Geohydrology of the Needles Area, Arizona, California, and Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 486-J

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By D. G. METZGER *and* O. J. LOELTZ

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GEOHYDROLOGY OF THE NEEDLES AREA, ARIZONA, CALIFORNIA, AND NEVADA

By D. G. Metzger and O. J. Loeltz

ABSTRACT

The Needles area, as defined in this report, includes Mohave and Chemehuevi Valleys, and extends from Davis Dam (57 miles south of Hoover Dam) southward to Parker Dam. It is in Mohave County, Ariz., San Bernardino County, Calif., and Clark County, Nev.

The principal landforms are rugged mountains, piedmont slopes, and flood plain. Locally, a pediment is present on the bedrock of the mountains bordering the west side of Mohave Valley. The highest summit in the Black Mountains is 5,216 feet above sea level, and in the Chemehuevi Mountains in Arizona, 5,148 feet above sea level. The piedmont slopes have gradients that range from about 100 to 300 feet per mile. The Colorado River flood plain in Mohave Valley has a maximum width of 5 miles. The former flood plain in Chemehuevi Valley is covered by Havasu Lake. In 1968, the average altitude of the Colorado River at Bullhead City, Ariz., was about 500 feet above sea level; at Topock, Ariz., about 455 feet. The average altitude of Havasu Lake is about 448 feet above sea level.

The consolidated rocks of the mountains, referred to collectively as bedrock, are relatively impermeable and form the boundaries of the ground-water reservoir. There is no evidence to indicate any sizable potential for development of ground water in the bedrock, although locally, small yields may be developed from fractures. The geologic units that are important in an evaluation of the water resources are the fanglomerate, the Bouse Formation, and the alluviums of the Colorado River and its tributaries.

The fanglomerate of Miocene(?) age is made up chiefly of cemented gravel composed of angular to subrounded and poorly sorted pebbles and some fine-grained material that are thought to come from a nearby source. It varies widely in thickness because it was deposited on an irregular surface having considerable local relief. The fanglomerate probably is a potential aquifer on the basis of grain size and degree of cementation. However, only meager subsurface data are available for substantiating this supposition because most wells are drilled either into Colorado River deposits or the Bouse Formation.

The Bouse Formation of Pliocene age is composed of a basal limestone overlain by interbedded clay, silt, and sand and by a tufa. The thickest known section is the 254 feet that was penetrated in well (B–16–20½) 11ccd; a much thicker section probably is present beneath the central part of Mohave Valley. Only two wells produce water from the Bouse, and these have limited yields. Because of the clay beds in the Bouse, it can be anticipated that the Bouse has a low permeability in the Needles area.

The alluviums of the Colorado River and its tributaries are the result of several periods of extensive degradation and aggradation by the Colorado River. The alluviums are divided into older alluviums, which are the deposits of several degradations and aggradations by the Colorado River, and younger alluvium, which is the deposit of the youngest aggradation. The alluviums are heterogeneous mixtures of gravel, sand, silt, and clay.

The alluviums are treated as a composite aquifer because of the obvious hydraulic continuity between the several alluviums and because of the difficulty of separating them on the basis of subsurface data. Most of the yield from wells that are perforated in these deposits comes from highly permeable beds of sand and gravel. Wells that tap a sufficient thickness of Colorado River gravels have specific capacities as high as 400 gallons per minute per foot of drawdown.

Ground water in the Colorado River alluviums in the Needles area occurs under water-table conditions. Ground water may occur under artesian conditions in or below the Bouse Formation.

Sources of recharge to the ground-water reservoir are the Colorado River, unused irrigation water, runoff from precipitation, and underflow from bordering areas. Of these, the Colorado River is by far the principal source. Recharge from unused irrigation water is, in a sense, a negative discharge inasmuch as practically all irrigation supplies are obtained from wells. Recharge by runoff from precipitation occurs in the sandy washes of the area. Recharge by underflow from bordering areas occurs where the major ephemeral streams such as the Sacramento, Piute, and Chemehuevi Washes enter the Needles area.

Ground water is discharged from the aquifers by wells and evapotranspiration. Discharge to the Colorado River, if it occurs at all, is negligible. Pumped ground water is used for municipal and domestic supplies and for irrigation. Ground water is discharged by evapotranspiration throughout the flood-plain area.

Under natural conditions the Colorado River annually overflowed its banks and flooded large parts of the adjacent lowland. Natural vegetation, consisting mainly of arrowweed, mesquite, and willow, thrived in the flood plain. Attempts were made to divert water from the Colorado River as early as 1891, either by gravity or by pumping, but the early attempts were unsuccessful mainly because of the uncontrolled flows of the river. Early plans for irrigating flood-plain lands by pumping from wells also proved unsuccessful. As a result, irrigation agriculture was gradually abandoned to the point where, during the 1940's, only a few hundred acres were being irrigated. However, irrigation agriculture was revived during the 1950's. During 1964–68, pumpage for irrigation ranged from about 12,000 to 21,000 acre-feet per year. However, diversion of river water for irrigation remained small, the acreage so irrigated being less than 2,000.

The closure of Hoover Dam, to the north of the area, in 1936, and of Parker Dam in 1938, caused major changes in the hydraulic regimen in the Needles area. The closure of Hoover Dam ended the annual spring floods and caused some scouring of the channel. The closure of Parker Dam and subsequent filling of Havasu Lake caused a rapid aggradation of the Colorado River channel in the immediate area of the lake. Within a few years the definable channel in the lower part of the flood plain east and southeast of Needles was obliterated. By 1944 the aggradation had caused river stages and consequently ground-water levels to rise sufficiently to threaten the town of Needles and the Atchison, Topeka, and Santa Fe Railway and to waterlog much land. To alleviate the situation, the U.S. Bureau of Reclamation initiated programs for dredging the river channel and for improving the channel geometry. Most of the dredging and channel improvement work in Mohave Valley was completed by July 1960. Work downstream from Topock was halted pending studies of the physical and ecological changes in the canyon downstream from Topock.

The average river stage from the northern end of Mohave Valley to a point about 10 miles north of Needles is now about 4 feet higher than it was under natural conditions. The differences in stage increase southward, so that at Needles the stage is about 8 feet higher and at Topock about 27 feet higher than under natural conditions. These higher river stages, which have resulted in a higher water table and therefore in increased evapotranspiration, have caused additional depletion of the available water supply.

The alluvial deposits commonly tapped by irrigation wells east of the Colorado River are very permeable. Hydraulic conductivities of about 10,000 gpd (gallons per day) per square foot are indicated at several sites in Arizona. Hydraulic conductivities between 1,000 and 5,000 gpd per square foot are indicated by four pumping tests made in California. Transmissivities of several hundred thousand to about a million gallons per day per foot are common for the alluvial deposits underlying much of the flood plain and for Colorado River gravel where it occurs beneath the alluvial slopes adjacent to the flood plain.

Limited soil-moisture studies suggest that in an area of rising water levels beneath the flood plain outside irrigated areas the capacity to store water is between 32 and 42 percent of the volume saturated by the rising water levels. Outside the flood plain, the capacity is less.

Under natural conditions, ground-water discharge in Mohave Valley averaged about 170,000 acre-feet per year. Ground-water recharge was a similar amount. Owing to the much more limited area of flood plain and water-loving vegetation in Chemehuevi Valley, both ground-water recharge and discharge were much less in that valley than in Mohave Valley.

Under present conditions in Mohave Valley about 150,000 acre-feet of water infiltrates directly from the river to the ground-water reservoir. Most of this infiltration occurs in a 37-mile reach of the river downstream from Bullhead City, Ariz. An infiltration rate of about 8,000 acre-feet per year per mile length of channel is indicated for a reach 2 miles upstream from Needles. This is twice the average rate of infiltration for the 37-mile reach. Most of the infiltration eventually supports the growth of phreatophytes which thrive on the flood plain.

The impounding of Havasu Lake behind Parker Dam effected a new control for ground-water levels in the valley adjacent to and above the reservoir. The average altitude of Havasu Lake of 448 feet rather than the previous river level became the new control for ground-water levels. Currently, the average lake level ranges from 27 feet higher at the gaging station near Topock, to 76 feet higher near Parker Dam, than did the river levels prior to 1938. As a result of this increase in head, a substantial quantity of water from the lake has infiltrated to the ground-water reservoir in the process of establishing new equilibrium conditions between the surface water and ground water. In recent years a new equilibrium has been virtually attained. Consequently, the interchange between surface water and ground water in Chemehuevi Valley is small—only a fraction of the interchange that is occurring in Mohave Valley.

Ground-water levels in the Needles area generally fluctuate within an annual range of 2 feet except near pumping wells, irrigated land, and the river. Water levels generally are between 9 and 12 feet below the land surface in the flood plain. On the alluvial slopes that border the flood plain, the depth to water is governed largely by the height of the land surface above the water level in the flood plain opposite a given site. In many areas the depth to water increases between 100 and 200 feet per mile with increasing distance from the flood plain.

A water budget for the Colorado River valley between Davis Dam and the gaging station near Topock for the period 1950–66 shows an annual streamflow depletion of about 180,000 acre-feet, an average unmeasured inflow of 30,000 acre-feet, and a negligible unmeasured outflow. The total depletion or consumptive use within the area thus is about 210,000 acre-feet, based largely on differences in streamflow measurements at the upper and lower ends of the valley. On the other hand, the annual consumptive use, based on acreages and rates of use, is estimated to be 188,000 acre-feet by natural vegetation, 12,000 acre-feet by crops, and 41,000 acre-feet by evaporation from open water surfaces, a total of 241,000 acre-feet. Because of the quantitative uncertainty of many of the budget items, no attempt is made to adjust the budget to eliminate the imbalance of 30,000 acre-feet that exists between the two methods used for computing consumptive use.

A similar budget for the Colorado River valley between Topock and Parker Dam shows an average annual streamflow depletion (after adjusting streamflow measurements for out-of-basin diversions and changes in content of Havasu Lake) of 151,000 acre-feet and an additional unmeasured annual net inflow of 24,000 acre-feet. The consumptive use in the area, based largely on differences between streamflow measurements, thus averages about 175,000 acre-feet per year. On the other hand, the annual consumptive use based on acreages and rates of use are estimated to average 4,000 acre-feet by natural vegetation and 140,000 acre-feet by evaporation. Consumptive use by irrigated crops is negligible. The difference of about 30,000 acre-feet between the total consumptive use computed by the two methods is equal to but opposite in sense to the difference that was indicated for the budget of the upstream river valley.

The greatest potential for developing additional beneficial use of water is the substitution of crops for the natural vegetation that has a low economic value and a high water-consumption rate. A substitution of crops for mesquite would limit the additional depletion of the total water supply to about 6,500 acre-feet per year.

Both the Fort Mohave and the Chemehuevi Indian Reservations have substantial, but as yet largely unexercised rights for diverting water from the Colorado River. Diversions of water by the Fort Mohave Indian Reservation will probably result in little additional depletion of the total supply because the average rate of use by crops is not likely to be greatly different from the rate of use by the natural vegetation they replace. Diversion of water for irrigation by the Chemehuevi Indian

Reservation, however, will result in an additional depletion of the total supply because the diversion presumably will be to lands that are not now supporting the growth of water-loving natural vegetation.

Additional water might be made available for beneficial use by affecting a reduction in the quantity of water consumed by natural vegetation. The U.S. Bureau of Reclamation (written commun., 1971) estimates that 45,000 acre-feet per year can be salvaged in the Mohave Valley by this method.

Chemical analyses of water from wells in the Needles area indicate that ground water is of better quality than that in other parts of the lower Colorado River area. Of the 95 samples of ground water that were analyzed, 46 analyses had dissolved solids of less than 1,000 mg/l (milligrams per liter) and six had less than 500; the smallest concentration found was 314 mg/l. On the other extreme, six analyses had dissolved-solids content of more than 2,000 mg/l; the largest concentration was 3,290 mg/l.

The chemical composition of ground water indicates that much of the water was derived from the Colorado River and that the ground water has been altered by three primary processes: concentration by evapotranspiration, precipitation of calcium and magnesium carbonates, and reduction of sulfate.

Ground water that contains about the same concentration of dissolved solids as Colorado River water (between 600 and 800 mg/l and less than 1.5 mg/l fluorides) is acceptable to the residents for domestic use. Locally, where water of this quality is not available, water exceeding these concentrations is used.

Concentration of dissolved solids in much of the ground water exceeds the usual standard for irrigation use. However, the fact that ground water is being used successfully indicates that other factors, such as salinity of soil, drainage, amounts of water applied, manner of application, and types of crops are also important.

INTRODUCTION

PURPOSE OF INVESTIGATION

An investigation of the ground-water resources of the Needles area, Arizona, California, and Nevada, began in 1960 as a part of a Federal appraisal of the water resources of the lower Colorado River area (fig. 1), which extended from Davis Dam south along the valleys of the Colorado River to the International Boundary, and to the Imperial Valley. The general objectives of the investigation in the Needles area were to determine the location, extent, and hydraulic characteristics of aquifers; the relation of the aquifers to the Colorado River and other conveyance channels; the amount of evapotranspiration; and the chemical character of the water.

The investigation in the Needles area is less detailed than the investigations of the other areas of the lower Colorado River. Throughout this report, therefore, reference will be made to the more detailed investigation of the Parker-Blythe-Cibola area (Metzger and others, 1972), which is adjacent to the Needles area (fig. 1). Many of the interpretations for the downstream study may be transferred with reasonable confidence to the Needles area because the two areas are similar in many respects as regards geology, chemical character of the water, and surface- and ground-water hydrology.

LOCATION OF AREA

The Needles area is mostly in Mohave County, Ariz., and San Bernardino County, Calif. A small part is in Clark County, Nev. The term "Needles area" is here used to include all the Colorado River valley from Davis Dam to Parker Dam, and it includes Mohave and Chemehuevi Valleys. However, the base map (pl. 1) includes only that part of Chemehuevi Valley in which ground water has been developed. Needles, Calif., is near the center of the area.

METHODS OF INVESTIGATION

Forty-three holes, 4 inches in diameter, and ranging in depth from 12 to 167 feet, were augered with a powered rig. Although the material below the water table sloughed, sandpoints could be installed readily in the loosened material. These wells were used to collect water samples and for periodic measurements of the water level. In addition, three holes were drilled to depths ranging from 18 to 21 feet using a hand auger, and completed with 5-inch casing. These wells were equipped with graphic water-stage recorders. Two privately owned wells also were similarly equipped.

Nine pumping tests were made to determine the water-bearing characteristics of the materials. Chemical analyses were made of 95 samples of ground water from sandpoint wells and other sources.

Selected analyses of ground water are given in table 9. The ground-water samples were obtained from shallow test holes drilled by the Geological Survey, from privately owned wells drilled for domestic, municipal, irrigation, or industrial supply, and from wells drilled for other Federal agencies. All tabulated analyses represent samples collected directly by the Geological Survey and analyzed either in a field laboratory at Yuma, Ariz., using rapid analytical methods, or at the Survey's permanent water-quality laboratory at Albuquerque, N. Mex., using standard Survey procedures.

The investigation was made under the general supervision of C. C. McDonald, project hydrologist. The ground-water section was prepared by the junior author; the rest of the report by the senior author.

SURFACE FEATURES

The Needles area is in the Sonoran Desert section of the Basin and Range physiographic province (Fenneman, 1931, p. 326–395). The section is characterized by roughly parallel mountains separated by alluvial basins

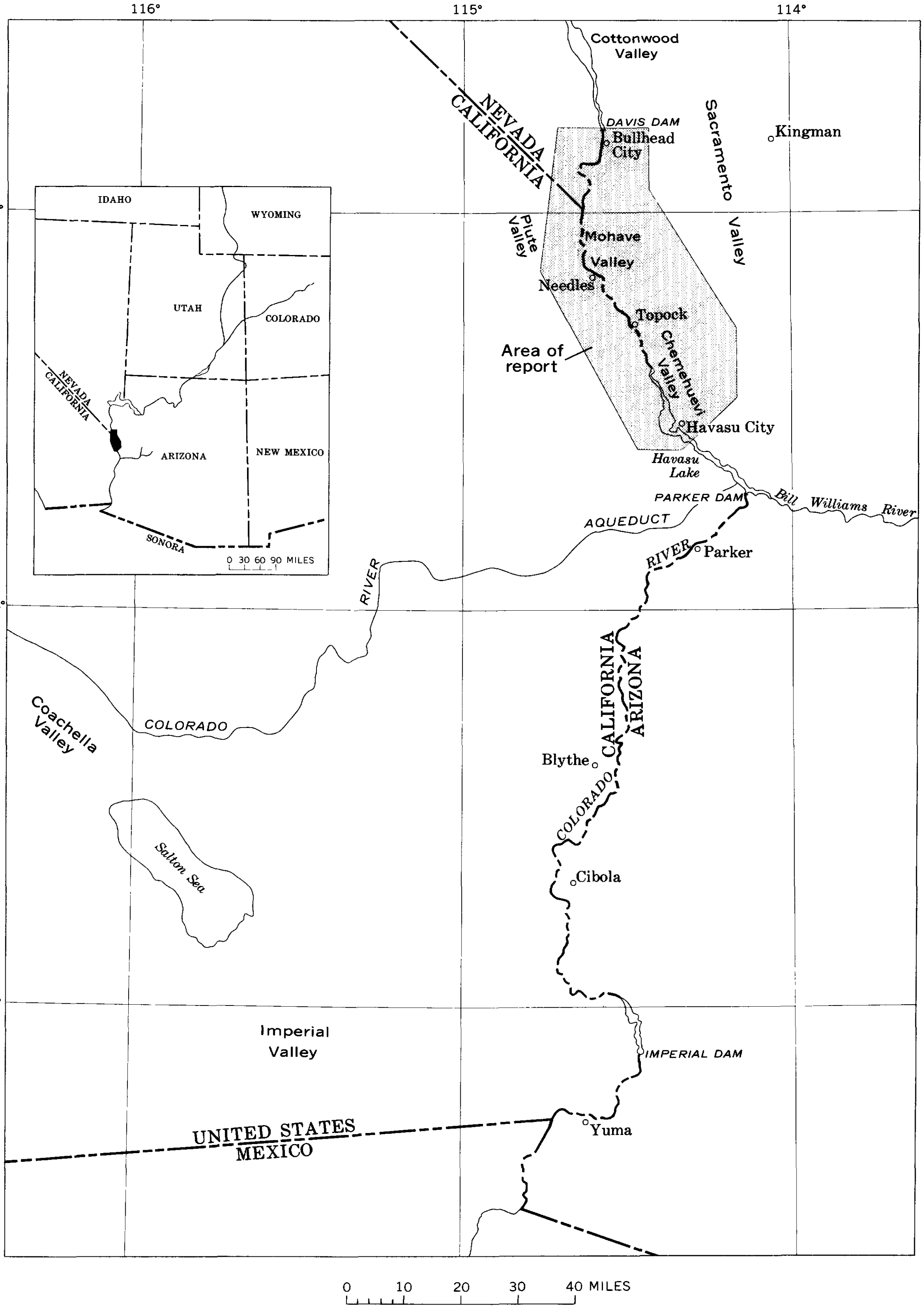


FIGURE 1.—Index maps showing location of the Needles area.

and by an arid and hot climate. Generally, the basins lie between sea level and 1,000 feet. Although the Sonoran Desert section is, for the most part, one of ephemeral drainage, the Needles area is exceptional in that it contains a perennial stream with a wide flood plain. However, the ephemeral nature of the drainage applies to the tributaries of the Colorado River, the master stream in the area.

The flood plain, as used in this report, is that part of the Colorado River valley (fig. 2) that has been covered by floods of the modern Colorado River prior to the construction of Hoover Dam. The flood plain is wider than the meandering course of the Colorado River, and it is bounded generally by a terrace. There are many indications of lateral shift of the channel of the Colorado River. This can be seen on aerial photographs which show many abandoned channels of the river.

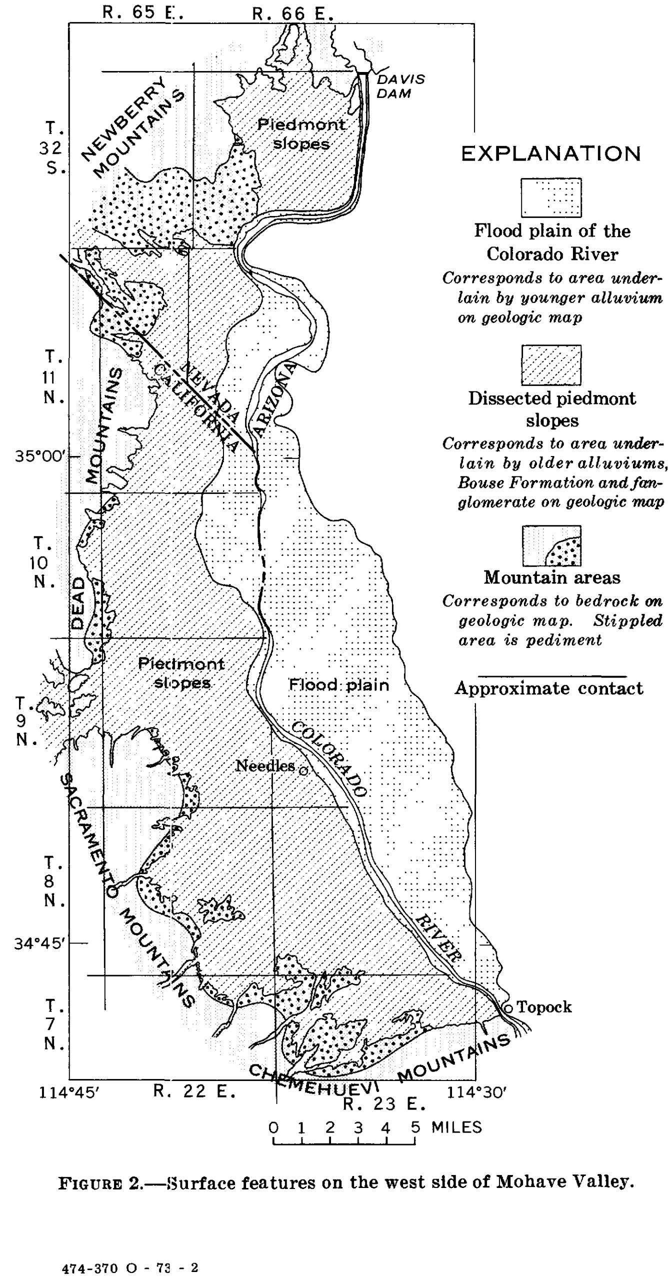


FIGURE 2.—Surface features on the west side of Mohave Valley.

The maximum width of the flood plain in Mohave Valley is about 5 miles. From Davis Dam southward for about 10 miles, the Colorado River is confined to a narrow flood plain cut in alluvial deposits. Then the flood plain widens and reaches its maximum width near Needles. In Chemehuevi Valley the flood plain is now covered by the waters of Havasu Lake. In 1968 the average altitude of the Colorado River at Bullhead City, Ariz., was about 500 feet above sea level; at Topock, about 455 feet. The average altitude of Havasu Lake is about 448 feet, and it remains fairly constant because of the requirements of the pumps operated and maintained by the Metropolitan Water District.

The mountains of the area are rugged and rise abruptly from the pediments, piedmont slopes, or the Colorado River in the bedrock narrows. The highest summits are in the Black Mountains (5,216 ft.) and in T. 14 N., R. 19 W. in the Chemehuevi Mountains (5,148 ft.). Many of the mountain crests are above 3,000 feet.

Between the flood plain and the mountains are the dissected piedmont or alluvial slopes. Locally, a pediment has been cut on the bedrock of the mountains bordering the west side of Mohave Valley (fig. 2).

The pediment is cut on granitic, metamorphic, and Tertiary sedimentary rocks. On the southeast part of the Newberry Mountains, the pediment is concave upward and has a slope that ranges from 400 feet per mile to 300 feet per mile near the river. On the Dead Mountains the pediment forms a narrow bench. South of Needles, the pediment has a slope of about 150 feet per mile and is very much eroded.

The piedmont slopes have gradients that range from about 100 to 300 feet per mile. The steepest gradient occurs on the piedmont slope between the Newberry and Dead Mountains. It is 330 feet per mile, and the slope is concave upward. Near the flood plain the gradient is about 240 feet per mile. The piedmont slopes from the Black Mountains east of Needles have gradients that range from 100 to 150 feet per mile. East of Havsau Lake, the gradients range from about 150 feet per mile near the lake to about 260 feet per mile near the mountains.

The washes generally have about the same gradient as the piedmont surfaces. In some localities, however, the washes have a gradient that is about 10 to 20 feet per mile more than that of the adjacent alluvial slopes. An example is the area west of Havasu Lake in T. 4 N. The washes near the edge of the map (pl. 1) are incised only about 20 feet below the adjacent alluvial slopes;

yet, near the lake, the washes are incised as much as 120 feet.

CLIMATE

The Needles area has a dry, warm climate, which is characterized by mild winters and hot summers, when temperatures above 100°F are common. The meager precipitation (fig. 3) is concentrated about equally in two periods, one in the summer and the other in the winter. The precipitation is the result of two different types of storm. In the summer, moist air from the Gulf of Mexico along with the high temperatures results in local thunderstorms. These can have high intensities, resulting in rapid, although local, runoff. The winter storms come from the Pacific Ocean and cause gentle rains with little or no runoff.

The annual precipitation on the flood plain and piedmont slopes is about 5 to 6 inches and on the higher mountains about 10 inches (Hely and Peck, 1964, pl. 3). Occasionally in August or September, moist air from tropical disturbances in the Pacific Ocean enters the desert and, coupled with the moist air from the Gulf of Mexico, causes heavy rains throughout the area. An example is the first of three storms in September 1939, which dropped 5.12 inches of rain on Needles, 2.70

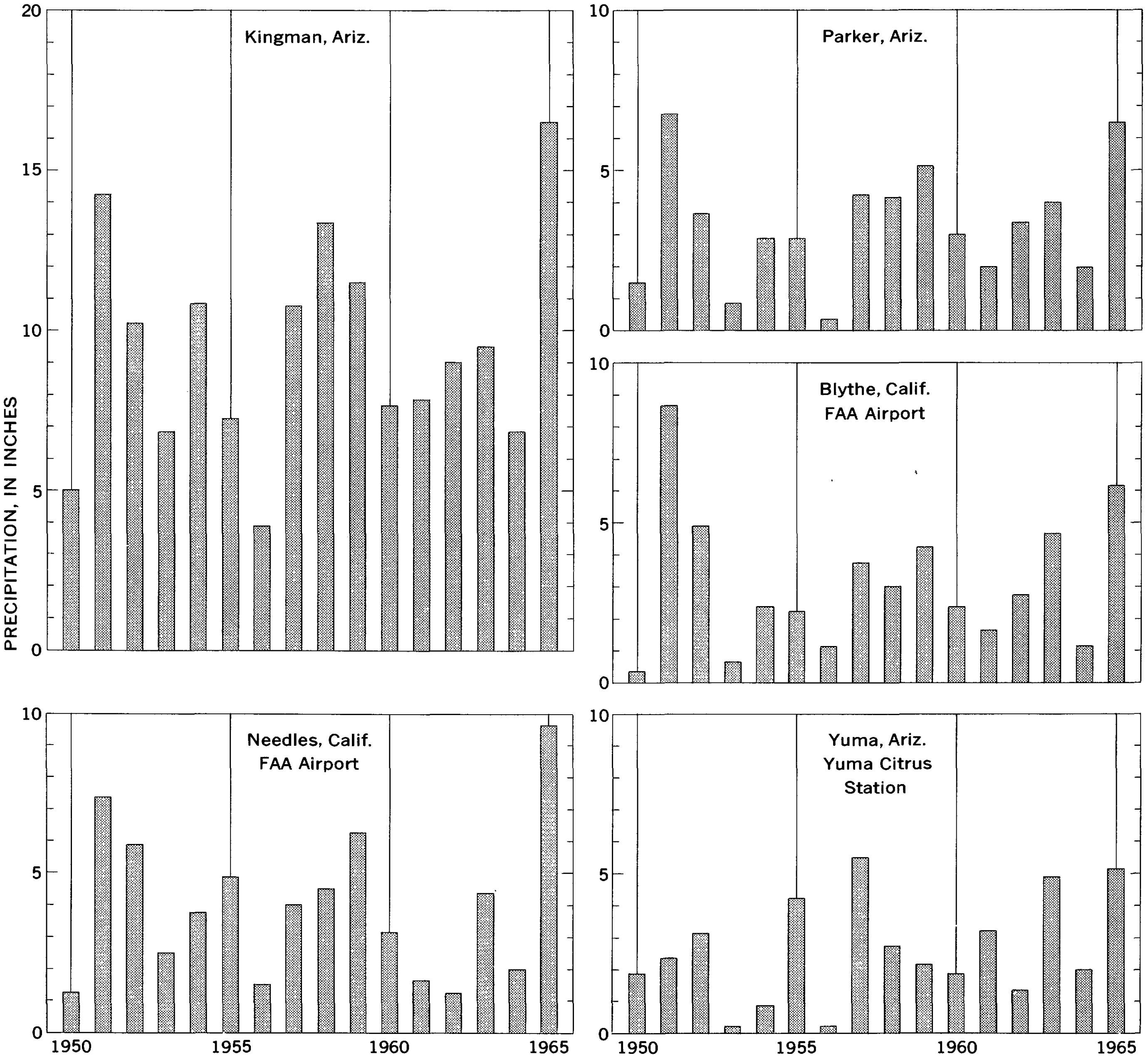


FIGURE 3.—Annual precipitation at five climatological stations in the lower Colorado River area, 1950–65.

inches of which fell between 4:30 a.m. and 10:30 a.m. on September 6. For the month of September 1939, 7.61 inches of rain was recorded, which is in sharp contrast to the average annual rainfall of less than 5 inches.

ACKNOWLEDGMENTS

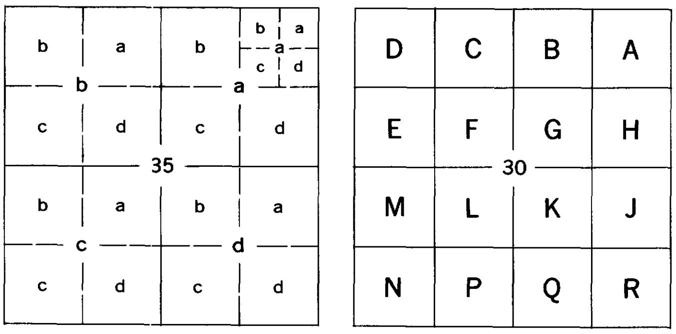
The authors wish to thank the many citizens of the Needles area who furnished information on their wells. Organizations which willingly supplied information on their wells include the city of Needles, Lake Havasu Irrigation and Drainage District, Oasis Utility Co., and El Paso Natural Gas Co.

WELL-NUMBERING SYSTEMS

Three systems of well numbers are used in this report because the Needles area is in Arizona, California, and Nevada. These systems were developed by the Geological Survey for use in the three States and are based on the Bureau of Land Management system of land subdivision.

In the Arizona system, wells are assigned numbers according to their locations in the land survey based on and Gila and Salt River base line and meridian which divides the State into four quadrants. For assignment of well numbers, these quadrants are designated counterclockwise by the capital letters A, B, C, and D, letter A being the northeast quadrant. Wells in the Needles area are in the B quadrant—that is, all are west of the meridian and north of the base line. For example, the first well inventoried in the NE¼NE¼NE¼ sec. 35, T. 18 N., R. 22 W. is given the number (B–18–22) 35aaa. The capital letter indicates that the well is north and west of the intersection of the base line and meridian.

The first set of numbers indicates the township (T. 18 N.); the second set of numbers indicates the range (R. 22 W.); and the third set, the section (sec. 35). Lowercase letters a, b, c, and d after the section number indicate the well location within the section (fig. 4). The first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These tracts also are designated counterclockwise beginning in the northeast quarter. Where more than one well is within a particular tract, the wells are distinguished by adding consecutive numbers beginning with one after the lowercase letters.



Arizona and Nevada systems

California system

FIGURE 4.—Sketches showing well-numbering systems.

In the California system, wells are assigned numbers according to their locations in the land survey based on the San Bernardino base line and meridian. For example, the first well inventoried in the NE¼ NE¼ sec. 30, T. 9 N., R. 23 E. is given the number 9N/23E–30A1. The part of the number preceding the slash (/) indicates the township (T. 9 N.), the number following the slash indicates the range (R. 23 E.), the number following the dash (–) indicates the section (sec. 30), and the letter following the section number indicates the 40-acre subdivision of the section (fig. 4). Within the 40-acre subdivision, the wells are numbered serially as indicated by the final digit. Thus, well 9N/23E–30A1 is the first well inventoried in the NE¼ NE¼ sec. 30, T. 9 N., R. 23 E. The letters N and E indicate that the entire area is north of the San Bernardino base line and east of the meridian.

In the Nevada system, wells are assigned numbers according to their locations in the land survey based on the Mount Diablo base line and meridian. For example, the first well inventoried in the SW¼SW¼SW¼ sec. 10, T. 33 S., R. 66 E. is given the number S33/66–10ccc. The number preceding the slash (/) is the number of the township (S33), the number following the slash is the range east of the meridian (66), and the number following the dash (–) is the section. The section is subdivided exactly as in the Arizona system described above. Thus, well S33/66–10ccc is the first well inventoried in the SW¼SW¼SW¼ sec. 10, T. 33 S., R. 66 E. The capital S indicates that the area is south of the Mount Diablo base line.

For numbers in all systems, if the location of a well is unverified, a "Z" is substituted for the letter following the section number. Where more than one well is reported for a section, the wells are numbered serially.

Because the Colorado River at some locations has shifted its course since the land survey networks were established, some land that was surveyed using the California network is now in Arizona and vice versa. Because the number given a well is based on the land survey network at the well site, it sometimes happens that a well now in Arizona will have a number based on the California land survey network, and a well that is now in California may have a number based on the Arizona network. These instances are noted in the report.

REPORTING OF WATER-QUALITY DATA

For water-quality data in this report, concentration of the various constituents is given in milligrams per liter, temperature is given in degrees Celsius (°C), and conductivity is given in micromhos at 25°C. The terms "parts per million" and "milligrams per liter" are practically synonymous for water containing as much as 5,000 to 10,000 mg/l (milligrams per liter) of dissolved solids. Temperature data can be converted to degrees Fahrenheit (°F) by using the following:

°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
32	0	51	11	70	21	89	32	108	42
33	1	52	11	71	22	90	32	109	43
34	1	53	12	72	22	91	33	110	43
35	2	54	12	73	23	92	33	111	44
36	2	55	13	74	23	93	34	112	44
37	3	56	13	75	24	94	34	113	45
38	3	57	14	76	24	95	35	114	46
39	4	58	14	77	25	96	36	115	46
40	4	59	15	78	26	97	36	116	47
41	5	60	16	79	26	98	37	117	47
42	6	61	16	80	27	99	37	118	48
43	6	62	17	81	27	100	38	119	48
44	7	63	17	82	28	101	38	120	49
45	7	64	18	83	28	102	39	121	49
46	8	65	18	84	29	103	39	122	50
47	8	66	19	85	29	104	40		
48	9	67	19	86	30	105	41		
49	9	68	20	87	31	106	41		
50	10	69	21	88	31	107	42		

GEOLOGIC UNITS AND EVENTS AND THE WATER-BEARING CHARACTERISTICS OF THE ROCKS

PERSPECTIVE

The geologic units that are important in an evaluation of the water resources of the Needles area are the fanglomerate, the Bouse Formation, and the alluviums of the Colorado River and its tributaries. The consolidated rocks of the mountains, referred to collectively as bedrock, are relatively impermeable, and form the boundaries of the ground-water reservoir. There is no evidence to indicate any sizable potential for ground-water development in the bedrock.

The absence of Paleozoic carbonate rocks precludes interbasin movement of substantial quantities of ground water through the mountains in a manner similar to that reported for the Paleozoic rocks of southern Nevada (Loeltz, 1960). Rather, the interbasin movement of water in the lower Colorado River area occurs, for the most part, in alluvium. However, some interbasin movement may occur through volcanic rocks, especially if the water levels in one basin are several hundred feet higher than those in an adjacent basin. Interbasin movement under these conditions is inferred to occur between Eldorado Valley, a basin of interior drainage west of the Colorado River below Hoover Dam, and the Colorado River valley. Rush and Huxel (1966, p. 18) conclude that the estimated average ground-water recharge of 1,100 acre-feet per year in Eldorado Valley must move eastward through volcanic rocks to the Colorado River valley because there is virtually no ground-water discharge in Eldorado Valley. (The water table beneath the playa in Eldorado Valley is at least 270 ft below land surface, and the water level there is about 800 ft higher than the Colorado River.)

Likewise, ground water may also be moving from Sacramento Valley through the volcanics of the Black Mountains to the Needles area. Although this possibility exists, such movement does not detract from the statement that there is no sizable potential for developing ground water from bedrock. The quantity of such movement would be of academic interest only. It would be nearly impossible to develop even low-production wells because such movement would be only through fracture zones and possibly along bedding planes.

Therefore, the bedrock was not investigated in detail, and the study of the geohydrology was oriented principally towards an understanding of the rock units that underlie the flood plain and piedmont slopes.

BEDROCK

Bedrock, as here used, includes all rocks older than the fanglomerate of Miocene(?) age, and is made up of igneous and metamorphic rocks of the basement complex, volcanic rocks of Mesozoic and Tertiary age, and sedimentary rocks of Tertiary age. Generally, the volcanic and sedimentary rocks are folded and dip steeply; this is in marked contrast to the overlying fanglomerate and alluvial deposits which dip gently.

The only rocks that can be dated with assurance are some of the Tertiary sedimentary rocks. These occur in the Sacramento Mountains about 10 miles west of Needles in sec. 4, T. 8 N., R. 21 E. (not shown on pl. 1). There, a vertebrate-fossil locality contains a fairly primitive species of *Merychippus*, which is probably middle Miocene in age (J. F. Lance, written commun., 1960). Sedimentary rocks, which are similar in that both are unmetamorphosed and have steep dips, are exposed in the northwest quarter of T. 7 N., R. 23 E. The rocks at both locations may be of the same relative age, but no stratigraphic study was made during the present investigation to establish whether they were the same sequence or of the same age.

All the rocks which are collectively referred to as bedrock are relatively impermeable. Thus, only small yields are likely to be developed and these principally from fractures. As an example, a bailer test made upon completion of well 7N/23E–10J1, which was drilled to a depth of 730 feet in the Tertiary sedimentary rocks and in which the depth to water was 90 feet, indicated that the maximum yield of the well was only 1½ gpm.

UNCONFORMITY AT THE BASE OF THE FANGLOMERATE

A major unconformity separates the bedrock and the fanglomerate, which is the basal deposit in the present valley. The rocks of the mountains had been severely deformed, and the outlines of the basin and ranges were probably formed prior to the deposition of the fanglomerate. The fanglomerate may have been deposited during the late phase of the structural deformation and the early phase of the present physiography. No attempt was made to define the structural history beyond the obvious differences in amount and direction of dip, intensity of faulting, and lithology, between the fanglomerate and older rocks.

THE FANGLOMERATE

The fanglomerate is composed chiefly of cemented sandy gravel that is probably from a nearby source. The fanglomerate of the Needles area has the same stratigraphic position and lithologic characteristic as the fanglomerate of the Parker-Blythe-Cibola area (Metzger, 1965); that is, the fanglomerate underlies the Bouse Formation and overlies tilted and faulted bedrock. Because the pre-Bouse fanglomerate can be differentiated from post-Bouse alluviums only where the Bouse Formation is present, the fanglomerate is differentiated only where it underlies the Bouse Formation. Elsewhere, it is arbitrarily assigned to the older alluviums. The fanglomerate is exposed about 8 miles southwest of Davis Dam, west of Topock, and in Chemehuevi Valley (pl. 1). The fanglomerate is also exposed locally beneath alluvium east of Havasu Lake in Chemehuevi Valley, although it is not shown as such on plate 1 because only one small outcrop of the Bouse Formation is present, and this is in the SE¼ sec. 33, T. 14 N., R. 20 W.

The gravel of the fanglomerate generally consists of angular to subrounded and poorly sorted cemented pebbles with a sandy matrix. The color of the fanglomerate depends on the predominant rock types represented by its constituent pebbles—gray where the material is derived from igneous and metamorphic rocks and brown or reddish brown where the material came from volcanic rocks or older consolidated sedimentary rocks of Tertiary age. Bedding surfaces of the fanglomerate generally dip from the mountains towards the basin. The fanglomerate, for the most part, has only gentle dips, ranging from 2° to 4°. It varies widely in thickness because it was deposited on an irregular surface.

The fanglomerate represents composite alluvial fans built from the mountains towards the valley. The debris of the fanglomerate probably represents a stage in the wearing down of the mountains following the severe structural activity that produced the basin-range topography in this area. The gentle and moderate tilting of the fanglomerate indicates that severe structural movements have not occurred since its disposition.

No fossils have been found in the fanglomerate in the Needles area, and therefore, no age designation can be assigned on this basis. However, the fanglomerate was deposited after the last major mountain making activity in which the present basins and ranges were outlined, and it underlies the Bouse Formation.

A maximum age for the fanglomerate can be inferred on the basis of the relation between the fanglomerate and rocks containing a vertebrate fauna west of Needles in the Sacramento Mountains, which is discussed under the section entitled "Bedrock." The fauna, which occurs in steeply dipping sedimentary rocks, contains a fairly primitive species of *Merychippus* and is probably middle Miocene in age according to J. F. Lance (written commun., 1966). Similar sedimentary rocks are exposed south of Needles in the northwest quarter of T. 7 N., R. 23 E., and are overlain unconformably by the fanglomerate. Because of this weak stratigraphic relation, the fanglomerate is referred to the Miocene(?), although it may in part be Pliocene because the Bouse is not dated precisely within the Pliocene.

Although the fanglomerate in the Needles area probably is an aquifer similar to that of the Parker-Blythe-Cibola area (Metzger, 1965), only meager data are available for substantiating this supposition because most wells are drilled either into the alluviums of the Colorado River and its tributaries or into the Bouse Formation. Only two wells are known to have pumped water from the fanglomerate. Well (B-16-20½)14bca in Mohave Valley about 4 miles east of Topock, Ariz., is perforated from 332 to 490 feet, and is reported to have yielded 56 gpm (gallons per minute) with a drawdown of 70 feet. Well (B-13-20)1cdd in Chemehuevi Valley was perforated from 625 to 950 feet and is reported to have been pumped at 500 gpm with a drawdown of 130 feet. The well was abandoned because of the high fluoride concentration of the water.

UNCONFORMITY BETWEEN THE FANGLOMERATE AND THE BOUSE FORMATION

The contact between the fanglomerate and the Bouse Formation is sharp (fig. 5) and represents a marked change in environment, from deposits laid down on

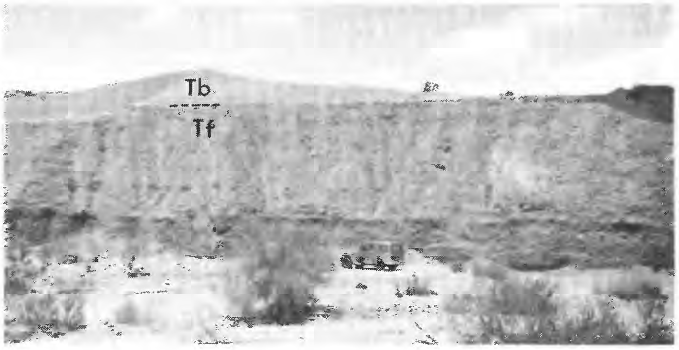


FIGURE 5.—Fanglomerate (Tf) overlain by the Bouse Formation (Tb) in NW¼ sec. 12, T. 7 N., R. 23 E. The thin white layer is the basal limestone of the Bouse, and it thickens to 4 feet about half a mile to the east.

land to those deposited in an extension of the Gulf of California. The fanglomerate represents alluvial fans that were built from the mountains, and thus locally, it represents drainage from the mountains toward the basins. There is no evidence—rounding and rock type—of rocks from a distant area; the detritus is derived from the nearby mountains. Also, there is no evidence of a major through-flowing stream such as the ancestral Colorado River crossing the area during the deposition of the fanglomerate.

The composition of the fanglomerate suggests interior drainage in a manner similar to the present-day closed desert basins of Nevada and part of California. Yet, no deposits that can be interpreted as having been deposited in a playa have been observed in outcrops. The subsurface data are too meager to warrant further speculations.

Drainage during the time of deposition of the younger part of the fanglomerate may have been external prior to the invasion of the Gulf of California. This would afford a mechanism by which the gulf invaded the area, namely by proceeding up a river valley as the area sank. However, there is no evidence supporting this possibility because a substantial part of the fanglomerate was removed by erosion before the deposition of the Bouse Formation. If there was external drainage prior to the deposition of the Bouse Formation, the meager data from the Needles area do not indicate the direction of the drainage. However, regional studies indicate that highlands were northeast and east of the area (M. E. Cooley, written commun., 1968) and that, if through drainage occurred prior to the transgression of the Gulf of California, then the direction of drainage from the Needles area probably would have been southward or southwestward.

BOUSE FORMATION

The Bouse Formation is a marine to brackish-water sequence that was deposited in an embayment of the Gulf of California. It is composed of three units, which are a basal limestone overlain by interbedded clay, silt, and sand; and a tufa (Metzger, 1968). Numerous outcrops are present in the Needles area (pl. 1); generally these have a thickness of only a few tens of feet. The thickest known section is 254 feet, which was penetrated in well (B–16–20½)11ccd. However, the Bouse may be considerably thicker beneath the central part of Mohave Valley.

The Bouse Formation rests unconformably on the fanglomerate. The Bouse Formation occurs as high as 1,800 feet above sea level on the flanks of the Black Mountains. The upper surface of the Bouse is erosional, each degradation of the Colorado River having removed some of the formation.

In Mohave Valley the Bouse Formation occurs at several localities near the mountains along the west side of the valley and at a site about 3 miles west of Topock (pl. 1). Several outcrops also occur east of Topock along U.S. Highway 66. Another outcrop is at an altitude of about 1,500 feet in T. 15 N., R. 20 W. The only outcrop found along the Black Mountains is in sec. 25, T. 20 N., R. 21 W. Six wells in Mohave Valley have been drilled into the Bouse, and of these, only two, in T. 16 N., R. 20½ W., have been drilled through the Bouse into the underlying fanglomerate. In well (B–16–20½)11ccd the Bouse occurred from 189 to 443 feet below land surface. Three other wells that were drilled into the Bouse are in secs. 14, 26, and 36, T. 19 N., R. 22 W. There, the Bouse is present at depths of 225, 211, and 240 feet or at altitudes of about 375, 390, and 370 feet above mean sea level, respectively. The Bouse also is present in well 7N/24E–6F1 from 44 feet to the total depth of the well at 190 feet.

In Chemehuevi Valley, extensive areas of the Bouse Formation occur west of and bordering Havasu Lake. The only outcrop found east of the lake, and this covers only a few acres, is in sec. 33, T. 14 N., R. 20 W. No wells on the east side of Chemehuevi Valley are known to have been drilled into the Bouse. It appears that the wells pass from Colorado River or locally derived deposits into the pre-Bouse fanglomerate. Three wells on the west side of the valley in sec. 36, T. 5 N., R. 24 E. probably were drilled into the Bouse because of the close proximity of Bouse outcrops. No logs were available to indicate whether or not this assumption is true.

The Bouse Formation also is exposed about 12 miles north of Davis Dam in Cottonwood Valley (fig. 1). In sec. 20, T. 23 N., R. 21 W., where about 40 feet is exposed, both the basal limestone and the interbedded unit are present. The Bouse is underlain by locally derived fanglomerate and overlain by alluviums of the Colorado River and its tributaries.

LITHOLOGY AND THICKNESS

The basal limestone of the Bouse Formation grades upward into the interbedded sequence of clay, silt, and sand. The tufa is distinct and was formed throughout the time of deposition of the basal limestone and interbedded sequence. There is always a sharp break between the tufa and either of the other two units, but it is not a significant time break.

BASAL LIMESTONE

The basal limestone is a white marly limestone that ranges in thickness from less than 1 foot to as much as 26 feet. It is thin bedded for the most part, although in Chemehuevi Valley some beds are massive. Locally, thin crossbedded gravel underlies the limestone. About 9 miles southeast of Davis Dam, the basal limestone has a minimum thickness of 25 feet on the basis of an incomplete section. About 3 miles west of Topock, Ariz., the limestone ranges in thickness from less than 1 foot to as much as 4 feet. In Chemehuevi Valley in T. 4 N., R. 24 E., the limestone is at least 26 feet thick (fig. 6). In the latter two localities, the limestone is overlain by the interbedded unit.

In the area west of Topock, the dip of the limestone is 5° to 6° northeast. West of Havasu Lake, the dip ranges from 1° to 5°; the more gentle dips are near the lake.

The basal limestone in the field may appear to be a tuff because it is white, fine grained, and contains many mica flakes. Noble (1931, p. 41–42) interpreted it in the field as a very fine volcanic ash. Later, after a chemical analysis proved the deposit to be largely calcium carbonate, he called it a calcareous marl, or chalk. During the present investigation, several insoluble residue determinations were made on this limestone. The insoluble residue was very fine grained and ranged from 10 to 30 percent; so it may well be, in part, volcanic ash.

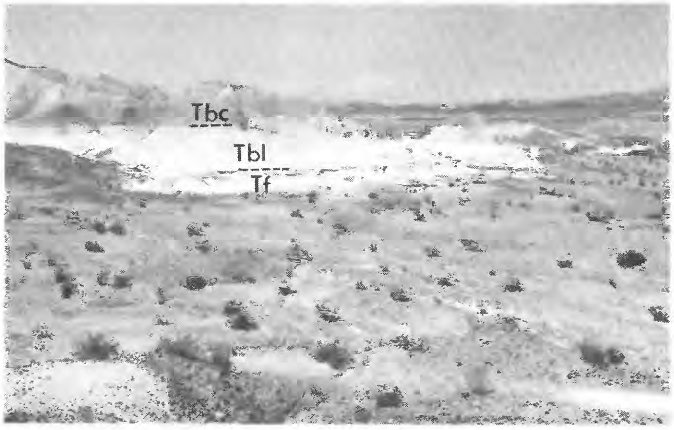


FIGURE 6.—Bouse Formation in east-central part of T. 4 N., R. 24 E. (unsurveyed into sections) in Chemehuevi Valley. The basal limestone is 26 feet thick. Fanglomerate (Tf), basal limestone (Tbl) and interbedded unit (Tbc) of Bouse Formation.

INTERBEDDED UNIT

The interbedded unit is composed of clay, silt, and sand. The beds are generally thin, and only a few are thicker than 10 feet. In the locality about 3 miles west of Topock, Ariz., the beds appear "varvelike," that is, they grade from fine sand upward to silt to clay. The represented cycles are seldom more than 10 feet thick, and probably do not represent varves but cycles of much longer periods.

Most of the clay beds are pale olive to pale yellowish green. One characteristic of the clay is that it swells when moistened, which may indicate that some of the clay is montmorillonite. Because of this characteristic, much of the outcrops are mantled by an amorphous greenish mass. Other characteristics of the clay in Mohave Valley are the extreme fineness of the clay and the absence of sand grains.

The silt and fine-sand beds are commonly grayish orange, or very light gray to very light pink. Most of the sand is only weakly compacted or cemented.

The thickest exposed section of the Bouse Formation is about 50 feet in the SW¼ sec. 1, T. 7 N., R. 23 E., west of Topock (fig. 7). The beds are flat lying or have only a gentle dip. About half a mile to the south in sec. 12, the interbedded unit has a dip of 4° northeast. In this area, sand dikes occur in the Bouse Formation. Some of the dikes are vertical, only about 1 foot wide and fill a small fault or fracture zone. However, others are masses of sand that intrude beds composed mostly of clay. Seemingly, this sand flowed upward, probably during the time of deposition of the Bouse, but this cannot be verified.

In other parts of the area, dips as high as 30° have been observed in the Bouse Formation. Although some of these dips may be the result of structural adjust-

FIGURE 7.—Interbedded unit of the Bouse Formation in east-central part of sec. 1, T. 7 N., R. 23 E. southeast of Needles, Calif. About 50 feet is exposed. The lighter beds are sand, and the darker beds are silt and clay.

ments, some of these must be the result of preconsolidation slumping during or soon after deposition of the Bouse. This can be demonstrated in T. 4 N., R. 24 E., in Chemehuevi Valley. One unit about 20 feet thick contains sand beds that dip as much as 15°. Because most of the unit is clay, which weathers into an amorphous slope, the exact nature of the disturbance cannot be determined. However, this unit rests on the basal limestone, which contains none of the abnormal features of the overlying unit.

TUFA

The tufa has been found at only three localities in the Needles area. One is in the SW¼ sec. 21, T. 9 N., R. 22 E., about 5 miles west of Needles where the tufa is on basement complex. Another is in the SW¼ sec. 25, T. 20 N., R. 21 W., about 9 miles southeast of Davis Dam where the tufa is on volcanic rocks (fig. 8). The third is in T. 4 N., R. 24 E. (unsurveyed), west of Havasu Lake, here, the tufa is on the two southernmost small outcrops of volcanic rocks.

At the first two localities the tufa is light to very light gray and porous. Individual rocks weather to an uneven surface with very sharp ridges, which is typical of some limestones in a desert environment. In the third locality the tufa is a mottled olive-gray to dusky-yellow rock and has numerous holes. The odd coloring suggests this tufa probably contains more impurities than the other. The tufa weathers to dusky yellow with some dark streaks and also is not as rough as the other after weathering.

The outcrops of the tufa that have been seen are very small, the total area being less than 1 acre. Yet, it is obvious that the original area covered by the tufa must have been considerable, so most of the tufa must have been subsequently eroded away. This inference is substantiated by the numerous boulders of the tufa that have been observed in Pleistocene local gravels. One such locality is west of Needles, where the local gravels are composed mostly of metamorphic rocks, yet a few boulders of unmetamorphosed limestone—the tufa—are present. Another area is in sec. 13, T. 15 N., R. 20 W., where isolated boulders occur in local gravels overlying the basal limestone of the Bouse. The source of this gravel was the Mohave Mountains to the south; yet no outcrops of the tufa were found on those mountains.

FIGURE 8.—Tufa of the Bouse Formation in the SW¼ sec. 25, T. 20 N., R. 21 W., about 9 miles southeast of Davis Dam, Ariz. The tufa is light in color and rests on volcanic rocks. Pick in right center of picture (circle) gives scale.

PALEONTOLOGY AND AGE

Fossils are not common in the Bouse Formation of the Needles area. The most abundant of the meager fauna is ostracodes, which occur both in the basal limestone and in the interbedded unit. A few charophytes have been found in the basal limestone. Some casts of clams and snails occur in the basal limestone in Chemehuevi Valley, but these are poorly preserved.

The age of the Bouse Formation is given as Pliocene (Metzger, 1968) with the understanding that some Colorado River deposits, which overlie the Bouse, are also Pliocene in age. Nothing was found in the Needles area to alter this interpretation.

WATER-BEARING CHARACTERISTICS

Only two wells in the Needles area probably produce water from the Bouse Formation. Well (B–16–20½)11ccd, which is perforated from 189 to 420 feet below land surface, yielded 50 gpm with a drawdown of 74 feet. This yield indicates a specific capacity of about 0.7 gpm per foot of drawdown. The other well, 8N/23E–20J1, which is perforated from 478 to 480 and 517 to 520 feet below land surface probably taps the Bouse because of the proximity of outcrops of the Bouse, and the report from the owner on the amount of clay penetrated during drilling of the well also indicates this.

One seep, Red Spring (fig. 9), issues from the Bouse in the NW¼ sec. 30, T. 10 N., R. 22 E. Because the spring is at an altitude of about 840 feet and about half a mile from the bedrock of the Dead Mountains, it is inferred that the water issuing from the seep represents discharge from only a limited area. The amount of the water discharging from this seep is very small, and no well-defined outflow channel is present. In all probability, the few phreatophytes at the spring use all the discharge in the summer.

Because of the clay beds in the Bouse, it can be anticipated that the Bouse has a low permeability in the

FIGURE 9.—Red Spring in NW¼ sec. 30 T. 10 N., R. 22 E. Spring in right center of picture is enclosed by wood fence and issues from Bouse Formation. Bouse Formation (Tb), alluviums of the Colorado River and its tributaries (QTa).

Needles area. Other than this, little can be added about the water-bearing characteristics because the data are so meager.

ALLUVIUMS OF THE COLORADO RIVER AND ITS TRIBUTARIES

Alluviums of the Colorado River and its tributaries are the result of several broad periods of degradation and aggradation by the Colorado River. The alluviums are divided into older alluviums, which are the deposits of several degradations and aggradations by the Colorado River, and younger alluvium, which is the deposit of the youngest aggradation.

The contact between the younger and older alluviums is the contact between the present flood plain of the Colorado River and the bordering terraces and alluvial slopes. Commonly, the contacts between the various units of the older alluviums can be differentiated only with great difficulty even in clear outcrops. The contacts are even more difficult to determine from subsurface data. Neither can the contact between the younger and older alluviums be separated readily as was done in the Parker-Blythe-Cibola area (Metzger and others, 1972). Only where the Bouse Formation underlies the younger alluvium, can the two be differentiated.

The water-bearing characteristics of the four units of the older alluviums and the younger alluvium are not discussed separately because of the obvious hydraulic continuity between the various alluviums, and because of the difficulty of separating the various alluviums on the basis of subsurface data.

OLDER ALLUVIUMS

The older alluviums of the Needles area (fig. 10) are subdivided using the terminology of the Parker-Blythe-Cibola area (Metzer and others, 1972). Unit A is not recognized in the Needles area. Unit B includes all deposits of the Colorado River and its tributaries that are older than unit C and younger than the Bouse Formation. Units C (piedmont gravels), D, and E are the same for the two areas.

UNIT B

Unit B is a sequence of heterogenous fluvial deposits of the Colorado River and its tributaries that unconformably overlies the Bouse Formation, and is overlain in turn unconformably by younger deposits of the Colorado River and its tributaries. Because this unit includes all deposits older than unit C (piedmont gravels) but younger than the Bouse Formation, the unit is made up of a considerable variety of rocks, and contains several units separated by erosional unconformities, and at least in one locality, an angular unconformity. Although these relationships can be seen in favorable outcrops, it is virtually impossible to visualize them from the available subsurface data.

Unit B is composed of silt, sand, gravel, and clay. A common lithology deposited by the Colorado River is a gray medium sand containing scattered well-rounded small pebbles. A unique lithology are the lenses of Colorado River pebble-cobble gravel, which are capable of yielding copious amounts of water to wells. The gravel consists of pebbles and cobbles that came from many miles upstream, and of others that came from the adjacent mountains. The pebbles and cobbles from upstream sources are rounded to well rounded and dense.

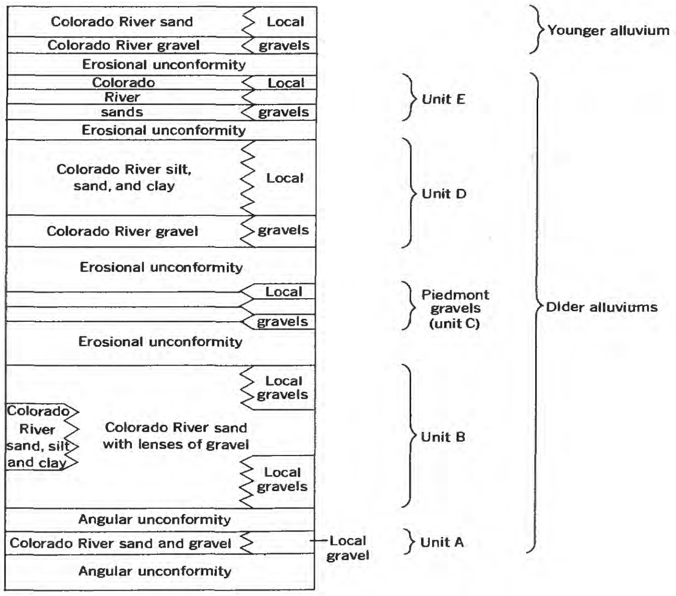


FIGURE 10.—Diagrammatic composite section showing the deposits of the Colorado River and its tributaries in the Parker-Blythe-Cibola area, Arizona and California. (From Metzger and others, 1972.)

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Some are recognized as coming from Cambrian quartzites (Tapeats and related sandstones), Mississippian crinoidal limestone, red cherts of the Pennsylvanian rocks, and drab cherts of the Permian limestones. Some black chert is also present, its source being the Shinarump Member of the Chinle Formation of Late Triassic age (M. E. Cooley, written commun., 1968). Interfingering with the Colorado River deposits are local gravel derived from the adjacent bedrock. This gravel may be subangular, subrounded or rounded. Invariably, the largest pieces of gravel, more than 1 foot in diameter, are locally derived.

A gravel deposit in the SE¼ sec. 5, T. 7 N., R. 24 E. deserves special mention because of the unusual size of the clastics (fig. 11). This is the coarsest gravel deposited by the Colorado River downstream from Grand Canyon. Some of the boulders are as much as 3 feet in diameter. Most of the boulders are subrounded to rounded and consist of highly-contorted gneiss and granitic and volcanic rocks, whose composition suggests local derivation. Several cobbles 8 to 10 inches in diameter are rounded to well-rounded quartzites which are rock types typical of those moved into the area by the Colorado River.

The variety of deposits included in unit B is best shown by the outcrops along the north side of Sacramento Wash in the SW¼ sec. 26, T. 16 N., R. 21 W. Here are five subunits of unit B (fig. 12), which from oldest to youngest are (1) Silt and clay overlain by well-rounded Colorado River gravel, (2) interbedded silt, sand, and clay, (3) rounded boulder gravel (local debris) overlain by sand and rounded to well-rounded gravel (local debris), (4) thin-bedded silt and sand overlain by sand containing well-rounded Colorado River gravel, and this, in turn, overlain by more thin-bedded silt and sand, (5) thin-bedded silt and sand with a 5-foot sand bed at base.

The geologic history of these subunits is as follows: (1) Deposition of subunit 1, (2) erosion of subunit 1, (3) deposition of subunits 2 and 3, the two apparently conformable, (4) erosion of subunit 3, (5) deposition of subunit 4, (6) structural adjustment, either as a result of a monocline, or a fault, (7) erosion of subunits 3 and 4, (8) deposition of subunit 5, and (9) erosion.

FIGURE 11.—Colorado River boulder gravel in the SE¼ sec. 5, T. 7 N., R. 24 E. Most of the boulders (as much as 3 ft in diameter) are locally derived and subrounded to rounded. Several cobbles (8 to 10 in. in diameter) are rounded to well-rounded quartzites which are rock types typical of Colorado River gravel. Pick in right center (circle) gives scale.

How far these subunits persist is not known. Further, these subunits are not to be construed as the breakdown of unit B, but rather as being only a part of unit B and to show the complexity of the deposits referred to unit B. Time did not permit detailed mapping of the deposits.

PIEDMONT GRAVELS (UNIT C)

Piedmont gravels are made up of debris from the adjacent bedrock. The unit is composed mostly of gravel, but sand and silt are also present. The thickness of individual gravels is not great and ranges from 10 to about 50 feet. The gravels, although thin, have the greatest areal distribution of any of the units bordering the flood plain. This is the unit that effectively conceals much of the older alluviums, Bouse Formation, and fanglomerate. The surfaces of some of the gravels have been exposed to weathering since before the deposition of unit D. Desert pavement has formed on the surfaces, and the gravel has a heavy coating of desert varnish. The gravels are cemented with calcium carbonate, and the oldest piedmont gravel bordering the Black Mountains contains much hard caliche.

The term "piedmont," as used herein, is the compound surface of the dissected, alluvial slopes between the mountains and the flood plain of the Colorado River.

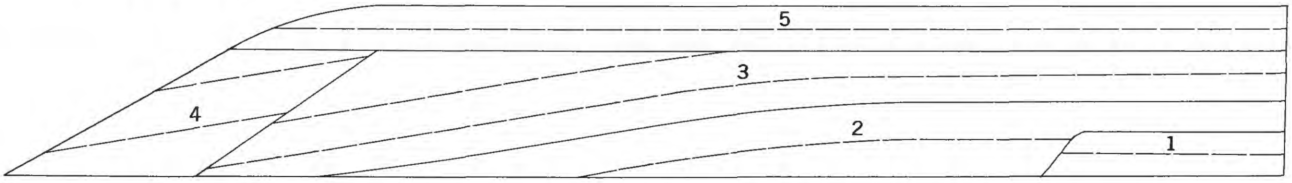

FIGURE 12.—Diagrammatic sketch along the north side of Sacramento Wash in SW¼ sec. 26, T. 16 N., R. 21 W., showing subunits of unit B of older alluviums. Dashed lines indicate trend of bedding.

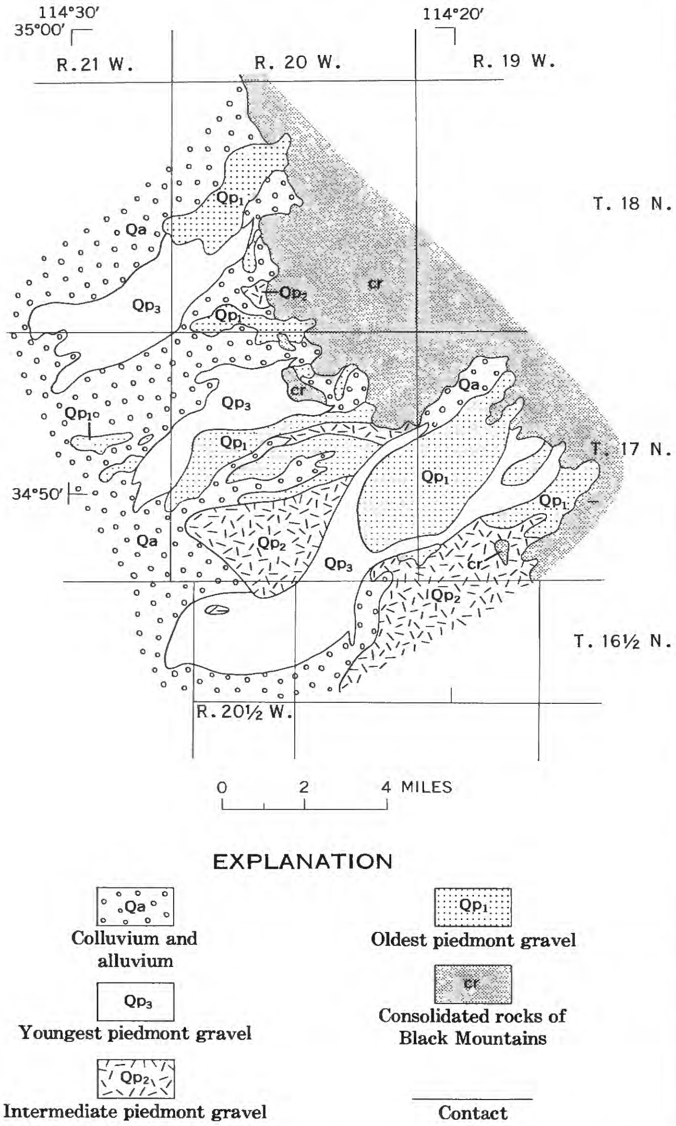

FIGURE 13.—Sketch map showing piedmont gravels near Black Mountains.

The overall cutting of the piedmont is controlled by the Colorado River. The term "piedmont gravels" is given to certain gravels deposited on some of these surfaces. It is restricted to deposits laid down during the period of downcutting that followed the deposition of unit B and before the deposition of unit D. This use of the term is not entirely satisfactory, but it seems to be the best term for these deposits which overlie erosional surfaces having local different levels. The problem could be resolved, perhaps, by giving formal names or some numeral sequence to the surfaces. These gravels and some of the surfaces would be referred to by some geologists as "pediment gravels" and "pediments." There is some merit to this because the gravels termed the "piedmont gravel" are thin and lie on the surfaces cut on older rock units, for the most part unit B. However, many people restrict the term "pediment" to an erosional surface developed on the bedrock of the mountains and not on the softer units upon which these gravels lie. The use of "pediment" for describing these surfaces is further complicated by the fact that these are compound or multiple surfaces and include capping gravel, each younger gravel having successive lower elevations. Three piedmont gravels near the Black Mountains (fig. 13) have a gradient towards the flood plain of 100 to 150 feet per mile. A projection of the surface on the highest gravel indicates that this gravel could have been graded to a point about 100 feet above the present flood plain. A projection of the surface on the lowest gravel intersects the present flood plain.

UNIT D

Unit D is made up of two facies: (1) interbedded sand, silt, and clay, and (2) local gravel. Although the basal gravel of unit D was recognized in the Parker-Blythe-Cibola area (Metzger and others, 1972), it is not included in the definition of unit D in the Needles area because of the absence of adequate subsurface data to determine if the gravel is present. The first facies occurs near the edge of the flood plain and was deposited by the Colorado River. The second occurs at the margins of deposition by the Colorado River and is the contribution of tributary washes. Unit D was deposited against and on the piedmont gravels and older units (fig. 14). Unit D occurs along both sides of the flood plain in Mohave and Chemehuevi Valleys and in the canyon between the two valleys. Near Davis Dam, it is 300 feet higher than the flood plain.

The interbedded sand, silt, and clay is generally tan in color with a slight pinkish or reddish tint to the outcrops. Some of the clay beds are darker shades of brown. The gravel interfingers with the fine-grained unit, and is

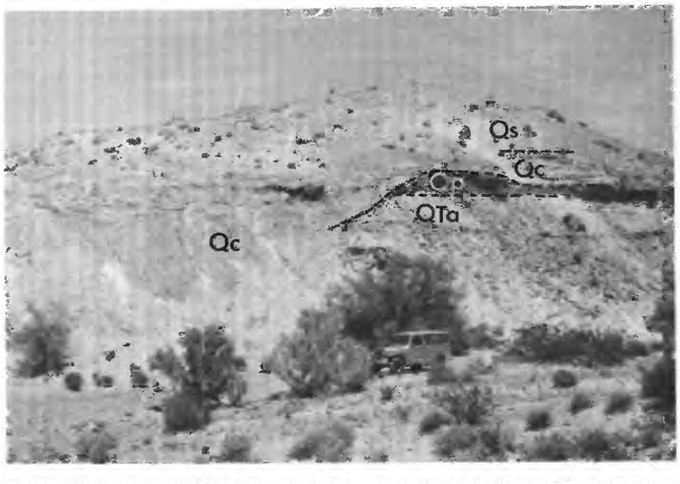

FIGURE 14.—Depositional contact between unit D of the older alluviums and older units in the NE¼ sec. 27, T. 17 N., R. 21 W. Unit D was deposited against erosional features cut on unit B and piedmont gravel. Unit B (QTa), piedmont gravel (Qp), unit D (Qc), unit E (Qs).

made up of subangular to subrounded pebbles and cobbles that were derived from the adjacent bedrock.

UNIT E

Unit E is made up of two facies: (1) Sand deposited by the Colorado River, and (2) gravel deposited by local tributaries. The sand has virtually the same areal distribution as the interbedded part of unit D. The sand was deposited on erosional surfaces cut into unit D and older units, and was laid down during oscillations of a major period of degradation by the Colorado River. Thus, sand capping the terrace bordering the flood plain is younger than sand of the same unit that occurs at a higher elevation.

The sand is tan, unconsolidated, medium, and fairly well sorted and contains scattered rounded to well-rounded pebbles. Because of its unconsolidated nature, it is easily attacked and moved by the wind, and forms gentle dune-covered slopes. The gravel facies is composed of subangular to subrounded cobbles derived from the adjacent bedrock. The elevation and slope of the gravel surface reflects the local base level (the Colorado River) to which the gravel was graded. As the Colorado River degraded, local gravels occurred at successively lower elevations.

YOUNGER ALLUVIUM

The younger alluvium includes flood-plain deposits of the Colorado River, wash deposits, and colluvium. Only the flood-plain deposits are shown on plate 1. The younger alluvium (excluding the colluvium) represents the last aggradation of the Colorado River, which continued until the river was controlled by Hoover Dam. The part that was deposited by the Colorado River extends from terrace to terrace, although at some places it is only a few feet thick because the present river is actively cutting into the terraces. The wash deposits extend from the flood plain up the present washes.

The younger alluvium was defined with confidence in the Parker-Blythe-Cibola area (Metzger and others, 1972). Near Parker the younger alluvium was deposited in a trench cut into the Bouse Formation. However, near Blythe the younger alluvium was deposited in a trench cut into older Colorado River deposits, and it was difficult to define the contact between the younger and older alluviums because the basal gravel of the younger alluvium apparently was deposited on gravels of the older alluviums. From the meager data that are available, it seems that conditions in Mohave Valley are more similar to those near Blythe than near Parker.

Five holes were drilled with a powered auger rig across the flood plain near Needles in an attempt to define the contact between the younger and older alluviums. The holes (fig. 15) ranged in depth from 117 to 167 feet and were entirely in Colorado River materials. The depth to the first pebble to cobble gravel ranged from 37 to 87 feet. Most of the material above the gravel was sand to silty sand with scattered gravel.

The results suggest that the deposits above the gravel are thinner than they are in the Parker-Blythe-Cibola area, and therefore, the thickness of the younger alluvium is probably less in the Needles area than farther south. These auger logs and logs of other wells indicate that near Needles the younger alluvium rests on older Colorado River deposits.

AGE

The oldest deposits of the lower Colorado River in the Parker-Blythe-Cibola area are at least late Pliocene in age and perhaps older (Metzger and others, 1972). The youngest is the modern flood-plain deposits of Holocene age. No basis for refining these age assignments was found during the study of the Needles area.

WATER-BEARING CHARACTERISTICS

The alluviums of the Colorado River are a heterogeneous mixture of gravel, sand, silt, and clay. All but a few wells in the Needles area yield water from sand and gravel of the alluviums. Many domestic wells are sandpoints installed only a few feet below the land surface. Large diameter wells are drilled generally only as deep as necessary into a pebble and cobble gravel. Therefore, very little is known about a composite thickness of the several Colorado River alluviums. The thickest known section is that in well (B–18–22)23bcc2, which was still in alluvial deposits at a depth of 310 feet.

Most of the yield from wells that are perforated in the alluviums come from highly permeable beds of sand and gravel. The Colorado River gravel has the highest permeability of any water-bearing rocks in the area. Wells that tap a sufficient thickness of these gravels have specific capacities over 100 gpm per foot of drawdown. The largest specific capacity determined during this investigation was that for well (B–19–22)36bab, which had a specific capacity of 400 gpm per foot of drawdown.

STRUCTURE OF SEDIMENTS

No attempt was made during this investigation to determine the structural history of the bedrock because the bedrock forms the boundary of the ground-water reservoir and is, for all practical purposes, a barrier to ground-water movement. Nevertheless, it is obvious that the structural history of the bedrock is much more involved than that of the sediments of the valleys. The granitic and metamorphic rocks are much fractured. The sedimentary and volcanic rocks older than the fanglomerate have been faulted and folded and commonly

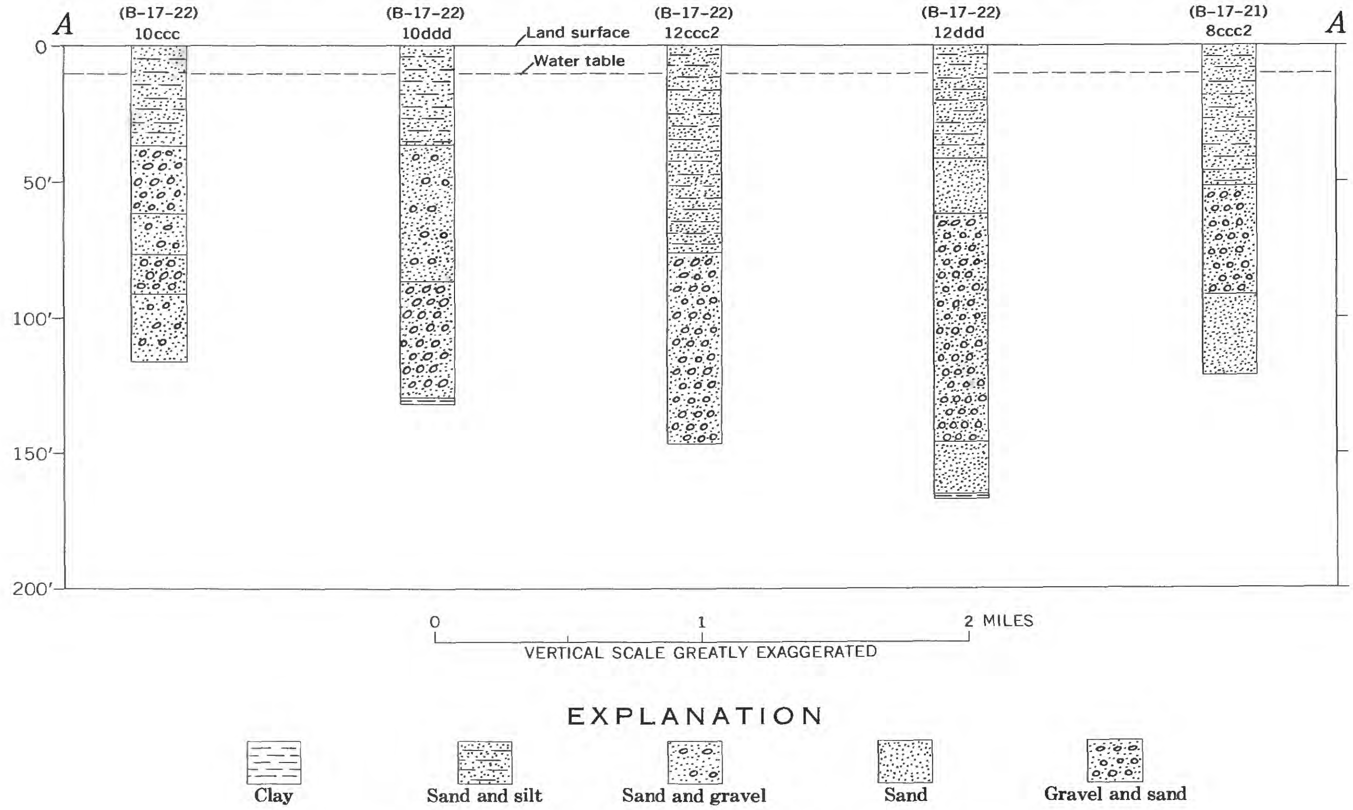

FIGURE 15.—Lithologic sections from auger holes near Needles, Calif.

have steep dips, which is in marked contrast to the gentle dips of most of the sedimentary rocks forming the ground-water reservoir.

Although most of the outcrops of unit B have beds with gentle dips, some outcrops have beds that indicate structural adjustments during and following deposition of the unit. Because unit B was not studied in detail during the present investigation, its structural history is not fully known. The structural adjustments during the deposition of unit B at a selected site along the north side of Sacramento Wash was given under the section on unit B (p. J14). Figure 16 shows the deformed sediments. This locality was also visited by Lee (1908, fig. 10B). Also in this area, several normal faults of small throw are present. On the basis of only the log of well (B-18-22)23bcc2, it may be tentatively concluded that unit B is downwarped beneath parts of the flood plain, in much the same manner as that noted near Blythe (Metzger and others, 1972). This is weakly substantiated by the presence of the Bouse at depths of 200 to 250 feet in T. 19 N., R. 22 W.

In T. 4 N., R. 24 E. (unsurveyed into sections), in Chemehuevi Valley, unit B along with the underlying Bouse Formation has been deformed into a syncline (fig. 17). The syncline is exposed for about 1,000 feet along a wash and trends northwest.

The piedmont gravels in T. 17 N., R. 20 W., are cut by a graben that has a displacement of about 10 feet. The graben is about a quarter of a mile wide and extends 2 miles northwest. It shows with particular clarity on aerial photographs because the gravels contain a heavy coating of desert varnish that make the lineations of the faults stand out. This is the only locality where displacement of the piedmont gravels was observed. Other lineations on the piedmont gravels have been noted, but in most places, these are scarps cut on the piedmont gravels that are now being exhumed.

FIGURE 16.—Deformed older alluviums of the Colorado River and its tributaries along north side of Sacramento Wash in SE¼ sec. 26, T. 16 N., R. 21 W.

FIGURE 17.—East limb of syncline in east center of T. 4 N., R. 24 E. (unsurveyed into sections). Bouse Formation (Tb) and locally derived alluvium (QTa).

Nowhere in the area has unit D, unit E, or the younger alluvium been observed to have been displaced by structural adjustments. Units D and E are not continuous throughout the area, so minor displacements could be hidden. However, major displacements are not present, and from the time of deposition of unit D to the present, major geologic controls have been stable.

GROUND-WATER RESOURCES OF THE NEEDLES AREA

OCCURRENCE

All but a few of the wells in the Needles area are completed in the alluviums of the Colorado River, in which the ground water occurs under water-table conditions. Two wells that may contain water under artesian conditions are in T. 16 N., R. 20½ W., about 3 miles east of Topock. These wells produce water from and below the Bouse Formation and fanglomerate, and similarly developed wells in the Parker-Blythe-Cibola area contain water under artesian conditions. However, there are no nearby wells in which to determine the depth to the water table. Some ground water also occurs under perched conditions. One small body of perched ground water occurs south of Chemehuevi Wash in T. 4 N., R. 24 E., as evidenced by the shallow depth to water of 5.7 feet in well 4N/24E–17Z1, which is an old dug well. Because of the nearby outcrops of the Bouse, it is assumed that this water is perched atop the Bouse. An interesting observation is that nearby Chemehuevi Wash is incised below the elevation of the water level in the well; yet, the wash contains only desert vegetation, which further suggests that the ground water tapped by the well is perched.

RECHARGE

Sources of recharge to the ground-water reservoir of the Needles area are the Colorado River, unused irrigation water, runoff from precipitation, and underflow from bordering areas. Of these, the Colorado River is by far the principal source. The role of the river as a source of recharge is given in more detail in the section in which ground water in recent years is discussed.

Recharge of the ground-water reservoir from excess irrigation water is, in a sense, only a negative discharge, inasmuch as practically all irrigation supplies are obtained from wells. The recharge from this source in recent years has been 5,000 to 10,000 acre-feet per year, if, as is likely, half the ground water that was pumped for irrigation was not used consumptively but returned to the ground-water reservoir. Additional details about pumpage for irrigation are given in the section in which the development of irrigation is discussed.

Recharge by runoff from precipitation occurs in the sandy washes and along major ephemeral streams such as Sacramento and Piute Washes. Most storms probably cause little runoff, and even much of this runoff is lost by evaporation or transpiration in the streambed. Only runoff from rains of high intensity contribute to recharge. Heavy rains in the arid southwest may seem anomalous, but these occur as a result of moist air moving into the area from tropical disturbances off the coast of Baja California. During these rare storms, it is common for 2 or 3 inches of rain to fall in a few hours. Such an intensity results in rapid runoff. As an example, during a storm in September 1939, Piute Wash at a point 8.5 miles northwest of Needles is reported to have had a maximum discharge of 30,000 cfs (cubic feet per second) or 39.0 cfs per sq mi (cubic feet per second per square mile); and Sacramento Wash at its mouth near Topock is reported to have had a maximum discharge of 15,000 cfs or 10.5 cfs per sq mi (Smith and Heckler, 1955, p. 5).

The sandy washes have well-developed channels from the bedrock areas to the flood plain, a feature that is in marked contrast to most ephemeral washes of the Mohave Desert. The major washes are incised and have well-defined banks and wide, flat bottoms that are mantled and underlain by sand and gravel. Thus, much of the runoff from the bedrock areas infiltrates into the sand and gravel and eventually part of the water recharges the ground-water reservoir. Another factor tending to accentuate the recharge possibilities in the washes is the cementation of the desert pavements of the piedmont gravels. Heavy rain on these gravels quickly becomes runoff that flows into the desert washes.

Recharge from areas bordering the Needles area occurs as underflow beneath Sacramento Wash, Piute Wash, and Chemehuevi Wash. The sources of this recharge are discussed in the section on "Water Budgets."

As stated in the discussion of the location of the area, the Needles area comprises the Mohave and Chemehuevi Valleys. These valleys are separated by the Chemehuevi Mountains except for a very narrow connecting section of the Colorado River valley. Although Chemehuevi Valley is recharged to the extent of the underflow through the alluvium of the river channel, this quantity is negligible and is also compensating when the entire Needles area is considered because it is outflow from Mohave Valley. This source of recharge and discharge, therefore, is not discussed further.

DISCHARGE

Ground water is discharged from the aquifers of the Needles area by wells and by evapotranspiration. Discharge to the Colorado River, if it occurs at all, is negligible.

The ground water pumped from wells is used for municipal and domestic supplies and for irrigation of land. The two principal communities in the area—Needles and Lake Havasu City (which is being built on the east side of Havasu Lake)—both use wells for municipal water supply. The wells of both cities obtain water from the alluviums of the Colorado River. In addition to the cities, numerous blocks of land are being subdivided. In some of these, one or two wells supply water for all the lots, whereas in others, individual wells supply each lot.

A common type of well construction, which is used on farms and homesites on the flood plain, is a sandpoint driven only a few feet below the water table. Another type is a cased hole drilled into the first "good" gravel, after which the casing is perforated in that gravel. Irrigation wells generally are between 12 and 20 inches in diameter, and all obtain water from the Colorado River deposits. Pumpage in 1968 was about 18,000 acre-feet (p. J21).

Ground water is discharged by evapotranspiration wherever the water table is near the land surface, which is throughout the flood plain area. This topic is discussed under the section, "Water Budgets."

The only area in Mohave Valley where discharge from the ground-water reservoir to the Colorado River might be occurring is along the east side of the river near Topock.

Prior to the filling of Havasu Lake in Chemehuevi Valley, some ground water must have discharged into the nonbedrock reaches of the river where the flood plain was narrow and did not contain water-loving vegetation, or where there was practically no flood plain. However, the filling of the lake with an attendant reversal of ground-water gradients near the lake caused water to move away from the lake into the sediments. As far as can be detected from the limited data available, the water table is presently nearly flat; so evidence for ground-water discharge to the lake is inconclusive. Eventually, however, the recharge from the adjacent mountains, meager as it may be, will cause a reestablishment of a ground-water gradient and discharge to the lake.

HISTORICAL SKETCH

The first white man to enter the area, according to the records, was a Spanish priest, Padre Fray Francisco Garcés, who in 1776 traveled northward from Yuma to visit the Mohave Indians. The next white man of whom records are available was Jedediah S. Smith, who visited the area 50 years later, in 1826. In 1858 a party under Lt. Joseph C. Ives (1861) explored the Colorado River from its mouth to the head of navigation at the lower end of Black Canyon, which is some 40 miles north of Davis Dam. The expedition was made by steamboat, a fact which proved the river to be navigable to that point. In 1861 a ferry was established across the Colorado River at Fort Mohave, Ariz. (about 15 miles north of Needles).

In August 1883 the Southern Pacific Railroad was completed eastward to the Colorado River at Needles where it joined the Atlantic and Pacific Railroad and provided rail service between the west coast and the Mississippi River. Thus, the region became much more accessible to the early travelers, some of whom settled in the area.

Needles, with a population of 2,807, was the only incorporated town in the entire Mohave Desert region in 1920 (Thompson, 1929). The town was supported largely by railroad activities, being a division headquarters of the Atchison, Topeka, and Santa Fe Railway, which purchased the two railroads that originally joined at Needles. Needles was also a trade center for the mining camps in the area.

In 1890 Fort Mohave was transferred to the Indian Service for use as a school. In 1922 the Fort Mohave Indian Reservation included several thousand acres near the school, as well as all the even-numbered sections on the lowlands in Arizona as far south as Topock. Thompson (1929) reported that at the time of his visit to the area in 1922 the water table was close to the land surface beneath the lowlands along the Colorado River and that water-loving vegetation was abundant. Cottonwood and willow thrived along the river and sloughs, and large mesquite trees, arrowweed, salt bush, and some salt grass occupied the rest of the lowland.

Thompson also noted that although the river channel lay near the western margin of the flood plain in the reach between Fort Mohave and Topock, the many lakes and abandoned river channels were evidence that in the past the river had occupied all parts of the flood plain. He further stated that the river always carried a large amount of silt, sometimes as much as 3 percent by weight of the entire flow. The water was so muddy that it was not used for domestic purposes without first filtering it or allowing the silt to settle.

The Indians were the only people using the river water in the early 1920's. Before the coming of the white man, the Indians had farmed the flood plain by planting seeds after the annual floods subsided. During the dry season, they carried water from the river to irrigate their crops.

Beginning in 1891, several attempts were made to divert water from the river, both by diversion canals and by pumping. None of the early attempts were successful because of the ever-changing channel and the annual floods. The settlers realized that levees were needed, both to protect the canals and to prevent flooding of the reclaimed land. As early as June 1915, the Cotton Land Co., which owned the odd-numbered sections on the Arizona side of the river, had spent $575,000 for irrigation works and flood protection, but without success (U.S. Congress, 1922).

Plans to use water from wells for irrigating flood-plain lands in the Indian Reservation also had been unsuccessful. A well drilled to a depth of 780 feet near the Indian School at Mohave City reportedly did not penetrate any extensive gravel beds and did not yield sufficient water for irrigation (Thompson, 1929). Prospects for irrigation by pumping from wells in the flood plain were believed to be poor principally because of the fine material likely to be found and the poor chemical quality of the ground water that had been obtained. Outside the flood plain, the prospects were also considered poor because of the greater depth to water, the inadequate yields, the dissected slopes, which would require extensive leveling, and the highly mineralized water that was obtained from a few existing wells. (Depths to water of more than 100 ft were considered impractical for irrigation.)

Hydrologic conditions remained fairly stable from the 1920's to the closure of two dams, Hoover Dam in 1936 and Parker Dam in 1938. The closure of Hoover Dam, 67 miles upstream from Davis Dam, ended the annual spring floods in the area and caused some channel scouring because relatively clear water was released from the dam. The closure of Parker Dam and the consequent filling of Havasu Lake caused a rapid aggradation of the Colorado River upstream from the lake. As the aggradation continued and moved upstream, the definable channel in the lower part of the flood plain east and southeast of Needles was obliterated, and the river flowed through a series of swamps and sloughs. By 1944 the aggradation had caused river stages and consequently ground-water levels to rise enough to threaten the town of Needles and the main line of the Atchison, Topeka, and Santa Fe Railway. To alleviate this situation, the U.S. Bureau of Reclamation initiated a program of dredging operations and improvements on the river-channel geometry. Dredging operations and channel-alinement work from the Big Bend area below Davis Dam to Topock were completed in July 1960. Only a limited amount of dredging was done below Topock before operations were stopped pending studies of the physical and ecological changes in the canyon downstream from Topock. In addition to the aforementioned channel improvement, a levee system was also constructed so that flows of 50,000 cfs and more could be controlled.

DEVELOPMENT OF IRRIGATION

Following the unsuccessful early attempts to irrigate land, previously described, the development of land for irrigation agriculture was gradually abandoned. Irrigated acreage, principally by diversion of river water, dropped from about 2,400 acres in 1914 and 1915 to about 850 acres from 1916–23, to 730 acres in 1924, to 630 acres in 1925–27, and to about 200 acres from 1928–45 (U.S. Bureau of Reclamation, 1953).

As interpreted from aerial photographs dated October 1947, only about 200 acres of the flood plain were being irrigated at that time. A similar acreage adjacent to the flood plain, principally in the Big Bend and Fort Mohave areas, also was being irrigated. During the 1950's the development of land for irrigation agriculture again thrived. By 1962, 3,090 acres of the flood plain (U.S. Bureau of Reclamation, 1963) and 300 acres east of the flood plain were being irrigated. Of the flood-plain land, 1,960 acres was irrigated with Colorado River water. About 1,400 acres of the total acreage was irrigated by pumping ground water. Using an estimated withdrawal rate of 6 acre-feet per year per acre irrigated, the pumpage was 8,400 acre-feet. Total other pumpage by the city of Needles and other users of ground water probably resulted in a total withdrawal of somewhat less than 12,000 acre-feet in 1962.

Beginning in 1964, the U.S. Geological Survey began an annual inventory of pumpage for irrigation from wells in the flood plain of the Colorado River and from wells adjacent to the flood plain as a part of its responsibility for measuring diversions, return flows, and consumptive use of Colorado River water in accordance with Article V (B) of the decree of the Supreme Court of the United States in *Arizona* v. *California* dated March 9, 1964. The results of the inventories as listed in annual administrative reports are summarized in the following table.

The data in the table show that pumping of ground water for irrigation remained rather constant through 1966 at between 12,000 and 15,000 acre-feet per year but that beginning in 1967 pumpage increased 50 percent as a result of new wells drilled in 1966. The newly developed land is limited principally to the odd-numbered sections (non-Indian land) east and north of Needles.

In addition to the above pumpage, the city of Needles pumps four wells for municipal use. Pumpage each year, 1964 through 1968, is listed as: 2,527; 2,113; 2,384; 3,230; and 2,946 acre-feet, respectively. Pumpage of ground water by other communities and the many resorts that line the river was an additional 1,000 acre-feet, and is continuing to increase as more resorts are built or existing ones are expanded. Thus, the total annual pumpage of ground water through 1966 was about 18,000 acre-feet or less; in 1967 about 25,000 acre-feet, and in 1968 about 22,000 acre-feet.

Pumpage from the river for irrigation has also been small to date. As stated previously, 1,960 acres were so irrigated in 1962, but in later years the acreage has been less.

TABLE 1.—*Annual pumpage of ground water, in acre-feet, for irrigation, 1964–68*

Year	Arizona			California			Total in area		
	Number of wells	Number of acres	Pumpage	Number of wells	Number of acres	Pumpage	Number of wells	Number of acres	Pumpage
1964	10	2, 250	13, 500	1	90	540	11	2, 340	14, 040
1965	8	1, 890	11, 520	2	140	840	10	2, 030	12, 360
1966	20	1, 885	11, 820	5	512	3, 132	25	2, 397	14, 952
1967	22	3, 107	18, 197	5	522	3, 132	27	3, 629	21, 329
1968	21	2, 336	15, 597	5	393	2, 358	26	2, 729	17, 955

RIVER STAGES

Because the Colorado River is hydraulically connected to the ground-water system, river stages directly influence rates of recharge to and discharge from the ground-water system and also the quantity of ground water that is stored in the system. The interchange between surface water and ground water depends not only on the difference between the river stage and the head in the ground-water system, but also the period of time over which the difference exists. Although detailed analysis of the recharge to or discharge from the ground-water system caused by changes in river stage is beyond the scope of the present study, some generalizations can be made about the relative amounts of ground-water recharge or discharge that have occurred in past years on the basis of the influence of river stage alone.

The earliest river stages that are considered to be representative of stages under natural conditions are those shown on a U.S. Geological Survey river profile and topographic map compiled in 1902–03. The river profile and stage are based on the altitude of the river at a discharge of 10,000 cfs. Changes in river stage from stages under natural conditions, therefore, should be indicated by differences between the river stages in 1902–03 and those of later dates.

The U.S. Geological Survey stream-gaging station near Topock has one of the longest records of stage and discharge on the lower Colorado River. Incomplete records dating back to February 1, 1917, show that prior to the control of the Colorado River by Hoover Dam in 1935 maximum discharges varied from 51,000 cfs, June 6, 1925, to 175,000 cfs, June 22, 1921. Respective stages were about 438 feet and 451 feet above mean sea level. Minimum discharges generally ranged from 2,000 cfs to about 6,000 cfs, with minimum stages generally being between 427 and 429 feet above mean sea level. The river profile map of 1902–03 indicates a stage of about 427 feet for a discharge of 10,000 cfs, which suggests that the river may have aggraded a few feet between 1902–03 and 1917.

Yearly maximum and minimum stages and discharges for the period 1933–67, which is principally a period of regulated flow, are shown in figure 18. It is seen that after 1935 the difference between maximum and minimum discharges averages only about 15,000 cfs. Differences between maximum and minimum stages likewise are small, ranging from only a foot or two in the middle 1940's to 7 feet in the middle 1960's. In contrast, earlier records show that prior to the regulation of flows by Hoover Dam in 1935, differences between yearly maximum and minimum discharges averaged about 100,000 cfs, and differences between maximum and minimum stages generally were about 15 feet, although in a few years differences were about 25 feet.

Of greater significance as regards ground-water levels, however, are changes in average stage of the river. If it is assumed that a stage midway between the maximum and minimum stages shown is a satisfactory

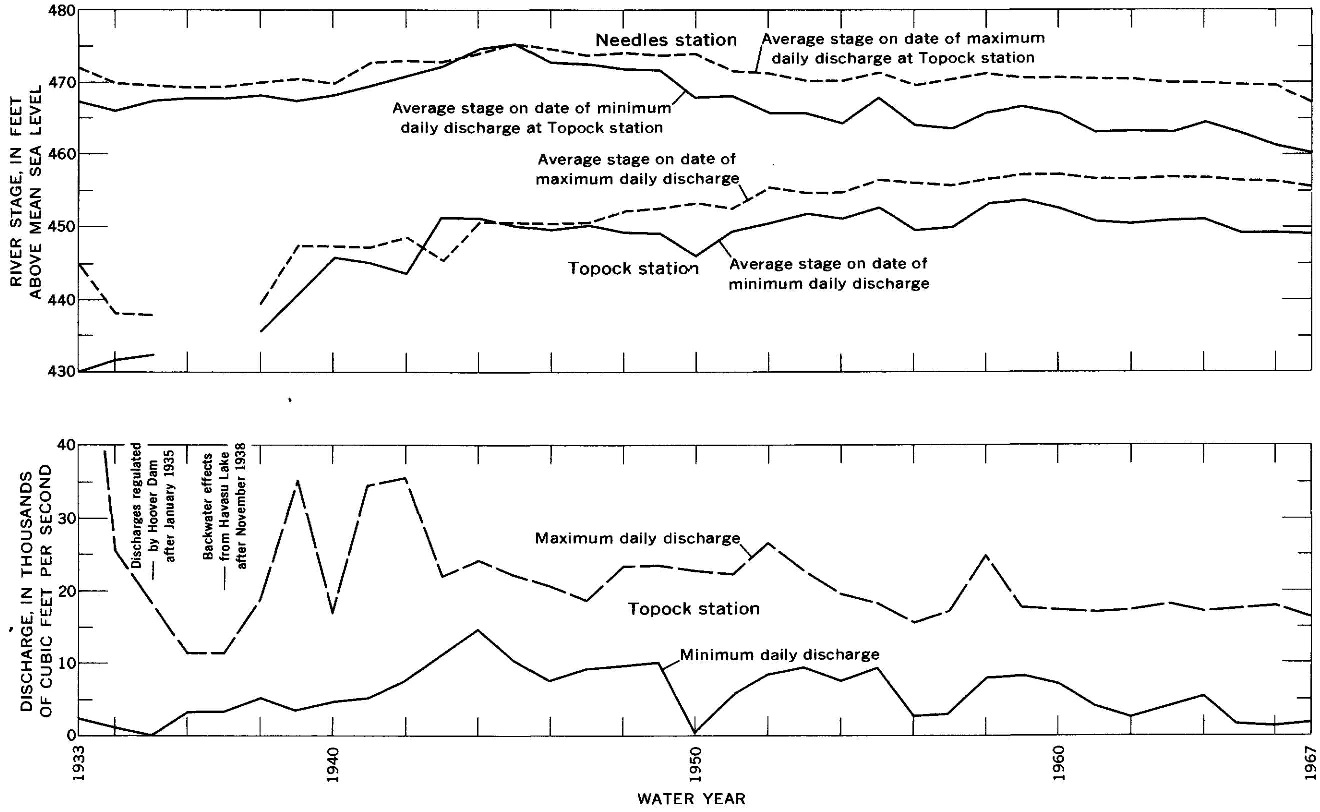

FIGURE 18.—Yearly maximum and minimum daily discharge and stage of Colorado River at Topock and Needles river stage stations, 1933–67.

approximation of the yearly average stage, then the data show that from an average stage of 438 feet in 1938, when backwater from Havasu Lake reached the station, the stage rose to 450 feet by 1944. There it remained until 1950, after which it gradually rose to a peak of 455 feet in 1959 and 1960. Between 1961 and 1967 the average stage gradually declined to 453 feet, which is about 15 feet above the stage in 1938, and about 25 feet above the stage for a comparable discharge in 1902–3.

River-stage records have been published for a station at Needles since 1933. However, discharges are not measured at the Needles station; so the discharges near Topock are used in this study to correlate stages and discharges. Average daily stages at Needles on dates of maximum and minimum discharge near Topock are plotted in figure 18 also.

Again assuming that a stage midway between the average daily stages on dates of maximum and of minimum discharge in any one year is a satisfactory approximation of the average stage for that year, the following observations can be made: The changes in average stage of the river at Needles differ from those near Topcock. The average stage at Needles rose from an altitude of about 468 feet in the middle 1930's to a maximum altitude of about 475 feet by 1945 and then gradually declined to 468 feet by 1952. This stage was maintained until 1960, after which it again gradually declined to about 465 feet in 1966 and 464 feet in 1967. It appears, therefore, that the 15-foot rise that occurred near Topock between 1938 and 1944 was accompanied by a rise of about 7 feet at Needles. Because the resultant rise of ground-water levels was causing some agricultural land to be waterlogged and causing damage to Needles and the railroad, the U.S. Bureau of Reclamation in 1947 began remedial measures for lowering water levels. Undoubtedly, the dredging and channel rectification work that followed were responsible for much of the 5-foot decline of average river stages that occurred between 1947 and 1952.

Changes in river stage upstream from Needles between 1902–3 and 1962–63 can be inferred by comparing river stages for the earlier period with river stages for the latter period which are recorded at river-stage stations maintained by the U.S. Bureau of Reclamation. The data for this comparison (shown in fig. 19) indicate that for a discharge of 10,000 cfs, stages in 1962–63 were 2 to 4 feet higher than in 1902–3 in the reach between Davis Dam and a section about 10 miles north of Needles. Presumably a similar relationship existed for other rates of discharge, including the average yearly discharge.

The foregoing comparisons show only the net change in stage between 1902–3 and 1962–63, not intermediate changes. More complete data at the U.S. Geological

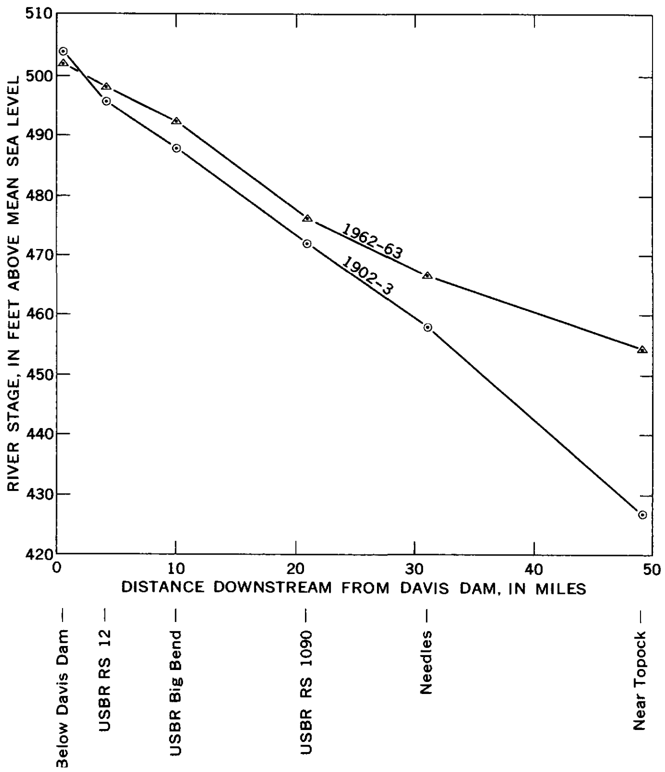

FIGURE 19.—Colorado River stages at selected sites in 1902–3 and 1962–63. Discharge rate is 10,000 cfs.

Survey gaging station below Davis Dam show that substantial intermediate changes may have occurred. The gaging station is half a mile downstream from the dam and 30½ miles upstream from the river stage station at Needles. Discharge and stage records were begun in March 1949 at about the time Davis Dam was completed. The river profile map for 1902–3 indicates that the river surface was at an altitude of about 504 feet when the discharge was 10,000 cfs. In 1949 the altitude of the river surface was almost 511 feet for a like discharge. This suggests that the river channel probably had aggraded about 7 feet between 1902 and 1949.

Discharge and stage data for the station below Davis Dam beginning in 1949 are shown in figure 20. Maximum discharges generally range between 25,000 and 30,000 cfs because of the regulation of releases from Hoover and Davis Dams. This rate of maximum discharge is only about one-fifth the maximum rates that were common under natural conditions.

The decline of stage during years of rather constant yearly discharge indicates that the river channel continually degraded after 1950. On the basis of discharge-stage relationships, it is computed that in 1962 the river stage was about 502 feet above sea level when the discharge was 10,000 cfs, or about 2 feet lower than the stage for a comparable discharge under natural conditions. Thus, although the river channel near the gaging-station site below Davis Dam was not much different in the 1960's from what it had been under natural conditions, in the interim the river channel evidently had aggraded at least 7 feet by 1949, and then had eroded back to near its natural altitude in a few years time following the release of relatively clear water from Davis Dam.

In summary, the average river stage from the northern end of Mohave Valley to a point about 10 miles north of Needles presently may be about 4 feet higher than under natural conditions. Southward from this point the differences in stage increase, so that at Needles the average river stage presently is about 8 feet higher than under natural conditions and at Topock, about 27 feet higher. These higher stages cause ground-water levels to rise a like amount near the river and a lesser although substantial amount at considerable distances from the river. Where the rise is sufficient to make ground water more readily available to water-loving vegetation or for evaporation, the rise results in additional depletion of the available water supply.

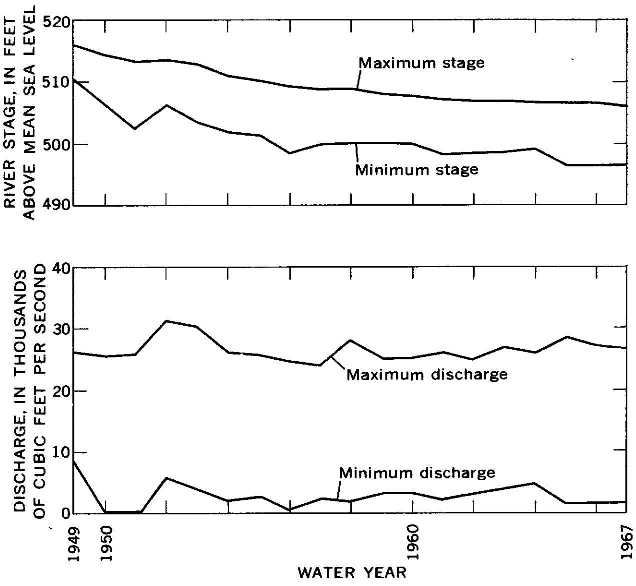

FIGURE 20.—Yearly maximum and minimum discharges and stages of Colorado River at gaging station below Davis Dam, 1949–67.

HYDROLOGIC CHARACTERISTICS OF AQUIFERS

DEFINITION OF TERMS

The term "aquifer" commonly is applied to a water-bearing formation or rock unit that is capable of yielding a satisfactory water supply. It may denote a single bed, or a sequence of beds whose individual permeable beds may be lenticular and vaguely bounded but which generally are not separated by extensive relatively impermeable beds.

Because a satisfactory water supply depends in large part on the conditions that must be met, "aquifer" is a relative term for which good, fair, or poor are commonly used to denote the degree to which the supply is satisfactory. However, these general terms are inadequate for a quantitative appraisal of an aquifer or aquifer system, or for comparing one supply with another. For these purposes, more specific terms as explained in the following discussion are used.

The principal characteristics of an aquifer that permit a quantitative analysis of its response to changes in supply or withdrawal are designated by two terms: "transmissivity" and "storage coefficient." The term "transmissivity," which is equivalent to the term "coefficient of transmissibility" introduced by Theis (1935), has been used by an increasing number of hydrologists in recent years because it is a more exact word than transmissibility for the hydraulic characteristic that it describes. In units commonly used by the Geological Survey, transmissivity is expressed as the rate of flow of water in gallons per day through a vertical strip 1 foot wide of the entire saturated thickness of the aquifer under a unit hydraulic gradient at the prevailing temperature of the water. In some applications it may be visualized more easily by expressing the width of aquifer cross section in miles and the hydraulic gradient in feet per mile.

The water-transmitting characteristics of a rock may also be expressed on a unit-area basis. The term commonly used for this purpose is "hydraulic conductivity" (formerly coefficient of permeability), which is the flow of water in gallons per day that will occur through a 1-square-foot cross section of the aquifer under a unit hydraulic gradient at a water temperature of 60°F (15.6°C). If the flow is that occurring at the prevailing temperature of the water, the term is referred to as the field hydraulic conductivity. Thus, the field hydraulic conductivity is related to the transmissivity by the formula

$$Pm=T$$

in which P is the field hydraulic conductivity, m is the saturated thickness of the aquifer in feet, and T is the transmissivity.

Under certain conditions, especially in alluvial material, it is necessary to differentiate between the horizontal and vertical hydraulic conductivity. The horizontal hydraulic conductivity of a particular bed ordinarily is substantially higher than the vertical hydraulic conductivity, owing to the size sorting and the alinement of tabular grains that occur during the deposition of alluvial materials. Values of horizontal hydraulic conductivity commonly range from a fraction of a gallon per day per square foot for clay and silt, to 10,000 gpd per sq ft (gallons per day per square foot) for well-sorted very coarse sand or less well sorted gravel.

Transmissivity values generally are determined from pumping tests if it is practical to make the tests and if test conditions are favorable. They also can be computed on the basis of the theoretical relation between transmissivity and the specific capacity of wells (Theis and others, 1963). (Specific capacity is the yield of a well per unit of drawdown after a specified period of discharge. In this study it is expressed as gallons per minute per foot of drawdown at the end of 1 day.) Both the above methods for estimating transmissivity were used in the present study.

The other important characteristic of an aquifer is its ability to store or to release water in response to changes in head. This characteristic commonly is designated by a dimensionless number, the storage coefficient (formerly coefficient of storage), which is the volume of water that is released from or taken into storage per unit surface area of an aquifer per unit change in the component of head normal to that surface (Ferris and others, 1962, p. 74).

The changes in storage that result from changes in head when water is confined, that is, when it occurs under artesian conditions, are due almost entirely to compressibility of the water and the aquifer. Storage coefficients under artesian conditions, therefore, are small, generally ranging from about 0.00001 to 0.01.

The changes in storage that result from changes in head when water is unconfined, that is, when it occurs under water-table conditions, are dependent almost wholly on the drainage characteristics of the aquifer material.

The volume of water involved in gravity drainage ordinarily is many hundreds or even thousands of times greater than the volume attributable to compressibility of the aquifer materials and of the water in the saturated zone; so the volume of water resulting from compressibility can be ignored. The volume of water involved in gravity drainage divided by the volume of porous material through which the water table moves, has been defined as the specific yield. Under dewatering and unconfined conditions the storage coefficient therefore is, for all practical purposes, equal to the specific yield. When water is going into storage, that is, when the water table is rising, the storage coefficient may exceed the specific yield if the material in which the water is being stored contains less moisture than it can retain against gravity drainage. The upper limit of the storage coefficient in the latter example is the porosity of the material. Under water-table conditions, the storage coefficient for clay and silt commonly ranges from almost zero to a few hundredths. For clean sand and gravel, it frequently ranges between 0.2 and 0.4.

By definition, the storage coefficient is not a function of time. It represents the ultimate change in storage regardless of the time necessary to achieve the change. In practice, the ultimate change is rarely, if ever, reached. Rather, it is approached within widely varying limits depending on the time since the change in head occurred and the physical properties of the water-bearing material. In a clean sand or gravel almost all the gravity drainage may be completed in a few hours or a few days, whereas in silt or clay, an appreciable part of the ultimate drainage may occur after weeks or months of drainage.

Storage coefficients used in conjunction with transmissivities permit the determination of the relative amounts of ground water that will be involved in storage changes and of those that will be involved in movement of ground water toward or away from an area for a given change in the ground-water supply. Conversely, the change in position and shape of the water table or piezometric surface that results from a given change in the supply of ground water can be used to compute the two characteristics.

Pumping tests are probably the most practical way for determining storage coefficients if artesian conditions exist, but they may be less practical than other methods if water-table conditions prevail. The failure of pumping tests to provide valid data for computing storage coefficients is due in most instances to the slow rate at which many water-bearing materials drain.

The mathematical formulas used for analyzing pumping tests assume an instantaneous change in storage with a change in head. Although this idealization may be closely approached under artesian conditions, it is rarely closely approached under water-table conditions. Therefore, storage coefficients computed from data obtained during pumping tests of unconfined aquifers are likely to be substantially less than the true storage coefficient unless the tests are made over a period of days and adjustments for protracted drainage are made.

In some areas a more practical approach for determining storage coefficients under water-table conditions is the use of a neutron moisture probe in conjunction with access tubes driven to depths of several feet below the water table. The average difference between the moisture content of material above the capillary zone and that of material below the water table is then considered an indicator of the amount of water that will go into storage as the water table rises. This approach was used for estimating storage characteristics of material underlying the flood plain in the Parker-Blythe-Cibola area and the Yuma area and to a limited extent in the Needles area. The field investigation in the Needles area was limited because the results of studies made in the aforementioned downstream areas were considered to be applicable to similar deposits in the Needles area also

The scientific principles which relate neutron-probe data to moisture content and the details of construction of access holes and of equipment used are explained in previous water-resources reports on the lower Colorado River area (Metzger and others, 1972 and Olmsted and others, 1972), and so will not be repeated here.

SOIL-MOISTURE STUDIES

Figure 21 shows typical profiles obtained during the soil-moisture studies. At access hole (B–17–22)11ccc, the average counts at 1-foot depth intervals from land surface to a depth of 7 feet are related to the moisture content in the zone of aeration above the capillary fringe. The average counting rate of about 780 per minute represents an average moisture content of about 3 percent. The increase in counting rate in the depth interval from 7 to 10 feet is due to increasing moisture content below the top of the capillary fringe. The average counting rate of about 8,000 per minute below 10 feet is related to a moisture content of about 47 percent in the zone of saturation. As stated previously, the difference between the moisture content above the capillary fringe and the content in the zone of saturation, 44 percent, is the basis for estimating the ability of the deposits to store water as the water table rises. Although the above assumption may be considerably in error for any one profile, it is considered a valid assumption if applied to the mean values of a large number of profiles.

The profile of access hole (B–18–22)35cad indicates that the water table and capillary fringe both were below a depth of 14 feet. It also shows that the moisture content in the zone of aeration is not uniform. The average counting rate of about 2,000 per minute between

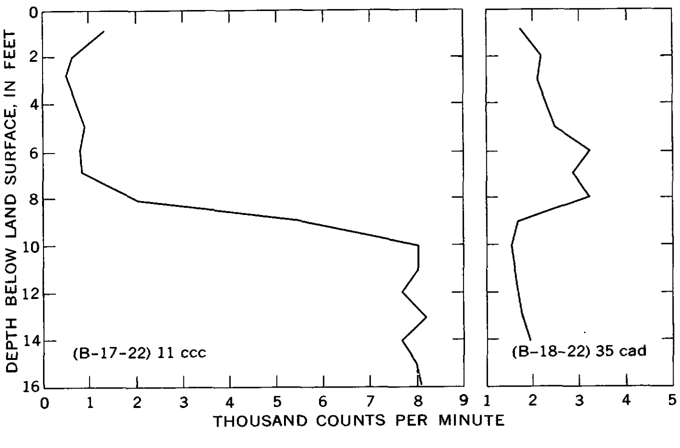

FIGURE 21.—Counts per minute at various depths below land surface obtained with neutron moisture probe at two sites in Needles area.

depths of 6 and 8 feet corresponds to a moisture content of about 10 percent, whereas the average counting rate of about 700 per minute from 10 to 12 feet corresponds to a moisture content of only 3 percent. If the moisture content in the zone of saturation is similar to that at site (B–17–22)11ccc, or 47 percent, the capacity to store water as the water table rises averages about 42 percent.

The foregoing two profiles, in themselves, are not an adequate basis for estimating the storage capacity of deposits at shallow depths beneath the flood plain in the Needles area. The results of similar studies in the downstream areas therefore are summarized (Metzger and others, 1972 and Olmsted and others, 1972).

At 11 sites in Parker Valley, the average moisture content in the zone of saturation was 45 percent, and in the zone of aeration above the capillary fringe, 6 percent. In Palo Verde Valley (also known as the Blythe area), average values at 16 sites for corresponding zones were 44 and 12 percent, indicating a storage capacity of 32 percent. Soil-moisture profiles of shallow flood-plain deposits in the South Gila Valley east of Yuma, Ariz., indicated a capacity for storage of about 37 percent and in the Yuma Valley, west and southwest of Yuma, about 42 percent. In contrast, the storage capacity at similar depths beneath Yuma Mesa was about 28 percent.

In no place did the soil-moisture studies include any appreciable thickness of coarse gravel because it was impractical to drive access tubes into these deposits. However, on the basis of studies in other areas (Johnson, 1967, p. D1), it is probable that the storage coefficient of gravel in the Needles area averages about 25 percent.

The soil-moisture studies suggest that in an area of rising water levels beneath the flood plain outside of irrigated areas the storage capacity is likely to be between 32 and 42 percent. A similar amount of water can be expected to be released from storage as water levels decline if sufficient time elapses for practically all gravity drainage to be completed. The actual amount that can be expected during a seasonal or shorter period of decline of water levels may be considerably less than the above amounts because of the slow drainage of fine-grained material. Storage coefficients beneath irrigated areas are likely to be less than beneath nonirrigated areas because the moisture content above the capillary fringe quite often exceeds the field capacity due to incomplete gravity drainage of excess irrigation water.

No studies were made of the storage capacity of material outside the flood plain. However, it is probable that the storage capacity of the deposits beneath the piedmont slopes is less than that of the shallow flood-plain deposits.

PUMPING TESTS

The principal objective of the pumping tests was to determine within reasonable limits the transmissivity of the main water-bearing deposits. Accordingly, tests were made in existing wells of large yield. For most wells the test was limited to obtaining data on the rate of recovery of water level after the well had been pumped at a constant rate for a known period of time. A few wells also yielded data on drawdown versus pumping time. No wells other than the pumped well were available for satisfactorily observing the effects of pumping or shutting down the pumped well. Consequently, the pumping-test data were inadequate for computing storage coefficients.

Where possible, the data were analyzed by use of the nonequilibrium formula of Theis (1935) or modifications thereof. However, because conditions at some of the sites were substantially different from those that were assumed in deriving the nonequilibrium formula, the plot of observed changes of water level with time sometimes deviated so far from the theoretical pattern that the Theis nonequilibrium formula obviously could not be used to compute even an approximate transmissivity value.

Sometimes the plot, although conforming to the theoretical pattern, nevertheless indicated unreasonably high values of transmissivity on the basis of the theoretical relation between transmissivity and specific capacity. Under these conditions the transmissivity indicated by the recovery data was also evaluated against a probable value based on the estimated hydraulic conductivity and thickness of the water-bearing material tapped by the well.

Recovery data for two wells are plotted in figure 22. The plot of recovery data versus time for well 11N/21E–36Q1 is typical of the pattern that was used for computing transmissivity by use of the Theis nonequilibrium formula. The transmissivity is inversely proportional to the slope of the plotted data during the early part of the recovery period at which time the slope is nearly constant.

The plot of recovery data versus time for well (B–19–22)26ddd is typical of some of the plots that followed the theoretical pattern a minute or two after pumping stopped, yet which resulted in computed values of transmissivity that were considered unreasonably high when compared to values computed from drawdown data versus time or from specific capacity data.

The results of the five pumping tests in Arizona and the four pumping tests in California that were made during the investigation are listed in table 2. Each of the transmissivity values computed by use of the Theis

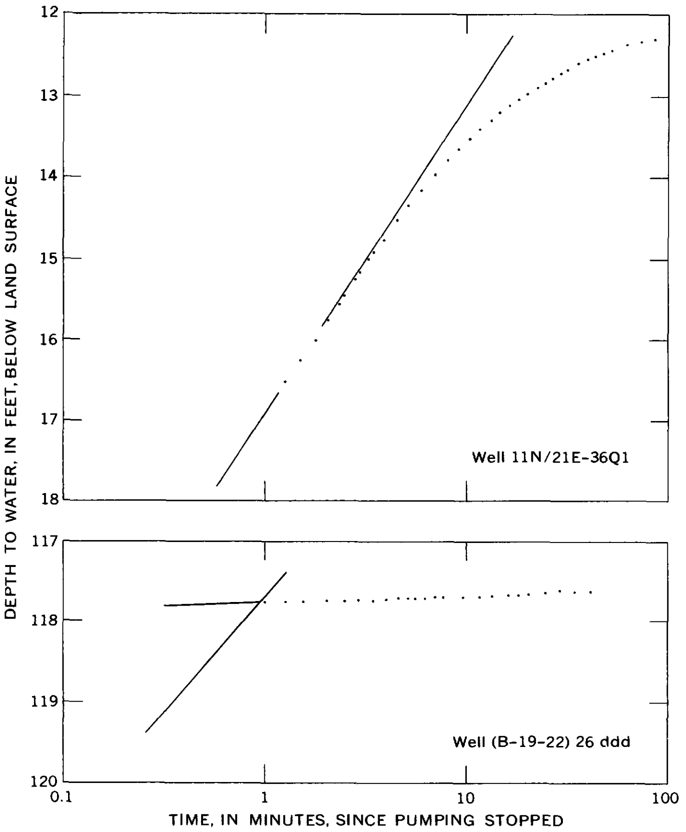

FIGURE 22.—Hydrographs of pumping-test data for selected wells.

nonequilibrium formula is classified as being a good, fair, or poor indicator of the transmissivity of the water-bearing deposits tapped by the well. A classification of good is assigned if the difference between computed transmissivity and the true transmissivity is thought to be less than 25 percent of the value listed; fair, if the difference is between 25 and 50 percent, and poor, if more than 50 percent. Consequently, none of the computed values is significant to more than two figures and most of them to one figure. The classification takes into account not only the degree to which the plotting of test data followed a theoretical pattern and the theoretical relation between transmissivity and specific capacity previously mentioned, but also the construction of the well, the possibility of leakage between strata tapped by the well, and any other known factors that might tend to invalidate the results.

Also considered was whether the hydraulic conductivity, as computed by dividing the indicated transmissivity by the thickness of strata tapped by the well, greatly exceeds the probable maximum hydraulic conductivity. Studies in downstream areas (Olmsted and others, 1972 and Metzger and others, 1972) indicate that the average maximum hydraulic conductivity of alluvial deposits that are at least several tens of feet thick probably is not much larger than 10,000 gpd per sq ft.

TABLE 2.—*Results of pumping tests*

[Type of test: D, drawdown; R, recovery; S, specific capacity. All wells completed in alluviums of the Colorado River]

Well	Owner or name	Date of test	Type of test	Depth interval tested (ft below land-surface datum)	Yield (gpm)	Draw-down (ft)	Specific capacity (gpm per ft)	Transmissivity *T* (gpd per ft)	Conformance of test data to theoretical values	Reliability of *T*	Indicated average field hydraulic conductivity (gpd per sq ft)	Remarks
						Arizona						
(B-18-22)15aab	D. Hulet	11- 1-62	R	60-95	1,720	20.8	83	240,000	Fair	Fair	6,900	Only part of aquifer tested.
			S					240,000			6,900	
27bbc	G. McKellip	11- 1-62	D	80-126	3,420	21.5	160	600,000	Good	Good	13,000	
			R					900,000	do	Fair	20,000	
			S					240,000			5,200	
(B-19-22)26ddd	S. Joy, Sr	11- 2-62	R	117-190	1,720	7.0	250	6,500,000	do	Poor		
			S					350,000			4,700	
36bab	do	11- 1-62	R	147-250	1,870	4.6	410	6,000,000	Poor	do		
			S					650,000			6,300	
36bac	do	11- 2-62	R	151-200	1,460	4.7	310	2,600,000	Fair	do		
			S					430,000			8,800	
						California						
9N/23E-29F1	City of Needles	6-20-63	R	7-65	650	3.0	220	600,000	Fair	Fair	10,300	
			S					300,000			5,200	
32K1	do	6-20-63	R	150-360	1,460	31.0	47	450,000	Excellent	Good	2,100	
			S					70,000			330	
11N/21E-36G2	Soto Bros	6-18-63	R	30-85	850	17.0	50	94,000	do	do	1,300	Only part of aquifer tested.
			S					75,000			1,400	
36Q1	W. Riddle	6-19-63	D	12-150	2,500	26.0	96	160,000	Good	do	1,200	Do.
			R					170,000	Excellent	do	1,200	
			S					140,000			1,000	

Because there is no known reason why average maximum hydraulic conductivities should be substantially higher in the Needles area than in the downstream areas, the reliability of the computed transmissivity is given a lower classification if the implied hydraulic conductivity is substantially higher than 10,000 gpd per sq ft.

The data show that the materials tapped by the wells in Arizona are very permeable, the hydraulic conductivity generally having a probable minimum value of 5,000 gpd per sq ft. The probable average hydraulic conductivity will be even higher to the extent that well losses are responsible for the observed drawdown. It is possible, therefore, that some of the actual hydraulic conductivities may be double the probable minimum values shown, in which case the deposits tapped by the wells are as permeable as any that are known to exist in the lower Colorado River area.

The hydraulic conductivity values indicate that yields of several thousand gallons per minute with drawdowns of tens of feet can be expected from large diameter wells that tap at least several tens of feet of the alluviums of the Colorado River.

The tests of wells in California suggest that similar yields and drawdowns can be obtained in the flood plain at Needles. Some 15 miles north of Needles, however, the yields for a given drawdown and depth of well are likely to be smaller because the hydraulic conductivity of the alluvium beneath the flood plain in this area apparently is more nearly 1,200 gpd per sq ft than the 5,000 gpd per sq ft which characterizes the water-bearing material tapped by the wells in Arizona that were tested.

GROUND WATER UNDER NATURAL CONDITIONS

MOHAVE VALLEY

Under natural conditions, the Colorado River annually overflowed its banks during the early summer runoff and flooded large parts of the flood plain, some of which were remote from the river. The flood waters commonly spread across the flood plain via abandoned channels. Some of the water returned directly to the river, but much of it was trapped, thereby forming sloughs and oxbow lakes. Some of the water evaporated; some of it infiltrated into the ground and became soil moisture, only to be evaporated or transpired later; and some of it infiltrated to sufficient depths to recharge the ground-water reservoir. In addition to this recharge by floodwater, the ground-water reservoir was also recharged by the infiltration of water directly from the river.

Over a period of years the recharge to the ground-water reservoir was equal to the discharge from it. The magnitude of the recharge therefore can be estimated by considering the quantity of ground water that was discharged. Ground water was discharged principally by the transpiration of water-loving vegetation and by evaporation from free water surfaces. The consumptive use by vegetation under natural conditions can be estimated on the basis of the consumptive use by natural vegetation during recent years, after making adjustments for the changes in that use that have occurred since natural conditions prevailed.

In the Mohave Valley, saltcedar was the dominant vegetation on about 25,000 acres in 1962, arrowweed on about 11,000 acres, mesquite on about 6,000 acres, and tules on about 4,800 acres (U.S. Bureau of Reclamation, 1963). Using data in the reference cited, it can be computed that the average rate of use in 1962 by saltcedar was 3.6 feet per year, arrowweed 3.5 feet per year, mesquite 2.5 feet per year, and tules 8.5 feet per year.

To relate the above data to natural conditions, one must recognize that saltcedar was not present in the valley under natural conditions. The 25,000 acres of saltcedar noted in 1962 was established sometime after the early 1920's. Because saltcedar is an aggressive plant, it is likely that it replaced other vegetation and also in some places became established on ground that up to that time had not supported the growth of water-loving vegetation. To the extent that saltcedar replaced arrowweed, it did not cause a significant change in the discharge of ground water because the average rates of use by the two species are about the same. However, where saltcedar replaced mesquite each acre of saltcedar resulted in an additional discharge of ground water of about 1 acre-foot per year on the average. Where the saltcedar became established on land that had not previously supported the growth of water-loving plants, each acre of saltcedar resulted in about 3.6 acre-feet per year additional discharge of ground water.

The number of acres of saltcedar that were replacements for other types of vegetation and that were new acreages are not known. However, on the basis of the distribution of natural vegetation in 1962 it seems probable that about half the saltcedar was a replacement for mesquite and half for arrowweed. If this is true, then the discharge of ground water on land where saltcedar was the dominant vegetation in 1962 would have been 12,000 acre-feet less under natural conditions, or about 78,000 acre-feet per year. Other downward adjustments of consumptive use are needed because much of the acreage mapped as being dominantly tules in 1962 was probably mesquite or arrowweed under natural conditions. If it is assumed that equal acreages of these species were replaced by tules, the consumptive use of water under natural conditions on the 4,800 acres of land occupied by tules in 1962 would have been about 15,000 acre-feet per year. Likewise, evaporation from free water surfaces was less under natural conditions than in 1962, principally because the open water that is now a part of the Havasu Lake National Wildlife Refuge did not exist until 1938. About 3,000 acres that was under water in 1962 probably supported vegetation under natural conditions. If an average rate of use of 3 feet per acre is assumed to have been used by the vegetation growing on this acreage, an annual consumptive use of 9,000 acre-feet is indicated. In addition, a like amount is assumed to have been consumptively used on the 3,000 acres of cropland that were irrigated in 1962, but which had supported the growth of natural vegetation before being cleared.

The total discharge of ground water in the Mohave Valley under natural conditions, therefore, is the sum of the four estimates just made, 111,000 acre-feet, plus the consumptive use of natural vegetation on the other land in the area, 58,000 acre-feet (U.S. Bureau of Reclamation, 1963, table 4, p. D–10)—a total of about 170,000 acre-feet per year. Because ground-water discharge and ground-water recharge were equal over a period of years, the foregoing figure is also an estimate of annual ground-water recharge under natural conditions.

As was stated earlier, the Colorado River was the principal source of this recharge, either by infiltration of water from the river itself or by the infiltration of part of the flood water that annually covered large areas of the valley. If only half the ground-water recharge resulted from infiltration of water directly from the river, an average infiltration rate of 2,500 acre-feet per year per mile of river length would suffice to supply the recharge in the 35-mile reach north of Topock where most of the consumptive use occurred.

Thus, under natural conditions ground water moved from the river to areas of ground-water discharge much as it does today. However, because the river stages then were considerably lower relative to the adjacent ground-water levels than they presently are (1969), especially in the southern half of the valley, infiltration of river water directly to the ground-water reservoir was considerably less under natural conditions than it is today. The contour lines of a water-level map showing natural conditions would therefore extend away from the river at a considerably larger angle than those shown on plate 2.

CHEMEHUEVI VALLEY

Under natural conditions the ground-water regimen in Chemehuevi Valley was considerably different from that in Mohave Valley. Although both areas were subject to annual flooding by the Colorado River, the flooded area in Chemehuevi Valley was much smaller than in Mohave Valley. The only extensive area that was subject to flooding in Chemehuevi Valley was about 10 square miles upstream from Site Six. Elsewhere only relatively narrow strips of land along the river were subject to flooding.

The depletion of the river as it passed through the valley was due principally to evaporation from the river itself and to the transpiration of water-loving vegetation whose source of supply was ground water that had infiltrated from the river or its flood waters. Depletion by evaporation is estimated to have averaged 32,000 acre-feet per year and by transpiration 20,000 acre-feet per year. The basis for the first estimate is an average width of the river of 0.15 of a mile for the 50-mile reach between the stream-gaging station near Topock and Parker Dam and a net annual evaporation rate of 6.75 feet (p. J37). The second estimate is based on an average rate of use of 3 feet per year by water-loving vegetation on 10 square miles of the flood plain upstream from Site Six. There was virtually no irrigation in the area; so the total consumptive use averaged only about 50,000 acre-feet per year.

Any substantial infiltration of water from the river to the ground-water reservoir was limited to the area of water-loving vegetation above Site Six. For most of the valley, therefore, water levels in alluvial deposits bordering the river would have had the same altitude as the mean annual stage of the river, and would have had a comparable downstream slope.

Stages of the Colorado River in 1902–3, adjusted for a discharge of 10,000 cfs, at intervals of 5 river miles below the stream-gaging station near Topock are listed in table 3. In general, water-level contours under natural conditions would have had similar values and would have been normal to the axis of the valley except in limited areas where substantial ground-water recharge from tributary areas or from precipitation in the bordering mountains was moving toward the river. In these areas the contours would trend slightly down valley from a line normal to the axis of the valley.

GROUND WATER IN RECENT YEARS

MOHAVE VALLEY

The ground-water regimen in recent years differs considerably from what it was under natural conditions. One of the principal reasons for the difference was the control of the river by the building of dams. The completion of Hoover Dam in 1936 ended the annual flooding of much of the area and consequently eliminated or greatly reduced much of the recharge to ground water that formerly resulted therefrom. Another major change in the ground-water regimen occurred with the closure of Parker Dam in 1938. The aggradation of the river channel which resulted from the closing of the dam is discussed in more detail in the section "River Stages." In addition to the aforementioned changes, changes in the ground-water regimen also resulted from the building of levees and dredging operations to control the course of the river and to maintain river stages at acceptable levels. Although several thousand acres of land were cleared and irrigated by pumping ground water, this development did not greatly alter the ground-water regimen because the consumptive use by crops was not greatly different from the consumptive use by the natural vegetation which it replaced.

Water-level contours for the Mohave Valley as of the 1960's are shown on plate 2. The contours in the flood plain for the most part were drawn on the basis of water-level data obtained during 1961–62 from a network of shallow observation wells established for this purpose, and on the basis of continuous records of river stage at about 10-mile intervals during the same period of time. Contours outside the flood plain were drawn on the basis of water levels in wells at various times during the period 1962–69. Comparisons of water levels measured at different times during the above period indicated that water levels were quite stable in most parts of the area. Spirit levels were run to most of the wells in the flood plain and to about half the wells on the alluvial slopes on either side of the flood plain. The altitudes of other wells were determined by hand level from nearby bench marks or by interpolation between 10-foot contours shown on the topographic map compiled by the U.S. Geological Survey from surveys made in 1902–3.

The contour map indicates that the Colorado River is losing water to the ground-water reservoir throughout its course through Mohave Valley. The ground water moves from the river to other areas in the flood plain, where it is discharged either by transpiration or by evaporation. An estimate of the magnitude of the infiltration of river water can be obtained by making use of data contained in the 1963 U.S. Bureau of Reclamation study and of data contained in other parts of this report.

The infiltration from the river in Mohave Valley is assumed to be equal to the consumptive use in the area that is not supplied directly either from surface water or from inflow other than the river. In the 1963 U.S. Bureau of Reclamation study, it is estimated that the annual consumptive use by saltcedar is 89,000 acre-feet, by arrowweed 40,000 acre-feet, by mesquite 16,000 acre-feet, and by other phreatophytes, excluding tules, 2,000 acre-feet. The 40,000 acre-feet consumed by tules, for the purposes of this analysis, is considered to be mostly river water that is diverted to the large body of open water in the Havasu Lake National Wildlife Refuge and therefore is excluded from the estimates of infiltration of river water. Infiltrated river water is also needed to replace the net quantity of ground water pumped for irrigation, which is about 12,000 acre-feet. The total discharge of ground water is the sum of the preceding estimates, about 159,000 acre-feet per year. Unmeasured runoff and ground-water inflow from tributary areas is a minor additional source (probably not much more than 5,000 acre-feet per year) for the ground water that is discharged in the area. Therefore, the infiltration of water directly from the river to the ground-water reservoir is about 150,000 acre-feet per year.

Most of the infiltration occurs in a 37-mile reach of the river downstream from Bullhead City, Ariz., which implies an average rate of about 4,000 acre-feet per year per mile length of river. However, the actual rate of infiltration at a particular section may be considerably different from the average rate. The actual rate of leakage will depend among other factors on the transmissivity of the deposits through which the ground water moves to points of discharge, the hydraulic connection between the river and the water-transmitting deposits, the distances to the areas of discharge, and the rate of the discharge. The resultant of these and other factors controlling the rate of infiltration are depicted in part by the location of the water-level contours on plate 2.

A crude estimate of the transmissivity in certain areas can be obtained by computing the discharge that is occurring in a strip bounded by the river, two parallel or nearly parallel flow lines, and a section of no further significant movement of water away from the river. The following example illustrates the use of the method.

Consider a 1-mile-wide strip of land extending northeast from the river at a reach about 2 miles upstream from Needles, Calif. The flow lines, at right angles to the contours, are nearly parallel and the section of no further movement of water from the river crosses near the northeast corner of sec. 1, T. 17 N., R. 22 W., or near the center of the closed 452-foot contour. The strip is about 4 miles long.

The consumptive use by native vegetation, which is mostly saltcedar, and by crops within the strip is about 3.5 feet per year, or about 2,200 acre-feet per mile distance from the river, a total of 8,800 acre-feet per year. Presumably, this is the rate at which water infiltrates from the river in this particular 1-mile reach. The average river stage is 470 feet above sea level, and the average water level at the far end of the strip is 452 feet above sea level. Assuming that the consumptive use is at a uniform rate, at a point midway between the river and the section of no further movement of ground water from the river, the rate of movement is half the rate of infiltration, or 4,400 acre-feet per year.

The hydraulic gradient causing this movement of water cannot be determined from the spacing of the water-level contours midway between the river and the section of no further movement of ground water from the river because the control for locating the contours is neither sufficiently detailed nor precise enough for this purpose. An indication of the probable gradient can be obtained, however, by using the average gradient of 4.5 feet per mile at the midway section.

The transmissivity can be computed according to the following formula:

$$T=893\frac{Q}{IL}$$

where T is the transmissivity in gallons per day per foot, Q is the rate of movement of ground water through the midway section in acre-feet per year, I is the hydraulic gradient, in feet per mile, and L is the width, in miles, of the section through which the movement is occurring. For the values previously cited

$$T=893\frac{(4{,}400)}{4.5}$$

$$=870{,}000 \text{ gpd per ft}$$

Although the estimate is crude, it is consistent with the results of pumping tests that were made a few miles north of the above area. In other parts of the valley conditions are less favorable for computing transmissivity by the above method.

The contours shown on plate 2 also indicate relative values of the transmissivities in some parts of the valley. The bunching of the contours east of the flood plain in the Fort Mohave area indicates either a zone of relatively low transmissivity or a hydraulic barrier somewhere between the 486- and the 474-foot contour. The 12-foot difference in gradient in 1 mile is about six times larger than the differences per mile upgradient and downgradient. No surface expression identifying the cause of this much steeper gradient was recognized. The gradients of about 2 feet per mile downgradient from the zone of relatively low transmissivity are compatible with the gradients that are common in areas of high transmissivity, such as are indicated by the pumping tests and specific capacities of the irrigation wells within the contours. Although there is no specific evidence to indicate the nature of the restriction to the movement of ground water east of the Fort Mohave area, it is possible that the northwestward projection of the alluvial slope in the Fort Mohave area is significant. Also, the fact that a well drilled to a depth of 780 feet in this area (p. J20) reportedly penetrated no appreciable thickness of gravel may be significant.

For lack of adequate control, the westward and eastward extent of the movement of ground water outside the flood plain could not be determined in most parts of the area. However, by recognizing that at least a small amount of ground water moves from the mountains towards the flood plain in all parts of the area, it follows that at some point between the river and the mountains there must exist a southward gradient and that between this point and the mountains the gradient must be toward the river rather than away from the river as it is in most areas where contours are shown on plate 2. The probable configuration of water-level contours showing this movement of water in opposite directions is indicated on the alluvial slope south of Needles, Calif., and also on the slope east of the flood plain northeast of Needles.

CHEMEHUEVI VALLEY

The completion of Hoover Dam in 1936 greatly improved control of the discharge of the Colorado River and eliminated the annual flooding of a limited part of Chemehuevi Valley. However, this did not greatly change the ground-water regimen in most parts of the valley. In contrast, the closure of Parker Dam in 1938 had a profound effect on the ground-water regimen because the surface elevation of Havasu Lake which resulted therefrom was 25 to 75 feet above the elevation of the ground water prior to the closure of Parker Dam. Changes in ground-water regimen that resulted from the impounding of water behind Parker Dam can be inferred from table 3. The increase in stage of surface-water levels is shown at intervals of 5 miles downstream from the stream-gaging station near Topock. The values of river stage were obtained from the plan and profile map of the Colorado River, adjusted for a discharge of 10,000 cfs, compiled by the U.S. Geological Survey from surveys made in 1902–3. These stages are considered to be representative of stages under natural conditions.

TABLE 3.—*Colorado River stages in 1902–3, estimated average stages of Havasu Lake, and increases in water-level stages at 5-mile intervals below stream-gaging station near Topock*

Distance below stream-gaging station near Topock (river miles)	Feet above mean sea level: Estimated average stages of Havasu Lake	Feet above mean sea level: Colorado River stage in 1902–3	Increase of water-level stage (ft)
0	453	426	27
5	451	420	31
10	449	414	35
15	448	410	38
20 [1]	448	405	43
25	448	398	50
30	448	389	59
35	448	380	68
40	448	372	76

---

[1] Site Six.

From table 3, it is seen that the water-level stage increased from 27 feet at the stream-gaging station near Topock to 76 feet 40 miles downstream, near Parker Dam. It follows that ground-water levels adjacent to the lake rose a like amount. At increasing distances from the lake, ground-water levels initially rose a lesser amount than near the lake; but with continuing infiltration from the lake they, too, eventually rose very nearly the same amount as did the lake. It is likely, therefore, that beneath the lower parts of the alluvial slopes, ground-water levels are very nearly the same altitude as the lake, about 448 feet above mean sea level. As the water from the lake recharged the ground-water reservoir, the recently infiltrated water displaced much of the prelake ground water and forced it away from the lake. The ground water that presently occupies the upper part of the saturated zone near the lake, therefore, is water that recharged the ground-water system after 1938. At a somewhat greater distance, the ground water is prelake water that has risen up through unsaturated deposits in response to increased heads resulting from the level of Havasu Lake being above prelake river levels.

Only a limited amount of ground water has been developed in Chemehuevi Valley. The principal development is at Lake Havasu City, Ariz., where ground water is pumped for municipal and industrial use. Elsewhere, the pumpage is mostly for domestic and quasi-public supplies for trailer parks and resort areas. The total pumpage is estimated at 3,000 acre-feet per year.

WATER-LEVEL FLUCTUATIONS

MOHAVE VALLEY

Ground-water levels in Mohave Valley generally fluctuate within an annual range of 2 feet. Exceptions are ground-water levels near pumped wells, irrigated land, and the river. Water levels near a well that is pumped will tend to fluctuate in response to the drawdowns and recoveries of water level resulting from the pumping. Water-level fluctuations in wells in or near land irrigated with surface-water supplies commonly show the effects of recharge from irrigation. They ordinarily reach peak stages shortly after the final irrigation and then recede to minimum stages just prior to the beginning of the next irrigation season. They also tend to rise from year to year until the increased gradient is sufficient to carry away the increase in ground-water recharge resulting from the irrigation.

Ground-water levels also fluctuate in response to fluctuations of river stage. In the Mohave Valley the annual range of mean daily river stage is about 6 feet. Near maximum stages generally persist April through August; near minimum stages, December through January. The daily range of stage at the gaging station below Davis Dam commonly is about 7 feet during the summer, owing largely to variations of releases through the turbines to meet the demands for electricity. The range in stage lessens downstream, although at Needles, Calif., daily ranges of 5 feet are common.

The influence of river stage on water levels in the Parker Valley were studied (Metzger and others, 1972). It was found that the daily fluctuations of river stage of about 4 feet affected ground-water levels to a marked degree only a few hundred feet from the river and that there was little evidence of substantial seasonal changes in ground-water levels attributable to river stages at distances of more than half a mile from the river. On the basis of the foregoing study and on the water-level fluctuations observed in wells in Mohave Valley, it is inferred that a similar relation between river stages and ground-water levels exists in Mohave Valley.

Fluctuations of water level in Mohave Valley result from the draft on ground-water supplies because of the transpiration of water-loving natural vegetation. A network of shallow wells having about a 1-mile spacing, east-west, and a 2-mile spacing, north-south, was constructed for the purpose of determining the pattern of these fluctuations. Observations were made monthly for more than a year in all the wells, and graphic water-stage recorders were maintained for almost 3 years on three wells. The general nature of the fluctuations that were observed are indicated by the hydrograph of water level in well (B–18–22)35aaa, which is near the center of the area of transpiration by natural vegetation (figure 23). The hydrograph shows that the water level follows a pattern that is repeated on an annual basis and that is affected almost entirely by the seasonal transpiration of natural vegetation.

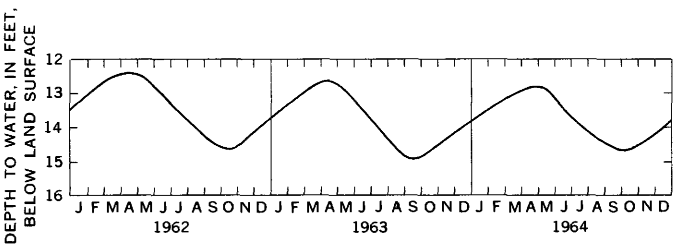

FIGURE 23.—Hydrograph showing depth to water, in well (B–18–22) 35aaa, 1962–64.

At distances of a mile or more from the flood plain, water levels probably fluctuate very little except beneath limited areas subject to recharge from infrequent severe storms.

CHEMEHUEVI VALLEY

Ground-water levels in Chemehuevi Valley fluctuate in response to changes in stage of Havasu Lake. However, the lake is usually maintained within 5 feet of the top of the regulating gates; so the fluctuations of groundwater levels due to changes in lake stage are limited to about 5 feet very near the lake and to smaller ranges at an increasing distance from the lake. At distances of a mile or more, water-level fluctuations due to changes in lake stage are likely to be only a small fraction of such changes. The fluctuations due to other causes, such as changes in rates of recharge or discharge, probably are very small also, except beneath limited areas that may receive a substantial amount of recharge from infrequent severe storms.

DEPTH TO GROUND WATER

Depth to ground water beneath most of the flood plain in Mohave Valley probably ranges between 9 and 12 feet. The depths to water in two-thirds of 25 shallow wells fairly well distributed over the flood plain were within this range. The minimum depth to water in the wells was 6 feet and the maximum, 20 feet.

Depths to water beneath the alluvial slopes bordering the flood plain depend largely on the height of the site above ground-water levels in the adjacent flood plain. A close estimate of the depth to water can be made by noting the altitude of the ground-water level as indicated on plate 2, and subtracting this altitude from the altitude of the land surface at the site in question. In many areas, the alluvial slopes have gradients between 100 and 200 feet per mile toward the flood plain, so depths to water increase at similar rates with distance from the flood plain.

Depth to water beneath most of the alluvial slopes of Chemehuevi Valley is governed largely by the height of a given site above the level of Havasu Lake. Exceptions, for which the depth may be much less are limited areas where the ground water is perched, or where the rate of recharge from a tributary area is sufficient to cause a steep hydraulic gradient between the well site and the lake.

Depths to water in most existing wells in both valleys are shown in table 10.

WATER BUDGETS

A water budget is a convenient means of accounting for the water supply of a given area. It can be presented in many different formats as long as the principle that inflow minus outflow is equal to consumptive use plus any decrease of storage or minus any increase of storage is adhered to.

In the present study, annual changes in storage are neglected for reasons given in the discussion of budget items in the section "Changes in Ground-Water Storage" (p. J37). The budget formula, therefore, reduces to the simpler form of inflow minus outflow equals consumptive use.

Because of the nature of the data that are available for the budget items, it is further convenient to analyze the measured inflow and outflow items separately from the unmeasured inflow and outflow items. The difference between measured inflow and outflow is the measured streamflow depletion, to which need be added the difference between unmeasured inflow and outflow items to obtain total inflow minus total outflow. The difference between these totals is the consumptive use based on the inflow-outflow method.

Following this analysis, consumptive use, based on areas and respective rates of use for these areas, is shown for the convenient categories of natural vegetation, crops, and evaporation from free water surfaces. The total should equal the difference between total inflow and total outflow as previously determined. Any inequality between the values is shown as an imbalance between the two methods for computing consumptive use.

The various items of water budgets for the Needles area and the reliabilities of the items are discussed in the following sections, after which budgets are presented for Mohave Valley and Chemehuevi Valley.

STREAMFLOW DEPLETION

Streamflow depletion is the difference between streamflow measurements made at the upper and lower ends of selected reaches. The U.S. Geological Survey maintains gaging stations below Davis Dam, near Topock, and below Parker Dam for measuring the discharge of the Colorado River and near Alamo, Ariz., about 32 miles eastward from Parker Dam, for measuring the discharge of the Bill Williams River. The Survey, by maintaining rigid standards for its equipment and stream-gaging procedures, attempts to keep measurement errors to a practical minimum, and is especially concerned about systematic errors which result in streamflow discharge figures being consistently too high or too low. Nevertheless, there exists a practical limit within which measurement errors can be kept.

The significance of a given error depends on the use that is being made of the particular discharge measurement. For example, in the study area, an error of 1 percent in a stream-discharge measurement causes an error of about 20 percent in a computation of streamflow depletion. The percentage error is magnified to the above extent because the ratio of stream discharge to streamflow depletion is about 20 to 1. (See table 4.)

The one out-of-basin diversion is made from Havasu Lake by the Metropolitan Water District of Los Angeles. The computed streamflow depletions are credited for this diversion and also for changes in storage content of Havasu Lake, where applicable, to obtain the values of streamflow depletion as used in the budgets and the discussion pertaining to the budgets.

Table 4 shows yearly values of flow for the period 1950–66 passing the U.S. Geological Survey gaging stations, the change in contents of Havasu Lake, the diversions to the Colorado River aqueduct of the Metropolitan Water District of Los Angeles, and computed streamflow depletions, or the difference in yearly flow between the gaging stations after adjusting measured flows, where applicable, for the inflows, diversions, and storage changes.

The departure of annual depletions from mean values is seen to be as much as 165,000 acre-feet for the upper reach and about 225,000 acre-feet for the lower reach. Some of the yearly variations are due to errors of measurement, some are caused by differences in temperature and precipitation, and some by conservation measures such as dredging and improvement of channel geometry.

The reliability of a single annual depletion or the average of even five annual depletions as a measure of the actual depletion is seen to be poor. Loeltz and McDonald (1969) determined to what extent streamflow measurements were a reliable indicator of long-term depletions barring consistent errors of measurement. They found that for any 17-year period of record, such as 1950–66, there was an even chance that the 17-year mean would not differ from a long-term mean, which is the true mean, by more than 14,000 acre-feet in the reach from Davis Dam to Topock, and by not more than 18,000 acre-feet in the reach from Topock to Parker Dam. Also, there was only one chance in 20 that differences would be more than 42,000 acre-feet for the upper reach and 55,000 acre-feet for the lower reach. These findings are used for evaluating the reliability of the streamflow depletion records when the budgets are analyzed in a later section of this report.

UNMEASURED RUNOFF

Unmeasured runoff consists of the runoff from hundreds of areas ranging in size from a fraction of a square mile to more than 1,500 square miles. It is impractical to measure the runoff from these small areas because of its small magnitude, infrequency of occurrence, and short duration. The runoff may range from practically nothing in an extremely dry year to many times the long-term average in a relatively wet year; this amounts to a range of several hundred thousand acre-feet in the study area. Consequently, unmeasured runoff can cause large differences in annual streamflow depletions.

To date, data are inadequate for reliably computing runoff from desert areas. Estimates of runoff for ungaged areas are commonly based on precipitation data, rainfall-runoff relations, character of the terrain, and other parameters. Recently, Moore (1968) proposed a different method for estimating runoff using as a basis the channel geometry and precipitation-altitude rela-

TABLE 4.—*Annual streamflows, diversions to Metropolitan Water District, changes in contents of Havasu Lake, and streamflow depletions, 1950–66*

[Quantities in thousands of acre-feet]

Calendar year	Colorado River below Davis Dam	Colorado River near Topock, Ariz.	Bill Williams River near Alamo, Ariz.	Change in contents of Havasu Lake	Diversion to Colorado River aqueduct	Colorado River below Parker Dam	Streamflow depletions		
							Davis Dam to gaging station near Topock	Gaging station near Topock to Parker Dam	Davis Dam to Parker Dam
1950	10, 830	10, 640	7	−53	179	10, 470	190	51	241
1951	9, 256	8, 973	96	+21	231	8, 672	283	145	428
1952	15, 760	15, 560	158	−54	175	15, 410	200	187	387
1953	11, 160	10, 980	7	+33	228	10, 650	180	76	256
1954	10, 410	10, 139	63	−3	341	9, 671	271	193	464
1955	8, 836	8, 617	35	−7	417	8, 141	219	101	320
1956	7, 743	7, 519	7	−1	481	6, 869	224	177	401
1957	9, 008	8, 882	16	−6	595	7, 997	126	312	438
1958	11, 740	11, 630	61	+8	540	10, 890	110	253	363
1959	9, 196	9, 059	17	+7	708	8, 186	137	175	312
1960	8, 763	8, 683	23	−5	894	7, 794	80	23	103
1961	8, 329	8, 035	6	−8	1, 103	6, 975	294	−29	265
1962	8, 453	8, 288	19	−2	1, 073	7, 159	165	77	242
1963	8, 533	8, 339	34	−5	1, 057	7, 251	194	70	264
1964	8, 022	8, 006	32	+4	1, 137	6, 652	16	245	261
1965	7, 735	7, 652	274	+17	1, 178	6, 356	83	375	458
1966	8, 169	7, 863	81	−18	1, 146	6, 684	306	132	438
Average, 1950–66	9, 526	9, 345	55	−4	675	8, 578	181	151	332

tionships. Both methods are used herein for estimating unmeasured runoff.

Hely (in Hely and Peck, 1964) estimated runoff rates for the entire lower Colorado River -Salton Sea area. He used the first cited method of estimating runoff to prepare a map showing runoff rates from small tracts (10 to 20 square miles), making no allowance for infiltration of runoff. The rates shown by Hely therefore are larger than those that occur wherever infiltration of runoff is substantial.

Runoff rates for several small drainage areas in Sacramento Valley (fig. 1) were determined by Moore using the second cited method (D. O. Moore, written commun., 1968). A comparison of local runoff rates as determined from the channel geometry method by Moore with rates computed by Hely shows large differences, even in the mountains where rates should be comparable. Because both methods are crude and because the results of one method are not known to be more nearly correct than those of the other, it is assumed that both methods have equal merit. On this basis it appears that reasonable rates of runoff from mountains can be obtained by multiplying the rates shown by Hely by a factor of 0.4. This same adjustment is considered applicable also to the Colorado River Valley for areas where the runoff from the mountains crosses only a few miles of alluvium before reaching the flood plain. Where the runoff crosses several tens of miles of alluvium as does the runoff from Sacramento and Piute Valleys and the subarea below the gaging station on the Bill Williams River near Alamo, obviously the runoff as computed from rates of local runoff must be reduced even more—perhaps to only 5 percent of the rates shown by Hely for the tributary valleys and to 10 percent for the Bill Williams River subarea.

Estimates of average annual runoff to the flood plain of the Colorado River or to the river itself from the various subareas are listed in table 5. The above estimates are about half of the estimates made by Loeltz and McDonald (1969), principally because Loeltz and McDonald used 40 percent of the runoff rates shown by Hely for all areas rather than using substantially lower percentages of the runoff that originates in large narrow tributary areas. Lower percentages for the tributary areas were not used in the earlier study because data for computing runoff on the basis of channel geometry were not available at the time the earlier study was made. Although the estimates of unmeasured runoff as computed for the earlier study are now thought to be too large, the principal conclusions of the earlier study remain unchanged because the unmeasured runoff is one of the smaller items of the budgets.

TABLE 5.—*Estimated average annual unmeasured runoff to the flood plain of the Colorado River*

Subarea	*Runoff (acre-feet)*
Colorado River valley:	
Davis Dam to Topock	12,000
Topock to Parker Dam	15,000
Tributary areas:	
Piute Valley	1,000
Sacramento Valley	2,500
Bill Williams River subarea	4,000
Total unmeasured runoff	34,500

GROUND-WATER INFLOW

Ground-water inflow is not measurable directly. One method of computing it is to multiply the transmissivity of the section across which flow is occurring by the width of the section and by the hydraulic gradient normal to the section.

A basis for estimating ground-water inflow that is especially applicable to inflow from tributary areas is the ground-water recharge resulting from precipitation in the tributary areas if ground-water recharge is due principally to precipitation and if the percentage of that recharge that eventually becomes inflow to the study area is known.

Eakin and others (1951, p. 79–81) have proposed an empirical relation between precipitation and ground-water recharge for use in central Nevada which has proved satisfactory for reconnaissance ground-water studies in that State. The method assumes that ground-water recharge generally is related to average annual precipitation in the following manner:

Average annual precipitation (inches)	*Percentage of precipitation that contributes to ground-water recharge*
More than 20	25
15 to 20	15
12 to 15	7
8 to 12	3
Less than 8	0

In the areas of Nevada for which the method was developed, three-fourths or more of the yearly precipitation occurs as snow which accumulates in the mountains during the winter. When the snow melts in the spring, it sustains the flow of streams for periods of weeks and months and thereby provides a very effective means of ground-water recharge. In the study area, however, and the lower Colorado River valley as a whole, only a very small percentage of the precipitation is snow. Almost all runoff, therefore, is in direct response to rain storms. As a consequence, most runoff persists only for a few hours, thereby limiting the depth of infiltration from a given storm. This fact, coupled with the infrequent occurrence of runoff, results in much of the infiltrated water being stored temporarily as soil moisture before being returned to the atmosphere rather than eventually recharging the main body of ground water.

In recognition of the much poorer conditions for recharge of ground water from precipitation that exist in the study area as compared with central Nevada, half the percentages of precipitation shown in the preceding table are used in the present study for computing ground-water recharge from precipitation.

Precipitation in the area is shown on maps prepared by Hely and Peck (1964, pl. 3). Using these maps and half the percentages shown in the preceding table, the recharge to ground water, and by inference also ground-water inflow for the various subareas, is estimated as listed in table 6.

Table 6.—Average annual ground-water recharge from precipitation

Subarea	*Recharge (acre-feet)*
Colorado River Valley:	
Davis Dam to Topock	Negligible
Topock to Parker Dam	880
Tributary areas:	
Piute Valley	2, 300
Sacramento Valley area	12, 300
Chemehuevi Valley (that part west of the Colorado River valley)	260
Bill Williams River subarea	4, 000
Total ground-water recharge (rounded)	20, 000

The above figures are half those computed by Loeltz and McDonald (1969) because the earlier estimates did not incorporate the downward adjustment of the percentages of precipitation that are used in the present study. The fact that the adjustment was not made in the earlier study does not materially change any of the conclusions that were reached in that study because ground-water recharge is small relative to most other budget values.

GROUND-WATER OUTFLOW

Ground-water outflow from one area commonly is ground-water inflow to an adjacent area. Ground-water outflow therefore can be computed by the same methods that are used for computing ground-water inflow. Ground-water outflow from the area upstream from the Topock gaging station computed as the product of ground-water gradient, width of saturated section, and transmissivity of the water-bearing material, is at most, a few hundred acre-feet per year, and is therefore neglected. The underflow at Parker Dam likewise is estimated to be so small that it, too, need not be included in the budgets.

CONSUMPTIVE USE BY NATURAL VEGETATION

The consumptive use of water by natural vegetation is one of the larger budget items. Estimates of this use in the flood plain were made by the U.S. Bureau of Reclamation (1963). These estimates supplemented by estimates of use for areas that were not included in the Bureau of Reclamation study are used for the water-budget items. The estimates of the Bureau of Reclamation were based on a field vegetative survey to which was applied water-use rates developed for the area by Blaney and Harris (1952).

Blaney and Harris (1952) utilized the Blaney-Criddle method (Blaney and Criddle, 1945), adjusting experimental data on water-use rates obtained in one area to make them applicable to another area having a different climate. The Blaney-Criddle method, expressed mathematically, is $U=KF$, in which U is the seasonal consumptive use, K is an empirical coefficient for a specific plant, and F is the sum of the monthly consumptive use factors (sum of the products of mean monthly temperature and monthly percent of daytime hours of the year).

In developing rates of use, Blaney and Harris (1952) utilized the results of studies of water use by natural vegetation made by the Geological Survey in Safford Valley, Ariz. (Gatewood and others, 1950). No K coefficients for saltbush were available, so coefficients that had been determined for comparable vegetation were used.

To obtain additional data on water use by natural vegetation, in 1961 the Geological Survey, in cooperation with the Bureau of Reclamation, began a study near Yuma, Ariz., of the use of water by arrowweed, saltbush, bermuda grass, and tules. These species were grown in tanks in their natural environment. The results of these studies (Hughes and McDonald, 1966; McDonald and Hughes, 1968) indicate that the K coefficient for arrowweed may be about 50 percent higher than the coefficient that was used by the Bureau of Reclamation. Conversely, the K coefficient for saltbush, as indicated by the tank studies, may be only two-thirds of the coefficient that was used by the Bureau of Reclamation.

If the differences are as large as these studies indicate, the estimate of consumptive use by arrowweed in the Mohave Valley would need to be increased about 20,000 acre-feet, whereas the estimate of consumptive use by saltbush would need to be lowered only 500 acre-feet. Because of the sparse acreage of vegetation in Chemehuevi Valley, no adjustments would be needed for that valley.

CONSUMPTIVE USE BY CROPS

The consumptive use of water by crops is a relatively minor part of the total budgets. In 1962, according to a survey made by the U.S. Bureau of Reclamation (1963), 3,050 acres in the flood plain north of Topock was being irrigated. Aerial photographs indicate that upstream from Topock an additional 310 acres were being irrigated outside the flood plain, making the total irrigated acreage 3,360 acres upstream from Topock. Detailed information on the acreages of various crops is not available.

In general, the crop mix is similar to that for the Parker and Palo Verde Valleys downstream from the study area. An average rate of use of 3.6 feet per year was used for computing consumptive use by crops in these valleys (Loeltz and McDonald, 1969). This rate of use is considered valid for computing consumptive use by crops in the present study also.

CHANGES IN GROUND-WATER STORAGE

Changes in ground-water storage are indicated by changes of water levels in wells. With an adequate network of observation wells and reasonable knowledge of the amount of water represented by an observed unit change of water level at each site, changes in the amount of ground water in storage can be computed. Significant changes in the trend of water levels over rather large areas for a period of a few years ordinarily result only from a major change or a combination of changes in: (1) the amount of land irrigated, (2) drainage systems, (3) the river channel alinement or profile, or (4) pumpage. The only major change that has occurred in the study area during the budget period is the improvement of channel alinement and geometry of the Colorado River in the reach between Big Bend and Topock which was begun in 1947 and completed in 1960. Although this improvement program lowered water levels over large parts of the flood plain, the average annual decrease in ground-water storage during the period 1950–60 is estimated to have averaged less than 1,000 acre-feet per year. Changes in ground-water storage in the study area, as stated earlier, therefore, are considered small enough to be omitted from the water budget.

EVAPORATION FROM WATER SURFACES

Evaporation, as a water-budget item in this report, is the net evaporation from a free water surface. It is based on the mean annual lake evaporation as shown by Hely and Peck (1964, pl. 6), less the average annual precipitation. Hely and Peck found that the available data on evaporation did not warrant mapping evaporation rates at less than 4-inch intervals. Their map shows annual lake evaporation in the Colorado River valley to be about 86 inches. A precipitation map by Hely and Peck (1964, pl. 3) indicates a mean annual rate of about 5 inches in the flood-plain area. The evaporation item in the budgets therefore is computed on the basis of an average rate of 81 inches (6.75 ft) annually, the same rate used by Loeltz and McDonald (1969). The area of free water surface was computed from aerial photographs.

COLORADO RIVER VALLEY BETWEEN DAVIS DAM AND PARKER DAM

Water budgets for the Colorado River valley between Davis Dam and Topock, and between Topock and Parker Dam are presented in tables 7 and 8, which follow.

The budget items are also shown in figure 24, which consists of graphs of the annual streamflow depletions (adjusted for out-of-basin diversions and changes in contents of Havasu Lake), the average of these depletions, the consumptive use estimates, and the unmeasured inflows to the several subareas. Figure 24 also shows the above information on a combined basis for the subarea, Davis Dam to Parker Dam.

Values of average consumptive use by natural vegetation, irrigated crops, and evaporation are plotted at the left side of the figure. The net unmeasured inflow is added graphically to the average annual streamflow depletion to show the total estimated depletion based on inflow-outflow items. The difference between the total depletion and the sum of the estimated consumptive use values is the imbalance.

TABLE 7.—*Water budget for Colorado River valley between Davis Dam and gaging station near Topock, 1950–66*

Budget item	*Quantity (acre-ft per yr)*
Inflow-outflow:	
Measured inflow minus measured outflow: Average annual streamflow depletion, 1950–1966 (table 4)	181,000
Unmeasured inflow minus unmeasured outflow:	
Unmeasured inflow (average):	
Runoff[1]	15,500
Ground water from tributary areas[2]	14,600
Total unmeasured inflow (rounded)	30,000
Minus unmeasured outflow (average)	Negligible
Total unmeasured inflow minus unmeasured outflow	30,000
Total inflow minus total outflow	211,000
Consumptive use:	
Natural vegetation (1962)	188,000
Irrigated crops (1962)	12,000
Evaporation (average)[3]	41,000
Total consumptive use	241,000
Imbalance: Difference by which inflow minus outflow is less than consumptive use	30,000

[1] From table 5, sum of quantities for Colorado River valley from Davis Dam to Topock, Piute Valley, and Sacramento Valley.

[2] From table 6, sum of quantities from Piute and Sacramento Valleys.

[3] 14,000 acre-feet from the Colorado River, and 27,000 acre-feet from other open water.

TABLE 8.—*Water budget for Colorado River valley between Topock and Parker Dam, 1950–66*

Budget item	*Quantity (acre-ft per yr)*
Inflow-outflow:	
Measured inflow minus measured outflow: Average annual streamflow depletion, 1950–1966 (table 4)	151,000
Unmeasured inflow minus unmeasured outflow:	
Unmeasured inflow (average):	
Runoff[1]	19,000
Ground water[2]	5,000
Total unmeasured inflow	24,000
Minus unmeasured outflow (average)	Negligible
Total unmeasured inflow minus unmeasured outflow	24,000
Total inflow minus total outflow	175,000
Consumptive use:	
Natural vegetation (1962)	4,000
Irrigated crops (1962)	Negligible
Evaporation (average)	140,000
Total consumptive use	144,000
Imbalance: Difference by which inflow minus outflow is more than consumptive use	31,000

[1] From table 5, sum of quantities for Colorado River valley from Topock to Parker Dam and Bill Williams River subarea.

[2] From table 6, sum of quantities (rounded) for Colorado River valley from Topock to Parker Dam, Chemehuevi Valley, and Bill Williams River subarea.

The imbalance for the subarea, Davis Dam to Topock, is nearly equal to but opposite the imbalance for the subarea, Topock to Parker Dam. One might postulate, therefore, that the records of streamflow near Topock may be about 30,000 acre-feet per year too high, on the average. The implied error is less than one-half of 1 percent of the measured flows at the gaging station near Topock, which is within the limits of accuracy claimed by the U.S. Geological Survey for its measurements. Errors in streamflow measurement therefore could be responsible for much or all of the apparent imbalance.

One might also postulate that much of the imbalance in the budgets is due to differences between the 17-year average depletion and the long-term or true depletion. As was stated in the discussion of streamflow depletion, there is an even chance that the 17-year mean depletion might vary as much as 14,000 acre-feet from the true mean. It follows therefore that there is one chance in four that the 17-year mean is too low by as much as 14,000 acre-feet.

Finally, any one or a combination of errors in any of the larger budget items might be responsible for the imbalances. This fact becomes evident when budgets are computed for other periods and also when the budgets are analyzed relative to budgets for river valleys downstream from the study area.

For example, a budget for the river valley between Parker Dam and Imperial Dam computed on the same basis as that used for the present study area shows the consumptive use estimates exceeding the inflow minus outflow estimates by 150,000 acre-feet a year on the average. To obtain a balanced budget between Davis Dam and Imperial Dam for the period 1950–66, it is therefore necessary to adjust budget quantities 150,000 acre-feet. In making these adjustments, it is assumed that the same percentage adjustment applies to each of the budgets. If all the estimates of consumptive use by crops and by natural vegetation are assumed to be too large by 15 percent and all the estimates of evaporation too large by 10 percent, a virtual balance between inflow less outflow quantities and consumptive use is obtained. The following additional assumptions regarding published flows at gaging stations are necessary to achieve balanced budgets for each of the three subareas:

Average annual streamflow records: (1) Below Davis Dam are correct, (2) near Topock are too high by 4,000 acre-feet, (3) below Parker Dam are too low by 40,000 acre-feet, and (4) at Imperial Dam are correct.

The foregoing approach for obtaining balanced budgets implies adjustments that differ considerably from those that appear warranted for obtaining balanced budgets only for the study area without regard to adjacent areas. The approach utilizing a uniform percentage adjustment for each of the subareas is considered a more logical approach than those which consider adjustments for each subarea without regard to adjacent subareas.

In view of all the uncertainties regarding true values of all the budget items, no specific adjustments for achieving balanced budgets for the study area are suggested. The budgets, as shown, indicate within reasonable limits the relative quantities of water consumed by crops, natural vegetation, and evaporation. They show that the principal causes of stream depletion are evaporation and consumptive use by natural vegetation.

Losses by evaporation can be lowered by suppressing the rate of evaporation and by reducing the area of open water. However, in the study area only a limited reduction of evaporation losses can be expected in the foreseeable future because large-scale evaporation suppression by chemical means on large bodies of open water that are subject to winds and currents is not presently practicable and because fish and wildlife interests oppose any large-scale draining of existing swamps and lakes.

Depletion of streamflow due to consumption of water by natural vegetation is estimated at 192,000 acre-feet per year, most of which, 188,000 acre-feet, is in the flood plain upstream from Topock. A large percentage of this use by natural vegetation undoubtedly will be

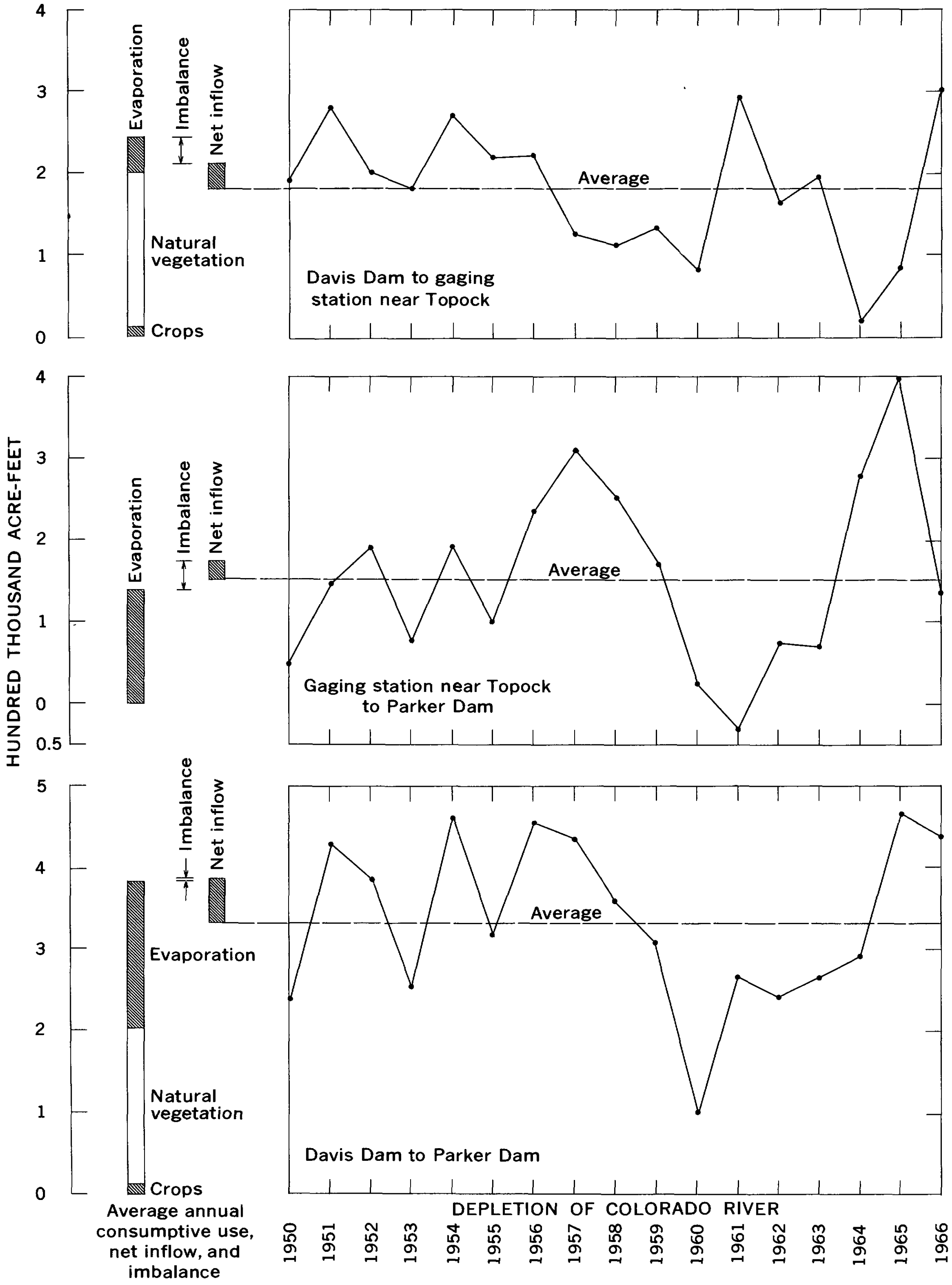

FIGURE 24.—Graphs showing annual depletion of Colorado River, average consumptive use, and net inflow for selected segments of Colorado River valley between Davis and Parker Dams.

used eventually for growing crops as additional land is converted to irrigation agriculture.

FUTURE DEVELOPMENT OF WATER RESOURCES

The greatest potential for developing additional beneficial use of water, as is pointed out in the section on water budgets, is the substitution of crops for natural vegetation having a low economic value and a high water-consumption rate. This kind of development is likely to occur in the flood plain north of Topock where arable land is available that presently supports the growth of native vegetation. In 1962 the vegetation in the flood plain upstream from Topock was predominantly mesquite on some 6,200 acres, mostly arrowweed on some 11,000 acres, and mostly saltcedar on some 24,000 acres. The average yearly rate of use of water was 2.54 feet by mesquite, 3.5 feet by arrowweed, and 3.6 feet by saltcedar (U.S. Bureau of Reclamation, 1963).

If the consumptive use rate by crops is assumed to average 3.6 feet per year, the substitution of crops for natural vegetation will result in little, if any, additional depletion of the supply except where mesquite is the natural vegetation that is replaced. The latter substitution would cause an additional depletion of about 1 acre-foot per acre, thus limiting the total additional depletion to slightly more than 6,500 acre-feet per year.

Eventually, Indians of the Fort Mohave and the Chemehuevi Indian Reservations probably will exercise their rights to divert water for irrigation. Under Supreme Court of the United States decree, article 8, *Arizona* v. *California*, *et al.*, dated March 9, 1964, subdivision (D), paragraph (1), the Fort Mohave Indian Reservation is entitled to divert main stream water in the lesser amount of 122,648 acre-feet annually or the quantity necessary to supply the consumptive use for irrigation of 18,974 acres and for the satisfaction of related uses, with priority dates of September 18, 1890, and February 2, 1911, subject to certain provisions that lands conveyed to the State of California pursuant to the Swamp and Overflow Lands Act [9 Stat. 519 (1850)] as well as accretions thereto, and lands patented to the Southern Pacific Railroad pursuant to the Act of July 27, 1866 (14 Stat. 292), shall not be included as irrigable acreage within the Reservation and that the above specified diversion requirement shall be reduced by 6.4 acre-feet per acre of such land that is irrigable. The quantities of the above provisions are subject to adjustment either by decree or agreement upon final determination of the reservation boundaries.

Although the ultimate exercising of these rights will represent a sizable diversion from the river, the actual additional depletion of the river will be only a small fraction of the gross diversion because the diversions are likely to be to lands that already are using water at a rate comparable to that of the crops that are likely to be substituted for the natural vegetation. However, the legal depletion of the water supply may be substantial as it is based on measured diversions less measured return flows, a method that likely will give a computed depletion that is at least equal to the consumptive use by crops.

Under the same decree, the Chemehuevi Indian Reservation is entitled to divert the lesser of 11,340 acre-feet of water from the main stem of the Colorado River or that quantity necessary to supply the consumptive use required for irrigation of 1,900 acres and for the satisfaction of related uses with a priority of February 2, 1907.

Diversions to the Chemehuevi Indian Reservation, which is between Topock and Parker Dam, will result in additional depletion of the available supply both in fact and legally. The lands that are likely to be irrigated are far enough above the flood plain of the river so that the natural vegetation on them does not use appreciable amounts of ground water. Any consumptive use by crops or otherwise therefore will be an additional depletion of the water supply. The legal depletion probably will be the quantity diverted unless credit is received for return flows to the river, most of which probably will be subsurface returns.

In contrast to the above developments, additional water might be made available for beneficial use by reducing the amount of water consumed by natural vegetation. A plan for effecting water salvage by eradicating natural vegetation and controlling its regrowth in selected areas where this procedure appears to be practicable has been developed by the Bureau of Reclamation. The U.S. Bureau of Reclamation (written commun., 1971) estimates that about 45,000 acre-feet per year in the Mohave Valley is salvable and thus is available for other needs either in that area or in downstream areas.

Undoubtedly future development in Mohave Valley will also include substantial pumpage of ground water either for irrigation or other uses. Most of this development will be by private interests. The depletion of the overall water supply that will result from such development will depend on how much of the consumptive use is an additional consumptive use rather than a substitute for an existing use. If the pumpage is for the irrigation of land presently supporting the growth of natural vegetation having a consumptive use requirement equal to that of the crops which replace it, no additional depletion will result. However, if the pumpage is for the irrigation of land where the natural vegetation uses little or no ground water, such as much of the land on the alluvial slopes bordering the flood plain, the consumptive use on such land will be entirely an additional depletion.

QUALITY OF WATER

Selected chemical analyses of water from wells and one spring in the Needles area are given in table 9. More than one analysis was available for many wells, so the analysis listed is either that of the first water sample obtained from a well or that considered to be the most representative.

The chemical analyses indicate that ground water in the Needles area is much better than that in the Parker-Blythe-Cibola area to the south. This was unexpected because both areas have a shallow water table beneath the flood plain in which large-scale evapotranspiration occurs. Of the 95 analyses given in table 9, 46 had dissolved-solids contents of less than 1,000 mg/l and six had less than 500 mg/l. The smallest dissolved-solids content was 314 mg/l from well (B-16-20½)11ccd. On the other extreme, only six analyses showed dissolved-solids contents of more than 2,000 mg/l. Of these, five were between 2,010 and 2,330 mg/l; the largest dissolved-solids content was 3,290 mg/l from well (B-17-21)8ccc2.

Selected analyses are also shown graphically by diagrams based on a method devised by Stiff (1951, p. 15). In the preparation of a Stiff diagram, the chemical equivalent concentrations of the cations, calcium, magnesium, and sodium (plus potassium), are plotted as proportionate line segments on equally spaced parallel lines to the left of a central axis; the equivalent concentrations of the anions, bicarbonate (plus any carbonate), sulfate, and chloride (plus any nitrate), are plotted on the same lines extended to the right of the axis. The ends of the plotted line segments are then connected, thereby forming a geometric pattern characteristic of the mixture of minerals making up the dissolved-solids content of the water whose analysis is plotted. Because the area of a Stiff diagram is not strictly proportional to the dissolved-solids content of the water represented by the diagram and because of the differences in the equivalent weights of the cations and anions, the corresponding dissolved-solids concentration is indicated beneath the individual diagram.

CHEMICAL CHARACTER OF COLORADO RIVER WATER

Knowledge of the chemical character of Colorado River water is important for understanding the quality of the ground water because the Colorado River is the dominant source of recharge to the aquifers of the Needles area. Although ground-water recharge is chemically altered by several processes, the water generally retains some characteristics of the river water. The chemical character of the river was investigated by Irelan (Metzger and others, 1972) as a part of the investigation of the Parker-Blythe-Cibola area, and the discussion that follows is based on that study.

The natural chemical regimen of the Colorado River was undoubtedly one of large seasonal variation in both composition and concentration because such variations have been documented by systematic sampling for chemical analysis. However, these sampling programs cannot be expected to duplicate the natural regimen because irrigation, which both reduced the natural river flows and added saline drainage water, was developed in the Upper Basin of the Colorado River before the sampling programs began. Records of a few years of sampling at Willow Beach (about 47 miles north of Davis Dam), Topock, and Yuma, prior to the construction of Hoover Dam, indicate that the usual salinity variations in the Lower Colorado River were very similar to those at the Grand Canyon gaging station (in Grand Canyon National Park). Therefore, the Grand Canyon record, with the qualification given above, probably is representative of the long-time chemical variations in the Needles area.

A relatively stable regimen of flow and salinity of the Colorado River at Grand Canyon existed from 1926, which was after most of the irrigation in the Upper Basin had been developed, until 1963, when Glen Canyon Dam (in Arizona but near Utah border) was closed. During spring floods in most years of this period, the Colorado River at Grand Canyon contained 200 to 300 mg/l dissolved solids, mostly calcium and bicarbonate, and the sulfate content always exceeded the chloride content. During low-flow periods in fall and winter, the river often contained 1,500 mg/l dissolved solids but rarely as much as 1,800 mg/l. The content was mostly calcium and sulfate, although considerable sodium and chloride were sometimes present.

The variations in the composition and concentration of the Lower Colorado River began to decrease as a result of the closing of Hoover Dam in 1936. By 1941, when Lake Mead spilled, the downstream seasonal variations virtually ended. Since 1941 the annual weighted average dissolved solids (sum) at the sampling station below Hoover Dam has ranged between 606 and 813 mg/l; the sulfate has ranged between 261 and 355 mg/l and the chloride between 62 and 108 mg/l. Day-to-day concentrations have been above or below the annual weighted average but in any one year they generally have departed less than 10 percent from the computed averages.

The chemical quality of the Colorado River at specified times during the periods just cited is shown in figure

25. The diagrams indicate the maximum and minimum concentrations for the years of minimum, median, and maximum flow during the period 1926–62 at Grand Canyon and the annual weighted averages for 1950, 1956, and 1965 at Colorado River below Hoover Dam. The wide annual variability of the chemical quality prior to the filling of Lake Mead, and the relatively uniform quality of water released from Hoover Dam are readily apparent.

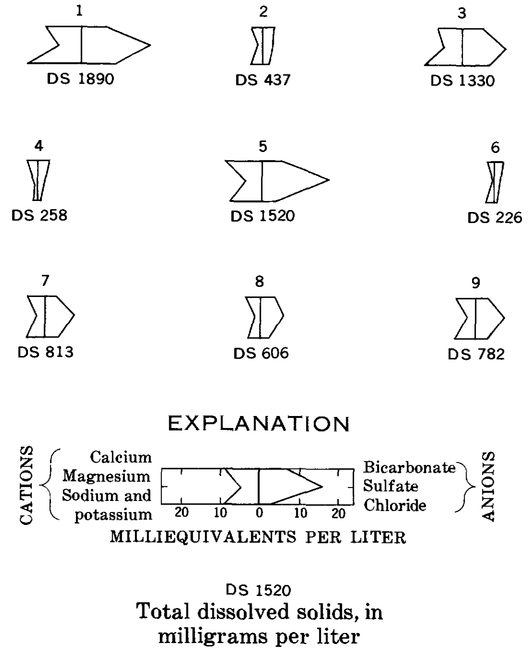

FIGURE 25.—Diagrams of selected chemical analyses of Colorado River water before and after the filling of Lake Mead.

Colorado River at Grand Canyon, 1926–62:

1. Minimum flow year, 1934, maximum concentration, Sept. 21–30.
2. Minimum flow year, 1934, minimum concentration, May 23–31.
3. Median flow year, 1936, minimum concentration, Jan. 1–10.
4. Median flow year, 1936, minimum concentration, May 21–31.
5. Maximum flow year, 1929, maximum concentration, Oct. 11–28, 1928.
6. Maximum flow year, 1929, minimum concentration, June 11–20.

Colorado River below Hoover Dam, 1941–65:

7. Maximum average dissolved-solids contents, weighted average, 1956.
8. Minimum average dissolved-solids contents, weighted average, 1950.
9. Weighted average, 1965.

CHEMICAL CHARACTER OF GROUND WATER

This section is principally a discussion of the chemical character of ground water obtained from the alluviums of the Colorado River because all but a few wells are perforated in these deposits. The discussion is divided arbitrarily into two parts on the basis of the depths of wells; one part pertains to shallow wells which are sandpoints driven only a few feet below the water table on the flood plain of Mohave Valley, and the other part pertains to all the other wells in both Mohave and Chemehuevi Valley.

Irelan (Metzger and others, 1972) concluded from a study of chemical analyses of water from wells in the Parker-Blythe-Cibola area that most of the ground water came from the Colorado River and was altered mainly by three primary processes: concentration by evapotranspiration, precipitation of insoluble calcium and magnesium carbonates, and reduction of sulfate. Because the chemical character of water for the Needles area is similar in many respects to that of the Parker-Blythe-Cibola area to the south, the principal findings of the study of the latter area are considered to be applicable to the Needles area also and are therefore widely drawn upon in the discussion that follows.

In making a hypothetical study of the processes by which the chemical composition of Colorado River water might be altered to the various concentrations of ground water in the area, Irelan assumed that the Colorado River initially contained 770 mg/l total solids and had a chemical composition similar to that shown by diagrams 7–9 in figure 25. The study showed that the process of evaporation within certain limits could produce water similar to known ground water but that beyond these limits the bicarbonate concentrations exceeded those found in ground water. To rectify this, it was assumed that chemical precipitation of calcium and magnesium carbonates begins whenever bicarbonate concentrations reach some specific level, and that as the bicarbonate concentrations exceed this level, precipitation becomes more and more pronounced. This, however, results in sulfate concentrations greater than the chloride concentrations, a condition which is not found in the more highly concentrated waters of the area.

One means of reducing the sulfate concentrations is by the precipitation of calcium sulfate; however, in order to do this, calcium concentrations must reach about 600 mg/l and sulfate about 2,000 mg/l, concentrations which also are not found in real analyses. Another means by which the hypothetical concentrations of sulfate may be reduced is by changing the sulfate to colloidal elemental sulfur, to sulfide ion, or to gaseous hydrogen sulfide (gas having the familiar rotten-egg odor) as a result of bacterial activity, generally in an anaerobic environment, or as the result of an irreversible reaction between the sulfate ion and the wetted but not necessarily dissolved organic matter. During the drilling of the deep test wells of the Parker-Blythe-Cibola area, hydrogen sulfide odor was noticed on many occasions. This, along with organic debris in the deposits, strongly suggests that sulfate reduction has occurred in the ground water.

These processes result in hypothetical analyses similar to many real chemical analyses of samples of water obtained in the Parker-Blythe-Cibola area, but there are analyses which are quite different. According to Irelan, some of the differences may be attributed to having assumed incorrect limits of concentrations at which various precipitates begin to form. Other differences, however, suggest that base exchange of calcium or magnesium for sodium, or of sodium for calcium or magnesium occurred during the transformation of some of the waters from river water to ground water at sites where the samples were obtained.

On the basis of the hypothetical analyses, Stiff diagrams can be prepared, which by visual comparison with Stiff diagrams from real analyses, can be used to show the alteration of Colorado River water after it enters the ground-water reservoir. This procedure is especially applicable along the flood plain of the Colorado River where many wells have been sampled, and there is little doubt but that the ground water has as its source, the Colorado River.

The fact that diagrams of chemical analyses of water from two wells are similar and that the samples have nearly exact concentrations of chemical constituents does not of itself necessarily prove that the two samples were derived from the same source. Two examples will be cited to illustrate this point. One example is a comparison between water from well (B–17–22)12ccc2 on the flood plain about 3 miles northeast of Needles (pl. 3) and water from well (B–22–18)12caa (not shown on pl. 3) in Sacramento Valley about 24 miles east of Davis Dam. Stiff diagrams prepared from the two analyses from these wells are very similar; in fact, the concentrations of individual constituents are also very similar. Yet, well (B–17–22)12ccc2 produced water that had as its source Colorado River water, whereas well (B–22–18)12caa produced water that had as its source local recharge from the mountains near Kingman. Another example is a comparison between samples from well (B–20–22)29acc south of Bullhead City (pl. 3) and well 9N/21E–10R1 (not shown on pl. 3) about 9 miles west of Needles in Piute Valley. The Stiff diagram for water from these wells is an hourglass pattern. The water from well (B–20–22)29acc probably originated as Colorado River water and was subject to a nearly complete sulfate reduction. The water from well 9N/21E–10R1 must have originated as local recharge within Piute Valley, a completely different source than that for the water from well (B–20–22)29acc.

The chemical character of water from 21 shallow wells in Mohave Valley ranges from 630 to 2,100 mg/l dissolved solids (sum). Stiff diagrams of analyses of water from these wells (pl. 3), in addition to the ground-water-contour map (pl. 2), which shows ground-water movement eastward from the river, suggest that the ground water was derived from the Colorado River and has been altered principally by the combined processes of evaporation, precipitation of calcium and magnesium carbonates, and sulfate reduction. Diagrams for samples from wells near the river (wells 11N/22E–30N1, (B–18–22)22aaa; and (B–17–22)10ccc) are identical with that of the Colorado River since the filling of Lake Mead. Other diagrams (those for samples from wells (B–18–22)3ccc and (B–17–22)14ccc) are similar to that of the Colorado River but slightly more concentrated, which could have been caused by evaporation only. Sulfate reduction, along with the other processes, is apparent from the shape of some of the diagrams (those for samples from wells (B–18–22)2ccc and (B–17–21)6ccc). Diagrams of the more concentrated waters suggest that Colorado River water has been altered by all three processes. Of the 21 shallow wells, eight yielded water having less than 1,000 mg/l dissolved solids. This concentration is lower than that found for most shallow water in comparable environment in downstream areas.

As might be expected, Stiff diagrams prepared for the rest of the analyses from wells in the Needles area (pl. 3) show considerably more variety of chemical types than for the shallow wells. Again, diagrams for most of the wells indicate alteration of Colorado River water by the three primary processes.

Diagrams of analyses of samples from wells near the river are a pennant pattern similar to those of Colorado River water (diagrams 7–9 in fig. 25). Some analyses are identical with that of water released from Hoover Dam after the filling of Lake Mead, and some show a slight increase in chemical constituents, which probably is caused by evaporation. Eastward from the river the concentrations of dissolved solids increase. If the water was derived from the Colorado River, the water has been altered primarily by evaporation, precipitation of carbonates, and sulfate reduction.

For the area about 4 miles east of the river in Tps. 17 and 18 N., the ground water probably is altered Colorado River water because ground-water contours (pl. 2) indicate that ground-water movement is towards this area from the Colorado River and because evapotranspiration occurs from the shallow water table beneath the flood plain. Thus, the ground water beneath this area probably is Colorado River water that had been concentrated by evaporation along with the other processes mentioned previously.

Although the explanation for the concentration is reasonable in the part of the flood plain just mentioned, some doubt about the validity of the explanation is cast when the analyses of samples from wells in T. 19 N., R. 22 W. (26aab, 26ddd, 36bab, and 36bac) are considered. These analyses show a range of dissolved solids from 1,120 to 1,620 mg/l and Stiff diagrams similar to those discussed above. Water-level contours indicate that the movement of ground water is southward and that the Colorado River may be a possible source. However, if the river is the source, the chemical quality of the water would have had to have been altered by evaporation and perhaps by other processes because the concentrations of chloride of the samples from the wells are much higher than any known concentrations of chloride of Colorado River water during historic time. Sufficient concentration by evaporation seems unlikely, however, because the flood-plain area in which such evaporation could occur appears to be inadequate. Furthermore, evapotranspiration near the wells is impossible because the depth to water is 90 feet and more.

It is possible that the water obtained from the wells represents a mixture of Colorado River water that has not been altered appreciably and of local recharge from precipitation on the mountains bordering the east side of the valley. However, the chemical quality of the local recharge probably is good because of the rock types composing the mountains. There are no wells east of the wells that were sampled for obtaining data regarding the chemical quality of the recharge from the mountains.

Still another possibility is that the water in the wells is a mixture of Colorado River water and of water containing relatively high concentrations of sodium and chloride that might be leaking upward through the Bouse Formation.

If any of the Stiff diagrams represent local recharge, the most probable is that of the sample from well (B–21–21)21cbb (pl. 3). The water likely is recharge from the Black Mountains to the east, although definitive evidence is lacking. Stiff patterns similar to the above were constructed from the analysis of samples from two other wells, well 8N/23E–20J1 and a well (not shown on pl. 3) near Chemehuevi Wash west of the report area. The source of water for the first well could be either the Colorado River or local recharge. The source for the second well is local recharge because the well is about 20 miles west of Havasu Lake, and the water level in the well is more than 400 feet higher than the lake.

Irelan (Metzger and others, 1972) suggests that Stiff diagrams of water in the Parker-Blythe-Cibola area that resemble an hourglass may be indicative of Colorado River water that has been altered by a nearly complete reduction of sulfate. Stiff diagrams of samples from several wells in the Needles area also can be explained on this basis. For example, wells (B–20–22) 29acc, (B–18–22)23bcc2, and (B–18–22)23ccc2 (pl. 3) all are near the Colorado River and are surrounded by wells containing altered Colorado River water. However, the same cannot be said about the hourglass diagrams of samples from the three wells that are near Topock and east of the Colorado River. Ground-water movement near the wells is westward to the Colorado River, the water from well (B–16–21)15add being local recharge, whereas that from the two wells in T. 16 N., R. 20½ W., probably represents ground-water underflow from Sacramento Valley. Well (B–16–19)8dab, some 10 miles eastward and which probably also represents underflow from Sacramento Valley has an analysis that plots as a pennant pattern. However, this water eventually may be altered by sulfate reduction as it moves westward to the type of water found in the three wells nearer Topock.

SUITABILITY OF GROUND WATER

Along the Lower Colorado River, the suitability of water for domestic use is based on the concentration of dissolved solids as compared to that of Colorado River water. Any water containing about the same concentration as Colorado River water (between 600 and 800 mg/l dissolved solids and less than 1.5 mg/l fluorides) is acceptable to residents as water for domestic use.

The more common constituents in drinking water are objectionable only when they are present in such concentrations as to be noticeable to the taste. Such concentrations are difficult to define because of differences between individuals. According to Hem (1959, p. 239–240): "A chloride concentration of 200 to 300 mg/l in water containing an equivalent amount of sodium is enough to give a noticeable salty taste to most people. The presence of sulfate in similar concentrations will have a laxative effect on some of those who drink the water." Many of the analyses given in table 9 contain or exceed the concentrations given by Hem. Nevertheless, where better water is not available, the water is used for domestic purposes.

Most of the analyses in table 9 contain less than 1.5 mg/l of fluoride, which is an upper limit on the amount of fluoride that may cause mottling of tooth enamel in children. Because the Needles area has an arid and hot climate, more water than average is consumed per person, and consequently the upper limit for fluorides may be somewhat less.

Whether water is suitable for irrigation depends not only on the chemical character of the water being applied but also on other factors such as salinity of the soil, drainage, amounts of water applied, manner of application, and types of crops to be grown. The most significant items relative to the chemical character of water are the dissolved-solids content, the amount of sodium relative to calcium and magnesium, and the concentration of substances, such as boron, that may be toxic to plants. The U.S. Salinity Laboratory (1954, p. 69–82) in its classification of irrigation waters lists the sodium hazard and the salinity hazard as two of the most significant factors to be considered. The sodium hazard is based on "the probable extent to which soil will adsorb sodium from the water and the rate at which adsorption will occur as the water is applied." The salinity hazard is much simpler to define, and is based solely on the electrical conductivity of the irrigation water. The salinity hazard is defined as low if specific conductance values, in micromhos per centimeter, are between 0 and 250, as medium if between 250 and 750, as high if between 750 and 2,250, and as very high if more than 2,250. For the Needles area, none of the analyses would be classified as having a low salinity hazard and only four as having a medium salinity hazard. The balance of the analyses would be classified as having a high to very high salinity hazard. Some of the analyses showing specific conductances in the very high salinity hazard range are for samples from irrigation wells that are being used successfully to grow crops in the Needles area. This indicates that chemical character alone is not adequate criteria to determine if a water is suitable for irrigation and that other factors such as those given in the first sentence of this paragraph also must be considered.

REFERENCES

Blaney, H. F., and Criddle, W. D., 1945, A method of estimating water requirements in irrigated areas from climatological data: U.S. Dept. Agriculture, Soil Conservation Service, 59 p.

Blaney, H. F., and Harris, Karl, 1972, Consumptive use of water rates in the lower Colorado River basin (provisional) *in* Report on water supply of the lower Colorado River basin, project planning report: U.S. Bur. Reclamation, Boulder City, Nev., 427 p.

Eakin, T. E., and others, 1951, Contributions to the hydrology of eastern Nevada: Nevada Water Resources Bull. 12, 171 p.

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill, 534 p.

Ferris, J. G., and others, 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, p. 69–174.

Gatewood, J. S., and others, 1950, Use of water by bottom-land vegetation in lower Safford Valley, Ariz.: U.S. Geol. Survey Water-Supply Paper 1103, 210 p.

Hely, A. G., and Peck, E. L., 1964, Precipitation, runoff and water loss in the lower Colorado River-Salton Sea area: U.S. Geol. Survey Prof. Paper 486–B, 16 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Hughes, G. H., and McDonald, C. C., 1966, Determination of water use by phreatophytes and hydrophytes: Am. Soc. Civil Engineers, v. 92, no. HY2, Proc. Paper 4714, p. 63–81.

Ives, J. C., 1861, Report upon the Colorado River of the West: U.S. 36th Cong., 1st sess., House Executive Doc. 90, 154 p.

Johnson, A. I., 1967, Specific yield—Compilation of specific yield for various materials: U.S. Geol. Survey Water-Supply Paper 1662–D, p. D1–D74.

Lee, W. T., 1908, Geologic reconnaissance of a part of western Arizona: U.S. Geol. Survey Bull. 352, 96 p., 11 pls., 16 figs.

Loeltz, O. J., 1960, Source of water issuing from springs in Ash Meadow Valley, Nye County, Nevada [abs.]: Geol. Soc. America Bull., v. 71, no. 12, p. 1917–1918.

Loeltz, O. J., and McDonald, C. C., 1969, Water loss in the lower Colorado River valley, Davis Dam to Imperial Dam: Am. Soc. Civil Engineers, v. 95, no. IR 1, Proc. Paper 6457, p. 65–78.

McDonald, C. C., and Hughes, G. H., 1968, Consumptive use of water by phreatophytes and hydrophytes near Yuma, Ariz.: U.S. Geol. Survey Prof. Paper 486–F, 24 p.

Metzger, D. G., 1965, A Miocene(?) aquifer in the Parker-Blythe-Cibola area, Arizona and California, *in* Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525–C, p. C203–C205.

——— 1968, The Bouse Formation (Pliocene) of the Parker-Blythe-Cibola area, Arizona and California, *in* Geological Survey Research: U.S. Geol. Survey Prof. Paper 600–D, p. D126–D136.

Metzger, D. G., Loeltz, O. J., and Irelan, Burdge, 1972, Geohydrology of the Parker-Blythe-Cibola area, Ariz. and Calif.: U.S. Geol. Survey Prof. Paper 486–G, (In press.)

Moore, D. O., 1968, Estimating mean runoff in ungaged semiarid areas: Internat. Assoc. Sci. Hydrology Bull., v. 13, p. 29–39.

Noble, L. F., 1931, Nitrate deposits in southeastern California, with notes on deposits in southeastern Arizona and southwestern New Mexico: U.S. Geol. Survey Bull. 820, 108 p.

Olmsted, F. H., Loeltz, O. J., and Irelan, Burdge, 1972, Geohydrology of the Yuma area, Arizona and California: U.S. Geol. Survey Prof. Paper 486–H, (In press.)

Rush, F. E., and Huxel, C. J., Jr., 1966, Ground-water appraisal of the Eldorado-Piute Valley area, Nevada and California: Nevada Dept. Conserv. and Nat. Resources, Water Resources-Reconn. Ser. Rept. 36, 29 p.

Smith, Winchell, and Heckler, W. L., 1955, Compilation of flood data in Arizona, 1862–1953: U.S. Geol. Survey open-file report, 113 p.

Stiff, H. A., Jr., 1951, The interpretation of chemical analyses by means of patterns: Jour. Petroleum Technology, p. 15.

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519–524.

Theis, C. V., Brown, R. H., and Meyer, R. R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells *in* Methods of determining permeability, transmissibility and drawdown: U.S. Geol. Survey Water-Supply Paper 1536–I, p. 331–340.

Thompson, D. G., 1929, The Mohave Desert region, Calif.: U.S. Geol. Survey Water-Supply Paper 578, 759 p.

U.S. Bureau of Reclamation, 1953, Memorandum supplement to report on water supply of the lower Colorado River basin, project planning report, November 1952: 48 p.

——— 1963, Lower Colorado River water salvage phreatophyte control, Arizona-California-Nevada, reconnaissance report: 57 p.

U.S. Congress, House of Representatives, Committee on irrigation of arid lands, 1922, Hearings on H. R. 11449, A bill to provide for the protection and development of the lower Colorado River basin, Appendix A: U.S. 67th Cong., 2d sess., p. 138–148.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture Handb. no. 60, 160 p.

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[Italic page numbers indicate major references]

TABLES 9–11

TABLE 9.—*Chemical analyses of water from wells and from Red Spring, Needles area, Arizona-California-Nevada*

[Analyses in milligrams per liter, except as indicated. Analyses made in U.S.G.S. laboratory, Yuma, Ariz., Use of water: Irr, irrigation; PS, public supply; Dom, domestic; T, test hole; Un, unused; S, stock]

Well	Date sampled	Perforated interval (feet below land-surface datum)	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Percent sodium
														Calcium, magnesium	Noncarbonate			
Arizona																		
(B-13-20) 4dbb	6-10-68	50-90	PS	24	127	52	212		172	450	268	1.1	1,220	530	389	1,970	7.4	46
15bcc	6-10-68	117-165	PS	21	92	39	313		236	370	192	1.2	1,050	390	196	1,650	7.5	54
(B-14-20) 16ccd	6- 6-68	180-280	S, PS	2	130	61	414		36	330	775	4.0	1,730	575	546	3,230	7.6	61
(B-16-19) 8 dab	6- 5-68		Dom	8	47	7.4	122		58	232	87	1.0	533	148	100	880	7.8	64
(B-16-20½)11 ccd	3- 9-62	189-420	Dom	16	21	4.3	91		144	33	77	3.0	314	70	0	602	7.6	74
14 bca	3- 9-62	332-490	Dom	16	36	8.5	158		120	73	203	3.2	558	125	26	1,060	7.7	73
(B-16-21) 15add	9-11-62		PS	35	30	13	86		158	62	84	.9	390	129	0	664	7.1	59
(B-17-21)5bcd	4-23-68		PS	26	143	65	342		208	280	642	.7	1,600	625	454	2,930	7.5	54
6ccc	5- 2-62	16-18	T	18	124	50	170		270	275	268		1,040	515	294	1,910	7.7	42
7abd	4-14-67		Irr	22	151	47	231		348	450	225	.9	1,300	570	284	2,100	7.7	47
7bbd	2-15-67		Irr	23	180	48	270		344	475	322	.6	1,490	645	363	2,390	7.9	48
7cbd	2-15-67		Irr	19	204	72	237		392	500	338	.5	1,570	805	484	2,530	7.6	39
8ccc1	5- 1-62	15-17	T	27	182	79	429		452	800	362		2,100	780	410	3,350	7.8	54
8ccc2	5-20-65	83-85	T	21	370	106	666		272	600	1,390		3,290	1,360	1,140	5,470	7.4	52
18ccb	5- 1-62	13-15	T	17	138	76	178		360	525	145		1,260	658	363	1,880	7.4	37
(B-17-22) 1baa	2-18-67	60-70	Dom	21	266	92	382		352	700	605	.8	2,240	1,040	752	3,580	7.7	44
10bbb	5- 1-62	10-12	T	21	221	76	135		410	550	178		1,390	865	529	2,140	7.45	25
10ccc	5-21-65	20-22	T	23	98	29	121		216	258	129	.9	765	364	187	1,250	7.7	42
10ddd	5-17-65	61-63	T	25	111	32	90		232	267	95	.5	737	408	218	1,200	7.5	32
11aaa	5- 1-62	16-18	T	18	94	61	144		248	412	118		971	486	282	1,520	7.4	39
11bbb	5- 1-62	16-18	T	13	156	56	390		326	538	455		1,770	620	352	2,770	7.4	58
11ccd	4-14-67		Irr	23	146	50	229		352	450	220	.8	1,300	570	282	2,100	7.4	47
11cdd	2-15-67		Irr	23	145	47	230		348	450	212	.8	1,280	555	270	2,030	7.5	47
12ccc1	5- 1-62	16-18	T	21	120	34	236		384	425	138		1,170	438	123	1,850	7.35	54
12ccc2	5-18-65	70-72	T	24	153	48	124		420	317	123	.4	999	580	236	1,620	7.7	32
12ddd	5-19-65	72-74	T	21	122	35	314		436	462	208	.7	1,380	450	92	2,220	7.7	60
13aaa	5- 1-62	19-21	T	23	174	62	293		454	600	235		1,610	690	318	2,470	7.5	48
13abb	3- 2-67		Irr	24	238	82	301		480	675	345	.8	1,910	930	536	2,910	7.6	41
13bbb	4-14-67		Irr	22	158	43	230		356	450	218	.9	1,300	570	278	2,090	7.5	47
13dcb	3- 2-67	64-143	Irr	25	150	45	313		380	538	260	1.2	1,520	560	248	2,420	7.6	55
14ccc	5- 1-62	13-15	T	13	143	42	179		306	450	141		1,120	528	277	1,730	7.65	42
15aba	2-15-67	30-65	PS	23	121	32	157		264	362	128	.8	956	435	218	1,480	7.5	48
15ddc	3- 2-67	35-65	PS	20	102	31	125		200	317	111	.6	807	380	216	1,310	7.5	42
(B-18-22) 2ccc	5- 2-62	16-18	T	16	89	23	99		220	167	126		630	316	136	1,080	7.3	40
3ccc	5- 2-62	16-18	T	16	126	43	143		226	433	117		991	490	304	1,390	7.6	39
13cbc	6- 3-64		Irr	17	80	25	177		228	192	212	.4	817	302	115	1,400	7.4	56
13ccc	5- 2-62	24-26	T	19	120	83	480		427	575	522		2,010	640	290	3,420	7.85	62
15aab	11- 1-62	60-95	Irr	20	105	30	120		256	233	136	.4	772	384		1,290	7.55	40
22aaa	5- 2-62	21-23	T	19	102	28	108		236	242	113		730	370	176	1,200	7.9	39
23abb	3- 1-67	65-95	Irr	19	71	17	94		204	110	119	.4	532	246	78	930	7.6	45
23bcc2	3- 1-67	60-304	PS	17	71	15	73		208	90	93	.4	463	238	68	829	7.6	40
23ccc2	3- 1-67		Dom	20	78	22	102		236	145	113	.4	598	284	90	1,020	7.8	44
23cdb	4-25-68		Un	19	180	48	218		288	470	278	.6	1,360	645	409	2,160	7.7	42
24aba	5- 2-62	19-21	T	20	108	49	356		306	425	390		1,500	470	219	2,520	7.5	62
25abb1	2-28-67		Irr	22	190	55	376		292	475	555	.6	1,870	700	460	2,990	7.7	54
25abb2	2-28-67		Dom	19	182	62	281		244	388	508	.6	1,560	710	510	2,690	7.7	46
27bbc	11- 1-62	80-126	S, Irr	18	102	27	94		170	292	88	.5	707	364	224	1,150	7.4	36
27ddd1	5- 2-62	29-31	T	15	135	37	115		288	312	127		885	490	254	1,500	7.5	34
27ddd2	2-28-67		PS	18	158	40	136		236	362	202	.5	1,040	560	366	1,700	7.9	35
27ddd3	2-28-67		PS	18	102	28	108		216	258	111	.5	734	368	191	1,210	7.6	39
35bbb	3- 6-62		Irr	14	105	37	137		254	325	117	.6	863	416	208	1,340	7.6	42
35bda	6- 3-64		Irr	17	158	44	161		240	412	212	.6	1,120	575	378	1,800	7.2	38
(B-19-22) 11bab	5- 2-62	22-24	T	22	70	25	265		256	362	190		1,060	278	68	1,770	7.3	68
11bbd	4-13-67		PS	24	105	34	159		224	338	148	1.2	921	400	216	1,530	7.6	46
14cca	4-13-67		Irr	19	82	31	348		220	375	365	1.1	1,330	332	152	2,240	7.5	70
15 abb	6- 3-64			15	76	22	134		200	275	87	.4	709	282	118	1,120	7.2	51
15 acb	9-18-62		Dom	18	79	24	121		182	283	82	.2	698	296	147	1,080	6.8	47
15 dad	4-13-67		Dom	18	68	20	152		224	183	145	.5	699	250	66	1,230	7.5	57
23 ccc	9-19-62		Dom	24	116	36	121		236	267	161	.4	843	437	244	1,350	7.1	38
26 aab	4-11-67	150-220	Irr	21	87	27	279		228	250	342	1.1	1,120	326	139	2,050	7.7	65
26 ddd	11- 2-62		Irr	22	150	53	293		182	400	468	.6	1,480	590	441	2,600	7.3	52
36 bab	11- 1-62		Irr	28	86	29	444		205	250	615	2.0	1,560	335	167	2,920	7.5	74
36 bac	11- 2-62		Irr	28	92	31	454		195	288	622	2.3	1,620	355	195	2,980	7.4	74
(B-20-22) 1 aca	4-23-68		PS	18	174	56	200		272	540	222	.7	1,350	665	442	2,090	7.7	40
1 add	6- 3-64		PS	24	180	50	145		154	400	302	.5	1,180	655	528	1,880	7.2	32
19 ada	9-18-62		PS	28	92	29	142		180	267	163	.3	811	348	200	1,270	7.0	47
25 bab	4-24-68		Dom	37	27	0.6	211		188	100	174	9.5	653	70	0	1,110	8.1	87
26 cdb	4-24-68		PS	38	73	3.4	212		152	120	282	4.0	808	196	72	1,430	7.4	70
26 dcd	4-24-68		PS	8	14	2.2	141		130	120	82	1.7	434	44	0	746	8.2	88
29 acc	9-18-62		S	24	52	14	73		162	95	81	.4	420	188	55	724	7.2	46
35 cdd	5- 7-68		Dom	44	65	10	805		128	140	1,200	4.5	2,330	204	99	4,430	7.7	90
(B-21-21) 21 cbb	3- 7-62		Dom	11	11	1.2	156		124	65	57	4.8	518	28	0	763	8.1	92
California																		
4N/24E-17Z1	5-13-68		Un	30	32	1.0	230		96	180	222	1.7	745	84	6	1,330	7.5	86
5N/24E-36K1	3- 8-62		PS	16	112	25	243		250	462	158	1.1	1,140	384	179	1,810	7.6	60
36K2	3- 8-62		PS	29	116	27	274		254	550	151	1.1	1,280	400	192	1,840	7.4	60
7N/24E-6F1	3- 7-62	28-180	PS	26	104	34	378		124	288	575	1.2	1,470	398	296	2,520	7.6	67
8N/23E-15A1	2-16-67	30-85	Irr	20	118	35	140		340	267	132	.4	882	440	161	1,410	7.6	41
15G1	2-16-67	39-53	Dom	10	108	29	114		192	300	118	.6	776	390	232	1,270	7.6	39
20J1	3- 7-62	478-520	PS	14	31	4.7	124		128	95	113	.8	446	97	0	785	7.7	74
9N/22E-1D1	6- 1-61		Dom	34	66	33	177		219	131	202	.4	711	300	120	1,220	7.5	49
1E1	1- 4-62		Dom	33	60	27	172		198	181	196	.9	772	260	98	1,280	7.5	59
9N/23E-28E1	5- 1-62	10-12	T	19	205	65	151		348	575	160		1,350	780	494	2,050	7.65	30
29E1	6-20-63		PS	36	100	58	227		192	225	414	1.5	1,160	486	328	2,040	7.5	50

TABLE 9.—*Chemical analyses of water from wells and from Red Spring, Needles area, Arizona-California-Nevada*—Continued

Well	Date sampled	Perforated interval (feet below land-surface datum)	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium
California—Continued																		
9N/23E-29E2	4- 5-61	----------	PS	28	94	26	114		208	277	86	.5	775	342	172	1,110	7.7	40
29E3	4- 5-61	----------	PS	36	106	34	200		211	388	176	.9	1,050	404	231	1,600	7.7	50
29E4	4- 5-61	40–76	PS	53	134	55	504		257	690	492	2.2	2,060	560	350	3,140	7.9	64
29F1	6-20-63	----------	PS	24	111	20	213		248	412	133	.8	1,040	358	154	1,490	7.3	56
30A1	4-11-67	38–82	PS	16	102	31	103		192	288	105	.6	742	382	224	1,250	7.6	37
32K1	6-20-63	150–160	PS	41	113	50	239		194	227	414	2.0	1,190	488	329	2,010	7.8	49
10N/22E-14C1	5- 1-62	13–15	T	24	186	57	155		342	488	176	--------	1,260	700	420	1,990	7.75	32
11N/21E-36K1	6-18-63	30–85	Irr	19	116	29	117		220	283	134	.4	808	410	230	1,270	7.45	38
36P1	6-19-63	----------	Un	17	122	33	142		228	362	130	.5	921	440	253	1,400	7.45	41
11N/22E-30N1	5- 1-62	14–16	T	17	111	32	110		190	333	104	--------	802	410	254	1,290	7.4	37
Nevada																		
S33/66-10ccc	5- 2-62	21–23	T	17	130	42	124		214	400	124	--------	944	498	322	1,500	7.4	35
Red Spring																		
10N/22E-30-C1	3-21-68	----------	S	52	36	5.4	166		344	60	77	8.0	576	112	0	910	7.9	76

Table 10.—Records of test and selected water wells, Needles area, Arizona-California-Nevada

Well: Location of well according to the Federal Land classification. See text for description of well-numbering systems.

Other number: Number assigned to test wells of the Geological Survey; number assigned to wells of irrigation districts; informal number assigned to some privately-owned wells.

Owner or user: Owner or user reported to the Geological Survey at the time the well was inventoried, not necessarily the original or present owner or user. L.H.I.D.D., Lake Havasu Irrigation and Drainage District.

Year completed: Known or reported year of completion of well.

Total depth: Greatest depth, in feet below land-surface datum, to which well was known or reported to have been drilled. Well may have been completed to a shallower depth, or filled in subsequently.

Completed depth: Depth, in feet below land-surface datum, to which well was cased or subsequently plugged.

Methods of construction: Letter symbols designate the following: D, drilled, method unknown; Dug, dug; C, drilled with cable-tool or percussion equipment; R, drilled with rotary-mud equipment; A, drilled with power or hand auger.

Casing diameter: Nominal inside diameter, in inches, of casing or pipe used in well. Where more than one figure is given, figures refer to diameter of casing in each successive segment from land surface downward.

Depth of perforated interval: Depth, in feet below land-surface datum, to top of highest perforations and base of lowest perforations.

Water level: Date measured by the Geological Survey, or reported (R) by owner or other agency. Depth to water in feet below land-surface datum. Ordinarily, the measurement made at the time of the well inventory appears here.

Type of pump: The following letters indicate the source of power: E, electric; G, gasoline; Ga, gas; D, diesel; W, wind; H, hand. The following letters indicate the type of pump: T, turbine; C, centrifugal; J, jet; S, submersible turbine; L, lift; P, pitcher. As an example, E, T refers to a turbine pump driven by an electric motor. For auger holes, G, J refers to gasoline operated compressor and airlift pump temporarily used to obtain water samples. Pumps are not maintained in auger holes.

Use: The use of the water is indicated by the following symbols: Irr, irrigation; PS, public supply; Dom, domestic; Ind, industrial or mining; T, test hole or well; Un, unused; Des, destroyed or filled in above the water table; S, stock.

Discharge: Measured or reported discharge of well, in gallons per minute.

Drawdown: Measured or reported drawdown, in feet, accompanying discharge in previous column.

Water quality: Date when water sample believed to be most representative of the present water at the depth of the perforated interval was obtained. Sum of determined dissolved constituents of water sample, in milligrams per liter by weight.

Water temperature: Temperature, in degrees Celsius (°C), of most recent sample of water pumped or bailed from well believed to represent water from the depth of the perforated interval. Temperatures taken with a Fahrenheit thermometer.

Other data available: Additional information about the well available in files of the Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the following letter symbols: L, driller's log; PT, pumping tests.

Well	Other number or name	Owner or user	Year completed	Total depth	Completed depth	Method of construction	Casing diameter	Depth of perforated interval	Water level: Date of measurement	Water level: Depth to water	Type of pump	Use	Discharge	Drawdown	Water quality: Date	Water quality: Sum of solids	Water temperature	Other data available
Arizona																		
(B-13-20)1cdd	Well 11	L.H.I.D.D	1963	1,000	1,000	C	12, 10	625–950	----------	480R	----------	Un	500	130	----------	------	----	L
4dbb	Well 3	L.H.I.D.D	1964	150	150	C	12	50–90	6-10-68	19.2	Ga, T	PS	------	------	6-10-68	1,220	----	
9aab	Well 8	L.H.I.D.D	1967	155	155	.C	12	20–110	----------	17R	----------	PS	------	------	----------	------	----	
13ccd	Well 5	L.H.I.D.D	1964	325	132	C	------	20–90	----------	205R	----------	Un	------	------	----------	------	----	L
15bcc	Well 2	L.H.I.D.D	1963	165	165	R	12, 10	117–165	----------	30R	Ga, T	PS	------	------	6-10-68	1,050	----	L
15ddb1	Well 4	L.H.I.D.D	1965	150	150	C	12	27–123	----------	18R	Ga, T	PS,Irr	------	------	----------	------	----	
15ddb2	Well 6	L.H.I.D.D	1965	153	153	C	12	28–150	----------	14R	Ga, T	Irr	------	------	----------	------	----	L
20dab	Well 9	L.H.I.D.D	1943	88	88	C	12	32–75	----------	25R	----------	Un	------	------	----------	------	----	
21bba	Well 1	L.H.I.D.D	1958	153	------	C	------	72–150	----------	30R	D, T	Irr	------	------	----------	------	----	
(B-14-19)28bcd	Well 7	L.H.I.D.D	1963	740	------	C	8	----------	----------	325R	----------	Un	------	------	----------	------	----	
(B-14-20)7aaa	----------	Pierce and Messer	1964	158	158	D	6	128–158	----------	105R	E, S	PS	------	------	----------	------	----	L
7ada	----------	Tomich and Chemowth.	1963	150	150	D	6	----------	----------	80R	E, S	Dom	------	------	----------	------	----	L
16ccd	----------	Rolfs and Hetzel	1962	300	300	C	8	180–280	----------	190R	E, S	S, PS	------	------	6- 6-68	1,730	----	L
(B-16-19)8dab	----------	U.S. Marble Corp	----	180	180	D	8	----------	----------	----------	E, S	Dom	------	------	6- 5-68	533	----	
(B-16-20)13bcc	----------	----------	----	------	------	D	8	----------	5-22-68	44.7	----------	Un	------	------	----------	------	----	
(B-16-20½)11ccd	Well 1	El Paso Natural Gas Co.	1950	880	880	D	8	189–420	----------	214R	E, S	Dom	50	74	3- 9-62	314	----	L
14bca	Well 2	do	1955	503	503	D	10	332–490	----------	214R	E, S	Dom	56	70	3- 9-62	558	33	L
(B-16-21)15add	----------	Golden Valley Land Co.	1961	290	290	C	12	----------	12-21-61	161.0	E, T	PS	------	------	9-11-62	390	----	L
(B-17-21)5bcb	----------	Colorado River Land Co.	----	100	100	D	6	----------	2-27-67	14.1	E, S	PS	------	------	4-23-68	1,600	----	
6ccc	----------	U.S. Geological Survey.	1962	18	18	A	1¼	16–18	5- 2-62	9.0	H, P	T	------	------	5- 2-62	1,040	21	

TABLE 10.—*Records of test and selected water wells, Needles area, Arizona-California-Nevada*—Continued

Well	Other number or name	Owner or user	Year completed	Total depth	Completed depth	Method of construction	Casing diameter	Depth of perforated interval	Water level		Type of pump	Use	Discharge	Drawdown	Water quality		Water temperature	Other data available
									Date of measurement	Depth to water					Date	Sum of solids		
								Arizona—Continued										
(B-17-21) 7abd		E. Parrish				D	20		2-15-67	12.2	E, T	Irr			4-14-67	1,260	22	
7bbd		do.				D					E, T	Irr			2-15-67	1,430	22	
7cbd		do.				D	20				E, T	Irr			2-15-67	1,530	22	
8ccc1		U.S. Geological Survey.	1961	17	17	A	1¼	15-17	8-10-61	9.9	H, P	T			5-1-62	2,100	22	L
8ccc2		do.	1965	122	85	A	1¼	83-85			G, J	T, Des			5-20-65	3,290	23	
17cdd		do.	1968	21	21	A	1¼	15-17	1-15-68	14.2	H, P	T						
18ccb		do.	1961	15	15	A	1¼	13-15	8-10-61	9.2	H, P	T			5-1-62	1,260	20	
21abb		do.	1968	27	26	A	1½	24-26	1-15-68	23.4		T						
30aaa		do.	1962	18	18	A	1¼	16-18	5-1-62	9.2		T						
(B-17-22) 1baa		Hartwich	1967	70	70	D	6	60-70	2-28-67	15.2	E, J	Dom			2-18-67	2,150	22	L
1bbd		Colorado River Land Co.	1967	175	175	D	12			20R	E, S	PS						L
10bbb		U.S. Geological Survey.	1961	12	12	A	1¼	10-12	8-10-61	6.8	H, P	T			5-1-62	1,390	20	
10ccc		do.	1965	117	22	A	1¼	20-22			G, J	T, Des			5-21-65	765	20	L
10ddd		do.	1965	132	63	A	1¼	61-63			G, J	T, Des			5-17-65	737	20	L
11aaa		do.	1962	18	18	A	1¼	16-18	5-1-62	9.2	H, P	T			5-1-62	971	21	
11bbb		do.	1962	18	18	A	1¼	16-18	5-1-62	9.0	H, P	T			5-1-62	1,770	21	
11ccd		E. Parrish				D	16		2-15-67	14.8	E, T	Irr			4-14-67	1,260	22	
11cdd		do.				D	16		2-15-67	35.1	E, T	Irr			2-15-67	1,220	21	
11ddc						D			1-18-68	17.8								
12ccc1		U.S. Geological Survey.	1961	18	18	A	1¼	16-18	8-10-61	9.4	H, P	T			5-1-62	1,170	21	
12ccc2		do.	1965	147	72	A	1¼	70-72			G, J	T, Des			5-18-65	999	21	L
12ddd		do.	1965	167	74	A	1¼	72-74			G, J	T, Des			5-19-65	1,380	22	L
13aaa		do.	1962	21	21	A	1¼	19-21	5-1-62	10.4	H, P	T			5-1-62	1,610	21	
13abb		J. Vanderslice		87		D	16			17R	E, T	Irr	2,500	33	3-2-67	1,750	21	
13bbb		E. Parrish				D	20		2-15-67	20.0	E, T	Irr			4-14-67	1,250	21	
13bcb		do.				D	16		2-15-67	15.4		Un						
13cbd		J. Vanderslice	1965	157		D	16	80-157	3-2-67	14.3	D, T	Irr						
13dcb		R. Chesney	1965	154	154	R	20, 16	64-143		16R	E, T	Irr	3,000	65	3-2-67	1,450	21	L
14ccc		U.S. Gcological Survey.	1961	15	15	A	1¼	13-15	8-10-61	7.2	H, P	T			5-1-62	1,120	22	
15aba		Bermuda Water Co.	1966	68	68	C	16	30-65			E, T	PS			2-15-67	888	22	
15ddc		do.	1962	70	70	C	16	35-65			E, T	PS			3-2-67	786		
23bbb						D	1¼		1-15-68	13.1								
(B-18-21) 31bbb		U.S. Geological Survey.	1961	18	18	A	5		1-9-62	8.8		T						
31dcd		do.	1968	22	21	A	1½	19-21	1-15-68	16.2		T						
(B-18-22) 2ccc		do.	1961	18	18	A	1¼	16-18	8-11-61	11.1	H, P	T			5-2-62	630	20	
3ccc		do.	1961	18	18	A	1¼	16-18	8-11-61	13.5	H, P	T			5-2-62	991	19	
11cbc		Hoefler	1957	63		D	20		3-1-67	13.0		Un						
13cbc		D. Hulet		90		D	20		6-4-64	15.2	E, T	Irr			6-3-64	817	23	
13ccc		U.S. Geological Survey.	1961	26	26	A	1¼	24-26	8-11-61	19.2	H, P	T			5-2-62	2,010	21	
15aab		D. Hulet	1957	95		D		60-95			E, T	Irr	1,720	21	11-1-62	772	20	PT
22aaa		U.S. Geological Survey.	1961	23	23	A	1¼	21-23	8-11-61	17.1	H, P	T			5-2-62	730	21	
23aad		L. Soto	1945	85	85	C	8				E, J	Dom						
23abb		do.	1926	100		C	12	65-95			E, T	Irr	1,350		3-1-67	558		
23bbd		R. Vanmater	1966	100		D	6		3-1-67	17.1	E, S	Dom						
23bcc1		G. McKellip	1963	152	152	R	12	112-152										L
23bcc2		do.	1963	310	304	D	20	60-304	3-1-67	11.7	E, S	PS			3-1-67	497		L
23cbb		F. Gregg		250	250	R	20		6-3-64	13.3	E, T	Irr						
23ccc1		Transwestern Pipeline.	1965	287	287	D	8				E, T	Dom						
23ccc2		do.	1960	79	79	D	6				E, S	Dom			3-1-67	598		
23cdb		G. McKellip	1965			D	20		3-1-67	13.0		Un			4-25-68	1,360		
24aba		U.S. Geological Survey.	1962	21	21	A	1¼	19-21	5-2-62	14.9	H, P	T			5-2-62	1,500	23	
25abb1		J. Hancock				D	20				E, T	Irr			2-28-67	1,790	23	
25abb2		do.				D	20		2-28-67	22.2	E, S	Dom			2-28-67	1,610	23	
27bbc		G. McKellip	1957	126	126	D	20	80-126		20R	E, T	S, Irr			11-1-62	707	19	PT
27ddd1		U.S. Geological Survey.	1962	31	31	A	1¼	29-31	5-2-62	18.9	H, P	T			5-2-62	885	21	
27ddd2		G. McKellip	1965			D	8			16R	E, S	PS			2-28-67	1,020		
27ddd3		Mohave Valley School.	1965	108		D	8			17R	E, S	PS			2-28-67	726		
34bbb		U.S. Geological Survey.	1961	21	21	A	5		1-11-61	12.8		T						
35aaa		do.	1961	21	21	A	5		1-10-62	13.2		T						
35bbb		G. McKellip	1960	94	94	D	20		11-28-62	19.8	E,T	Irr			3-6-62	863	21	L
35bbc		do.				D						PS						
35bda		do.	1963	150	150	R	20		6-3-64	18.4	E,T	Irr			6-3-64	1,120	22	
(B-19-22) 3dbb		U.S. Geolcgical Survey.	1968	27	26	A	1½	24-26	6-4-68	11.3		T						
9dca		do.	1968	21	21	A	1¼	19-21	1-17-68	17.5		T						
11bab		do.	1962	24	24	A	1¼	22-24	5-2-62	17.7	H, P	T			5-2-62	1,060	22	
11bbd		Palm Villa				D	8		4-13-67	19.4	E, T	PS			4-13-67	918		
14cca		C. Dunlop	1965	230	230	D	16			120R	E, T	Irr	2,300	18	4-13-67	1,340	27	L
15abb		G. Gideon		130	130	D	8			70 R	E, T				6-3-64	709	26	
15acb		W. Highfill		120	120	D	8			60R	E	Dom			9-18-62	698		
15dad						D	8		4-13-67	97.0	E, S	Dom			4-13-67	738		
21bcb		U.S. Geological Survey.	1968	32	32	A	1¼	30-32	6-4-68	22.5		T						
23ccc		H. Soto	1960	150		D	10			92R	E, S	Dom			9-9-62	843	26	
26aab		Rio Research	1964	228	228	D	20	150-220			E, T	Irr			4-11-67	1,230	28	L
26baa		S. Joy, Jr				D	14		6-3-63	91.0		Un						

TABLE 10.—*Records of test and selected water wells, Needles area, Arizona-California-Nevada*—Continued

Well	Other number or name	Owner or user	Year completed	Total depth	Completed depth	Method of construction	Casing diameter	Depth of perforated interval	Water level		Type of pump	Use	Discharge	Drawdown	Water quality		Water temperature	Other data available
									Date of measurement	Depth to water					Date	Sum of solids		
								Arizona—Continued										
(B-19-22)26ddd	--	S. Joy, Sr.	1958	190	--	D	21	--	11- 2-62	117.4	Ga, T	Irr	1,720	7	11- 2-62	1,480	28	PT
27aba	--	--	--	113	--	D	8	--	4-11-67	68.4	W, L	--	--	--	--	--	--	
36bab	--	S. Joy, Sr.	1958	250	250	D	20	--	11- 1-62	147	Ga, T	Irr	1,870	4.6	11- 1-62	1,560	28	L, PT
35baa	--	--	--	130	--	D	6	--	5- 8-69	77.5	E, S	Dom	--	--	--	--	--	
36bac	--	S. Joy, Jr.	1960	200	200	D	20	--	11- 2-62	150.7	Ga, T	Irr	--	--	11- 2-62	1,620	28	PT
(B-20-22)1aca	--	River Queen Trailer Court.	--	120	120	D	12	--	--	27R	E, S	PS	--	--	4- 3-68	1,350	--	
1add	--	W. Snyder	1963	249	249	D	12	--		153R	E, S	PS	--	--	6- 3-64	1,180	28	
17bcd	Well 3	Oasis Utility Co.	--	200	--	D	8	--	--	--	--	Un	--	--	--	--	--	
17bdd	Well 2	do	--	72	--	D	20	--	--	--	E, S	PS	550	--	--	--	--	
19ada	--	J. Foster	1960	150	150	D	16	--	--	--	E, J	PS	--	--	9-18-62	811	--	
19cda	--	do	--	--	--	D	18	--	6- 4-69	28.4	--	Un	--	--	--	--	--	
23bcd	Well 1	Oasis Utility Co.	1965	200	200	D	8	190-200	--	146R	E, S	PS	135	4	--	--	--	L
25bab	--	J. Rodarmel	1967	318	318	D	5	--	--	288R	E, S	Dom	--	--	4-24-68	653	--	
26cca	--	R. Procter	1968	165	--	D	6	--	5- 8-69	98.4	E, S	PS	--	--	--	--	--	
26cdb	--	C. Lewis	1961	150	--	D	6	--	--	--	E, S	PS	--	--	4-24-68	808	--	
26dcd	--	do	1968	220	220	D	6	--	--	--	E, S	PS	--	--	4-24-68	434	--	
29acc	--	--	--	80	--	D	20	--	--	--	--	S	--	--	4-18-62	420	--	
32aaa	--	U.S. Geological Survey.	1968	20	20	A	1¼	18-20	1-18-68	18.4	--	T	--	--	--	--	--	
35bbb	--	C. Lewis	1960	104	--	D	8	94-104	--	48R		Un	--	--	--	--	--	
35cdd	--	--	--	--	--	D	6	--	--	--	E, T	Dom	--	--	5- 7-68	2,330	--	
35dcc	--	J. Wilson	1968	168	--	D	6	--	5- 8-69	60.8	N	--	--	--	--	--	--	L
(B-21-21)21cbb	--	O. Buck	1951	490	108	D	8	--	--	--	E, S	Dom	--	--	3- 7-62	518	--	
								California										
4N/24E-17Z1	West well	--	--	8.4	8.4	Dug	36×42	--	5- 3-68	5.7	--	Un	--	--	5-13-68	745	--	
5N/24E-36K1	--	Havasu Water Co.	1958	462	462	C	8	--	--	30R	E, S	PS	150	--	3- 8-62	1,140	--	L
36K2	--	do	1958	428	428	C	8	--	--	80R	E, S	PS	--	--	3- 8-62	1,280	--	
36L1	--	do	1958	520	520	C	8	--	--	130R	--	Un	130	30	--	--	--	
7N/23E-10J1	--	Southern California Gas Co.	1957	730	--	C	16	--	4-24-63	89.7	--	Un	3	--	--	--	--	L
7N/24E-6F1	--	San Bernardino County.	1961	190	190	C	10	28-180	3- 7-62	21.9	E, T	PS	350	12.5	3- 7-62	1,470	--	L
8N/23E-15A1	--	U.S. Fish and Wildlife Service.	1965	90	90	D	16	30-85	2-16-67	6.7	E, T	Irr	1,800	42	2-16-67	846	19	L
15G1	--	do	1965	53	53	C	8	39-53	--	10R	E, C	Dom	150	15	2-16-67	762	--	L
20J1	--	C. Tonjes	1950	521	521	D	6	478-520	--	250R	E, S	PS	--	--	3- 7-62	446	34	
20K1	--	J. Tayloe	1969	594	--	D	6	--	--	280R	E, S	Dom	--	--	--	--	--	
20Q1	--	C. Tonjes	1957	396	396	C	12, 10	373-385	--	295R	--	Un	15	55	--	--	34	
9N/22E-1D1	--	Pacific Light and Gas Co.	1960	165	--	D	6	--	--	--	E, T	Dom	--	--	6- 1-61	711	--	
1E1	--	M. Johnson	--	120	112	D	8	--	1- 4-62	95.7	E, J	Dom	--	--	1- 4-62	772	--	
9N/23E-28E1	--	U.S. Geological Survey.	1961	12	12	A	1¼	10-12	8-10-61	6.5	H, P	T	--	--	5- 1-62	1,350	19	
29E1	Well 1	City of Needles	--	--	--	D	--	--	--	--	E, T	PS	--	--	6-20-63	1,160	23	
29E2	Well 2	do	--	--	--	D	--	--	--	--	E, T	PS	750	--	4- 5-61	775	20	
29E3	Well 3	do	--	--	--	D	--	--	--	--	E, T	PS	1,000	--	4- 5-61	1,050	21	
29E4	Well 4	do	1954	83	83	D	16	40-76	--	14R	E, T	PS	1,500	28	4- 5-61	2,060	22	L
29F1	--	do	1961	65	--	D	16	--	6-20-63	10.2	E, T	PS	650	3	6-20-63	1,040	--	PT
29L1	--	Atchison, Topeka, and Santa Fe Railroad.	1929	200	--	C	16	--	1-26-61	12	--	Un	--	--	--	--	--	
29Q1	--	do	--	92	--	D	--	57-82	--	--	E, T	Ind	1,200	--	--	--	--	L
29Q2	--	do	--	90	--	D	--	--	--	--	E, T	Ind	--	--	--	--	--	
30A1	--	City of Needles	1967	98	98	C	20	38-82	4-10-67	8	E, T	PS	2,800	26	4-11-67	750	17	L
30A2	--	do	1968	100	100	C	20	50-85	4-25-68	14.5	--	PS	--	--	--	--	--	L
32K1	Well 5	do	1960	360	360	D	16	150-360	4- 6-61	50.1	E, T	PS	2,250	18	6-20-63	1,190	30	L, PT
10N/22E-10F1	--	U.S. Geological Survey.	1968	27	26	A	1½	24-26	--	--	--	T	--	--	--	--	--	
11B1	--	U.S. Bureau of Reclamation.	--	--	--	A	1¼	--	5- 7-69	13.0	--	T	--	--	--	--	--	
13Q1	--	U.S. Geological Survey.	1968	22	21	A	1½	19-21	6- 4-68	9.2	--	T	--	--	--	--	--	
14C1	--	do	1961	15	15	A	1¼	13-15	8- 7-61	11.1	--	T	--	--	5- 1-62	1,260	20	
22D1	--	do	1968	57	57	A	1½	55-57	6- 3-68	48.2	--	T	--	--	--	--	--	
23C1	--	do	1961	--	--	A	1¼	--	1-10-68	9.1	--	T	--	--	--	--	--	
23P1	--	do	1961	23	23	A	1¼	21-23	8- 7-61	15.0	--	T	--	--	--	--	--	
11N/21E-36G1	--	Soto Bros	1950	50	50	D	16	30-50	4- 6-61	10.4	G, C	Irr	--	--	--	--	--	
36K1	--	do	1950	85	--	D	16	30-85	--	12R	G, T	Irr	--	--	6-18-63	808	21	PT
36P1	--	W. Riddle	1958	150	--	D	18	--	4- 6-61	10.6	--	Un	--	--	6-19-63	921	21	PT
11N/22E-30N1	--	U.S. Geological Survey.	1961	16	16	A	1¼	14-16	8- 7-61	11.3	--	T	--	--	5- 1-62	802	18	
31C1	--	W. Riddle	--	143	--	D	18	--	4- 6-61	15.4	D, T	Irr	--	--	--	--	--	
31C2	--	do	--	--	--	D	18	--	4- 6-61	13.0	--	Un	--	--	--	--	--	
31F1	--	do	--	140	--	D	18	--	4- 6-61	13.4	D, T	Irr	--	--	--	--	--	
								Nevada										
S33/66-10ccc	--	U.S. Geological Survey.	1962	23	23	A	1¼	21-23	5- 2-62	15.4	H, P	T	--	--	5- 2-62	944	21	
17add	--	do	1968	48	48	A	1½	46-48	6- 4-68	29.6	--	T	--	--	--	--	--	
20cdc	--	do	1968	27	26	A	1½	24-26	6- 4-68	15.3	--	T	--	--	--	--	--	
S34/66-5Z1	--	do	1968	30	30	A	1½	28-30	6- 4-68	18.5	--	T	--	--	--	--	--	
5Z2	--	do	1968	27	27	A	1½	25-27	6- 4-68	19.4	--	T	--	--	--	--	--	

TABLE 11.—*Selected modified driller's logs of eight wells in the Needles area*

[Modified from original only by giving lithology first and by addition of geologic units by senior author]

Well 8N/23E-20K1

[Location: NW¼NW¼SE¼ sec. 20, T. 8 N., R. 23 E., San Bernardino base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Composite	70	70
Sand and some gravel	30	100
Bouse Formation:		
Bentonite and brown clay	20	120
Shale, blue	170	390
Brown color, water	4	394

Well (B-13-20)15bcc

[Location: SW¼SW¼NW¼ sec. 15, T. 13 N., R. 20 W., Gila and Salt River base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Surface	46	46
Sand, fine, and gravel	24	70
Sand, fine	15	85
Sand, coarse, and gravel	65	150
Gravel, big	15	165

Well (B-16-20½)14bca

[Location: NE¼SW¼NW¼ sec. 14, T. 16 N., R. 20½ W., Gila and Salt River base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Sand, surface	50	50
Sand, coarse, gravel	40	90
Gravel, coarse, sand	30	120
Clay, gray	5	125
Sand, medium	30	155
Gravel, medium	5	160
Bouse Formation:		
Clay, blue	187	347
Fanglomerate:		
Sand and gravel	63	410
Gravel	14	424
Gravel, fine	79	503

Well (B-19-22)26aab

[Location: NW¼NE¼NE¼ sec. 26, T. 19 N., R. 22 W., Gila and Salt River base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Sand, gravel, and boulders	130	130
Sand and gravel	35	165
Sand	15	180
Sand and gravel	20	200
Boulders	11	211
Bouse Formation:		
Clay and gravel	7	218
Clay, sandy	7	225
Clay	3	228

Well (B-20-22)35dcc

[Location: SW¼SW¼SE¼ sec. 35, T. 20 N., R. 22 W., Gila and Salt River base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Sand and boulders	75	75
Sand and gravel	65	140
Bouse Formation:		
Clay, blue	5	145
Clay, white	10	155
Fanglomerate:		
Sand and gravel	13	168

Well 7N/24E-6F1

[Location: SE¼NW¼ sec. 6, T. 7 N., R. 24 E., San Bernardino base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Gravel, 3 in. to sand	22	22
Gravel, 2 to 8-in. rock	22	44
Bouse Formation:		
Clay	18	62
Shale	8	70
Clay, blue	32	102
Clay, gray, with rock	10	112
Rock, gray solid	6	118
Clay, gray with rock	20	138
Clay, with softer rock	16	154
Rock, with clay	36	190

Well 9N/23E-32K1

[Location: NW¼SE¼ sec. 32, T. 9 N., R. 23 E., San Bernardino base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Boulders and sand	10	10
Clay	3	13
Boulders and sand	81	94
Clay	7	101
Sand, hard with 6 to 12 in. gravel lenses	99	200
Gravel, coarse	16	216
Bouse Formation:		
Bentonite	144	360

Well (B-20-22)23bcd

[Location: SE¼SW¼NW¼ sec. 23, T. 20 N., R. 23 W., Gila and Salt River base line and meridian]

	Thickness (feet)	Depth (feet)
Alluviums of Colorado River and its tributaries:		
Clay, gravel, and boulders	45	45
Clay	5	50
Clay, sandy	10	60
Silt	10	70
Sand, coarse	10	80
Sand, fine	85	165
Gravel	5	170
Sand and gravel	13	183
Boulders, sand, and gravel	17	200

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