Spotted Range.

The sequence and age of structural events in parts of the area and in adjacent regions have been described by several geologists.[68] The following discussion is a brief summary of their findings. Block faulting may have occurred previous to or at the same time as extensive folding and thrusting, the first clearly recognized structural event in the area. The folding and thrusting involved strata of Mesozoic age in this area. In adjacent regions early Tertiary sediments were also involved in the thrust faults and in folds; thus the period of compression took place during the Laramide orogeny. Also, Longwell suggests that many of the normal faults in the region probably developed not later than early Cenozoic time. Following the development of folds and thrust faults, and previous to the deposition of the

[67]Hewett, D. F., op. cit., p. 52, pls. 1 and 2.

[68]Nolan, T. B., op. cit., pp. 460–465; Hewett, D. F., op. cit., pp. 53, 54; Glock, W. S., op. cit., pp. 335–337; Longwell, C. R., op. cit., pp. 551–584; also, The geology of the Muddy Mountains, Nevada: U. S. Geol. Survey Bull. 798; Low-angle faults in the Basin and range province: Am. Geophys. Union Trans., vol. 26, part 1, pp. 107–118, 1945; and Hunt, C. B., op. cit.

Muddy Creek formation, a period of extensive block faulting took place. Since middle (?) Tertiary time block faulting has continued on a relatively minor scale. Evidence that major faults and other large-scale structural activities displaced the Pliocene (?) and Pleistocene (?) alluvial deposits was not observed anywhere in the area. However, about 3 miles west of Whitney, Nevada, and in the vicinity of the city of Las Vegas in the south part of Las Vegas Valley, small normal faults of possible Recent or late Pleistocene age were observed in the Pliocene(?) and Pleistocene(?) alluvial deposits and in the Muddy Creek formation (see pp. 69–71). These faults are probably confined to the late alluvial and relatively unconsolidated sediments and probably do not cut the older bedrock as do faults of Recent age in adjacent regions.[69]

EFFECT OF GEOLOGIC STRUCTURE ON THE MOVEMENT OF GROUND WATER

Most fault zones in the area are cemented and therefore ground water is not ordinarily transmitted along them. Rather, water tends to be stopped by faults, and where the attitude and permeability of the rock strata are favorable, the water is brought to the surface as springs. Joints in the rocks undoubtedly transmit water, but not necessarily large quantities, unless the rock is susceptible to solution and large cavities and solution channels are present. The Goodsprings dolomite and most of the Bird Spring formation are good examples of much-jointed yet impervious rock. In many localities in the area, springs are localized at the upper contact of the Goodsprings dolomite even where it is much deformed and jointed. The Sultan and Monte Cristo limestones are relatively soluble and contain numerous solution openings, which generally are along joint planes. These two formations transmit considerable quantities of water where fault and joint systems are well-developed and enlarged by solution.

In summary, faults generally act as ground-water dams; joints generally do not transmit large quantities of water except where they occur in relatively soluble formations. The faults in the valley fill are of paramount importance to ground-water movement in Las Vegas Valley (see pp. 69–71).

SUMMARY OF GEOLOGIC HISTORY

The history of the area covered by this report seems to include the following stages:

(1) During most of Paleozoic time the area was a part of the

[69] Longwell, C. R., Faulted fans west of the Sheep Range, southern Nevada: Am. Jour. Sci., vol. 20, 5th ser., pp. 1–13.

Cordilleran geosyncline, and huge thicknesses of limestone, dolomite, shale, and sandstone were deposited. Clastic sediments characterized the earlier part of the Cambrian period and were succeeded by organic and chemical sediments which were deposited in the seas of medial Cambrian time and the succeeding periods. Clastic materials were not again the dominant type of deposit until Permian time, when a vast thickness of continental sandstone was deposited in the Supai formation. Unconformities in the Paleozoic rocks in the southern part of the area indicate periods of emergence and erosion during part of the Lower Cambrian epoch, part of the Middle Devonian epoch, and possibly during part of middle Mississippian time. Lack of deposits of Ordovician and Silurian sediments indicates possible emergence during those periods also, in some parts of the area.

(2) A period of emergence and extensive erosion occurred near the end of the Paleozoic era. This period of emergence and erosion is represented by the unconformity above the Kaibab formation. In some places in the Spring Mountains the Kaibab formation and part of the underlying Supai formation were removed by erosion.

(3) A period of oscillation between marine and continental conditions then occurred, during which the marine limestones and shales of the Moenkopi formation were deposited. This period culminated in complete emergence at the end of Lower Triassic time, with erosion of the Moenkopi and deposition of the continental Shinarump and Chinle formations and the Aztec sandstone.

(4) Following (3) was a period of erosion and uplift accompanied by tear and thrust faulting and probably preceded and accompanied by extensive block faulting. At least four great sheets of Paleozoic rocks were thrust southward, overriding other Paleozoic rocks and Mesozoic strata. This period of orogeny and erosion occurred after late(?) Jurassic time and probably extended well into Tertiary time, for in adjacent regions rocks deposited during the Tertiary period (the Overton and Horse Spring formations) were involved in folds. Probably extensive volcanic activity took place in the south part of the area which resulted in the extrusion of volcanic rocks (the Black Canyon group of Ransome). A topography similar to that of the present was the end result of the period of orogeny and erosion, and the present ranges and basins probably were outlined.

(5) Vast quantities of glassy lavas were extruded in the southern part of the area and in adjacent regions. The great thicknesses of sand, silt, and clay of the Muddy Creek formation were

deposited in oscillating lakes, which at times were rather deep and extensive. Deposition of these beds continued until late in Miocene time and were apparently accompanied by block faulting and local minor folding.

(6) Presumably near the end of Miocene time, deposition of the Muddy Creek sediments ceased and a period of erosion took place, during which large quantities of the Muddy Creek and allied formations were eroded from Las Vegas and Indian Spring Valleys and a surface of considerable relief was formed in the valleys. It is possible that the Colorado River had cut through southeast Nevada by this time and that Las Vegas Valley was tributary to it. Also, climatic conditions probably changed because at this time thick alluvial-fan deposits began to form and the quiet lacustrine conditions characteristic of Muddy Creek time had disappeared.

(7) The building of huge alluvial fans and aprons continued throughout the rest of the Tertiary period and well into the Quaternary period. While these thick deposits were forming, numerous basaltic and andesitic laval flows occurred in regions adjacent to Las Vegas Valley. Early in the Pleistocene epoch, the Spring Mountains and adjacent ranges were probably nearly buried in alluvial materials which extended in altitude within 3,000 feet of the top of Charleston Peak.

(8) After the period of alluviation, Las Vegas and Indian Spring Valleys were affected by lowering of the base level until the latter part of Pleistocene time, when the base level seems to have arisen and the two valleys were aggraded. This period of aggradation was brief and resulted only in the deposition of the thin deposits of the Pleistocene lake beds and thin supplementary deposits of gravels in the mountains. It was followed by a lowering of base levels and renewed erosion of the alluvial fans, a process which has resulted in the present-day landscape and which is going on today.

PHYSICAL CHARACTERISTICS AND WATER-BEARING PROPERTIES OF THE VALLEY FILL

Introduction—Many well-exposed sections of the valley fill are present on the higher parts of the alluvial aprons, but at lower altitudes in the valleys knowledge of the character of the alluvial sediments depends largely upon evidence obtained by the construction of wells. Approximately 235 logs of wells in Las Vegas, Pahrump, and Indian Spring Valleys are listed (see tables, appendixes I and II). Many of these logs may not be accurate because they were prepared from the drillers' memories, or because descriptions of the materials penetrated by the wells were inadequate and measurements of the thickness of the material were in error. The places where wells have been drilled cover only a small part of the total area of valley fill, and the character of the sediments underlying the undrilled fill must be interpreted from other data or from evidence furnished by logs from nearby wells. Moreover, the sediment occur in discontinuous, irregular, and lenticular beds typical of alluvial deposition in arid and semiarid regions. In many instances, it is not possible to correlate the various water-bearing or other horizons encountered by the wells. However, the general character and extent of the aquifers and confining beds can be determined from these records and from supplementary geologic and hydrologic evidence.

The well records, geology, and hydrology show that permeable materials are most abundant in the higher parts of the alluvial apron in the form of widespread thick lenses of coarse gravel with some sand and small amounts of silt and clay. Farther down on the alluvial fans these lenses become thinner, more irregular, narrower, and discontinuous, and finger into thick deposits of silt and clay that underlie the central parts of the valleys. On the west side of Las Vegas Valley, south of La Madre Mountain, this change from a predominance of coarse materials to fine-grained sediments is especially abrupt. It largely occurs in a strip of land from 2 to 5 miles wide immediately west of a line from Tule Springs to the city of Las Vegas, thence south to a point about 3 miles west of Pittman. West of this strip the valley fill consists of gravel and sand with only a few thin fingers of silt and clay extending short distances west up the alluvial apron. East of this strip only thin beds of sand and gravel are interfingered with thick, widespread silt and clay layers. The beds of sand and gravel become progressively finer and better-assorted to the east, and most of them grade into silt and clay. Only a few sand and gravel beds, possibly only one bed (see pl. 6B) in the upper 1,000 feet of valley fill in Las Vegas Valley, extend east across the valley and are thus co-extensive with lenses of coarse material that are a part of the alluvial apron on the east side of the valley.

No wells are known to have reached the consolidated rocks of early Tertiary age or older anywhere in the valley. It appears that the deepest wells in the valley penetrate the beds of middle (?) or late (?) Tertiary age (the Muddy Creek formation), sediments that are considered a part of the valley fill. Therefore, the thickness of the valley fill is unknown.

Las Vegas Valley. The sand and gravel beds are the aquifers that transmit and store most of the ground water used in Las Vegas Valley. The silt and clay beds are confining layers that hold the water under pressure in the aquifers but transmit only small quantities of water. Part of the water stored in the confining beds probably drains slowly out of them when the head is lowered during periods of large discharge through wells.

Although it is difficult to recognize beds of marked horizontal extent in the valley fill, a persistent layer of light greenish-blue to dark-blue, plastic clay is penetrated by many wells in Las Vegas Valley (see pls. 6A and B). This blue clay ranges from 10 to 60 feet and averages about 20 feet in thickness. It occurs at depths ranging from 380 to 450 feet below land surface, at an altitude of about 1,550 feet in the vicinity of the city of Las Vegas and west of the large scarp that runs through the east part of the city and thence north to the vicinity of the Kyle Ranch. West of this scarp the blue clay is encountered in wells as far north as the Gilcrease Ranch, as far west as U. S. Highways 95 and 91, and as far south as secs. 20, 21, and 22, T. 22 S., R. 61 E. East of this scarp the blue clay bed is encountered at about the same depths below the land surface. However, here the beds are from 150 to 250 feet lower in altitude, or at altitudes ranging from about 1,300 to 1,400 feet. The clay has been penetrated by wells drilled as far north as U. S. Highway 91, as far south as Pittman, and as far east as sec. 32, T. 21 S., R. 62 E. It is a distinctive and persistent bed that was probably deposited in a lake, and that has been displaced by faulting since its deposition (see pls. 6A and B, and pp. 69, 70).

Several relatively thick sand and gravel lenses are present beneath the blue clay in the vicinity of the city of Las Vegas. They occur at depths ranging from 450 to 700 feet and west of the city are as much as 100 feet thick. To the south they grade into thinner lenses of fine- to medium-grained sand. These gravel lenses also thin to the east and most of them finger into the clays just east of Las Vegas and Whitney. Only a few wells have been drilled deeper than 450 feet north of Las Vegas and only two logs are available from this vicinity. These logs indicate that the sand and gravel lenses between depths of 450 and 700 feet thin toward the north.

A few wells drilled to depths of more than 700 feet have encountered thin water-bearing, medium- to fine-grained sand lenses, with a little fine gravel as deep as 1,255 feet. These materials differ considerably from the overlying sand and gravel beds, for they are finer-grained, better-assorted, and more thinly and evenly bedded. They are characteristically thin sand lenses with a little fine gravel interbedded with thicker beds of reddish silty clay. The sand and gravel lenses are rarely more than 5 feet thick and average about 2 feet. The clay beds are generally about 25 feet thick but range from 1 foot to about 100 feet in thickness. The sand and gravel lenses generally contain some silt and clay and consequently do not readily yield large quantities of water to the wells which penetrate them. The sediments making up the valley fill below about 700 feet in the vicinity of the city of Las Vegas are lithologically similar to beds of the Muddy Creek formation that are widespread in basins and valleys adjacent to Las Vegas Valley. As the Muddy Creek formation is present in parts of Las Vegas Valley also (see pp. 55, 56), these beds may belong to that formation, although diagnostic evidence is lacking.

In Paradise Valley, 5 to 10 miles south of the city of Las Vegas between Arden and Whitney, sedimentation was especially irregular. Apparently only the shallower beds in the upper 400 feet contain relatively widespread sand and gravel lenses and even these beds are poorly assorted and contain only irregular lentils of clean coarse-grained materials. The blue clay apparently is not present in much of Paradise Valley. The deeper sand and gravel beds that occur below 400 feet contain much silt and clay. Much gypsum is present in the bedrock in Cottonwood Valley, which lies about 15 miles west of and tributary to Paradise Valley. As a result, gypsum has been deposited with the sediments in this part of Las Vegas Valley.

Another conspicuous feature of the valley fill that is of paramount significance to the occurrence of ground water is the faults that occur near the city of Las Vegas and west of Whitney (see pls. 1 and 6A and B). The offset resulting from these faults is best shown by the displacement and slight tilting of the blue clay beds. In places this displacement has been as much as 150 feet. Other evidence of faulting near the scarps may be found west and southwest of Whitney, where the terrace surface of each scarp appears to tilt downward against the face of the next scarp west. Also, one scarp abuts beds of the Muddy Creek formation, which are flexured and probably broken at the point of abutment. West of the city of Las Vegas, brecciated caliche and caliche-cemented gravel were observed in excavations along one of the scarps in that vicinity. These faults are largely responsible for the scarps in the valley fill in the south part of Las Vegas Valley. The scarps roughly indicate the extent and number of faults in the valley fill. The faults nearly all occur within the narrow strip along the toe of the Red Rock fan, where the abrupt change from predominantly coarse to predominantly fine material takes place. It appears that they are the result of differential compaction of the sediments, the finer-grained beds having settled considerably more than the coarser-grained materials, thus causing faults in the beds where there is a rapid lateral change in the grain size of the sediments.

Comparison of the results of first-order leveling by the Geological Survey and the Coast and Geodetic Survey in the vicinity of the city of Las Vegas in 1915 and 1935 indicates some settlement. Two bench marks in the city settled about 3 inches, and two other bench marks settled more than 2 inches during that period. These four bench marks are in places underlain by predominantly fine-grained materials interbedded with thin strata of coarse-grained sand and gravel. Bench marks about 4 to 6 miles northwest of the city of Las Vegas settled less than 1 inch during the same period. The bench marks northwest of the city are underlain by valley fill that is predominantly coarse-grained and that contains only thin strata of fine materials. Bench marks farther from the valley axis showed little or no settlement during the period 1915 to 1935. In 1940 and 1941 levels were again run by the Coast and Geodetic Survey to some of the bench marks. These levels were part of a net that was established to determine the amount of settlement in the Lake Mead Basin above Hoover Dam.

Preliminary results from this leveling show that the south-central part of Las Vegas Valley settled from 1 to 3 inches during the period from 1935 to 1941. The maximum settlement took place in the vicinity of the city of Las Vegas. Very little settlement, less than one-half inch, occurred high up on the alluvial aprons. The amount of settlement near the city, a locality that is unaffected by the weight of the water and silt in Lake Mead, was over half the maximum settlement in the immediate vicinity of the loaded lake bed. The increase in the rate of settlement in the period 1935–1941 over that of the period 1915–1935 appears to be largely the result of increased discharge of the artesian water and the consequent release of upward pressure on the confining beds during the period 1930 to 1941. The settlement in Las Vegas Valley as a whole appears to be the result of compaction of the sediments of the valley fill, and the faults, as stated before, are probably caused by the differential compaction of the fine-grained and coarse-grained sediments.

These faults in the valley fill undoubtedly act as a partial barrier that impedes the movement of ground water through the various aquifers. The moderately permeable beds in many places were probably offset against the less permeable beds, thus wholly or part damming the flow of the water through the permeable beds. Some of the ground water thus impeded by the faults moves upward along the fault zones and issues as springs near the traces of the faults. The location and origin of Las Vegas, Kyle, Stevens, and several other such springs near the foot of the scarps in Las Vegas Valley is apparently a result of this faulting.

Most of these conditions of the valley fill in the vicinity of the city of Las Vegas are indicated in the diagrammatic sections, plate 6A and B. These sections are based on the logs of the wells indicated, supplemented by the logs of nearby wells and by interpretation of all available geologic and hydrologic data.

In the north part of Las Vegas Valley, north of Tule Springs Ranch, only a few wells have been drilled. Fragmentary records of the wells drilled at Corn Creek Ranch indicate that water-bearing sand and gravel lenses were encountered at depths of about 350 to 500 feet, but that mostly clay and caliche were penetrated by the drill. These wells were drilled to about 500 feet. Approximately 2½ miles northwest of Corn Creek Ranch, well (S-17-59) 20bc was drilled to a depth of over 300 feet. This well is reported to have penetrated thick beds of clay and caliche and only a few thin beds of sand and gravel. Wells drilled west of the Corn Creek Ranch in the central part of the valley are reported, by drillers and other interested persons, to have encountered very little sand and gravel. Thus, it appears that the east and central parts of the north half of Las Vegas Valley, north of the Tule Springs Ranch, are underlain by fine-grained materials with only occasional thin lenses of sand and gravel. The large alluvial fans that head in Kyle, Deer Creek, and Lee Canyons and that underlie most of the west side of the north part of the valley probably contain much thicker, more continuous, and more regularly deposited lenses of coarse materials. Their position, size, and slope are similar to those of the alluvial apron on the west side of the valley farther south. However, no wells have been drilled in this part of the valley and little information is available regarding the character of the sediments underlying it.

Pahrump Valley. In Pahrump Valley, the valley fill is probably similar to that in Las Vegas Valley. However, no conspicuous fault scarps cut the surface and evidence from the few available well logs is not complete enough to verify the presence of faulting in the valley fill. The logs and other data indicate that an abrupt change in grain size of the materials, similar to the change in the vicinity of Las Vegas and Tule Springs, occurs in the vicinity of Pahrump and Manse Ranches and in other places along the toes of the alluvial fans. The presence of the large Bennetts Springs at the toe of the Pahrump fan and the Manse Spring at the toe of the Manse fan may be an indication of faulting at these places. Logs of wells drilled in the vicinity of the springs and in localities to the north and east show a large proportion of coarse-grained materials. Logs of wells drilled west of the springs and in the basin lowlands along the lower margin of the alluvial apron show larger proportions of finer materials with only occasional thin gravel and sand strata. The sediments underlying the interfan areas, especially between the Pahrump and Manse fans, also appear to be relatively fine-grained, even near the upper margin of the alluvial fan. A few wells drilled in the vicinity of the Pahrump and Manse Ranches reach depths of about 900 feet. These are the deepest wells in Pahrump Valley. Logs of these wells indicate that only the younger sediments of late (?) Tertiary and Quaternary age were penetrated and that the older consolidated rocks were not encountered. Therefore, as in Las Vegas Valley, the maximum thickness of the valley fill is unknown. The deeper beds encountered by these wells are possibly of the same age as the Esmeralda (?) or Muddy Creek formations. No deep wells are known to have been drilled in the central part of the valley and little is known about the character of the valley fill. However, it probably corresponds to the central part of Las Vegas Valley, where the valley fill is largely silt and clay with very few interbedded sand and gravel lenses.

Indian Spring Valley. A complete record is available of only one deep well, (S-16-56) 8ab, in Indian Spring Valley. This well was drilled to a depth of 576 feet at the U. S. Army Air Field near Indian Springs. The logs of this well and of several other wells in the vicinity of Indian Springs indicate that water-bearing sand and gravel layers were encountered at depths of 22 feet, 45 feet, 70 feet, 165 feet, and 570 to 604 feet. These aquifers are interbedded with clay and caliche layers. Thus, the valley fill in Indian Spring Valley is probably similar to the valley fill in the other two valleys discussed in this report.

STREAMS AND SPRINGS

Perennial streams do not occur in Las Vegas, Pahrump, and Indian Spring Valleys and most of the intermittent streams have no regular seasonal flow. Surface water runs in the washes only during and following infrequent storms. Water from a few of the larger springs, such as those in Deer Creek, Cold Creek, and Clark Canyons, runs for a short distance in the washes below the springs and soon percolates into the gravels. Intermittent Spring, and the Pahrump Valley Springs in the central part of Pahrump Valley, discharge large quantities of water in the spring of the

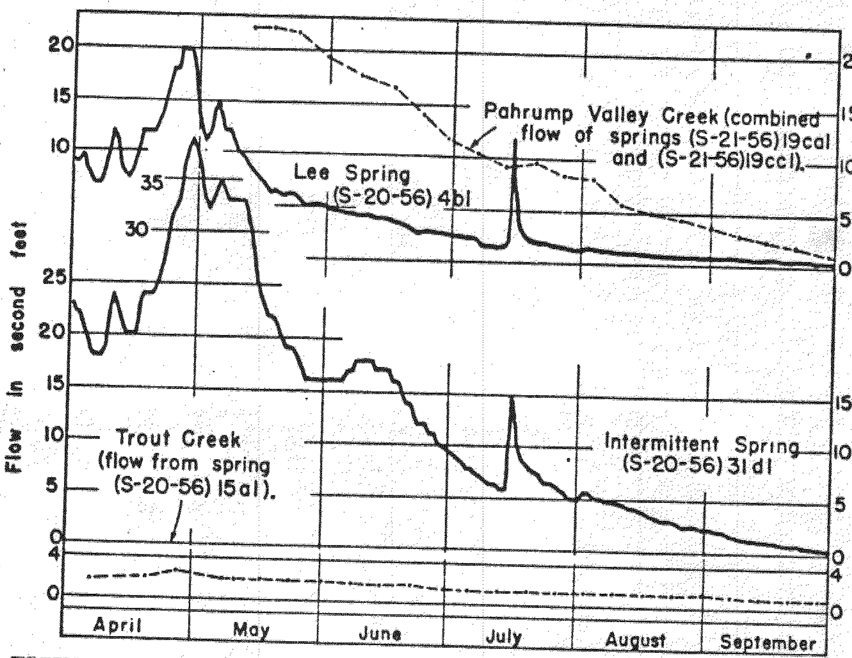

FIGURE 8—Graph showing flow of four springs in Pahrump Valley for the period April to September 1916. (Based on measurements by Albert Quill; see U. S. Geol. Survey Water-Supply Paper 450-C, pp. 61, 62, 1921.)

year (see fig. 8). The resulting streams flow for several miles below the springs but eventually percolate into the alluvial fan. During the rest of the year the water disappears into the gravels within a short distance of the springs. Ordinarily at least a few small streams would be present in a region where the mountains rise to altitudes ranging from 8,000 to 12,000 feet, and where the annual rainfall in the mountains is as much as 30 inches. Many high ranges in the Great Basin with approximately the same average annual precipitation do contain a few perennial and many intermittent streams that flow at regular intervals. The dearth of streams in the Spring Mountain and Sheep Ranges is largely the result of the highly permeable limestone bedrock and alluvial gravels that compose most of the surfaces of the ranges and the alluvial aprons. These formations are veritable "sponges" that soak up the water from precipitation before it can become concentrated in the larger gullies and washes as streams. Thus much of that part of the water from precipitation that ordinarily runs off as streams in regions similar to the Spring Mountain and Sheep Ranges, enters and recharges the ground-water reservoir in this area.

The largest and most important perennial springs in the area occur in the valleys and issue from the gravels of the alluvial apron. Most of these springs undoubtedly discharge water from the artesian aquifers of the valley fill and most of them are probably located along fault zones in the fill. Unlike the springs in the mountains, these valley springs discharge relatively steady flows of water throughout the year. Most of the fluctuation in discharge from these springs is caused by interference from nearby discharging wells. Typical examples of the large springs in the valleys are the Las Vegas, Tule, and Corn Creek Springs in Las Vegas Valley, and Bennetts and Manse Springs in Pahrump Valley. In addition to the artesian springs, many gravity springs are found in the valleys where the water table intersects the land surface. These gravity springs and seeps are especially numerous near the base of the scarps in Las Vegas Valley. Data for the well-known springs in the valleys are given in the tables on pages 76 to 80.

A few large and many small springs are found in the Spring Mountains. A few small springs occur in the other ranges in the area. Most of the springs are of the fifth or sixth magnitude, many are smaller, a few are larger, and none are of the first magnitude.[70] Most of the mountain springs are the contact type. Generally they occur along fault zones, where permeable water-bearing beds have been broken and the broken ends have been forced against impermeable beds as a result of movement along

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[70] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 53, 1923.

First magnitude, 100 second-feet or more; second magnitude, 10 to 100 second-feet; third magnitude, 1 to 10 second-feet; fourth magnitude, 100 gallons per minute to 1 second-foot (448.8 g.p.m.); fifth magnitude, 10 to 100 gallons per minute; sixth magnitude, 1 to 10 gallons per minute; seventh magnitude, 1 pint to 1 gallon per minute; eighth magnitude, less than 1 pint per minute.

the faults. Occasional springs are also found along the contacts of permeable and impermeable beds where favorable conditions of attitude and outcrop of the beds allow water under the force of gravity to come to the surface.

Discharge from most of the mountain springs fluctuates considerably. Many of the springs go dry in the late summer or fall and start flowing again during the spring melt of the following year. The discharge of some of the springs fluctuates greatly as a result of added recharge during local storms. Generally the discharge of springs that issue from cavernous limestone fluctuates most, and that from springs that are along fault zones appears to fluctuate least. Figure 8 illustrates the wide fluctuation of the discharge from Intermittent and Lee Springs, both of which issue from limestone rocks. It also shows the fluctuation of the Pahrump Valley Springs. These springs probably issue from limestone underlying the gravels near the contact of the alluvial apron and the mountains. Fluctuations of the flow of Trout Creek, which originates from springs along a fault zone, are also shown. The location of many of the springs is shown on plate 1. The name, location, discharge, and temperature, where available, are shown in the following table for the most important and best-known springs. The numbering system used for designating each spring is similar to that used for designating wells and is described in appendix I, pages 8 and 9. Available analyses of water from some of the springs are given in table 5, appendix II.

Discharge of Well-Known Springs in Las Vegas, Pahrump, and Indian Spring Valleys and the Adjacent Mountains

Location	Name	Discharge Date	Discharge Gallons per minute	Remarks
(S-15-60) 24	Wiregrass Spring	Apr.-July	.5±	Discharge estimated by the Desert Game Refuge Engineer, 1938-1940.
		Aug.-Mar.	.25±	
(S-16-55½) 11a	Mesquite (Cactus) Spring	7-30-46	.5±	Discharge estimated.
(S-16-56) 16b1	Indian Springs	12-15-12	405	See Water Supply Paper 365, table facing p. 30. T. 78° F. See analysis, Table 4, Appendix II.
		3-18-46	400	Discharge estimated.
(S-17-53) 27c	Horseshutem Spring	1916	8±	See Water Supply Paper 450, p. 76.
		7-14-45	10	Discharge estimated.
(S-17-59) 34a1	Corn Creek Spring	12- 8-12	90	See Water Supply Paper 365. See analysis, Table 4, Appendix II.
(S-18-54) 7	Rainbow Spring	1916	2±	See Water Supply Paper 450, p. 76.
(S-18-54) 1d	Cold Creek Spring	11- 9-44	690	
(S-18-55) 2a	Willow Spring	12-17-30	340	Discharge estimated—State Engineer of Nevada.
(S-18-55) 20c	Wheeler Spring	1916	1±	See Water Supply Paper 450, p. 76.
		7-14-45	1±	Discharge estimated.
(S-18-55) 23b	Trough Spring	9-13-45	30	Discharge estimated.
(S-18-55) 35	Buck Spring	1916	1±	See Water Supply Paper 450, p. 76.
		9-13-45	25	Discharge estimated.
(S-19-54) 14c	Horse Spring	1916	1±	See Water Supply Paper 450, p. 76.
(S-19-56) 3c	Scout Canyon Spring	6-26-42	4.7	Measurements by U. S. Forest Service.
		7-29-42	Dry	
		9-29-42	Dry	
		6-21-43	6.7	
		7-23-43	4.8	
		8-27-43	1.9	
		9-29-43	1.0	
		7-31-44	Dry	
		8-31-44	Dry	
		7- 9-46	10.9	
		8- 2-46	11.4	
		9- 2-46	9.3	
(S-19-56) 10c	Three Springs	6-26-42	44.0	Measurements by U. S. Forest Service.
		7-29-42	17.4	
		9-29-42	21.0	
		6-21-43	40.0	
		7-23-43	23.8	
		8-27-43	21.5	
		9-29-43	22.1	
		8- 4-44	15.5	
		8-31-44	12.4	
		7- 5-45	15.1	
		8- 1-45	11.3	
		9- 4-45	39.0	
		7- 9-46	27.3	
		8- 2-46	21.4	
		9- 2-46	13.5	

Location	Name	Discharge: Date	Discharge: Gallons per minute	Remarks
(S-19-56) 25a	Stanley "B" Spring	6-27-42	20	Measurements by U. S. Forest Service.
		7-30-42	15	
		9-29-42	12.1	
		6-21-43	37	
		7-24-43	27.2	
		8-28-43	22.8	
		9-27-43	18.2	
		7-31-44	15.5	
		8-31-44	12.4	
		7- 4-45	24.4	
		8- 6-45	27.0	
		9- 3-45	34.0	
		7- 8-46	18.1	
		8- 3-46	21.2	
		9- 3-46	16.4	
(S-19-56) 35d	Rainbow Creek Spring	6-27-42	135.4	Measurements by U. S. Forest Service.
		7-30-42	79.2	
		9-29-42	29.0	
		6-22-43	282.0	
		7-24-43	192.4	
		8-28-43	101.7	
		9-26-43	61.0	
		7-31-44	105.0	
		8-30-44	90.0	
		7- 1-45	199.0	
		8- 4-45	121.0	
		9- 4-45	174.0	
		7- 6-46	110.5	
		8- 1-46	93.5	
		9- 3-46	69.7	
(S-19-57) 7c	Deer Creek Spring	6-27-42	54.1	Measurements by U. S. Forest Service.
		7-29-42	29.2	
		9-29-42	12.6	
		6-21-43	81.7	
		7-23-43	68.6	
		8-27-43	76.7	
		9-29-43	56.9	
		8- 5-44	78.8	
		8-31-44	34.1	
		7- 5-45	42.5	
		8- 1-45	74.2	
		9- 4-45	84.0	
		7-11-46	51.0	
		8- 3-46	50.9	
		9- 7-46	41.0	
(S-19-60) 9c1	Tule Spring	1912 (?)	210	Largest spring in group. See Water Supply Paper 365, p. 39. T. 69.5° F.
		12-21-12	180	Discharge estimated by J. T. McWilliams.
		4-20-29	270 to 450	See Agricultural Experiment Station Bull. 136, p. 24. See analysis, Table 4, Appendix II. See following table for additional measurements.
(S-20-52) 1c1	Buol Sixmile Spring	1916	.0	See Water Supply Paper 450, p. 76.
		8- 5-27	34	See Agricultural Experiment Station Bull. 136, p. 32. See analysis, Table 4, Appendix II.
		7-15-46	10	Discharge estimated.

Location	Name	Discharge Date	Discharge Gallons per minute	Remarks
(S-20-53) 14dc1	Bennetts Springs	1875	3,370	Reported by Mr. Bennett in 1905.
		9-30-16	2,125	Two larger springs. See Water Supply Paper 450, p. 63. T. 76.5° F. See analysis, Table 4, Appendix II.
		6-19-39	1,590	
		7-18-43	2,520	Two larger springs. Measurement by State Engineer of Nevada. Springs cleaned out.
(S-20-56) 4b1	Lee Spring	See Fig. 8	-------	See Water Supply Paper 450, p. 61.
(S-20-56) 15a1	Trout Spring	See Fig. 8	-------	See Water Supply Paper 450, p. 62.
(S-20-56) 31d1	Intermittent Spring	See Fig. 8	-------	See Water Supply Paper 450, p. 62. See analysis, Table 4, Appendix II. T. 57° F.
(S-20-57) 1c1	Harris Spring	10- -35	50	Discharge estimated.
(S-20-61) 15dc1	Kyle Spring	5-29-09	315	Reported.
		9-16-12	405	See Water Supply Paper 365, p. 39. See analysis, Table 4, Appendix II. T. 76° F.
(S-20-61) 30ddc1	"Little" Las Vegas Spring	2-22-08	2,700-3,150	Reported by Judge M. S. Beal.
(S-20-61) 30ddd1	"Open" Las Vegas Spring	9-23-12	2,580	See Water Supply Paper 365, table facing p. 30. See analysis, Table 4, Appendix II. T. 73° F.
(S-20-61) 31aab1	"Big" Las Vegas Spring	12-21-12	2,390	Discharge estimated by J. T. McWilliams. See following table for other discharge measurements.
(S-21-54) 3bc1	Manse Springs	1877	2,700	Reported by Harsha White and Joseph Yount, 1905.
		9-30-16	1,445	See Water Supply Paper 450, p. 63. T. 75° F.
		8- 5-27	960	See Agricultural Experiment Station Bull. 136, p. 32. See analysis, Table 4, Appendix II. T. 75° F.
		1- -37	1,350	Measurements by State Engineer of Nevada.
(S-21-56) 19ca1 and 19cc1	Pahrump Valley Springs	See Fig. 8	-------	See Water Supply Paper 450, p. 62.
(S-21-61) 1cc1	Red Spring	9-10-45	15	Discharge estimated.
(S-21-62) 29db1	Grapevine Spring	12- 2-46	10	See analysis, Table 4, Appendix II. Discharge estimated.
(S-21-62) 30dc1	Stevens (Mesquite) Spring	3-28-45	25	Discharge estimated.
(S-22-54) 14d1	Steve Brown Spring	8- 5-27	65	See Agricultural Experiment Station Bull. 136, p. 32. See analysis, Table 4, Appendix II.
		5- 5-46	20	

Location	Name	Discharge: Date	Discharge: Gallons per minute	Remarks
(S-22-56)				
1b1	Robert's Lower Ranch Spring	5- 5-46	8	Discharge estimated.
(S-22-58)				
20c1	Mountain Springs	1916	1±	See Water Supply Paper 450, p. 77. Probably only one spring.
		3- -22	40	Discharge estimated by Hewett.* Flow from six springs.
		5- 5-46	20	Estimated flow at trough below springs.
(S-22-59)				
7c1	Cottonwood Spring	9-18-12	225	See Agricultural Experiment Station Bull. 136, p. 26.
		5- 5-46	225	Reported by users. See analysis, Table 4, Appendix II.
(S-23-55)				
5b1	Stump Spring	1916	1±	See Water Supply Paper 450, p. 77.
		6-12-45	2±	Discharge estimated.
		5- 5-46	2±	Discharge estimated.

*Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nev.: U. S. Geol. Survey Prof. Paper 162, p. 5, 1931.

Measurements* of the Discharge of Las Vegas Springs, 1924–46

Date	Discharge in Gallons Per Minute: (S-20-61) 30ddc1 "Little" Spring	(S-20-61) 30ddd1 "Open" Spring	(S-20-61) 31aab1 "Big" Spring	Combined flow of springs
1924	------	------	------	2,020†
1925	------	------	------	1,916†
1926	------	------	------	2,030†
March 3, 1927	668	354	1,009	2,031
September 5, 1928	660	290	674	1,624
July 23, 1929	740	411	830	1,981
December 28, 1929	655	306	740	1,701
April 30, 1930	633	323	668	1,624
June 27, 1930	695	323	695	1,713
July 14, 1931	623	306	712	1,641
1932	------	------	------	1,638†
1933	------	------	------	1,660†
July, 1934	569	230	663	1,462
June 6, 1935	719	285	749	1,753
April 6, 1936	611	246	725	1,582
June 22, 1936	689	246	749	1,684
February 24, 1938	695	212	725	1,632
1939	610	245	609	1,464
May 16, 1940	503	250‡	610	1,363
August 3, 1940	503	264	609	1,376
March 8, 1941	554	250‡	420	1,224
May 8, 1941	554	250‡	470	1,274
July 26, 1941	554	225‡	434	1,213
August 25, 1941	423	225	470	1,118
May 5, 1942	411	220‡	459	1,080
July 15, 1942	217	200‡	368	785
August 15, 1942	368	200‡	411	979
September 15, 1942	368	200‡	411	979
March 15, 1943	452‡	200‡	504	1,156
June 15, 1944	404	200‡	432	1,036
August, 1945	500	200‡	500	1,110
September, 1946	410	200‡	500	1,135

*By Las Vegas Land and Water Co., unless otherwise indicated.
†Measured by George Hardman, Nevada Agricultural Experiment Station.
‡Estimated.

Measurements* of the Discharge of Tule Springs, 1922–1946

Date	Discharge in gallons per minutes
1922	340
1923	476
1924	480
1925	530
1926	470
1927	470
1928	275
1929	311
1930	275
1931	243
1932	231
1933	228
1934	228
1935	205
1936	138
August 11, 1943	314†
December 17, 1943	277†
August 7, 1944	243‡
January 21, 1945	278‡
August 16, 1945	215‡
August 2, 1946	135‡

*Measurements by George Hardman, Nevada Agricultural Experiment Station, unless otherwise indicated.
†Measurements by Office of the State Engineer of Nevada.
‡Measurements by the U. S. Geological Survey.

OCCURRENCE OF GROUND WATER

GENERAL RELATIONS

Las Vegas, Pahrump, and Indian Spring Valleys are in the east-central part of the Southwestern Bolson ground-water province.[71] Features of ground-water occurrence in the valleys are similar to those typical of the province, because the main aquifers are sand and gravel lenses in the valley fill which is composed largely of sediments of late Tertiary age overlain by deposits of Quaternary age. As in many other valleys in the Southwestern Bolson province, precipitation is the source of the water that is taken from the aquifers in the valley fill. Most of the water comes from the higher mountains where precipitation is heavier. Only smaller and generally negligible amounts of water are derived directly from precipitation on the valley floor and the lower parts of the alluvial apron.

After the water falls as rain and snow, part of it percolates into the bedrock of the mountains and into the gravels of the higher parts of the alluvial aprons. It then moves into and through the valley fill. As the water moves down the alluvial aprons it becomes confined in the sand and gravel beds between the relatively impermeable silt and clay layers that thicken and become more numerous toward the axes of the valleys. Artesian pressure is created by the weight of the water held at higher

[71]Meinzer, O. E., Occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, pp. 300–313, pl. XXXI, 1923.

levels on the alluvial aprons, and is maintained by these confining beds of silt and clay that prevent or impede upward movement of the water. In many instances the sand and gravel beds either grade into the fine silts and clays or are faulted off, thus impeding widespread lateral movement. When the confining beds are penetrated by wells or broken by faults the water rises in the wells or along the faults as a result of this pressure. In some places in Las Vegas and Pahrump Valleys the artesian pressure is above the land surface and the water flows at the surface.

The confining beds are not wholly impermeable, and appreciable quantities of water leak through the beds, especially in the vicinity of the fault zones. This water percolates upward and, with water from irrigation and leaky wells, maintains the water level in the shallow beds near the land surface in the central parts of the valleys.

THE "NEAR-SURFACE" WATER

The first water encountered in dug and drilled wells in the vicinity of the city of Las Vegas is at depths ranging from 1 to 50 feet below the land surface. Throughout Las Vegas Valley below altitudes of about 2,100 feet water is frequently near enough to the surface to support such plants as rushes, salt grass, willows, mesquite, and other phreatophytes (see pl. 7). Near Henderson, south of the city of Las Vegas along U. S. Highway 91, west of Tule Springs, north of La Madre Mountain in the north part of the valley, and on other high portions of the alluvial slopes, the first water is encountered at depths of 50 to 100 feet or more below the land surface. The upper surface of this first water encountered in wells is referred to in this report as the "near-surface" water level. The water is under artesian pressure in some places and is unconfined in other localities. It is locally referred to as the "surface water."

Near-surface water occurs at shallow depths in most of the central part of Pahrump Valley, also and in the vicinity of Mesquite (Cactus) Spring and Indian Springs, in Indian Spring Valley.

CONFINED WATER

Aquifers that yield artesian water when penetrated by wells are present at the toes of the Red Rock and Kyle Canyon fans in Las Vegas Valley. In the vicinity of Las Vegas and Tule Springs these aquifers are especially permeable and yield large flows of water to wells and springs. North of La Madre Mountain and the Tule Springs Ranch, in the north part of Las Vegas Valley, a few aquifers that yield only small quantities of water have been penetrated by wells. Ground-water occurrence north of Tule Springs Ranch has been discussed in a foregoing section of this report (see p. 71).

More than two-thirds of the wells in Las Vegas Valley, south of La Madre Mountain and Gass Peak, bottom in materials that lie below a depth of 200 feet and above the blue-clay horizon. They draw water from several sand and gravel lenses which occur at approximate depths of 250, 300, 350 to 400, and 450 feet. This group of aquifers is designated as the Shallow Zone of aquifers and supplies nearly two-fifths of the total quantity of water withdrawn from wells and springs in Las Vegas Valley. Until about 1940 it was the principal source of ground water in the valley.

Another zone of aquifers underlies the blue clay in Las Vegas Valley and occurs at depths ranging from 500 to 700 feet. This group is designated as the Middle Zone of aquifers. Many wells of large yield have tapped these aquifers since 1940. In the period 1940 to 1946 about one-half the ground water used in Las Vegas Valley was withdrawn from aquifers in this zone. Well logs show that the materials making up these aquifers are especially permeable in the southwest part of T. 20 S., R. 61 E., and in the northwest part of T. 21 S., R. 61 E. The materials grade into fine-grained sand south and east from this locality. Northward too few wells have been drilled into the Middle Zone to demonstrate adequately the water-bearing properties of the materials that compose the aquifers.

All the aquifers below about 700 feet have been included in the Deep Zone of aquifers. Only small quantities of water are withdrawn from the aquifers in this zone because they are thin and generally contain much silt and clay, and are penetrated by only a few wells.

In Pahrump Valley the most productive aquifers occur at the toes of the Pahrump and Manse alluvial fans. The area between these two large fans appears to be underlain by fine materials and no wells of large yield have been developed there. The Manse fan receives most of its recharge from Carpenter and Trout Canyons and the Pahrump fan receives its recharge from Wheeler and Clark Canyons. Water-level fluctuations in wells located on the two fans do not appear to be interrelated. Thus, the two fans can be treated as separate ground-water districts.

On the Pahrump fan wells drilled in the vicinity of the Raycraft, Buol, Kink, and Caton Ranches, 1 to 3 miles north of Bennetts Springs on Pahrump Ranch, penetrated aquifers that yielded flowing water at depths of about 175 to 200 feet, 285 to 350 feet, and 450 to 500 feet. At the Pahrump Ranch, aquifers were encountered at depths of 190 to 210 feet, 224 to 235 feet, 290 to 295 feet, and 332 to 495 feet. Two deeper wells drilled on the Pahrump Ranch are reported to have penetrated a few thin aquifers that yield only small quantities of water at depths ranging from 500 to about 900 feet. On the Caton property in sec. 27, T. 19 S., R. 53 E., aquifers were encountered at 98, 165, 285, 360, and 390 to 416 feet. The driller reported that the flow of the Caton well increased as the well was drilled from 416 to 480 feet, therefore additional aquifers were probably penetrated between these levels. About 1½ miles north, in the NE¼ sec. 22, the Van Horn well (S-19-53) 22ab1, penetrated no aquifers that yielded flowing water, but confined water was struck in aquifers at depths of 124 and 240 feet, and possibly at depths between 260 and 540 feet. In sec. 10, T. 19 S., R. 53 E., water-bearing beds were encountered between 90 and 250 feet. The water was probably confined in these beds but the water level in the well rose only within 90 feet of the land surface.

On the Manse fan, in the vicinity of the Manse Ranch, several wells that yield copious flows of water have penetrated aquifers at depths of about 220 to 280 feet, 325 to 350 feet, 400 to 480 feet, 570 to 580 feet, and 600 to 650 feet. The flow from two of the wells drilled to more than 700 feet was reported to have increased between the depths of 650 and 730 feet. Wells drilled to depths of more than 900 feet reportedly have not struck aquifers of large yield below 730 feet.

Waring[72] reports several test wells that were drilled during 1914–1916 in the vicinity of Mound Spring, about 2 miles south of Manse Ranch, by the Oasis Land Company. His description of these wells indicates the nature of the water-bearing materials underlying this locality and it is here quoted:

> Water under artesian pressure was encountered in all of (the wells), and in two (wells) * * * small flows were obtained. (One) was sunk to a depth of 135 feet a few yards from Mound Spring and in August, 1916, the water rose 15 feet above the surface. (In another well) flows were struck at depths of about 200 and 300 feet but were lost in gravel at 535 feet. After the well was filled to about 475 feet below the surface a slight flow was again developed. In August, 1916, the flow was about

[72] Waring, G. A., Ground water in Pahrump, Mesquite, and Ivanpah Valleys, Nev.-Calif.: U. S. Geol. Survey Water-Supply Paper 450, p. 65, 1921.

> one gallon a minute * * *. It is said that in the Spanker wells * * *, 3 miles southwest of Mound Spring (probably wells (S-21-54) 31dd1 and (S-21-54) 31dd2, water from the lower strata did not rise higher than 65 feet below the surface, and that the first struck at 23 feet, flowed down the well to the 65 foot level.

In 1946 the near-surface water level in a dug well adjacent to the cased wells was about 20 feet below the surface, and the deeper water level in the cased well was about 70 feet below the surface.

Farther south, at the old J. B. Yount Ranch, now known as the Hidden Ranch, at least two deep wells have been drilled in unsuccessful attempts to obtain flowing water. One of these wells was drilled to a depth of 320 feet, and Waring[73] reported that "a flow was not obtained, but at 225 feet water was struck in fine sand beneath clay under pressure that caused it to rise within 6 feet of the surface." This well is probably well (S-22-54) 25c1, listed in table 3 of appendix II of this report. The other well, (S-22-54) 25a1 in this report, was drilled to a reported depth of 888 feet. The driller reported that no sand and gravel lenses—only clay layers—were encountered. The water level in the well stood about 17 feet below the surface in September 1946. The Yount Ranch lies at the toe of the alluvial apron on the south side of the Manse fan and at the north edge of the alluvial fan that heads in Lovell Canyon. Thus it lies between two large fans, and confirms the expectation that deposits of fine materials would be thick and predominant, and coarse water-bearing materials would be scarce or absent in the valley fill.

Occurrence of ground water in Indian Spring Valley has been discussed in the section on physical characteristics and water-bearing properties of the valley fill (see p. 72).

GROUND WATER IN LAS VEGAS VALLEY

THE NEAR-SURFACE WATER

Many wells tap the near-surface water in Las Vegas Valley. Only a few of these wells are used for water supply because most of them are test holes or have been abandoned in recent years. Monthly measurements of water levels have been made in about 45 of these wells during all or part of the period 1944 to 1946. Water-level measurements made before December 31, 1945, have

[73] Op. cit.

been published[74] and measurements made in 1946 will be published in a forthcoming report. Most of these shallow wells were drilled in the valley south of the Tule Springs Ranch and it has been possible to determine by measurement and spirit leveling the altitude of the near-surface water level in much of this locality. Plate 7 illustrates by means of contours the shape and position of the ground-water surface of the near-surface water at the end of March 1946. The contours are lines along which the ground-water surface is the same altitude above sea level. The maximum hydraulic gradient and the direction of movement are perpendicular to these contours. In Las Vegas Valley high on the alluvial apron and in some other places, this ground-water surface is probably an unconfined water table, but in the lower parts of the valley the water is generally confined and is under slight artesian pressure. The map of the ground-water surface shows that it slopes steeply toward the city of Las Vegas from the vicinity of Tule Springs, and less steeply from the city to the lower part of the valley near Las Vegas Wash, where it intersects or is within a few feet of the land surface. The near-surface water level also intersects or is within a few feet of the land surface at the foot of and along the faces of the scarps near Las Vegas and west of Whitney. The contours show the effect of recharge to the near-surface water in the vicinity of Las Vegas Springs and the city of Las Vegas, where they bulge east toward the axis of the valley. The flattening of the water surface between the 2,100- and the 2,050-foot contours west of Las Vegas indicates that recharge to the near-surface water occurs there. The recharge has resulted in a high water level in this locality, and the high level has made difficult road building and construction of basements, sewers, and other excavations, especially within the city limits of Las Vegas.

DISCHARGE

Only a small quantity of near-surface water, probably not more than 200 acre-feet a year, is discharged by wells in Las Vegas Valley. Most of this water is withdrawn from wells in the central part of the valley east of the city of Las Vegas.

Most of the discharge from the near-surface water occurs by

[74]Robinson, T. W., Maxey, G. W., Fredericks, J. C., and Jameson, C. H., Water levels and artesian pressure in wells in Las Vegas Valley and in other valleys in Nevada, 1913-1945: State of Nevada, Office of the State Engineer, Water Resources Bull. 3, 1947.

transpiration and evaporation where the water level is at or within 10 feet of the land surface. No detailed studies of such loss have been made, although the places where the near-surface water level is within 10 feet of the surface, comprising about 5,000 acres, have been mapped (see pl. 7). Here the natural vegetation is largely salt grass and mesquite with some cottonwood and other phreatophytes. It is estimated that the natural discharge may range from 5,000 to 8,000 acre-feet a year.

A measurement of the sewage passing through the Las Vegas sewage-disposal plants in February 1947 showed a flow of about 3,600 gallons a minute. The amount of water supplied by the water company to the city, and from a few wells within the city, was about 2,700 gallons a minute. Thus about 900 gallons a minute of excess water was unaccounted for. As the sewer lines in parts of the city are below the near-surface water level, and as some sections of the lines leak, it appears that this excess water is supplied by the near-surface water. If this condition exists, the sewers are, in effect, acting locally as drains.

The sewage effluent is discharged onto the land surface east of Las Vegas, where it spreads over a considerable tract of relatively flat lying land. A large part of this effluent is undoubtedly disposed of by direct evaporation, and the remainder recharges the near-surface reservoir. No studies were made of this recharge, but tentative estimates indicate that it is probably about equal to the unaccounted-for excess sewage. Thus there probably is little net loss from the near-surface reservoir as a result of drainage by the sewerage system, and the total discharge from the near-surface water is between 5,000 and 8,000 acre-feet annually.

WATER-LEVEL FLUCTUATIONS

In Las Vegas Valley the greatest fluctuations of water levels in wells that tap the near-surface water are seasonal. It was not possible to obtain accurate long-period records of daily fluctuations resulting from evaporation and transpiration because no suitable observation wells were available. It is known from fragmentary records that such fluctuations do occur.

The hydrographs in figure 9 show typical seasonal fluctuations of the near-surface water level in several shallow wells in Las Vegas Valley. Nearly all these hydrographs show annual fluctuations that range from 1 to 3 feet. The water level is generally highest in April or May and lowest in September or October. Thus, the declines follow the yearly period of heavy draft on the artesian aquifers at which time hydrographs of the water levels

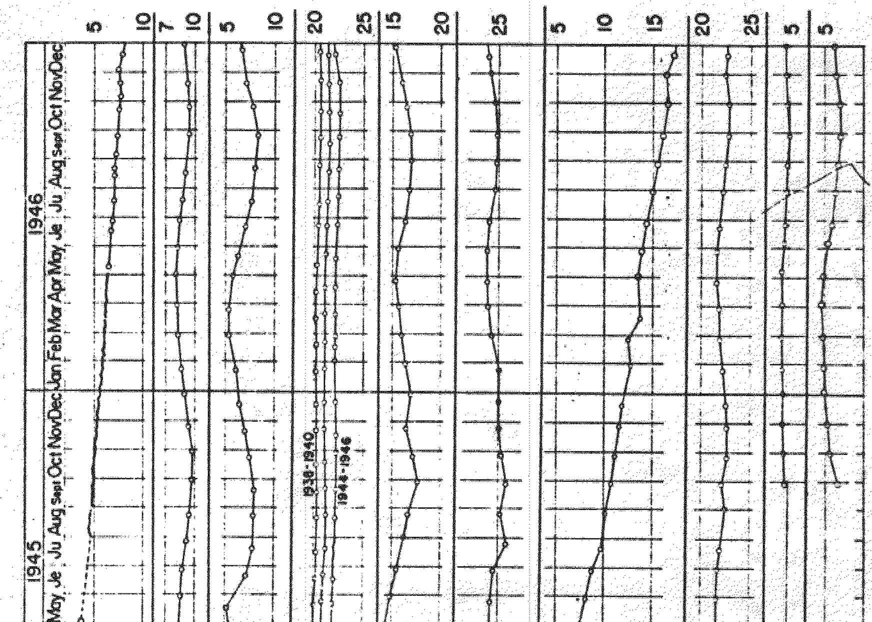


FIGURE 9—Hydrographs showing fluctuation of the level of the "near-surface" water in 10 wells in Las Vegas Valley.

in artesian wells also show declines. The declines of the near-surface water level lag about 2 months behind the declines of confined water levels. Apparently these fluctuations are the result of changes in the amount of recharge to the near-surface reservoir received from the artesian aquifers. These changes in the amount of recharge are caused largely by fluctuations in discharge from flowing wells, the lesser recharge occurring when the artesian wells are discharging. The annual fluctuations of the near-surface water level may also be partly a result of increased discharge of the water by evaporation and transpiration during the growing season.

The four upper hydrographs in figure 9 show the continuous yearly decline of the near-surface water level during the period of record in shallow wells that were drilled north and west of the scarps near Las Vegas and Whitney. This decline is especially large west of Tule Springs at Stillwell Spring well (S-19-60) 21ccc1. A small flow of water is reported to have issued from Stillwell Spring well during the early period of settlement in Las Vegas Valley, but in recent years the spring has dried up and a casing has been placed in the spring opening. The water level in this casing has continued to decline for several years. Although the decline of the near-surface water level has been smaller in the wells farther south, it has continued throughout the period of record. This decline is probably a result of the continual diminution of recharge from the confined water. In the vicinity of Las Vegas the near-surface water level has not declined appreciably in recent years (see hydrographs for wells (S-20-61) 28aba1 and (S-21-61) 4aab1, fig. 9), and is at about the same stage that it was reported to be between 1905 and 1944. East of Las Vegas in T. 20 S., R. 62 E., and in the north part of T. 21 S., R. 62 E., the near-surface water level has risen in the last few years (see hydrographs for wells (S-20-61) 23ddb2 and (S-21-62) 4aaa1, fig. 9). The rising water level in this vicinity is largely a result of increased recharge from the continually increasing amount of waste water and sewage effluent from the city. Also more recharge to the near-surface water has resulted from increased local irrigation.

Farther south, in the vicinity of Las Vegas Wash and Whitney, near-surface water levels apparently declined between 1928 and 1944. In 1928 at least and probably earlier, there was flow in Las Vegas Wash, because Hardman[75] measured 1 second-foot of

[75]Hardman, George. The quality of the water of southeastern Nevada: drainage basin and water resources: Nevada Agr. Exper. Sta. Bull. 136, p. 28, 1934.

water on March 5, 1928. He reported this to be about the normal summer flow in Las Vegas Wash at that time. No records are available to indicate the source of the flow. It may have been waste from flowing wells or local discharge of the near-surface water, or both. Early in 1944 the wash was dry, and apparently it had been for several years, although the near-surface water level intersected or was near the land surface in several places in the wash. Probably this cessation of flow and decline in water level resulted from better conservation and control of flowing wells in Las Vegas Valley during the period 1928 to 1944.

Between the spring of 1942 and the fall of 1943 waste water from the Basic Magnesium Project was discharged into ditches and tanks on the alluvial apron east of the plant and west and north of Pittman. It appears quite likely that some of this waste water recharged the near-surface water in the vicinity of Pittman, because the near-surface water levels rose a few months after the practice was started. On the east side of Pittman, basements and cesspools were flooded and small springs formed on the slope in late 1943 and early 1944. When this occurred the two large evaporation tanks south of Pittman were abandoned and the waste water from the magnesium plant was transported by ditches around Pittman, thence into Las Vegas Wash. After the tanks were abandoned the water level in the vicinity of Pittman declined rapidly (see hydrograph for well (S-22-62) 1cba1, fig. 9). Late in 1944 water, probably representing the waste from the Basic Magnesium Project, started flowing from springs in the old channel in Las Vegas Wash. From 1 to 2 second-feet of water was flowing in the wash in the fall of 1946. It appears that near-surface water levels north of the wash are little affected by this waste water because in three wells in that area they are still declining. (See hydrographs for wells (S-21-62) 21cdd1, (S-21-62) 27aad1, and (S-21-63) 30cdd1, fig. 9).

RECHARGE

An unknown quantity of confined water leaks upward along the fault zones in the valley fill in the vicinity of Las Vegas Springs and in Paradise Valley about 2 miles west of Whitney. Much of this water flows from the springs but undoubtedly a large part of it percolates laterally into the near-surface water reservoir, because the near-surface water level is high and the water-level contours indicate recharge in the vicinity of the springs. In many places the near-surface water level intersects the land surface and thus forms small seeps, springs, and marshy places. The water that leaks upward along the fault zones is probably the larger part of that recharged to the near-surface reservoir in Las Vegas Valley. Small quantities of water are apparently supplied to the near-surface reservoir by upward leakage through the confining beds of the deeper aquifers and from a few leaky deep wells. In wells far from and topographically above the faulted zones, the near-surface water level fluctuates more or less synchronously with the confined water levels. For example, when the Wick well, (S-22-61) 3dda1 was drilled to a depth of 335 feet it discharged approximately 1,400 gallons a minute for more than a month. Water levels were affected not only in the deeper wells in the vicinity but also in dug or other shallow wells as far as 2 miles away. The similarity in the seasonal and long-term fluctuations of water levels in the near-surface and artesian wells undoubtedly indicates that the two systems are at least imperfectly interconnected and that the near-surface water level is in large part maintained by water percolating upward from the artesian aquifers.

In the vicinity of the city of Las Vegas waste water from irrigation, cooling, and sewerage contributes greatly to the near-surface reservoir. Most of the waste water is discharged from the sewage-disposal plants east of the city and flows east and south toward Las Vegas Wash. In this vicinity the near-surface water level is rising from year to year because the amount of water discharged from the sewage disposal plant is also increasing. Waste water from a few uncontrolled wells and from irrigation contributes somewhat to the near-surface reservoir in the north part of T. 22 S., R. 61 E., and in the southeast part of T. 21 S., R. 62 E., in Paradise Valley. Since 1941 several large resort hotels and casinos have been constructed along U. S. Highway 91 south of Las Vegas, in secs. 9 and 16, T. 21 S., R. 61 E. These establishments dispose of waste water in cesspools and septic tanks. In recent years appreciable quantities of water have thus been discharged into the near-surface reservoir and locally this has resulted in a slight rise of the water level.

Most of the water-bearing material which transmits and stores the near-surface water is exposed at low altitudes in the valley where the average annual precipitation is less than 10 inches. Probably most of this precipitation is lost by transpiration and evaporation, and only small inappreciable quantities of water from direct precipitation on the land surface recharge the near-surface water.

Sufficient data are not available to estimate accurately the quantity of water annually available for recharge to the near-surface reservoir. Determination of the amount of leakage from the deeper aquifers would require a detailed study beyond the scope of this investigation. It is possible that the total annual recharge to the near-surface water now is approximately equal to or a little less than the total annual discharge, because the near-surface water levels have declined slightly.

QUALITY AND UTILIZATION

The foregoing discussion indicates that possibly as much as 8,000 acre-feet of near-surface water is available annually for development and use. However, the character and occurrence of most of the near-surface water limit its development and utilization for some purposes in most of the valley. The materials that transmit and store the water are generally thin and consist of poorly assorted, coarse- to fine-grained sediments that do not have a high transmissibility. Therefore, the wells that tap these aquifers yield only relatively small quantities of water when they are pumped from economically feasible depths. For example, the Marracci well, (S-20-62) 19bbb1, a shallow well typical of those east of Las Vegas, yields only 22 gallons of water a minute with a drawdown of 8 feet, or 2.75 gallons per foot of drawdown. Other wells in this vicinity yield about the same or lesser amounts of water at similar drawdowns. Therefore, these wells generally cannot be used in operations that require large quantities of low-cost water, such as irrigation of the ordinary field crops.

The chemical character of the near-surface water varies widely in the valley. Results of a few analyses of samples collected from shallow test holes and wells are given in table 4, appendix I. These analyses show only the dissolved mineral content and do not indicate the sanitary condition of the waters. They show that the near-surface water in the vicinity of Las Vegas and north and south of the city, west of the fault scarp that extends from the Kyle Ranch to about 3 miles west of Pittman, contains from 175 to 400 parts per million of dissolved solids, chiefly calcium and magnesium bicarbonates with some calcium sulfate. Locally the first water encountered in wells may contain as much as 1,000 to 2,000 parts per million of dissolved solids, principally calcium, magnesium, and sodium sulfate and bicarbonates. However, this highly mineralized water comes from only the extreme upper limits of the near-surface reservoir. At slightly greater depths the near-surface water is of better quality. East of the city of Las Vegas, in the lower part of the valley as far south as

Charleston Boulevard the near-surface water is similar to that in the locality described above. Farther south in Paradise Valley, in the vicinity of Whitney, and near Las Vegas Wash, the near-surface water contains from 650 to over 3,000 parts per million of dissolved solids, chiefly calcium, magnesium, and sodium sulfate with some bicarbonate and chloride.

Waters best fitted for domestic and stock purposes contain less than 500 parts per million of dissolved solids and, generally, waters with more than 1,000 parts per million are not satisfactory for these uses. Waters containing more than 2,000 parts per million of dissolved solids, especially when the predominating constituents are calcium, magnesium, and sodium sulfates and bicarbonates, are generally not satisfactory for irrigation (see p. 113). Generally water for either industrial or cooling use is satisfactory even when the dissolved-salt content is very high, although waters containing more than 4,000 parts per million may cause incrustation, corrosion, or other problems.

The evidence presented in the foregoing paragraphs indicates that the near-surface water cannot be widely developed for large-scale irrigation, and that in parts of the valley its chemical character is unsuited for both domestic use and irrigation. However, it appears that the near-surface water can be used satisfactorily for cooling nearly everywhere in the valley. The relatively low temperature of this water, which ranges from 60° to 70° F. throughout the valley, makes it even more satisfactory for cooling than the warmer confined waters. It is satisfactory for domestic and stock use where sanitary conditions are favorable except in most of Paradise Valley and in the vicinity of Whitney and Las Vegas Wash. Before the near-surface water is put to domestic use the sanitary condition should be carefully checked. In several places in Las Vegas, and east and south of the city, large quantities of untreated and poorly treated sewage waters undoubtedly percolate into the near-surface aquifers and probably render water from these aquifers unsuitable for human consumption.

CONFINED WATER

Most of the wells in Las Vegas Valley penetrate aquifers that yield water under sufficient pressure to cause it to flow at the land surface, or to rise within a short distance of the surface. The character, distribution, and number of aquifers and the occurrence of ground water in these aquifers have been discussed in some detail in earlier sections of this report. The following paragraphs describe the form and position of the generalized piezometric surface, the direction of movement, the fluctuations of the water levels, the discharge and recharge, and the quality of the confined water.

The piezometric or pressure-indicating surface of an aquifer—the surface to which water in wells penetrating the aquifer will rise under its full head—is defined by the static levels in the wells. The form and position of a piezometric surface gradually change, and such changes are indicated by the fluctuations of the water level in the wells. In Las Vegas Valley, as in many of the intermontane valleys and basins in the Great Basin, there are several aquifers at different depths (pl. 6A, and B). Each aquifer has its own piezometric surface; the deeper aquifers generally have the higher surfaces. As a result of irregular and locally limited deposition of the sediments that comprise the aquifers and confining beds, as well as faulting in the valley fill, leakage due to improper construction of wells, and other factors, pressures tend to become equalized by movement of water within the wells and formations. Thus, the measured shut-in pressure represents a composite effect of pressures in all aquifers tapped by a given well. Therefore, it is not possible to delineate separate piezometric surfaces for each of the aquifers encountered by wells drilled in Las Vegas Valley. However, numerous periodic measurements of water levels in certain wells separately cased in more than one aquifer indicate that such different piezometric surfaces do exist. This condition is illustrated by the hydrographs in figure 12.

The general direction of movement of the confined water can be determined from the measurements when they are referred to sea-level datum. For example, water levels in wells of approximately equal depth west and north of the city of Las Vegas reach higher altitudes than water levels in similar wells in the city and south and east of the city. Also, water levels in the west part of Paradise Valley reach higher levels than water levels in the vicinity of Whitney and in the east part of Paradise Valley.

Plate 8 shows contours on a composite piezometric surface for the spring of 1944, when water levels in the basin were at approximately the highest stage for the year. These contours connect points of equal altitude on the piezometric surface. The direction of movement and of maximum hydraulic gradient is at right angles to these contours. Thus, the contours in plate 8 show that north of the city of Las Vegas the general slope, and hence movement of the water, is southeast. In the immediate vicinity of and south of the city the movement is toward the east and northeast.

As a result of continued large withdrawal of ground water from wells two large cones of depression have been formed, one to the west of Las Vegas and the other in the east central part of the city. These cones appear on plate 9 as relatively flat areas of the piezometric surface because the large contour interval and the steeply sloping piezometric surface do not permit showing closed contours.

DISCHARGE

Wells

Most of the confined water used in Las Vegas Valley flows from wells. Only a few wells are pumped. Records of the discharge from wells are available for the year 1912 and the period of 1924–1946. There were no wells in the valley prior to 1906. The estimated annual discharge from wells is shown as part of the graph in figure 3 and is given, in acre-feet, in the following table for the years 1912 and 1924–1946:

Year	Amount	Year	Amount
1912	15,200	1935	17,100
1924	17,300	1936	17,400
1925	19,300	1937	17,800
1926	18,400	1938	18,200
1927	17,300	1939	17,900
1928	18,600	1940	16,900
1929	18,500	1941	18,700
1930	17,300	1942	19,600
1931	17,500	1943	22,100
1932	19,200	1944	25,300
1933	17,500	1945	23,900
1934	16,700	1946	28,500

NATURAL DISCHARGE

Confined water in Las Vegas Valley is also discharged from springs and by upward leakage. Geologic study of the southeast part of Las Vegas Valley has yielded no evidence that an appreciable amount of confined water escapes from the valley underground. Study of the valley margins indicates that escape of confined water by underground passage is unlikely in any part of the valley. Therefore, the total discharge of confined water from Las Vegas Valley is represented in the estimates of well discharge, spring discharge, and upward leakage.

Springs

Large quantities of water are discharged from the artesian springs in the vicinity of Las Vegas and the Tule Spring Ranch.

Smaller flows of water issue from Stevens, Kyle, and Corn Creek Springs. Estimates and measurements of the discharge of these springs are available for the years 1905–1907, 1912, and 1924–1946. The estimated annual discharge is shown as a part of the graph in figure 3 and is given, in acre-feet, in the following table for the years 1905–1907, 1912, and 1924–1946:

Year	Amount	Year	Amount
1905	6,400	1934	4,100
1906	6,400	1935	4,100
1907	6,400	1936	4,000
1912	5,300	1937	4,100
1924	5,100	1938	4,100
1925	5,000	1939	3,800
1926	5,000	1940	3,700
1927	4,800	1941	3,400
1928	4,200	1942	3,000
1929	4,100	1943	3,300
1930	4,200	1944	3,000
1931	4,200	1945	3,100
1932	4,100	1946	3,200
1933	4,100		

Upward Leakage

In addition to the water discharged from springs, appreciable quantities of confined water leak upward along the fault zones and into leaky wells, and through the confining beds of the aquifers. This water recharges the near-surface reservoir and is then largely discharged by evaporation and transpiration. The total amount of water lost by leakage from the artesian aquifers is unknown. It is not more than 8,000 acre-feet, the maximum estimated discharge from the near-surface water, and could be considerably less. In the discussion of the over-all safe yield of Las Vegas Valley on page 108 this water is taken into consideration as a part of the near-surface water.

Utilization

Most of the confined water discharged from wells and springs since 1942 has been used in four fairly distinct localities. The largest quantities of water, nearly three-fourths of the total amount used in the valley, are used in the vicinity of the city of Las Vegas in an area of about 22 square miles. Most of this water is used for cooling and domestic purposes and only a small quantity is used for irrigation. In Paradise Valley, south of the city of Las Vegas, and in the vicinity of Tule Springs most of the water withdrawn from wells and springs is used for irrigation. North and east of the city of Las Vegas, in the central and east parts of the valley, the Las Vegas Army Air Field has used large quantities of confined water for domestic purposes. The estimated annual discharge of confined water from wells and springs in each of these localities and in the valley for the years 1905, 1912, 1924, 1941, 1944, and 1946 is tabulated below:

Location	1905	1912	1924	1941	1944	1946
Vicinity of Las Vegas	5,200	9,700	17,800	17,400	20,100	23,200
Paradise Valley, south of Las Vegas	200	10,000	3,500	3,900	4,000	4,600
Tule Springs area	360	300	700	500	3,100	3,200
All others	640	500	400	300	1,100	700
Total	6,400	20,500	22,400	22,100	28,300	31,700

The discharge for 1905 was from springs only. This amount probably represents the total discharge of confined water from the springs for the period prior to settlement of the valley. The discharge figure for 1912 includes water from both wells and springs and shows the approximate increase of discharge of confined water during the early period of well development. From 1912 to 1941 approximately the same quantity of confined water was withdrawn from wells and springs each year, and from 1941 to 1946 there was a considerable increase in withdrawals. This information is also presented in figure 3.

Most of the ground water withdrawn between 1905 and 1946 has been used for domestic purposes, cooling, and limited irrigation. The amount of land irrigated has remained about the same since 1912, but from 1912 to 1940 the population increased about sevenfold. Thus, during the early part of the period 1912 to 1940, a considerable amount of water was not beneficially used. The tremendous increase in population in the valley between 1941 and 1946 (fig. 2), and greater conservation of water since 1939 have resulted in more complete utilization of the present discharge of water from wells and springs. Only about 15 percent of the total discharge ran to waste in 1946.

The maximum use of water occurs during August, and the minimum use during December or January. In the period 1938–1946 a daily average of about 34 acre-feet of water was withdrawn during the month of highest use (fig. 10).

Water Levels

Between 1920 and 1936, water levels in many of the wells that tap the confined water in Las Vegas Valley were measured from time to time by George Hardman of the State Agricultural Experiment Station. During the period 1938 to July 1944, monthly measurements were made in about 50 observation wells by the staff of the State Engineer of Nevada. Beginning in July 1944, monthly measurements were made by the U. S. Geological Survey in 65 wells and, in addition, five automatic water-level recorders were maintained on selected wells. During 1945 and 1946 monthly measurements were made on 56 wells, weekly measurements were made on two wells, daily measurements for part of the period were made on one well, and two pressure recorders and six automatic water-level recorders were maintained for all or nearly all of the period. Also during the years 1944 to 1946, several pumping tests were conducted that required many measurements of water levels in several wells for short periods of time. All water-level measurements made in the Las Vegas Valley prior to December 31, 1945, have been published.[76] Measurements made in 1946 will be published in a future report. Therefore, only measurements of water levels in selected wells are published in the present report. Conclusions reached in this report were based on computations involving all water-level measurements available. The altitude of the measuring points of all the wells in which water levels were measured were determined by instrumental leveling. The piezometric surface shown in plate 8 and the discussion on page 93 are based on these water-level data and, as will be shown in the succeeding paragraphs, data on the level of the confined waters are of paramount significance with regard to ground-water occurrence in Las Vegas Valley. They indicate the areas of recharge and discharge to the ground-water reservoir and the direction of movement of ground water.

SEASONAL AND LONG-TERM FLUCTUATIONS OF THE WATER LEVEL

Both seasonal and long-term fluctuations of the water levels in Las Vegas Valley indicate changes in the amount of storage in the ground-water reservoir. These fluctuations are illustrated by the hydrographs in figures 4, 10, 11, and 12 and are discussed in detail in the succeeding pages. Small daily fluctuations that result from changes in barometric pressure, earth tides, etc., are poorly shown in the hydrographs of automatic water-level recorders or are masked by the fluctuations of greater magnitude. These small fluctuations do not indicate substantial changes in the

[76]Robinson, T. W., Maxey, G. B., Fredericks, J. C., and Jameson, C. H., Water levels and artesian pressure in wells in Las Vegas Valley and other valleys in Nevada, 1913–1945: State of Nevada, Office of the State Engineer, Water Resources Bull. No. 3, 1947.

amount of storage in the reservoirs and are not discussed further.

Long-term records of water levels in wells penetrating the artesian aquifers are available for only a few wells in the valley. Hydrographs of water levels in three of these wells, the Kidder well, (S-20-60) 36dbb1, and the Horace Taylor wells, (S-20-60) 24bac1 and (S-20-60) 24dac1, are shown in figure 4. These wells are about 3 miles west and 4 miles northwest of Las Vegas, respectively, and are between the recharge area and the main discharge area in Las Vegas Valley. The hydrographs show a

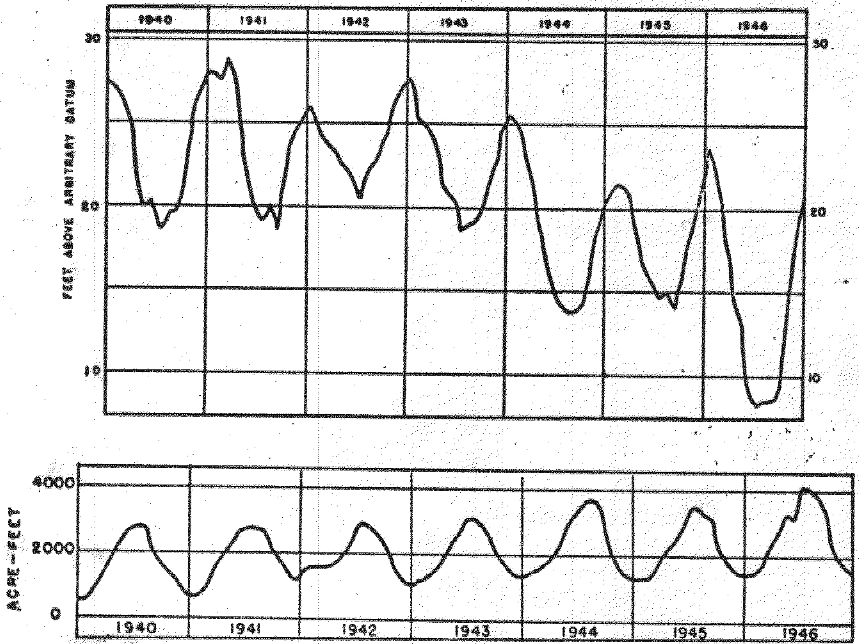


FIGURE 10—Upper graph shows mean monthly level in Las Vegas Valley, based on monthly measurements of water level in 15 selected wells. Lower graph shows estimated monthly discharge of wells and springs in Las Vegas Valley.

continuous decline in water level from 1925 to 1946. Other fragmentary records of water levels in the valley also show this decline. Some wells that flowed prior to and during the early part of the period of record have now ceased to flow. As mentioned before, the flow of artesian springs in the valley has also diminished during this period, as well as during the period 1905 to 1925 (see fig. 3).

Figures 11 and 12 show hydrographs of water levels for the period 1939 to 1946 in the Hicks, Caskey, Papus, Ellis, Lewis, Haggard, Allen, and Parks wells in the city of Las Vegas, where

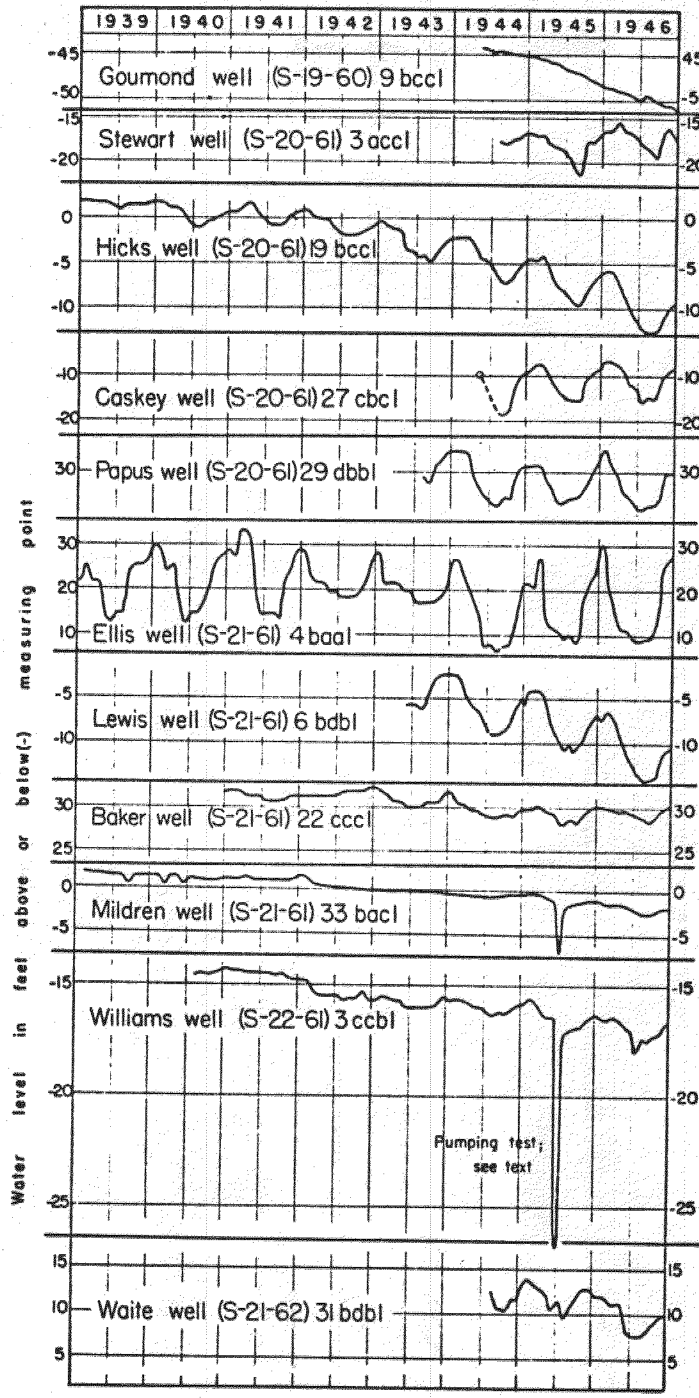


FIGURE 11.—Hydrographs showing fluctuation of the level of the confined water in 11 wells in Las Vegas Valley.

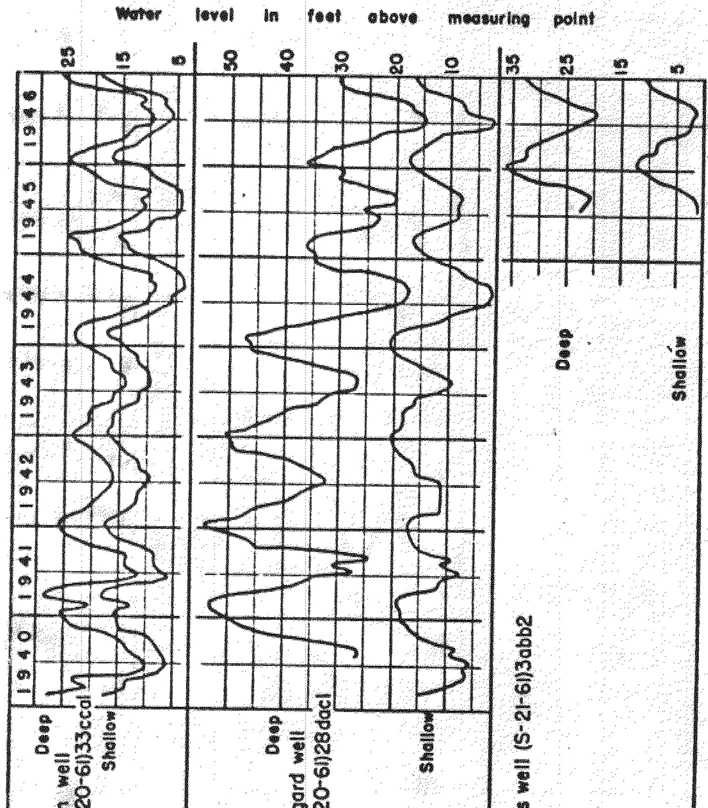


FIGURE 12.—Hydrographs showing the fluctuation and difference in head of the water level in wells penetrating two aquifers, where the well is cased separately to the shallow and deep aquifer. (See Appendix I, table 2, for well construction.)

the water-level decline has been greatest, as much as 10 feet during the 8 years. The decline of water levels during the same period in wells south of Las Vegas in Paradise Valley, and north of the city in the vicinity of Tule Springs, has been much less. The water-level decline in these localities is best indicated by the hydrographs shown for the Baker, Mildren, Williams, and Waite wells in Paradise Valley, and for the Goumond well near Tule Springs. Figure 10, a graph showing the mean monthly water level in 15 selected wells in Las Vegas Valley for the period 1940–1946, also shows this progressive decline. The decline may be the result, in small part, of interference from nearby wells. However, the greater part is due to the development of a cone of depression caused by large withdrawals from closely spaced wells in the vicinity of the city of Las Vegas. Apparently this cone of depression has grown outward from the center of discharge in the vicinity of the city, resulting in a decline of water levels and a reduction in the area of flowing wells. The shrinkage in the area of flowing wells between 1912 and 1946 is shown on plate 2.

In several places near Las Vegas, especially in the eastern parts of secs. 4 and 9 and the western part of sec. 16, T. 21 S., R. 61 E., wells that are pumped heavily are also closely spaced. Heavy withdrawals from such small localities are producing excessive interference, resulting in an abnormally large decline in water levels.

The yearly rate of the decline of water levels in many wells has increased progressively since 1940 and the average water level in the valley declined rapidly from 1943 to 1944 and from 1945 to 1946. Water levels may be expected to decline until the cones of depression in the piezometric surface caused by the withdrawal of water from wells and springs have grown sufficiently to intercept the amount of recharge necessary to balance the total withdrawal of ground water. The discussion of the safe-yield indicates, however, that the discharge in the valley in 1946 exceeded the recharge. Therefore, if withdrawal of water from the aquifers is continued at the 1946 rate, water levels will decline continually, regardless of the magnitude of growth of the depression cones, because the recharge will be continually exceeded and no balance will be reached.

The major seasonal fluctuations of the confined water levels are caused by the seasonal draft. These fluctuations are shown by the hydrographs. The flowing wells are opened in the spring of the year and closed in the fall. There is no set time for opening or closing the wells, but the first wells are generally opened early in March or late in February and by late April most of the wells are flowing at their maximum discharge. In the fall the first wells are closed in the latter part of September and most of the wells are closed and discharge is at a minimum by November 1. The effects of this practice are clearly illustrated in the hydrographs. The highest water levels are generally reached in the early part of February and the lowest levels in September.

Seasonal fluctuations that occur as a result of recharge to the ground-water reservoir are not readily noted in the hydrographs, for they are masked by fluctuations of greater magnitude. However, in figure 10 the highest peaks of the hydrograph showing the average water level in the valley apparently lag about 12 to 18 months behind the years when the heaviest precipitation occurred. For example, the heaviest precipitation on record for Las Vegas occurred in 1941, and even though ground-water withdrawals were greater in 1942 than in 1941, water levels rose higher in the winter of 1942–1943 than in the winter of 1941–1942. There is considerable lag between the periods of heavy precipitation and the spring melt, and the effect of recharge from these sources to the ground-water reservoirs in the valleys is suggested on page 72 in the discussion of the springs in Pahrump Valley. Therefore, it appears possible that the high water levels reached in the winter of each year are partially caused by water percolating into the ground-water reservoir from the previous spring melt in the recharge areas. However, further observation and longer records are needed before more definite conclusions can be made concerning fluctuations resulting from recharge.

Permeability, Specific Capacity, and Interference Tests

The aquifers in Las Vegas Valley act both as storage reservoirs and as conduits to transmit the water from areas of recharge to points of withdrawal. The storage capacity of the aquifers depends upon their vertical and horizontal extent and upon the amount of effective pore space in the materials. Where the water is unconfined, the storage capacity is a measure of the amount of water that will drain from the material by gravity. Where the water is confined under pressure the storage capacity is very much smaller, as it is a measure of the compression of the water itself and of the expansion of the aquifer and associated beds caused by the artesian pressure. The rate at which the water moves through the materials of an aquifer depends upon the field coefficient of permeability (the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent), the cross-sectional area, and the hydraulic gradient. It may be expressed in terms of the transmissibility, which is the field coefficient of permeability multiplied by the thickness of the aquifer in feet. The amount of ground water available for use, and therefore the yield of wells and springs, is limited by these factors and by the amount of recharge.

The specific capacity of a well is the discharge of the well in gallons of water per minute per foot of drawdown of the water level after several hours of flow or pumping. Although the specific capacity depends upon the construction of the well, it also reflects, more or less, the relative transmissibility and storage capacity of the materials from which the well withdraws water. In other words, wells tapping very permeable aquifers generally have large specific capacities, whereas wells tapping less permeable aquifers have low specific capacities. In Las Vegas Valley similar well-drilling methods have been used by the drillers and the construction of wells has been more or less uniform. Therefore, it is probable that the specific capacities of wells are reasonably good indicators of the relative transmissibility of the materials which compose the aquifers tapped by the wells.

Many tests of specific capacity were made on the wells in the valley, and plate 8 was prepared to show the approximate range in specific capacity and zones of differing specific capacity in the vicinity of Las Vegas. Specific capacities recorded for wells in the valley range from about 1 to 100. For wells in the vicinity of and west of Las Vegas Springs the specific capacity averages more than 50, whereas the average for wells east of the scarps is considerably less than 10. It is probable that the zones of high and low permeability are similar to the zones of large and small specific capacity, as shown in plate 8. Other pumping tests described in the following paragraphs and evidence from geologic studies of the valley indicate that this is true. Thus, the most permeable materials in the vicinity of Las Vegas are those of the west and north, and the least permeable are those in and east of the city.

During January and February 1946, when the piezometric surfaces were at their highest and most stable level, interference tests were made in three widely separated localities in the valley. Water levels within the suspected radius of influence of the test wells were stabilized as much as possible by securely capping or controlling the flow of all wells in the localities for at least 24 hours before the tests. The test wells were than allowed to discharge for a period of time during which their discharge and the pressures or discharge of the surrounding wells were measured at frequent intervals. After the discharge period, pressure measurements were made on the test wells and adjacent wells for at least 24 hours.

In test No. 1, the Sunrise Acres Water Association well (S-20-61) 36caa2 was pumped from 10:11 a. m. on January 24, 1946, until 4:10 p. m. of the same day. The average discharge during the period was 180 gallons per minute and the maximum drawdown of the water level in the well was 90 feet. Pressures in three adjacent wells were carefully measured. One of these wells, U. S. Geological Survey test hole (S-20-61) 36cbc1, is only 25 feet deep and penetrates none of the aquifers tapped by the pumped well. The other two wells, owned by William Clark, (S-20-61) 36ccd1, and by L. G. and M. C. Biel (S-20-61) 36ccb1, are 200 feet and 346 feet deep and about 1,200 feet south of and 1,100 feet west of the test well, respectively, and tap aquifers from which the pumped well also withdraws water. It appears that a cone of depression around the pumped well large enough to affect measurably the water levels in these wells was not formed during the short period the well was pumped, because the pressures of the observation wells were constant throughout the test period. The water level in the U. S. Geological Survey test hole also remained constant. The pressure-recovery data obtained when discharge from the well ended were used to calculate the permeability of the aquifer at the well by the Theis graphical method. The transmissibility is about 1,350 gallons per day per foot and, using 45 feet as the combined thickness of the aquifers, the permeability thus is about 30 gallons per day per square foot of cross-sectional area.

In test No. 2, the Henry Wick well (S-22-61) 3dda1, was opened at 3:30 p. m. on February 12, 1946, and closed at 11.05 a. m. on February 14. The average discharge during the period was 1,380 gallons per minute and the drawdown was 59.0 feet. The Wick well is 335 feet deep. The measurable pressure reduction in adjacent wells ranged from 6.5 feet in a well a mile away to 0.2 foot in wells nearly 3 miles away. However, the magnitude of the reduction effect observed at the wells is not always proportional to their distance from the discharging well. This may be because of differences in the depths of the wells and the horizons at which they are perforated, as well as lateral and vertical changes in permeability within the same aquifers. For example, the water level in the Dewey Williams well (S-22-61) 3ccb1, almost 1 mile from the discharging well, declined 6.3 feet. Water levels in the two Wick wells (S-22-61) 3ddb1 and (S-22-61) 2ccc1, about 400 feet and 1,000 feet from the discharging well, respectively, declined only 3.0 feet in the former and 0.6 foot in the latter. The water level in the Fitzpatrick well (S-22-61) 4bcc1, a well only 145 feet deep and nearly 2 miles from the discharging well, declined 3.45 feet, whereas the water level in the Reed well (S-22-61) 2cbc1, about 600 feet deep and 400 feet away, declined only 2.3 feet.

Other results of the effect on the adjacent wells were reductions in flow. The flow of the Nickerson well (S-22-61) 3caa1, about half a mile distant, declined from 171 to 133 gallons per minute or 22 percent. The flow of the Rohr Company well (S-22-61) 10bda1, about 1 mile away, was reduced by 100 gallons per minute, or 28 percent, and the flow of the Hair well (S-22-61) 3bda1, more than half a mile away, was reduced by 17 gallons per minute or 24 percent. These three wells are about the same depth and evidently tap the same aquifers as the discharging well. The permeability determined from the recovery data is about 5,000 gallons per day per square foot of cross-sectional area, using a thickness of 25 feet for the aquifer estimated from logs of nearby wells.

In test No. 3 the Las Vegas Land and Water Company well, (S-20-61) 31dac1, was opened at 11:45 a. m. on February 20, 1946, and closed at 11:45 a. m. on February 21, 1946. The flow during the period was about 4.05 second-feet or 1,800 gallons per minute and the drawdown was 54.75 feet. The depth of the well is 940 feet and it is perforated from 548 to 750 feet and 800 to 904 feet. Most of the water discharged by the well issues from an aquifer 550 to 750 feet below the land surface, and only small quantities come from the aquifer at 800 to 904 feet. The pressure reduction in the adjacent wells that were measured ranged from 4.45 feet to 0.2 foot. In wells that tapped aquifers at depths ranging from about 500 feet to more than 700 feet in depth the magnitude of the reduction effect was approximately proportional to their distance from the discharging well. Water levels in wells tapping shallower aquifers declined, but not in proportion to the distance of the wells from the discharging well. For example, in the Kidder well, (S-20-60) 36dbb1, about 1.31 miles away from the discharging well, the water level declined 0.72 feet during the discharge period, whereas the water level in the Lewis well, (S-21-61) 6bdb1, 1 mile from the discharging well, declined only 0.58 foot in the same period. The flow from adjacent wells that were left open during the test was also reduced. In the R. B. Griffith well, (S-20-61) 32acc1, the flow decreased from 200 to 181 gallons per minute, a reduction of about 9.5 percent. The permeability at the discharging Las Vegas Land and Water Company well, (S-20-61) 31dac1, was determined by the Theis recovery method to be about 1,200 gallons per day per square foot of cross-sectional area, based on a logged thickness of 200 feet for the aquifers.

Two test holes were drilled during the summer of 1946 to determine the thickness and permeability of the aquifers in the vicinity of Tule Spring. One of these holes, well (S-19-60) 27bdc1, was drilled to a depth of 905 feet and the other, well (S-19-60) 33bba1, was drilled to 1,008 feet. Recovery tests run on these wells indicate that the average permeability of the aquifers to a depth of 1,000 feet in that part of Las Vegas Valley lying between the Gilcrease Ranch and La Madre Mountain is about 1,000 gallons per day per square foot of cross-sectional area, based on about 100 feet as the combined thickness of the aquifers. The log of the Gilcrease house well, (S-19-60) 23bbc1, shows largely clay and silt, and probably only inappreciable quantities of water move south through these materials toward the vicinity of Las Vegas. As previously stated, the consolidated rocks of which La Madre Mountain is composed are impermeable and transmit negligible quantities of water. Also, it appears that the materials lying deeper than 1,000 feet in the tested area are probably impermeable. Thus, it appears that most of the water that moves south from the high parts of the Spring Mountains, probably the source of most of the recharge to the ground-water reservoir in Las Vegas Valley, must pass through the narrow strip of permeable materials between the Gilcrease house well and La Madre Mountain. The average hydraulic gradient of the piezometric surface in this strip is about 50 feet per mile, and the width of the strip is estimated to be about 4.5 miles. Therefore, if the permeability is about 1,000 gallons per day per square foot of cross section and the section of permeable materials is 100 feet thick, the total amount of water transmitted through the aquifers is 22,500,000 gallons per day, or 25,000 acre-feet annually. Because of probable variations in the permeability and thickness of the aquifers, the actual figure may be considerably more or less, but at least it is of the correct order of magnitude.

Recharge

As has been mentioned previously, the area enclosed by the drainage boundary of Las Vegas Valley can be considered as a separate ground-water basin. Thus, the ultimate source of the ground water must necessarily be within this drainage boundary. However, only a small part of the water that falls as rain and snow on the watershed reaches the ground-water reservoir. Undoubtedly large quantities are lost by transpiration and evaporation before the water has deeply penetrated the soil and rocks that make up the surface of the basin. An appreciable fraction of the measured precipitation probably never reaches the soil but falls on trees and plants and evaporates following the storms. Studies of this problem have been made in other regions, the physical characteristics of which resemble, more or less, those of Las Vegas Valley. From the results of these investigations it can be safely assumed that in very dry places of low precipitation only negligible quantities of water reach the under-ground reservoirs, and most of the precipitation is dissipated by evaporation and transpiration. For this reason it appears probable that most of the basin beneath the 6,000-foot contour on the east slope of the Spring Mountains, and beneath 6,500-foot contour on the much more arid slopes of the Sheep Mountains, where the average annual rainfall is less than 10 inches, contributes negligible amounts of water to the ground-water reservoir in Las Vegas Valley.

Sufficient data are available to estimate the average quantity of water that falls annually as precipitation on the east slope of the Spring Mountains, tributary to Las Vegas Valley. It is estimated that between altitudes of 6,000 and 8,000 feet, an area of 61,000 acres, the quantity is 81,500 acre-feet; that between 8,000 and 10,000 feet, an area of 18,000 acres, the quantity is 33,000 acre-feet; and above 10,000 feet, an area of 5,000 acres, the quantity is 10,500 acre-feet. On the basis of fragmentary records, field observations, and comparison of conditions on the west and south slopes of the Sheep Mountains with the conditions in the Spring Mountains, it is estimated that between 6,500 and 8,500 feet on the Sheep Mountains, an area of 35,500 acres, the average quantity of water that falls as precipitation is 29,500 acre-feet, and that above 8,500 feet, an area of 5,375 acres, the quantity is 6,700 acre-feet.

Only a small part of the total water from precipitation percolates deeply enough to recharge the ground-water reservoir.

At present, estimates of this fraction must be based on inadequate knowledge of the process. Determination of the quantity of water that actually infiltrates to depth and enters the ground-water aquifers is a complex problem involving many fundamental factors, some of which have been incompletely studied. It requires lengthy, detailed studies far beyond the scope of this investigation.

In the Las Vegas Valley drainage basin, allowance must be made for two important conditions that differ from those in other regions where some study of the problem has been made. Most important of these is the permeability, exposed area, and surface slope of the aquifers where they crop out and where they consist of highly permeable sand and gravel strata that overlaps the more or less impermeable bedrock high up on the mountain slopes. This condition is conducive to infiltration and, therefore, materially reduces the runoff; thus much of that part of the water from precipitation that ordinarily leaves the recharge area as streams in other regions is caught by these permeable gravels and percolates into the aquifers in the recharge areas in Las Vegas Valley. Indeed, no perennial streams flow beyond the upper margin of the alluvial apron. The other condition important in this basin is the aridity of Las Vegas Valley. Most studies of recharge conditions have been made in less arid regions than the Las Vegas Valley. It appears that, although these two conditions tend to offset each other, the proportion of the water from precipitation that enters the ground-water reservoir in the mountains may be greater than that proportion in most other regions where detailed recharge studies have been made.

On this basis it is estimated that 20 percent of the water from precipitation between altitudes of 6,000 and 8,000 feet and 25 percent of that precipitation above 8,000 feet on the east slope of the Spring Mountains, and possibly 20 percent of that from precipitation above 6,500 feet in the Sheep Mountains, recharges the ground-water reservoir in Las Vegas Valley. These estimates are based on the best available data, largely from similar but less arid regions. Thus, the total average annual quantity of water available for recharge to the ground-water reservoir in Las Vegas Valley probably is between 30,000 and 35,000 acre-feet per year.

The Las Vegas Valley basin on the east side of the Spring Mountains is naturally divided by a long bedrock spur known as La Madre Mountain. As previously explained, the rocks composing this spur form a highly impermeable barrier around which ground water from the part of the basin north of La Madre Mountain must pass in order to reach that part of Las Vegas Valley south of Tule Spring Ranch. On the same basis as above, it is estimated that about 24,000 acre-feet of ground water a year originates north of the La Madre Mountain spur. Data based on the hydrologic properties of the aquifers, presented on page 106, indicate that the quantity of water passing through the permeable materials between Gilcrease Ranch and La Madre Mountain is about 25,000 acre-feet annually. This estimate, which was independently determined, is of the same order of magnitude as the estimate of recharge based on precipitation north of La Madre Mountain.

QUALITY

As a part of the investigation, 44 samples of the confined water from the various zones of aquifers were collected and analyzed. The results of the analyses, in addition to results from many analyses made during previous studies, are shown in table 4, appendixes I and II. The analyses were made by the University of Nevada Experiment Station, the United States Geological Survey, and the Nevada Department of Food and Drugs. The analyses show only the dissolved mineral content and do not indicate the sanitary condition of the waters.

As shown by the results of the analyses, the dissolved mineral matter in the confined water consists chiefly of bicarbonates and sulfates of calcium and magnesium, with smaller amounts of silica, sodium and potassium, carbonate, and chloride. A few of the samples were analyzed for fluoride and nitrate and both constitutents were found in small quantities. In the following paragraphs the chemical character of the waters is discussed in its relation to the location and stratigraphy and the use to which the water is put in Las Vegas Valley.

QUALITY IN RELATION TO LOCATION AND STRATIGRAPHY

The chemical character of the waters, as shown by the analyses, ranges considerably in Las Vegas Valley. The waters from wells and springs in the vicinity of the Las Vegas and the Tule Springs, in Tps. 19 and 20 S., Rs. 60 and 61 E., and in the north half of T. 21 S., R. 61 E., are similar in character and contain less dissolved solids than the waters from wells and springs elsewhere in the valley. These waters have a lower temperature than other confined waters in the valley. The waters from wells in the vicinity of Winterwood Ranch, Whitney, and Pittman, in Tps. 21 and 22 S., R. 62 E., contain more dissolved solids and have higher temperatures than other confined waters in the valley. The chemical character of the waters from wells in Paradise Valley, in the south part of T. 21 S., R. 61 E., in the southeast part of T. 21 S., R. 62 E., and in the north part of T. 22 S., R. 61 E., is more or less similar to that of the waters in the vicinity of the city of Las Vegas, but they contain considerably larger quantities of dissolved solids, mostly in the form of calcium sulfate, and the temperature of the waters is higher. The valley fill in the vicinity of and north of the city of Las Vegas was largely derived from carbonate rocks. The sediments composing the valley fill south and east of the city of Las Vegas were eroded from mountains containing many gypsum beds and some igneous rocks in addition to large amounts of limestone and dolomite. Therefore, the valley fill in Paradise Valley and near Whitney and Pittman contains much gypsiferous material. It appears that the larger concentrations of sulfate in the ground waters in these localities are due to solution of gypsum in the sediments of the valley fill as the water passes through them. The water-bearing beds in the vicinity of Whitney and Pittman, near the Winterwood Ranch, and in other sections of the lowest part of the valley are not very permeable and are farther from the source of the ground water. Thus the water travels farther through the sediments and there is much greater opportunity for it to become more highly mineralized. It is also possible that in some localities in this part of Las Vegas Valley some ground water has been trapped in the aquifers and there is little or no circulation. Such trapped water would undoubtedly become highly mineralized in aquifers containing large quantities of gypsum and other minerals. The following table, which is based on many of the analyses listed in tables 4 and 5 in the appendixes, shows the differences in the chemical character of the waters from wells and springs in the three localities discussed above.

It also shows that, in each of the three localities, the average concentration of the chemical constituents of the waters from the three zones of aquifers are quite similar. However, there are considerable differences from one locality to another. In some instances the true average character of the waters from the different aquifers may not be clearly shown because the quantities in the table are based on only a few samples and are probably not representative. Also, the apparent similarity of the waters from the different zones of aquifers may be a result of the mixing of these waters by natural leakage and leakage in the vicinity of improperly constructed wells, especially if it occurs at the wells from which the water samples were taken. Certain differences in the waters from the various aquifers are discernible. The

Average Concentration of Chemical Constituents and Average Temperature in the Shallow, Middle, and Deep Zones of Aquifers in Three Areas in Las Vegas Valley.

Zone of aquifers	Number of samples	Total solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na and K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness	Percent Sodium (Na)	Temperature, °F.
Vicinity of Las Vegas and Tule Springs												
Shallow	26	322	18[1]	50	22	14	228	41	8	211	22	71[2]
Middle	11	328	----	45	25	8	225	32	7	215	8	72[1]
Deep	8	291	18[3]	39	20	26	206	45	7	180	24	75[4]
Paradise Valley												
Shallow	16	711	24[5]	120	44	24	204	315	28	481	10	79[6]
Middle	2	775	--	131	44	25	175	375	29	512	10	
Deep	1	580	36	79	39	33	195	232	20	357	18	
Vicinity of Whitney, Pittman, and Winterwood Ranch												
Shallow	6	2,922	59[7]	244	121	455	125	1,383	443	1,097	47	
Middle	7	3,122	50	240	89	602	115	1,678	303	963	58	76[8]
Deep	2	2,170	----	91	14	589	122	1,161	184	287	81	

[1]Average of 9 samples. [2]Average of 16 samples. [3]Average of 3 samples. [4]Average of 6 samples. [5]Average of 8 samples. [6]Average of 10 samples. [7]Average of 4 samples. [8]Average of 2 samples.

average temperature of water from wells tapping the Shallow Zone of aquifers in the vicinity of Las Vegas is 1 degree lower than that of the waters believed to be from the Middle Zone and 4 degrees lower than that of waters believed to be from the Deep Zone. Also, waters believed to be from the Deep Zone of aquifers in all three areas appear to contain less dissolved solids, are not so hard, and contain a greater proportion of sodium and potassium than waters from either the Shallow or Middle Zones in the same areas. Waters percolating through sediments below the land surface assume the temperature of the materials making up the aquifer. It is well known that a temperature gradient is established in the earth's crust and that under normal conditions the temperature of the materials beneath the surface of the earth increases with depth. Thus the higher temperature of the waters from the deeper aquifers of Las Vegas Valley, a common phenomenon in the intermontane valleys of the Great Basin, is due to warming of the waters as they percolate deeper beneath the land surface. It is not possible to explain completely why the waters from the Deep Zone of aquifers contain less dissolved solids than those from the upper aquifers; many factors of the problem are unstudied and possibly unknown. Possibly part of the water enters the deeper aquifers first, where they crop out at the highest elevations in the foothills, and leaks upward to the shallower aquifers. This would favor increased concentration of the dissolved solids in the upper aquifers, for the water would necessarily have to pass slowly through considerably more sediments and would thus have an opportunity to dissolve larger quantities of mineral matter.

QUALITY IN RELATION TO USE

In the following discussion the general statements concerning the quality of water in relation to use are adapted, in large part, from publications of the United State Geological Survey, the Nevada State Agricultural Experiment Station, and the Nevada Department of Food and Drugs.

Dissolved Solids. After a natural water has evaporated there is a residue consisting of a mixture of minerals, usually some organic matter, and some water of crystallization. This residue is composed of the solids that were dissolved in the water and is shown and referred to as "dissolved solids" in the tables and text of this report. Water containing more than 2,000 parts per million may be unsafe for agriculture, although such water is used in many places where no better is available. If it contains more than 1,000 parts per million it is generally unsuitable for domestic use, although, as for agriculture, inferior water is used in many places. Such water is likely to contain enough of certain constituents to lend an unpleasant taste to it or to make it unsuitable in other respects. In general, water containing less than 700 parts per million of dissolved solids is usually safe for irrigation and is quite satisfactory for domestic use, except for difficulties resulting from its hardness or corrosiveness.

The analyses in tables 4 and 5 in the appendixes show that only wells in the vicinity of Whitney and Pittman and near the Winterwood Ranch yielded waters unsatisfactory for domestic purposes or unsafe for irrigation. Most of the water from wells in the vicinity of Las Vegas and north shows a content of dissolved solids ranging from 200 to nearly 500 parts per million. A few miles south of Las Vegas in Paradise Valley the water contains from 400 to more than 800 parts per million.

Hardness. The hardness of water is most commonly recognized when soap is used with the water in washing. Calcium and magnesium cause nearly all of the hardness of ordinary waters. Water having a hardness of less than 50 parts per million is considered soft, and water with a hardness of 50 to 100 parts per million only slightly increases the consumption of soap when used for ordinary purposes. When water with more than 150 parts per million must be used for municipal supplies it is generally profitable to soften it, although water with a hardness of as much as 250 parts per million is widely used without treatment.

Calcium and magnesium are also the chief active agents in the formation of scale in steam boilers and in other vessels in which water is heated or evaporated. Water with less than 90 parts per million of scale-forming constituents (largely calcium and magnesium, with some suspended matter) is considered good; with 90 to 200 parts per million it is considered fair; with 200 to 430 parts per million it is poor; and with more than 430 parts per million it is bad for boiler use.

As shown by tables 4 and 5 of the appendixes, the hardness of the confined water in Las Vegas Valley ranges greatly. All the water is hard and none is good for use in boilers without treatment. In the vicinity of Las Vegas and north of the city the hardness ranges from 102 to about 300 parts per million. Farther south the water is harder and in the vicinity of Whitney, Pittman, and the Winterwood Ranch the hardness is as high as about 3,000 parts per million, and generally is more than 500 parts per million.

Sodium and Potassium. Sodium, in combination with the sulfate and carbonate radicals, forms the salts that are most commonly referred to as alkalies in agricultural and soil studies. Potassium occurs only in small concentrations in the ground waters of Las Vegas Valley and is calculated and reported with the sodium. The concentration of sodium is commonly expressed as a percentage rather than in parts per million in alkali studies. The percentage of sodium is calculated from analytical results expressed in milligram equivalents per kilogram. The results are obtained by dividing the parts per million of sodium, calcium, and magnesium by their chemical combining weights, 23, 20, and 12.24, respectively; then 100 times the milligram equivalents of sodium is divided by the sum of the milligram equivalents of sodium, calcium, and magnesium. In milligram equivalents $\frac{100\ Na}{Na + Ca + Mg}$ equals the percentage of sodium. Water containing a percentage of sodium of less than 50 is considered safe for irrigation, provided that other conditions, such as type of soil and drainage, are favorable. Water containing more than 60 percent of sodium is considered unsafe for irrigation.

Results of computations based on analyses of representative samples of water from wells in the vicinity of the city of Las Vegas and Paradise Valley are given in the table on page 111. They show that the water is safe for irrigation in these localities.

Results of similar computations for water from wells in Whitney, Pittman, and the Winterwood Ranch are also shown and indicate that the water is unsafe for irrigation.

Sulfate. Sulfate in water that contains much calcium and magnesium causes the formation of hard scale in boilers and increases the noncarbonate or so-called "permanent" hardness (hardness that cannot be mostly removed by boiling the water). Excessive quantities of sulfate are harmful to plants and usually water with more than about 500 parts per million is considered unsafe for irrigation. Also, high-sulfate water is laxative or purgative, especially when present with magnesium, and is therefore quite often unsatisfactory for domestic use. Water containing more than 400 parts per million of sulfate usually has a distinctive taste.

In the water of Las Vegas Valley sulfate ranges from 19 to more than 4,000 parts per million, as shown by the analyses. The water highest in sulfate is that in the vicinity of Whitney, Pittman, and the Winterwood Ranch, where the presence of sulfate and sodium renders the water unsuitable for both irrigation and domestic purposes. In the vicinity of the city of Las Vegas only a few wells yield water with more than 100 parts per million of sulfate and most of the water contains less than 60 parts per million. Most of the wells in Paradise Valley yield water with more than 400 parts per million of sulfate. As previously mentioned, the higher concentration of sulfate in the water in the south part of the valley is probably the result of solution by the ground water of gypsum from the gypsiferous sediments in this vicinity and adjacent localities to the west.

Chloride. Water that contains more than 250 to 300 parts per million of chloride is slightly brackish. Higher concentrations of chloride are correspondingly more salty to the taste, 1,000 parts per million being near the limit of potability. Excessive chloride concentration may result in corrosion, and it is also harmful to plants. Water containing more than about 400 parts per million of chloride may be unsafe for irrigation. Chlorides of calcium and magnesium also contribute to the hardness of water.

In Las Vegas Valley, the water from wells and springs in the vicinity of the city of Las Vegas contains chloride ranging from a trace to less than 30 parts per million. In Paradise Valley the water has a chloride concentration ranging from 10 to more than 100 parts per million. In the vicinity of Whitney, Pittman, and the Winterwood Ranch, concentrations of chloride are as high as 1,140 parts per million, most samples having 200 to 500 parts per million. Thus, in the last-named locality enough chloride is present in most of the water to give it a brackish taste and, in some places, to render the water unsafe for irrigation.

Fluoride. Fluoride in water has been shown to be associated with the dental effect known as mottled enamel, which may appear on the teeth of children who, during the formation of permanent teeth, drink water containing more than 1.5 parts per million of fluoride. If the water contains as much as 4 parts per million of fluoride, 90 percent of the children drinking the water are likely to have mottled enamel.

Only a few samples of water from wells in Las Vegas Valley were analyzed for fluoride, and all of the samples showed 0.6 part or less per million.

GROUND WATER IN PAHRUMP VALLEY

GENERAL RELATIONS

As in Las Vegas Valley, near-surface water is first encountered in wells in Pahrump Valley on the basin lowlands and near the lower margin of the alluvial apron at depths ranging from 1 to 50 feet. This water is usually under slight artesian pressure, but in many places it is unconfined. The near-surface water reservoir apparently is recharged in part by water from the deeper aquifers, although only small quantities of near-surface water are used in the valley or lost by transpiration and evaporation. It appears that most of it is of satisfactory quality for watering stock. Although it contains considerable quantities of dissolved minerals, in most places it is potable and, in a few places, is used for domestic purposes. As in Las Vegas Valley, shallow wells yield only small quantities of water (1 to 5 gallons per minute per foot of drawdown) when pumped and are, therefore, generally unsatisfactory for irrigation. At the present time there is little or no need for water for industrial or cooling purposes in Pahrump Valley. Therefore, the near-surface water is not especially important as a source of water supply in the valley and it was not studied in great detail and is not discussed further in this report. Beneath the near-surface water reservoir are several aquifers that contain confined water, which forms the main source of supply in Pahrump Valley.

DISCHARGE AND RECHARGE

Records of the discharge of wells and springs in Pahrump Valley are fragmentary and only a few measurements of the discharge have been made. Estimates based on these incomplete records are summarized in the following table:

Average Discharge in Pahrump Valley

Period	Amount (acre-feet per year)
1916 to 1937	9,600
1937 to 1940	7,000
1940 to 1946	17,500

During the period 1916 to 1937 most of the discharge was from springs. During that period about 7,300 acre-feet a year was discharged annually in the vicinity of the Pahrump Ranch. During the period 1937 to 1946 several wells that yielded large amounts of water were drilled. In the vicinity of the Manse Ranch about 9,700 acre-feet of water was discharged in 1946 and more than three-fourths of it came from wells. Almost 3,200 acre-feet was discharged from wells in the vicinity of Pahrump Ranch in 1946, and about 4,400 acre-feet flowed from Bennetts Springs. Thus the total discharge in the vicinity of the Pahrump Ranch in that year was about 7,600 acre-feet.

Pahrump Valley is an enclosed ground-water basin, and there is no loss of water from it by underflow. However, some water is discharged by evaporation and transpiration from places where the near-surface water level is close to the surface. Adequate study to determine the amount of water thus lost has not been made, and therefore an estimate of the total discharge of ground water from Pahrump Valley is not available; however, under natural conditions it must have equalled the recharge.

The valley is underlain and enclosed on all sides by impermeable bedrock. Therefore the source of ground-water must necessarily be the precipitation that occurs within the drainage boundaries of the valley. This drainage area is, in many respects, similar to that of Las Vegas Valley and, as in that valley, estimates of the amount of water available for recharge to Pahrump Valley can be made from precipitation data. As explained on page 107, most of the water for recharge comes from precipitation at the higher altitudes. The only areas high enough to contribute appreciable quantities of recharge are the west slopes of the Spring Mountains. These slopes however, are more arid than the east slopes and undoubtedly lose much larger quantities of water by evaporation and transpiration. The appearance of the vegetation indicates that there is considerably less precipitation on the west slopes. Thus, they correspond closely to the west slopes of the Sheep Range which border Las Vegas Valley.

The greater aridity of the west slopes is clearly shown by the distribution of vegetation. Along the east slopes of the Spring Mountains, in Las Vegas Valley, the juniper and pinon pine belt extends as low as 5,000 feet and species characteristic of this belt flourish at altitudes ranging from 6,000 to 7,500 feet. On the west slopes of the mountains, in Pahrump Valley, juniper, pinon pine, and associated plants do not ordinarily grow below an altitude of 6,000 feet, and in few places are thick growths observed below 6,500 feet. Higher up on the slopes on the east side of the range, fir and white pine grow as low as 7,100 feet and thick growths of these and associated plants are common at the higher altitudes. On the west slope of the range, fir and pine do not ordinarily grow beneath 8,000 feet, and even at higher altitudes thick growths of these trees are rare. This evidence, coupled with other evidence from field observation and fragmentary precipitation data, indicate that precipitation below 6,500 feet contribute only small, probably inappreciable, quantities of water to the ground-water reservoir. Thus, the recharge area contributing appreciable quantities in Pahrump Valley consists of 61,000 acres between the altitudes of 6,500 and 8,500 feet and 19,700 acres above the 8,500-foot contour. The area draining into the Pahrump fan and the north part of Pahrump Valley is 32,000 acres between 6,500 and 8,500 feet, and 10,700 acres above 8,500 feet. The remainder of the area drains into the Manse fan and the south part of the valley.

In a manner similar to that used for estimating water for recharge in Las Vegas Valley it is possible to estimate these quantities for Pahrump Valley. As previously noted, this method yielded estimates for Las Vegas Valley that closely checked independently derived estimates based on other data. Assuming that 20 percent of the precipitation beneath an altitude of 8,500 feet and 25 percent of the precipitation above 8,500 feet reaches the ground-water reservoirs, it appears that the annual increment to the ground water in Pahrump Valley is about 23,000 acre-feet. On the basis of the figures given above, it appears that about 12,000 acre-feet of water is annually available for recharge to the Pahrump fan and the north part of the valley and that about 11,000 acre-feet of water is annually available to the Manse fan and the south part of the valley.

WATER-LEVEL FLUCTUATIONS

During 1945 and 1946 the water levels in three wells in Pahrump Valley were measured periodically. During most of that period water-level recorders were maintained on these wells. Hydrographs based on the water-level records are shown in figure 13. They show that fluctuations of water levels in wells in the vicinity of both the Manse and Pahrump Ranches are closely related to changes in the amount of water used in the valley. Thus the highest water levels occur in January and the lowest levels occur in September or October. The hydrographs also show a continuous year-to-year decline in water levels in the observation wells. It appears that water levels are dropping at a rate of about 1 foot a year in the wells on the Manse fan and that the

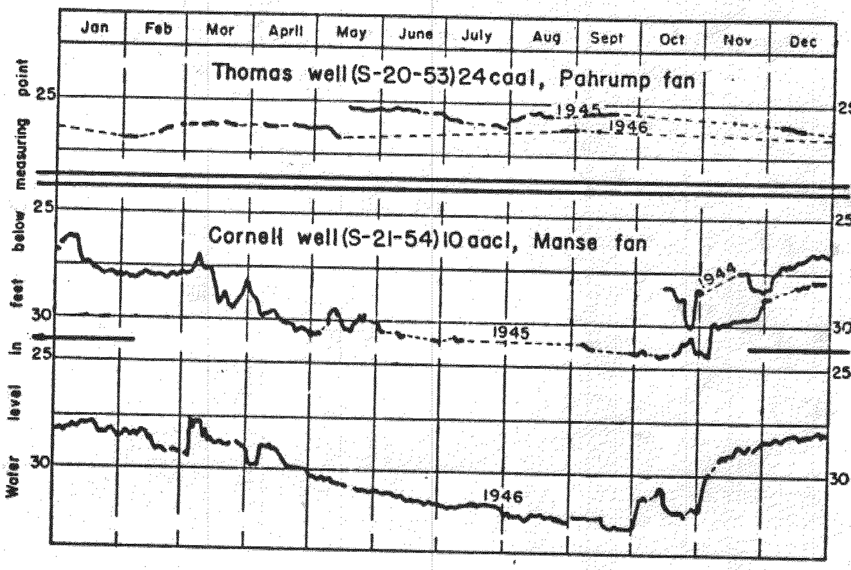


FIGURE 13—Hydrographs showing fluctuation of the level of the confined water in two wells in Pahrump Valley.

decline is less in the well on the Pahrump fan. The water-level decline is probably a result of the growth of two large cones of depression in the piezometric surfaces of the aquifers, which are caused by the large withdrawals of water in the vicinity of the Manse and Pahrump Ranches. Water levels in both localities may be expected to continue to decline until the cones have grown sufficiently to intercept the amount of recharge necessary to balance the total discharge of ground water.

Minor fluctuations caused by changes in barometric pressure and by earth tides are known to occur in wells in Pahrump Valley. The fluctuations are not discussed in this report because they do not reflect, or only temporarily reflect, substantial changes in the movement or storage of ground water.

QUALITY

Results of analyses of water from wells and springs in Pahrump Valley are given in table 4, appendix II. These analyses show that, although the water near the center and on the west side of the valley contains higher concentrations of dissolved solids, all the water is suitable for domestic use and is safe for irrigation. However, the water is hard and none would be classed as good for use in boilers, although most of it is fair for this use.

GROUND WATER IN INDIAN SPRING VALLEY

As in Las Vegas and Pahrump Valleys, the first or near-surface water is encountered by wells at depths of less than 100 feet in the lower parts of Indian Spring Valley. It is believed that this shallow water is recharged largely by the runoff from springs. Most of the wells in the valley are shallow and draw water from the near-surface reservoir and, according to reports by residents in the valley, this water is unconfined.

The few deep wells that penetrate aquifers containing confined water were drilled to depths ranging from 400 to 604 feet.

Most of the ground water discharged in Indian Spring Valley comes from Indian Springs. It is estimated that an average of approximately 800 acre-feet of water a year was discharged from the ground-water reservoir during the years 1905 to 1942 and in 1946. During the period 1943–1945 the total annual discharge increased to more than 1,450 acre-feet as a result of pumping of wells at the U. S. Army Air Field at Indian Springs.

No long-period records of water-level fluctuations are available for Indian Spring Valley. Reports by residents and well owners and occasional water-level measurements indicate that there has been little change in water levels in the valley in the last 20 years.

Recharge to the ground-water reservoir in Indian Spring Valley comes mostly from the north slopes of the Spring Mountains. Fragmentary records and the appearance of the vegetation indicate that the annual precipitation on these slopes below an altitude of 6,500 feet is less than 10 inches. The area tributary to the valley between the altitudes of 6,500 and 8,500 feet is about 20,000 acres, and that above 8,500 feet is about 350 acres. On the basis used for estimating the recharge to Las Vegas and Pahrump Valleys, from precipitation data, it appears that about 4,700 acre-feet of water is available to the ground-water reservoir in Indian Spring Valley; thus the discharge by evapo-transpiration must be substantial.

Results of analyses of water samples from two wells in Indian

Spring Valley are shown in table 4, appendix I. One of the samples from the Harnedy well, (S-16-56) 9bb2, is of water from the shallow aquifer of the near-surface reservoir and the other sample is from a deep well drilled by the U. S. Army. Results of several analyses of near-surface water were published by Hardman,[77] but it has not been possible to identify the wells from which the samples for his analyses were taken. An analysis of the water from Indian Springs is given in table 4, appendix II. All these analyses show that the water from the ground-water reservoir in the vicinity of Indian Springs is hard but suitable for domestic use and safe for irrigation. Although the near-surface water appears to contain a slightly higher concentration of sodium than the confined water, it has about the same character in other respects.

SUMMARY

From the foregoing discussion the following conclusions may be drawn: The only source of ground water for the three valleys is precipitation on the higher areas of the Spring and Sheep Mountains. However, only a small part of this precipitation recharges the alluvial fan and valley fill materials that compose the ground-water reservoirs. Estimates based on the available precipitation data show that the annual recharge to the ground-water reservoir in Las Vegas Valley is between 30,000 and 35,000 acre-feet, and it is approximately 23,000 acre-feet to the ground-water reservoir in Pahrump Valley.

The discharge from wells and springs in Las Vegas Valley was less than 30,000 acre-feet through 1945 and that figure was exceeded for the first time in 1946. Discharge from wells and springs in Pahrump Valley through 1946 never exceeded 17,500 acre-feet. In the vicinity of Las Vegas there are areas of local overdevelopment, as a result of close spacing and heavy pumping of wells. Water levels have been declining and are continuing to decline in Las Vegas Valley. In Pahrump Valley water levels have also declined during the short period of record. In both valleys, the ground-water levels may be expected to continue to decline until the cones of depression in the piezometric or pressure indicating surface caused by the withdrawal of water from wells and springs have grown sufficiently to intercept the recharge necessary to balance the total withdrawals of ground water. In Las Vegas Valley, where the withdrawal from wells approaches

[77] Hardman, George, and Miller, M. R., The quality of the waters from southeastern Nevada; drainage basins and water resources: Univ. of Nevada Agr. Exper. Sta. Bull. 136, p. 29.

the total annual recharge, this may be expected to take longer than in Pahrump Valley. The available data indicate that continued withdrawal of substantially more than 35,000 acre-feet of ground water annually will result in overdevelopment of the ground-water supply in Las Vegas Valley. Some ground water appears to be available for additional development in Pahrump Valley. Sufficient data are not available to show whether a substantial unused supply is available in Indian Spring Valley.

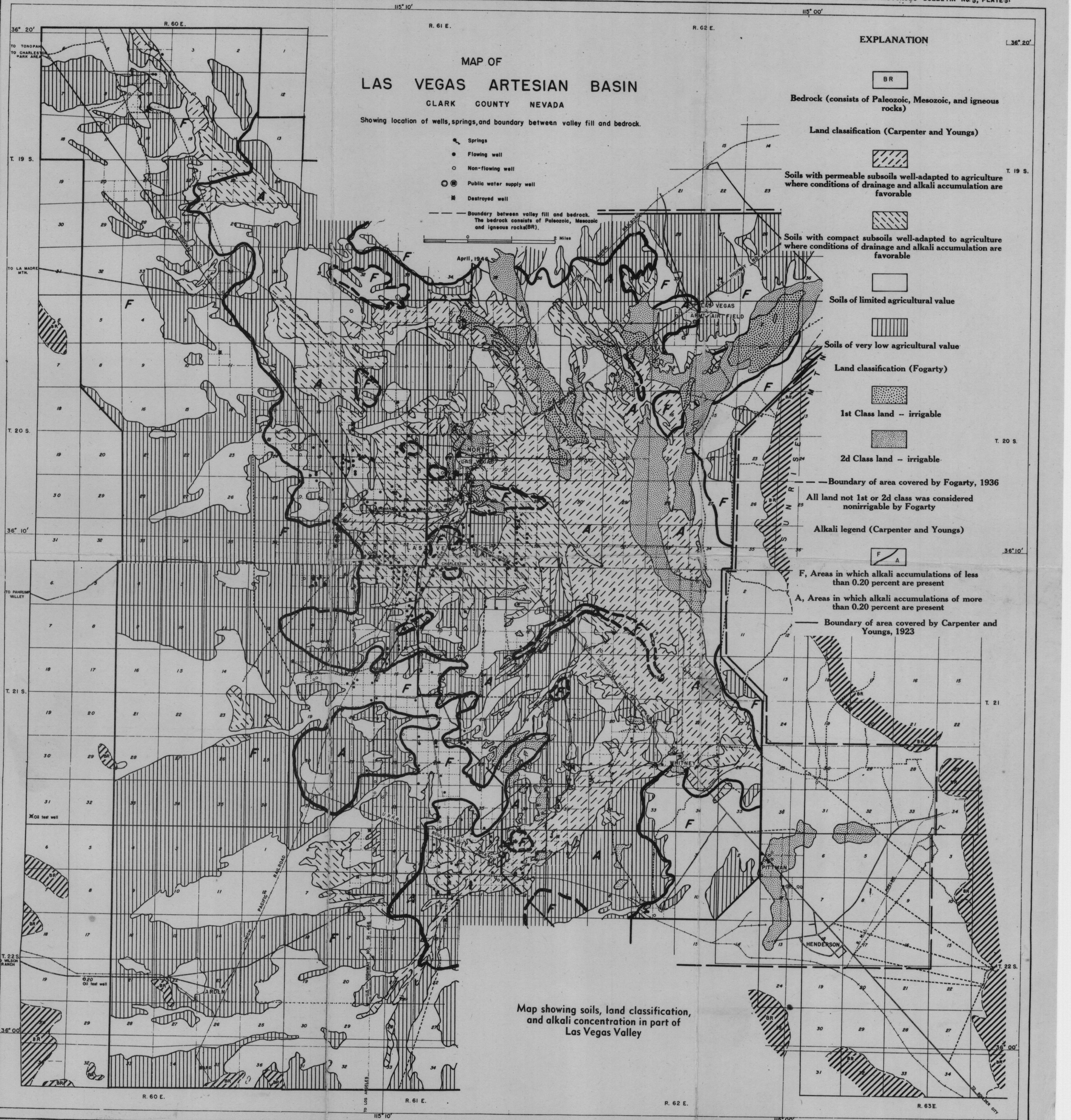

GENERAL GEOLOGIC MAP
OF
LAS VEGAS, PAHRUMP, AND INDIAN SPRING VALLEYS,
CLARK AND NYE COUNTIES, NEVADA
Scale
1 0 1 2 3 4 MILES
1946
EXPLANATION
SEDIMENTARY ROCKS
Qyal
Younger alluvial deposits.
(Valley fill and playa deposits, largely silt, and clay, some sand and gravel; locally permeable, secondary source of ground water).
Recent
Ql
Lake and playa deposits.
(Silt, and silt clay, low permeability).
Pleistocene
Quaternary
QToa
Older alluvial deposits.
(Gravel, sand, some silt, little clay; highly permeable, forms principal source of ground water).
Pleistocene(?) and Pliocene(?)
Tme
Muddy Creek and Esmeralda(?) formations.
(Silt, clay, and volcanic ash, few thin lenses of water-bearing sandstone, and pebble conglomerate; permeable in part).
Pliocene(?) and Miocene(?)
Tertiary
TKJR
Horse Spring formation, Overton fanglomerate, Aztec sandstone, Chinle formation, Shinarump conglomerate, and Moenkopi formation.
(Limestone, sandstone, and shale; permeable where brecciated and jointed).
Triassic, Jurassic, Cretaceous, and Tertiary(?)
PCksb
"Late Paleozoic" rocks, Kaibab limestone, Supai, and Bird Spring formations.
(Sand, silty limestone, limestone, dolomite, and some shale; generally impermeable).
Carboniferous and Permian
CDms
"Middle Paleozoic" rocks, Monte Cristo, and Sultan limestones.
(Cavernous limestones, highly impermeable along faults and joints).
D€
"Early Paleozoic" rocks, Goodsprings dolomite, and Bright Angel shale. Includes pre-Cambrian rocks at base of Frenchman Mountain.
(Limestone, shale, sandstone, and quartzite).
Cambrian to Devonian
IGNEOUS ROCKS
QTv
Basalt series, lavas of The River Mountains, and Ransome's Black Canyon group.
Tertiary and Quaternary
Approximate formation boundary.
Non-flowing well
Spring
Flowing well
SPRING MOUNTAINS
NEVADA NATIONAL FOREST
SHEEP RANGE
HIDDEN FOREST
DESERT RANGE
THREE LAKES VALLEY
LAS VEGAS VALLEY
PAHRUMP VALLEY
PAHRUMP FAN
MANSE FAN
KYLE CANYON FAN
RED ROCK FAN
LA MADRE MOUNTAIN
FRENCHMAN MTN.
RIVER MOUNTAINS
Mc CULLOUGH RANGE
YUCCA FOREST
Not mapped
Las Vegas
Las Vegas Army Air Field
Henderson
Indian Springs
Charleston Pk.
Hayford Pk. 9730
Sheep Pk. 9706
Gass Pk. 6940
Black Mtn 5045
NYE COUNTY
CLARK COUNTY
NEVADA
CALIFORNIA
SEE INSET NO. 1
SEE INSET NO. 2
SEE INSET NO. 3
Inset No. 1. Location of wells and springs in the vicinity of Pahrump, Nevada.
Inset No. 2. Location of wells and springs in the vicinity of Manse Ranch, Nevada.
Inset No. 3. Location of wells and springs in the vicinity of Indian Springs, Nevada.
Scale of insets
0 2 miles


MAP SHOWING AREAS OF BEDROCK AND VALLEY FILL, DRAINAGE BOUNDARY, AREAS OF ARTESIAN FLOW, AND PRECIPITATION STATIONS.
Scale
1 0 1 2 3 4 MILES
1946
EXPLANATION
BR VF
Boundary between bedrock, BR; and valley fill, VF.
Area of artesian flow, 1946.
(Dashed-line symbol indicates exact boundary; remainder of boundary approximate).
Boundary of area of artesian flow, 1912.
Boundary of drainage basin.
Precipitation station.
Scarps in valley fill.
3000
Contours on land surface.
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
R. 54 E.
R. 55 E.
R. 55-1/2 E.
R. 56 E.
R. 57 E.
R. 58 E.
R. 59 E.
R. 60 E.
R. 52 E.
R. 53 E.
R. 61 E.
R. 62 E.
R. 63 E.
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
T. 22 S.
T. 23 S.
T. 24 N., R. 8 E., S.B.M.
SPOTTED RANGE
PINTWATER RANGE
THREE LAKE VALLEY
DESERT RANGE
SHEEP RANGE
HIDDEN FOREST
Hayford Pk 9730
Sheep Pk 9706
YUCCA FOREST
LAS VEGAS RANGE
Gass Pk 6940
INDIAN SPRING VALLEY
Army Air Field
Indian Springs
To Tonopah
To Alamo
CLARK COUNTY
NYE COUNTY
Mt Stirling 8183
Johnnie
To Las Vegas and Tonopah
Cold Creek Ranch
Corn Creek Ranch
State Highway No. 52
Lee Canyon Rd.
U.S. Highway No. 95
PAHRUMP VALLEY
SPRING MOUNTAINS
Charleston Pk 11910
Kyle Canyon Rd.
State Highway No. 39
State Highway No. 16
LAS VEGAS VALLEY
Tule Spring Ranch
Gilcrease Ranch
Lovell
Dike
Apex
To Salt Lake City
U.S. Highway No. 91-93
Las Vegas Army Air Field
Wann
North Las Vegas
LAS VEGAS
FRENCHMAN MT.
LA MADRE MOUNTAIN
Pahrump Ranch
Manse Ranch
Roberts Ranch
RED ROCK
To Death Valley Jct.
State Highway No. 52
To Shoshone
NEVADA
CALIFORNIA
Bracken
Boulder Jct
Whitney
LAS VEGAS WASH
Pittman
Basic Magnesium Project
Henderson
RIVER MOUNTAINS
To Boulder City
Blue Diamond
Pierce
Arden
U.S. Highway No. 91-466
Potosi Mt 8500
BIRD SPRING RANGE
NOT MAPPED
Bard
Sloan
Rhoden Ranch
To Sandy
To Los Angeles
McCULLOUGH RANGE
Black Mt 5043

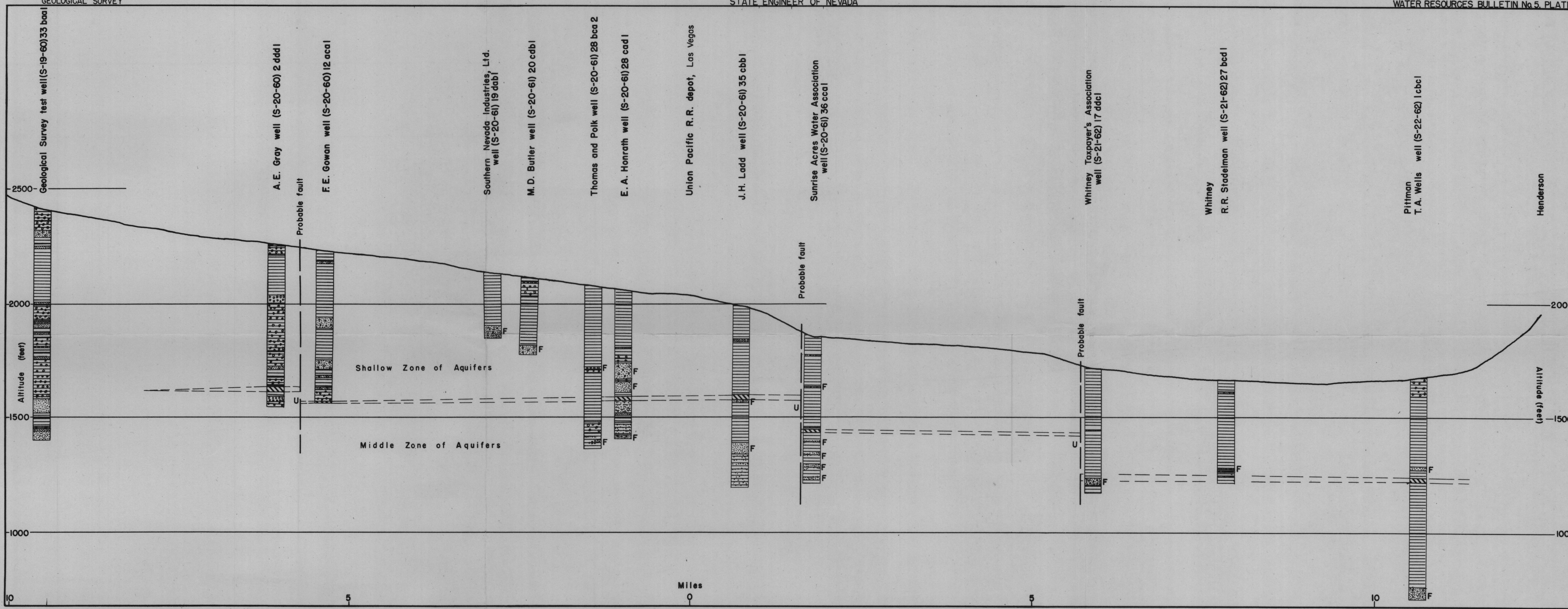
UNITED STATES DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY

STATE ENGINEER OF NEVADA

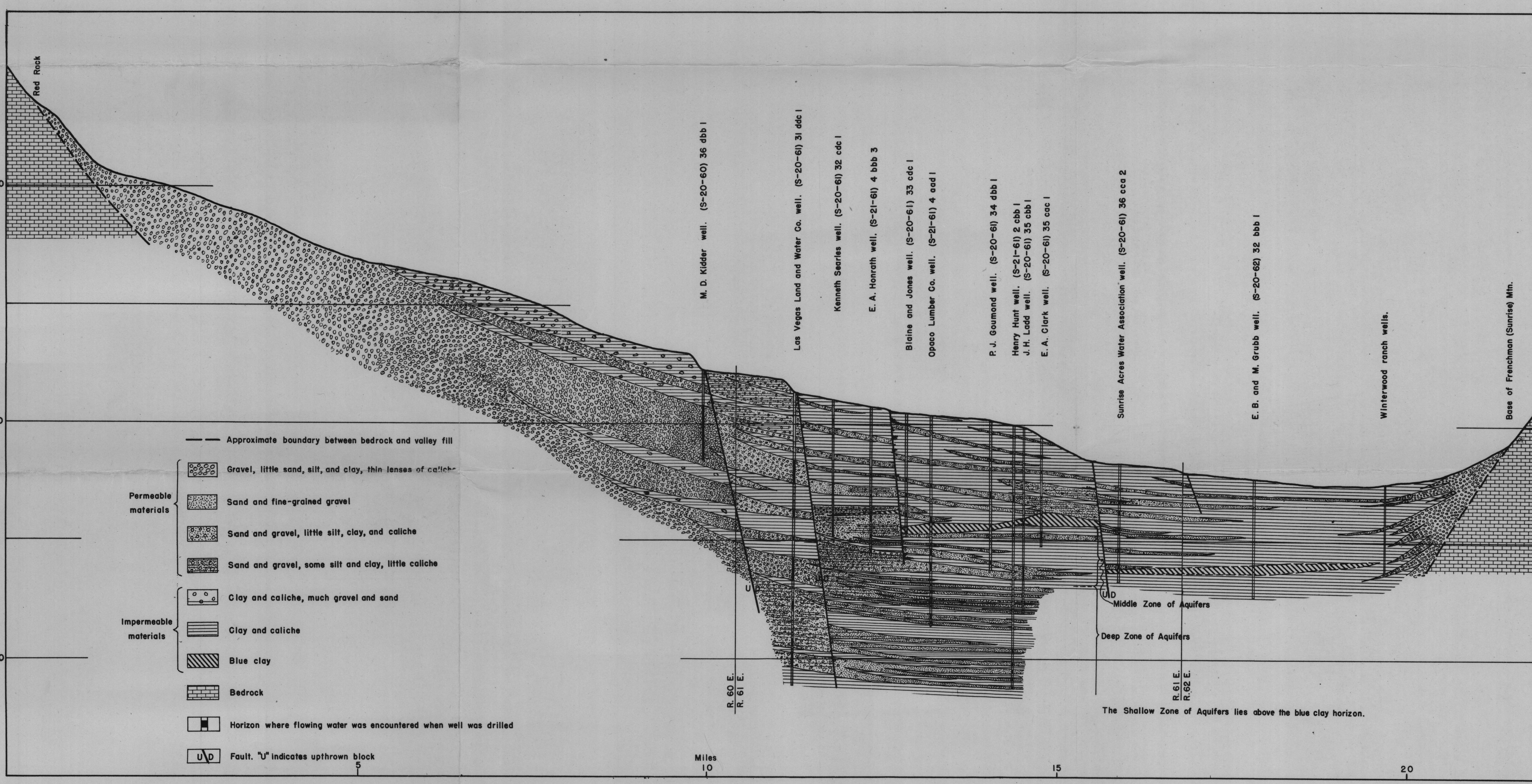
WATER RESOURCES BULLETIN No. 5, PLATE 5



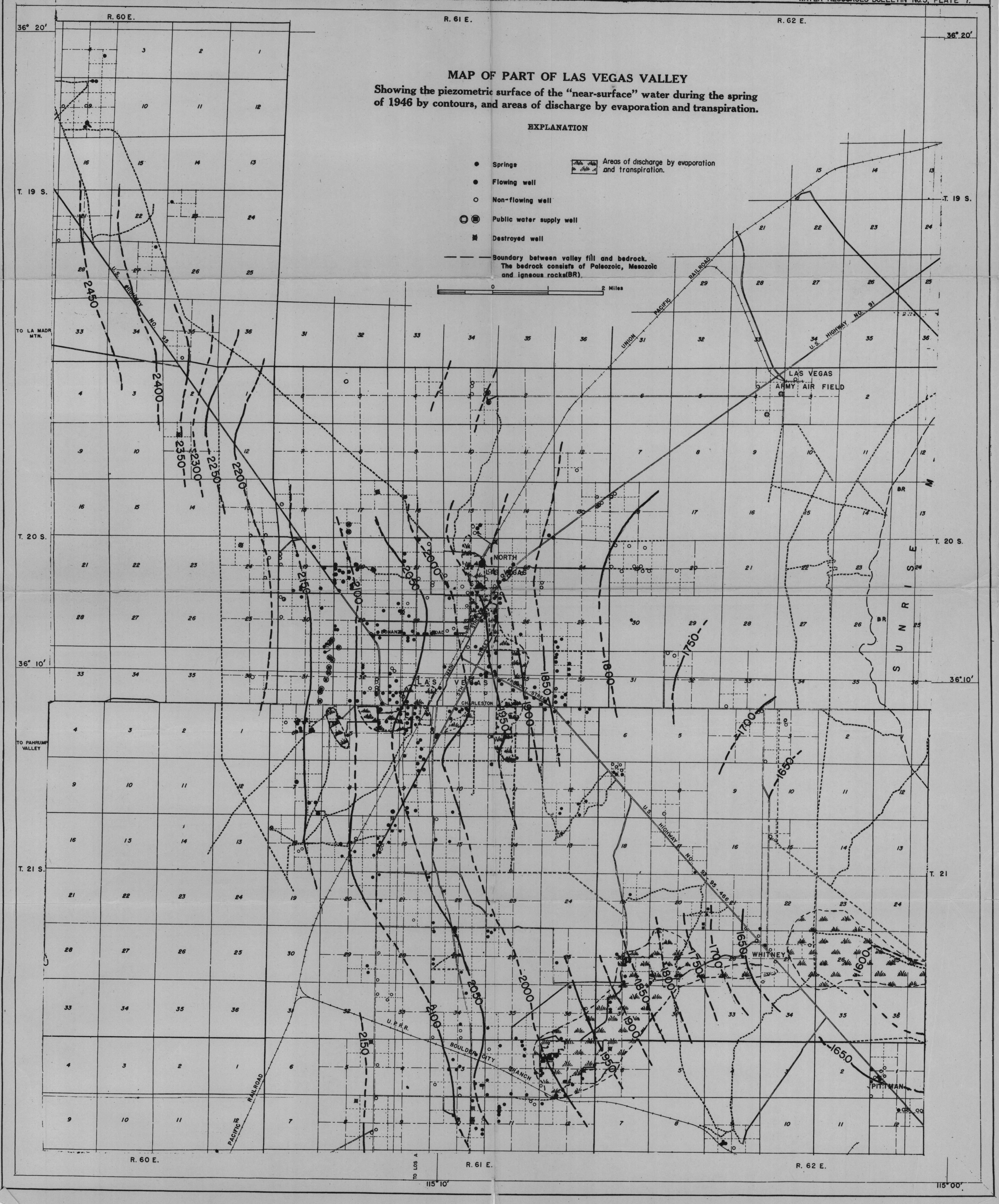
Map showing soils, land classification, and alkali concentration in part of Las Vegas Valley



A. NORTHWEST-SOUTHEAST SECTION (A-A' ON PLATE 1) OF LAS VEGAS VALLEY
Showing the extent and apparent displacement of the blue-clay horizon as indicated by well logs. "F" indicates horizons where flowing water was encountered.



B. EAST-WEST SECTION (B-B' ON PLATE 1) OF LAS VEGAS VALLEY
Based on well logs and other geologic data, showing lateral grading in grain size of the sediments and faulting in the valley fill.


MAP OF PART OF LAS VEGAS VALLEY
Showing the piezometric surface of the "near-surface" water during the spring of 1946 by contours, and areas of discharge by evaporation and transpiration.
EXPLANATION
Springs
Flowing well
Non-flowing well
Public water supply well
Destroyed well
Areas of discharge by evaporation and transpiration.
Boundary between valley fill and bedrock. The bedrock consists of Paleozoic, Mesozoic and igneous rocks (BR).
0
2 Miles
R. 60 E.
R. 61 E.
R. 62 E.
36° 20'
36° 10'
T. 19 S.
T. 20 S.
T. 21 S.
115° 10'
115° 00'
TO LA MADR MTN.
TO PAHRUMP VALLEY
U.S. HIGHWAY NO. 95
U.S. HIGHWAY NO. 91
UNION PACIFIC RAILROAD
LAS VEGAS ARMY AIR FIELD
NORTH LAS VEGAS
LAS VEGAS
CHARLESTON
FREMONT
WHITNEY
PITTMAN
SUNRISE M
U.P.R.R. BOULDER CITY BRANCH
PACIFIC RAILROAD
BR
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600

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WATER RESOURCES BULLETIN No. 5, PLATE 8.