Geohydrology of the Parker-Blythe-Cibola Area, Arizona and California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 486-G

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By D. G. METZGER, O. J. LOELTZ, *and* BURDGE IRELNA

WATER RESOURCES OF LOWER COLORADO RIVER—SALTON SEA AREA

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A comprehensive study of the water resources of the area, including the paleohydrology of the lower Colorado River and the history of irrigation

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GEOHYDROLOGY OF THE PARKER-BLYTHE-CIBOLA AREA, ARIZONA AND CALIFORNIA

By D. G. Metzger, O. J. Loeltz, and Burdge Irelan

ABSTRACT

The Parker-Blythe-Cibola area, as defined in this report, extends from the bedrock narrows north of Parker, Ariz., southward for about 85 miles along the valley of the Colorado River to the bedrock narrows below Cibola, Ariz. The area is about midway between Hoover Dam and the Gulf of California. It includes parts of Yuma County, Ariz., and Imperial, Riverside, and San Bernardino Counties, Calif.

The principal landforms are mountains, piedmont slopes, and flood plain. The mountains are rugged and rise abruptly from the piedmont slopes. The highest points are in the Big Maria Mountains, about 3,350 feet above sea level, and in the Dome Rock Mountains, about 3,314 feet above sea level. The piedmont slopes are dissected by washes that head in the mountains, or exceptionally, in adjacent, but topographically, distinct basins. The slopes have gradients that range from 35 to more than 100 feet per mile, although most gradients range from 50 to 70 feet per mile. In many places the slopes terminate in terraces bordering the flood plain. West of Blythe and also near Parker, a cut surface between the piedmont slope and the flood plain is about 70 feet higher than the flood plain. Near Ehrenberg and east of Cibola, the piedmont slopes terminate in terraces older than unit D of the older alluviums.

The Colorado River flood plain ranges from less than 1 mile wide, in both the narrows above Parker and the narrows below Cibola, to 9 miles wide in Parker and Palo Verde Valleys. It is about 3 miles wide at Palo Verde Dam. The flood plain ranges in elevation from about 360 feet near Parker to about 210 feet near Cibola, a distance of 70 miles.

The mountains form the boundaries of the ground-water reservoir and offer little potential for the development of ground water. There is no evidence in southwestern Arizona or southeastern California of any substantial interbasin movement of ground water through the bedrock masses of the mountains. The many rock types that comprise the mountains are referred to as bedrock in this report; they include metamorphic and igneous rocks of the basement complex, metamorphosed Paleozoic and Mesozoic sedimentary rocks, and Tertiary volcanic and sedimentary rocks. Locally, wells of limited yield may be developed in the Tertiary volcanic and sedimentary rocks.

The geologic units that are important in an evaluation of the water resources are the Miocene(?) fanglomerate, the Bouse Formation, and the alluviums of the Colorado River and its tributaries.

The Miocene(?) fanglomerate is made up chiefly of cemented gravel composed of angular to subrounded and poorly sorted pebbles and of some fine-grained material that are thought to come from a nearby source. In exposures near Parker, it locally contains thin flows of basalt. Because the fanglomerate was deposited on an irregular surface having considerable local relief, it varies widely in thickness. Locally, it is absent, but in the Milpitas Wash area, it is at least 2,100 feet thick. Bedding surfaces in the fanglomerate dip from the mountains towards the basin.

The fanglomerate is a potentially important aquifer, a fact which was first recognized during this investigation. Near Parker, wells with specific capacities of as much as 15 gallons per minute per foot of drawdown have been developed in the fanglomerate. Where the fanglomerate is thin or tightly cemented, only very limited yields can be obtained.

The Bouse Formation of Pliocene age was deposited in an embayment of the Gulf of California. It is composed of tufa and a basal limestone overlain by interbedded clay, silt, and sand. Well logs indicate a continuity of the formation throughout the area. The thickest section of the Bouse Formation is the 767 feet penetrated in the drilling of U.S. Geological Survey test well LCRP 27.

Throughout most of the area, wells in the Bouse Formation will yield very limited quantities of water. In the area west of Moon Mountain, however, the upper part of the Bouse Formation as penetrated by wells is mostly sand that yields water at moderate rates. In test well LCRP 27 this sandy zone had a specific capacity of 13½ gallons per minute per foot of drawdown.

Toward the end of deposition of the Bouse Formation, the area of study was a vast body of water with mountains appearing as islands. After the withdrawal of the water from the embayment, the Colorado River entered the area, and much of the Bouse Formation was removed. After the river became established, the mountains began to rise relative to the basins. This relative rise was sufficiently slow so that the river was able to cut downward in dense rocks and carve the present-day canyons.

The alluviums of the Colorado River and its tributaries are the result of several broad periods of degradation and aggradation by the Colorado River. Although several of these periods are documented for the Parker-Blythe-Cibola area, the alluviums are divided only into older and younger alluviums; the older alluviums represent several degradations and aggradations, and the younger alluvium represents the youngest

aggradation. For discussion in this report, the older alluviums are divided, from oldest to youngest, into unit A, unit B, piedmont gravels (unit C), unit D, and unit E.

Unit A is composed mostly of cemented gravel that came from a nearby source, and it is similar to the Miocene(?) fanglomerate. Unit A is recognized as a distinct unit only near Cibola where it is separated from the fanglomerate by the Bouse Formation.

Unit B of the older alluviums is a sequence of heterogeneous fluviatile deposits. The most common lithology is a gray medium sand containing well-rounded small pebbles. Lenses of rounded to well-rounded cobble gravel yield copious amounts of water to wells. Some of the cobble gravel is composed of dense rocks that came from many miles upstream. The gravel includes rocks of Cambrian quartzite, Mississippian limestone, and chert from the Pennsylvanian and Permian limestones. Silicified wood also is found in the unit. Unit B occurs as deep as 600 feet beneath the flood plain at Blythe and as high as 450 feet above the flood plain on La Posa Plain.

Piedmont gravels (unit C) are of local origin and were deposited on cut surfaces graded to the Colorado River. Successive lowerings of the Colorado River resulted in several gravels at successively lower elevations. Southwest of Cibola, three different depositions of piedmont gravels are recognized. Desert pavements, composed of rocks having a heavy coating of desert varnish, have developed on these gravel slopes.

Unit D consists of a basal pebble to cobble gravel overlain by interbedded sand, silt, and clay. It was deposited against and on the piedmont gravels and older units, and locally is as high as 200 feet above the present flood plain.

Unit E is mostly unconsolidated sands that are easily transported by wind. As a result, it occurs on a belt of sand parallel to the flood plain. It also contains scattered rounded to well-rounded pebbles.

The younger alluvium that underlies the modern flood plain is composed of a basal gravel overlain by sand that was deposited by the Colorado River and of local gravel deposited by ephemeral tributaries. The younger alluvium generally is from 90 to 125 feet thick, and its basal gravel, 5 to 20 feet thick. Although the gravel is absent locally, the alluvium is continuous throughout the flood plain.

Most of the wells in the Parker-Blythe-Cibola area yield water from sand and gravel of the various units of the Colorado River alluvium. Although the units can be differentiated in surface exposures, only the younger alluvium generally can be recognized on the basis of subsurface data.

The Colorado River gravel has the highest hydraulic conductivity of any rocks in the area. Wells that tap a sufficient thickness of these gravels have specific capacities larger than 100 gallons per minute per foot of drawdown.

The paleohydrology of the lower Colorado River is carried back in geologic time to a time when geologic controls were stable, and therefore, to a time when the Colorado River was graded to its base level, the Gulf of California. The river has maintained a virtually uniform valley slope through two degradations and two aggradations, the causes of which were external.

The evidence in the Parker-Blythe-Cibola area neither supports nor disproves a fluvial connection between the Death Valley region and the Colorado River valley. If there was a connection, however, it was not younger than the time of deposition of unit B of the older alluviums.

One of the significant findings of this investigation is the absence of evidence of structure in piedmont gravels (unit C), unit D, unit E, and younger alluvium. The attitudes of the Miocene(?) fanglomerate, Bouse Formation, and unit B in the Cibola area indicate that the latest uplift of the mountains has been caused by small-scale structure over a zone extending 1½–2 miles from the mountains. This last rejuvenation of the mountains occurred after deposition of the Bouse Formation and after the Colorado River was in the area.

Ground water in the Parker-Blythe-Cibola area occurs under both unconfined and confined conditions. Most wells are completed in Colorado River alluvium where unconfined, or water-table, conditions prevail. Test wells drilled during this investigation indicate that the lower part of the Bouse Formation and the Miocene(?) fanglomerate contain artesian (confined) water. The artesian aquifers have not been developed to any appreciable extent.

Sources of recharge to the ground-water reservoir are the Colorado River, precipitation, and underflow from areas bordering the Parker-Blythe-Cibola area. The Colorado River recharges the aquifers directly by infiltration in some reaches and indirectly by infiltration of part of the water diverted from the river for irrigation. Direct recharge from precipitation is very limited, and recharge from infiltration of runoff from rainfall is only a minor part of the total recharge.

Ground water pumped from wells is used for municipal and domestic supplies, drainage, and irrigation. The city wells in Parker obtain most of their water from the Miocene(?) fanglomerate. The city wells in Blythe obtain all their water from unit B of the older alluviums. Most farms have domestic wells, many of which utilize sandpoints installed only a few feet below the water table. Only four drainage wells, drilled near Poston and maintained by the Bureau of Indian Affairs, are currently in operation. Three irrigation wells have been drilled on the Parker Mesa, 13 in the Vidal area, and 48 on the Palo Verde Mesa.

Ground water is discharged by evapotranspiration throughout most of the flood-plain area. Ground water also is discharged to drains in irrigated areas and to the Colorado River in some reaches. Throughout most of the area, the discharge is from the younger alluvium to the river. South of Cibola, although definitive evidence is lacking, some ground water is believed to be discharged from the Miocene(?) fanglomerate to the river.

Under natural conditions, phreatophytic vegetation covered some 108,000 acres of the flood plain in Parker Valley. About 73,000 acres was mesquite; the balance was dominantly arrowweed. Annual evapotranspiration under natural conditions is estimated at 220,000 acre-feet.

Irrigation with Colorado River water was first attempted in Parker Valley about 1870. In 1915 an attempt to develop ground water for irrigation in the east-central part of the valley failed because of poor chemical quality of the water. As late as 1920, almost the entire agricultural development was restricted to T. 9 N., R. 20 W. By 1927, almost 20 percent of the cleared lands was not producing because of lack of drainage and excessive alkali.

In 1948 the bringing of new lands into cultivation was accelerated. By 1955 because of a lack of adequate drainage, about 5,000 acres of previously irrigated land was out of production. In recent years, drainage facilities have been augmented, and water logging is only a minor problem.

A generalized water-level contour map for Parker Valley as of 1964 shows the buildup of the water table under irrigated areas, and the effectiveness of drains in controlling these mounds. Northward from the north boundary of T. 7 N., the Colorado River is receiving water from the irrigated areas: southward, the Colorado River is losing water to the ground-water reservoir.

Movement of ground water to the Colorado River north of the aforementioned boundary is estimated to average less than 16,000 acre-feet annually. Movement of water from the river to the ground-water reservoir south of the boundary is estimated to average about 88,000 acre-feet annually. An interceptor drain which parallels the river in this latter reach recovers some 17,000 acre-feet yearly, which is returned to the river below Palo Verde Dam. The total amount of water moving between the river and the ground-water system today is not greatly different from the amount that is estimated to have moved between these systems under natural conditions.

Ground-water levels in Parker Valley generally fluctuate within an annual range of 1 or 2 feet. Exceptions are ground-water levels near pumped wells, irrigated land, and the river. Diurnal fluctuations of river stage affect ground-water levels to a marked degree only to distances a few hundred feet or less from the river. There is little evidence of substantial seasonal changes in ground-water levels attributable to river stage at distances greater than half a mile from the river.

The depth to water beneath the flood plain of Parker Valley in 1942 ranged from about 5 feet below land surface near the river to about 25 feet at the eastern edge of the flood plain and averaged somewhere between 10 and 15 feet. The depth to water in 1961 ranged between 5 and 10 feet in irrigated areas and between 10 and 15 feet in areas of natural vegetation. The depths to water beneath the terraces bordering the flood plain are relatively unchanged from depths that existed under natural conditions.

Under natural conditions, native vegetation occupied about 114,000 acres of Palo Verde Valley and about 19,000 acres of Cibola Valley. The rate of use of ground water averaged about 2 feet per year, of which one-half is assumed to have been derived from infiltration of annual overflow of the river, and one-half, by infiltration directly from the river.

By 1912 about 12,000 acres was being irrigated. The final major period of agricultural development resulted in the creation of the Palo Verde Irrigation District in 1923. By 1965 about 84,000 acres was being irrigated by diversion from the Colorado River. Probably less than 50 acres was irrigated in Cibola Valley from the turn of the century to the 1940's. In 1962 about 5,800 acres was being irrigated by Colorado River water. The only area in the Palo Verde and Cibola Valleys where any substantial amount of ground water has been pumped for irrigation is Palo Verde Mesa. In 1965 about 200 acres of land was irrigated by pumping. In 1965 and 1966 many new wells were drilled, so that by 1967 there were 48 irrigation wells on the mesa.

In 1962 the canal system of the Palo Verde Irrigation District consisted of 295 miles of main canals and laterals with capacities ranging from 30 to 2,100 cubic feet per second. The drainage system consisted of more than 150 miles of open drains and more than 50 miles of tile drains. In general, hydrologic conditions in Palo Verde Valley are tending to stabilize under the almost full development of an agricultural economy based on irrigation with Colorado River water.

Much of the recharge to ground water from irrigation is captured by drains, but some returns directly to the Colorado River. Some recharge either from irrigation or leakage from the main canals moves westward under Palo Verde Mesa and then south and southeastward and returns to Palo Verde Valley.

In the area between Palo Verde Dam and Ehrenberg, about 30 000 acre-feet annually is moving eastward from the river; part of this amount is derived from infiltration of river water, and part, by ground water underflow from the irrigated area west of the river. In other areas some reaches of the river gain water and some lose water.

A ground-water mound underlies the northern part of Cibola Valley. Ground water from this area discharges water either to the Colorado River or to the Borrow Pit Drain in Palo Verde Valley that parallels the river. The southern part of Cibola Valley is an area of native vegetation that discharges about 30,000 acre-feet per year by evapotranspiration, of which about 20,000–25,000 acre-feet is probably derived from direct infiltration from the Colorado River. Most of the infiltration occurs in an 8-mile reach, suggesting an infiltration rate of 2,500–3,000 acre-feet per year per mile of river channel.

Most of the land in the flood plain of Palo Verde Valley is being irrigated and is served by an extensive and adequate drainage system. As long as the economy of the area is principally agricultural, based on an ample supply of surface water for irrigation, ground-water conditions in the foreseeable future will be much the same as they are at present. Additional development of irrigation in Cibola Valley may result in substantial amounts of ground water being pumped for either irrigation or drainage.

The pattern of water-level fluctuations in the Palo Verde and Cibola Valleys is a combination of the effects of changes in river stages, irrigation, and consumptive use by phreatophytes. Rarely does the resultant effect exceed 3 feet, except when irrigation is the dominant cause of the fluctuations.

The average depth to water beneath the irrigated lands within the Palo Verde Irrigation District in 1962 was 6.5 feet. In the northern part of Cibola Valley, water levels in 1962 generally were only about 5 feet below land surface; in the southern part, the water levels average 10 feet below land surface. The depths to water beneath the terraces bordering the flood plain range from 70 to 300 feet below land surface.

Water budgets for Parker Valley and for Palo Verde and Cibola Valleys were determined by two methods: (1) The inflow-outflow method, utilizing streamflow records for the period 1957–66, and (2) the consumptive-use method.

Water consumption for Parker Valley by the inflow-outflow method is estimated at 300,000 acre-feet per year. This figure includes a measured depletion of water supply, utilizing streamflow records, of 295,000 acre-feet, plus an average unmeasured runoff and ground-water inflow of 8,000 acre-feet minus an average unmeasured ground-water outflow of 3,000 acre-feet. Water consumption computed by the consumptive-use method is estimated at 307,000 acre-feet per year, which consists of consumptive use by natural vegetation of 167,000 acre-feet, consumptive use by irrigated crops of 118,000 acre-feet, and evaporation losses of 22,000 acre-feet.

Water consumption for Palo Verde and Cibola Valleys computed by the inflow-outflow method is estimated at 391,000 acre-feet per year, on the basis of a measured depletion of water supply utilizing streamflow records of 361,000 acre-feet, plus an average unmeasured runoff and ground-water inflow of 30,000 acre-feet. Water consumption by the consumptive-use method is estimated at 477,000 acre-feet per year, which consists of consumptive use by native vegetation of 136,000 acre-feet, consumptive use by irrigated crops of 321,000 acre-feet, and evaporation losses of 20,000 acre-feet.

The budget imbalance for Parker Valley is 7,000 acre-feet per year, and for Palo Verde and Cibola Valleys, 86,000. Much of the latter imbalance probably results from a consistent error in streamflow measurements at Palo Verde Dam. Because the water budgets are not precise, further refinement of the figures is not warranted.

Transmissivities computed from 43 pumping tests and considered fairly reliable ranged from a low of less than 100 to a high of 700,000 gallons per day per foot. In Parker Valley the storage capacity for material underlying the flood plain but above the capillary fringe is 39 percent, based on moisture-profile surveys at 15 sites using a neutron moisture probe. In Palo Verde Valley the storage capacity for material in a similar environment is 32 percent, based on moisture-profile surveys at 16 sites.

The chemical quality of the ground water in the Parker-Blythe-Cibola area can generally be related to the source and movement of the water. Ground water acceptable for domestic or public supply or for irrigation occurs at various depths under most of the area, but there are sizable parts beneath which satisfactory water is limited to thin strata or is absent. The chemical quality of the ground water is influenced to a marked degree by the local geology, but it is also influenced by former flooding of the river, evaporation, transpiration by native vegetation, and by irrigation developments.

Except where the water has been freshened as a result of irrigation, much of the shallow ground water beneath the flood plain is of relatively poor quality. Except near the Colorado River, the shallow ground water in the nonirrigated part of the southern part of Parker Valley is several times more concentrated than the river water, the concentration increasing with distance from the river. Shallow ground water of poor quality is found also beneath the nonirrigated or recently irrigated land in the Cibola Valley and the southern part of the Palo Verde Valley.

Most of the large capacity wells in the Colorado River flood plain obtain water from alluvium which is hydraulically connected to the Colorado River. Water in the river now generally contains between 650 and 800 milligrams per liter dissolved solids; sulfate is the predominant constituent. Wells in the Parker Valley that pump from the principal gravel zone yield water which is similar in composition to, but somewhat more concentrated than, the water from the Colorado River. Water from the principal gravel zone beneath other parts of the flood plain, notably near the eastern margin of Parker Valley south of Bouse Wash, the southern part of Palo Verde Valley, and the Cibola Valley, contains sufficient chloride to make it unsatisfactory for most domestic uses, and marginal to unsatisfactory for sustained irrigation. Some wells in the Palo Verde Valley yield water similar to the Colorado River, but others, particularly near the city of Blythe, which obtain water from beneath the basal gravel of the younger alluvium, yield water that is somewhat less concentrated and that contains considerably less sulfate than the river water.

Water pumped from some wells on the piedmont slopes bordering the Colorado River flood plain is of better chemical quality than the ground water in the adjacent parts of the flood plain. Beneath the mesa east of Parker most of the ground water is similar in composition to, but lower in dissolved solids than, the Colorado River water. However, the fluoride content of the ground water is higher than in most other areas and apparently increases with depth. Water of somewhat better quality than Colorado River water is obtained from public supply wells in the Vidal Valley, Calif., but several irrigation wells in the lower part of the valley yield water that is more concentrated than Colorado River water. Some of the wells on the piedmont slope on the east side of the Colorado River, both north and south of Ehrenberg, Ariz., yield water similar to that at Parker, but most of the wells there yield water that is considerably more concentrated than the present-day Colorado River water. West of Blythe, irrigation wells on the Palo Verde Mesa yield water ranging from a little less than, to about three times, the concentration of Colorado River water. Several recently completed wells on the Palo Verde Mesa yielded water that was more saline than that from older wells. A few small capacity wells near desert washes and on alluvial slopes on both sides of the Colorado River valley yield good quality water that is unlike, and lower in concentration than, the Colorado River water.

The composition of water obtained from many wells in the Parker-Blythe-Cibola area can be explained if the ground water is assumed to have originated as shallow infiltration from the Colorado River, from irrigation canals, or from irrigated fields, and to have been altered mainly by three primary processes—concentration by evaporation, precipitation of insoluble calcium and magnesium carbonates, and reduction of sulfate.

INTRODUCTION

PURPOSE OF INVESTIGATION

An investigation of the ground-water resources of the Parker-Blythe-Cibola area, Arizona and California, began in 1960 as a part of a Federal appraisal, known as the Lower Colorado River Project (LCRP), of the water resources of the lower Colorado River. The area studied (fig. 1) extends from Davis Dam south along the valleys of the Colorado River to the international boundary and to Coachella and Imperial Valleys. The general objectives of the investigation in the Parker-Blythe-Cibola area were to determine the location, extent, and hydraulic characteristics of aquifers, relationship of the aquifers to the Colorado River and other conveyance channels, evapotranspiration, and chemical character of the water.

LOCATION OF AREA

The Parker-Blythe-Cibola area is about midway between Hoover Dam and the Gulf of California. It is in Yuma County, Ariz., and Imperial, Riverside, and San Bernardino Counties, Calif.

The term "Parker-Blythe-Cibola area" is herein used to cover the area extending from the bedrock narrows north of Parker, Ariz., downstream for about 85 miles along the valley of the Colorado River to the bedrock narrows south of Cibola, Ariz. (pl. 1). The area extends from the Colorado River to the bedrock of the mountains, and has an average width of about 25 miles. Blythe, Calif., is near the center of the area. Lee (1908, p. 45) referred to this long valley as the "Great Colorado Valley," a term that has not survived. Following the terminology of the local residents, the valley has been arbitrarily subdivided into the Parker, Palo Verde, and Cibola Valleys.

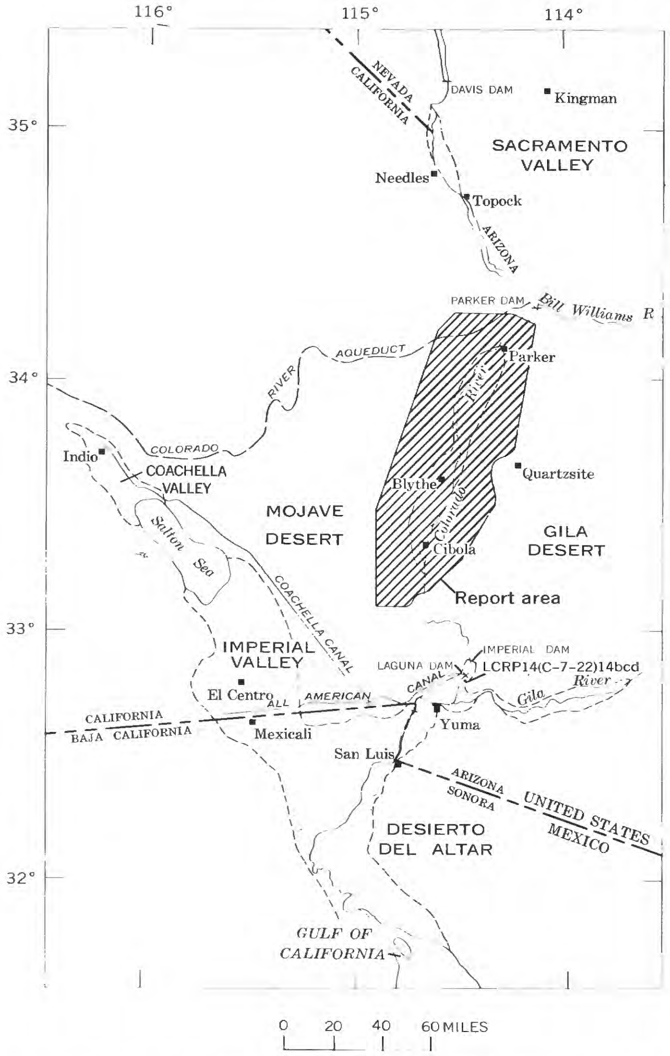

FIGURE 1.—Index map of lower Colorado River area showing the location of the Parker-Blythe-Cibola area.

FIGURE 2.—Installing a sandpoint observation well by means of an auger rig. The sandpoint well is pumped by airlift using the compressor on the bed of the pickup truck.

METHODS OF INVESTIGATION

Detailed information was obtained from numerous test wells. Ten wells, ranging in depth from 276 to 1,000 feet, were drilled under contract. Of these wells, two were 6 inches, two were 8 inches, and six were 12 inches in diameter. (Results of all but the 6-inch wells are shown on plate 2.) The 8- and 12-inch wells were drilled by the cable-tool method, which allowed the quality of water to be determined at depth and suggested the variability of permeability.

Eighty-seven holes, all 4 inches in diameter, were augered with a powered rig (fig. 2). Although the material below the water table sloughed, sandpoints were installed readily in the loosened material, to depths as much as 231 feet. The auger holes were used as stratigraphic probes to collect water samples and for periodic measurements of the water level.

The 8- and 12-inch test wells and numerous other wells were pumped to determine the water-bearing characteristic of the materials. The total number of aquifer tests was 42.

Chemical analyses were made of 149 samples of water from test wells, sandpoint wells, and other sources.

A neutron probe was used to determine the moisture content of the materials at 1-foot intervals, generally to depths of 16 feet, at 30 sites fairly well distributed throughout the flood plain. The steel access tubes for the probes were driven to the required depth by means of a gasoline-powered hammer.

Geophysical determinations included two seismic profiles, a gravity map of the area, and earth-resistivity surveys.

The investigation was under the general supervision of C. C. McDonald, project hydrologist. The section of the report on quality of water was prepared by Burdge Irelan. The sections on Parker Valley, Palo Verde and Cibola Valleys, water budgets, pumping tests, and ground-water storage—all under the topic of ground-water resources—were prepared by O. J. Loeltz. The remainder of the report was prepared by the senior author.

SURFACE FEATURES

The Parker-Blythe-Cibola area is in the Sonoran Desert section of the Basin and Range physiographic province (Fenneman, 1931, p. 326–395). The section is divided by the Colorado River; the western part is the Mojave Desert, and the eastern, the Gila Desert. The section is characterized by an arid and hot climate and by roughly parallel mountains separated by alluvial basins. 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 Parker-Blythe-Cibola 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 herein used, is that part of the Colorado River valley 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 is bounded generally by a terrace.

There are many indications of lateral shift of the channel of the Colorado River during historic time. This shift can be seen in a comparison of early maps with recent aerial photographs. An interesting example is the abandoned mining town of La Paz northeast of Blythe. This town was founded on the east bank of the Colorado River in 1862. In a flood in 1870 the river developed a new channel to the west which left La Paz without a landing, and the town rapidly lost its prominence in the frontier economy. By 1902–3, when the first profile of the river was surveyed, the river was on the west side of the flood plain. The present position of the river is about midway between the two historic extremes.

The flood plain throughout most of the area is between 3 and 9 miles wide. It is less than 1 mile wide near Parker, increasing to about 9 miles in the Parker Valley. It narrows to about 3 miles at the Palo Verde Dam, and then increases to about 9 miles in the Palo Verde Valley. In the Cibola Valley, the flood plain is between 3 and 4 miles wide, and then it narrows to less than 1 mile in the bedrock narrows below Cibola. The elevation of the flood plain near Parker is about 360 feet above sea level; below Cibola, it is about 210 feet. This indicates a slope of about 150 feet in about 70 miles.

The mountains, although not very high, are rugged, and rise abruptly from the alluvial slopes or from the Colorado River in the bedrock narrows. The highest summit in the area, in the Big Maria Mountains, is more than 3,000 feet above the flood plain and about 3,350 feet above sea level. The next highest summit is in the Dome Rock Mountains, elevation 3,314 feet. Most of the other mountain crests in the area are below 3,000 feet.

Between the flood plain and the mountains are dissected piedmont or alluvial slopes. Generally, one extensive surface is present; however, east of Cibola Valley, and about 100 and 200 feet above the most extensive surface, isolated remnants indicate higher piedmont slopes. As determined from topographic maps, most of the piedmont slopes have gradients that range from 50 to 70 feet per mile. Extremes are 35 feet per mile near McCoy Wash, and more than 100 feet per mile, east of Cibola.

The piedmont slopes in many places terminate in terraces bordering the flood plain. West of Blythe and near Parker, however, a cut surface about 70 feet higher than the flood plain is present between the piedmont slope and the flood plain. Near Ehrenberg and east of Cibola, the slopes terminate in terraces older than unit D of the older alluviums.

The piedmont slopes are dissected by washes that head in the mountains, or exceptionally, in adjacent, but topographically distinct, basins. The major washes are Bouse and Tyson Washes in Arizona, and Milpitas Wash in California. Minor washes include Osborne, Mohave, and Gould Washes in Arizona, and Vidal and McCoy Washes in California.

The tributary washes of the Colorado River have a characteristic cross section as they enter the flood plain. The section has steep banks and wide relatively flat bottoms. The section persists far up the drainage whether it is on alluvium or bedrock.

CLIMATE

The Parker-Blythe-Cibola area has a dry, warm climate, which is characterized by mild winters and hot summers. The climate is uncomfortable only in midsummer when temperatures above 100°F are common. The climate is pleasant the rest of the year, and it is a rare day when the sun does not shine at least for a part of the day.

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 and the high temperatures result in local thunderstorms. These thunderstorms can have high intensities, resulting in rapid runoff. The winter storms come from the Pacific

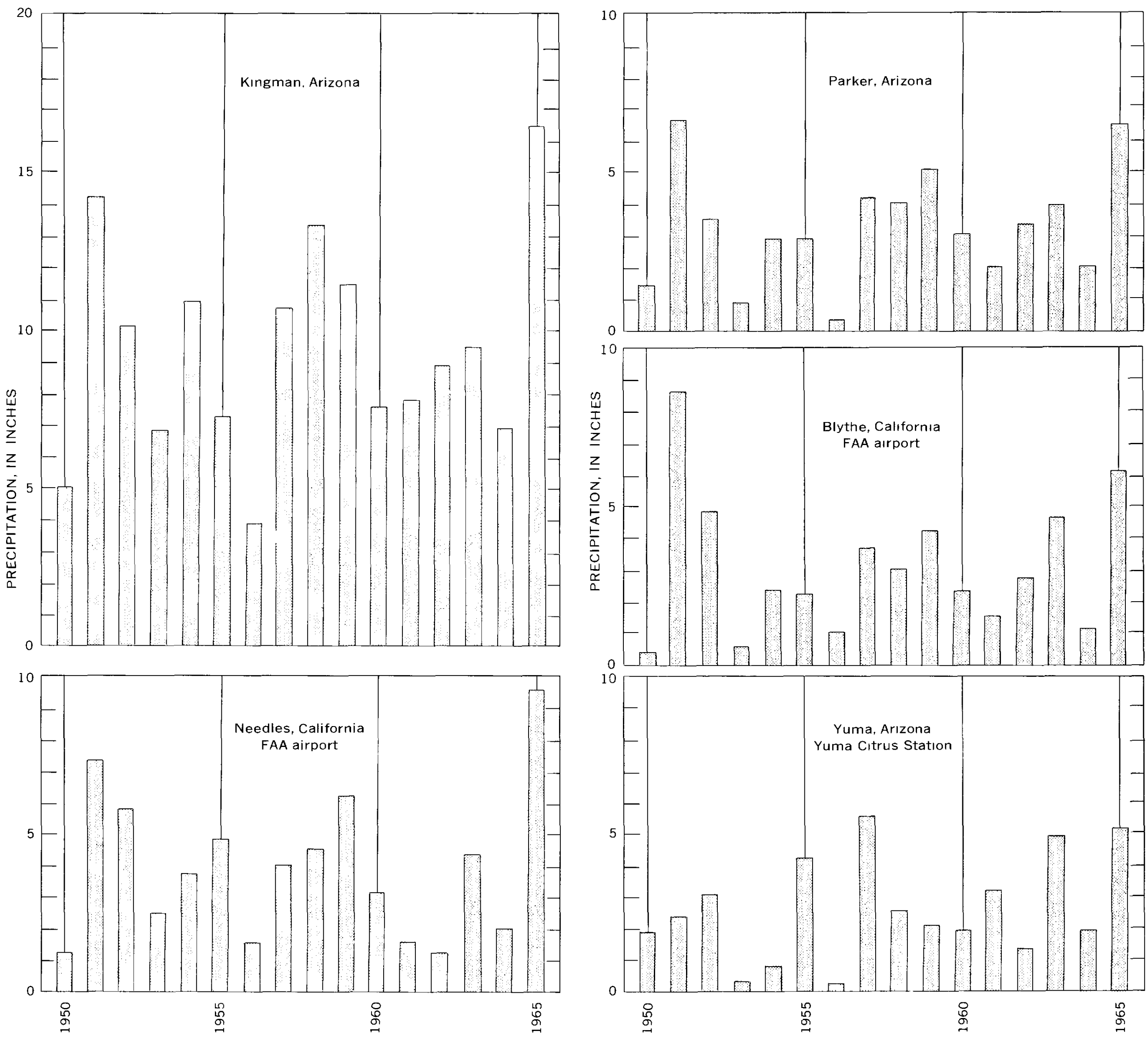

FIGURE 3.—Annual precipitation at five climatological stations in the lower Colorado River area, 1950–65.

Ocean and cause gentle rains with little or no runoff. Occasionally in August or September, moist air from tropical disturbances in the Pacific Ocean enter the desert, and coupled with the moist air from the Gulf of Mexico, can cause heavy rains throughout the area. An example is the storm of September 4–6, 1939, which dropped 5½ inches of rain on Parker, 3.4 inches on the 5th alone.

The annual precipitation on the flood plain and piedmont slopes of the area is from less than 4 to about 5 inches, and on the mountains, from about 5 to 8 inches (Hely and Peck, 1964, pl. 3). During the three unusual storms of September 1939, the area received from 6 to about 9 inches of rain, which is about double the precipitation in an average year.

ACKNOWLEDGMENTS

The authors wish to thank the many citizens of the Parker-Blythe-Cibola area who furnished information during the investigation. These include personnel of the Palo Verde Irrigation District, in particular Mr. John Blakemore, and of the Colorado River Indian Reservation, specifically Mr. Judd Allsop. Many data were furnished by well drillers, including Messrs. Jack Hamilton, Larry Hood, Lowell Mann, and Everett McBride. Mr. John Fillon, Soil Conservation Service, was very helpful in supplying data that he had collected.

Appreciation is expressed to the Southern Pacific Co. for copies of their unpublished reports on the Cibola area.

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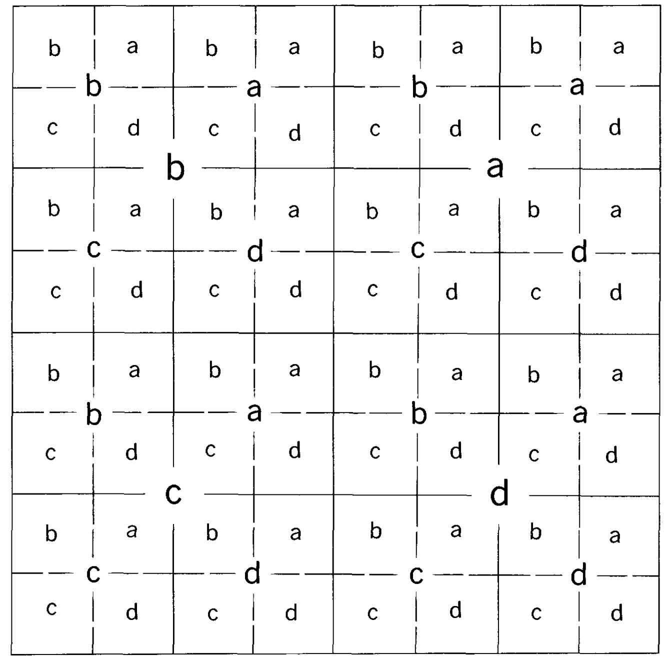
The fossils of the Bouse Formation were identified by Mrs. P. B. Smith (foraminifers), D. W. Taylor (mollusks), A. M. Keen (mollusks) and I. G. Sohn (ostracods). The vertebrates from unit D of the older alluviums were identified by C. A. Repenning.

WELL-NUMBERING SYSTEMS

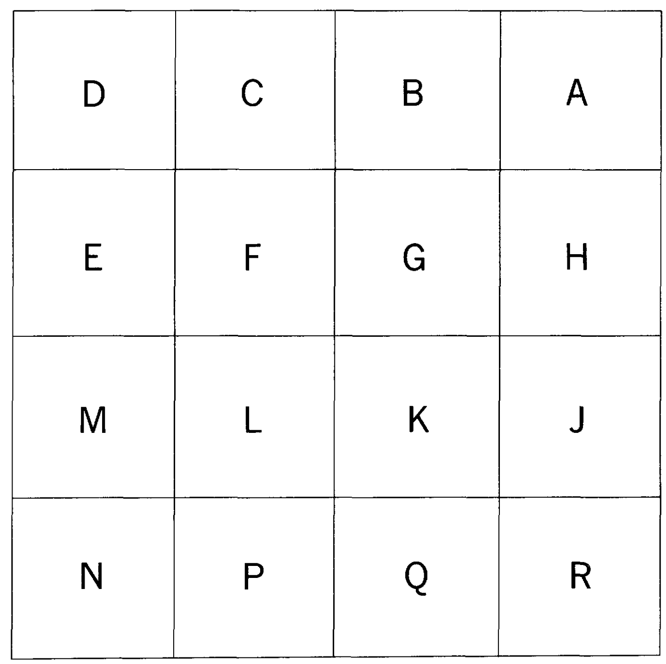
Two systems of well numbers are used in this report because the Parker-Blythe-Cibola area is in Arizona and California. These systems were developed by the U.S. Geological Survey for use in the two States and are based on the Bureau of Land Management system of land subdivision.

In the Arizona system, wells are assigned numbers according to their locations in the land survey based on the 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, the letter A being the northeast quadrant. Wells in the Parker-Blythe-Cibola area are in either the B or C quadrant—that is, all are west of the meridian and either north or south of the base line. For example, the first well inventoried in the NE¼NE¼NE¼ sec. 31, T. 7 N., R. 21 W. is given the number (B–7–21)31aaa. The capital letter indicates that the well is north and west of the intersection of the base line and meridian. The first number indicates the township (T. 7 N.); the second set of numbers indicates the range (R. 21 W.); and the third set, the section (sec. 31). 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 1 after the lowercase letters.

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 NE¼NE¼ sec. 20, T. 6 S., R. 22 E., is given the number



Arizona system



California system

FIGURE 4.—Sketches showing subdivision of section for assignment of well numbers.

6S/22E–20A1. The part of the number preceding the slash (/) indicates the township (T. 6 S.), the number following the slash indicates the range (R. 22 E.), the number following the hyphen (–) indicates the section (sec. 20), 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 6S/22E-20A1 is the first well inventoried in the NE¼NE¼ sec. 20, T. 6 S., R. 22 E. The letters N and S are used to indicate whether the well lies north or south of the base line. The letter E indicates that the entire area is east of the San Bernardino meridian.

For numbers in both 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

Water-quality data in this report are given in milligrams per liter (mg/l), degrees Celsius (°C), and micromhos at 25°C. The terms "parts per million" and "milligrams per liter" are practically synonymous for water containing as much as 5,000–10,000 mg/l of dissolved solids. The exact amount is dependent on the nature of the dissolved material. Temperature data given in tables 7–10 and 13 and 14 can be converted to degrees Fahrenheit (°F) by using the following scales:

°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 Parker-Blythe-Cibola area are the Miocene(?) 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 limited amount of Paleozoic carbonate rocks precludes interbasin movement of substantial quantities of water through the mountains in a manner similar to that reported for the Paleozoic rocks of southern Nevada (Loeltz, 1960). Interbasin water movement in this part of the Sonoran Desert probably occurs only in alluvium, generally where the ephemeral surface drainage exits from a basin. An example is the ground-water cascade at a bedrock narrows northwest from Bouse along Bouse Wash. The depth to water at Bouse is about 30 feet at an elevation of about 900 feet. Below the narrows the water table becomes deep, and this, in turn, grades to the water table of the flood plain below Parker. This ground-water cascade would not occur if there was substantial interbasin movement of water through the mountains.

Absence of significant interbasin movement through bedrock can be inferred between the upper drainage of Bouse Wash, about 40 miles east of Ehrenberg and along U.S. Highway 60–70, and McMullen Valley, about 15 miles farther east across the bedrock of the Little Harquahala Mountains. The elevation of the water table to the west of the mountains is about 1,000 feet, whereas the elevation to the east is about 1,700 feet. The absence of springs on the west side of the mountains indicates no ground-water discharge, and therefore no significant hydrologic connection through the mountains between the two valleys.

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

BEDROCK

Bedrock, as herein used, includes all rocks older than the Miocene(?) fanglomerate, and is made up of igneous, metamorphic, and sedimentary rocks. The bedrock is differentiated on the base map (pl. 1) into pre-Tertiary and Tertiary rocks. The pre-Tertiary rocks include the metamorphic and igneous rocks of the basement complex and metamorphosed Paleozoic and Mesozoic sedimentary rocks. The Tertiary rocks include volcanic and sedimentary rocks. Commonly, the bedrock is folded and dips steeply; this is in marked contrast to the overlying fanglomerate which dips gently.

The bedrock comprises the mountains; consequently, the outlines of the mountains are virtually the outlines of the bedrock exposures. Three isolated outcrops of very small areal extent project above the flood plain. These are (1) in NW¼ sec. 3, T. 8 N., R. 20 W., (2) in NW¼ sec. 25, T. 7 N., R. 21 W., and (3) in SW¼ sec. 2, T. 6 N., R. 21 W.

The basement complex of the bedrock includes gneiss, schist, and intrusive rocks, of which some have been referred to the Precambrian and others to the Mesozoic (Wilson, E. D., 1960; Bishop, 1963). Granite in the western part of the Riverside Mountains has been dated by the potassium-argon (K-Ar) method as 98.5 ± 4.0 million years (Bishop, 1963), which indicates Cretaceous age. Metamorphosed Paleozoic and Mesozoic sedimentary rocks occur in the McCoy Mountains (Miller, 1944), in the Big Maria Mountains (Hamilton, 1964), and as outcrops of small extent northeast of Parker. Other rock types include volcanic rocks of the Palo Verde, Chocolate, Trigo, Buckskin, and Whipple Mountains. The youngest of the volcanic rocks includes a sequence of basic lavas that at Black Peak is 900 feet thick.

The Tertiary sedimentary rocks include fanglomerate older than the Miocene(?) fanglomerate, conglomerate, sandstone, shale, limestone, and breccia. These sedimentary rocks are older than the youngest volcanic rocks, and at least a part of the sedimentary sequence contains interbedded lava flows. No attempt was made to decipher the history of these rocks. Nevertheless, it is obvious that these sediments were laid down in basins far different from the present basins because these rocks are now a part of the mountains, and they have been faulted and folded. No fossils have been found, so the age is in doubt. They are younger than the metamorphism of the Paleozoic and Mesozoic rocks, but probably are not younger than Miocene.

With two exceptions, 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; but no sizable potential exists for ground-water development.

Possible exceptions are some of the Tertiary sedimentary rocks and the younger volcanic rocks. Within the thick series of moderately cemented sandstone and conglomerate underlying the lavas at Black Peak, and also exposed about 7 miles to the north, there may be sufficient hydraulic conductivity to allow the development of small production wells. In fact, it is suspected that some shallow wells along the Colorado River northeast of Parker obtain water from Tertiary sedimentary rocks. The proximity of the Colorado River may have been an important factor in the yield of these wells.

The younger basic lavas may also be a potential source where they are saturated. A pumping test of LCRP 20, which bottomed in 75 feet of basalt,[1] indicated a much higher transmissivity for the basalt than was indicated by the specific capacity of the well (tables 5, 12). This fact suggests that a hydraulic conduit system in the basalt, probably resulting from fractures, was not fully open to the well. An earth-resistivity survey at this site did not indicate bedrock; the basalt, therefore, may be only of limited extent.

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. Older fanglomerates and megabreccias that occur in the mountains may represent the erosional products during earlier stages of the formation of the mountains. No attempt was made to decipher the structural history beyond the obvious observations, such as 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 probably is from a nearby source. In exposures near Parker, the section locally contains thin flows of basalt. The fanglomerate underlies the Bouse Formation and overlies tilted and faulted bedrock.

The fanglomerate is exposed extensively north of Parker and south of Cibola (pl. 1). The only other outcrops occur on the flanks of the Riverside Mountains and near an unnamed bedrock mass south of Bouse Wash and east of the Colorado River flood

[1] "Basalt," as used in this report, implies only that the extrusive igneous rock is dark, aphanitic, and generally vesicular.

plain. However, results from test drilling and logs of other wells indicate that the fanglomerate occurs extensively in the subsurface (Metzger, 1965).

LITHOLOGY AND THICKNESS

The fanglomerate is made up chiefly of angular to subrounded and poorly sorted cemented pebbles with a sandy matrix. The composition of the pebbles is similar to those in the present-day washes. The color depends on the matrix and the predominant rock types represented by its constituent pebbles—gray where they are from the basement rocks, and brown or reddish brown where they came from volcanic rocks or older Tertiary sedimentary rocks.

An altered zone in the fanglomerate generally occurs beneath the Bouse Formation. This zone may be as much as 20 feet thick and has an irregular base. It may represent a deeply weathered zone developed prior to the inundation of the waters of the Bouse embayment. This zone can be interpreted from the action of a rig during the drilling of deep test wells. Upon penetrating the base of the Bouse Formation, the drilling was easier for 5–20 feet, then much harder as more highly cemented rock was encountered. The change could not be readily determined by an inspection of the cuttings, probably because the cementation had been leached, and only the drilling rate indicated the softer zone.

Although pebbles are the common class size in the fanglomerate, some boulders as large as 3 feet in diameter are present. During the drilling of the fanglomerate from 811–998 feet in LCRP 22, several cobbles of welded tuff as large as 7 inches in diameter were brought up in the mud scow.

Bedding surfaces in the fanglomerate generally dip from the mountains towards the basin. In the Cibola area in sec. 16, T. 2 S., R. 23 W., near the mountains, the fanglomerate dips 17° toward the basin. This dip is a warping because faults were not observed. The fanglomerate dips only 2° half a mile to the west. Exposures are clear, and the dip was determined to range from 2° to 17°.

Northeast of Parker near Osborne Wash, the fanglomerate dips 1°–2° southward. To the northeast near the bedrock, it dips 5°–6°. The cause of this change in dip could not be determined because of the poor exposures. One possibility is a warping of the fanglomerate similar to that observed in the Cibola area. Possibly the change in dip is due to two similar gravel units affected differently by tilting and separated by an unconformity. In this case, the fanglomerate now having the larger dip was deformed and eroded prior to deposition of the fanglomerate now having the smaller dip. Some credence is lent to this last possibility by outcrops in sec. 27, T. 10 N., R. 19 W., which show this type of structure.

The fanglomerate varies widely in thickness. In LCRP 27, the fanglomerate was absent, and the Bouse Formation rested directly on older Tertiary rocks. In LCRP 20, only 73 feet of fanglomerate was penetrated. The other deep test wells penetrated 200 feet of the fanglomerate because this thickness probably was sufficient to test the hydraulic conductivity and chemical quality of the water.

An oil test in sec. 6, T. 11 S., R. 21 E., south of Milpitas Wash, penetrated about 2,100 feet of "conglomerate" above volcanic rocks. This oil test started in the fanglomerate near the contact with the Bouse Formation. Because the fanglomerate is exposed over a considerable area near here and has dips as much as 10°, it seems likely that the entire 2,100 feet is the fanglomerate.

North of Parker the fanglomerate dips 4° towards the south for a distance of about 4 miles. Assuming a uniform sequence with no repetition by faulting, a thickness of about 1,500 feet probably exists.

CONDITIONS OF DEPOSITION

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 deposition.

The 2,100 feet penetrated by oil test 11S/21E–6G1 probably is not a uniform bedded sequence. Intuitively, one would expect that this thickness represents deposits resulting from minor uplifts and erosions, and that there may be several unconformities within this sequence.

AGE

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

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 of California. The fauna, which occurs in steeply dipping

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sedimentary rocks, contains a fairly primitive species of *Merychippus* and is probably middle Miocene according to J. F. Lance (written commun., 1966). These sedimentary rocks are exposed south of Needles and are overlain unconformably by the fanglomerate. Because of this weak stratigraphic relationship, the fanglomerate is referred to the Miocene(?), although it may in part be Pliocene because the Bouse is not dated precisely within the Pliocene.

WATER-BEARING CHARACTERISTICS

The two most important characteristics that govern the water-yielding capability of the fanglomerate are its poor sorting and cementation, even though the fanglomerate contains much sand and gravel. Results of test drilling indicate that specific capacities of 15 gpm per ft (gallons per minute per foot) of drawdown from a 200-foot thickness of fanglomerate may be obtained, although some parts of the fanglomerate are so cemented that little or no water is yielded to wells. Only three of the test wells (LCRP 15, 21, 22) penetrated a sufficient section of the fanglomerate to warrant test pumping. The results obtained are useful only as point sources of information. Nevertheless, LCRP 15 and 22 are described in order to show the divergent characteristics of the fanglomerate.

Test well LCRP 15, about 2 miles east of Parker (pl. 1), is a good example of how the variation in cementation may affect the water-yielding capability of some wells that are perforated in the fanglomerate. Bailer tests during drilling, the rate of drilling, and the well cuttings are used in inferring the type of cementation. The fanglomerate occurred from 275 feet to the bottom of the hole at 520 feet. Casing was placed to 340 feet, and the well was drilled "open hole" to 520 feet. The drilling was slow and hard from 275 to 399 feet, and bailer tests indicated specific capacities ranging from very little to 1 gpm per ft of drawdown. From 399 to 465 feet, the drilling was faster and much easier, and a bailer test from 340 to 434 feet indicated a production of 65 gpm with an 8-foot drawdown. From 465 to 520 feet, drilling was again very hard, except for less-cemented material from 481 to 493 feet. Upon completion of drilling, the casing was perforated from 275 to 340 feet, and a preperforated liner was installed from 330 to 520 feet. A test on the perforated section from 275 to 520 feet indicated a specific capacity of 15 gpm per ft of drawdown. Most of the yield was obtained at depths between 399 and 465 feet.

The transmissivity of the fanglomerate in LCRP 15 as determined from a pumping test was about 18,000 gpd per ft (gallons per day per foot). Dividing this by the perforated interval of 234 feet, the average hydraulic conductivity is computed to be about 80 gpd per sq ft (gallons per day per square foot). However, as mentioned previously, 78 feet probably produced most of the water. Thus, this 78 feet probably has a hydraulic conductivity 2 or 3 times as great as the average computed hydraulic conductivity, and the balance of the fanglomerate may be only a small fraction of the average.

The fanglomerate was also strongly cemented at well 11S/21E–5F1. The well was drilled open hole to a depth of 750 feet, and the depth to water was 283 feet. The results of a bailer test indicated mostly a dewatering of the hole. An optimistic appraisal of the rate of yield of the well would be 1 gpm with a drawdown of 100 feet; therefore, the hydraulic conductivity is very low.

The fanglomerate in LCRP 22 (6½ miles south of Ehrenberg) was perforated from 820 to 985 feet. During drilling, there was no noticeable change in the degree of sorting of cuttings from the fanglomerate, and the drilling rate was remarkably constant. For these reasons, it is assumed that the hydraulic conductivity may be fairly uniform for this perforated interval. By dividing the transmissivity of 12,000 gpd per ft by the perforated interval of 165 feet, the average hydraulic conductivity is about 70 gpd per ft, which in this well probably represents that of the individual beds.

Ground water in the fanglomerate occurs under artesian conditions where the fanglomerate is overlain by the Bouse Formation. Wells perforated in the fanglomerate in which positive artesian heads (that is, the water level stands above the local water table) have been found are: LCRP 15, 1 foot; LCRP 20, 4 feet; and LCRP 22, 42 feet. Well (B–1–23)28abb, an irrigation well north of Cibola, is reported to have little or no positive artesian head in the fanglomerate, an anomaly that cannot be explained with available data.

UNCONFORMITY BETWEEN THE FANGLOMERATE AND THE BOUSE FORMATION

The contact between the fanglomerate and the Bouse Formation is sharp and represents a marked change in environment from deposits laid down on land to those deposited in an extension of the Gulf of California. As this investigation progressed, it became apparent that this contact represented a significant time break because the fanglomerate-type lithology does not appear in the Bouse Formation.

The fanglomerate represents alluvial fans that were built from the mountains, and thus locally, it represents drainage from the mountains towards the basins.

There is no evidence—rounding or rock type—of being transported from remote areas because the detritus is derived from the nearby mountains. But, in relation to the Parker-Blythe-Cibola area, the evidence does not define whether the drainage was internal or external. 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 material that can be interpreted as having been deposited in a playa (other than in LCRP 27, to be discussed in the next paragraph) has been recognized in the subsurface data, nor has any been observed in outcrops. Because the subsurface data are meager, it is possible that such deposits exist but have not been penetrated by wells. An interpretation of a gravity map of the Parker-Blythe-Cibola area indicates a deep structural trough north of Blythe trending northwest parallel to the Big Maria Mountains; however, the nature of the rocks filling this trough cannot be obtained from the gravity data. Further, no wells in this area have completely penetrated the Bouse Formation.

The material penetrated beneath the Bouse Formation in LCRP 27 is a clayey sandstone containing pods of gypsum. The well was drilled "open hole" from 915 to 961 feet. The well was bailed until the depth to water was 270 feet; after 48 hours, little or no recovery had occurred, which indicates a dense rock. A softer zone just beneath the Bouse Formation contained water with a high percentage of $CaSO_4$. This sandstone may represent a playa facies of the fanglomerate, but so little is known because this is the only well that has penetrated this type of material. Or, the sandstone may be a part of the Tertiary breccia of the Riverside Mountains (Hamilton, 1964) which is exposed about 8 miles northwest of LCRP 27. Because of the induration of the sandstone in LCRP 27, the last possibility may have more credence.

The 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 be a mechanism by which the gulf invaded the area 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 Parker-Blythe-Cibola area do not indicate the direction of the drainage; it could have been to the north, east, or west, as well as to the south. However, regional guidance indicates that highlands were northeast of the area (M. E. Cooley, written commun., 1968) and that, if through drainage occurred prior to the transgression of the Gulf of California, the direction of drainage from the Parker-Blythe-Cibola area probably was to the south or southwest.

BOUSE FORMATION

DEFINITION

The Bouse Formation is a marine to brackish-water sequence that is composed of a basal limestone overlain by interbedded clay, silt, and sand, and a tufa (Metzger, 1968). The Bouse Formation was deposited in an embayment of the Gulf of California, and it includes the sediments that have been referred to informally as the "Cibola beds" (Wilson, E. D., 1962, p. 72) and the "lakebeds near Parker" (Ross, 1923, p. 25).

The Bouse Formation is principally a subsurface unit. Although exposures are numerous in the Parker-Blythe-Cibola area (pl. 1), they generally have a thickness of only tens of feet. The results obtained from the drilling of eight test wells during this investigation, and from other wells, indicate a much greater thickness of this formation than is apparent from outcrops and a continuity of the formation throughout the area (pl. 1).

The Bouse Formation rests unconformably on the Miocene(?) fanglomerate, and the contact is sharp (fig. 5). In all the test wells that penetrated the Bouse

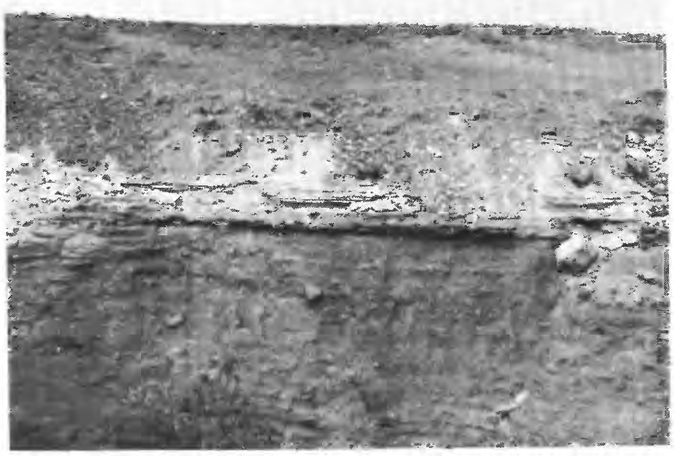

FIGURE 5.—Sharp contact and color contrast between the Miocene(?) fanglomerate and the basal limestone of Bouse Formation in the NW¼ sec. 28, T. 9 S., R 21 E. The basal limestone, about 8 feet thick, is overlain by a piedmont gravel.

Formation, the contact with the underlying and overlying units could be determined easily. The basal contact ranges in elevation from several hundred feet below sea level to as high as 1,050 feet above sea level. The upper surface of the formation is erosional, and because each degradation of the Colorado River removed some of the formation, the original thickness may be very difficult, if not impossible, to determine.

DISTRIBUTION AND THICKNESS

The Bouse Formation occurs in the subsurface throughout the Parker-Blythe-Cibola area (pl. 1). In the northern part of the Colorado River flood plain, the Bouse underlies younger alluvium at a depth no greater than about 130 feet. Near Blythe, the Bouse occurs at a depth of about 600 feet beneath unit B, and possibly unit A, of the older alluviums. Near Cibola, the Bouse underlies younger alluvium at a shallow depth. Surface exposures of the Bouse Formation occur in the Cibola area, near Parker, and as scattered outcrops of small areal extent near the mountains throughout the rest of the area.

The thickest section known is the 767 feet in LCRP 27, where the Bouse Formation is overlain by younger alluvium. Assuming no structure between LCRP 20, 10 miles northeast of LCRP 27, and the outcrops to the east, an assumption that may or may not be valid, the thickness may be as much as 900 feet. The upper surface in the outcrops is an erosional unconformity like that at LCRP 27.

The basal limestone was found in all test wells that penetrated the Bouse Formation. The thickness of the limestone in the test wells is as follows: LCRP 22, 5 feet; LCRP 27, 24 feet; LCRP 20, 7 feet; LCRP 21, 10 feet; and LCRP 15, 9 feet. The basal limestone is about 100 feet thick in the area south and southeast of Cibola, and in the lower part of the Milpitas Wash drainage basin. About 20 feet of the limestone, including one thin (about 4-in.-thick) ashfall tuff, is exposed near the drainage divide between Milpitas Wash and Imperial Valley in sec. 4, T. 12 S., R. 20 E. The limestone crops out to the north along Osborne Wash and the Colorado River near Parker, where generally it is less than 4 feet thick.

The interbedded unit occurs extensively in the subsurface in the Parker-Blythe-Cibola area. All but one of the test wells penetrated a part of the unit. In addition, the logs of many private wells indicate that the wells are bottomed in this interbedded sequence. This unit is by far the thickest unit in the Bouse Formation. As an example, this unit was 743 feet thick in LCRP 27, whereas the basal limestone was only 24 feet thick. The unit is exposed south of Bouse Wash along the terrace bordering the flood plain south to Moon Mountain, south of Vidal, and along Osborne Wash and the Colorado River near Parker. Small outcrops occur in the Cibola area and on the flanks of the Big Maria and Riverside Mountains. The thickest exposed section, in the SW¼ sec. 26 and the SE¼ sec. 27, T. 8 N., R. 20 W., is about 215 feet thick.

The tufa occurs on the lower slopes of most of the mountains in the area. The more extensive outcrops are in T. 2 N., R. 21 W., and on Moon Mountain. It is less than 1 foot thick, but it effectively conceals the older rocks.

LITHOLOGY

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

BASAL LIMESTONE

The basal limestone (fig. 6) in secs. 9 and 16, T. 2 S., R. 23 W., about 4 miles south of Cibola, is composed of three subunits. The lower subunit is composed of thin-bedded marly white limestone containing one 5-foot bed of barnacle coquina, and is about 50 feet thick. The middle subunit is a crossbedded light-tan barnacle-coquina limestone, about 20 feet thick. The upper subunit is a marly white limestone,

FIGURE 6.—The basal limestone of the Bouse Formation near Cibola, in the NW¼ sec. 16, T. 2 S., R. 23 W. The contact between the fanglomerate and the basal limestone is in the center of the picture (see arrow). The two white layers are thin-bedded marly limestone, each 15 feet thick. The dark layer between the white layers is a lens not more than 10 feet thick of subrounded to rounded gravel. The dark capping material is a barnacle coquina. About 60 feet of the limestone is exposed in this picture.

about 30 feet thick. These subunits vary laterally, to the extent that the subdivision was not recognized in the outcrops west of the Colorado River.

The dip of the limestone at the above-cited reference section is 2° in a N. 5° W. direction. The dip is remarkably uniform, except near the mountain front where the limestone has been warped upward.

During the drilling of the test wells, the top of the limestone was easily detected. The color of the drilling mud changed from the dark gray, which was characteristic of the interbedded clay, silt, and sand, to white. The limestone drilled easily and was generally reported by drillers as white clay. Marl was the most abundant type of material, and pebbles were present.

Along Osborne Wash and the Colorado River near Parker, the limestone is white, thin-bedded, and marly. It contains one thin (about 1-in.-thick) chert layer in the NW¼ sec. 34, T. 10 N., R. 19 W.

Gravel, a minor lithologic type in the basal limestone, occurs in lenses and as scattered rocks (as large as boulder size). One gravel lens (fig. 6) ranges in thickness from 0 to 10 feet. The gravel is composed of metamorphic, igneous, and volcanic rocks, which suggests local derivation. The gravel is subrounded to rounded, and commonly the pebbles have an iron stain. A gravel lens on the flanks of the Palo Verde Mountains is 9 feet thick and has crossbeds that dip 30°; the crossbeds are terminated sharply at top and bottom. Some crossbeds are composed mostly of pebbles, 1–2 inches in diameter, and others, mostly of pebbles ¼–½ inch in diameter. Thin limestones, both above and below this gravel, contain barnacle plates.

The other scattered gravel has the same dip as the limestone and grades basinward into limestone. A few pebbles of tufa of the Bouse Formation occur in some of this gravel, which indicates that tufa antedated some of the limestone.

INTERBEDDED UNIT

The thickest and most extensive exposure of the interbedded unit occurs south of Bouse Wash and east of the Colorado River flood plain (fig. 7). Here, the Bouse Formation is flatlying, rests on a fanglomerate that dips 5° to the west, and is overlain by piedmont gravel.

At this locality the formation is about one-half clay, and is mostly thin bedded. Few of the beds are thicker than 10 feet, an exception being a bed of fine sand that is 25 feet thick. During deposition of this sand, a subaqueous channel evidently was scoured to a depth of 12 feet, then filled with crossbedded sand, after which an additional 13 feet of horizontal-bedded sand was deposited.

FIGURE 7.—Interbedded unit of the Bouse Formation near Bouse Wash in the SW¼ sec. 26, T. 8 N., R. 20 W. About 215 feet of clay, silt, and sand are exposed. The Bouse Formation rests on the fanglomerate (see arrow) which crops out in the wash in the foreground.

Some of the beds grade upward from sand at the base to silt to clay. The beds may be less than 1 foot to as much as 20 feet thick. Although the thinner ones appear "varvelike," most are too thick to be considered varves, and instead, represent cycles of much longer periods.

Most of the clay beds are pale olive to pale yellowish green. Others are red, yellow, or gray. A characteristic of the clay is that it swells when moistened, which may indicate that some of the clay is montmorillonite. Because of this characteristic, the outcrops are mantled by an amorphous greenish mass.

The silt and fine-sand layers are commonly grayish orange, or very light gray to very light pink. Most of the sand is only weakly compacted or cemented; however, some thin sandstone layers are well cemented with calcium carbonate. Some of the light-gray sand layers contain numerous black minerals that result in a "salt and pepper" appearance.

Cuttings from wells of the interbedded unit have some characteristics different from those in outcrops. One of the most noticeable is the dark color. Cuttings of clay, when wet, are dark blue, dark gray, or dark green, and are generally referred to by drillers as "blue clay." When dried, the cuttings are a gray or green. The sand is all gray or dark gray; none of the lighter hues of the outcrops have been observed.

Another noticeable difference is in the induration of the sediments. Some of the clay cuttings are sufficiently indurated to be classed as claystones. In drilling, the claystone is relatively brittle, and some break up into cubes and others have a conchoidal fracture. As long as the clay and claystone are kept saturated —one sample was kept in water for 4 years—they remain solid and do not break down. However, if they become completely dry, and then are put in water, they swell and crumble readily, similar to outcrop samples.

Drilling action indicates that the sand is more compacted or cemented than would be suspected from inspection of outcrops. Some of the sand is well indurated, but it occurs as thin beds, or streaks as reported by well drillers.

Two minor constituents of the cuttings are microscopic pyrite crystals and small pebbles. The pyrite crystals occur as minute crystal groups, and pyrite fills the tests of some microfossils.

Some of the cuttings contain small pebbles, for the most part enclosed by clay. Because the pebbles are "floating" in the clay, it is inferred that they were probably dropped into the body of water from rafts of vegetation. The pebbles are rounded to well rounded, and composed of dense rocks, such as volcanic, granitic, and quartzitic rocks. The pebble assemblage is significantly different from that in the gravel deposits of the Colorado River.

No marker beds have been recognized in the interbedded sequence, possibly because of the limited subsurface data and the monotony of the sequence. Some thin beds (less than 1 in. thick) may eventually be shown to be marker beds. These beds are white limestone composed mostly of barnacle plates. One bed occurs in the section south of Bouse Wash and east of the flood plain, one is south of Vidal, Calif., and another is in the southwestern part of T. 2 S., R. 23 E. None of these beds has been recognized in test wells, but this is not surprising when one considers the limited thickness of the beds.

Three of the test wells penetrated a large amount of sand of the interbedded unit in the uppermost part of the drilled section. At LCRP 27, the upper 175 feet of the formation contained 146 feet of sand, and only 29 feet of silt and clay. At LCRP 4, the upper 310 feet was mostly sand. At LCRP 16, the upper 145 feet contained 141 feet of sand. In these wells the remainder of the drilled section contained much more clay. Similar thicknesses of sand have not been observed in outcrops of the Bouse Formation.

TUFA

The most prominent characteristic of the tufa is the peculiar manner in which it covers the bedrock. It has many forms, and is draped on the bedrock. Locally, the tufa is plastered to vertical cliffs and occurs on small ridges and valleys. This results in steep initial dips on adjacent sides of a ridge that give the false impression that the limestone has been folded into small anticlines and synclines. The tufa is everywhere a thin deposit, from less than 1 inch thick to a maximum of a few feet thick. Locally, it may be less than 1 foot thick, yet effectively conceals the bedrock (fig. 8). Thin coatings have been observed that completely cover small hills. In other places, they may conceal the slopes of a hill, yet leave a small topknot where the bedrock is exposed. Another form of tufa is similar to cave stalactites. The stalactitic tufa is generally on nearly vertical cliffs, draping downward in large lobes.

The tufa is exposed at many places in the Parker-Blythe-Cibola area, but most of the outcrops are very small, some only a few square feet in area. The highest exposure is about 1,000 feet above sea level in the Dome Rock Mountains.

The tufa varies from a very hard, dense to a soft, porous limestone, and from white to dark gray in color. It is for the most part, however, a resistant rock, and rather light in color.

Some of the outcrops, when viewed for the first time, and also where the outcrop is small, appear to be hot-spring deposits. However, the tufa is so widespread and in places forms such extensive exposures that little of it is likely to be of hot-spring origin. As an example, on the lower slopes of Moon Mountain, it completely covers metamorphic rocks. It would be an unusual system of springs in metamorphic rocks that would produce such a deposit.

Locally, cavities have been found in the tufa. These cavities range from a few inches to about 2 feet in diameter. They are lined with a dense finely laminated limestone that is botryoidal and smooth. Some of the laminæ are dark, probably due to the presence of a manganese mineral.

Some of the tufa has a fibrous appearance, but apparently has a high porosity. This fibrous appearance has been accentuated by desert erosion.

A deposit similar to the tufa of the Bouse Formation has been described in the Santa Rosalia area, Baja California, Mexico. I. F. Wilson (1948, p. 1774–

FIGURE 8.—Looking toward Whipple Mountains from isolated mountain south of Bouse Wash showing thin tufa of Bouse Formation on bedrock (basement complex). Bedrock (pT), Miocene(?) fanglomerate (Tf), tufa of Bouse Formation (Tbt), interbedded clay, silt, and sand of Bouse Formation (Tbf), piedmont gravel of older alluviums (QTa).

1775) in describing the basal marine deposit of the Boleo Formation of early Pliocene age states:

It averages only 1–2 meters in thickness, only rarely thickening to more than 5 meters * * *. It completely covers the smaller hills, but wedges out against the higher ridges and islands that were completely covered by the sea. The limestone follows all the topographic irregularities of the Comondú surface on which it was deposited. Steep dips are common, and in places the limestone clings to remarkably steep slopes and even small cliffs on the Comondú volcanics, to which it is literally plastered. The origin of the limestone is obscure, but it may have been formed partly through the agency of organisms that adhered to the rocky slopes, headlands, and islands of the Comondú volcanics as they were engulfed by the sea.

The physical description, age, and stratigraphic position of Wilson's basal marine deposit is somewhat similar to that of the tufa of the Bouse Formation. Definitive evidence to prove that this similarity is nothing more than a coincidence is lacking, however, because similar deposits are not recognized in the intervening Imperial Valley and Yuma area.

PALEONTOLOGY

Fossils are common in the Bouse Formation, although the number of species is small. Some of the fossils are marine, but they are not helpful in determining the age of the Bouse Formation. The fossils include foraminifers, mollusks, ostracodes, charophytes, and barnacles. The tufa is believed by the author to be primarily the work of algæ, but no paleontologic study has been made to verify this.

Cuttings obtained from the Bouse Formation during the drilling of the test wells were submitted to Mrs. P. B. Smith, U.S. Geological Survey. From a preliminary appraisal, Smith (written commun., 1967) reports eight species of marine foraminifers. She concludes that the

fossils are more characteristic of a normal marine environment in the southern part of the area than near Parker. In the northern area, samples tend to be monospecific, generally entirely composed of *Ammonia beccarii* (Linne). To the south, more species appear and whereas the assemblage is not one that has been reported from any modern environment, the presence of the *Globigerinas* indicates a marine environment.

The foraminifers as identified by Mrs. Smith are *Ammonia beccarii* (Linne), *Eponidella palmerae* Bermudez, *Elphidium* cf. *E. gunteri* Cole, *Bolivina subexcavata* Cushman and Wickenden, *Rosalina columbiense* (Cushman), *Quinqueloculina* sp., *Globigerina* sp., and *Cibicides* sp. Most of these species were also found by Smith in cores from Danby and Cadiz Dry Lakes, west of Parker (Smith, 1970).

Marine clams from the Bouse Formation include *Halodakra*, *Diplodonta*, *Macoma*, and *Mulinia?* Marine snails include *Batillaria* and *?Barleeia*. A brackish-water snail, *Tryonia?* also has been identified. Fresh-water snails include *Fontelicella*, *Physa*, and ?Hydrobiidae. Most of the mollusks were identified by D. W. Taylor (A. M. Keen, Stanford University identified *Halodakra*, *Diplodonta*, and *Macoma*). Of particular interest is the marine snail *Batillaria*. Taylor (D. W. Taylor, written commun., 1967) states that "although the genus is living in warm-temperate to tropical waters of the Caribbean and East Asia, it is unknown on the Pacific Coast of North America as a native."

Ostracodes from the Bouse Formation were identified by I. G. Sohn. These include *Ilyocypris* or *Limnocythere*, *Candona*, *Cytheromorpha?*, *Candoniella*, and several species of *Cyprideis*. These fossils were both brackish- and fresh-water types.

The mollusks, by their limited collections and the limited fauna, are indicative of an environment different from that of open marine waters (D. W. Taylor, written commun., 1967). According to Taylor, the presence of fresh-water types and the occurrence of *Chara* are significant in indicating a brackish-water environment. Also, although the salinity was sufficiently high at times to support the limited marine fauna, the water of the embayment was definitely more brackish than marine.

AGE

As discussed in the preceding section, a definitive age assignment for the Bouse Formation based on fossils is not possible at this time. However, a minimum age for the Bouse Formation is the time of entry of the Colorado River into the Basin and Range province because the Bouse is older than deposits of the lower Colorado River. As will be explained below, the age of the Bouse Formation can be established broadly as Pliocene.

Gravel of the Colorado River that underlies lava about 10 miles west of the Grand Wash Cliffs at Sandy Point, Ariz., indicates that the Colorado River at the time of outpouring of the lava had eroded older deposits until it was at a grade similar to the present. This lava has been dated as 2.6±0.9 million years (Damon, 1965, p. 40). The erosion of the older deposits indicates a substantially earlier date for entry of the ancestral Colorado River into the Lake Mead area.

A thin tuff, which occurs in the limestone of the Bouse Formation near the drainage divide between Milpitas Wash and Imperial Valley in sec. 4, T. 12 S., R. 20 E., has been dated twice by the potassium-argon method. The first analysis (P. E. Damon, written commun., 1967) indicated an age as equal to, or greater than, 3.02±1.15 million years. This age is considered a minimum because of partial devitrification of the glass. A second analysis (P. E. Damon, 1970) on the nondevitrified part of the tuff indicated an age of 8.1±0.5 million years.

The outcrops of the Bouse Formation near the drainage divide between Milpitas Wash and the Imperial Valley indicate a marine connection between the two areas during the time of deposition of the Bouse. Therefore, a correlation between the Bouse Formation and some of the marine sediments of the Imperial Valley undoubtedly exists. However, the limited collections and the limited fauna of the Bouse Formation prevent a paleontologic correlation with rocks in the Imperial Valley at this time (D. W. Taylor, written commun., 1967; P. B. Smith, written commun., 1967). Furthermore, controversy exists on the ages of the rocks of the Imperial Valley (Allison, 1964).

The previous discussion indicates that a definitive age assignment within the Pliocene for the Bouse Formation is impossible at this time. The earliest deposits of the lower Colorado River are at least late Pliocene in age and perhaps older. The oldest marine formation of the Imperial Valley with which the Bouse Formation may be tentatively correlated is the Imperial Formation of late Miocene or early Pliocene age. The youngest marine formation would be that beneath deltaic sediments that could be demonstrated to have been transported by the Colorado River, a topic not covered in the literature. Because of the uncertainty of assigning an age, the Bouse Formation is referred to as Pliocene with the understanding that some of the lower Colorado River deposits are also Pliocene.

WATER-BEARING CHARACTERISTICS

The Bouse Formation may be divided into two zones, an upper and a lower, for the discussion of the water-bearing characteristics. The use of the terms "upper" and "lower" refers to the position of the zones as they were penetrated in wells and are not necessarily stratigraphic zones. The upper is mainly sand, but it cannot be stated with assurance that this is the uppermost part of the Bouse Formation. The available data are too meager to determine the lateral and vertical variations of sand, silt, and clay within the Bouse Formation—for example, the possibility of lateral gradation from the sand to a finer grained unit, and the amount of the Bouse Formation that was removed during the three degradations by the Colorado River.

The upper zone is an aquifer and the lower zone is an aquitard. Results of pumping tests indicate that specific capacities as high as 15 gpm per ft of drawdown may be obtained from the upper zone. The best that may be expected from the lower zone is only 1 or 2 gpm per ft.

The upper zone was identified in only three test wells (LCRP 4, 16, 27). It is suspected that this zone is penetrated in some of the deep wells near Blythe. However, it is difficult to separate the zone in drillers' logs because of the similarity in description to that of the Colorado River deposits. It is necessary to have cuttings in order to differentiate the Bouse Formation from overlying Colorado River sand.

The upper zone in LCRP 27 is 175 feet thick, of which only 29 feet is clay and silt. Two characteristics distinguish the upper zone from the lower. One is the large amount of sand, and the other is the grain size. The upper zone contains medium to coarse grains and some pebbles, whereas the lower zone contains only fine to very fine grains.

LCRP 27 was perforated selectively from 194 to 722 feet. Results obtained from a vertical current meter in this well during a pump test indicated that 90 percent of the water from the Bouse Formation came from 194 to 289 feet. The specific capacity for the entire perforated section was about 15 gpm per ft, and of this, about 13½ gpm per ft came from the upper zone.

The lower zone is about one-half clay and silt and about one-half fine to very fine sand. During drilling of this zone with a cable-tool rig, the formation yielded enough water for drilling operations, but because the material is fine grained and tight, one cannot expect it to produce much water. The lower zone was 592 feet thick in LCRP 27, and yielded 1½ gpm per ft of drawdown.

Artesian conditions occur only in the lower zone. During the perforating of LCRP 27, an opportunity was provided to verify this fact. The first perforations that were cut in the casing were from 700 to 725 feet. The next morning the water level was 6.1 feet below land surface. Upon completion of all perforations, the composite water level was 13.2 feet below land surface. This level gives an artesian head of about 7 feet above the local water table for the depth interval of 700 to 725 feet.

POST-BOUSE DEGRADATION AND AGGRADATION BY THE COLORADO RIVER

The contact between the Bouse Formation and the overlying deposits of the Colorado River and its tributaries is an erosional surface (figs. 9, 10). At least three degradations of the Colorado River have been recognized since the deposition of the Bouse Formation, and each of these removed some of the formation. This discussion, however, is concerned primarily with the first, which was the most severe, and probably most of the Bouse Formation that was removed from the area was eroded at this time.

The topography toward the end of deposition of the Bouse Formation can be surmised from the relationships between the Bouse and older rocks. Much of the bedrock was covered, whereas other parts appeared as islands in this vast embayment. For example, about 10 miles south of Parker, the present attitude of the Bouse is horizontal and it abuts against the bedrock; this was obviously an island in the Bouse embayment.

The topography following the deposition of the Bouse Formation is reflected locally in an overlying cemented layer. Near Moon Mountain (fig. 10), this layer is about 3 feet thick and is the basal layer of unit B of the older alluviums, the oldest post-Bouse deposit of the Colorado River in this area. The layer is well cemented by calcium carbonate and is a colluvial deposit.

South of Cibola, the Bouse dips about 2° in a basinward direction. This dip along with the warping near bedrock, if projected southward, rises and would project over the present Trigo Mountains. The presence of marine fossils as far north as Parker and the absence of bedded evaporite deposits as far north as Needles indicate accessibility of oceanic currents to the area and little variation in salinity.

The Colorado River from the Lake Mead area to the Gulf of California flows "across the structural grain." The river passes alternately from wide alluvial-filled valleys through canyons composed of basement and other resistant rocks. For the river to have established itself in such a position, it may have started on a surface that was cut on the Bouse Formation, particularly in the reach downstream of Needles. The absence of evaporite deposits or a thick clay sequence in the post-Bouse alluvium of the lower Colorado River area suggests that the river was not ponded for any appreciable time in its history. That is, the river as it left the Lake Mead area did not become ponded in each succeeding basin to the Gulf of California. Regardless of the exact mechanism by which the Colorado River reached the Gulf of California, the Colorado River became established in its

FIGURE 9.—Outcrop showing unconformities bordering the flood plain in sec. 1, T. 5 S., R. 23 E. Notice creep of Bouse Formation and colluvium from piedmont gravel that was formed prior to deposition of unit D, and on the left the apparent blending together of two gravels of local origin but of different ages. Bouse Formation (Tb), piedmont gravel (Qp), colluvium (Qcol), unit D (Qf) and local gravel of unit E (Qg).

present position in the Basin and Range province after the deposition of the Bouse Formation.

The Bouse Formation was easily eroded by stream action, and part of the Bouse was removed. The latest uplift of the mountains in relation to the basins occurred after the river was in the area, and movement was sufficiently slow that the river eroded the Bouse until bedrock was reached. With continuing slow regional uplift the bedrock was also eroded, and in places the lower Colorado River began entrenching canyons.

ALLUVIUMS OF THE COLORADO RIVER AND ITS TRIBUTARIES

The alluviums of the Colorado River are the result of several broad periods of degradation and aggradation by the Colorado River. Degradation, as herein used, is primarily erosional, and aggradation is primarily depositional. The usage here is in a geologic sense, and is contrasted with cutting and filling, which are minor events in periods of either degradation or aggradation. In a period of degradation, there can be deposition of alluvium because minor aggradation may occur during a major period of degradation. Conversely, in a major period of aggradation, there can be minor degradation.

Although several degradations and aggradations of the Colorado River have been documented for the Parker-Blythe-Cibola area, the alluviums of the Colorado River and its tributaries have been divided only into younger and older alluviums (pl. 1). The younger alluvium is the deposit of the youngest aggradation by the Colorado River, whereas the older alluviums are the deposits of several degradations and aggradations. For discussion in this report, the older alluviums are divided into units A–E, with E being the youngest (fig. 11).

The contact between the younger and older alluviums is between the present flood plain of the Colorado River and the bordering terraces, alluvial slopes, or bedrock. The contacts between the various units of the older alluviums can be differentiated in clear outcrops, sometimes only with great difficulty. From subsurface data, the younger and older alluviums can generally be separated, but the various units of the older alluviums cannot readily be separated (pl. 3).

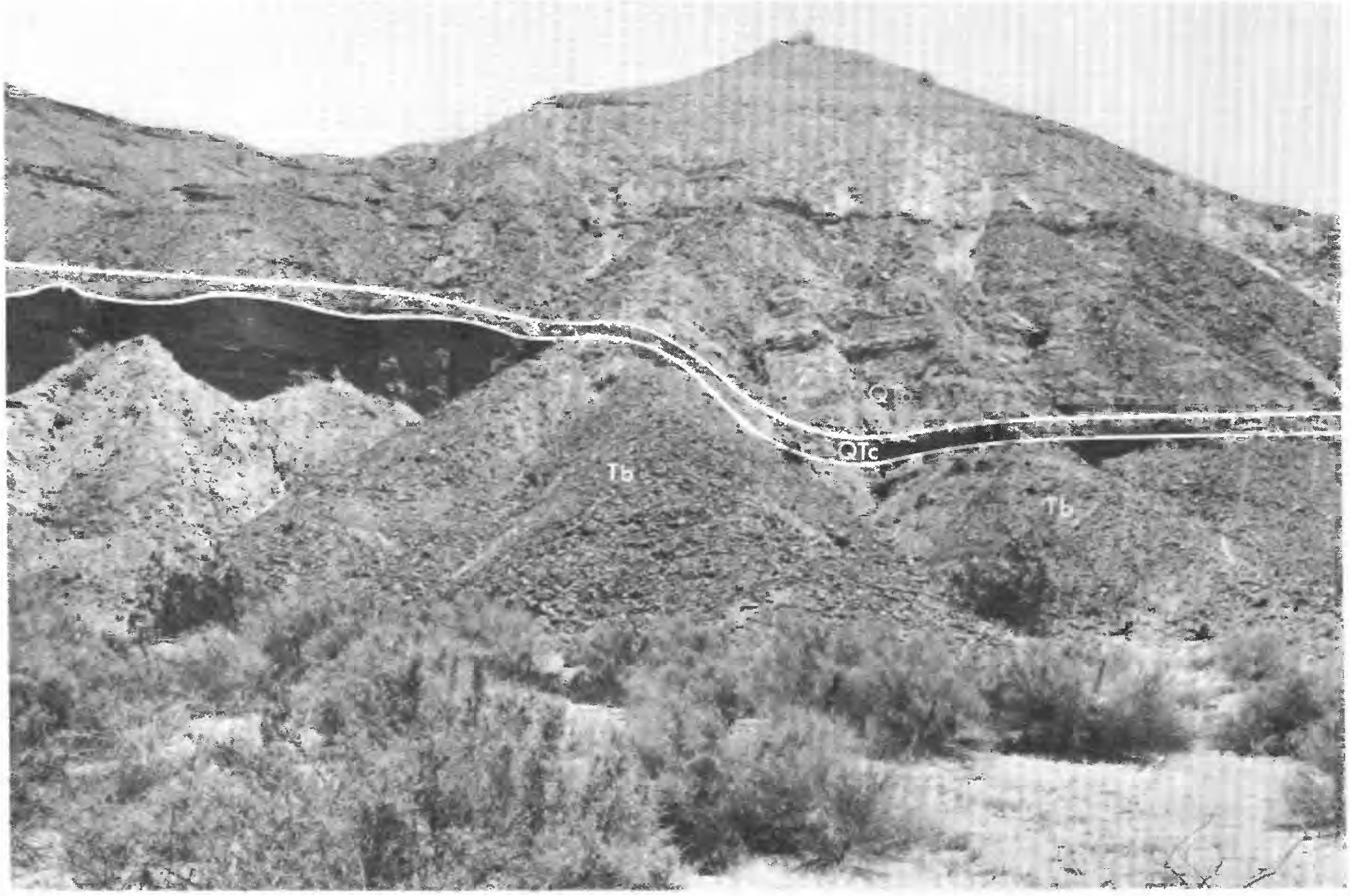

FIGURE 10.—The west side of Moon Mountain showing a cemented layer that indicates topography prior to deposition of unit B of older alluviums. The cemented layer is about 3 feet thick. Bouse Formation (Tb), cemented layer (QTc) of older alluviums, unit B of older alluviums (QTa).

The water-bearing characteristics of the five 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 from subsurface data.

OLDER ALLUVIUMS

UNIT A

Unit A is recognized only near Cibola and is composed chiefly of cemented gravel that came from the nearby bedrock areas. It overlies unconformably the Bouse Formation and underlies unconformably unit B of the older alluviums (fig. 19, p. 37). It is not readily distinguished from the Miocene(?) fanglomerate or from the cemented gravel of unit B. In the NE¼ sec. 9, T. 2 S., R. 23 W., unit A is in fault contact with the Miocene(?) fanglomerate, and only the fact that unit A rests on the basal limestone of the Bouse Formation permits a separation of the two.

Unit A can be separated from unit B only at exposures that show an angular unconformity between them. Elsewhere in the area, unit A has not been recognized because of the absence of unconformities. Nevertheless, cemented gravel now referred to as unit B, but in reality may be unit A, include (1) those near the mountains east of Ehrenberg, and (2) those near the Big Maria Mountains.

Unit A is made up of angular to subangular pebbles composed principally of volcanic rocks, although some schist and granitic rocks are present. About 80 feet is exposed, but it is not known how much of the unit that the section represents.

The local debris in the gravel suggests that this is an alluvial fan deposit. Because no playa or evaporite deposits are known in the Parker-Blythe-Cibola area, the Colorado River probably entered the area after the deposition of the Bouse Formation. Although the limited exposures of the identified unit A do not contain Colorado River gravels, some rounded to well-rounded gravels included at the base of unit B near

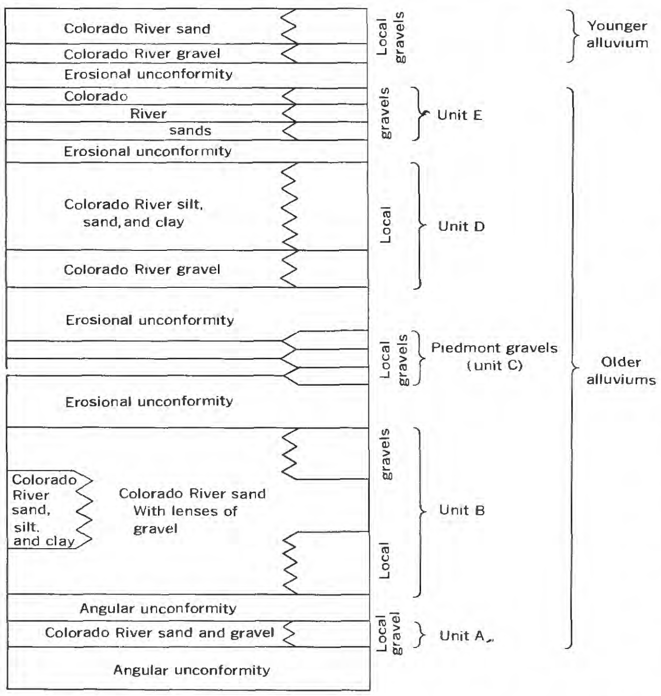

FIGURE 11.—Diagrammatic composite section showing the deposits of the Colorado River and its tributaries.

Hart Mine Wash may be a part of this sequence, and unit A may be associated with the early stage of the modern Colorado River in the Parker-Blythe-Cibola area.

UNIT B

Definition

Unit B is a sequence of heterogeneous fluviatile deposits of the Colorado River and its tributaries that unconformably overlies the Bouse Formation, and locally in the Cibola area, unit A. The unit is overlain unconformably by younger deposits of the Colorado River and its tributaries.

Although unit B can readily be distinguished from the other Colorado River deposits on the surface, this distinction cannot readily be made from subsurface data. No criteria were developed during this investigation to differentiate the various Colorado River gravels from subsurface data. The only exception is in differentiating unit B from the younger alluvium. This younger alluvium has a pebble-cobble gravel at a depth of about 100 feet which may be 20–30 feet thick. If a gravel indicated on a well log is 60–70 feet thick beneath the flood plain, it would be suspected that part of the gravel is from unit B, and part, from the younger alluvium; but an exact depth for the contact cannot be determined from available data. Because of the lack of contrary evidence, the older alluvium is considered as one aggradation; however, it may represent two or more.

Distribution

Unit B occurs throughout the area from Parker to Cibola. Some of the exposures are very near to bedrock, and these exposures indicate aggradation from one side of the valley to the other. One exposure of a Colorado River gravel occurs at about 700 feet elevation in sec. 29, T. 5 N., R. 20 W. about a quarter of a mile from the bedrock of the Dome Rock Mountains. On the opposite side of the valley about 9 miles west of Blythe, a cobble gravel rests on bedrock of the McCoy Mountains at an elevation of about 420 feet above sea level. In T. 1 N., R. 22 W., on the north tip of the Chocolate Mountains, unit B occurs at an elevation of about 700 feet. In La Posa Plain, it occurs at an elevation of 900 feet.

An inspection of well data near Parker indicates that unit B does not underlie the flood plain, but is beneath the terraces on both sides of the flood plain. Logs of wells in the flood plain indicate that the younger alluvium rests directly on the Bouse Formation.

Near Blythe, unit B occurs as deep as 600 feet below the flood plain. It is also present under the terraces on both sides of the flood plain. In LCRP 22, unit B occurs from a depth of 48–254 feet. In this hole, it is overlain by wash deposits of the younger alluvium and underlain by the Bouse Formation.

Lithology and Thickness

Unit B is a sequence of heterogeneous fluvial deposits and is composed of silt, sand, gravel, and a minor amount of clay. The most common lithology is a gray medium sand containing scattered well-rounded small pebbles. Locally, small lenses of pebbles occur, and these generally are less than 10 feet thick. A feature of some of the lenses is a conspicuous yellowish color, probably resulting from an iron stain. Silicified wood fragments are always associated with these iron-stained gravels. Gravel makes up only a minor part of unit B in some parts of the area. This is well demonstrated by subsurface data. In LCRP 5, about 3 miles northeast of Ehrenberg, unit B occurs from 45 feet to the total depth of the well at 471 feet, and is mostly sand, with some scattered pebbles (table 14). On the Palo Verde Mesa, gravel occurs in the subsurface only within a couple of miles from the edge of the mesa. Most of the new irrigation wells to the west obtain all their production from sand.

A unique lithology of unit B is the lenses of Colorado River pebble-cobble gravel. These lenses are not common, but where encountered in wells, they yield copious amounts of water. The gravel is made up of pebbles and cobbles that came from many miles upstream, and others that came from tributaries. Those from upstream sources are rounded to well rounded and are composed of dense rocks. Some are recognized as coming from Cambrian quartzites (Tapeats and related sandstones), Mississippian crinoidal limestones, red cherts of the Pennsylvanian rocks, and drab cherts of the Permian limestones. Some black chert is also present; this chert is from the Shinarump Member of the Chinle Formation of Late Triassic age (M. E. Cooley, written commun., 1968). The rocks of local origin are more angular, but can be subangular, subrounded and rounded. Invariably, the largest pieces of gravel are from the nearby mountains. Whereas the well-rounded cobbles from upstream sources are from 6 to 8 inches in diameter, those from local sources may be as large as 11 inches.

The previous discussion deals with the Colorado River deposits of unit B. It would be expected that local gravels interfinger with the Colorado River deposits, although this interfingering has not been observed. One reason probably is the similarity of such local gravels to the younger piedmont gravels (unit C), and the difficulty of distinguishing these two gravels. About 100 feet of local gravels is exposed east of Ehrenberg along U.S. 60–70 near the bedrock of the Dome Rock Mountains. The gravel is composed principally of metamorphic rocks, is moderately cemented, and dips about 2° towards the river. The gravel is older than the piedmont gravel, but the relationship to the Colorado River deposits of unit B could not be determined. The gravel weathers into rounded dissected hills. Basinward it is covered by piedmont gravel, and because of the similarity of the two gravels, they cannot readily be distinguished. Although this local gravel is assigned to unit B, there is a possibility that it may be a part of unit A. Similar local gravels having the same doubtful relationships occur on the flanks of the Big Maria Mountains.

Another sequence assigned to unit B is a fine-grained unit north of Tyson Wash and east of the flood plain. The exact relationship to the medium-gray sand of unit B was not determined. It could be a facies of the medium-gray sand, or it could represent a separate aggradation. This unit overlies the Bouse Formation and underlies the piedmont gravel. About 75 feet is exposed; it is composed of a buff medium and silty sand and chocolate-colored clayey silt. The unit becomes coarser toward the bedrock, and it grades into local gravel with sand. It is somewhat similar to unit D, but it is more indurated.

The total thickness of unit B cannot be determined, although a partial thickness is indicated from well logs and exposures. Near Blythe, unit B occurs as deep as 600 feet below the flood plain at an elevation of about 340 feet below sea level. On La Posa Plain, Colorado River gravel occurs at an elevation of about 900 feet above sea level; this gives a variance in elevation of 1,240 feet. This thickness, however, probably is not a true one because some structure has warped and made minor displacements of the earlier Colorado River deposits. Moreover, this large apparent thickness may be a result of structure, or unrecognized aggradations.

Silicified wood is common in the older alluvium. Some of the pieces are as long as 4 feet and as thick as 6 inches in diameter. The wood is water worn, and silicification occurred after deposition. The silicified wood, where exposed, has a heavy coating of desert varnish. Weathering has accentuated the grain in the wood, and the silicification of the wood structure has been faithfully reproduced. On fresh breaks, the wood is drab gray and has little coloring.

PIEDMONT GRAVELS (UNIT C)

Piedmont gravels (unit C) 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. In LCRP 5, a piedmont gravel is 45 feet thick.

The "piedmont," as herein used, is the compound surface of the dissected alluvial slopes between the mountains and the flood plain of the Colorado River. The overall cutting of the piedmont is controlled by the Colorado River. The term "piedmont gravels" refers to those gravels deposited on some of these surfaces. The use of the word "piedmont gravels" 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 that overlie 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 distinction because the gravels termed the "piedmont gravel" are thin, and they lie on the surfaces cut on older rock units, for the most part unit B. However, many use the term "pediment" where the surface is developed on the bedrock of the mountains and not on the softer units upon which these gravels lie. Moreover, the use of "pediment" is further complicated by the fact that these are compound or multiple surfaces and include capping gravel, each younger gravel having successive lower elevations.

The piedmont gravels are of local origin, and were deposited on cut surfaces graded, or nearly graded, to the Colorado River and its flood plain. Successive lowering of the Colorado River resulted in several gravels at successive lower elevations, forming a range in elevation of about 200 feet. The surfaces below and on top of the piedmont gravels have a gradient towards the flood plain of 100–200 feet per mile. At least three surfaces with the overlying gravel are present east of Cibola. The oldest and highest occurs near the bedrock of the mountains. A projection of the surface on the highest gravel using a gradient of the lower surfaces indicates that the gravels could have been graded to a point about 200 feet above the present flood plain. The gravels, although extremely 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 piedmont gravels have been exposed to weathering since before the deposition of unit D. The surface forms a desert pavement, and the gravel has a heavy coating of desert varnish. On the pavement southeast of Ehrenberg the composition of the surface is pebbles of vein quartz and schist fragments. The schist weathers more readily than the quartz, and the quartz now forms about 60 percent of the fragments. The composition on the surface of younger gravels from the same bedrock area contains only about 30 percent quartz.

UNIT D

Unit D (fig. 12) is made up of two facies: (1) basal gravel overlain by interbedded sand, silt, and clay, and (2) local gravel. The first has the greatest areal extent and was deposited by the Colorado River. The second, a minor facies, occurs at the margins of deposition and is the contribution of tributary washes. Unit D was deposited against, and on, the piedmont gravels and older units.

Unit D occurs along both sides of the flood plain throughout the area. It also is present in the Colorado River canyon above Parker and in the canyon below Cibola. South of Parker and near Bouse Wash, the lower unit occurs as high as 200 feet above the flood plain.

The most extensive outcrop is the scarp of the Palo Verde Mesa west of Blythe where the uppermost part of unit D occurs as high as 150 feet above the present

FIGURE 12.—Units D and E of the older alluviums of the Colorado River northeast of Ehrenberg, Ariz., in the NW¼ sec. 30, T. 4 N., R. 21 W. Unit D is composed of silt and sand. The lighter material on the left is a sand lens about 15 feet thick. A tusk of a proboscidian was found at the base of this lens at the place marked T. Unit E caps the ridge, and the uneven topography formed on the sand is the result of wind action that has formed a discontinuous mantle of dunes.

flood plain. The present surface on unit D is remarkably smooth, and it is at an elevation of about 410 feet above sea level. This surface may represent either the uppermost deposition of unit D or a surface formed during the degradational phase that followed. The absence of sand on this surface suggests that this may be an upper limit of deposition.

In the subsurface this unit is present in some of the wells on the Palo Verde Mesa, but as has been pointed out, it cannot definitely be separated from the older alluvium. In LCRP 15 on the Parker Mesa, the upper 199 feet of material penetrated is referred to this unit and unit E, although it is recognized that some of the gravel from 145 to 199 feet may be older.

The basal gravel of unit D deposited by the Colorado River, as determined from the cuttings obtained during the drilling of LCRP 15, is made up of fragments of pebble and cobble size. The larger pieces, as much as 9 inches in diameter, are of local origin and are from metamorphic, igneous, and volcanic sources. These are subangular to rounded, and they are not so well rounded or have as high a sphericity as the pebbles and cobbles that came from many miles upstream. Those from upstream are rounded to well-rounded and are made up of dense rocks. Included are fragments of quartzites of many types, cherts, dense limestone, metamorphic, and igneous rocks. Other material in the basal gravel are clayballs, some well indurated. These balls, as large as 3 inches in diameter, have an armor of small rounded to well-rounded pebbles. The source of clay for the well-indurated clayballs is not known; however, the source for the less consolidated clayballs was probably the Bouse Formation because some of these balls contain foraminifers.

The basal gravel of local origin is made up of subangular to subrounded material that came from the adjacent bedrock. Locally, this gravel is deposited against eroded surfaces of piedmont gravel and unit B of the older alluviums. The upper surface of the gravel is very smooth.

The interbedded sand, silt, and clay is generally tan with a slight pinkish or reddish cast to the outcrops. Some of the clay beds are darker shades of brown. The greatest exposed thickness is about 120 feet along the scarp west of Blythe.

The beds forming the scarp west of Blythe appear to be flat or nearly flat, and some beds extend for a considerable distance along the scarp. However, because these beds were deposited by the Colorado River and differential structural movements have not occurred since the beds were deposited, the beds probably have a very gentle dip southward, probably about the same as the present gradient of the Colorado River.

Vertebrate fossils are found in the fine-grained unit north of Ehrenberg. These fossils, with one exception, are in thin clay deposits, and have lithologic and bedding characteristics of having been deposited in small shallow flood-plain lakes. These deposits are not extensive and are lenticular. The largest one has a maximum width of about a quarter of a mile, and in its thickest part, is about 6 feet thick. The extent of the deposit down the valley is not known. None of the fossils collected so far have proved definitive as to age, other than the general designation of Blancan (late Pliocene to early Pleistocene) or younger (C. A. Repenning, written commun., 1965). The fossils include turtle, snake, lizard, bird, and large mammals. Invertebrates also occur in these clays.

A part of a proboscidian tusk (figs. 12, 13) was found in a cobble gravel at the base of a sand lens in the NW¼NW¼NW¼ sec. 30, T. 4 N., R. 21 W. The gravel consisted of only one layer of cobbles. The tusk had a sharp curvature of 2 feet, a maximum diameter of 8 inches, and a length of 5½ feet. The part of the tusk that was attached to the skull was 7½ inches in diameter, and the other end was 6 inches in diameter. The total length of the tusk may have been 10 or 11 feet.

The gravel facies of unit D is made up of subangular to subrounded cobbles that were derived from the adjacent bedrock. Areally, these facies do not make up a significant part of the alluvium, but they reflect the local contribution to the Colorado River of that time. The gravel interfingers with the fine-grained unit. This relationship is exposed near the middle of sec. 23, T. 1 N., R. 25 E., about 1 mile west of Earp, Calif.

FIGURE 13.—Proboscidian tusk from unit D in the NW¼ sec. 30, T. 4 N., R. 21 W. The tusk is not complete; however, the piece is 5½ feet long with a curvature of 2 feet. The maximum diameter is 8 inches. The end near the shovel was the part attached to the skull. The other broken end was 6 inches in diameter.

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 (fig. 12) 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 grained, fairly well sorted, and contains scattered rounded to well-rounded pebbles. Because of its unconsolidated nature, it is easily attacked and also moved by the wind, and it forms gentle dune-covered slopes. The gravel facies (fig. 11) is composed of subangular to subrounded cobbles derived from the adjacent bedrock. The gravel 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.

EOLLIAN SAND DEPOSITS

The eolian sand is a surficial deposit occurring at various places throughout the area. The sand is tan to light tan and fine to medium. Three occurrences are (1) on the terrace along the east side of the flood plain, (2) on the drainage divide between the Parker-Blythe-Cibola area and the desert basins to the west, and (3) on La Posa Plain.

The sand along the edge of the flood plain is derived from the unconsolidated unit E of the older alluviums. Only the larger outcrops of this type are shown on plate 1, and those shown are all on the east side of the flood plain. The sand on the drainage divide occur at two localities, one on the divide between Chuckwalla Valley and Palo Verde Mesa and the other between Rice Valley and the Parker Valley. In these localities the sand is being blown from the desert basins eastward into the Colorado River valley. This can be seen in T. 3 S., R. 23 E., where a northward bedrock extension of the Big Maria Mountains acts as a windbreak. This shows especially well on aerial photographs as a sharp demarcation between piedmont slopes that are, and those that are not, covered by sand. The third occurrence, which is the most extensive exposure, is on La Posa Plain on both sides of Bouse Wash. There, the sand that is probably derived from Colorado River deposits forms dunes that trend northeast.

YOUNGER ALLUVIUM

The preyounger alluvium topography was the Colorado River meandering on a flood plain nearly as wide as, but in a broad trench about 100 feet deeper than, the present flood plain. Scouring during the major floods of that time produced a greater depth for the base of the younger alluvium.

The younger alluvium is composed of (1) a basal gravel overlain by sand that was deposited by the Colorado River, (2) gravel with sand that was deposited by and in the tributary washes, and (3) colluvium. Colluvium occurs at many places along the edges of the flood plain and along washes; however, the outcrops are too small to show on plate 1.

The younger alluvium (excluding the colluvium) represents the last aggradation of the Colorado River, which has continued until the river was controlled. The younger alluvium 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 gravel with sand facies extends from the flood plain up the present washes.

Although debris from the nearby mountains was carried to the Colorado River during the time of deposition of the younger alluvium, the debris was reworked by the Colorado River. This reworking can be shown by the present meandering of the Colorado River. For example, in the 15-mile reach of the Colorado River below Ehrenberg, the Colorado River flows on the east side of the flood plain. Thus, washes that enter the flood plain in this reach do not build deltas such as those for Tyson and Bouse Washes because the Colorado River removes the local debris. As the Colorado River meanders from one side of the flood plain to the other, the river removes deltas composed of local debris from one side and then from the other. For these reasons, wash deposits probably are not interbedded with Colorado River deposits beneath the present flood plain.

LITHOLOGY AND THICKNESS

The basal gravel is composed of rounded to well-rounded pebbles and cobbles, and a minor amount of sand. The rocks are dense and came from many miles upstream. The sand above the basal gravel is fine to medium, grayish orange, and contains scattered small pebbles. Locally, a minor amount of gravel or clay is present. The upper few feet of the younger alluvium generally is clay or silt deposited during floods of the Colorado River, and is considered to represent the present soil of the flood plain. Carbonized wood fragments obtained during the drilling of wells had radiocarbon-age determinations made by the Geological Survey (see section on "Age of the Colorado River Alluviums").

Near Poston, the thickness and lithology of the younger alluvium was determined on the basis of nine auger holes (fig. 14). As it turned out, this area was ideal because the younger alluvium was deposited in a broad trench cut into the Bouse Formation, and therefore, the thickness of the younger alluvium could be determined accurately. At this section, the younger alluvium is from 90 to 125 feet thick beneath at least 6 miles of the 8-mile-wide flood plain. The basal gravel is from 5 to 20 feet thick, although it was absent in two of the nine holes. Later, LCRP 20 was drilled near this section, which added more data on the younger alluvium.

Near Blythe the contact between the younger alluvium and older deposits is much more difficult to determine because, in that area, the younger alluvium was deposited in a trench cut into older deposits of the Colorado River. Plate 3 shows that considerable gravel was encountered in wells near Blythe, and that a persistent gravel occurs at depths between about 80

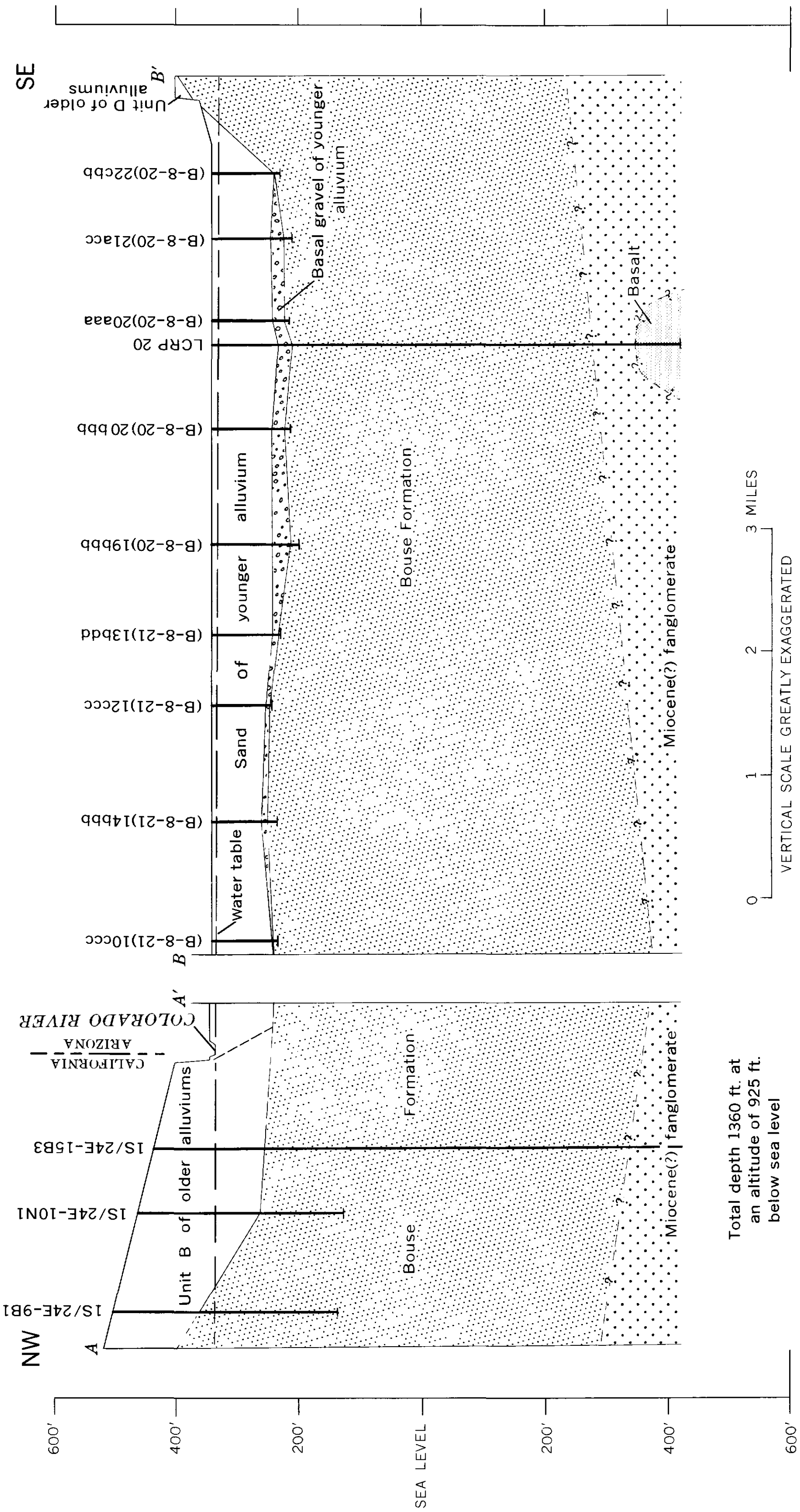

Figure 14.—Sections near Vidal, Calif., and Poston, Ariz. Trace of sections shown on plate 1.

and 140 feet, which is interpreted to be the basal gravel of the younger alluvium. However, not all of this gravel may be a part of the younger alluvium because older gravels occur beneath this gravel, and there is the probability that the true basal gravel was deposited on older gravels. For example, a gravel zone was penetrated in well 6S/23E–35E1 from 110 to 156 feet. Although this zone is interpreted as the basal gravel, the zone could be (1) only in part the basal gravel, or (2) entirely older than the basal gravel.

Farther south near Cibola, the contact between the younger alluvium and older deposits can be determined because the younger alluvium was deposited in a trench cut in the Bouse Formation (pl. 1). For example, the younger alluvium in well (C–1–24)36-bbb2 is 128 feet thick, and the basal gravel is 22 feet thick (tables 13).

The tributary gravel facies is composed of sand and subangular to subrounded pebbles and cobbles that were derived from nearby bedrock. The gravel floors and underlies the many washes that enter the flood plain. In LCRP 22, this gravel is 48 feet thick.

AGE OF THE COLORADO RIVER ALLUVIUM

The Colorado River entered the Parker-Blythe-Cibola area following the withdrawal of the Bouse embayment. If the age of the Bouse were known, this would provide a maximum age for the Colorado River; however, as discussed on page 18, the age of the Bouse can only be given broadly as Pliocene.

The younger alluvium can be dated with some assurance on the basis of carbon-14 age determinations, which were made by the Isotope Geology Branch of the Geological Survey. The determinations were made from carbonized wood fragments obtained during the drilling of wells. Two samples were obtained from well 6S/23E–23G1 in the city of Blythe; one (lab. No. W–1143) from 57 feet which was dated as 5,380±300 years B.P. (before present), and one (lab. No. W–1142) from 344 feet which was dead. Also, two samples were obtained from well 6S/23E–24J1 (California well number, but well is in Arizona) about 2 miles north of Ehrenberg; one (lab. No. W–1501) from 67 feet which was dated as 6,250±300 years B.P., and one from 110 feet which was dated as 8,610±300 years B.P. Because scouring occurs, the sample obtained from 110 feet may have been emplaced when the surface of the flood plain was at a somewhat higher level. This suggests that the deposition of the younger alluvium may have began as much as 10,000 or even 15,000 years B.P. The younger alluvium represents one period of degradation, and therefore, it is referred to the Holocene.

North of Ehrenberg, several localities in the fine-grained part of unit D of the older alluviums contain vertebrate fragments, and one in NW¼NE¼NW¼ sec. 8, T. 4 N., R. 21 W., contains a variety of material. According to C. A. Repenning (written commun., 1965), the fossils include snail, clam, ostracode, fish, snake, lizard, bird, and rodents; however, the fossils indicate only a Blancan or younger age. The large tusk (p. 25) from this area is of little help because the tusk could have been from either a mammoth or a mastodon.

J. S. Newberry (1861, p. 38) found a proboscidian tooth between present Boulder and Davis Dams in a gravel beneath a clay which is recognized by Longwell (1963, p. E15) as a part of the Chemehuevi Formation, and which is unit D of the older alluviums of this report. Newberry identified the tooth as from *Elephas primigenius*. According to C. A. Repenning (written commun., 1966), *E. primigenius* Blumenbach would be called *Mammuthus* in present-day taxonomy, and the genus is known in North America only in middle and late Pleistocene. Therefore, unit D is referred to the middle and late Pleistocene.

In the Lake Mead area, a basalt at Sandy Point, about 10 miles west of the Grand Wash Cliffs and along the Colorado River, has been dated as 2.6±0.9 million years (Damon, 1965, p. 38–40). The basalt overlies Colorado River gravel and was extruded after the Colorado River had eroded to a depth similar to the present grade. The erosion of the older deposits indicates a substantially earlier date for entry of the ancestral Colorado River into the Lake Mead area. The gravel is older than units D and E of the older alluviums, and probably older than the piedmont gravels. For this reason, the gravel may be correlative with a part of unit B.

In summation, the younger alluvium is Holocene in age. Units D and E of the older alluviums are probably middle to late Pleistocene. The piedmont gravels are somewhat older, but there is no reason to assume that they are much older; therefore, they are believed to be Pleistocene. Units A and B are probably Pliocene and Pleistocene.

SECTION AT PARKER DAM

Prior to the construction of Parker Dam in the narrow canyon carved in gneiss, many test holes along several sections were drilled to bedrock. One of these sections is shown in figure 15. The Colorado River water surface at this section is about 375 feet above sea level. The maximum thickness of the alluvial fill

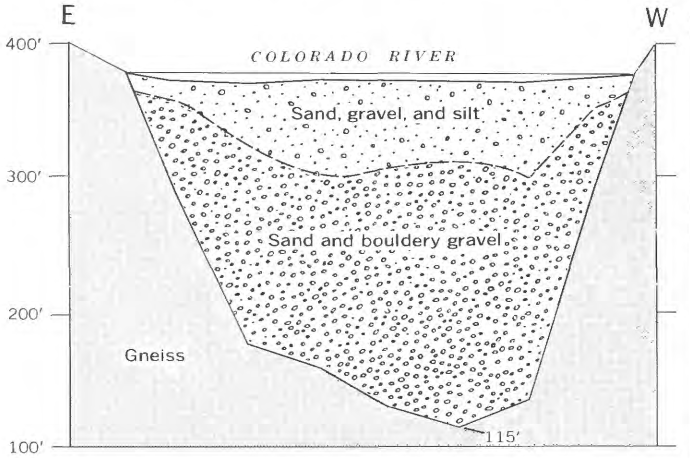

FIGURE 15.—Section at Parker Dam. Based on test holes drilled by the U.S. Bureau of Reclamation prior to construction of Parker Dam.

is 260 feet, and there is a twofold breakdown in the alluvium. The lower and thickest unit is made up mostly of bouldery gravel. The upper part is sand, gravel, and silt with mostly silt and sand down to 20 feet. Because of the thickness of the fill at this damsite, none of the structures downstream, such as the Palo Verde Weir and the Imperial Dam, were designed by the Bureau of Reclamation to rest on bedrock, and therefore, no test drilling to bedrock at those locations was done.

Although there is a twofold breakdown in the alluvium, and much of the fill must be younger alluvium, the two cannot be readily related to the units described under Colorado River alluvium. The contact is too shallow to be between the younger alluvium and one of the older alluviums. The Colorado River is confined between bedrock outcrops at this point; so scouring during the major floods probably was much deeper than it was where the river was flowing on a wide flood plain. Evidence of deep scouring was observed during the excavation for Hoover Dam when a sawed timber was found which had been buried under nearly the full thickness of fill (Longwell, 1936, p. 1455), about 150 feet.

THE CHEMEHUEVI FORMATION

The "Chemehuevis gravel" (now called the Chemehuevi Formation) was named by W. T. Lee (1908, p. 18, 65–66) and was described as a series of gravels laid down during a period of aggradation by the Colorado River. It was stated that the gravel extended "from the mouth of the Grand Canyon to the Gulf of California." It is not clear how much of the Colorado deposits were included in the original definition of the "Chemehuevis gravel." Two units are those shown on his Plate III-B, entitled "Chemehuevis gravel near Bulls Head (near Davis Dam)." These are described (Lee, 1908, p. 42) as a lower unit of well-stratified sand and silt, and an upper unit of very loose sand and gravel. Because these two units did not contain much gravel, Longwell (1936, p. 1444) changed the name to the Chemehuevi Formation. These two units are recognized southward along the valleys of the Colorado River and are referred to in the Parker-Blythe-Cibola area as units D and E of the older alluviums.

Lee (1908, p. 9) made a part of his reconnaissance by boat from Needles, Calif., southward to Yuma, Ariz. This may be a clue to the units that he included and to the statement that he makes that the "Chemehuevis gravel" extends from the Grand Canyon to the Gulf of California. The senior author has made river trips extending from Willow Beach (south of Hoover Dam), with breaks around existing dams, southward to Imperial Dam (north of Yuma). One of the geologic features that is readily observable, not only in the valleys but in the canyons, is a sequence of fine-grained sediments with a capping of sand, the "Chemehuevis gravel." In the reach from Willow Beach to Needles, the two units rest on eroded surfaces cut on older river deposits. Near Ehrenberg, this can also be seen, although it is not so clear cut as to the north. Because near Ehrenberg the fine-grained unit is not readily separated from underlying older river deposits, Lee (1908, p. 46) referred the entire section to the "Chemehuevis gravel." However, the same features that he described for the "Chemehuevis" and older river deposits in Mohave Valley (p. 41–42) can be observed near Ehrenberg (fig. 16).

Longwell (1936) made a study of the Chemehuevi Formation in the Lake Mead area. He advanced two hypotheses to explain the deposition of the Chemehuevi Formation: (1) lacustrine, and (2) fluvial. He states that the fine-grained unit has many features of lacustrine sediments, and that the overlying sand may represent topset beds of a delta. However, he points out the lack of a suitable natural dam that would have formed this lake. Longwell traced the Chemehuevi as far south as Parker. His second hypothesis is based on the statement by Lee (1908) that the formation extended to the Gulf of California. Longwell (1936) concludes that the sum of evidence does not favor ponding, but that future work should test this possibility. In later publications, Longwell (1946, 1954, 1960, 1963) favors the ponding hypothesis, but he states that the absence of a suitable natural dam obscures the origin of the Chemehuevi.

Units D and E of the older alluviums are not referred to the Chemehuevi Formation because (1) the units are separated by an erosional unconformity, and

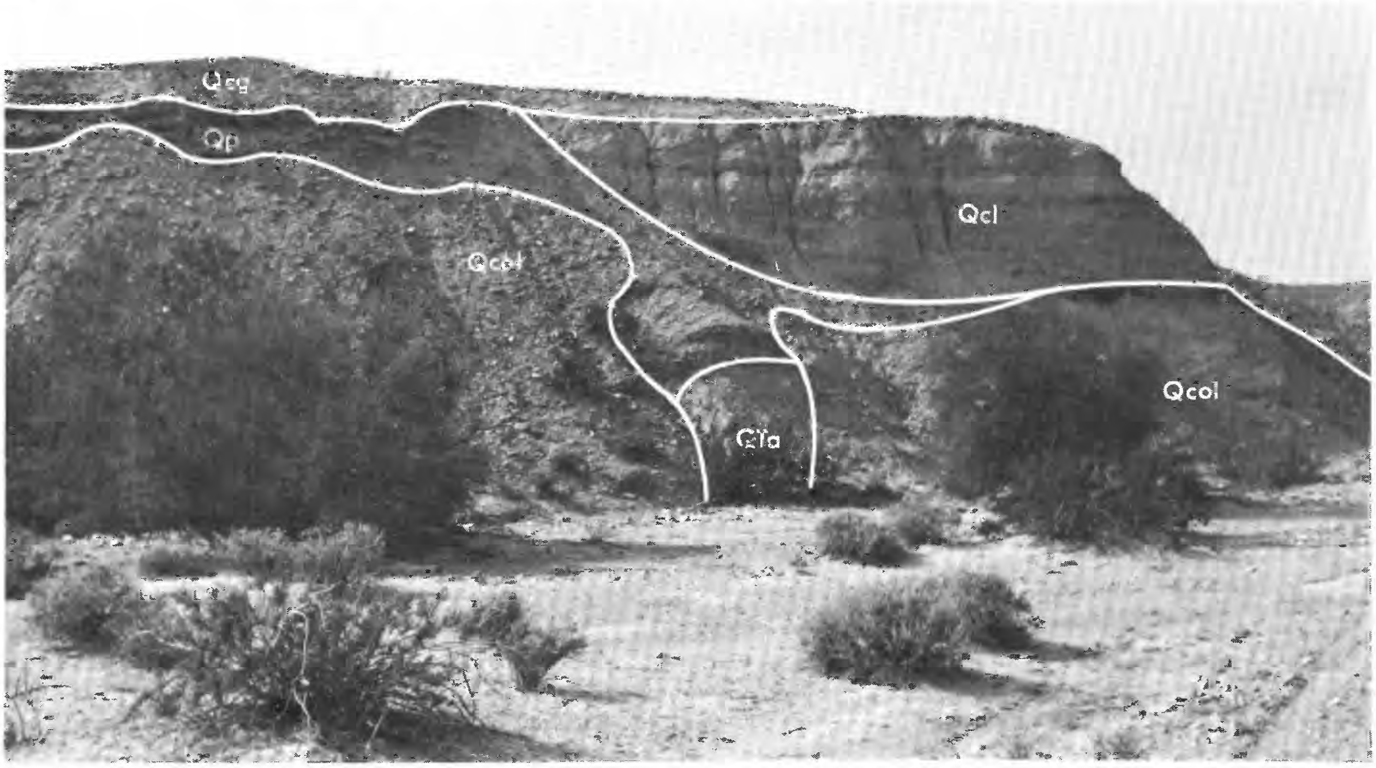

FIGURE 16.—Depositional contact between unit D of the older alluviums and older units in the southwest bank of a wash in the SE¼ sec. 36, T. 4 N., R. 22 W. Unit D was deposited against erosional features cut on unit B and piedmont gravel. Unit D (QTa), piedmont gravel (Qp), unit D (Qcl), local gravel of unit E (Qcg), and colluvium (Qcol).

(2) the units were deposited by the Colorado River, unit D during a period of aggradation, and unit E during a period of degradation. Furthermore, the two units cannot be of lacustrine origin because of the absence of a suitable natural dam that would cause ponding of the Colorado River. The two units are present not only in the wide valleys of the lower Colorado River but also in the canyons between the valleys; one outcrop occurs about 22 miles south of Cibola in the canyon between the Parker-Blythe-Cibola area and the Yuma area. The presence of these outcrops of units D and E at similar heights above the present river in the canyons indicates little or no structural activity of the mountains during or since the time of their deposition. The possibility of a lava dam can be rejected because all lava flows in the area are much older. It seems inescapable that the units as recognized in the Parker-Blythe-Cibola area were deposited by the Colorado River during a time in which the Colorado was graded to the Gulf of California.

WATER-BEARING CHARACTERISTICS

The Colorado River alluvium is a heterogeneous mixture of gravel, sand, silt, and clay. The only, somewhat continuous, unit that can readily be differentiated is the younger alluvium, which is composed of a basal gravel overlain by sand. Beneath this unit, and under the piedmont slopes, no continuity of beds is apparent from the available data. This, in a way, seems logical because the beds were laid down by fluvial processes, and various particle sizes are to be expected.

Most of the wells in the Parker-Blythe-Cibola area yield water from the sand and gravel of the Colorado River alluvium. Many of the domestic wells utilize sandpoints installed 15–20 feet below the land surface. Another common type of domestic well is a small diameter casing (for example, 4 in.), unperforated, and with the lower end in the coarse gravel of the younger alluvium.

A composite thickness of the alluvium of the Colorado River and its tributaries would be more than 1,000 feet. However, owing to the several erosional and depositional periods of the Colorado River, the thickness is much less.

Palo Verde Hospital well 2 (6S/23E–32G2) in Blythe was drilled to a depth of 590 feet, all in Colorado River alluvium. About half a mile to the west at the city of Blythe well 11 (6S/23E–32E1), drilled to a depth of 725 feet, the base of the Colorado River alluvium is placed tentatively at a depth of 506 feet based on the driller's log. Well 6S/22E–15Q1 on the Palo Verde Mesa, drilled to a depth of 585 feet, is entirely in Colorado River alluvium. In well 5S/22E–28C1 on the Palo Verde Mesa, the base of the Colorado River alluvium is at a depth of 607 feet.

In contrast, beneath most of the flood plain on the Colorado River Indian Reservation, the thickness of the Colorado River alluvium—all younger—is less than 130 feet.

The production from wells that are perforated in the Colorado River alluvium comes from the highly permeable beds of sand and gravel. The Colorado River gravel has the highest permeability of any water-bearing rock in the area. Wells that tap a sufficient thickness of these gravels have specific capacities of more than 100 gpm per ft of drawdown. However, most of the Colorado River alluvium is composed of material that is finer grained than gravel, so that in many areas it is necessary to perforate casing in the sand.

The data collected during the testing of LCRP 15 near Parker indicate the production characteristics that may be expected from the Colorado River gravel. The Colorado River alluvium occurs from the surface to a depth of 199 feet. Below this is 76 feet of claystone and some siltstone. The static water level for the alluvium was 152.5 feet below land surface. The aquifer is 41 feet thick and contains 34 feet of gravel and 7 feet of coarse sand. The well was perforated from 177 to 200 feet. It was pumped at a rate of 930 gpm and had a drawdown of 7.5 feet. This is a specific capacity of 124 gpm per ft of drawdown. The transmissivity is about 300,000 gpd per ft. Dividing this figure by the thickness of the aquifer (41 ft) gives a hydraulic conductivity of 7,300 gpd per sq ft. This test is one of the few where the data can be related to an isolated aquifer, and extraneous factors, such as leakage and thickness, can be eliminated. In this test the aquifer is from the water table down to a relatively impermeable unit. Therefore, some confidence can be given to the hydraulic conductivity, which represents the magnitude that may be expected from a clean well-sorted rounded Colorado River gravel.

On the Palo Verde Mesa west of Blythe, Colorado River gravel has been found only in wells near the edge of the mesa, such as wells 6S/22E–15Q1 and 6S/22E–1H1. Most logs of wells on the mesa indicate sand with only a very minor amount of gravel in the Colorado River alluvium. The hydraulic conductivity for the sand may range from 200 to 1,000 gpd per sq ft (based on the assumption that the specific capacity multiplied by 2,500 and divided by the perforated interval will give the order of magnitude for the coefficient, see p. 69).

PALEOHYDROLOGY OF THE LOWER COLORADO RIVER

Hydraulic factors, such as slope, width, depth, velocity, bed roughness, and sediment size, can be measured in studies of a present river and can be treated quantitatively (Leopold and Maddock, Jr., 1953). However, when an investigation shifts to past conditions of a river, or paleohydrology, the study of the factors becomes more qualitative, and the investigation is limited to only two factors. These are the characteristics of the sediment and the slope of the valley through which the river flowed. The size of the sediment as determined from well cuttings or as seen in outcrops may be indicative of only a small part of the sediment transported by the past river. An example is the coarse gravel deposited by the Colorado River, which would be indicative of only the larger particles moved by the river at that time.

The other factor that can be considered is the slope of the past flood plain or valley. As used in this report, the valley slope is the maximum slope of the flood plain upon which the river is operating. It is a figure that can be derived from subsurface data. For example, the basal gravel of the younger alluvium represents a wide deposit laid down as the river meandered from side to side, and the slope of the base can be compared to that of the present flood plain. From the data, however, nothing can be said about the true gradient of the river that deposited the gravel, other than it was less than the slope given.

The valley slope of the Colorado River in the Parker-Blythe-Cibola area during the last degradation and aggradation is, within the accuracy of the available data, virtually of the same magnitude as the valley slope of the present flood plain regardless of the size of the material being transported. That the slopes of graded rivers do not change materially with a change in base level has been pointed out by Mackin (1948, p. 472–475) and Leopold and Miller (1954, p. 61–66). In the lower Colorado River, the valley slope, virtually the same as the present, can be inferred to extend back in geologic time in which there has been no structural adjustments. The base level to which the present Colorado River is graded is the Gulf of California, and it follows that during periods of degradation or aggradation under similar slopes, the river was also graded to its base level, the Gulf of California.

GEOLOGIC CONTROLS ON THE LOWER COLORADO RIVER

The Colorado River from the Lake Mead area to the Gulf of California flows through a series of canyons and wide valleys. For the area of this report, these include the canyon where Parker Dam was built, the wide valley of the Parker-Blythe-Cibola area, and the canyon in the Chocolate Mountains between Cibola and the Yuma area.

The section at Parker Dam (fig. 15) shows the thickness of the alluvial material at that site. This indicates bedrock at a depth of 260 feet. In LCRP 14 at Laguna Dam (fig. 1), the alluvial and fine-grained materials occur to a depth of 457 feet beneath the original flood-plain surface. Other borings in the canyons also indicate a considerable thickness of fill. Thus, in the area of this investigation, more than 200 feet of easily eroded alluvial material would have to be eroded before the Colorado River would be on bedrock.

Units D and E of the older alluviums occur not only in the wide valleys but in the canyons. The presence of these deposits in the canyons plus the major terrace that has been cut on unit D (a topic discussed on p. 33), both at comparable heights above the present river, suggest that little or no structural activity has occurred in the area since the downcutting following the deposition of unit D.

Therefore, the paleohydrology of the Colorado River can be carried back in geologic time for a period in which the local major geologic controls in the area from Parker Dam to Yuma have been stable, and because of the stability of these controls, the Colorado River was graded to its base level, the Gulf of California.

FEATURES OF THE COLORADO RIVER PRIOR TO DEVELOPMENT

The U.S. Geological Survey during 1902–3 made a topographic survey of the Colorado River from the Hoover Dam site south to the international boundary below Yuma, Ariz. Because this survey was made prior to the building of dams on the Colorado River, it represents virgin conditions of the Colorado River.

The river from mile 530 near Parker to mile 615 below Cibola had gradients that ranged from 1.2 to 2.0 feet per mile. Through this 85-mile reach of the river, the river dropped 143 feet, which gives an average gradient of 1.7 feet per mile. The average valley slope through this reach was 2.3 feet per mile.

From mile 615 to mile 665 near Laguna Dam, the river had a gradient of about 1.3 feet per mile. Throughout this reach, the river is in a canyon cut in the Chocolate Mountains. The canyon has a sinuous path, and the maximum slope of the flood plain is only slightly greater than the gradient of the river.

The sediment carried by the present river was determined during a study of Lake Mead (Smith, W. O., and others, 1960). One of the findings is that the present Colorado River does not transport coarse gravel, and that smaller gravel occurs only in the center of the channel in the easternmost 2 miles of the reservoir. The median particle size of sediment carried by the Colorado River (Gould, 1960, p. 197) is 44 microns (silt size). For the lower Granite Gorge, which is at the head of the delta, the median particle size is 150 microns (fine sand size); 97 percent was less than 500 microns (medium sand), and 100 percent was less than about 700 microns (coarse sand size).

Prior to the construction of the dams, most of the material now deposited in Lake Mead would have been carried through the Parker-Blythe-Cibola area to the Gulf of California. Both minor filling during floodflows and minor cutting would have occurred. For example, the Colorado River near La Paz in the last 100 years has migrated across the flood plain and back, and neither significant deposition nor erosion has occurred.

VALLEY SLOPE DURING DEPOSITION OF THE SEVERAL COLORADO RIVER DEPOSITS

The younger alluvium has two units, a basal gravel overlain by sand. Although the modern river is not moving particles coarser than sand, the river during the time of deposition of the basal gravel was moving pebbles and cobbles.

In LCRP 14 at Laguna Dam (fig. 1), there are two gravels, either of which or the zone, could be the basal gravel of the younger alluvium. One is from 99 to 114 feet and the other is from 133 to 147 feet beneath the original land surface, which is now covered with about 14 feet of sand and silt that was deposited behind Laguna Dam. For the purpose of this discussion, it does not matter which is the basal gravel of the younger alluvium. The one from 99 to 114 feet is at the same position beneath the flood plain as those near Parker (fig. 15), which would indicate a valley slope similar to the present slope of the flood plain between the section near Parker and that at Laguna Dam. If the one from 133 to 147 feet is the basal gravel, this would indicate an increase in the valley slope of about 20–25 feet in about 100 miles, or about 0.2–0.3 foot per mile. These figures show how little the valley slope has varied during the time of deposition of a pebble to cobble gravel as contrasted with the present conditions in which no coarse gravel is carried.

A terrace formed during the time of unit E of the older alluviums and prior to the deposition of the younger alluvium occurs at Parker, west of Blythe as a part of the Palo Verde Mesa, and on bedrock at Black Point (fig. 17). A similar terrace farther downstream is the Yuma Mesa. These terraces are at a somewhat similar height above the present flood plain; about 60 feet at Parker, about 70 feet at Black Point, about 70 feet on the Palo Verde Mesa, and about 70 feet on the Yuma Mesa. Exact figures for the heights are of little value for this discussion. The purpose is to show a similarity in heights, which again suggests that the valley slope during this time was little different from that of the present valley slope, or about 2–3 feet per mile.

Little can be determined from available data on the slopes of the flood plain during deposition of the older Colorado River deposits. Unit D of the older alluviums occupies a position adjacent to the present flood plain, and because the fine-grained deposits appear to be flat lying (a gradient of 2 or 3 ft per mile coupled with isostatic responses to loading with this volume of sediments would be difficult to detect), this may suggest that the beds were deposited with slopes similar to the present. However, this suggestion may not be valid because no marker beds have been found within this fine-grained sequence.

During the time of deposition of units A and B, structural adjustments occurred. Because of the uncertainties in defining these structures, and relating them to the pebble to cobble gravels that occur in units A and B, little can be surmised about the valley slope at that time.

DEGRADATIONS AND AGGRADATIONS OF THE COLORADO RIVER

Following the withdrawal of the Bouse embayment, the Colorado River began to flow through the Parker-Blythe-Cibola area to the Gulf of California.

FIGURE 17.—Looking south showing the "70-foot" terrace at Black Point in the SW¼ sec. 7, T. 5 S., R. 24 E. The terrace is cut on bedrock (metasedimentary rocks).

Soon thereafter, the mountains began to rise relative to the basins. The Bouse Formation was eroded easily, and in the localities of the present canyons, the Colorado River eroded to bedrock. The differential movement was sufficiently slow that the Colorado River became entrenched in the canyons and has maintained its position since that time.

The earliest aggradations of the Colorado River resulted in the deposition of units A and B of the older alluviums. During and after the deposition of these units, differential movement occurred between the mountains and the basins, as is shown by the presence of these units as deep as 600 feet below the flood plain at Blythe and as high as 450 feet above the flood plain on La Posa Plain. Following the deposition of unit B, the Colorado River was graded to the Gulf of California. Degradations and aggradations since this time cannot be related to events within the Parker-Blythe-Cibola area.

Following deposition of units A and B, a period of degradation began. The base level of the Colorado River lowered, and the river began to erode older units. During periods of stability of the base level of the Colorado River, piedmont gravel of local origin was deposited, and three such gravels are present in the Cibola area. The topography towards the end of deposition of the youngest piedmont gravel is shown on plate 4. Degradation continued until the Colorado River was entrenched in older deposits and was scouring to a depth of about 130 feet below the level of the present flood plain (see pl. 1, near Parker). Nothing is known of the character of the material being transported at this time.

Following this period of degradation, a period of aggradation began, which resulted in the deposition of unit D of the older alluviums. At the beginning of this aggradation (pl. 4), the river was moving pebbles and cobbles. Then a change occurred in the size of material carried by the river, and silt, sand, and clay were deposited. Aggradation continued until the river was operating at about 200 feet above the present flood plain (pl. 4).

Again the character of the river changed, and a period of degradation began. Also, as is reflected in the size of the material deposited by the river, the river moved mostly sand with some small gravel. During this degradation, sand of unit E was deposited at successively lower elevations. A time of stability of the Colorado River during this period resulted in the cutting of the "70-foot" terrace with its thin coating of sand.

Degradation continued until the Colorado River again was entrenched in older deposits and was scouring to a depth of about 130 feet below the level of the present flood plain (pl. 4). Data are not available to indicate the time that the river remained in this position; however, about 10,000 years or perhaps as much as 15,000 years ago, the river began its final aggradation which culminated in the present flood plain and topography (pl. 4). At the beginning of this aggradation, the river was moving pebbles and cobbles. Then the size of the material being moved by the river changed, and the river moved mostly sand, which has continued to the present.

In summation, the Colorado River, beginning at the time of deposition of the piedmont gravels, has had the following history: (1) degradation, piedmont gravels; (2) aggradation, unit D; (3) degradation, unit E; and (4) aggradation, younger alluvium. Furthermore, these changes have occurred under virtually the same valley slope.

The youngest aggradation began about 10,000–15,000 years ago, and this time, in a broad sense, correlates with the rise of sea level during late Wisconsin time. For the Gulf of California, the late Wisconsin rise in sea level began about 17,600 years ago when sea level was 68 fathoms (408 ft) below the present sea level (Curray and Moore, 1964, p. 208). This fact suggests that the deposition of the younger alluvium may be related to a rise in sea level during the late Wisconsin. Whether this reasoning can be carried back in geologic time is speculative at present. Factors such as configuration of the Colorado River delta and the sediment transported by the river must be accounted for. Nevertheless, the evidence in the Parker-Blythe-Cibola area is clear—that is, the Colorado River has maintained a virtually uniform valley slope through two degradations and two aggradations, the causes for which were external to the area.

DRAINAGE FROM DEATH VALLEY REGION TO THE COLORADO RIVER

A surface-water connection between the Death Valley region and the Colorado River was suggested by Hubbs and Miller (1948, p. 83–84), on the basis of relict fishes and of fossil cyprinodonts to the fishes in the Colorado River. The fossil cyprinodont indicated to them "that the connection was a rather ancient one, perhaps late Pliocene or early Pleistocene." Blackwelder (1954, p. 39) stated that the surface-water connection was not necessarily direct from Death Valley to the Colorado River, but that the Mojave River could have drained to the Colorado River, then the river diverted to Death Valley by the building of the Pisgah volcano (fig. 18). In this manner, the fishes could have reached Death Valley without a direct connection with the Colorado River. Regardless of the manner in which the fishes got to Death Valley, it seems that the presence of the fishes indicates a surface-water connection between parts of the Mojave Desert and the Colorado River. Because the connection has been postulated to have been in the Parker-Blythe-Cibola area, some discussion of the evidence from this area seems warranted.

Previous speculations on the nature of the drainage from Death Valley to the Colorado River have been that the drainage flowed through the areas now occupied by Bristol, Cadiz, and Danby Lakes. This would have to be in the lower reaches of the speculative drainage, along the present position of Vidal Wash to the Colorado River. Another possible connection, which is as probable as the other and is based on as little data, is south from Cadiz Lake area to the Palen and Ford Lakes in Chuckwalla Valley and then eastward to the Colorado River near the present city of Blythe (fig. 18).

Danby and Ford Lakes are basins of interior drainage nearest to the Colorado River. According to Bassett and Kupfer (1964, p. 33–34), shorelines of Pleistocene lakes, which are typical of many areas of the Great Basin, are not present near Bristol, Cadiz, or Danby Lakes. This fact would tend to rule out deep pluvial lakes. The divide between Danby Lake and

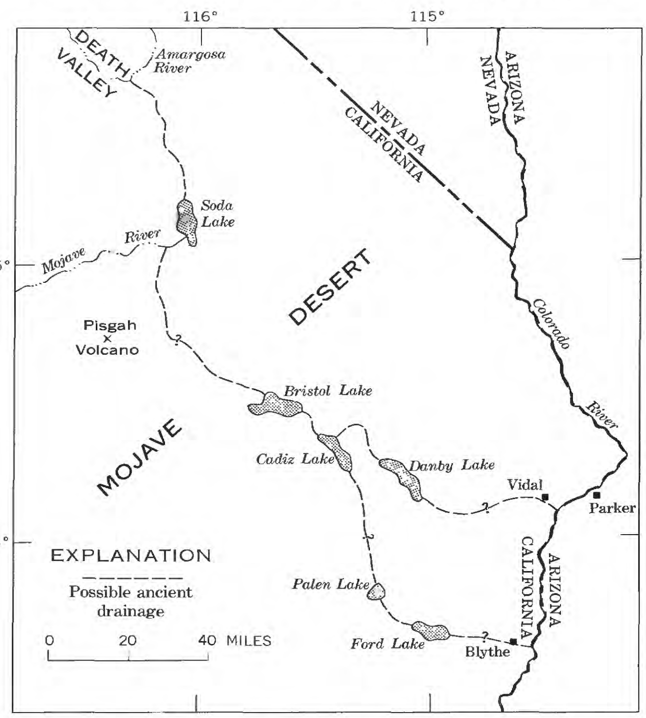

FIGURE 18.—Possible ancient drainage in the eastern Mojave Desert, California.

the Vidal Wash drainage is at an elevation of 951 feet above sea level, which is about 340 feet higher than Danby Lake. A pluvial lake would have been that deep before it overflowed to the Colorado River.

The surface of Ford Lake is about 355 feet above sea level, and about 100 feet lower than the divide between Chuckwalla Valley and the Blythe area. Features on aerial photographs, such as faint lines on alluvial fans and small ridges, suggest a shoreline at about 400 feet. There are no indications of higher shorelines, which would indicate a shallow lake and one which did not overflow to the Colorado River.

Thus, the data for Cadiz and Ford Lakes indicate that neither area contained deep pluvial lakes that would have overflowed to the Colorado River, suggesting that the present topography is of little value in verifying an ancient drainage. The depth to the Bouse Formation in Danby 1 test hole is thought to be at 520 feet, which indicates the amount of post-Bouse deposition. If the rate of deposition were known, the 520 feet would indicate the time that the basin has had interior drainage. For Searles Lake, G. I. Smith (1962, p. C68) estimates the rate of mud deposition to be about 1 foot per 1,000 years. Although this rate of deposition may not be valid to a depth of 500 feet or it may not apply to Danby Lake, it may suggest that Danby Lake has had interior drainage for much, if not all, of the Pleistocene.

The materials under the divide between Ford Lake and Palo Verde Mesa are discussed under "Underflow to Palo Verde Mesa from Chuckwalla Valley." The data do not suggest a buried channel, yet they do not rule out the probability.

Two drillers' logs are available for wells in Vidal. The depth to the Bouse Formation in one is 83 feet, and in the other, 225 feet. Because these wells are only 40 feet apart, one of the logs must be in error. Some of this fill could be from the Mojave Desert, but there is no evidence to indicate that it is anything but deposition from the drainage area of Vidal Wash.

In summary, the evidence from the two localities of the Parker-Blythe-Cibola area through which the speculative drainage would have passed is inconclusive in regard to an old drainage from the Mojave Desert to the Colorado River. From the geologic history of the area, nevertheless, it is possible to indicate a time at which a connection may have occurred.

The geologic unit that is critical in our evaluation is the piedmont gravels. South of Vidal a piedmont gravel, which is at a higher elevation than Vidal Wash, caps the Bouse Formation and extends southwest to the mountains. Therefore, Vidal Wash during the time of deposition of this piedmont gravel was at a higher elevation than it is now (about 600 ft near Vidal). This elevation is about the same as the surface at Danby Lake, which is about 610 feet. Because there would have to be a gradient from the Danby area to the Vidal area, this suggests that there was no connection between Mojave Desert and the Parker-Blythe-Cibola area during the time of deposition of this piedmont gravel. A similar history could be developed for the divide west of Blythe.

If there was a surface water connection between the Mojave Desert and the Parker-Blythe-Cibola area, the connection would have been during the time of deposition of unit A or B of the older alluviums. Following the withdrawal of the water from the Bouse embayment, the Colorado River entered the area, and it could have been during this time that a drainage extended from the Mojave Desert to the Colorado River. During the time of deposition of units D and E, structural adjustments occurred. Although these were sufficiently slow for the Colorado River to maintain its position as it eroded downward forming the present canyons of the lower Colorado, it may have been that the river from the Mojave Desert was not large enough to erode the uplifted mountains; thus, the basins of the Mojave Desert could have been isolated. This would suggest that, if there was a connection, it could have been in the Pliocene or early Pleistocene.

Lastly, it is not known if there was a relationship between the Bouse embayment and the fishes of the speculative drainage. However, this relationship, if it existed, is too little understood and complex to warrant further discussion.

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 a barrier to ground-water movement. Nevertheless, it is obvious that the structural history of the bedrock is much more involved and severe than that of the sediments of the valleys. The granitic and metamorphic rocks are much fractured. The Paleozoic rocks have been metamorphosed, faulted, and folded. The sedimentary and volcanic rocks older than the Miocene(?) fanglomerate have been faulted and folded, and commonly have steep dips, which is in marked contrast to the gentle dips of the sedimentary rocks forming the ground-water reservoir.

One of the significant findings of this investigation in the Parker-Blythe-Cibola area is the absence of field evidence for structure in the piedmont gravels or younger rock units, other than several slump blocks that border the flood plain northeast of Moon Mountain. The blocks have been rotated, and the beds dip steeply eastward. The slumping probably occurred prior to the deposition of the younger alluvium when a wide trough had been excavated in older units. Except for these relatively minor features, no displacements or abnormal dips have been found in the piedmont gravels or younger units. If any of the piedmont gravels were cut by faults, these features would show markedly on aerial photographs because desert pavements have formed on these gravels and the rocks have a heavy coating of desert varnish. However, no lineations have been found cutting these gravels anywhere in the area.

In only one locality has unit B been cut by faults. The locality is about 2 miles southeast of Cibola in sec. 33, T. 1 S., R. 23 W., along the north side of Hart Mine Wash. The faults are small normal faults and are associated with the structure shown in figures 19 and 20. Although this is the only locality where unit B has been observed to be cut by faults, other faults may be concealed beneath colluvium derived from the piedmont gravel.

Although little faulting has been observed, subsidence has occurred during or since the deposition of unit B and prior to the deposition of the piedmont gravel. Downwarping of the Palo Verde Valley centered at Blythe is indicated from subsurface data (pl. 1). Unit B occurs as deep as 600 feet beneath the present flood plain in Blythe, yet it is absent in the subsurface south of Cibola. Also, unit B occurs as high as 450 feet above the present flood plain on La Posa Plain. Although these outcrops of unit B suggest that these structural adjustments have occurred, the exact nature and location of the structure is unknown.

The attitudes of the sediments of the Cibola area indicate that the latest uplift of the mountains has been caused by small-scale displacements over a zone extending 1½ to 2 miles from the mountains (fig. 19). Although none of these displacements may have a "throw" as large as about 500 feet, the differential movement between the mountains and the Blythe area probably is as much as 1,000 feet and may be as great as 2,000 feet. Although these displacements are well exposed only in the Cibola area, there are field indications that the mountains north of Parker exhibit similar structure.

Three types of structure, all downdropped basinward, are present in the sediments southeast of Cibola and east of the Colorado River flood plain (fig. 19). One is a warping of the sediments near bedrock. The second is small-scale normal faulting. The third is a structure that has an early phase that has resulted in the slumping of the Bouse sediments; the middle and later phases are warping and small-scale normal faulting.

The warping of the sediments near bedrock has been observed in a few places in the Cibola area, and the rocks involved are the fanglomerate and the basal limestone of the Bouse Formation. The piedmont gravel, which also occurs there, has not been warped. Thus, the warping is post-Bouse Formation and pre-piedmont gravel. The dip of the sediments near bedrock is as high as 17°; within a short distance basinward, the dip decreases to about 2°. No control that would determine the magnitude of this warping and the amount of the uplift of the mountain in relation to the basin is available on the "upthrown" side of this structure.

The largest of the normal faults is in the NE¼ sec. 9, T. 2 S., R. 23 W. The fault trends true north, dips 57° westward, and has a throw of about 150 feet on the basis of displacement of the basal limestone of the Bouse Formation. The fanglomerate dips 16° westward on the upthrown side. The downthrown side is made up of a few feet of fanglomerate, about 30 feet of the basal limestone and 115 feet of unit A of the older alluviums. The dip of all three is gentle, about 1° or 2° westward toward the basin.

An excellent exposure of the third structure occurs about 2 miles southeast of Cibola in sec. 33, T. 1 S., R. 23 W., along the north side of Hart Mine Wash (fig. 20). The amount of downcutting by Hart Mine Wash is about 100 feet which provides a good exposure of the structure. The sediments involved include the Bouse Formation and units A and B of the older alluviums. These units are capped by piedmont gravel, which has not been involved in the structure. The strike of this structure is N. 35° E., and the structure is parallel to the bedrock-sediment contact at a distance of 1½ miles.

The Bouse Formation is greatly contorted for about 600 feet along the wash. The sediments, mostly sand but with some fossiliferous clay, have a variety of attitudes (fig. 21): some beds are vertical; some are folded; some clay beds are overturned; and minor faulting, both normal and thrust, cut the sediments. Colluvium conceals the sediments for about 3,000 feet along the north side of the wash, where the next outcrop is a few feet of the basal limestone, which dips about 2° down the wash.

Two possibilities as to how the contortion occurred are slumping westward to a channel and slumping as a result of structure. The contorted zone does not show the effects of rotation of slump blocks in which the

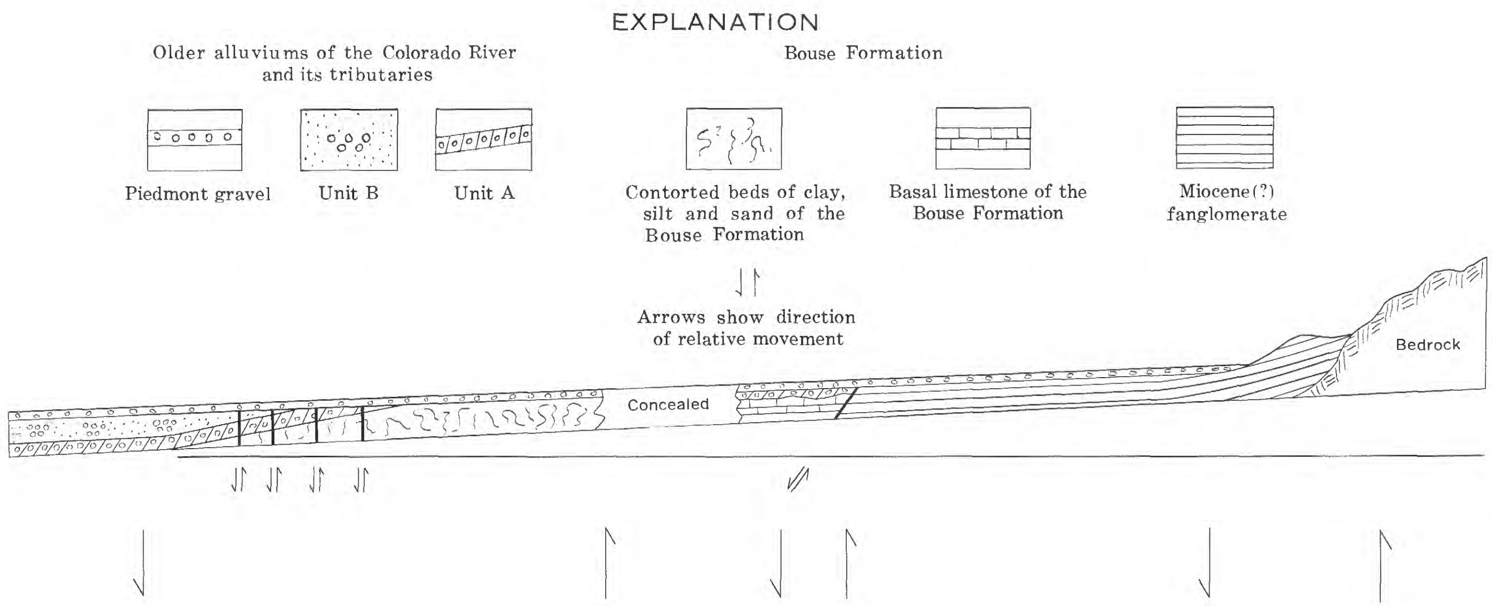

FIGURE 19.—Diagrammatic section southeast of Cibola, Ariz., showing structure of sediments.

FIGURE 20.—Structure along north side of Hart Mine Wash. Unit A (QTa) is overlain by unit B (QTb), which is capped with piedmont gravel (Qp).

dips of the beds are opposite to the direction in which the block rotated. Another factor tending to rule out this possibility is the apparent absence of a channel for the sediments to slump into. The second possibility is that the contortion is a result of slumping westward caused by structure, either folded or faulted at depth, and downthrown to the west. This type structure can probably be inferred from the overlying beds, a topic to be developed in the following paragraphs.

The contorted zone is overlain by about 50 feet of unit A of the older alluviums (fig. 20), which has an apparent dip of 10° that flattens to about 2° to the west within a few hundred feet. The fanglomerate is overlain by about 75 feet of unit B, which is apparently horizontal in the section but may have a slight southward dip. Capping the sequence is about 25 feet of piedmont gravel, which has an initial dip of about 2° to the west. All units but the piedmont gravel are

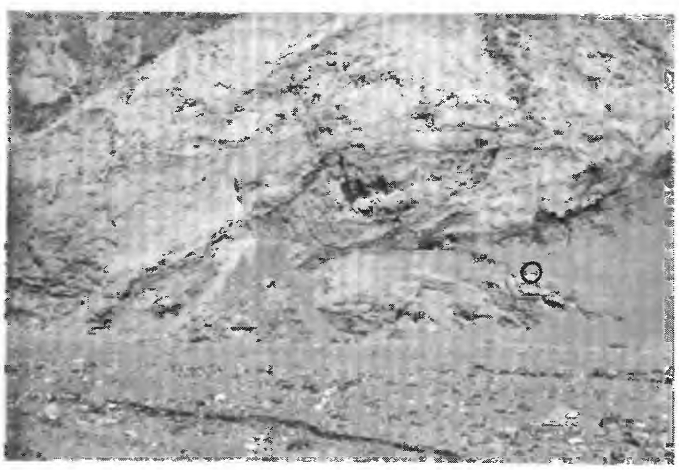

FIGURE 21.—Contorted beds of the Bouse Formation on north side of Hart Mine Wash. Pick below right center of picture (circle) gives scale.

cut by small normal faults, all having throws of less than 20 feet and all downdropped to the west.

The geologic history of the deposits exposed at this locality begins with the deposition of the Bouse Formation. This deposition was followed by the formation of the contorted zone, then erosion that beveled the contorted zone. Alluvial fans formed which are the unit A of this report. Warping of unit A preceded the deposition of unit B. The sediments were then broken by small normal faults. Finally, the sediments were eroded, and the piedmont gravel was deposited.

The structural history of the deposits overlying the contorted zone indicates a warping downthrow to the west followed by minor normal faulting also with downthrow to the west, then a cessation of the structure-forming process followed by erosion. Thus, each unit contains less structure than the underlying unit with a dying out of the structure prior to the deposition of the piedmont gravel. Extending this structural history back to the contorted zone, it may represent the most displacement, with downthrow to the west.

The Milpitas Wash area is another in which structure of the sediments can be inferred. Near the Colorado River flood plain, the contact between the fanglomerate and the basal limestone of the Bouse Formation is at an elevation of about 260 feet above sea level. The contact is exposed continuously for 6 miles westward where it reaches an elevation of about 650 feet above sea level. The next outcrops of the limestone are a few scattered, small outcrops about 6 miles southward and about 2 miles north of the drainage divide between Milpitas Wash and the Imperial Valley at an elevation of about 1,050 feet above sea level. Because of the increasingly higher elevations in a given direction of the base of the limestone, these outcrops are considered a part of the basal limestone, although it is possible that these outcrops may represent a higher stratigraphic position within the Bouse Formation. Nevertheless, the outcrops indicate a renewed uplift of the Chocolate Mountains subsequent to the deposition of the Bouse Formation.

In summation, the structural history as described in this section began after the formation of the outlines of the present mountains. The locally derived Miocene(?) fanglomerate may represent the erosion of the latter stages of this structure. The Bouse Formation suggests a regional lowering, and after the deposition of the Bouse, a regional rising along with the entry of the lower Colorado River. Soon thereafter, the mountains began to rise relative to the basins. The Bouse Formation was eroded easily and, in the localities of the present canyons, the Colorado River eroded to bedrock. The uplift of the mountains was sufficiently slow that the Colorado River became entrenched, and the canyons of the lower Colorado River began to form. From the time of deposition of the piedmont gravels to the present, no structural activity has occurred.

GROUND-WATER RESOURCES OF THE PARKER-BLYTHE-CIBOLA AREA

OCCURRENCE OF GROUND WATER

Ground water in the Parker-Blythe-Cibola area occurs under both water table and artesian conditions. Most of the wells are completed in Colorado River alluvium, which contains water under water-table conditions. Only the deep test wells drilled into and through the Bouse Formation and into the fanglomerate for this investigation contained water under artesian conditions.

Ground water occurs in the Bouse Formation both under water-table and artesian conditions. Only three wells (LCRP 4, 16, 27) tapped strata containing water under water-table conditions. These wells tapped sands in the Bouse Formation that evidently were not separated from sand of the overlying Colorado River alluvium by a layer of material sufficiently impermeable to result in artesian conditions.

The lower part of the Bouse Formation contains much clay, silt, and fine sand, and artesian conditions generally prevail. This is illustrated at LCRP 27, which was selectively perforated from 722 to 194 feet below the land surface. The perforator, with pipe, was installed to 722 feet, and water was added until the casing was full, which is a precaution against heaving should the casing happen to be perforated opposite a loose sand. The interval 697–722 feet was then perforated. The next morning, the depth to water in the casing was 6.08 feet below land surface. The perforator was raised to 654 feet, which was analogous to removing a slug of water from the hole. The interval 647–654 was then perforated, after which the depth to water was 7.38 feet below the land surface. Ten minutes later, the water level had recovered to 6.97 feet below land surface or about 0.9 foot lower than when only the interval 697–722 was perforated. Upon completion of perforations of each higher interval, and allowing the water in the well to become adjusted to the new conditions, the depth to water became greater. Upon completion of all perforations, the depth to water was 13.20 feet below land surface, which is indicative of the water table for this locality. Thus, the measurements taken during the perforation of this well indicated an artesian head of about 7 feet for the lowermost perforated interval, and lesser heads at shallower depths. Only the upper sand in this well, which was the most permeable zone, reflected water-table conditions.

The fanglomerate contains water under artesian conditions, as is shown by the height of water levels above the water table in the following three wells: LCRP 15, 1 foot; LCRP 20, 4 feet; and LCRP 22, 42 feet.

RECHARGE

Sources of recharge to the ground-water reservoir of the Parker-Blythe-Cibola area are the Colorado River, precipitation, and underflow from bordering areas.

The Colorado River recharges the aquifers directly by seepage in some reaches and indirectly by diversions from the Colorado River in the form of seepage from canals and irrigated land. This recharge is clearly shown by the ground-water contour map (pl. 5) which indicates that the river is the dominant influence on the ground-water reservoir and which shows the buildup of mounds and ridges beneath the irrigated land and the canals.

Recharge from precipitation occurs directly by infiltration of rainfall and indirectly by infiltration of runoff from rainfall. Direct recharge from rainfall is an insignificant amount compared to the amount that is recharged from runoff. Heavy rains in the arid Southwest may seem anomalous, but they occur as a result of moist air moving into the area from tropical disturbances off the coast of Baja California (Gatewood, 1945). During one of these rare storms, it is common for 2 or 3 inches of rain to fall in a few hours. Rain of this intensity falling on a sandy terrain, such as the unit E of the older alluviums, may infiltrate into the material to a sufficient depth to cause recharge to the ground-water reservoir.

Opportunity for recharge from runoff exists in the ephemeral washes of the Parker-Blythe-Cibola area. The washes have well-developed channels from the bedrock areas to the flood plain, a feature that is in marked contrast to most washes of the Mojave Desert. The major washes are incised, and have sharp banks and wide, flat bottoms that are mantled and underlain by sand and gravel. Thus, much of the runoff from the mountains, upon leaving the bedrock, infiltrates into the sand and gravel and eventually part of the water recharges the ground-water supply. Another factor tending to accentuate the recharge possibilities in the washes is the cementation of desert pavements formed in the piedmont gravels. The washes are incised in the piedmont gravel, and heavy rain quickly forms runoff that flows into the desert washes.

Recharge by underflow from areas bordering the Parker-Blythe-Cibola area are from five principal areas: (1) Bouse Wash area and area to the south beneath La Posa Plain, (2) Tyson Wash, (3) Vidal area, (4) Chuckwalla Valley, and (5) Milpitas area. Under natural conditions, underflow also entered the Parker-Blythe-Cibola area through the alluvium beneath the Colorado River as ground-water outflow from Chemehuevi Valley. With the building of Parker Dam in 1938, however, this underflow was cut off because the damsite was excavated to bedrock. Ground-water underflow from Bouse, Tyson, and Vidal Washes is estimated on the basis of precipitation-recharge relationships in a subsequent section. The estimates of underflow that were made as a result of the present fieldwork are described for Tyson Wash, Chuckwalla Valley, and Milpitas area in the sections that follow.

UNDERFLOW BENEATH TYSON WASH

Tyson Wash drains an area about 15 miles wide between the Plomosa and Kofa Mountains on the east and the Dome Rock Mountains on the west and extends as far as 30 miles south of Quartzsite. Tyson Wash slopes northward towards Quartzsite, then gradually swings westward passing successively through two gaps in the Dome Rock Mountains before reaching the Colorado River valley. Near Quartzsite, domestic water is obtained at a shallow depth. This shallow water, which may be perched, extends as far as 5 miles north of Quartzsite where a depth to water of 35 feet below land surface was measured in stock well (B–5–19)31a.

Because of the occurrence of ground water in other areas of southwestern Arizona, such as near Bouse, Harrisburg Valley southeast from Salome, and the lower end of Harquahala Plains, one would expect ground-water underflow beneath Tyson Wash at shallow depths in the gaps in the Dome Rock Mountains. However, there is no indication of shallow water in either gap. The trees in the wash are paloverde and ironwood, which are found along most desert washes and are not indicative of shallow ground water.

The alluvium along Tyson Wash was tested by seven auger holes (fig. 22) in an attempt to get information on the underflow along the wash. Five holes were augered in sec. 18, T. 5 N., R. 20 W., and two holes in sec. 8, T. 5 N., R. 20 W. The five holes in sec. 18 penetrated bedrock at depths of 57, 28, 33, 32, and 43 feet. No saturated material was found in any of

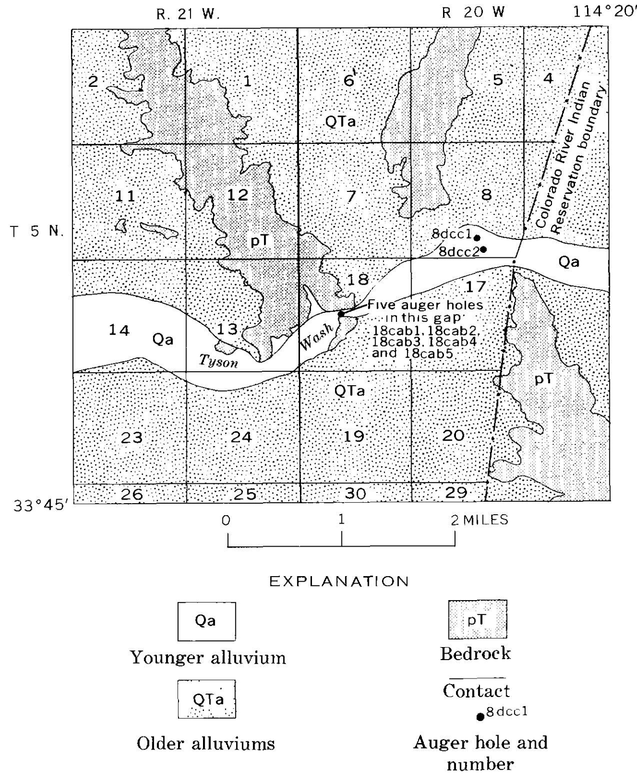

Figure 22.—Location of test holes along Tyson Wash, Ariz.

the holes, which indicated that very little, if any, ground water moves beneath Tyson Wash at this locality. However, because the holes showed a shallow depth to bedrock and because the base of the alluvium to the east is at a much greater depth, ground water probably moves southwestward through the older alluvium beneath secs. 8 and 17.

The first hole drilled in sec. 8 (8dcc1) was augered to a depth of 77 feet and then abandoned because of difficult drilling. The next hole (8dcc2) was augered to a depth of 167 feet. Bedrock was probably encountered because this is as far as the auger would penetrate, although this was not verified because it was impossible to core with the drilling equipment. There were no indications that the hole bottomed in saturated material, but nevertheless, a sandpoint was installed at a depth of 162 feet. Three days later, the hole was checked, and the sandpoint was dry. The land surface is at an elevation of about 505 feet, and the sandpoint was at an elevation of about 343 feet above sea level.

Based on the dry hole at an altitude of about 343 feet, there is some question whether there is underflow through this gap. It may be that either (1) the material at the bottom of the south hole was only cemented material rather than bedrock, or (2) there may be deeper fill north or south of this hole in the gap. The width of the gap between bedrock outcrops is only 0.7 mile, which, coupled with the depth of the fill that is known to be dry, very much limits the width of the section that might be saturated.

If there is ground-water movement beneath Tyson Wash, available data indicate that the direction of movement is northwestward from the stock well about 5 miles north of Quartzsite for 6 miles to the gap, then southwestward for about 4 miles where a projected water-table contour from the flood plain would be at an elevation of about 285 feet. The difference in elevation between the two points is about 415 feet, indicating a gradient of 41.5 feet per mile and a water-table elevation of 451 feet in the gap. However, the hole was dry at 343-feet elevation. Another possibility is that the low gradient as determined along the Colorado River flood plain of about 2 feet per mile could be projected to the gap. This would give an elevation of about 293 feet under the gap, and an apparent gradient to the stock well of 68 feet per mile, which is unusually high.

The available data are so meager that only possibilities can be given on the underflow beneath Tyson Wash. The first is that there is no ground-water underflow, the only contribution for Tyson Wash being the runoff and the resulting recharge from this runoff that occurs west of the east gap. Under this possibility the ground-water movement from Quartzsite would be northward, then westward to the north of the Dome Rock Mountains and on to the Colorado River flood plain.

Another possibility is that a part of the underflow goes through the east gap in secs. 8 and 17 (fig. 22), but that most of it moves northward as in the first possibility. The third possibility, which may have less basis than the others, is that all the underflow goes through the east gap. If this were true, then the underflow would be small, and the recharge to the large area south of Quartzsite would be a small percentage of the precipitation.

UNDERFLOW TO PALO VERDE MESA FROM CHUCKWALLA VALLEY

Brown (1923, p. 103–105) was the first to recognize that underflow occurred from the Chuckwalla Valley to the Palo Verde Mesa. There were sufficient wells and adequate topographic maps to verify this underflow, which occurs under an alluvial topographic divide. The divide between Chuckwalla Valley and the Palo Verde Mesa (fig. 23) is in the west half of Tps. 6, 7 S., R. 21 E. Drainage to the west is to Ford Lake where the runoff evaporates, and that to the east is to the Colorado River.

Geophysical surveys (seismic and gravity) were made to define the cross-sectional area through which the ground water flows to the Colorado River. Seven shotholes were used for the seismic survey. These were in a line extending from the McCoy Mountains south to the Mule Mountains (fig. 23). The north and south shotholes were near the bedrock of the mountains, which is composed of metamorphic rock. A change in velocity from 6,830 feet per second to 13,300–16,800 feet per second was recorded for the southern half of the line. The interface between these velocities sloped uniformly from a shallow depth near the mountains on the south to a depth of about 1,500 feet below land surface near the shothole between secs. 4 and 5. The record north to the McCoy Mountains was of poor quality because of induced current from a nearby powerline.

The gravity data based on one-half-mile stations indicated a depth to basement near the center of the line of about 2,500 feet below land surface, assuming a density contrast between the fill and basement of 0.45 (D. R. Mabey, written commun., 1966). The south half of the line showed a gradual deepening of the bedrock. The north half, close to the mountains, indicated a sharper decrease in the depth to bedrock.

The nearest deep well is about 4 miles east of the divide in sec. 14, T. 7 S., R. 21 E. This well was drilled to 1,368 feet and contained the following units: (1) from 0 to 527 feet, alluvium; (2) from 527 to 845 feet, Bouse Formation; and (3) from 845 to 1,368 feet, fanglomerate. The contacts as listed are arbitrary because they are based on an interpretation of driller's and electric logs. The contact between the Bouse Formation and Colorado River alluvium could be higher in the log because much fine-grained material was logged above 527 feet. The contact between the Bouse Formation and the fanglomerate is thought to be at 845 feet where there is a marked change to higher resistivity. From what little is known, an equally valid selection, on the basis of changes in resistivities, would be at 750 feet. The well was perforated from 700 to 900 feet and had a specific capacity of about 5 gpm per ft of drawdown.

The nearest deep well west of the line is about 6 miles from the drainage divide. The driller's log indicates that alluvium was penetrated from land surface to a depth of 160 feet; the Bouse Formation, from 160 to 930 feet; and the fanglomerate, from 930 to 1,139 feet. The well was perforated from 853 to 1,083 feet and is reported to have had a specific capacity of about 11 gpm per ft of drawdown.

Data from the few wells available indicate that the water-table gradient beneath this alluvial divide is

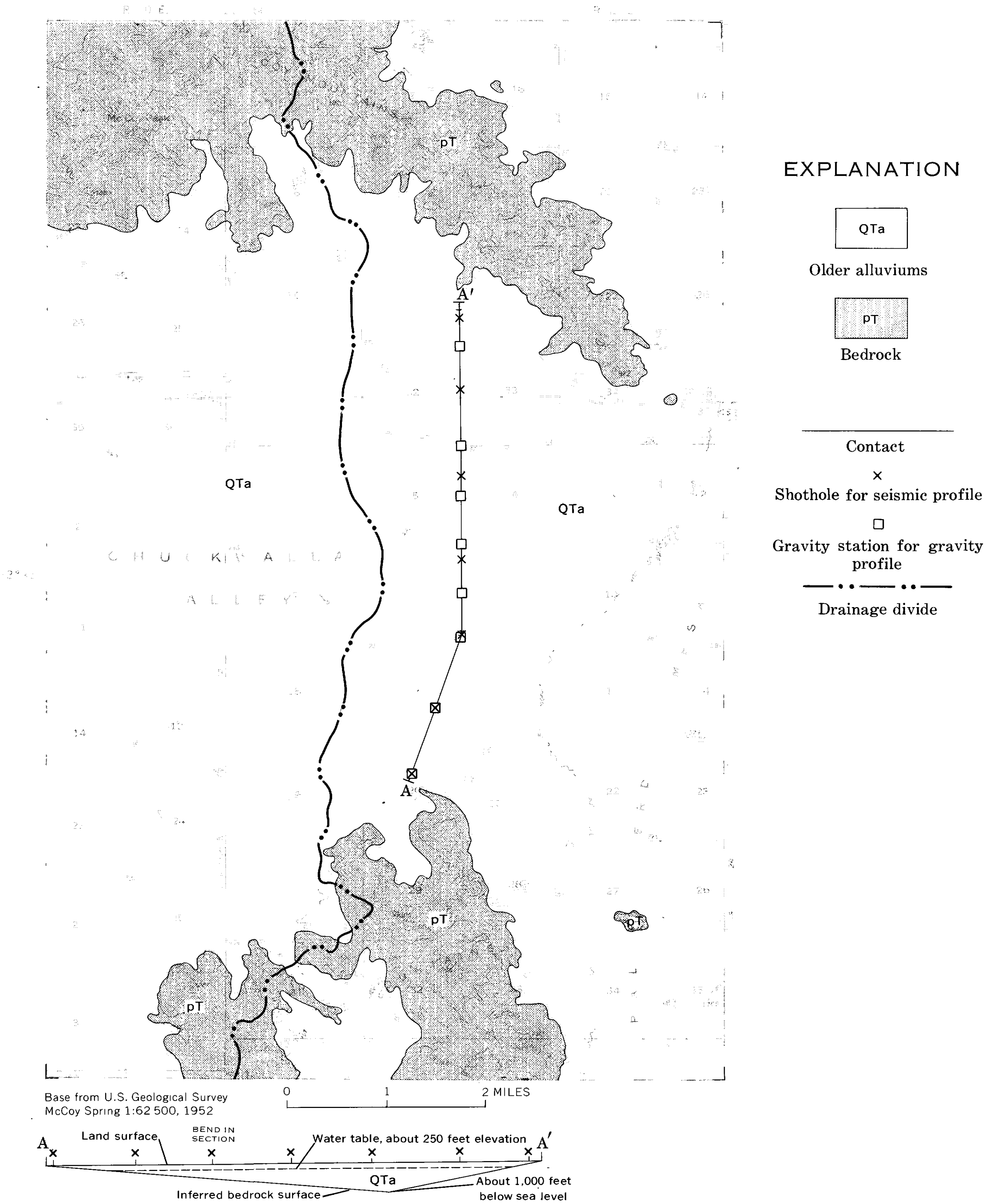

Figure 23.—Area near drainage divide between Chuckwalla Valley and Palo Verde Mesa, Calif., showing shotholes, gravity stations, and geophysical profile.

eastward and about 2 or 3 feet per mile. The low gradient can be explained in either of two ways: it indicates a high transmissivity, or it indicates a very low recharge rate in Chuckwalla Valley.

The logs and specific capacities of the two wells discussed above do not indicate high transmissivity. In fact, the specific capacity of wells that are perforated in the fanglomerate is only 15 gpm per ft of drawdown or less. Thus, the meager data suggest that neither the Bouse Formation nor the fanglomerate is very transmissive at this locality. If a more transmissive medium is present, it would have to be a buried alluvial channel that drained Chuckwalla Valley to the Colorado River. Although there are no well data in the Palo Verde Mesa that suggest the above possibility, the data are not complete and thus the evidence for such a channel may not have been found as yet. Furthermore, it would be difficult to verify such a channel, because much of the alluvial material under the Palo Verde Mesa was deposited by the Colorado River. The distinction between Colorado River deposits and deposits from a tributary drainage would be difficult to detect from drillers' logs. The regional geology of the area does not rule out the probability of a buried alluvial channel. This drainage could have been through this gap or through the gap near Vidal. Thus, there could be an old channel in this area, but it would have to be of sufficient width and depth in the zone of saturation to be of significance in groundwater movement today.

The other possibility is that the low gradient of the water table indicates that a small amount of recharge occurs in Chuckwalla Valley. This may very well be the most reasonable possibility because this valley is one of the driest parts of the Mojave Desert. An isohyetal map (Hely and Peck, 1964, pl. 3) of the lower Colorado River shows that much of the valley receives less than 3 inches of precipitation per year, and that the bordering mountains receive only as much as 6 inches. Under these conditions, ground-water recharge from precipitation would be extremely low.

Chuckwalla Valley, a desert basin of interior drainage, contains two playas, Ford and Palen Lakes (Brown, 1923, p. 101–102). There is no natural discharge of ground water from Ford Lake because the water table is beneath the root zone. Palen Lake, on the other hand, is reported to have growths of mesquite and saltbush, which suggests that ground water is at a shallow depth and that it provides water to support the growth of these plants.

The natural discharge of ground-water from Chuckwalla Valley occurs in part at Palen Lake, and as outflow to the Palo Verde Mesa. Based on the seismic and gravity profiles, a section (fig. 23) was prepared showing the depth of fill near the divide between Chuckwalla Valley and the Palo Verde Mesa. The deepest part of the fill is estimated to be about 1,500 feet thick based on the seismic profile, and is north of the midpoint of the section. Because so little is known about the thickness of fill, the section is arbitrarily shown as a triangle. The width of the saturated section is 20.500 feet, or nearly 4 miles. The saturated section, based on a depth to water of about 250 feet, thus has an area of about 13 million square feet.

As has been discussed previously, the available data indicate moderate transmissivity for the water-bearing reach near the divide. The highest transmissivity that seems reasonable for the Bouse and older units is about 30,000 gpd per ft. With this transmissivity, a water-table gradient of 3 feet per mile and a 4-mile width of saturated section, the underflow would be only about 400 acre-feet per year.

Although the transmissivity as defined above may be considerably in error, it is unlikely that the true transmissivity is, for example, as much as 10 times greater than the 30,000 gpd per ft, which would give an underflow of about 4,000 acre-feet per year. A transmissivity of 300,000 gpd per ft is indicated only for Colorado River deposits, and as there is no evidence that the Colorado River entered the Chuckwalla Valley, it seems unlikely that the transmissivity is that much.

UNDERFLOW FROM MILPITAS WASH AREA

The Milpitas Wash drainage area is one of the larger areas tributary to the Parker-Blythe-Cibola area. To determine the section through which the ground water flows, a seismic survey was made, three sandpoint wells were augered in Milpitas Wash, and a bailer test was run on an unused, uncased hole in sec. 5, T. 11 S., R. 21 E. (fig. 24). This section was chosen because some of the aspects of the subsurface geology could be inferred from outcrops. The Bouse Formation is exposed in the center of the area and dips northeast about 4°, and the underlying fanglomerate is well exposed in the southern part of the area. An oil test in sec. 6 which started near the contact between Bouse Formation and the underlying fanglomerate penetrated about 2,100 feet of "conglomerate" (the fanglomerate of this report) before entering a volcanic sequence. Some outcrops of the Bouse Formation occurred north of Milpitas Wash; therefore, it can be inferred on the basis of field evidence that the distribution of the Bouse Formation in the cross section is a broad U-shape.

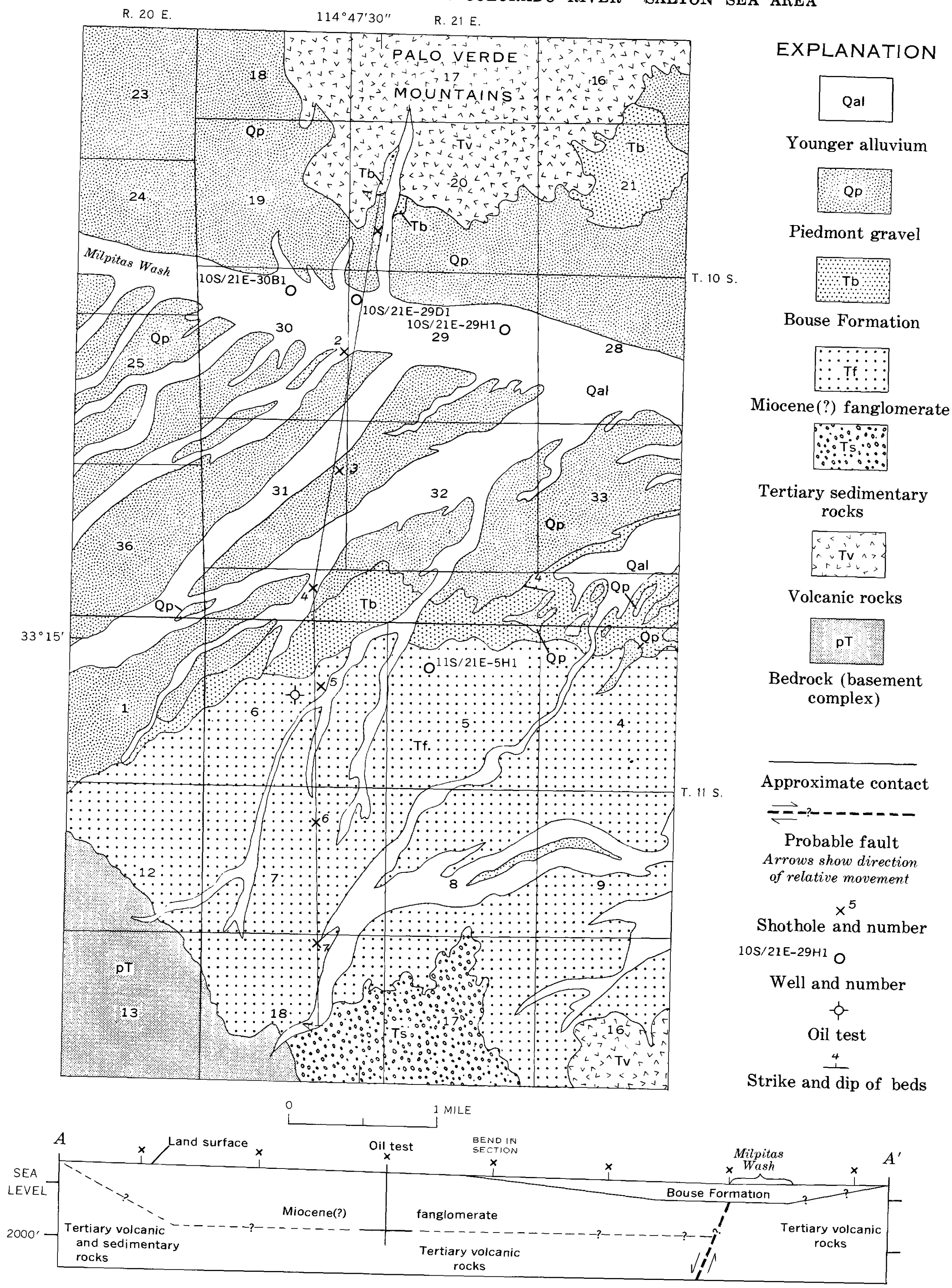

FIGURE 24.—Milpitas Wash area, California, showing geology, locations of shotholes and wells, and section based on geological and geophysical data.

Unfortunately, the seismic survey yielded little information that was not known from field data. One of the disappointing aspects was that an interface between the Bouse Formation and the fanglomerate was not recognizable from the seismic survey. The distance between shot points was about 4,400 feet. It is thought that a much shorter spread probably would have been more effective in determining this contact (Joel Watkins, written commun., 1964).

One shallow interface was determined from the survey. The depth of the interface at the several shot points was as follows: S.P. 1, 75 feet; S.P. 2, 103 feet; S.P. 3, 135 feet; S.P. 4, 86 feet; S.P 5, 49 feet; S.P. 6, 62 feet; and S.P. 7, 23 feet. Beneath this interface, the rocks underlying the northern and southern parts of the line transmitted the seismic shock wave at a velocity of 8.650 feet per second. The velocity beneath the central part of the line was 11,000 feet per second. However, the interface cut across the bedding planes of the fanglomerate and the Bouse Formation, and as such, it could not be related to the two units. The velocity of 11,000 feet per second was so high that deeper interfaces could not be determined from the data.

The depth to water under Milpitas Wash ranges from about 43 to 57 feet (see accompanying table), and the elevation of the water table ranges from 470 to 420 feet above sea level, which indicates a gradient of about 50 feet per mile down the wash. The driller's logs indicate that the water table is in the fine-grained sequence of the Bouse.

South of Milpitas Wash, well 11S/21E-5H1 has a depth to water of 283 feet at an elevation of about 280 feet, which is considerably lower than that beneath Milpitas Wash. The well was drilled entirely in the Miocene(?) fanglomerate. The results of a bailer test on this well indicated a specific capacity of less than 0.1 gpm per ft of drawdown, and a transmissivity of less than 100 gpd per ft. Although very low, this measured transmissivity is not necessarily that of the fanglomerate at all places beneath Milpitas Wash.

Runoff from precipitation in the Milpitas Wash area comes from well-defined tributaries to Milpitas Wash and then flows to the Colorado River. Thus, when runoff in Milpitas Wash is of sufficient duration to saturate materials beneath the streambed to depths beyond those supplying water for evapotranspiration requirements, the ground-water reservoir receives recharge. The water levels in the auger wells are indicative of this recharge. These water levels and the one in sec. 5 suggest a ridge of ground water under Milpitas Wash, with a sharp gradient to the south. This interpretation was used on the ground-water contour map (pl. 5). On the basis of the discussion given in this section, a meaningful estimate on the amount of underflow at the cross section (fig. 24) cannot be made.

Records of water wells, Milpitas Wash area, California

Well	Depth of well (feet)	Depth of perforated interval (feet)	Depth to water (feet below land surface)	Elevation of water table (feet above mean sea level)
10S/21E-29D1	232	136–138	45.7	420
29H1	84	82–84	57.4	470
30B1	74	72–74	43.4	450
11S/21E-5H1	752	(1)	283.2	280

[1] Open hole.

DISCHARGE

Ground water is discharged from the aquifers of the Parker-Blythe-Cibola area by wells, evapotranspiration, effluent seepage into drains and the Colorado River, and as underflow through the alluvium in the canyon downstream from Cibola.

The ground water pumped from wells is used for municipal and domestic supplies, drainage, and irrigation of land. The two principal communities in the area, Parker and Blythe, both use wells for municipal water supply. The city wells in Parker obtain most of their water from the fanglomerate, whereas the city wells in Blythe obtain their water from the older alluvium.

Most of the farms have wells for domestic use. Many of the wells are sandpoints that are installed only a few feet below the water table. Another type of construction is the use of small diameter casing (4 in. is common) with the casing open at the lower end. The wells are drilled into the first "good" gravel, then developed, and a submersible pump is installed. Only four drainage wells are currently in operation. These wells are south of Poston and are maintained by the U.S. Bureau of Indian Affairs.

The amount of pumpage from the ground-water reservoir for irrigation is small compared to the amount of surface water diverted for irrigation. Wells that were drilled for irrigation are on the Parker Mesa, in the Vidal area, on the Palo Verde Mesa, and along the Colorado River. Three irrigation wells have been drilled on the Parker Mesa. In the spring of 1967, two were in use. The land is leased from the Bureau of Indian Affairs on long-term bases in anticipation that citrus will be the principal crop. On the mesa in the Vidal area, 13 irrigation wells have been drilled, and in the spring of 1967, 11 were in use. On the Palo Verde Mesa, an area that has expanded rapidly, 48 irrigation wells have been drilled; however, only about 30 were in use in the spring of 1967.

Several irrigation wells have been drilled along the Colorado River in this area; however, only two of these were inventoried during the present investigation. The wells are drilled into the basal gravel of the younger alluvium.

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 on "Water Budgets."

Discharge of ground water as effluent seepage to drains occurs in the area irrigated by surface water diverted from the Colorado River. The irrigated areas in the Colorado River Indian Reservation and in the Palo Verde Irrigation District contain many miles of drains that prevent the farmland from becoming waterlogged. The ground-water contour map (pl. 5) reflects the influence of the drains on the water table.

Discharge from the ground-water reservoir to the Colorado River occurs in some reaches. This can be determined from the ground-water contour map (pl. 5) and will be discussed more fully in the section on "Water Budgets." This discharge is from the younger alluvium to the river. In the lower end of the valley, the discharge from the younger alluvium includes ground water that is discharged from the Bouse Formation and the fanglomerate. The dip of these latter two units in the area above the bedrock narrows is northward. Because the Bouse Formation underlies the flood plain from Parker to Cibola, artesian conditions exist in the fanglomerate. Thus, the only place where water in the fanglomerate can discharge from the reservoir is in the area south of Cibola. The water in the fanglomerate and the Bouse Formation pass into the younger alluvium, and then, because of the constriction of the valley at the lower end, the water discharges from the younger alluvium to the Colorado River.

PARKER VALLEY

GROUND WATER UNDER NATURAL CONDITIONS

Before the Colorado River was harnessed by Hoover Dam in 1935, it regularly overflowed its banks during the spring runoff and flooded parts of Parker Valley. As the river receded some of the flood water drained directly back to the river; some, however, was trapped in ponds and sloughs, and some infiltrated into the soil and became ground water.

Harris (1923, p. 109) states that in 1915 and 1916 much of the area was covered with an uneven growth of brush and some moderate-sized trees. Mesquite, catclaw, and small brush were said to prevail on the higher ground; willow, water rushes, arrowweed, and cottonwood, in the vicinity of water.

From the foregoing account and the results of a vegetation survey made by the U.S. Bureau of Reclamation (1963[2]) in the spring of 1962, the distribution of vegetation under natural conditions can be inferred fairly well.

Of some 108,000 acres in the flood plain between Parker Dam and Palo Verde Dam, 71,000 acres were mapped in 1962 as areas supporting the growth of phreatophytes, the principal natural vegetation in the flood plain. (The term "natural vegetation" as used in this report includes both indigenous and exotic uncultivated plants.) Arrowweed and mesquite were the dominant species, the arrowweed generally growing in a belt 1–2 miles wide adjacent to the river. Mesquite was more widespread, occupying almost all the remainder of the flood plain, except where the land had been cleared for irrigation. Because of the location of the cleared land, it is probable that mesquite also had been the dominant species under natural conditions. On the basis that the distribution of the phreatophytes in 1962 in undeveloped areas fairly well represents the distribution under natural conditions, it can be inferred that under natural conditions the total acreage of mesquite was the 37,000 acres mapped in 1962 plus 36,350 acres that had been cleared of mesquite prior to being irrigated, a total of about 73,000 acres, or about 70 percent of the flood-plain area. The acreage of the other species of phreatophytes under natural conditions probably was similar to the acreage mapped in 1962, about 34,000 acres, of which arrowweed was the dominant species.

Thus, under natural conditions there were somewhat more than 100,000 acres of the flood plain from which ground water was being discharged to the atmosphere. Because over a period of years the water levels beneath the flood plain remained at fairly constant stages, the amount of ground-water recharge to the area probably equaled the ground-water discharge. Although some of the recharge came from tributary areas, and some from the infiltration of occasional flood flows from tributary areas and from the flooding of parts of the valley by the Colorado River, a large part undoubtedly was derived from the infiltration of the Colorado River water into permeable deposits underlying the river channel itself. This movement of ground water from the river channel to the area of discharge of ground water by natural vegetation is indicated by the ground-water contours in figure 25, which is adapted from a map prepared by the Colorado River Agency, Parker, Ariz. (written commun.,

[2] Unless otherwise noted, all estimates of acreages and rates of use of water by natural vegetation that are used in the present study are based on the cited report.

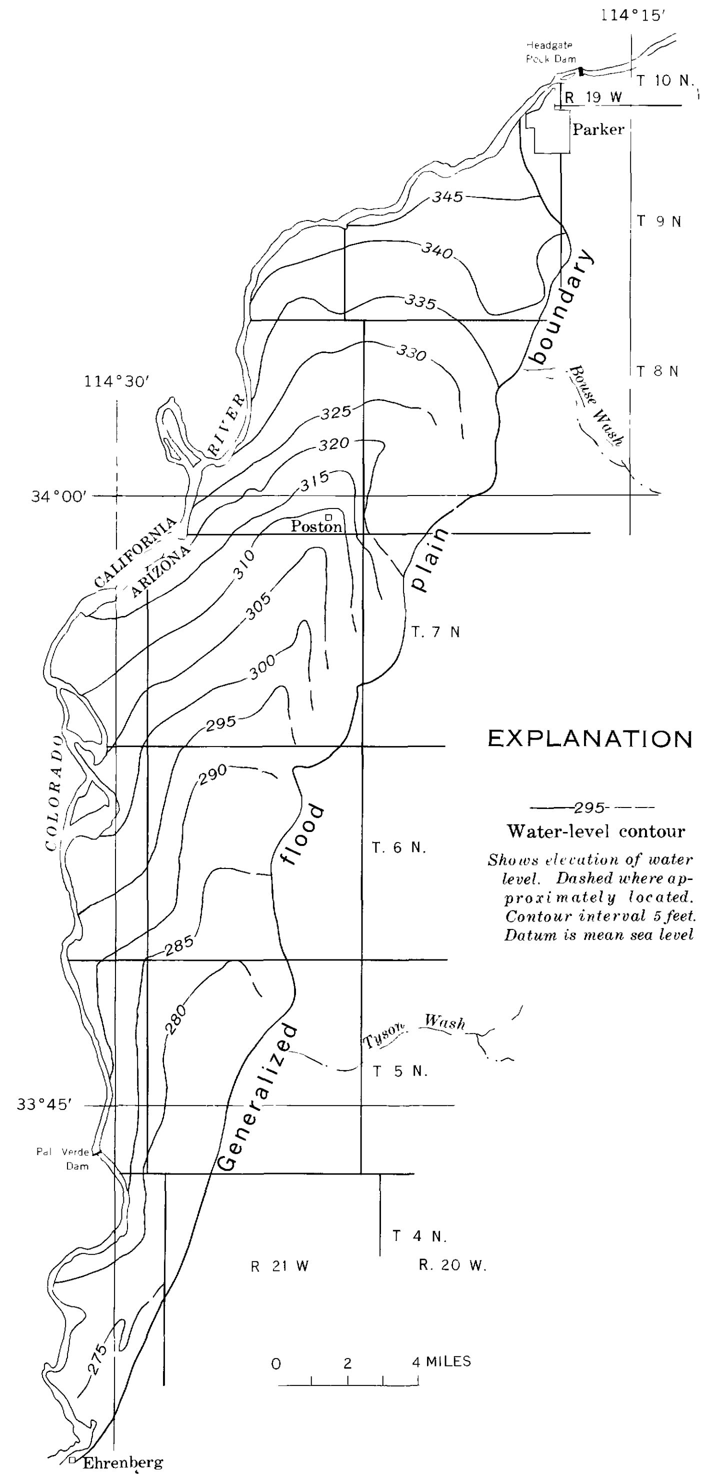

FIGURE 25.—Generalized water-level contours in the Arizona part of Parker Valley, 1940–41.

1961), showing contours of the water surface beneath the flood plain as determined from a survey made by the agency during 1940–41. Except in the northern part of the valley, mainly in T. 9 N., R. 20 W., where irrigation with river water had caused water levels to rise, the water-level surface in 1940–41 probably was still about the same as it was under natural conditions.

A detailed analysis of the shape and gradients of the contours is not warranted because the control that was used by the Colorado River Indian Agency is not known. In a general sense, however, it appears that the 340-foot contour in the northern part of the valley may reflect the buildup of water levels from irrigation. Also, the contours indicate some westward movement of ground water from near the eastern margin of the valley towards a ground-water trough whose axis is east of the centerline of the flood plain. Part of the westward movement probably is due to water that infiltrates from the Colorado River north of Parker and moves southward beneath Parker Mesa toward discharge areas in the flood plain, and part is due to ground-water recharge from tributary areas moving westward to discharge areas in Parker Valley.

The principal tributaries entering the reach from the east are Bouse Wash, which enters Parker Valley about 7 miles south of Parker, and Tyson Wash, which enters the flood plain in T. 5 N., R. 21 W. Some ground-water recharge undoubtedly occurs near the washes themselves because of the infiltration of periodic flows and floods, but it is not known if the bulk of the ground-water recharge occurs beneath the washes. It is possible that much of the ground-water recharge enters the valley at points somewhat distant from the mouths of these washes, because subsurface controls that govern the movement of ground water may not underlie the topographic lows. The contours also have a southward gradient that is related to the southward gradient of the river. Were there no significant ground-water discharge in the flood plain, the contours would tend to become normal to the river and approach the gradient of the river.

The strong eastward component of the water-level contours away from the river toward the area of ground-water discharge, as shown in figure 25, suggests that the ground-water discharge by evapotranspiration strongly influenced the movement of ground water in the valley. Where the contours trend northeast and the river south, the eastward gradient owing to discharge by natural vegetation is equal to the gradient of the river, or about 2 feet per mile. Where the contours trend north of northeast, the eastward component of the gradient exceeds the gradient of the river. As the contours approach a direction more nearly northward, or parallel to the river, the influence of the ground-water discharge becomes dominant.

MAGNITUDE OF GROUND-WATER MOVEMENT

The magnitude of the movement of ground water from the river to areas of discharge can be estimated on the basis of the evapotranspiration requirements of vegetation under natural conditions and the probable part of this requirement that was derived from the river by direct infiltration to the ground-water system.

The evapotranspiration requirements of the vegetation under natural conditions are estimated by assuming that the rates of evapotranspiration for the various species of vegetation were similar to rates for the same species in recent years. Using data obtained by the U.S. Bureau of Reclamation (1963), it is computed that the average net consumptive use in areas of mesquite in Parker Valley is 1.9 feet per year, and by arrowweed, 2.4 feet per year. Applying these rates to the 73,000 acres of mesquite and the 34,000 acres of dominantly arrowweed that are estimated to have grown in the area under natural conditions (p. 46) results in a net consumptive use by vegetation of about 220,000 acre-feet annually. This use was supplied largely by the infiltration of flood water that annually overflowed parts of the valley and by the infiltration of water directly from the river. If the latter is assumed to have supplied one-half the consumptive use requirements, the direct infiltration of river water to the ground-water system would have been about 110,000 acre-feet annually.

TRANSMISSIVITIES

Transmissivities (see section on "Pumping Tests") commonly are computed on the basis of data obtained during controlled pumping tests. A generalized transmissivity value, however, can be computed by dividing the rate at which water passes through a given width of the full thickness of the saturated material by the product of the width of the section and the hydraulic gradient normal to the section. If the rate is expressed in gallons per day per mile width of saturated material, and the hydraulic gradient in feet per mile, the transmissivity will have the dimension of gallons per day per foot, a unit commonly used by the U.S. Geological Survey. The above method is used to compute a generalized transmissivity for a part of Parker Valley. The computations are based on the water-level contours shown in figure 25 and on the probable rate at which ground water was transmitted under natural conditions.

Theoretically, if it is assumed that the rate of ground-water discharge due to evapotranspiration is uniform for each unit area, and that the transmissivity is constant, then the gradient due to ground-water discharge will decrease from a maximum at the river to zero at a section where there is no component of ground-water movement away from the river. Midway between the river and the aforementioned section, the component of the gradient away from the river will be that needed to transmit half the quantity of water leaving the river; the component will also be the average gradient between the river and the section of no movement away from the river.

One of the better areas for determining the probable magnitude of the movement of ground water on the above basis appears to be eastward of the river between the points where the 320- and 300-foot contours intersect the river. The distance from the river to the section of no further movement away from the river generally ranges between 4 and 6 miles and averages about 5 miles. The ground-water gradient about midway between the river and the line of no movement eastward averages about 5 feet per mile. If the southward component of this gradient is assumed to be due to the slope of the river, and if 2 feet per mile is a fair value for the gradient of the river, then the eastward component, or that due to transpiration of the vegetation, is slightly more than 4.5 feet per mile.

The rate of use of ground water by natural vegetation in this area is computed to have been about 2.1 feet per year, based on the distribution of mesquite and arrowweed and their respective rates of use. This consumptive use was supplied by the annual flooding of parts of the valley by the river and by the movement of ground water from the river channel itself. If half the consumptive use is assumed to have been supplied from each source, then 3,360 acre-feet annually ($5 \times 640 \times 2.1 \div 2$) would have to infiltrate to the ground-water reservoir along each mile of river channel. At each 1-mile-wide section midway between the river and the section of zero movement away from the river, the quantity would be half the above amount, or 1,680 acre-feet annually. In order to transmit the ground water at this rate under the computed hydraulic gradient of slightly more than 4.5 feet per mile, the deposits transmitting the water must have a transmissivity of about 330,000 gpd per ft.

A transmissivity of this magnitude seems to be reasonable considering the nature of the deposits where they are known and the results of pumping tests. However, because of the generalizations that necessarily were made, and the uncertainty of the estimates of rate of ground-water movement and accompanying gradient, it is possible that the true average transmissivity for the above area may be as much as double or as little as half the computed figure.

Transmissivities for other parts of the valley are not computed quantitatively. In the southern part of the valley, the average eastward gradient appears to be similar to the gradient in T. 7 N., R. 21 W. However, the rate of transmission at the section midway between the river and the section of no eastward movement of water is less than in T. 7 N., R. 21 W., because of the shorter distance. It is probable, therefore, that the transmissivity is less in the southern part of the valley than in T. 7 N., R. 21 W.

In the northern part of the valley the contours are more widely spaced than in T. 7 N., R. 21 W., and the direction of the contours is not so readily attributable to the movement of ground water from the Colorado River to satisfy evapotranspiration requirements of the area. It is possible that by 1941 irrigation with Colorado River water in this part of the valley supplied most of the evapotranspiration requirements and thus the rate of movement of ground water from the river was much less than in the areas farther south where irrigation was not practiced.

HISTORICAL DEVELOPMENT OF IRRIGATION [3]

Irrigation with Colorado River water was first attempted in Parker Valley about 1870, but the project was unsuccessful because the headgate structure failed. Another plan in 1874 involving a diversion at Headgate Rock and four tunnels also was unsuccessful, as was a later project involving the use of water wheels to divert water from the river. By 1914, however, a total of about 460 acres was being irrigated. In 1915 an attempt to develop ground water for irrigation in the east-central part of the valley failed because of the poor chemical quality of the water. As late as 1920 almost the entire agricultural development was restricted to T. 9 N., R. 20 W.

In the early years the ground water was sufficiently far below the land surface so that it did not prevent the full development of the root system of crops. However, as more land was brought into cultivation and as irrigation with surface water became the dominant method of irrigation, water levels rose sufficiently close to the land surface to waterlog much of the cultivated area. In addition, the alkali content of the soil water became so high that plant growth was impaired or prevented.

Because of a lack of drainage and excessive alkali, about 20 percent of the original trust patent allotments was of no use to the Indians by 1927. Most of the land that was adversely affected was in the eastern part of T. 9 N., R. 20 W.

In 1934, four wells were drilled along the northern part of the irrigated area in T. 9 N., R. 20 W., parallel to the river in order to lower the water table. The wells discharged into the supply canals, and were used successfully until 1937 or 1938. After that date the wells were no longer needed because water levels in the irrigated area drained by the wells had dropped sufficiently to eliminate waterlogging. The drop in water levels was principally in response to the degradation of the river channel caused by the release of relatively clear water following the filling of Hoover Dam.

In 1936, the distribution system consisted of about 60 miles of canals, and the drainage system, of about 15 miles of open drains. The drainage system discharged into "Seventeen Mile Slough," which trends south-southwestward through the middle of T. 7 N., R. 21 W., and which currently is part of the Lower Main Drain. In 1942 when the present-day Headgate Rock diversion dam was completed, the irrigated acreage still was almost wholly in T. 9 N., R. 20 W., and in the northwestern part of T. 8 N., R. 20 W.

The program for bringing new lands into cultivation was accelerated in 1948. Much of the new land was south of Poston. In 1952, four drainage wells were put into operation near the eastern edge of the irrigated area in T. 7 N., R. 21 W., to alleviate waterlogging. Unfortunately, the program for developing drainage did not keep pace with the program for irrigating new land, and so by 1955 about 5,000 acres of land that had been irrigated at one time was out of production. In recent years, the drainage facilities have been augmented throughout the valley to the point where waterlogging is only a minor problem.

Figure 26 shows the net irrigated acreage in the Colorado River Indian Reservation for the years 1914–65, inclusive, which for all practical purposes is also the irrigated acreage for Parker Valley. The extent of the irrigated acreage as of 1964 is shown on plate 5.

GROUND WATER IN RECENT YEARS

The historical sketch of irrigation development in Parker Valley implies that changes in the ground-water regimen resulted principally from the use of river water for irrigation. Irrigation by pumping ground water has never been a significant part of the irrigation development. Ground water is pumped principally as a means for controlling water levels in areas where surface drains do not exist or where surface

[3] The following account of development of irrigation in Parker Valley is based largely on information contained in unpublished data of the Colorado River Agency, Parker, Ariz.

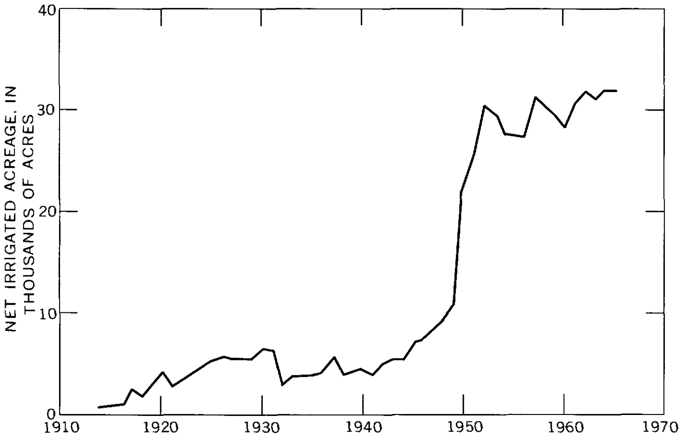

FIGURE 26.—Net irrigated acreage in Colorado River Indian Reservation, 1914–65. Irrigated acreage 1941–50, inclusive, obtained from U.S. Bureau of Reclamation (1953) report; 1951–57, inclusive, from U.S. Bureau of Indian Affairs (no date) report; 1958–65, inclusive, from crop reports furnished by U.S. Bureau of Indian Affairs.

drains are inadequate, and, to a limited extent, for domestic use.

Generalized water-level contours in Parker Valley in 1964 are shown on plate 5. The contours were adapted from maps furnished by the Colorado River Indian Agency which showed the configuration of the water table in the irrigated areas. The observation well network of the Indian Agency is based on a grid having one-quarter-mile spacing.

Outside the irrigated areas within the flood plain of the river, the locations of the contours were determined on the basis of water levels in the shallow wells of the network that was established during the present investigation by the U.S. Geological Survey. The grid spacing, where practicable, was 1 mile in an east-west direction and 2 miles in a north-south direction. Outside the flood plain, the control was limited to water levels in existing wells and in test wells drilled by the Geological Survey during the present investigation. The control for the contours beneath the irrigated areas, therefore, is much better than outside the irrigated areas.

The contours show that irrigation with surface water results in the building of a ground-water mound beneath the irrigated areas. The effectiveness of the drains in controlling the growth of these mounds is also shown by the configuration of the contours. In most of the irrigated areas, the drains appear to be very effective in controlling the height of the mounds and their lateral growths. Outside irrigated areas, the drains also generally serve as controls on water levels.

Of special interest is an interceptor drain paralleling the Colorado River from a point near the north line of T. 7 N. southward to its outfall into the Colorado River just below Palo Verde Dam. This drain was designed to limit the movement of ground water away from the river following the construction of Palo Verde Dam which raised water levels in the river upstream. The contours show the desirability for this drain. Southward from about the north boundary of T. 7 N., the Colorado River is losing water to the ground-water system to a marked degree; whereas, north of the above line, the ground-water system is discharging to the Colorado River or to areas westward therefrom. The effectiveness of the interceptor drain appears to be greatest southward from a section about midway between the northern and southern boundaries of T. 6 N., R. 22 W.

The effectiveness of the drain is indicated by its base flow, which represents the flow that is due to the discharge of ground water. This flow is estimated at about 23 cfs (cubic feet per second) for the years 1963–66, on the basis of the average of the minimum daily flow for each month. The chemical quality of the water is almost identical with that of the Colorado River, which is further evidence of its source.

Two other drains carry excess water from the valley. One, the Upper Main Drain, provides drainage for some 17,000 acres of the 19,000 acres in the northern block of irrigated land. In recent years, it has discharged to the Colorado River at a point about 1 mile north of the northern boundary of T. 7 N. Its base flow is estimated at 125 cfs on the same basis as that used to estimate the base flow of the interceptor drain. The other principal drain, the Lower Main Drain, begins about 1 mile north of the north line of T. 8 N., R. 20 W., and continues southward to its discharge point into the Colorado River about 1 mile downstream from Palo Verde Dam. Some 14,000 acres of irrigated land, about 2,000 of which are in the northern block of irrigated land, are served by this drain. Its base flow is estimated at 90 cfs, on the same basis as that used to estimate the base flow of the other drains.

MAGNITUDE OF GROUND-WATER MOVEMENT

The magnitude of the movement of water between the river and the ground-water system in Parker Valley can be estimated by analyzing the water supply available to, and discharged from, each of the blocks of irrigated land served by the Upper and Lower Main Drains.

One of the items needed to make this analysis is an estimate of the rate at which water is diverted for irrigation. The rate commonly is computed from records of diversions from the river, waste returns, and irrigated acreages. Records of waste return are not available for Parker Valley. However, it is thought that fairly good estimates of waste return can be made by subtracting the base flow of the drains from the records of measured return flows to the river.

In the preceding discussion the base flows of the drains were estimated at 23 cfs for the interceptor drain, and 90 and 125 cfs for the two main drains, a total of 238 cfs, or 172,000 acre-feet annually. In the period 1959–65, the measured return flows to the river ranged from 213,000 to 299,000 acre-feet annually and averaged 261,000 acre-feet. Subtracting the base flow of the drains from the measured return flow indicates that the waste flow averaged 89,000 acre-feet per year. The yearly diversion from the river during the above period ranged from 378,000 to 485,000 acre-feet and averaged 436,000 acre-feet. Subtracting the waste flow from the diversion from the river shows that, on the average, 347,000 acre-feet of water per year either was diverted to the irrigated land or leaked from the distribution system. The yearly irrigated acreage during the period ranged from 29,600 to 32,000 and averaged 31,000. The average net rate at which water was diverted for irrigation thus was about 11.2 acre-feet per year per acre irrigated.

It is recognized that the measured return flows include some water other than waste water and the base flow of the drains. The principal source is some unmeasured runoff that enters the drainage system from tributary areas or from within the valley. However, the amount probably is small; therefore, it would not significantly lower the computed rate of 11.2 acre-feet per year per acre irrigated. Even if the rates were as little as 10.2 feet or as much as 12.2 feet per acre, the total movement between the river and the ground-water system would not be changed appreciably. The principal effect of a change in rate is to reduce or to increase the infiltration from the river to the ground-water system in the reach below Poston wasteway and correspondingly to increase or to decrease the discharge of the ground-water system to the river north of Poston watseway. These changes are almost compensating because of the relatively small difference in the blocks of irrigated land served by each of the main drains.

In order to obtain a breakdown of the total movement between the river and the ground-water system, it is necessary to analyze the water supply and water requirements of the areas that are contributing ground water to the river separately from the areas that are receiving water by direct infiltration from the river. A convenient breakdown is to consider the water supply and requirements of the block of irrigated land, and other nearby land that is served by the Upper Main Drain discharging near Poston wasteway, separately from the block of irrigated land and other land that is served by the Lower Main Drain.

The average annual supply of water available for consumptive use for land served by the Upper Main Drain is estimated as:

Water supply:	*Amount (acre-feet)*
Ground-water inflow—	
From Bouse Wash	1,200
Across northeast boundary	3,400
Unmeasured runoff to ground-water supply	4,800
River water diverted for irrigation of 17,000 acres at 11.2 ft	190,400
Total	199,800
Rounded	200,000

The inflow of ground water across the northeast boundary is infiltration from the area north of Bouse Wash. It is estimated on the basis that the transmissivity is 500,000 gpd per ft, the gradient averages 1.5 feet per mile, and the width of the section is 4 miles. Virtually all the unmeasured runoff is from Bouse Wash (p. 61) and is assumed to be available for consumptive use within the area.

Average annual consumptive use in the area is estimated as:

Consumptive use:	*Amount (acre-feet)*
Crops: 17,000 acres at 3.6 ft	61,000
Natural vegetation: 11,000 acres at 2.3 ft	25,000
Total	86,000

The basis for the estimate of consumptive use of water by crops is given in the section on "Water Budgets" (p. 63).

The foregoing analysis indicates that the supply available to the area exceeds the water use in the area by 114,000 acre-feet a year, which amount therefore represents the outflow of ground water from the area. The base flow of the drain serving this area, which represents part of the ground-water outflow, is 91,000 acre-feet per year. The outflow southward from the area is estimated at about 7,000 acre-feet per year, on the basis that the transmissivity averages 300,000 gpd per ft, the hydraulic gradient is 4 feet per mile, and the section is 5 miles wide. The remainder of the outflow, 16,000 acre-feet per year, therefore either discharges to the Colorado River or moves to areas west of the river where evapotranspiration by some 6,000 acres of natural vegetation is estimated to be about 20,000 acre-feet yearly, and where ground water is being pumped for irrigation in the lower part of Vidal Valley. The average annual movement of water from the ground-water system to the river in the area north of Poston wasteway, therefore, probably is not more than 16,000 acre-feet, and may be considerably less.

A similar analysis was made of the water supply and consumptive use for the block of irrigated and other lands south of the Poston wasteway served by the Lower Main Drain system. The average annual supply of water available for consumptive use is estimated as follows:

Water supply:	Amount (acre-feet)
Ground-water inflow:	
Tyson Wash	350
Across northern boundary	7,000
Unmeasured runoff to ground-water supply	2,600
River water diverted for irrigation:	
14.000 acres east of river at 11.2 ft	156,800
1.600 acres west of river at 6 ft	9,600
Total	176,350
Rounded	176,000

Ground-water inflow from Tyson Wash was determined on the basis described in the section on Water Budgets" (p. 61); inflow across the northern boundary is the outflow from the northern block of irrigated land. Virtually all the unmeasured runoff to the area is from Tyson Wash and is considered as part of the supply available for consumptive use. A diversion rate of 6 feet per acre per year was used for land west of the river because this land is irrigated by pumping water from the river rather than by diverting water from the river by gravity, as is done for the land east of the river.

Average annual consumptive use in the area is estimated as follows:

Consumptive use:	Amount (acre-feet)
Crops:	
14.000 acres east of river at 3.6 ft	50,000
1,600 acres west of river at 3.6 ft	6,000
Natural vegetation: 54,000 acres at 2.3 ft	124,000
Total	180,000

On the basis of the foregoing analysis the consumptive use in the area served by the Lower Main Drain exceeds the supply available from diversions and sources other than infiltration of Colorado River water by about 4,000 acre-feet. The average annual infiltration of water from the river to the ground-water system therefore is the above amount plus the outflow of ground water to the Lower Main Drain, 65,000 acre-feet; the outflow across the southern boundary, estimated at 2,000 acre-feet; and the base flow of the interceptor drain, 17,000 acre-feet—a total of 88,000 acre-feet.

Thus, in Parker Valley the movement of water between the Colorado River and the ground-water system in recent years can be summarized as a movement of ground water to the Colorado River from the block of irrigated land north of the Poston wasteway of less than 16,000 acre-feet per year, and a movement of river water directly into the ground-water system south of Poston wasteway of about 88,000 acre-feet per year, or a probable gross movement of water between the river and the ground-water system of about 100,000 acre-feet per year. For the 14-mile reach of the river north of Poston wasteway, the average annual rate of movement of ground water to the river probably is less than 1,000 acre-feet per mile. Between Poston waterway and Palo Verde Dam, the average annual rate of infiltration of river water to the ground-water system is about 4,000 acre-feet per mile.

The degree to which the present-day rates of infiltration from the river approach the maximum rate is not known. At infiltration rates of about 4,000 acre-feet per mile per year, which seem to be occurring over much of the reach, the required vertical hydraulic conductivity for the material underlying an average river width of 660 feet is about 1 gpd per sq ft.

Seepage tests in Parker Valley in 1956 and 1957 using the ponding method indicated the average vertical hydraulic conductivity of materials underlying 55 miles of canals and laterals to be 5.5 gpd per sq ft (Colorado River Agency, Parker, Ariz., written commun., 1961). Studies of seepage losses in unlined canals in other areas indicate that vertical hydraulic conductivities commonly average at least 3 gpd per sq ft. For example, the seepage loss from the All-American Canal in a 15-mile reach west of Yuma averages about 4,000 acre-feet per year per mile. Relating this rate to its average width of 175 feet gives an average vertical hydraulic conductivity of 4 gpd per sq ft.

Although it seems that considerably higher rates of infiltration of river water to the ground-water system than presently are occurring can be attained, any project that will depend on substantially higher rates of infiltration should be initiated only after adequate studies have established the feasibility of obtaining and maintaining the higher rates.

GROUND WATER IN FUTURE YEARS

The total amount of water moving between the river and the ground-water system today is not greatly different from the amount that is estimated to have moved between these systems under natural conditions (p. 48). Under natural conditions, however, the river was discharging to the ground-water system throughout its reach, but today because of irrigation, the ground-water system north of the Poston wasteway is discharging westward to, and beyond, the river. A similar change will tend to be brought about in the southern half of the valley as more land is brought into cultivation and irrigated. The buildup of ground-water levels that almost invariably accompanies such development will reduce the gradient away from the river, thereby reducing the outflow from the river. In view of the present limited depths to water in much of the area, however, it seems that the rise of water levels that can be tolerated will not be sufficient to reduce greatly the gradient away from the river.

As land is cleared of natural vegetation and converted to irrigated farmland, the amount of ground water consumed by natural vegetation will decrease and the amount consumed by crops will increase. However, one amount is not likely to balance the other, because in Parker Valley the yearly consumptive use by crops is 3.6 acre-feet per acre whereas that by natural vegetation is 2.3 acre-feet per acre. Thus, for each acre of natural vegetation that is cleared and replaced with irrigated crops, an average of 1.3 acre-feet of additional water will be required. Because the Colorado River is the ultimate source of any additional water it, too, will be depleted a like amount. From the water budget for Parker Valley (p. 64) it can be computed that, if all the natural vegetation were to be replaced with crops, some additional 92,000 acre-feet of water would be consumed.

WATER-LEVEL FLUCTUATIONS

Ground-water levels in Parker Valley generally fluctuate within an annual range of 1 or 2 feet. Exceptions are ground-water levels near pumped wells, irrigated land, and the river. Water levels sufficiently close to a well that is pumped intermittently will tend to fluctuate in response to the drawdown just outside the well casing that is necessary to produce the yield of the well. Ground-water levels at points very near the river tend to fluctuate with the stage of the river. Commonly, the annual range of river-stage fluctuations near Parker is 3 feet, but at the Water Wheel river-stage station, about 6 miles downstream from Poston wasteway, it is about 6 feet. Near-peak stages generally persist April through August; minimum stages, December through February.

Water levels in observation wells 100 and 200 feet from the river's edge at the Water Wheel river-stage station fluctuated at about half the magnitude of the river-stage fluctuations and lagged behind river stages 3–5 hours. Water levels in a well 1,000 feet from the river fluctuated at about one-twentieth the daily amplitude of the river and lagged 6–8 hours behind the stage changes of the river.

A specific example of the fluctuations is shown in figure 27. On March 17, 1964, when the river stage had

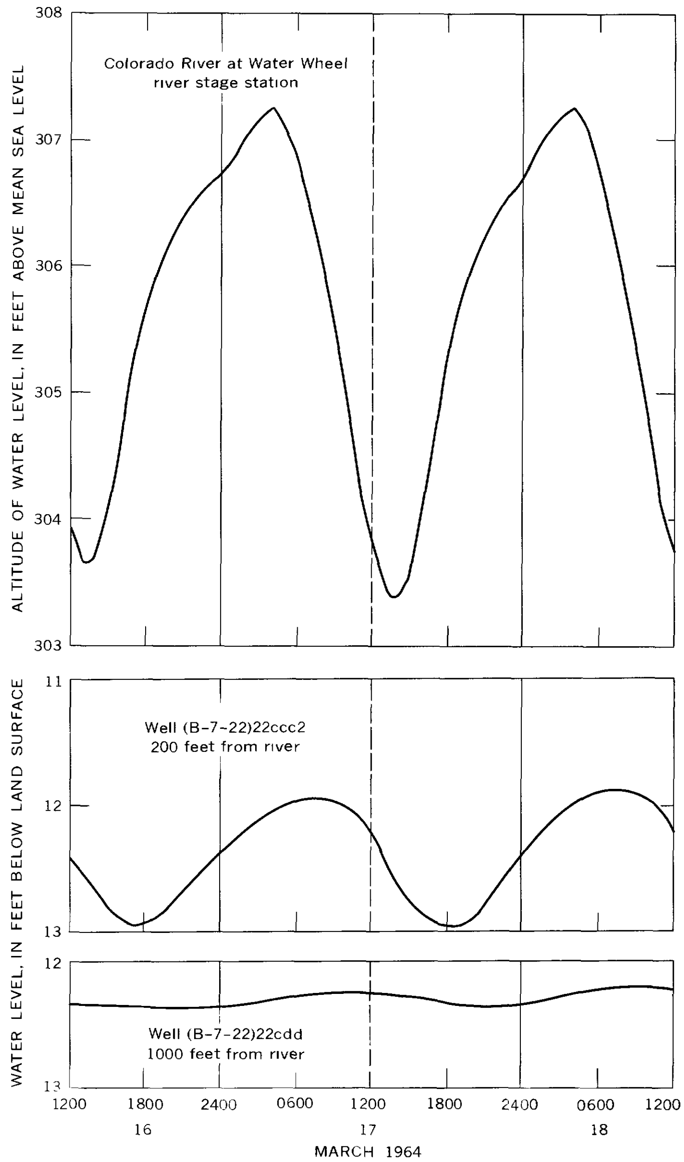

FIGURE 27.—Hydrographs of Colorado River at Water Wheel river-stage station and of two shallow wells 200 and 1,000 feet from the river near that station.

an amplitude of 3.9 feet and reached its low stage at about 1400 MST, the water level in the well 200 feet from the river had an amplitude of 1.05 feet and reached its low point at about 1800 MST; and the water level in the well 1,000 feet from the river had an amplitude of 0.125 foot and reached its low point at about 2200 MST. Over longer periods of time the differences in stage between the river and the water levels in wells are less pronounced. For example, the mean daily river stage at the Water Wheel station was 3 feet higher on April 4, 1964, than on January 20, 1964; at the well 200 feet from the river, the water level was 2.75 feet higher on April 4 than on January 20; and at the well 1,000 feet from the river, the water level was 2.2 feet higher on April 4 than it had been on January 20.

These examples indicate that daily fluctuations of river stage affect ground-water levels to a marked degree only a few hundred feet from the river, but changes in stage that persist over a longer period of time cause changes in ground-water levels at greater distances from the river.

Figure 28 shows the stage of the Colorado River at the Water Wheel river-stage station from October 1962 to June 1964, inclusive, and hydrographs for three shallow wells, ¾ mile, 1¾ miles, and 2¾ miles east of the river-stage station. Whereas the river stage is high from April to August, the water levels in the wells peak in March or April and then decline during the summer. Only the hydrograph for well (B-7-22)23ccc, three-quarters of a mile east of the river, appears to be influenced sufficiently by the stage of the river to have a pattern somewhat different from that which one might expect for a well in an area where the principal draft on the ground-water supply is evapotranspiration of natural vegetation. In such areas the water levels are highest at the beginning of the growing season, usually March or April in the present study area, and then decline to a minimum stage in August or September, followed by a gradual rise through the

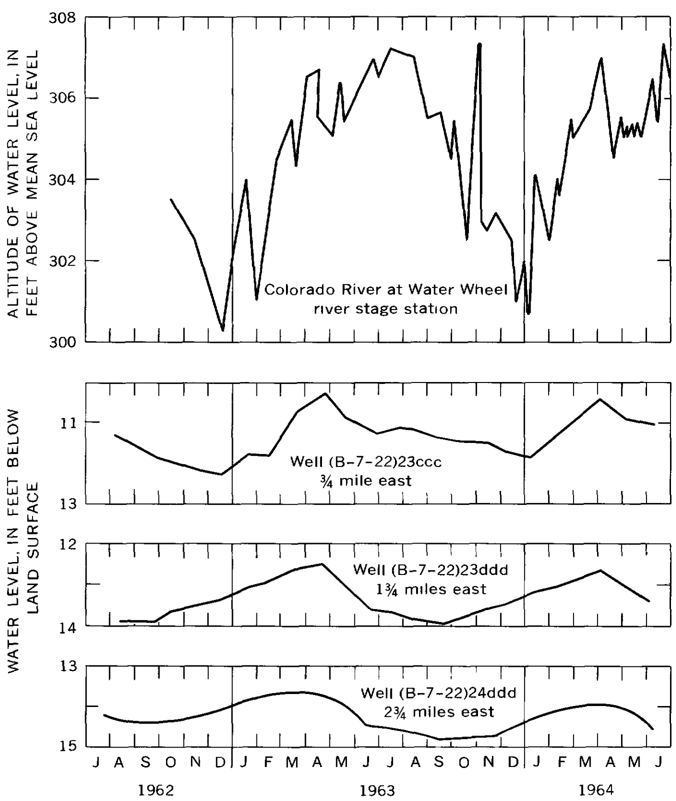

FIGURE 28.—Hydrographs of Colorado River at Water Wheel river-stage station and of three wells east of the station.

fall and winter. This typical pattern is shown by the hydrographs of wells (B-7-22)23ddd and B-7-22)-24ddd.

The hydrograph for well (B-7-22)23ccc also shows the effects of the seasonal draft on ground water by evapotranspiration processes, but the pattern is modified by seasonal changes in stage of the river. The modifications are a possible increase in amplitude of the seasonal fluctuations and a continuation of the summer decline of water levels through the fall and early winter. The latter is the best evidence of the influence of river stages on ground-water levels.

Seasonal changes in river stage are difficult to identify on the hydrographs of other wells similarly located in areas of natural vegetation a mile or more from the river. Actually, there is little evidence of substantial seasonal changes in ground-water levels attributable to river stage at distances greater than half a mile from the river.

DEPTH TO GROUND WATER

The depth to water beneath the flood plain under natural conditions can be inferred from a map prepared by the Colorado River Agency, Parker, Ariz. (written commun., 1961) that shows the depth to ground water in 1942. The map shows that the depth to ground water generally ranged from about 5 feet below the flood plain near the river to about 25 feet below the flood plain at its eastern edge, and that it averaged somewhere between 10 and 15 feet below the flood plain. Similar depths to water probably prevailed under natural conditions, except in the northern part of the flood plain in T. 9 N., R. 20 W., and T. 9 N., R. 21 W., where, because of irrigation, the depth to water in 1942 probably was at least several feet less than under natural conditions.

The diversion of surface water for irrigation caused ground-water levels beneath the irrigated areas to rise. In some areas the rise was 10 feet or more in a few years. As a result, water levels beneath almost all the irrigated land were close enough to the surface to impair the productivity of the crops or to cause abandonment of the land. A system of drains eventually kept water levels at an acceptable depth below land surface beneath most of the irrigated areas. By 1957 the water level beneath only about 10 percent of the irrigated land was less than 4 feet below land surface, and beneath most of the irrigated land it was more than 6 feet below land surface. A map showing the depth to water beneath the flood plain of Parker Valley as of 1961, prepared by the U.S. Bureau of Reclamation (1963, pl. 3), shows that beneath, and adjacent to, the principal irrigated areas the depth to water generally is between 5 and 10 feet, although beneath some 6,000 acres it is less than 5 feet.

In the area of natural vegetation in the southern half of the valley between the irrigated land and the river, the depth to water generally is between 10 and 15 feet. As this land is cleared and irrigated, it can be anticipated that water levels beneath the newly irrigated land will rise and that within a relatively few years a system of drains to maintain a satisfactory depth to water for crops will be needed.

The depths to ground water beneath the terraces bordering the flood plain are thought to be relatively unchanged from natural conditions. The depths to water can be estimated on the basis of the elevation of the land surface at a particular site and the estimated elevation of the nearest water-level contour shown on plate 5.

PALO VERDE AND CIBOLA VALLEYS

GROUND WATER UNDER NATURAL CONDITIONS

The occurrence and movement of ground water under natural conditions in Palo Verde and Cibola Valleys probably were similar to the occurrence and movement of ground water in the Parker Valley. The only major source of water was the Colorado River, which rose to flood stage late each spring. Low areas, sloughs, and swamps probably were flooded every year, but extensive additional areas were flooded only in years of exceptionally high runoff.

An indication of the types of vegetation that were dominant under natural conditions can be obtained from the accounts of the early investigators of the water resources of these valleys. Brown (1923, p. 243) states that in 1917 the natural flood-plain land, where it had not been cleared, supported a rank growth of vegetation that fed on ground water. In some areas the growth consisted almost entirely of dense growths of mesquite; at other places, of saltbush and arrowweed; and at still other places, of dense thickets of willows. Salt grass also was rather widespread. He also mentions the many lagoons and the cane thickets that bordered them.

It is unlikely that any significant acreage of saltcedar existed as early as 1917, for Brown (1923) did not include the species in his description of the vegetation. Robinson (1958, p. 70) notes that prior to 1915, collections of the species, *Tamarix gallica*, tamarisk, or saltcedar, in the United States were made only infrequently. Saltcedar is a very aggressive, adaptable, and spreading shrub, and since its introduction to the United States, it has spread rapidly and infested large areas of river bottom and low lying ground in Arizona, southern California, New Mexico, and Texas. Therefore, the rather extensive areas of saltcedar that now exist in these valleys probably developed within the past 50 years or less. The natural vegetation that the saltcedar replaced is not known, but it probably was arrowweed and, to a limited extent, mesquite. The significance of the replacement lies in the fact that saltcedar uses ground water at a considerably higher rate than the vegetation it replaced.

The flood-plain boundaries under natural conditions probably were much the same as exist at present (pl. 5). If so, about 114,000 acres in Palo Verde Valley and about 19,000 acres in Cibola Valley comprised the flood plain, most of which supported the growth of natural vegetation. Both the reports by the early investigators and the study by the U.S. Bureau of Reclamation (1963) as to the types, occurrence, and rates of use of various species of natural vegetation suggest that the rate of use of ground water by natural vegetation prior to agricultural development averaged about 2 feet per year. If, on the average, one-half this use is assumed to have been derived from soil moisture resulting from the annual flooding of the Colorado River, 1 foot per year would need to be derived from the infiltration of water directly from the Colorado River into the ground-water system. The magnitude of this infiltration thus would average about 114,000 acre-feet annually for the reach of the river bordering Palo Verde Valley, and about 19,000 acre-feet annually, for the reach bordering Cibola Valley.

The movement of ground water through the valleys was away from the Colorado River to the principal areas of ground-water discharge, the phreatophyte areas, combined with a southward gradient that was controlled by the gradient of the river. Ground water from tributary areas tended to maintain gradients toward the flood plain and thus prevented extensive movement of ground water away from the flood plain.

HISTORICAL DEVELOPMENT OF IRRIGATION

The first notice of appropriation to divert water from the Colorado River to irrigate land in Palo Verde Valley was made on July 17, 1877, by Thomas H. Blythe. The "Blythe Rancho," as it was called, consisted of 40,000 acres of land in the north-central part of the valley acquired under the Swamp and Overflow Act (Palo Verde Irrigation Dist., 1961). A gravity intake structure diverted water from the river. Blythe irrigated only a part of his holdings because he was primarily interested in the raising of livestock.

In 1904 the Palo Verde Land and Water Co. purchased the Blythe holdings and embarked on a program of furthering agricultural development, which was seriously hindered by destructive floods on the Colorado River. In 1908 the Palo Verde Mutual Water Co. was organized. The existing diversion works, canals, ditches, levees, and water rights of the Palo Verde Land and Water Co. were exchanged for 60 percent of the stock of the mutual company. The mutual company proposed the extension of the existing irrigation system to include the reclamation of some 60,000 acres of land in addition to the Blythe lands. Agricultural development in the valley was given added impetus in 1910 when all Government land in the valley was opened for entry under the homestead and desertland entry laws.

Brown (1923, p. 244) states that by 1912 some 12,000 acres was being irrigated. At that time the Palo Verde Canal was capable of carrying sufficient water to irrigate 20,000 acres; also, some levees had been built for protecting the lands from floods. In 1917 the principal crops were alfalfa, cotton, milo, maize, and other small grain.

The Palo Verde Joint Levee District was organized in 1918 for the purpose of extending the levee system to protect further the lands against flooding by the river. In 1921 the Palo Verde Drainage District was organized. Bonds were issued to finance a system of drains that proved to be effective in lowering water levels where they had become excessively high.

The final major period of agricultural development began in 1923 upon the passing of a special act by the California legislature which created the Palo Verde Irrigation District. Under the act, the duties and functions of the levee and drainage districts were combined into one organization. The act also authorized the irrigation district to acquire the properties and rights of the Palo Verde Mutual Water Co. In 1925 this authorization was exercised and since then the Palo Verde Irrigation District has been the sole operating agency in the Palo Verde Valley.

Development of irrigation in the valley proceeded steadily after 1938, according to the U.S. Bureau of Reclamation (1953) and various reports of the Palo Verde Irrigation District subsequent to 1950. Irrigated acreages for the years 1914–65 are shown in figure 29.

For any one year during the period 1959–64, between 25 and 30 percent of the acreage was in alfalfa; about 20 percent in cotton; 10–15 percent in barley; about 10 percent in cantaloupes or lettuce; and between 5 and 10 percent in milo or maize.

The development of irrigation in Cibola Valley is not so well documented as it is for Palo Verde Valley. A small amount of land, probably less than 50 acres, was irrigated from near the turn of the century to

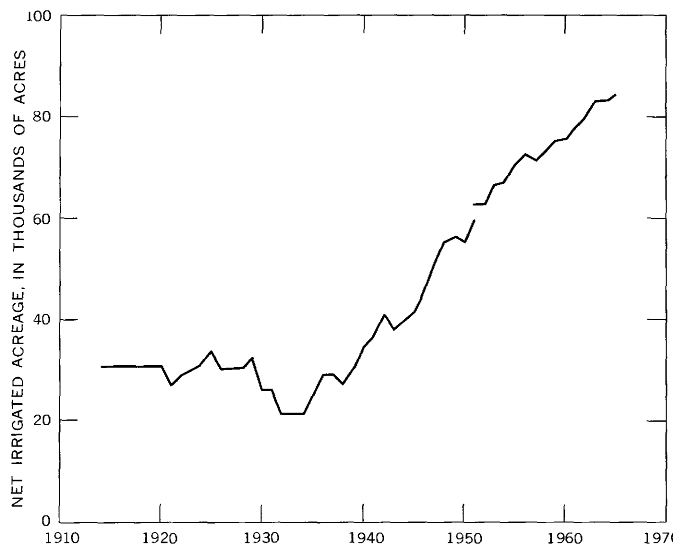

FIGURE 29.—Net irrigated acreage, in Palo Verde Irrigation District, 1914–65. Irrigated acreage 1914–51, inclusive, obtained from U.S. Bureau of Reclamation (1953) report; 1951–65, inclusive, from crop reports by Palo Verde Irrigation District.

the 1940's. By 1951, according to a U.S. Geological Survey topographic map (Cibola, Ariz.–Calif., 1951) showing culture as of that date, about 1,300 acres were cleared. Another topographic map prepared by the Geological Survey at a later date indicates that in 1955 some 3,500 acres had been cleared. On the basis of maps prepared by the U.S. Bureau of Reclamation (1963), it is estimated that in 1962 about 5,800 acres, or somewhat less than one-third of the land in the flood plain, was being irrigated. Aerial photographs of the valley in April 1964 indicate a like amount of acreage being irrigated or having been cleared for irrigation at that time.

Practically all the irrigation in both Palo Verde and Cibola Valleys was accomplished by diverting water from the Colorado River. The only area where any substantial amount of ground water has been pumped for irrigation is Palo Verde Mesa. Prior to 1950 the pumpage was insignificant. In 1965 about 200 acres of land was irrigated by pumping. In 1965 and 1966 a large number of irrigation wells were drilled as part of the procedure for acquiring Federal land under the desertland entry laws. Several irrigation wells also were drilled on privately owned land. It is anticipated, therefore, that the pumpage from wells on Palo Verde Mesa will increase substantially within the next few years.

GROUND WATER IN RECENT YEARS

Almost all the available land in the valley part of the Palo Verde Irrigation District has been irrigated in recent years. In 1962 the canal system of the Palo Verde Irrigation District consisted of 295 miles of main canals and laterals with capacities ranging from 30 to 2,100 cfs (Palo Verde Irrigation Dist., 1962). The drainage system consisted of more than 150 miles of open drains and more than 50 miles of tile drains. In general, hydrologic conditions in Palo Verde Valley are tending to stabilize under the almost full development of an agricultural economy based on irrigation with Colorado River water.

Water-level contours in the Palo Verde Valley and the Cibola Valley area in 1964 are shown on plate 5. The map was compiled from data furnished by the Palo Verde Irrigation District which included the elevations of water levels in more than 200 observation wells within the district boundaries; from water levels in the observation well network of the U.S. Bureau of Reclamation in Cibola Valley and the southwestern part of Palo Verde Valley in Imperial County, Calif.; and from water levels in wells outside the area covered by the above networks. The latter wells included shallow wells in the Palo Verde Valley east of the Colorado River drilled and periodically measured by the U.S. Geological Survey, and about 30 privately owned wells, principally on Palo Verde Mesa. The elevations for all the wells, except those on Palo Verde Mesa, probably are correct within a few tenths of a foot. The vertical control for wells on Palo Verde Mesa is the topography and other data shown on U.S. Geological Survey topographic maps, 7½-minute series. Elevations of water levels beneath Palo Verde Mesa, as shown on plate 5, may differ by several feet from the actual elevations, but the general configuration of the water surface is believed to be correct.

The contours show the ground-water mounds that result from irrigation with surface water and also the effectiveness of the drains in many areas in controlling the buildup and spreading of the mounds. The effectiveness of the main drain in the southern part of Palo Verde Valley in lowering water levels is particularly evident.

Much of the recharge to ground water from irrigation is captured by the drains; some returns directly to the Colorado River, and some, either from irrigation or leakage from the main canals, moves westward under Palo Verde Mesa and then south and southeastward as it returns to Palo Verde Valley. Whether ground water from Palo Verde Valley moves as much as 4 or 5 miles westward beneath the mesa as indicated by the contours is not certain because of the lack of precise vertical control in the mesa area. The contours indicate that gradients under that part of the mesa lying north of Blythe are relatively flat, which, in turn, suggests that the aggregate water-transmitting ability of the deposits is relatively good. Additional information, such as that provided by strategically located test wells together with precise water-level elevations, is needed to define better the movement of ground water beneath the mesa.

Ground water from irrigated land near the river in the Palo Verde Valley between Palo Verde Dam and Ehrenberg, Ariz., moves toward the Colorado River, and in some areas eastward beyond the river. However, the amount of ground water that is moving toward and beyond the river is difficult to determine because ground-water gradients and transmissivities are not sufficiently well known. One measure for estimating the movement of ground water eastward from the river is the yearly amount of evapotranspiration from the flood plain east of the river between Palo Verde Dam and Ehrenberg. The report of the U.S. Bureau of Reclamation (1963, p. 44) indicates that in this area phreatophytes were using almost 37,000 acre-feet of water annually. Except for about 2,000 acre-feet that was available because of the irrigation of some 780 acres of land by pumping from the river, and except for the amount by which inflow to the area across the northern boundary and from tributary areas eastward exceeds the outflow across the southern boundary, a difference of a few thousand acre-feet at most, the evapotranspiration requirements must be met either by infiltration from the river or by movement of ground water from beneath irrigated lands west of the river. Therefore, the movement of ground water away from the river in the reach north of Ehrenberg probably is about 30,000 acre-feet per year. How much of this movement is derived from infiltration of river water and how much is derived from ground water west of the river are not known.

Southwestward from a point about 4 miles south of Ehrenberg, where the river is against the east side of the flood plain, ground-water gradients from the irrigated land west of the river are definitely toward the river for a distance of about 5 miles. As there is no appreciable discharge of ground water east of the river, the ground water is probably discharging to the river. A few miles farther downstream, the direction of the movement is reversed. Near the south line of T. 8 S., R. 22 E., the ground-water gradients are away from the river toward the irrigated lands of the Palo Verde Valley. It appears that the Borrow Pit Drain receives water from the river where both the drain and the river traverse westward across the valley on generally parallel courses slightly more than a mile apart. After the river again swings sharply southward, it continues to lose water for a distance of 4 or 5 miles, either to the Borrow Pit Drain or to the Outfall Drain into which the Borrow Pit Drain discharges.

In the northern part of Cibola Valley the water-level gradients are toward the river in the same reaches that the gradients are away from the river toward the Borrow Pit Drain in Palo Verde Valley. It is possible, therefore, that some water from Cibola Valley may pass beneath the river and discharge into the Borrow Pit Drain.

In the southern half of Cibola Valley all the ground-water gradients are away from the river toward an area of low water levels that appears to be centered about 1½ miles southwest of Cibola. The low water levels underlie the central part of a rather large area of vegetation that is bounded to a large extent either by the river or irrigated land. The area of low water levels probably results from the discharge of ground water by phreatophytes. The magnitude of the movement of water from the river to the ground-water system is indicated by the consumptive use of the natural vegetation in the area. It is estimated that about 7,000 acres were supporting the growth of phreatophytes in 1962. Much of this natural vegetation was saltcedar or arrowweed for which the average rate of use of ground water was about 4.5 feet per year, indicating that the discharge of ground water was about 30,000 acre-feet per year. A few thousand acre-feet of this ground-water discharge may have been derived from excess irrigation water, and an even smaller amount from inflow from tributary areas to the east, but 20,000–25,000 acre-feet were probably derived from infiltration of river water. Much of the infiltration appears to have occurred in an 8-mile reach of the river, which suggests rates of 2,500–3,000 acre-feet per year per mile of river channel.

GROUND WATER IN FUTURE YEARS

Most of the land in the flood plain of Palo Verde Valley is being irrigated and is served by an extensive and adequate drainage system. As long as the economy of the area is principally agricultural based on an ample supply of surface water for irrigation, ground-water conditions in the foreseeable future will be much the same as they are at present. Additional development of irrigation in Cibola Valley may result in substantial amounts of ground water being pumped for either irrigation or drainage.

The net depletion of water that results from the irrigation of new lands depends on the extent to which the consumptive use owing to the new development exceeds the consumptive use that existed previously. For example, bringing new land into cultivation in the flood plain probably would result in little, if any, additional depletion of water because the consumptive use by crops may be little, if any, more than the consumptive use by the natural vegetation that is replaced. On Palo Verde Mesa, on the other hand, the consumptive use by crops will result almost wholly in additional depletion because the consumptive use on the mesa on undeveloped land is negligible.

The available supply of water during years of short supply of surface water can be augmented temporarily by pumping ground water from storage. The net gain in water from such pumpage consists of the gross pumpage and the decrease in evapotranspiration losses, reduced by the amount of the decrease in return flows from drains and the increased infiltration from the river that results from the pumping. For these reasons, pumping ground water to augment temporarily the available supply will be most effective when the pumping is done in areas that are as far removed from drains, either manmade or natural, as hydraulic and economic conditions will permit.

Additional water can be made available for beneficial use on a perennial basis by taking measures to reduce the consumptive use of water by phreatophytes having little or no economic value, or by substituting crops for the phreatophytes. Conservation measures are currently in progress by various Government agencies in connection with improvements in the alinement and the channel dimensions of the Colorado River and in the deepening of drains. These and other measures for salvage of water will increase as the demands for the beneficial use of water approach the available supply.

WATER-LEVEL FLUCTUATIONS

Throughout most of the irrigated land in the flood plain, especially in Palo Verde Valley, water levels are controlled by drains to the extent that the amplitude of annual fluctuations is commonly only a few feet. Minimum stages ordinarily occur just prior to the irrigation season, and maximum stages, near the end of the season.

In areas not directly influenced by irrigation or changes in river stage, water levels fluctuate in response to transpiration by natural vegetation, the amplitude of the fluctuations rarely exceeding 2 feet annually. Maximum stages occur in early spring followed by declines to minimum stages, generally in September, followed by gradual recoveries during the winter months.

Water levels in wells that are half a mile or less from the river commonly fluctuate in response to changes in stage of the river in a manner similar to those in the Parker Valley. If the well is within a few hundred feet of the river, the response may be delayed only a few hours and may represent a major part of the change in stage of the river. At greater distances the short-term response is less in magnitude and may disappear altogether. However, the influence of seasonal changes in river stage in some instances may be identified by corresponding changes, but of considerably less amplitude, at distances of a mile or more from the river. River stages between the gaging stations below Palo Verde Dam and the station below Cibola Valley commonly have an annual amplitude of between 4 and 6 feet, the maximum stages occurring from April through July, and the minimum stages, in December and January.

In many of the observation wells in Cibola Valley and in areas outside the Palo Verde Irrigation District, the pattern of water-level fluctuations is a combination of the effects of changes in river stages, irrigation, and consumptive use by phreatophytes. Rarely does the resultant effect exceed 3 feet, except when irrigation is the dominant cause of the fluctuations. In Cibola Valley, in areas where the drainage of irrigated lands is not adequate, water levels beneath, or adjacent to, irrigated areas rise 4 or 5 feet during the irrigation season after which they recede, commonly to levels a foot or so higher than existed at the beginning of the season.

DEPTH TO GROUND WATER

The average depth to water beneath the irrigated lands within the Palo Verde Irrigation District in 1962 was 6.5 feet below land surface, or about 0.3 foot greater than in 1961 (Palo Verde Irrigation Dist., 1962). Furthermore, the 1962 annual report states that the rehabilitation of the Palo Verde Lagoon and Outfall Drain by dredging, which was begun by the district in January 1960, was effectively lowering water levels.

Deepening the Outfall Drain and the drains emptying into it, together with the river channel alinement improvements that have been made since 1962, or are yet to be completed, will cause water levels beneath much of the southern part of the valley to stabilize at levels several feet lower than would otherwise occur.

In 1962, water levels in the northern part of Cibola Valley generally were only 5 feet or so below land surface, probably owing to a rise of water levels resulting from irrigation with river water. In the southern part of the valley, water levels averaged 10 feet below land surface.

Depths to water in alluvial deposits outside the flood plain are dependent in large measure on the height of the land surface at a particular site above the water level in the adjacent flood plain. The depths to water generally range from 70 to 300 feet below land surface.

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WATER BUDGETS

A water budget is a convenient means of accounting for the water supply of a given area. It is based on the principle that inflow minus outflow or minus changes in storage equals consumptive use.

In the present study, changes in storage are neglected for reasons given in the discussion of budget items (p. 63). Inflow minus outflow is separated into measured and unmeasured components. The measured component is the streamflow depletion. The unmeasured component is the difference between the sum of unmeasured runoff and ground-water inflow and the ground-water outflow. The components are added to obtain the total inflow minus the total outflow. The various consumptive-use values are also listed and totaled. Any difference between total inflow minus total outflow and the total consumptive use is shown as an imbalance.

The budgets are presented in the form described above because the reliability of the mean annual streamflow depletion, which is measured inflow less measured outflow, has been analyzed (Loeltz and McDonald, 1969). Budget imbalances, therefore, can be evaluated on the basis of imbalances to be expected because of variations of annual streamflow depletions.

The various items of a water budget and their reliabilities are discussed in the following sections, after which a budget for Parker Valley and a combined budget for Palo Verde and Cibola Valleys are presented.

STREAMFLOW DEPLETION

Streamflow depletion is the difference between streamflow measurements made at the upper and lower ends of a given reach. Although streamflow measurements are subject to errors as are any other physical measurements, the U.S. Geological 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 that result in streamflow-measurement figures being consistently too high or too low.

Table 1 shows the average annual discharge and depletion of the Colorado River for the period 1957–66, inclusive, the period of record for the three gaging stations in the area maintained by the Geological Survey.

From the table, the average annual flow of the Colorado River through each of the two principal subreaches is seen to be about 20 times the depletion in either reach. Consequently, any percentage error of

TABLE 1.—*Average annual discharge and depletion (in 1,000 acre-feet) of Colorado River, 1957–66*

Calendar year	Discharge, Colorado River below—			Depletion	
	Parker Dam	Palo Verde Dam [1]	Cibola Valley	Parker Dam to Palo Verde Dam	Palo Verde Dam to gaging station below Cibola Valley
1957	7, 997	7, 783	7, 342	214	441
1958	10, 890	10, 730	10, 350	160	380
1959	8, 186	8, 097	7, 689	89	408
1960	7, 794	7, 452	7, 063	342	389
1961	6, 975	6, 703	6, 350	272	353
1962	7, 159	6, 831	6, 460	328	371
1963	7, 251	6, 904	6, 504	347	400
1964	6, 652	6, 236	5, 948	416	288
1965	6, 356	5, 998	5, 777	358	221
1966	6, 680	6, 258	5, 895	422	363
Average	7, 594	7, 299	6, 938	295	361

[1] Includes diversions to Palo Verde Canal.

streamflow measurement at the end of a reach causes about 20 times that percentage error in the computed depletion of the reaches just upstream and downstream.

This sensitiveness of computed depletions to streamflow-measurement errors can be reduced by considering several subreaches as a single reach, because the depletions then will be a larger percentage of the streamflow. This technique was used by Loeltz and McDonald (1969) in a study of the depletions of the Colorado River between Davis and Imperial Dams for the period 1950–66, inclusive. The results of that study, as they pertain to water budgets for Parker, Palo Verde, and Cibola Valleys, are used in the present study.

The annual streamflow depletions vary considerably from year to year and cover a rather wide range (table 1; fig. 30). Some of the yearly variations are due to errors of measurement; some are caused by differences in temperature and precipitation; and some, by differences in agricultural practices.

UNMEASURED RUNOFF

Unmeasured runoff is a budget item that is especially difficult to evaluate because it 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. Measurement of the runoff from these areas is impractical because the runoff is infrequent and of short duration. It may range from a negligible amount in extremely dry years to many times the long-term annual average in relatively wet years, a range of several hundred thousand acre-feet for the study area. Consequently, it can cause rather large differences in annual streamflow depletions.

Hely (Hely and Peck, 1964) prepared a map showing the estimated mean annual runoff from small tracts (10–20 sq mi) which included the present study area. Hely estimated runoff on the basis of precipitation data, rainfall-runoff relations, and character of the terrain, with no adjustment for absorption of runoff in the alluvium. The local runoff rates shown by Hely, therefore, need to be adjusted downward if they are to be used to compute runoff at a section downstream from an area or reach where a significant part of the local runoff infiltrates into the alluvium.

Moore (1968) proposed a method for estimating runoff on the basis of channel geometry and precipitation-altitude relationships. Although no estimates of mean annual runoff based on this method are available for the Parker-Blythe-Cibola area, runoff rates for several small drainage areas in Sacramento Valley (fig. 1) about 60 miles north of the study area, have been determined (D. O. Moore, written commun., 1968). A comparison of local runoff rates for Sacramento Valley, as indicated by Hely, with rates indicated by the channel geometry method prepared by Moore shows large differences, even in the mountains where the two methods should give comparable results. 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 Valley and that from several of the larger long and narrow tributary areas of the Parker-Blythe-Cibola area, the runoff as computed from rates of local runoff must be reduced even more—perhaps to only 5 or 10 percent of the rates shown by Hely.

Estimates of average annual runoff to the flood plain of the Colorado River or to the river itself from various subareas of the study area, as determined on the above basis, are given in table 2. The above estimates are considerably less than 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 considerably lower percentages where the runoff originates in large nar-

TABLE 2.—*Summary of estimated average annual local runoff to the flood plain of the Colorado River*

Subarea	Runoff (acre-feet)
Colorado River valley:	
Dome Rock Mts.–Trigo Mts.–Chocolate Mts	16, 200
Whipple Mts	2, 300
Big Maria Mts.–Riverside Mts	2, 300
Palo Verde Mts.–Mule Mts	1, 200
Tributary areas:	
Vidal Wash	1, 300
McCoy Wash	800
Milpitas Wash	1, 200
Bouse Wash	4, 800
Tyson Wash	2, 600
Total runoff	32, 700

row 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.

GROUND-WATER INFLOW

Ground-water inflow is not measurable directly. One basis for computing it is to multiply the estimated transmissivity of the section across which the flow is occurring, by the width of the section, and by the hydraulic gradient normal to the section. Rarely are all these factors known precisely, but often they can be estimated within reasonable limits.

For example, the underflow at the gaging station below Parker Dam is estimated on the above basis to be less than 1,000 acre-feet per year, and therefore, negligible as an inflow water-budget item for Parker Valley. On the other hand, the underflow in the river valley near Palo Verde Dam is estimated at about 3,000 acre-feet per year, and is shown as an inflow item for the water budget for Palo Verde and Cibola Valleys.

If ground-water inflow is derived principally from precipitation, it can be estimated on the basis of ground-water recharge from that precipitation. 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 proven satisfactory for reconnaissance ground-water studies in that State. The method assumes that ground-water recharge is generally related to average annual precipitation in the following manner:

Average annual precipitation (inches)	Percent of precipitation that contributes to ground-water recharge
More than 20	25
15–20	15
12–15	7
8–12	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, thereby providing 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 rainstorms. 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 to central Nevada, one-half the percentages of precipitation shown in the preceding table are used in the present study for computing ground-water recharge from precipitation.

Maps prepared by Hely and Peck (1964, pl. 3) show that only small parts of three subareas receive an average of 8 inches or more of precipitation. Applying one-half the percentages given in the preceding table to the areas of their respective precipitation zones indicates that the average annual ground-water recharge in the subarea drained by Bouse Wash is 1,200 acre-feet; in the subarea drained by Tyson Wash, 350 acre-feet; and in the subarea drained by Vidal Wash, 250 acre-feet. Because this recharge is not consumed in the subareas, it is also a measure of the ground-water inflow to the Colorado River valley.

The above figures are one-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. This difference does not materially change any of the conclusions that were reached in the earlier study because ground-water recharge is very 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 areas in the flood plain is computed as the product of ground-water gradient, width of saturated section, and transmissivity of the water-bearing material. It is considered negligible, except for Parker Valley.

CONSUMPTIVE USE BY NATURAL VEGETATION

The consumptive use of water by natural vegetation is one of the larger budget items. Estimates of this use are based on studies made by the U.S. Bureau of Reclamation (1963), supplemented by estimates of use for areas that were not included in the Bureau of Reclamation study. The estimates of the Bureau 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 U.S. Geological Survey in Safford Valley, Ariz. (Gatewood and others, 1950). No K coefficients for saltbush or carrizo cane were available, so coefficients that had been determined for comparable vegetation were used.

To obtain additional data on water use by natural vegetation, the Geological Survey, in cooperation with the Bureau of Reclamation, in 1961 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 the first 4 years of the study (Hughes and McDonald, 1966) 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 55 percent of the coefficient that was used by the Bureau of Reclamation. Additional studies are needed to verify these differences.

If the differences are as great as preliminary results indicate, the estimate of consumptive use of water by arrowweed in Parker Valley as given would need to be increased about 25,000 acre-feet per year, and in Palo Verde and Cibola Valleys, about 7,000 acre-feet per year; the estimate of use by saltbush would need to be lowered less than 1,000 acre-feet per year.

Hughes and McDonald (1966) questioned whether the Blaney-Criddle use factor tends to be a constant for all types of phreatophytes. Should it not, the applicability of the Blaney-Criddle method would be reduced. Current research (Robinson, 1964) is accumulating additional data on these and other factors which may influence the rate of water use, especially by saltcedar and arrowweed.

CONSUMPTIVE USE BY CROPS

The estimated use of water by crops is a major item of the water budget. Records of annual acreages of irrigated crops are available for lands in the Palo Verde Irrigation District and the Colorado River Indian Reservation. However, the amount of double cropping that was done, or the amount of duplication in reporting crops under various categories, is not always ascertainable.

Blaney and Harris (1952) derived rates of consumptive use of irrigation water by most crops grown in the study area. Using these rates, the Bureau of Reclamation estimated that the average annual rate of use by crops in the Parker and Palo Verde Valleys during the period 1914–45, inclusive, was 3.2 acre-feet per acre. Loeltz and McDonald (1969), using the same rates, computed the average annual rate of use by crops grown in the study area during the period 1959–62, inclusive, to be 3.4 acre-feet per net acre irrigated.

The two rates of use are not strictly comparable because the first is the rate for the gross acreage of crops, whereas the second is the rate for net irrigated acreage. Therefore, part of the difference is due to double cropping, and part is due to differences in the kinds of crops grown during the two periods.

In addition to the aforementioned uncertainties that affect the reliability of an estimate of consumptive use by crops, there is some question about the preciseness of the K factors that are used in the Blaney-Criddle formula. K factors for some crops as proposed by Erie, French, and Harris (1965) differ significantly from K factors proposed by Blaney and Harris (1952). The factors proposed in 1965 were computed on the basis of consumptive use by crops under irrigation practices which resulted in optimum yields. The investigation was carried on over a period of many years on private farms and University of Arizona Experiment Station farms near Tempe and Mesa, Ariz. Consumptive use was computed from gravimetric soil-moisture measurements on soil samples taken at depths and locations that were thought to be adequate for evaluating the average soil-moisture distribution and the depletion of soil moisture by the crops that were studied.

The more significant differences in values of the K factors between those proposed in 1952 and in 1965 are an increase of about 40 percent for alfalfa and barley, and about 25 percent for cotton. The significance of the difference in K values is shown by typical consumptive-use estimates for the Palo Verde Irrigation District for 1961 as computed by C. C. McDonald (written commun., 1967) using K values proposed by Blaney and Harris (1952), and K values proposed by Erie, French, and Harris (1965). In the first instance, the net consumptive use is 262,000 acre-feet and the average rate of use, 3.4 feet per year; in the second instance, the use is 365,000 acre-feet and the rate of use, 4.7 feet per year. Similar differences in average rates of consumptive use were obtained for the years 1960 and 1962. Rates for crops grown in the Colorado River Indian Reservation in Parker Valley during the period 1960–62, inclusive, averaged about 3.4 feet per year using K values proposed in 1952, and about 4.2 feet per year using K values proposed in 1965.

Because of the uncertainties about rates of consumptive use by various crops, the selection of a specific rate of use necessarily is somewhat arbitrary. Loeltz and McDonald (1969), recognizing these uncertainties, used an average annual rate of 3.6 acre-feet per acre for estimating consumptive use of irrigation water by crops grown in the lower Colorado River valley for the period 1961–63. This rate is used in the present study. The rate is somewhat higher than the rates obtained by using K values proposed by Blaney and Harris (1952), and less than the rate based on K-factor values proposed by Erie, French, and Harris (1965). The values of the latter K factors were reduced because, as was stated above, they were determined for crops grown under irrigation practices that provided optimum yields. Many of the crops in the study area are grown under less favorable conditions, and therefore, their consumptive use is inferred to be less than would be indicated by using the full value of the K factors proposed in 1965.

CHANGES IN GROUND-WATER STORAGE

Changes in ground-water storage are indicated by changes in water levels in wells. With an adequate network of observation wells and knowledge of the amount of water represented by an observed change in water level at each site, changes in the amount of ground water in storage can be computed rather accurately. Significant changes in the trend of water levels over rather large areas for a period of a few years ordinarily result only from major changes in (1) the amount of land irrigated, (2) drainage systems, (3) the river-channel alinement or profile, (4) pumpage, or some combination of the above changes. Major changes of the above type, except for pumpage, have occurred in parts of the study area at one time or another, and consequently, there have been periods of a few years when the change in ground-water storage in a major subarea may have amounted to several tens of thousands of acre-feet per year. However, in a few years following any of the above events, the year-to-year changes in ground-water storage become insignificant because a new equilibrium is established.

The change in the ground-water-storage item of a water budget for the study area therefore might be significant in a given reach if the budget is for a period of only a few years. For periods of 10 years and more this item is insignificant compared to the other items of the budget, and therefore is disregarded.

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 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 lake evaporation near the Colorado River 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 annually. The area of free water surface, principally the river, was computed from aerial photographs.

PARKER VALLEY, AND PALO VERDE AND CIBOLA VALLEYS

The factors that are used for computing the values of most of the water-budget items for Parker Valley (table 3), and for Palo Verde and Cibola Valleys (table 4) are either indicated in the budget or the basis for the values given has been explained in the discussions of budget items. Some of the budget items are average values because the average value can be estimated more reliably than values for individual years. However, the estimated use of water by natural vegetation and crops is shown for the period 1961–63, inclusive, because this period centers about the only known year for which a detailed survey of the natural vegetation is available.

The budgets are presented in a form that shows the average annual measured depletion of the Colorado River as it passes through the above valleys. To this depletion is added the unmeasured depletion, consisting of unmeasured inflows less unmeasured outflows, to obtain an estimate of water use in the budget area based on inflow and outflow items. Water use in the area is also shown as the sum of all consumptive-use and evaporation estimates. The imbalance, which is the difference between the two estimates of water use, is shown as the last item of the budgets.

Many of the budget items also are shown in figure 30, which consists of graphs of the annual streamflow depletions, the average of these depletions, the consumptive-use estimates, and the net unmeasured inflows

TABLE 3.—*Water budget for Parker Valley* [1]

Budget items	Amount (acre-feet per year)
Inflow-outflow:	
Measured inflow minus measured outflow: Average annual streamflow depletion, 1957–66 (fig. 30)	295,000
Unmeasured inflow minus unmeasured outflow:	
Unmeasured inflow (average):	
Runoff	6,000
Ground water from tributary areas	2,000
Ground water from upstream reach	(2)
Total unmeasured inflow	8,000
Minus:	
Unmeasured outflow (average): Ground water flow across lower boundary [3]	3,000
Total unmeasured inflow minus unmeasured outflow	5,000
Total inflow minus total outflow	300,000
Consumptive use:	
Natural vegetation [4] (1961–63)	167,000
Irrigated crops [5] (1961–63)	118,000
Evaporation	22,000
Total consumptive use	307,000
Imbalance: Difference by which inflow minus outflow is less than consumptive use	7,000

[1] Excludes 9,230 acres south of Palo Verde Dam, which are in the reach of the Colorado River, Palo Verde Dam to gaging station below Cibola Valley.
[2] Negligible.
[3] Assuming transmissivity of 0.5 mgd per ft, hydraulic gradient of 2 ft per mile, and effective width of 3 miles.
[4] 71,000 acres at 2.3 ft per yr plus 1,000 acres at 3.6 ft per yr.
[5] 31,040 acres in Colorado River Indian Reservation plus 1,640 acres outside reservation.

TABLE 4.—*Water budget for Palo Verde* [1] *and Cibola Valleys*

Budget items	Amount (acre-feet per year)
Inflow-outflow:	
Measured inflow minus measured outflow: Average annual streamflow depletion, 1957–66 (fig. 30)	361,000
Unmeasured inflow minus unmeasured outflow:	
Unmeasured inflow (average):	
Runoff	27,000
Ground water from tributary areas	(2)
Ground water from upstream reach [3]	3,000
Total unmeasured inflow	30,000
Minus:	
Unmeasured outflow (average): Ground water	(2)
Total unmeasured inflow minus unmeasured outflow	30,000
Total inflow minus total outflow	391,000
Consumptive use:	
Natural vegetation [4] (1961–63)	136,000
Irrigated crops [5] (1961–63)	321,000
Evaporation	20,000
Total consumptive use	477,000
Imbalance:	
Difference by which inflow minus outflow is less than consumptive use	86,000

[1] Includes 9,230 acres of land in Parker Valley that are in the reach of Colorado River, Palo Verde Dam to gaging station below Cibola Valley.
[2] Negligible.
[3] Assuming transmissivity of 0.5 mgd per ft, hydraulic gradient of 2 ft per mile, and effective width of 3 miles.
[4] 9,230 acres in Parker Valley at 3.6 ft per yr; plus 6,000 acres in Palo Verde Irrigation District at 4 ft per yr; plus 18,000 acres outside above areas at 4.4 ft per yr.
[5] 80,000 acres in Palo Verde Irrigation District plus 9,050 acres outside district.

to the subareas. Values of the 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.

It is seen that the imbalance for Parker Valley is very small relative to the quantities that comprise the budget, but that the imbalance of 86,000 acre-feet for Palo Verde and Cibola Valleys, is relatively large—about 20 percent of the estimated consumptive use. Some possible causes of an imbalance of this size are explored in the following discussion.

The extent to which annual variations in streamflow depletions might be responsible for imbalances was determined by Loeltz and McDonald (1969). They found that for the reach, Palo Verde Dam to gaging station below Cibola, there was an even chance that the annual variations of streamflow depletions might cause any 10-year mean to deviate as much as 15,000 acre-feet from a long-term or true mean, and that there was one

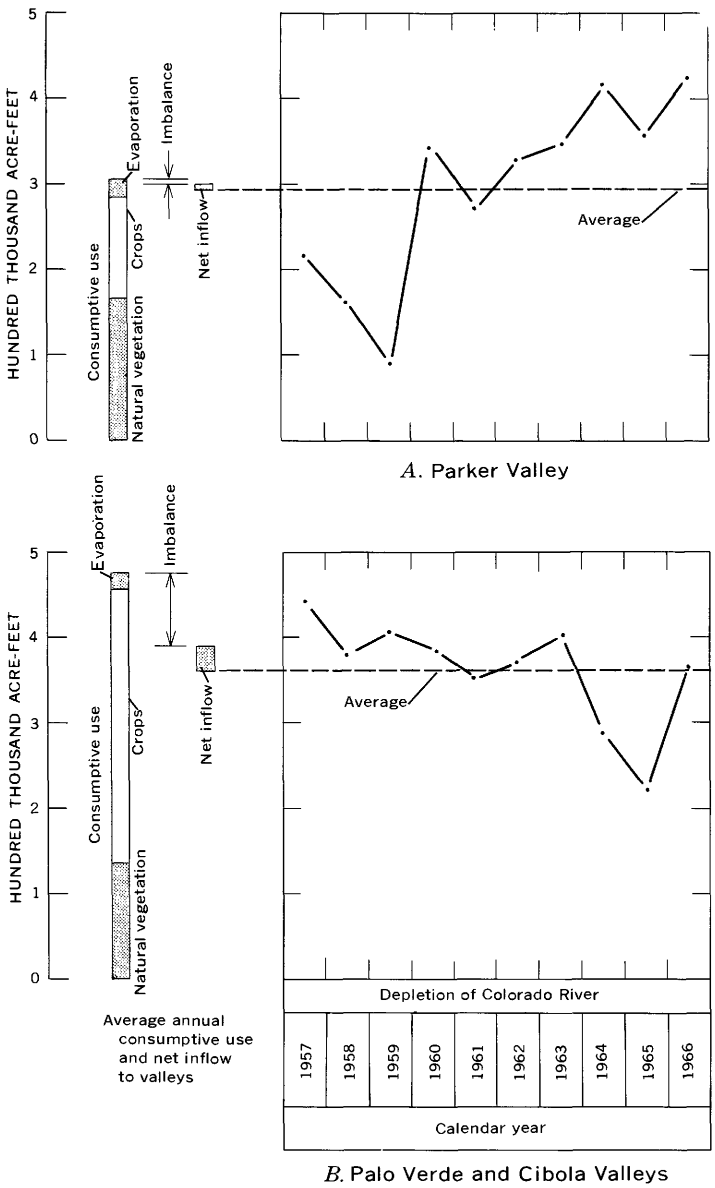

FIGURE 30.—Annual depletion of Colorado River, average consumptive use, and net inflow for Parker (exclusive of 9,230 acres below Palo Verde Dam), Palo Verde (includes 9,230 acres of Parker Valley below Palo Verde Dam), and Cibola Valleys.

chance in twenty that the deviation might be as much as 45,000 acre-feet. Computations made during the present study indicate that there is only one chance in a thousand that the deviation will be as much as 86,000 acre-feet. Other factors, therefore, are likely to be responsible for much of the imbalance.

The effects of small percentage errors in streamflow measurements on budget imbalances are considerable. Table 1 gives the average annual flow of the Colorado River through the study area as somewhat more than 7,000,000 acre-feet. Thus, an error of measurement of but 1 percent at any one gaging station will change the indicated depletion for the reach just above and below the gaging station by somewhat more than 70,000 acre-feet per year and will change the depletions relative to one another by more than 140,000 acre-feet per year. If it were postulated that streamflow measurements at Palo Verde Dam averaged 40,000 acre-feet below the true value, the budgets for each of the subareas would show imbalances of about 46,000 acre-feet, thereby reducing the original large imbalance of 86,000 acre-feet to a more reasonable value.

It is also apparent that small percentage errors in estimates of consumptive use can cause relatively large imbalances. For example, an error of 10 percent would cause an imbalance of almost 80,000 acre-feet.

The other budget items involving unmeasured runoff and ground-water recharge from tributary areas, although less reliable, percentagewise, than the streamflow measurements and estimates of consumptive use, are less likely to be responsible for large imbalances because they total only about 35,000 acre-feet.

In a further effort to evaluate which of any aforementioned errors might reasonably be responsible for the imbalance shown in table 4, water budgets for a like period were prepared for three other of the five subareas between Davis Dam and Imperial Dam which were studied earlier by Loeltz and McDonald (1969). A study of all five subareas showed that imbalances could be brought to reasonably low values by many different combinations of assumptions regarding the reliability of the various budget values. One set of assumptions that resulted in a virtual balance of all the budgets consisted of the following:

1. Estimates of consumptive use for native vegetation and crops as originally computed are too high by 15 percent.
2. Estimates of evaporation are too high by 10 percent.
3. Average streamflow records:

   Below Davis Dam are too high by 7,000 acre-feet;

   Near Topock are too high by 39,000 acre-feet;

   Below Parker Dam are too low by 21,000 acre-feet;

   Below Palo Verde Dam are too low by 53,000 acre-feet;

   At gaging station below Cibola are too low by 28,000 acre-feet; and

   At Imperial Dam are too high by 14,000 acre-feet.

Although the above assumptions seem reasonable, they are not necessarily true. In view of all the uncertainties regarding true values of the budget items, no attempt is made to adjust the budget values given in tables 3 and 4 to achieve balanced budgets. The budgets, whether adjusted or not, show the relative amount of water consumed by crops, natural vegetation, and evaporation.

PUMPING TESTS

Under favorable conditions, pumping tests are useful for determining the water-transmitting and water-storage properties of material tapped by wells.

In the present study, pumping tests were used to determine the water-transmitting property of water-bearing material but not its water-storage properties. Experience in other areas and attempts during the early stages of the present investigation had demonstrated that rarely, if ever, would the conditions under which the pumping tests were to be made be satisfactory for determining water-storage properties. Therefore, the storage property of water-bearing material beneath the flood plain was determined by means of a neutron moisture probe, as will be described in the following section.

Pumping tests are analyzed according to mathematical formulas which assume that the water-bearing material is homogeneous, isotropic, and sufficiently extensive that the effects of the discharge do not reach the outer boundaries of the system, and that the discharge is wholly water released from storage within the system. Furthermore, such release of water is assumed to be simultaneous with a drop in head resulting from the discharge. Hydrologic and geologic conditions in alluvial deposits rarely meet all these assumptions because alluvial deposits characteristically are heterogeneous and anisotropic. Nevertheless, experience has shown that under favorable conditions meaningful results can be obtained for tests involving alluvial deposits.

The ability of water-bearing material to transmit water is commonly designated by its transmissivity. In this study, transmissivity is expressed in gallons per day per foot and represents the number of gallons per day that will be transmitted under the prevailing temperature of the water through a cross-sectional area of the water-bearing material that is 1 mile wide and includes the full thickness of the aquifer under a hydraulic gradient of 1 foot per mile normal to the section.

Another measure of the water-transmitting property of rocks is the rate at which water is transmitted per unit area per unit gradient normal to that area. In the present study, this property is referred to as the hydraulic conductivity. It is equivalent to transmissivity per foot of thickness of the water-bearing material and is expressed as the number of gallons per day that is transmitted through a 1-foot-square section of the material under a hydraulic gradient of 1 foot per foot at the prevailing temperature of the water.

The hydraulic conductivity of individual strata yielding water to a well can be determined with reasonable accuracy by the following procedure if the transmissivity of all strata tapped by the well is known or can be estimated satisfactorily.

A current meter or other rate-of-flow measuring apparatus is used to determine the rates at which water enters the well from a particular stratum while the well is being pumped at a known rate of discharge. Then, assuming that the transmissivity of the stratum yielding a given flow bears the same relation to the total transmissivity of all the strata that yield water to the well as the flow from the stratum under study bears to the total flow, the transmissivity for the stratum under study is computed. Finally, the computed transmissivity is divided by the thickness of the stratum to obtain the hydraulic conductivity.

Where such surveys are not available, an average, although less reliable, hydraulic conductivity can be computed by dividing the transmissivity by the length of the screen or the total length of perforated casing. Hydraulic conductivities were computed on the basis of one of the aforementioned methods for most of the water-bearing material tapped by wells on which pumping tests were made (table 5).

Some water-bearing material, as commonly described in drillers' logs or that comprises a lithologic unit, may have a hydraulic conductivity range small enough so that a given hydraulic conductivity can be said to be typical of the material. Under these circumstances, the hydraulic conductivity can be used to compute transmissivity by multiplying the typical hydraulic conductivities by the corresponding thickness of the water-bearing units and summing the products. This method is also useful for estimating transmissivities where pumping tests pertain only to part of the total known thickness of the water-bearing material.

During the present study transmissivities usually were determined on the basis of the water-level response in a pumped well to changes in discharge rates, including cessation of pumping. For some tests it was possible to observe changes in water level with time while the well was being pumped, but for others it was more meaningful and practical to observe changes with time following the cessation of pumping.

Figure 31 shows graphs of changes in water level with time for pumping tests. The pattern of the changes versus time are typical of most of the results. The patterns for wells (B–9–19)5ddd and (B–7–21)31aaa are fairly close to the patterns that theoretically should be observed if the transmissivity is to be computed according to the following formula:

$$T=\frac{264(Q)}{\Delta s},$$

where T is the transmissivity, in gallons per day per foot; Q is the discharge of the well, in gallons per minute; and Δs is the intercept, in feet, of the water-level trend line over 1 log cycle of time.

The concave upward pattern for well 1S/24E–10Q1 is unusual. Commonly, the recovery pattern is convex upward. A concave upward pattern may result from any one of several boundary conditions, such as a partial hydraulic barrier, or a decrease in transmissivity with distance from the pumped well. The latter condition probably causes the concave upward recovery pattern for well 1S/24E–10Q1 because the water-bearing deposit tapped by the well is the older alluviums, which in this area have a saturated thickness of only about 100 feet and which lessen in thickness in a westward direction (fig. 15).

The more common convex upward patterns may result from failure of a well to penetrate fully the water-bearing material or from leakage to the strata tapped by a well from overlying or underlying strata.

Straight-line segments of various slopes as shown for well 6S/23E–29R1 commonly indicate the presence of hydraulic boundaries within the area of influence of pumping. Large well-entrance losses also tend to produce a pattern similar to that shown for the above well.

The results of 43 pumping tests made during the present study are summarized in table 5. Of special interest are the transmissivities that were computed on the basis of the pumping-test data and the estimated reliability of the transmissivity values.

The reliabilities are classed as either excellent, good, fair, or poor indicators of the transmissivity of the water-bearing material tapped by the wells. The classification takes into account the construction of the well; the possibility of leakage from one stratum to another by movement either within the well casing or a gravel envelope outside the casing; the storage capacity of

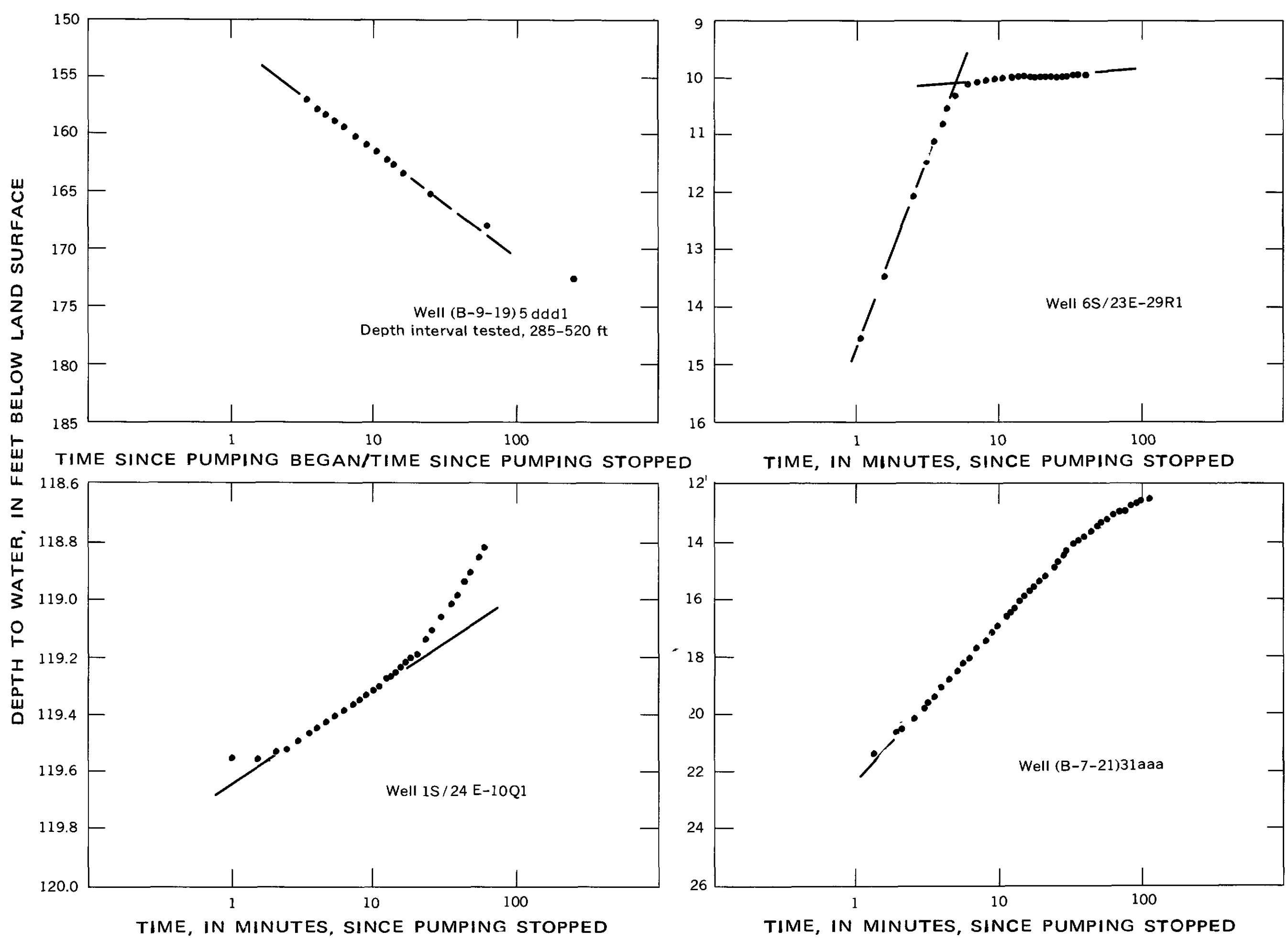

FIGURE 31.—Hydrographs of pumping-test data for selected wells.

TABLE 5.—*Results of pumping tests*

Type of test: D, drawdown; R, recovery; SD, step-drawdown.
Geologic source: YAs, younger alluvium, sand; YAg, younger alluvium, basal gravel; B, Bouse Formation; Bu, upper part of Bouse Formation; Bl, lower part of Bouse Formation; OA, older alluviums of the Colorado River; F, fanglomerate; Br, bedrock.
Owner or name: USBIA, U.S. Bureau of Indian Affairs; USBLM, U.S. Bureau of Land Management.

Well	Owner or name	Date of test	Yield/drawdown (gpm/ft)	Depth interval tested (feet below land surface)	Type of test	Transmissivity (T) (gpd per ft)	Conformance of test data to theoretical values	Reliability of T	Indicated average field hydraulic conductivity (gpd per sq ft)	Geologic source
				Parker Valley						
(B-4-22)2bca	Riverview Farms	6- 8-64	2,200/21	112-130	R	700,000	Good	Fair		YAg
36bab	LCRP 5	6- 7-62	190/37	132-140	R	1,000,000	Fair	Poor		OA
(B-6-21)20ddd	LCRP 4	10-27-61	500/15	120-130	D, R	1,900,000	do	do		YAg
20ddd	do	6-16-65	375/32	200-300	R	27,000	Poor	Fair	270	Bu
(B-7-21)14acd	USBIA No. 7	10-24-62	1,560/35	25-195	R	75,000	Good	Good	440	YAs; YAg
14dcd	USBIA No. 8	10-25-62	1,400/10	25-153	R	460,000	do	do	3,600	YAs; YAg
23acd	USBIA No. 9	11- 2-62	1,050/14	[1] 25-160	D, R	120,000	Fair	Fair	900	YAs; YAg
23dcd	USBIA No. 10	10-25-62	885/12	[1] 25-156	D, R	40,000	do	do	310	YAs; YAg
31aaa	LCRP 27	6- 4-65	630/43	194-722 194-260	SD, R	33,000	Good	Good	63 330	B Bu
32daa	Poston 3, No. 1	6-13-63			R	55,000	do	Fair		Bu [2]
33cbb	Poston 3, No. 3	6-13-63	125/91	184-208	R	1,750	do	do	73	Bu
(B-8-19)5bba	LCRP 21	9-18-64	44/100	812-838 open hole 844-1,000	R	16,700	Fair	Poor	92	Br
5bba	do	1-12-65	600/40	635-1,000 635-745	SD, R	60,000	Good	Good	165 430	F, Br F
(B-8-20)29baa	LCRP 20	6-24-64	264/65	688-763	SD, R	80,000	do	do	1,060	Br [3]
(B-9-19)5ddd	LCRP 15	9-13-63	930/7.5	175-199	R	300,000	do	do	12,500	OA
5ddd	do	9- 6-63	605/40	285-520	R	17,000	Excellent	do	72	Bl
(B-9-20)1dbc1	City of Parker 5	10-24-62	200/76	90-231	R	1,400	Fair	Fair	10	Bl, F
1dbc2	City of Parker 7	7-17-63	900/127	263-400	R	24,000	Good	Good	175	F
11dbc	USBIA No. 2	6-14-63	780/48	28-118	R	400,000	do	do	4,400	YAs; YAg
14cdd	USBIA No. 4	6-17-63	1,600/52	50-138	D, R	300,000	Poor	Fair	3,400	YAs; YAg
				Vidal Valley						
1S/24E-9K1	V. Ruzicka	6-17-64	210/50		R	275,000	do	Poor		OA
10F1	V. Ruzicka and others	6-17-64	705/26	160-198	R	200,000	Good	Good	5,300	OA
10Q	Rio Mesa Ranch	6-17-64	1,800/25	142-222	D, R	1,600,000	Poor	Poor		OA
16B1	V. Ruzicka	6-16-64	265/13	130-200	R	260,000	Fair	Fair	3,700	OA
				Palo Verde Valley						
(B-2-22)16bba	LCRP 22	9-28-64	925/126	820-985	SD, R	12,000	Fair	Fair	73	F
(B-3-21)7db	USBLM	6- 7-63	100/150	423-443	R	600	do	do	30	OA, F(?)
5S/22E-28C2	U.S. Citrus Corp.	10-25-62	1,450/?	270-358 382-600	R	64,000	Good	Good	210	OA
6S/22E-11H1	H. M. Neighbour	6-18-64	665/9	165-235	R	700,000	Fair	Fair	10,000	OA
15M1	E. Weeks	6-12-63	475/21	168-315	R	500,000	Poor	Poor	3,400	OA
15Q1	do	9-16-63	712/12	346-356 530-548 558-572	R	290,000	Good	Good	6,900	OA
32R1	W. Passey	6-11-63	650/66	120-123 402-408 479-488	R	420,000	do	Fair		OA
35R2	Southern Counties Gas Co.	10-23-62	520/15	302-326	R	150,000	Fair	do	6,200	OA
6S/23E-24J1	Clayton Ranch	7- 8-64	2,180/50		R	1,900,000	Poor	Poor		YAg
29R1	City of Blythe 8	10-23-62	360/33	264-276 354-368	R	320,000	do	do	12,300	OA
32D1	City of Blythe 9	10-23-62	520/31	122-132 168-286	R	430,000	do	do	3,400	YAg; OA
32P1	City of Blythe 1	10-23-62	470/12	245-270 290-296	R	496,000	do	do	10,000	OA
S/22E-4P1	J. E. Mason	10-23-62	100/1.6		R	1,700,000	Good	do		OA
8S/21E-13A1	LCRP 16	8-28-63	670/32	39-55 88-92 108-115	D	63,000	do	Fair	2,300	YAs; YAg
13A1	do	8-28-63	670/32	39-55 88-92 108-115	R	1,200,000	do	Poor		YAs; YAg
13A1	do	8-14-63	515/140	395-415 424-430	R	170,000	Fair	Fair	6,500	OA
11S/21E-5F1	Southern Pacific Co.	9-17-63	1/100	open hole 286-752	R	<100	Poor	Good		F
				Cibola Valley						
(C-1-24)36bbb1	Arizona Game and Fish Comm.	6-14-63	2,300/74	102-117	D R	400,000 1,200,000	Fair Poor	Poor do		YAg

[1] Estimated.
[2] Well is 375 feet west of pumped well (B-7-21)33cbb.
[3] Formation specific capacity, about 20 gpm/ft.

the well casing and the gravel pack relative to the rate at which the well had been discharging; and any other factors that might tend to invalidate the results, such as failure of the response to follow a theoretical pattern, or an unreasonable ratio between the transmissivity and the specific capacity (gallons per minute per foot of drawdown) of the well. Meyer (in Theis and others, 1954) prepared a graph showing the relation between storage coefficient, transmissivity, specific capacity, and well diameter. From this graph it can be determined that for conditions commonly existing at irrigation wells in the present study area, the ratio of the theoretical values of transmissivity to the specific capacity after 24 hours of pumping is about 1,500. This ratio, however, does not include the effects of well losses, whereas the specific capacity determined from field data does. The foregoing ratio, therefore, must be increased if it is to be used as a criterion for checking the reasonableness of the transmissivity obtained from pumping-test data. Based on a study of the results of numerous pumping tests in other areas where conditions are similar to those in the study area, it was concluded that ratios of transmissivity to observed specific capacity could be expected to range between 2,000 and 3,000. When ratios were much higher, and there was no reason to suspect that the specific capacity was limited because of well construction, the resulting transmissivity was considered to be of little value as an indicator of the transmissivity of the material tapped by the well. Data obtained during step-drawdown tests were helpful in evaluating the extent to which head loss in the well reduced the observed specific capacity, and thus were helpful in checking the reasonableness of the ratio between the transmissivity and specific capacity.

Another criterion that was used for determining the reliability of transmissivity values was whether different test conditions or data at different times during the test resulted in consistent computed values of transmissivity.

In several instances the transmissivity determined on the basis of recovery measurements was 20 times larger than the transmissivity determined on the basis of drawdown measurements. The reasons for this apparent disparity are not known. Considerable leakage from material both above and below the strata tapped by the well may have occurred, but such leakage was not evidenced by a diminution in the rate of drawdown or recovery greater than that which theoretically should occur when leakage is absent or when it is only a minor contribution to the yield of the well. Unreasonably high transmissivities based on recovery measurements were obtained for a few wells, generally where the material tapped by the well was only a fraction of the permeable material penetrated. In no instance did the recovery data indicate a transmissivity that was unreasonably small.

COMMENTS ON TESTS FOR WHICH RELIABILITY OF TRANSMISSIVITY IS CLASSIFIED AS POOR

In table 5, the reliabilities of 14 of the transmissivities were classified as poor. The reasons for assigning this classification to particular transmissivity values are given in the following paragraphs.

The reliability of the transmissivity for the material tapped by well (B–4–22)36bab is classified as poor because it is unreasonably high. This high transmissivity probably results from substantial leakage from sands both above and below the 8-foot gravel stratum tapped by the well. A similar situation exists in well (B–6–21)20ddd, where substantial leakage probably occurs from sands overlying the 10-foot-thick gravel section, and possibly from sands underlying a 6-foot-thick section of silty clay at the base of the gravel.

The reason for the seemingly too high value for the transmissivity of material tapped by well (B–8–19)-5bba at depths between 812 and 838 feet and between 844 and 1,000 feet is not apparent. It is possible that the specific capacity is not so low as the 0.44 gpm per ft that was indicated by the bailing test on September 18, 1964. A rate-of-flow test by means of a deep-well current meter on January 12, 1965, after water-bearing zones at shallower depth had been tapped showed that, when the well was being pumped at a rate of 600 gpm, about 80 gpm were being yielded by the material that had been tested by bailer on September 18, 1964. The drawdown was about 40 feet, indicating a specific capacity of about 2 gpm per ft, or more than four times the specific capacity obtained during the bailing test. The transmissivity of about 16,000 gpd per ft that was indicated by the rate of recovery of water levels following the bailing test, however, still is too large to be reconciled with even the specific capacity of 2 gpm per ft that was indicated on January 12, 1965.

The transmissivity at well 1S/24E–9K1 is apparently too high. Unfortunately, no driller's log or other information on the water-bearing materials tapped by the well is available, which might provide some clue as to why the transmissivity values are too high.

The reliability of the transmissivity of the material tapped by well 6S/22E–15M1 is considered poor because the recovery data did not follow the theoretical pattern. If the transmissivity of about 500,000 gpd per ft as given in table 5 is correct, then the specific capacity of the well would be expected to be several times greater than that shown, unless well losses were abnormally high.

The reliability of the transmissivity for well 6S/23E–24J1 is considered poor because the recovery data for the first 5 minutes indicate a transmissivity about 3 percent of the transmissivity given in table 5, the latter being based on a uniform recovery rate that persisted for the next 1½ hours. The reasons for the abrupt break in recovery rate and the resultant higher transmissivity are not known. On the basis of the specific capacity of the well, the transmissivity should be less than one-tenth of the transmissivity listed.

The reliabilities of the transmissivities for the three wells owned by the city of Blythe are considered poor because the recovery of water levels in these wells also have abrupt breaks in rate of recovery 2–6 minutes after pumping ceased. The transmissivities given in table 5 are based on the much slower rate of recovery that follows the abrupt change in recovery rate. Transmissivities computed on recovery data prior to these abrupt changes would be one-tenth to one-twentieth of the values given in the table. The transmissivities computed on the basis of the recovery of water levels during the first few minutes after pumping stopped would be more nearly those that might be indicated by the specific capacities of the wells. The reason for the abrupt change in rate of recovery is not known. There is a possibility that the change results from the effects of cessation of pumping reaching a much more transmissive zone than that in the immediate vicinity of the wells or that well losses are unusually high.

The reliability of the transmissivity for well 7S/22E–4P1 is rated as poor because the transmissivity is unreasonably high considering that the saturated material penetrated by the well is, at most, 100 feet thick, and the probability that only a small fraction of the length of casing in this material was perforated. The well undoubtedly taps very permeable material because the recovery of water level was almost complete within 40 seconds after pumping stopped. During the next 15 minutes the recovery was only an additional 0.02 foot, and after that, the rate of recovery was too small to be measurable.

The transmissivity computed for the upper zone of material tapped by well 8S/21E–13A1 is classed as poor because it is unreasonably high on the basis of specific capacity, the transmissivity indicated by change in drawdown while the well was being pumped, and the thickness of the material times the probable maximum average hydraulic conductivity of about 10,000 gpd per sq ft that seems to be characteristic of alluvial material in the lower Colorado River region.

The transmissivities for material tapped by well (C–1–24)36bbb1 are classified as poor because they are unreasonably high considering the thickness of the gravel tapped by the well, the specific capacity of the well, and the patterns of the water-level drawdown and recovery data. The water-level data, both for the pumped well and a well 21 feet from the pumped well, indicated that considerable leakage to the strata tapped by the well was obtained from overlying material both during and following the 2-hour period of pumping. On the basis of the specific capacity and the more than 15 feet of drawdown that was noted in an observation well 21 feet from the pumped well, it seems probable that the transmissivity of the gravel tapped by well (C–1–24)36bbb1 is between 50,000 and 100,000 gpd per ft rather than the values that are given in table 5.

EVALUATION OF PUMPING TESTS

The fact that many of the pumping tests yielded results that could not be used to compute transmissivities that were considered reliable or representative of the area was not wholly unexpected. The complex relationships that the hydraulic conductivities of the water-bearing materials bear to one another, the partial tapping of the water-bearing material by wells, the lack of adequate observation wells, the short duration of the tests, and the limited scope of the pumping-test procedures tended to lessen the validity of many of the analyses. However, it was not economically feasible, nor in many instances would it have been practical, to construct the number and kinds of wells and to conduct the detailed and long-term tests that probably would have provided substantially better data for computing transmissivities.

The tests, as made, did provide valuable information at many sites about the transmissivity of the water-bearing material tapped by the wells. However, because most wells tapped only a part of the full thickness of a given stratigraphic unit, the computed transmissivity values are less than those for the entire unit. Although the pumping-test data alone are not adequate for determining transmissivity values that can be expected for the various lithologic units, the data when considered in conjunction with the geology suggest that transmissivity values ranging from a few hundred thousand gallons per day per foot to somewhat more than half a million gallons per day per foot probably are characteristic of much of the younger alluvium and also the older alluviums. Likewise, transmissivity values about an order of magnitude less than the above—that is, values ranging from a few tens of thousands to somewhat more than fifty thousand gallons per day per foot—probably are characteristic of the better water bearing deposits of the Bouse Formation and of the fanglomerate.

GROUND-WATER STORAGE

One of the objectives of the present study was to ascertain the amount of ground water that goes into, or is released from, storage for each unit change of ground-water level. This information is useful in planning any development that involves changes in ground-water level, such as pumping ground water, constructing drainage facilities, or utilizing the ground-water reservoir to augment the surface-water reservoir system.

Storage characteristics commonly are designated by a dimensionless number called a storage coefficient. The storage coefficient (formerly called the coefficient of storage in much of the literature) has been defined as 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).

When water is confined—that is, when it occurs under artesian conditions, the changes in storage that accompany changes in head are due almost solely to compressibility of the water and of the aquifer. Storage coefficients under artesian conditions, therefore, are small, generally ranging from about 0.00001 to 0.01. Although artesian conditions exist at least to some extent in much of the study area, storage characteristics under water-table conditions are of primary interest, because under almost any plan for utilizing ground-water resources, the response of the system in areas where unconfined conditions exist will be a criterion for judging the success or failure of the development. For practical purposes, the storage coefficient under water-table conditions is the volume of water that is released by gravity drainage divided by the gross volume of the water-bearing material through which the water table declines. In clays and silts it may range from almost zero to a few hundredths. As grain size, uniformity, and sphericity increase, the coefficient also increases. For clean sand and gravel, it commonly ranges between 0.2 and 0.4.

The storage coefficient has no time limit; it represents the ultimate change in storage. In practice, the ultimate drainage is seldom, if ever, reached; rather, it is approached within widely varying limits, depending on the length of time since the change in head occurred and the physical properties of the water-bearing material. In a clean coarse sand or gravel, almost all the gravity drainage may occur in a matter of hours or a few days at most, whereas in silts or clays, appreciable drainage may persist for weeks and months.

Under favorable conditions pumping tests are useful for determining storage characteristics. Under artesian conditions, they probably are the only practical method for obtaining storage coefficients. Under water-table conditions, pumping tests are less practical in many instances than are other methods. The failure of pumping tests to provide valid data for computing storage coefficients is due in large part to the slow rate of drainage of many of the water-bearing materials. The formulas used for analyzing pumping tests, as was stated in the preceding section, are based on the assumption of an instantaneous change in storage with a change in head.

A neutron moisture probe seemed to be more practical than pumping tests as a means of obtaining storage characteristics for most of the water-bearing materials that were likely to be in the zone of water-level fluctuations. Differences in the water content between material beneath the water table and the relatively dry material above the capillary zone as determined by means of the neutron moisture probe provide a measure of the storage capacity of the materials.

The probe used in the soil-moisture studies consisted of a 5-millicurie fast-neutron source, a slow-neutron detector tube, and transistorized amplifier circuit. The theory of operation is that the number of fast neutrons that are converted to slow neutrons and that are picked up by the detector depends primarily on the number of hydrogen atoms in the material surrounding the probe, and this number, in turn, is largely a function of the free water in the material. The rate at which slow neutrons are detected is registered visually by the glow of five decade counters. By means of a calibration curve, rates of count are converted to percent of soil moisture by volume.

The probe was lowered to the desired depths inside steel tubing having an inside diameter of 1.50 inches and an outside diameter of 1.625 inches. Where possible, 18-foot lengths of the tubing were driven into the soil by means of a gasoline-operated hammer. The tubes then were cleared of soil and water and a watertight plug was set at the lower end. The counting rates at 1-foot depth intervals were then determined.

Moisture-profile surveys were made at 15 sites in Parker Valley and at 16 sites in Palo Verde Valley. The sites were distributed fairly well throughout the flood plain of these areas. Although the sampling density was light, it was part of a larger study that included several other areas in the lower Colorado River region. The general conformity of the findings for the two valleys with those in the other areas lends some support to the hypothesis that the sampling program provided results that are representative of the storage characteristics of most of the materials that are, or are likely to be, in a zone of rising or falling water levels.

The most reliable method for relating counts per minute to moisture content seemed to be a laboratory determination of the moisture content of a sample collected in the field within a fraction of a foot from an access tube in a zone where the counting rate indicated a uniform moisture content for at least a foot above and below the horizon from which the sample was obtained. After the moisture content of many samples of various kinds of material having different moisture contents and counting rates was determined, the calibration curve shown in figure 32 was adopted as fairly representing the relation between moisture content and counting rate for the type of access hole and the method of construction that were used in Parker and Palo Verde Valleys. Figure 33 shows the counting rate at 1-foot depth intervals at the various

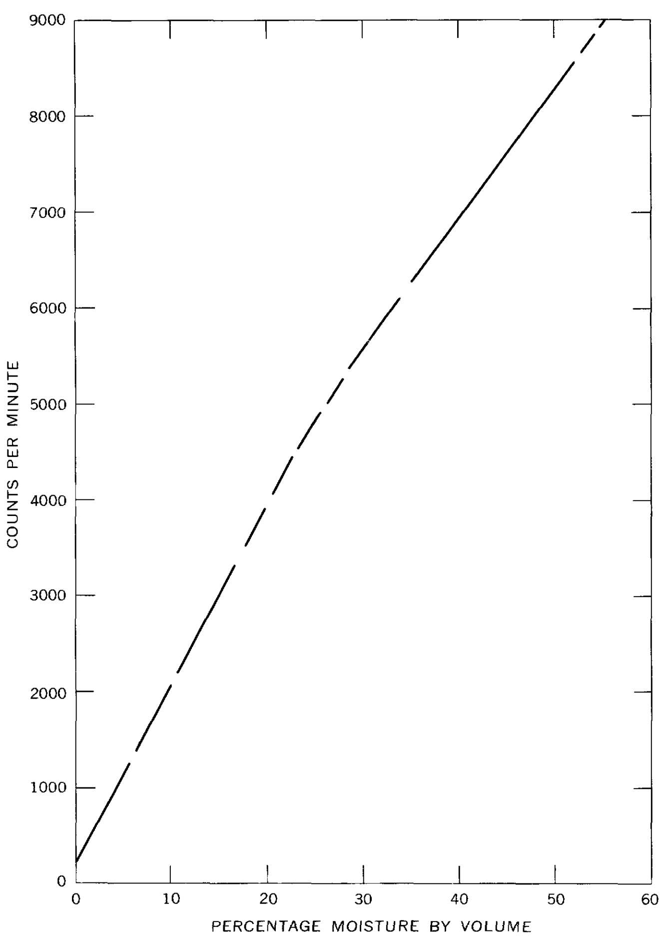

FIGURE 32.—Relation between moisture content and counts per minute.

sites in Parker Valley. The average counting rate in the zone of saturation at 11 sites where such zones were known to exist, was 7,700 cpm (counts per minute), corresponding to a moisture content of about 45 percent. The average counting rate in the zone of aeration above the capillary fringe at 11 sites was about 1,300 cpm, equivalent to a moisture content of about 6 percent. The difference of 39 percent in moisture content between the two zones is a measure of the average storage capacity of the materials that were penetrated by the access tubes in Parker Valley.

The counting rates at 1-foot depth intervals at various sites in Palo Verde Valley are shown in figure 34. The average counting rate in the zone of saturation was about 7,500 per minute, equivalent to a moisture content of about 44 percent. The counting rate in the zone of aeration above the capillary fringe was higher and showed considerably more variation in Palo Verde Valley than in Parker Valley. The average rate at seven sites where the zone of aeration above the capillary fringe could be identified was about 2,400 cpm, equivalent to a moisture content of about 12 percent. The difference of 32 percent in moisture content between the two zones is a measure of the storage capacity of the materials penetrated by the access tubes in Palo Verde Valley.

The average moisture content of material in the zone of saturation that was penetrated by access tubes in the flood plain of Palo Verde Valley is but 1 percent less than the average moisture content of materials in the zone of saturation in the flood plain of the Parker Valley. For practical purposes, then, the porosity of the near-surface materials beneath the flood plain in both valleys is about the same.

The reason for the higher moisture content in the zone of aeration in Palo Verde Valley than in Parker Valley is not readily apparent. The access tubes generally were installed at sites of comparable environment in both valleys, most sites being near, or adjacent to, drainage ditches and in areas of natural vegetation of low to moderate density. It is inferred, therefore, that the soils at the access tube sites in Palo Verde Valley generally are finer grained and so are able to retain more moisture against gravity drainage.

The figures of 39 percent for storage capacity in Parker Valley and of 32 percent in Palo Verde Valley are higher than those commonly used for estimating storage capacities of ground-water systems, most estimates being between 10 and 20 percent. Although it is possible that the ratio between counts per minute and moisture content for saturated conditions is somewhat higher than that shown in figure 32, it is doubtful that

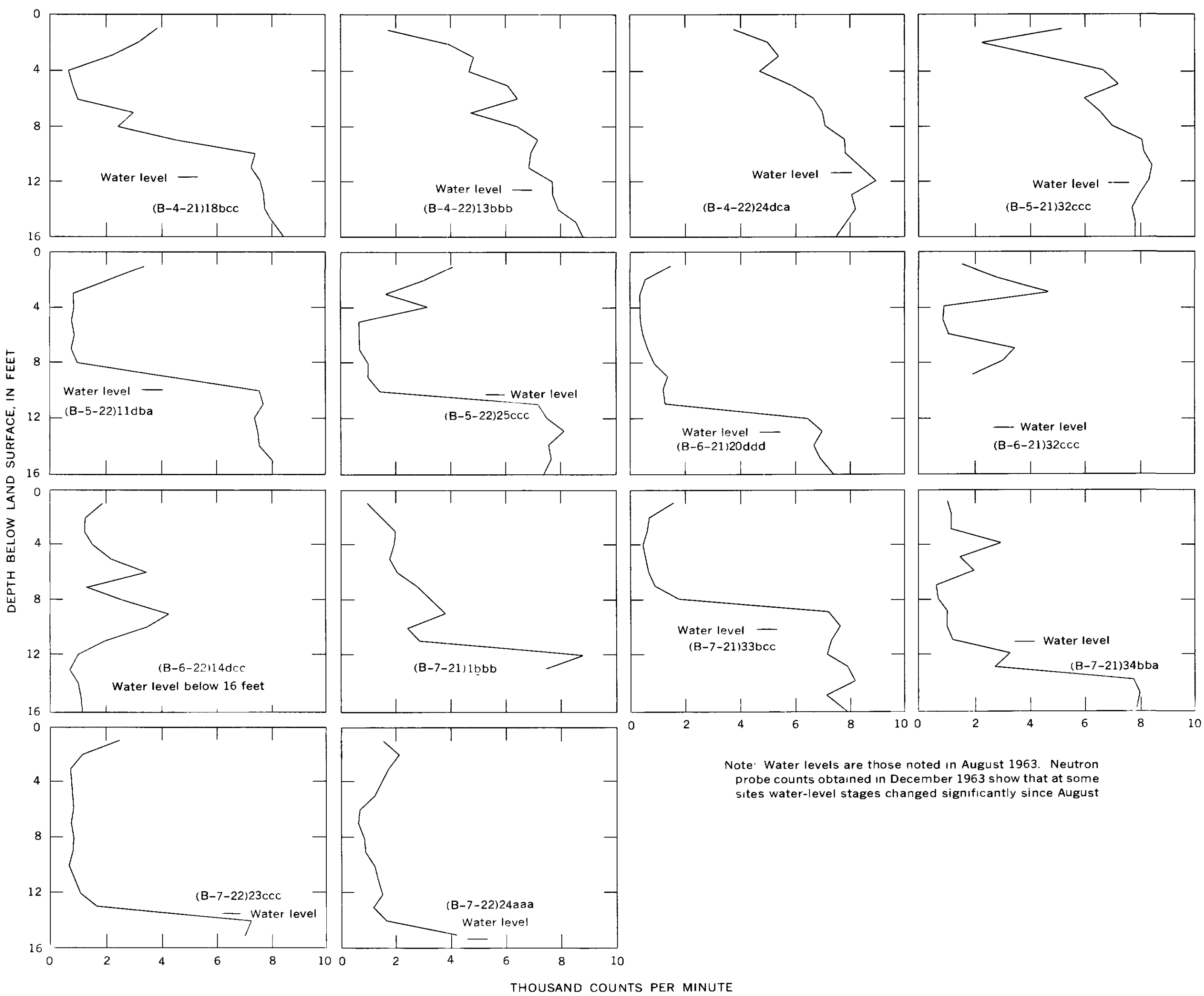

FIGURE 33.—Results obtained by use of neutron moisture probe at 14 sites in Parker Valley, Ariz.

the storage capacities of the two valleys have been overstated by as much as 5 percent.

The average moisture content of about 6 percent in the zone of aeration above the capillary fringe in Parker Valley is less than is commonly assumed. It is possible that some of the water in the zone which ordinarily would not drain by gravity may have been removed by plants to meet their transpiration requirements. However, the survey of the access tubes in Parker Valley was made in mid-December, so the probability of a substantial reduction of moisture content because of transpiration is lessened. The survey in Palo Verde Valley, in contrast, was made in the latter part of June, when transpiration requirements are high, yet the average moisture content of the material in the zone of aeration above the capillary fringe in Palo Verde Valley was about double that in Parker Valley.

The soil-moisture determinations included all types of material except gravel. It was impractical to drive the access tubes through any appreciable thickness of coarse gravel. However, on the basis of studies in other areas (Johnson, 1964), it is probable that the storage coefficient for gravel is between 25 and 40 percent.

The study of storage characteristics suggests that in an area of rising water levels beneath the flood plain outside of irrigated areas, the storage capacity is about 35 percent of the volume of material through which the water table rises. A similar capacity is indicated for an area beneath which water levels decline if sufficient time elapses for practically all gravity drainage to be completed. The amount of water that will be released from storage during shorter periods of drain-

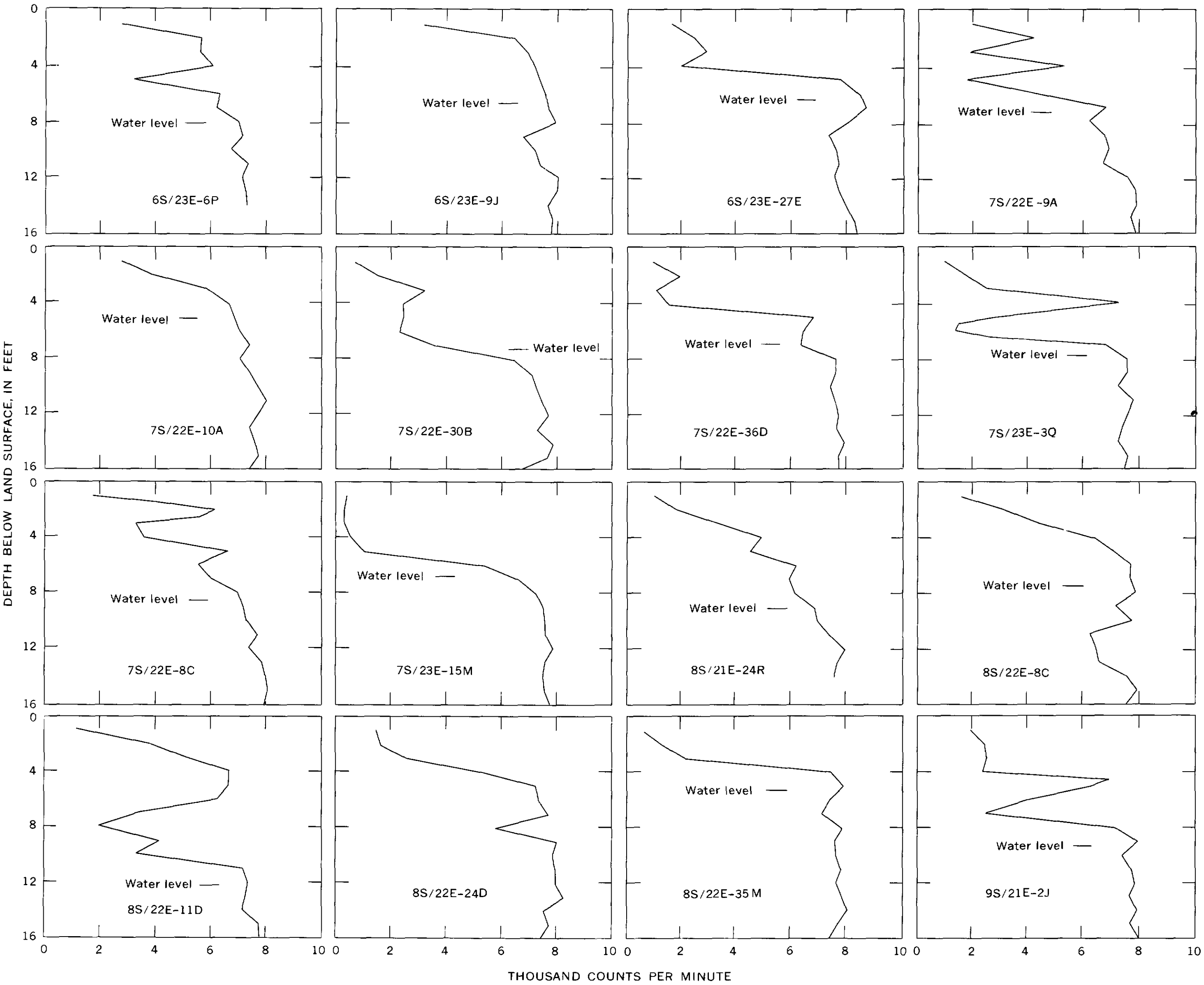

FIGURE 34.—Results obtained by use of neutron moisture probe at 16 sites in Palo Verde Valley, Calif.

age will depend on the particle size of the material and the ease with which the water can drain to the water table. A layer of fine-grained material underlying coarse-grained material will retard the rate at which the latter normally would drain, and thus the drainage will be even less than would be indicated on the basis of the kinds of material being drained.

QUALITY OF WATER

Chemical quality, herein defined as the complex of chemical and physical properties imparted to water by its dissolved-mineral content, significantly controls the use of water. In the Parker-Blythe-Cibola area the availability of good quality water has only recently become a limitation on economic growth. Until a few years ago almost all irrigation in the area was by diversion of water from the Colorado River. Only part of the valley lands and none of the uplands were irrigated, and the flow of the Colorado River was greater than needed to supply the irrigated lands of the area and all downstream use. Under this condition ground water was used almost exclusively for rural, domestic, and small city public supplies.

Recently, use of Colorado River water has increased, in both the Parker-Blythe-Cibola area and elsewhere upstream and downstream, until presently there is little surplus surface water, and it appears that the flow of the river may not be sufficient to meet all projected future needs. Within the past few years irrigation with pumped ground water in the Parker-Blythe-Cibola area has expanded from limited parts of the Colorado River flood plain not served by canals to include large areas on the piedmont areas. This expansion of irrigation by pumping ground water is continuing.

The continuing reduction of flow of the Colorado River, the increasing development of ground water for irrigation, and the growing population with its need for more water, all point to the desirability of determining to what extent ground water of good chemical quality is available in the Parker-Blythe-Cibola area.

SOURCES OF INFORMATION

Selected analyses of Colorado River water and analyses of ground water obtained from all clearly identifiable well sources in the Parker-Blythe-Cibola area are given in tables 6 and 7–10, inclusive. The ground-water samples came from shallow observation wells; from augered wells as deep as 231 feet drilled to obtain geologic and chemical quality information; from deep test wells drilled by the U.S. Geological Survey during the present investigation; and from private wells drilled for domestic, municipal, irrigation, or industrial supply. More than half the 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 customary Survey procedures. The other analyses include older data from the files and publications of the Geological Survey and other agencies, and analyses obtained from well owners, well drillers, and other individuals.

PRESENTATION OF DATA

The analyses given in tables 6 and 7–11, inclusive, are stated in milligrams per liter (mg/l) except as noted, according to the usual practice of the Geological Survey. As the methods of analysis used by other than Geological Survey laboratories were mostly unknown, the analyses from non-Survey sources were checked for cation-anion balance and internal consistency prior to inclusion in the tables. Analyses not originally stated in milligrams per liter were recomputed to this unit.

The tables include major constituents and properties of water stated on the original analytical reports plus others readily computed from the analytical data. Minor or trace constituents shown on some of the original reports, but which did not affect the suitability of the water as a domestic or irrigation supply, are not included.

Whenever terms describing the general chemical character of a water are used in this report, cations are named first followed by the anions as in the following examples: (1) "calcium bicarbonate" designates a water in which calcium amounts to 50 percent or more of the cations, and bicarbonate, 50 percent or more of the anions; (2) "sodium-calcium bicarbonate" designates a water in which sodium and calcium are given in order of concentration but neither represents 50 percent of the cations; (3) "sodium sulfate-bicarbonate" designates a water in which sulfate and bicarbonate are first and second in abundance of the anions but neither represents 50 percent of the anions; (4) "mixed cation" or "mixed anion" waters are waters in which the three cations or three anions are present in approximately equal amounts. In areas where the cations have variable proportions but the anion proportions are relatively fixed, the waters are described by anion designation alone.

The tables do not represent a complete inventory of all chemical analyses accumulated during the Parker-Blythe-Cibola geohydrologic investigation. Rather, they include only selected analyses from nearly contemporary analyses from the same well source and from series of analyses that did not show important concentration changes during the sampling record. Older analyses of samples obtained from wells whose exact locations are now unknown usually were omitted, although a few such analyses were included in the tables where their inclusion provided the only clue to probable water-quality characteristics in a particular area.

All the analyses in the tables do not have the same validity and accuracy because of varied conditions of sample collection and storage prior to chemical analysis and because some samples were analyzed by more precise methods than others. The nature of these variations are important in drawing conclusions about variations of water quality. Small differences in the tabulated concentrations or properties commonly may not be significant, but large differences probably represent real differences in chemical quality. For example, table 9 gives two analyses from well 6S/23E–32M1, a public supply well of the city of Blythe, Calif., which are nearly alike, except for fluoride content. Then follows three analyses from well 6S/23E–32P1, also a city of Blythe well, which show increasing concentrations of all reported constituents with time. Thus, it seems that the quality of water obtained from the first well did not change materially, but that perhaps something was wrong with one or both fluoride determinations as it is unlikely that only one ionic constituent would change concentration with time. The quality of water from the second well apparently did change from sample to sample, probably because of differential movement of water to the well caused by continued pumping.

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Visual comparisons and identification of generalized types of water, as indicated by chemical analyses, are facilitated by the use of a graphical representation originated by Stiff (1951, p. 15). On the Stiff diagrams 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 and 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 geometric patterns characteristic of the mixture of minerals making up the dissolved solids in the water whose analysis is plotted. Because the areas of the Stiff diagrams are not strictly proportional to the dissolved-solids content of the waters represented by the diagrams, and because of the differences in the equivalent weights of the cations and anions, the corresponding dissolved-solids concentrations are indicated on the individual diagrams.

When Stiff diagrams are plotted from water analyses representing samples collected from different ground-water and surface-water sources, many of the patterns are repetitive. Some of the repetitive patterns characterize water obtained from particular kinds of rock, as limestone or gypsum; others characterize certain streams, particularly rivers below large reservoirs, as the Colorado River below Hoover Dam; still others characterize ground water from particular areas or zones in a formation, or water that has moved through specific rock units. Ground waters that are mixtures of water from two sources rather commonly show Stiff patterns intermediate between the patterns of the individual sources, although solute precipitation and other chemical changes may bring about patterns not truly intermediate between those of the source waters.

This grouping of ground-water analyses, according to Stiff patterns, is a useful method for summarizing chemical information. Figure 35 shows Stiff diagrams typical of average Colorado River water and of common types of ground water from the Parker-Blythe-Cibola area. Some of the different diagram patterns are named, as explained in subsequent discussions.

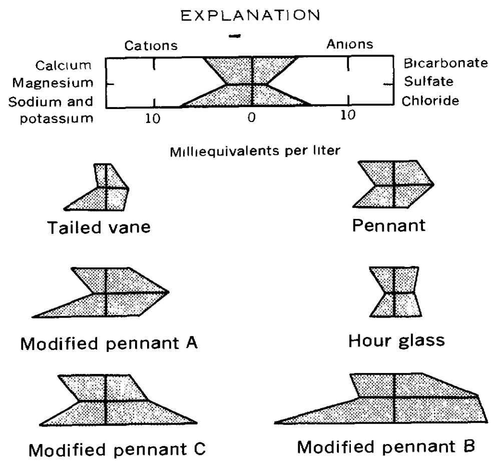

FIGURE 35.—Generalized types of water.

CHEMICAL CHARACTER OF THE COLORADO RIVER WATER

The chemical characteristics of nearly all the ground water in the Parker-Blythe-Cibola area are related to those of the Colorado River water because most of the area's ground water originally came from the river, having infiltrated either directly from its channel or from flooded land. Although during and after infiltration the ground water has been chemically altered by numerous processes, it generally has retained some characteristics related to those of the river water. Consequently, describing variations in the chemical character of the ground water is facilitated by first considering the variations in the composition and concentration of the Colorado River water itself.

The virgin, or natural, chemical regimen of the Colorado River was undoubtedly one of large seasonal variation in both composition and concentration, as such variation has been found at all unregulated points on the river and its tributaries where there have been programs of systematic sampling for chemical analysis. The exact patterns of the original variations cannot be determined, however, because large-scale irrigation was developed in the Upper Basin many years before the first-sustained sampling programs were initiated. This large-scale irrigation both reduced the natural river flows and added saline drainage to them.

Most of the irrigation in the Upper Basin was developed prior to 1926; consequently, the chemical records obtained at the Grand Canyon gaging station from 1926 until 1963, the latter year being the year Glen Canyon Dam first was closed, represent a relatively stable regimen of flow and salinity. The records show that during spring floods in most years the Colorado River water at Grand Canyon contained as little as 200–300 mg/l dissolved solids, consisting mainly of calcium and bicarbonate, and that during floods the sulfate concentrations always exceeded the chloride concentrations. It is unlikely that under virgin conditions the minimum concentrations were much less than during 1926–63 as the volumes of drain water entering the river at such times must have been small compared to the flood volumes.

During low-flow periods in fall and winter the dissolved-solids concentrations at Grand Canyon often reached 1,500 mg/l and in rare years (as in 1934) reached 1,800 mg/l for a few days. At the higher concentration levels the dissolved solids consisted mainly of calcium sulfate, although they sometimes included considerable sodium chloride. The calcium and magnesium bicarbonates, although present in greater absolute concentrations than during floodflows, were still only a minor part of the dissolved solids.

Records of a few years of sampling at Willow Beach, Topock, and Yuma, prior to construction of Hoover Dam, indicate that the usual salinity variations in the lower reaches of the Colorado River were very much like those at Grand Canyon. Therefore, the Grand Canyon record probably is representative of the long-time salinity variations in the Parker-Blythe-Cibola area, even though the maximum concentrations of the Grand Canyon record may have been a little greater than occurred under virgin conditions.

Annual weighted average analyses and sample analyses showing the maximum and minimum concentrations of dissolved solids for the years of minimum flow (1934), median flow (1936), and maximum flow (1929) during the period 1926–62, as given in table 6, illustrate the pre-Hoover Dam variations in the chemical quality of the Colorado River water that reached the Parker-Blythe-Cibola area.

After Hoover Dam began to impound water (1935) the previous variations in the composition and concentration of Colorado River water in the Parker-Blythe-Cibola area began to decrease as a result of the mixing of floodflows and low flows in Lake Mead. By 1941, when Lake Mead reached the highest level attained to date, 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 corresponding sulfate concentration has ranged between 261 and 355 mg/l; and the chloride concentration has ranged between 62 and 108 mg/l. Day-to-day concentrations have, of course, been somewhat above or below the annual concentrations, but in any one year they generally have departed less than 10 percent from the computed averages.

Annual weighted average analyses and individual analyses showing maximum and minimum dissolved solids below Hoover Dam for selected years after 1940 (table 6) indicate the range in variation in dissolved constituents characterizing the water of the lower Colorado River as stabilized by Lake Mead.

During or after infiltration, the Colorado River water may be altered considerably by chemical precipitation. Thus, both calcium and magnesium may react with bicarbonates to form insoluble calcium or magnesium carbonates at concentration levels only moderately higher than those present in Colorado River flows. Consequently, ground water that is recently derived from the river may contain somewhat less calcium, magnesium, or bicarbonate than the river.

Calcium sulfate, the most insoluble common sulfate salt, does not precipitate until sulfate concentrations reach about 2,000 mg/l; and all common chloride salts are much more soluble than sulfate salts. Consequently, neither the sulfate nor the chloride concentrations are likely to be changed by precipitation reactions; so the ratio of their concentrations in ground water can be used as an indicator of recent infiltration from the Colorado River.

Since 1941 the ratio of sulfate in mg/l to chloride in mg/l in the Colorado River water has almost always ranged between 3 and 5 and has generally been less than 4. Therefore, it seems reasonable to infer that direct infiltration of water from the river or irrigation systems has occurred wherever analyses of ground water from the Parker-Blythe-Cibola area shows dissolved-solids concentrations in the range 600–1,000 mg/l and sulfate to chloride ratios in the range 3–5.

RELATION OF WATER QUALITY TO GEOLOGY AND HYDROLOGY

The water-bearing rocks of the Parker-Blythe-Cibola area, as discussed under geology, are subdivided into a fanglomerate which overlies bedrock, the Bouse Formation which is marine to brackish, and the alluviums of the Colorado River which are further differentiated into several units. Water probably moves freely between the sands and gravels of the alluvial units and from them into the sands of the uppermost part of the Bouse Formation, except where local impermeable clay layers are present. Consequently, all the water-bearing rocks beneath the flood plain and terraces of the Colorado River above the less permeable part of the Bouse Formation constitute a single ground-water reservoir that is hydraulically connected to the Colorado River. No beds containing appreciable quantities of soluble mineral salts have been found in these deposits; therefore, all the dissolved minerals now in the ground water must have originated from the Colorado River or from local recharge.

Presently, water is recharged to the Parker-Blythe-Cibola ground-water reservoir mostly as seepage from the Colorado River, irrigation canals, and irrigated land. Some water, in general considerably less mineralized than Colorado River water, is recharged to the reservoir as infiltration of runoff from the ephemeral

TABLE 6.—*Selected analyses of Colorado River water*

[Results in milligrams per liter, except as indicated]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (NA)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Percent sodium
Colorado River at Grand Canyon, period unaffected by large upstream reservoirs, 1926–62																
Minimum flow year 1934																
Maximum concentration, Sept. 21–30	2,600	13	184	74	339	11	254	826	308	0.5	8.5	1,890	764	556	2,860	49
Minimum concentration, May 23–31	17,800	22	65	15	60	5.8	176	131	51	.0	.7	437	224	80	680	36
Weighted average	6,431	15	105	39	159	6.1	206	392	136	--	5.1	960	422	254	1,460	45
Median flow year 1936																
Maximum concentration, Jan. 1–10	4,100	14	138	58	230	5.8	273	513	230	.3	8.4	1,330	583	360	1,980	46
Minimum concentration, May 21–31	68,900	13	50	11	22	5.0	155	62	17	.2	1.3	258	170	43	420	22
Weighted average	16,970	16	83	23	79	6.0	186	228	61	.3	2.4	591	302	149	900	36
Maximum flow year 1929																
Maximum concentration, Oct. 11–28, 1928	14,000	15	208	56	196	7.7	206	798	128	--	5.4	1,520	750	580	2,040	36
Minimum concentration, June 11–20	86,400	14	36	12	20	7.0	117	63	15	--	1.2	226	140	44	360	23
Weighted average	26,800	18	74	23	73	6.2	164	229	48	--	2.5	555	279	144	850	36
Colorado River below Hoover Dam, 1941–65																
Maximum level, Lake Mead, 1941																
Maximum concentration, Mar. 1–10	9,010	12	114	30	112	5.8	169	370	93	0.3	3.9	824	408	270	1,230	38
Minimum concentration, Sept. 1–10	27,900	11	98	25	85	7.5	143	315	68	.5	3.5	684	348	238	1,040	36
Weighted average	16,200	11	110	28	98	6.4	153	355	79	.3	3.0	766	390	264	1,140	36
Maximum average dissolved-solids content 1956																
Maximum concentration, July 1–10	12,050	--	106	33	117		176	--	--	--	--	879	400	256	1,250	39
Minimum concentration, Jan. 11–20	10,360	13	100	33	108	4.8	168	340	99	.3	3.2	785	385	248	1,180	38
Weighted average	10,770	--	104	32	117	5.3	170	350	103	.3	3.7	813	391	252	1,230	39
Minimum average dissolved-solids content 1950																
Maximum concentration, Dec. 11–20	21,810	13	88	25	76		168	268	70	.2	2.2	639	322	185	984	38
Minimum concentration, Oct. 11–20	21,190	11	76	23	76		152	232	58	.4	1.4	553	284	160	877	37
Weighted average	17,870	11	84	26	81		158	257	66	--	1.9	606	316	187	927	36
1965																
Maximum concentration, May 1965	14,180	10	107	27	119	5.6	156	354	112	.3	1.3	813	380	252	1,240	40
Minimum concentration, Oct. 1964	9,539	10	96	27	105	5.0	158	303	95	.4	1.7	721	350	220	1,130	39
Weighted average	10,940	10	101	29	115	5.4	156	335	108	.4	1.6	782	371	243	1,210	40

desert washes and from the bedrock areas on both sides of the flood plain.

Movement of water through the reservoir is very slow compared to the velocity of river flow and is by many devious paths and with very irregular mixing of the various filaments of flow. At any time some of the water in the ground-water reservoir has infiltrated to it within the preceding few days, but much more has been in transit for many years, and an appreciable fraction has probably been in the reservoir for thousands of years.

Generally, distinctive patterns of chemical composition extend both laterally and vertically through more than one stratigraphic unit. Because, commonly, the various units of the alluvium are not readily differentiated from well logs, it is frequently difficult to determine the stratigraphic unit from which a particular water sample was obtained. Consequently, detailed description of water-quality variation according to the individual stratigraphic unit is precluded. However, by simplifying the geologic subdivisions into three zones—designated hereinafter as the shallow, principal gravel, and deep zones—summary statements for observed water-quality variations under the flood plain, can be made.

The division into three zones is satisfactory to a lesser degree for describing water-quality variations beneath the piedmont slopes, perhaps because the younger alluvium is present only beneath the flood plain. Consequently, the water-quality variations outside the flood plain are discussed by individual areas rather than by zones.

Great variation in both composition and concentration in different parts of the ground-water reservoir has resulted from the variable quality of water entering the reservoir, the continual increasing concentration of ionic solutes by evapotranspiration, the irregular mixing of the water caused by differences in head and hydraulic conductivity, and the unceasing chemical reactions between the dissolved ions of the water and the dissolved ions and the minerals of the formations through which the water moves. Some of the ground water is very saline (contains more than 10,000 mg/l dissolved solids), and some is fresh (contains less than 1,000 mg/l).

THE SHALLOW ZONE UNDERLYING THE FLOOD PLAIN

The shallow zone underlying the flood plain is in the sand of the younger alluvium and extends from the water table downward for not more than about 30 feet. Water-quality variation in this zone can be related to both evapotranspiration and recharge. Evapotranspiration is greatest in the parts of the flood plain where the water table is less than 5 feet below the land surface. It generally decreases as the depth to water increases, and probably is very small where the depth to water is greater than 20 feet. Evapotranspiration results in increases in ionic concentrations and in some chemical precipitation, particularly in and near the capillary fringe. Recharge from flood waters or water applied for irrigation generally decreases the concentration in the shallow zone. Sometimes, however, ground water in the shallow zone may become saline as a result of poor drainage or insufficient leaching of irrigated soils. Because both the opportunities for evapotranspiration and recharge vary greatly, there is considerable variation in water quality in the shallow zone.

Analyses of water samples from shallow-zone wells (table 7) indicate that the dissolved-solids concentrations in the shallow zone generally range between 600 and 6,000 mg/l, although higher concentrations have been noted. Selected analyses plotted as Stiff diagrams (pl. 6) indicate the usual compositional patterns of shallow-zone water. The lower concentrations (less than 1,000 mg/l) seem to be from small parts of the ground-water reservoir that have been flushed by river water, canal leakage, or possibly wherein remnants of past flood waters from the washes have been trapped. The higher concentrations (greater than 3,000 mg/l) probably result from concentration by evapotranspiration. The usual concentrations of dissolved solids in the shallow-zone water probably is less than 2,000 mg/l, except where the water table is only a few feet below the land surface.

The narrow flood plain between Parker Dam and Parker is the site of numerous retirement and vacation homes, trailer courts, and small service businesses that are reported to obtain domestic water from shallow sandpoint wells. Although shallow wells were not sampled during the present investigation, several old analyses (not tabulated because of uncertain locations) indicate that the shallow-zone water in the above area generally resembles Colorado River water, although some of it contains more sodium and chloride than the river water.

Part of Parker Valley that is south and southwest of Parker has been irrigated with Colorado River water for many years. A drainage network now maintains a water table of satisfactory depth for growing crops, but at one time poor drainage resulted in both a high water table and salt accumulations in the irrigated soils so that some farmland had to be abandoned for a few years. White saline crusts can still be seen along the edges of some fields and ditches in the former problem area, but the present drainage system seems to have been generally effective in lowering the water table and facilitating the leaching of saline soils. Shallow wells were not available for sampling in the problem area, but analyses of water samples collected from several drains during two sampling surveys indicate that the recent drain waters have generally contained between 1,500 and 2,500 mg/l dissolved solids and that they are rather similar in composition to Colorado River water, except that they contain somewhat more chloride in proportion to other anions. These analyses suggest that shallow wells near the drains probably would yield water sufficiently low in mineral content for most uses and that even better water might be obtained by drilling shallow wells near the main canals.

The most discriminating data for characterizing water-quality conditions in the shallow zone are those obtained from the Parker Valley south of Poston. Analyses of samples collected from 38 shallow observation wells (one in California) fairly well distributed throughout the nonirrigated part of the valley probably are representative of original conditions in most of the Parker Valley. These analyses indicate that

TABLE 7.—*Chemical analyses of water from wells from the shallow zone underlying the flood plain, Parker-Blythe-Cibola area, Arizona and California*

[Analyses are in milligrams per liter, except as indicated. Analyses made in U.S. Geological Survey laboratory, Yuma, Ariz.]

Water temperature: Temperature, in degrees Celsius (°C). Temperatures taken with Fahrenheit thermometer.

Geologic source: YAs, younger alluvium, sand; YAw, younger alluvium, wash deposits.
Use of water: Dom, domestic; Ind, industrial or mining; T, test hole or well; S, stock.

Well	Date sampled	Perforated interval (feet below land-surface datum)	Temperature (°C)	Geologic source	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium
PARKER VALLEY **Arizona**																			
(B-4-22) 1dbc	4-24-62	17-18	23	YAs	T	26	130	40	193	268	375	212	----------	1,110	490	270	1,780	7.45	46
22aaa	4-25-62	17-18	22	YAs	T	14	100	25	150	203	383	80	----------	854	352	186	1,140	7.10	48
25bda	4-25-62	17-18	22	YAs	T	23	238	84	1,030	300	1,200	1,200	----------	3,930	940	694	6,080	7.40	70
34aaa	4-25-62	17-18	21	YAs	T	23	70	43	89	191	150	165	----------	636	352	196	1,150	7.45	35
35cba	4-25-62	17-18	22	YAs	T	19	206	65	330	262	400	615	----------	1,770	780	565	3,040	7.70	48
(B-5-21) 8ccc	4-27-62	17-18	----------	YAs	T	16	208	108	747	336	1,020	885	----------	3,150	965	690	5,040	7.50	63
20ccc	4-27-62	17-18	----------	YAs	T	25	388	190	1,370	494	1,900	1,660	----------	5,780	1,750	1,340	8,200	7.40	63
29ccc	4-25-62	17-18	22	YAs	T	14	490	177	873	328	1,150	1,690	----------	4,280	1,950	1,680	7,090	7.30	49
29ddd	4-25-62	17-18	22	YAs	T	17	64	9.8	337	272	150	245	----------	1,160	200	0	1,970	7.65	79
30ccc	4-25-62	17-18	22	YAs	T	20	156	59	257	318	325	418	----------	1,390	630	369	2,350	7.55	47
(B-5-22) 11dcd	4-25-62	17-18	21	YAs	T	22	78	23	95	168	250	69	----------	621	289	156	990	7.15	42
24ccc	4-25-62	17-18	----------	YAs	T	14	102	30	108	181	333	84	----------	761	378	230	1,100	7.60	38
25ccc	4-25-62	17-18	21	YAs	T	15	174	51	178	265	525	155	----------	1,230	644	426	1,780	7.50	40
(B-6-21) 20ccc	4-27-62	17-18	----------	YAs	T	20	226	77	277	318	675	368	----------	1,800	880	619	2,790	7.45	41
21ddd	4-27-62	17-18	----------	YAs	T	22	444	188	1,970	419	2,500	2,280	----------	7,610	1,880	1,540	10,900	7.50	70
32ccc	4-27-62	17-18	----------	YAs	T	34	588	300	1,530	588	300	1,530	----------	7,220	2,700	2,340	10,600	7.40	55
34ccd	4-27-62	17-18	----------	YAs	T	18	198	90	558	278	850	685	----------	2,540	865	637	3,960	7.65	58
(B-6-22) 12cdc	4-25-62	17-18	----------	YAs	T	13	140	45	159	230	462	149	----------	1,080	534	346	1,680	7.60	39
24ddd	4-25-62	17-18	23	YAs	T	17	138	47	195	248	462	197	----------	1,180	538	334	1,870	7.60	44
26baa	4-25-62	22-23	----------	YAs	T	16	141	46	166	267	500	115	----------	1,120	540	321	1,590	7.50	40
35ddd	4-25-62	22-23	----------	YAs	T	21	211	56	246	308	512	358	----------	1.560	756	504	2,440	7.60	41
(B-7-21) 4aaa	4-26-62	17-18	----------	YAs	T	21	258	85	386	372	725	550	----------	2,210	995	690	3,480	7.55	46
5baa	4-26-62	17-18	22	YAs	T	20	175	52	162	290	512	165	----------	1,230	650	412	1,810	7.50	35
8ddd	4-26-62	24-25	23	YAs	T	29	89	46	402	372	450	362	----------	1,560	410	105	2,560	7.75	68
16aaa	4-26-62	12-13	22	YAs	T	24	132	62	305	373	550	262	----------	1,520	584	278	2,450	7.70	53
18aaa	4-26-62	22-23	25	YAs	T	25	122	44	221	284	475	169	----------	1,200	486	253	1,790	7.55	50
19ddd	4-26-62	17-18	22	YAs	T	23	190	82	493	382	675	615	----------	2,270	810	497	3,600	7.40	57
20ddd	4-26-62	17-18	22	YAs	T	23	88	34	353	312	512	240	----------	1,410	360	104	2,280	7.60	68
31cdd	4-26-62	17-18	24	YAs	T	20	326	145	590	395	800	1,090	----------	3,170	1,410	1,090	5,120	7.40	48

(B-7-22) 14aad	4-26-62	22-23	22	YAs	T	18	191	51	161	262	550	178		1,280	688	473	1,980	7.75	34
23ccc	4-26-62	17-18	22	YAs	T	24	99	31	128	190	342	101		820	376	220	1,240	7.75	42
23ddd1	4-26-62	22-23		YAs	T	12	156	55	234	299	525	237		1,370	616	371	2,280	7.55	45
24ddd	4-26-62	17-18		YAs	T	25	148	68	360	424	400	475		1,690	650	302	2,700	7.45	55
35ddd	4-26-62	18-19		YAs	T	16	136	43	159	223	475	131		1,070	516	333	1,590	7.65	40
California																			
IN/26E-18N1	6-2-33	16-58		YAw	Ind		[1] 92	[1] 28	[1] 127	[1] 180	258	147		[2] 811	345	200			44
IS/24E-34N1	5-3-62	31-32	24	YAs	T	14	155	52	196	318	538	145		1,260	600	339	1,810	7.50	42
6S/23E-25G1	4-24-62	15-16	21	YAs	T	33	392	200	579	608	1,600	635		3,740	1,800	1,300	5,090	7.40	41
PALO VERDE VALLEY																			
Arizona																			
(B-2-22) 9cba	2-9-62			YAs	Dom, S	17	88	25	162	304	170	175		789	322	72	1,330	7.50	52
(B-3-22) 22bbb	4-24-62	11-12		YAs	T	21	254	54	735	598	1,180	525		3,060	855	364	4,240	7.60	65
27bbb	4-24-62	17-18		YAs	T	21	170	70	329	548	675	194		1,730	710	260	2,650	7.35	50
California																			
6S/22E-11R2)	3-21-67	18-21	24	YAs	T	39	124	84	270	436	575	202	0.9	1,510	655	298	2,400	7.50	47
13Q2	3-23-67	20-22	21	YAs	T	20	126	69	358	304	800	208	1.3	1,730	600	350	2,630	7.70	56
14L2	3-31-67	30-34	24	YAs	T	22	134	60	319	300	500	358	.9	1,540	580	334	2,590	7.70	54
26E2	3-28-67	19-21	24	YAs	T	16	121	41	113	280	312	113	.7	857	470	240	1,420	7.40	24
26G2	3-28-67	19-21	22	YAs	T	22	146	74	140	248	500	175	1.3	1,180	670	466	1,930	7.50	31
7S/22E- 3D2	3-30-67	18-20	25	YAs	T	22	56	35	461	320	525	335	1.8	1,600	284	22	2,650	7.70	78
3H2	3-30-67	20-22	23	YAs	T	20	98	55	148	216	400	139	.9	969	470	293	1,570	7.40	41
8S/21E-24A1	2-13-63			YAs	Dom	23	182	55	223	346	600	181	1.1	1,440	680	396	2,160	7.60	42
8S/22E-8D1	2-15-63			YAs	Dom	22	191	59	172	340	538	180	.9	1,330	720	441	1,960	7.50	34
19A1	3- -63			YAs	Dom	24	151	73	120	390	412	130	1.4	1,110	675	355	1,770	7.30	28
9S/21E-1N1	2- 7-63			YAs	Ind	19	158	63	1,640	572	1,250	1,740		5,160	655	186	8,170	7.90	84
CIBOLA VALLEY																			
Arizona																			
(C-1-23) 19caa	12-14-61			YAs	Dom, S	37	91	10	343	202	190	462		1,230	268	102	2,250	8.05	74
30aca	12-14-61			YAs	Dom, S	36	40	4	195	267	130	133		672	118	0	1,110	8.00	78
(C-2-23) 19dcd	11-19-62	24-32		YAs	Dom	36	149	70	299	556	462	265		1,560	660	204	2,390	8.10	50
California																			
10S/21E-14P2	6- -63	at 6		YAs	Dom	32	98	37	175	180	388	159	0.6	980	396	248	1,520	7.75	49

[1] Estimated.

[2] Dissolved solids.

water in the shallow zone near the river has almost the same composition as the Colorado River water, except for the small areas where the water table is less than about 6–8 feet below the land surface. In some of these shallow water-table areas the dissolved-solids concentrations are several times the concentrations of the river water, and the sodium and chloride concentrations have increased proportionately more than the other ionic constituents. The water in the shallow zone also becomes more mineralized as the distance from the river increases (probably because the percentage of ground water that is evapotranspired increases), with the result that 5 or 6 miles east of the river dissolved-solids concentrations of 4,000–5,000 mg/l are common and the chloride and sulfate concentrations often are nearly equal.

No analyses of water from the shallow zone are available in the northern part of the Palo Verde Valley, but analyses of water from drains in this area indicate that shallow water probably contains less than 2,000 mg/l dissolved solids. Analyses of samples collected from shallow auger holes in the central part of the Palo Verde Valley, near the Palo Verde Mesa west of Blythe, indicate that the water in the shallow zone, although somewhat variable in quality, is similar to moderately concentrated Colorado River water, some of which has been partially softened by base exchange. Water similar to Colorado River water is obtained from several small domestic wells that are near irrigation canals in the Palo Verde Valley south of Blythe and from domestic and stock wells in the Cibola Valley. Drainage water in the southern part of Palo Verde Valley, south of Ripley, is mostly moderately to rather highly mineralized (3,000–15,000 mg/l), possibly because a considerable amount of land is being leached in the area. Salt crusts on ditch banks and in some fields suggest that large parts of both valleys contain rather poor water in the shallow zone. The analyses of water from two shallow wells in the Cibola Valley show unusually low sulfate concentrations, suggesting either active sulfate reduction in the sediments or considerable recharge of low-sulfate water derived from occasional runoff in the desert washes.

The shallow zone is now used as a source of water mainly for rural domestic and stock use and for supplying camp and cabin-site needs along the river. It is unlikely that the zone could supply large quantities of good quality water indefinitely. The sites for which analytical data are available suggest that the shallow zone probably will yield water that is satisfactory for domestic uses at sites that may be distant from the river and where poor quality water may occur at depth, provided the sites are near canals.

In considering future water developments in relation to water quality, the shallow zone should be regarded not only as a potential source of water but as a possible source of objectionable salts. Large areas in the southern parts of the Parker and the Palo Verde Valleys recently have been, or are being, prepared for irrigation with Colorado River water. Soluble salts undoubtedly will be leached from these newly irrigated areas and the resulting saline effluents will be added to the river's mineral load below the drain outlets, which will increase the salinity of the water diverted from the river downstream. Saline water from these leached areas may also move downward into the underlying gravel aquifer, so that, locally, the water in that aquifer may become more saline than it is at present.

THE PRINCIPAL GRAVEL ZONE UNDERLYING THE FLOOD PLAIN

As discussed under geology, the younger alluvium of the Colorado River flood plain in the Parker-Blythe-Cibola area generally contains a distinctive basal gravel that is 5–20 feet thick near Poston (fig. 14), and whose base is generally from 90 to 125 feet beneath the flood plain. A minor amount of other gravel overlies the basal gravel in part of the area, and near Blythe a large amount underlies it. Study of the chemical analyses of ground water indicates that commonly there is local consistency in the chemical character of water obtained from the basal gravel, although there is recognizable variation from one locality to another. Well logs show that many wells are perforated not only opposite the basal gravel but also above or below it. Consequently, the term "principal gravel zone" is used mainly with reference to water produced from the basal gravel of the younger alluvium, but it is recognized that some of the chemical analyses assigned to the zone represent inclusions of water from above or below the basal gravel.

In much of the Colorado River flood plain the chemical characteristics of water in the principal gravel zone (table 8; pl. 6) are similar to those of water in the shallow zone above it. Near the Colorado River, however, water from the principal gravel zone seems generally to be less concentrated than water from the shallow zone. Moderately to highly mineralized water in the principal gravel zone commonly contains somewhat more chloride in proportion to sulfate than does water in the shallow zone having about the same dissolved-solids content, possibly because sulfate reduction has been operative for a longer period of time.

The chemical quality of water in the principal gravel zone in different parts of the Parker Valley is rather variable as shown mainly by analyses of water samples obtained from auger holes but corroborated by a few old analyses of samples obtained from wells no longer in existence and by analyses representing domestic, municipal, drainage, and test wells. Apparently, there have been some changes in composition and concentration in the last 30 years or so, resulting from the regulation of river flows by dams and additional irrigation.

Some of the water obtained from the principal gravel zone in the narrow northward extension of the Parker Valley between Parker and Parker Dam is similar to present Colorado River water, and some is moderately more mineralized. An analysis made in 1933 during the drilling of well 2N/27E–10Z1, which furnished water used in construction of the Metropolitan Water District's California aqueduct, is not much different from other analyses of water from the gravel zone in the narrow part of the valley north of Parker. Two samples from a 110-foot well (B–11–18)21adc, about three-fourths of a mile south of Parker Dam, show a considerable decrease in salinity from January 1958 to August 1963. The decrease suggests some flushing of the water-bearing deposits downstream from Parker Dam, probably both as a result of pumping the wells and because Headgate Rock Dam raised the water level in the river channel, thereby increasing the rate of infiltration of river water into the alluvium.

Water obtained from wells in the flood plain near Parker that are perforated opposite the principal gravel zone has about the same general composition as present Colorado River water, although it is moderately more concentrated. Water from the gravel zone near the Parker Mesa is somewhat less concentrated than the river water, and it contains somewhat less sulfate but more chloride. West and southwest of Parker, at least as far as the vicinity of Poston, water from the principal gravel zone generally is similar chemically to the Colorado River water, although it is as much as 50 percent more concentrated. This characteristic persists southward through the central part of the valley nearly to its lower end. More mineralized water, containing from about 2,000 to as much as 8,000 mg/l dissolved solids, is present in the principal gravel zone near the piedmont slope in a belt on the east side of the valley that extends from a few miles south of Bouse Wash to Tyson Wash. Characteristically, as the concentration of this water increases, both the chloride and sulfate contents increase; however, the most concentrated samples contained more chloride than sulfate. In the most southerly part of Parker Valley near the river, the water in the principal gravel zone generally has about the same composition as the river water, but is slightly more concentrated.

In most of the Palo Verde Valley north of Ripley the water in the principal gravel zone probably is good to fair in quality and contains less than 1,500 mg/l dissolved solids. Analyses of water produced solely from the zone, however, are available only for limited areas because most municipal, industrial, and larger domestic wells in the more thickly settled central part of the valley that were sampled also tap the underlying deep zone that contains water having a dissolved-solids content generally of less than 800 mg/l. Various records of wells (mostly logs) near Blythe show that numerous small-diameter rural domestic wells extend to depths of 100–150 feet and probably obtain water mainly from the principal gravel. Although these small-diameter wells are largely unrepresented by chemical analyses, their number and distribution indicate that water satisfactory for domestic and stock use is rather widely available in the principal gravel zone.

Analyses of water samples collected by the U.S. Geological Survey from five auger holes that penetrated only the top part of the gravel in the western edge of the Palo Verde Valley indicate the presence of slightly altered, to moderately concentrated water of the Colorado River type. However, one auger hole in the same area but near a large drain yielded water that was about three times as concentrated as river water, the increases in sodium and chloride being comparatively large. Analyses of water samples obtained from wells along the east side of the flood plain and within about 1 mile of the river indicate that in this belt, at least as far south as Ripley, water in the principal gravel zone generally is similar to present Colorado River water, except that it may contain somewhat more calcium bicarbonate.

Very little information is available about water quality in the principal gravel zone in the southern part of Palo Verde Valley. A sample obtained from LCRP 16 when that well was being test pumped was a sodium sulfate-chloride water, very high (8.0 mg/l) in fluoride, and unlike any water that had been sampled in the principal gravel zone farther north. The unusually high sodium and fluoride contents of this water suggest that the water may have undergone base exchange with, and also dissolved fluoride from, sediments derived from volcanic rocks.

An analysis made by the Geological Survey in 1917 indicates that better quality water was obtained from a 100-foot well (8S/22E–17Z1) in the present community of Palo Verde than has been obtained in or

TABLE 8.—*Chemical analyses of water from wells from the principal gravel zone underlying the flood plain, Parker-Blythe-Cibola area, Arizona and California*

[Analyses are in milligrams per liter, except as indicated]

Water temperature: Temperature, in degrees Celsius (°C). Temperatures taken with Fahrenheit thermometer.
Geologic source: YA, younger alluvium; YAs, younger alluvium, sand; YAw, younger alluvium, wash deposits; YAg, younger alluvium, basal gravel; OA, older alluviums; B, Bouse Formation; F, fanglomerate.

Use of water: Irr, irrigation; PS, public supply; Dom, domestic; Ind, industrial or mining; T, test hole or well; Un, unused; S, stock.
Remarks: Analyses by following laboratories A, U.S. Geological Survey, Albuquerque, N. Mex.; T, U.S. Geological Survey, Tucson, Ariz.; W, U.S. Geological Survey, Washington, D.C.; Ariz, State of Arizona; Calif., State of California; Y, U.S. Geological Survey, Yuma, Ariz.; P, private.

Well	Date sampled	Perforated interval (feet below land-surface datum)	Temperature (°C)	Geologic source	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium	Remarks
Parker Valley, Arizona																						
(B-4-21)6abb	3-13-63	114-115	23	YAg	T	24	94	13	533		272	575	442			1,820	286	63	2,990	7.70	80	Y
(B-4-22)35cdb	3-19-63	104-105	22	YAg	T	25	226	63	413		440	625	505			2,080	825	464	3,470	7.30	52	Y
(B-5-21)9ccc	3-28-63	125-126	23	YAg	T	23	844	351	1,500		428	1,850	3,220			8,000	3,550	3,200	12,100	7.30	48	Y
18aaa	3-12-63	113-114	23	YAg	T	23	265	80	438		282	750	660			2,360	990	759	3,660	7.50	49	Y
21bbb	3-28-63	127-128	24	YAg	T	23	572	188	931		316	1,250	1,890			5,010	2,200	1,940	7,820	7.40	48	Y
(B-5-22)26ddd	3-14-63	114-115	21	YAg	T	13	94	30	88		162	275	91	0.5		672	358	225	1,120	7.50	35	Y
(B-6-21)2bab	2-28-63	113-114	24	YAg	T	23	286	167	1,630		560	1,800	1,800			6,050	1,400	941	9,280	7.65	72	Y
16bdd	11- -15	0-98	23	YAs, YAg	T		[1] 291	[1] 89	724		653	763	948			[2] 3,540	1,090	557			59	Ariz
18ccd	3- 7-63	119-120	23	YAg	T	24	116	37	175		236	362	175	.9		1,010	440	246	1,640	7.70	46	Y
20bbb	3- 4-63	113-114	23	YAg	T	19	238	82	380		340	538	650			2,080	930	651	3,490	7.75	47	Y
20ddd	10-27-61	120-130	24	YAg	T (LCRP 4).	36	575	186	1,000	14	216	1,430	1,950	.3	6.1	5,300	2,200	2,020	7,800	7.60	50	A
	6- 5-62	120-130	24	YAg		23	586	206	963		459	1,350	1,860			5,220	2,310	1,930	8,160	7.40	48	Y
20ddd2	5-18-62	119-120		YAg	T	30	604	232	1,040		406	1,500	2,000			5,610	2,460	2,130	8,450	7.40	48	Y
(B-6-22)1abb	2- 6-63	79-80	23	YAs	T	23	73	24	160		198	325	89	.6		794	280	118	1,220	7.55	55	Y
23baa1	2- 6-63	84-85	22	YAs	T	21	72	34	98		156	275	83	.6		662	320	192	1,050	7.20	40	Y
23baa2	2-11-63	110-111	23	YAg	T	21	134	63	167		240	462	198	.8		1,170	595	398	1,840	7.60	38	Y
35dcc	3-18-63	104-105	23	YAg	T	22	106	51	207		220	350	268	.4		1,110	474	294	1,840	7.35	49	Y
(B-7-21)13aba	2-27-63	104-105	23	YAg	T	24	159	53	367		432	600	308			1,730	615	261	2,750	7.80	56	Y
14acd	10-24-62	25-187	23	YAs, YAg, B	Dom	24	226	71	337		384	650	423		1.9	1,920	854	539	3,120	7.30	46	Y
14acd	8- -63	25-187		YAs, YAg, B	Dom		218	68	336		279	748	410			1,920	825	595	3,000		47	Ariz
14dcd	1961	25-153		YAs, YAg, B			337	122	532		398	925	856	.5		2,970	1,340	1,020	4,400		46	Ariz
	7-31-62	25-153	21	YAs, YAg, B		26	316	115	512		406	850	820			2,840	1,260	927	4,460	7.60	47	T, Boron= 0.28
	8- -63	25-153		YAs, YAg, B			308	112	524		401	944	775			2,860	1,230	901	4,400		48	Ariz
15ccd	2- 9-61	110-218		YAg, B	PS	32	212	60	234	5.9	330	460	375	.5	1.8	1,540	776	506	2,390	7.40	39	A
	1961	110-218		YAg, B			208	74	207		310	473	346	.5		1,460	823	569	2,300		35	Ariz
16Z1	1916	0-72		YAs	T		[1] 129	[1] 39	153		493	134	194			[2] 1,170	485	80				Ariz
23acd	11- 2-62		22	YAs, YAg, B(?)	Dom	26	334	123	625		412	1,050	900		2.1	3,260	1,340	1,000	5,120	7.40	50	Y, Boron= 0.33
	8- -63			YAs, YAg, B(?)	Dom		343	126	596		408	1,040	905			3,220	1,380	1,040	4,800		48	Ariz.
23dcd	10-25-62		22	YAs, YAg, B(?)	Dom	24	396	173	948		420	1,400	1,390		2.3	4,540	1,700	1,360	6,990	7.30	55	Y
							464	209	995		412	1,580	1,570	.7		5,020	2,020	1,680	7,000		52	Ariz
31aaa	3-24-65	At 104		YAg	T (LCRP 27).	22	154	49	194		252	438	243	.8		1,230	585	378	1,930	7.80	42	Y
33ccd	8-10-42	100-124	26	YAg	Un		[1] 234	[1] 71	554		380	620	800			[1] 2,490	880	568				?
(B-7-22)12ddb	2- 7-63	113-114	22	YAg	T	22	104	28	111		186	317	93	.6		769	374	222	1,150	7.50	39	Y
		91-92	22	YAs		20	113	26	126		206	342	97	.4		827	388	219	1,240	7.35	41	Y
23ddd2	5-10-63	82-83	23	YAs	T	22	164	48	193		280	475	213			1,260	605	376	1,950	7.70	41	Y
(B-8-20)4baa	2-15-63	94-95	23	YAg	T	23	123	36	197		246	462	141	.7		1,110	454	252	1,690	7.80	49	Y
20bbb	1-28-63	99-100	22	YAg	T	26	262	84	572		474	1,180	445			2,810	1,000	612	3,960	7.55	55	Y
29baa	3-26-64	At 113		YAg	T (LCRP 20).	27	186	81	566		364	925	540	.9		2,510	795	496	3,820	7.40	61	Y
(B-8-21)1baa	2-10-61	122-138		YAg	PS	28	158	40	180	4.9	402	433	124	.5	1.3	1,170	560	230	1,720	7.60	41	A
11ccc	5-11-63	78-79	23	YAs	T	19	263	74	157		240	588	348	.5		1,570	960	763	2,430	7.80	26	Y
14bbb	1-28-63	73-74	23	YAs	T	21	271	67	161		294	600	308	.6		1,580	950	709	2,530	7.40	27	Y
28cdd	2-13-63	82-83	21	YAs	T	19	131	39	198		254	450	170	.6		1,130	488	280	1,710	7.80	47	Y
	2-13-63	89-90	21	YAg	T	20	147	35	346		280	638	261	.6		1,590	510	280	2,320	7.90	60	Y
36bdc	2- 9-61	90-125		YAg	PS	26	92	23	179	4.0	266	307	121	.5	.5	884	324	106	1,370	7.60	54	A
(B-9-20)11dbc	6-14-63	28-118	21	YAs, YAg.	Un	18	115	39	137		222	391	110	.6	.1	919	446	264	1,390	7.55		A, Boron= 0.14
14cdd	6-17-63	50-138	23	YAs, YAg.	Un	28	88	23	285		308	472	136	.9	.2	1,180	316	64	1,770	7.80	66	A, Boron= 0.30

14dab	2-15-63	52-53	22	YAs	T	33	84	59	155		280	392	107	1.3		971	454	224	1,410	7.80	43	Y
14Z1	1930(?)			YAs	Dom		105	34	181		256	360	144	3.2		954	402	192			50	Ariz
20cbd	8-15-63		24	YAg	Dom, S	22	134	31	158		224	438	117	.4		1,010	462	278	1,400	7.70	34	Y
24cba	2-13-63	63-64	23	YAs	T	25	115	22	259		146	512	200	1.6		1,210	376	256	1,820	7.60	60	Y
	2-13-63	86-87	24	YAg(?)		26	110	23	220		149	412	208	1.6		1,080	370	248	1,750	7.75	56	Y
25caa	2-15-63	84-85	23	YAg	T	28	51	11	136		123	183	121	1.9		594	172	71	971	7.50	63	Y
36aba	3-5-63	62-63	26		T	29	41	13	173		117	183	167	3.5		668	155	59	1,150	7.75	71	Y
(B-9-21)35baa	2-5-63				T	20	207	52	213		300	650	191	.6		1,480	730	484	2,220	7.40	39	Y
(B-11-18)21adc	1-7-58				Dom	22	184	71	593	13	244	714	780	.8		2,500	740	540	4,030	7.80	63	P
	8-29-63					23	132	32	437		234	500	492	2.0		1,740	460	268	2,920	7.60	67	Y
Parker Valley, California																						
1N/25E-24N1	6-4-64	72-142		YA, F(?)	PS	13	192	56	166		162	450	332	0.6		1,290	710	577	2,060	7.45	34	Y
2N/27E-10Z1	6-8-33	28-97		YAw, F	Ind		[1]108	[1]32	[1]434		[1]240	566	433			[2]1,740	402	206			68	?
3S/23E-14B1	11-13-62				Dom	21	116	39	99		330	233	107			780	448	178	1,320	7.45	32	Y
6S/23E-24J1	7-8-64		23	YAw, F	Irr	22	122	35	140		280	350	111	.7		921	448	218	1,410	7.75	40	Y
Palo Verde Valley, Arizona																						
(B-4-22)2bca	6-18-64	112-130	22	YAg	Irr	19	153	42	163		352	417	132	0.5		1,100	556	268		7.70	39	Y
Palo Verde Valley, California																						
6S/22E-11R1	3-27-67	75-77	24	OA(?)	T	21	138	56	295		288	450	369	0.9		1,470	575	339	2,420	7.70	53	Y
13Q1	3-23-67	114-116	22	YAg	T	22	108	39	138		324	262	135	.5		867	430	164	1,450	7.50	41	Y
14L1	3-31-67	90-94	24	OA(?)	T	24	135	59	315		300	500	352	1.0		1,540	580	334	2,600	7.70	54	Y
26E1	3-28-67	62-64	23	YAs	T	16	135	59	127		240	350	208	.8		1,020	580	383	1,740	7.80	32	Y
26G1	3-28-67	77-79	22	YAs	T	20	159	60	193		332	500	191	.8		1,290	645	373	2,080	7.70	39	Y
	2-6-62	110-177		YAg, OA		13	124	34	128		308	317	102			872	448	196	1,320	7.65	38	Y
6S/23E-32D1	10-23-62	122-186	24	YAg, OA	PS	21	143	38	163		338	375	141	.3	0.6	1,050	514	237	1,610	7.45	41	Y, Boron=0.14
32Z1	10-16-17			YA	Dom	23	69	22	92		297	81	95			530	263	19			43	W
32Z2	10-16-17			YA	Dom	29	76	20	87		297	79	96			535	272	28			41	W
32Z3	10-16-17			YA	Dom	29	51	23	108		295	81	92			532	222	0			52	W
36N1	1960	110-177		YAg, OA	PS		120	48	102	3	293	290	140	.3		823	500	260	1,260		31	P
	2-6-62	110-177		YAg, OA		13	124	34	128		308	317	102			872	448	196	1,320	7.65	38	Y
7S/22E-3D1	3-29-67	45-49	22	YAs	T	19	47	17	312		236	400	177		2.0	1,090	186	0	1,810	7.70	79	Y
3H1	3-30-67	114-118	23	YAg	T	23	175	91	541		400	700	658	.9		2,390	810	482	3,900	7.40	59	Y
5D1	2-7-62	104-190		YAg, OA	Ind	14	108	26	140		293	225	147			806	378	138	1,290	7.80	45	Y
7S/23E-17D1	2-14-62	112-147		YAg, OA	S	17	129	36	239		302	375	249			1,200	468	220	1,880	7.70	53	Y
17E1	2-14-62				S	13	172	54	321		322	575	345			1,640	650	386	2,410	7.50	52	Y
8S/21E-13A1	8-28-63	39-115	24	YAs, YAg	T (LCRP 16).	30	29	12	736	7.0	271	730	517	8.0	.3	2,200	123	0	3,420	8.60	92	A, Boron=1.0
	8-28-63	39-115	24	YAs, YAg		27	65	13	705		384	700	500			2,200	215	0	3,660	7.70	88	Y
8S/22E-17Z1	11-6-17			YA	Dom, S	20	63	20	146		281	175	101		1.5	665	240	8			57	W
9S/21E-2J3	3-27-63	93-95	24	YAs	T	25	57	24	1,540		608	1,150	1,340			4,400	242	0	6,950	7.95	93	Y
2J4	5-15-62	50-52		YAs	T	8	98	79	892		571	1,080	655			3,100	570	102	4,820	8.00	77	Y
2P1	5-7-63	102-104	24	YAg	T	23	470	165	4,560		600	3,440	5,450			14,400	1,850	1,360	21,100	7.40	84	Y
2Z1	11-6-17			YS(?)	Dom	21	64	27	153		289	214	102			726	271	34			55	W
2Z2	5-11-50			YA(?)	Dom		99	29	221		305	355	163			1,020	366	116	1,540		57	
2Z3	3-9-54			YA(?)	Dom		76	24	232	6	325	338	134	2.8		975	288	22		8.10	63	Calif
2Z4	3-9-54			YA(?)	(?)		202	63	1,440	16	471	1,200	1,460	1.8		4,620	765	377		7.90	80	Calif
2Z5	3-9-54			YA(?)	(?)		178	60	512	8	395	652	570	1.1		2,180	692	366		7.80	61	Calif
2Z6	10-14-58			YA(?)	(?)		164	60	410	14	432	570	412			1,850	655	300			57	Calif
2Z7	8-2-59			YA(?)	(?)		164	33	550	9	270	860	480	5.0		2,240	545	323		8.30	68	Calif
2Z8	4-6-61			YA(?)	(?)		169	54	540	7.5	483	508	655			2,180	644	248		8.10	64	Calif
2Z9	6-9-61			YA(?)	(?)		138	44	405	8	359	517	410	1.2		1,700	525	231		8.10	62	Calif
3N1	3-15-63	109-110	26	YAg	T	25	190	62	1,190		121	850	1,660			4,040	730	631	6,830	7.55	78	Y
11A1	3-27-63	104-105	23	YAg	T	21	246	99	2,540		520	2,050	2,820			8,040	1,020	594	12,300	7.60	84	Y
	3-27-63	119-120	22	YAg	T	21	310	123	3,250		504	2,550	3,750			10,300	1,280	866	15,600	7.60	85	Y
11A2	5-8-63	99-100	23	YAg	T	21	41	13	1,080		524	850	840			3,110	156	0	5,060	8.00	94	Y
11K1	3-26-63	109-110	21	YAg	T	24	110	43	144		328	317	117	.7		920	452	183	1,470	7.70	41	Y
23C1	7-29-63	15-100		YAs	Un	26	780	378	6,300		852	4,600	8,300			20,800	3,500	2,800	29,500	7.20	80	Y
24D1	5-9-63	104-105	22	YAg	T	20	7.8	2.3	370		364	325	135	2.4		1,040	29	0	1,670	8.10	96	Y
Cibola Valley, Arizona																						
(B-1-23)28bdc	12-21-64	20-210		YAs, YAg, OA	Irr	37	318	65	572		240	725	950	1.0		2,800	1,060	863	4,380	7.20	54	Y
31cdc	2-13-62	127-140		OA(?)	S(?)	1	320	154	1,920		23	1,350	2,960			6,720	1,480	1,410	10,700	8.20	74	Y
(C-1-24)36bbb	6-14-63	102-117	22	YAg	Wildlife(?)	28	353	821	134		372	952	1,360		0.2	3,830	1,430	1,120	5,940	7.30	56	A, Boron=0.42
(C-2-23)19adc						38	414	101	829		300	1,020	1,380			3,930	1,450	1,200	6,220	7.65	55	Y

[1] Estimated. [2] Dissolved solids.

near this community in recent years. Several analyses of samples of water obtained from wells at now uncertain locations in or near Palo Verde by agencies of the State of California during the period 1950–61, when the State was attempting to assist the public in obtaining better quality water, indicate more saline water than that analyzed in 1917. Other recent local information suggests that water which is considered entirely satisfactory for domestic use is not available near Palo Verde, and also that wells in the area tend to produce poorer quality water after extended use.

Samples of water obtained from auger holes near Palo Verde during the present investigation covered a wide range of concentrations, most concentrations exceeding 3,000 mg/1. The salinity of the water from the auger holes apparently increased somewhat with depth and rather rapidly with distance from the river.

Although the evidence is scanty, it suggests that locally, at least, the mineral content of ground water in the southern part of Palo Verde Valley has increased in recent years. The increased salinity may result partly from irrigation, but more likely because the leaching that resulted from the annual flooding of much of the land that occurred prior to the construction of Hoover Dam no longer takes place.

Cibola Valley is not served by a network of irrigation canals as is Palo Verde Valley so there probably is more opportunity for local salt accumulation. All four analyses representing water from the principal gravel zone in Cibola Valley are indicative of moderately saline water (3,000–10,000 mg/l). Sodium and chloride are the major constituents, but calcium and sulfate are also present in substantial amounts.

THE DEEP ZONE UNDERLYING THE FLOOD PLAIN

The deep zone is arbitrarily defined for convenience in water-quality descriptions to include all the saturated materials beneath the Colorado River flood plain that underlie the principal gravel zone. As explained previously, the upper boundary of the zone was selected because chemical analyses of water samples from the Parker Valley showed similarity to that depth and because an apparent change in water quality occurred somewhere beneath the basal gravel of the younger alluvium in Palo Verde Valley. The bottom of the zone is assumed to be bedrock, although for practical purposes it is the lowermost part of saturated rocks about which water-quality information is available or can be inferred.

The deep zone is described as a unit not because water quality in the zone is assumed to be uniform, but because the paucity of information about water-quality variation with depth or by geohydrologic unit does not permit greater differentiation. Unit B of the older alluviums, which is at the top of the zone, is a major source of water in the central and northern parts of the Palo Verde Valley and is represented by a considerable number of analyses from those areas, but only a few analyses are known to represent water from the deep zone in the Parker Valley, the southern part of the Palo Verde Valley, and the Cibola Valley (table 9). In order to generalize about the flood plain areas with the limited information available, it is assumed that chemical analyses of water obtained at equivalent depths from production and test wells on the piedmont slopes also represent water quality in the deep zone under nearby flood-plain areas. Stiff diagrams representing analyses of water from the deep zone in both the flood plain and piedmont areas therefore are grouped together on plate 6.

The deep zone in the Parker Valley is almost unexplored as a water-supply source because only one production well and three Geological Survey test wells in the flood plain have been sampled adequately to determine the quality of the water that it yields. The number of wells in the adjacent piedmont area that have been sampled at depths equivalent to the deep zone is also small. Consequently, conclusions about the variability of chemical characteristics of water in the deep zone in the Parker Valley are considered preliminary. Nevertheless, the available information suggests that usable water is found in the deep zone in a large part of the valley.

A sample of fresh water from well (B–8–21)36bc which was drilled for a Job Corps camp at Poston in 1966 and which tapped the lower part of the Bouse Formation, was soft, low in bicarbonate, contained moderately more sulfate than chloride, and more fluoride than desirable for drinking water. Similar water, except that the fluoride concentrations ranged from moderately low to excessively high for drinking water, was indicated by several samples from the Bouse and underlying formations obtained from Geological Survey test wells LCRP 20 and 27 in the flood plain and LCRP 15 and 21 on the Parker Mesa. The Stiff diagrams plotted from these analyses are very similar and are recognized as a water type, referred to hereinafter as the tailed-vane type. Water whose analysis plotted as the tailed-vane Stiff pattern was not obtained from any of the flood-plain shallow zone or principal gravel zone wells. Consequently, it seems that, at least under the flood plain, the tailed-vane Stiff pattern is an indicator of water from the deep zone.

TABLE 9.—*Chemical analyses of water from wells from the deep zone underlying the flood plain, Parker-Blythe-Cibola area, Arizona and California*

[Analyses are in milligrams per liter, except as indicated]

Water temperature: Temperature, in degrees Celsius (°C). Temperatures taken with a Fahrenheit thermometer.
Geologic source: YA, younger alluvium; OA, older alluviums; Bu, Bouse Formation, upper; Bl, Bouse Formation, lower; B, Bouse Formation; F, fanglomerate; Br, bedrock.

Use of water: PS, public supply; Dom, domestic; Ind, industrial or mining; T, test hole or well; S, stock.
Remarks: Analyses by following laboratories A, U.S. Geological Survey, Albuquerque, N. Mex.; Y, U.S. Geological Survey, Yuma, Ariz.; Calif, State of California; P, private.

Well	Date sampled	Perforated interval (feet below land-surface datum)	Temperature (°C)	Geologic source	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium	Remarks
Parker Valley, Ariz.																						
(B-6-21) 20ddd	6-16-65	200-300	26	Bu	T (LCRP4)	26	130	35	453		196	425	602	1.0		1,770	470	310	2,990	7.70	68	Y, after 2 hr pumping.
		200-300	26	Bu	T (LCRP4)		146	40	481		196	438	678	1.1		1,910	530	370	3,260	7.70	66	Y, after 5 hr pumping.
(B-7-21)31aaa	4- 1-65	268-283		Bu	T (LCRP 27)	22	92	36	310		212	362	352	1.4		1,280	376	202	2,110	7.60	64	Y
	4- 8-65	At 442		Bl	T (LCRP 27)	23	50	12	342		200	362	268	.8		1,160	176	12	1,890	8.00	81	Y
	4-15-65	At 613		Bl	T (LCRP 27)	16	39	7.4	387		236	375	272	.8		1,220	128	0	1,950	7.70	87	Y
	5-21-65	900-921		Br	T (LCRP 27)	15	620	20	215		39	1,700	202	5.0		2,800	1,630	1,600	3,650	7.00	22	Y
	6- 4-65	194-722	26	B	T (LCRP 27)	27	70	18	221		224	217	225	1.1		891	248	64	1,480	7.60	66	Y
(B-8-20)29baa	4-23-64	At 515		Bl	T (LCRP 20)	21	50	4.9	384		77	462	298	6.0		1,260	145	82	2,090	7.40	85	Y
	5-11-64	604-623		Bl, F	T (LCRP 20)	18	35	2.6	326		62	362	258	6.0		1,040	98	47	1,740	7.70	88	Y
	5-14-64	604-661		Bl, F	T (LCRP 20)	2	39	1.8	344		71	375	278	4.5		1,080	105	47	1,830	7.30	88	Y
	5-15-64	614-689		F	T (LCRP 20)	17	32	0	305		44	338	240	6.5		960	80	44	1,580	7.65	89	Y
	6-10-64	665-740		F, B	T (LCRP 20)	13	28	.2	329		36	375	250	5.5		1,020	71	42	1,740	8.60	91	Y
	6-24-64	688-763	29	Br	T (LCRP 20)	12	34	1.2	333		47	388	252	6.0		1,050	90	52	1,740	8.20	89	Y
	6-24-64	688-763	29	Br	T (LCRP 20)	15	42	.7	337	3.1	70	386	258	5.4		1,070	108	50	1,760	8.10	86	A, Boron=1.3
(B-8-21)36bc	10-12-66	340-467		Bl	PS		28	3	292		77	292	248	3.5		902	83	20		7.90	88	P
Palo Verde Valley, Calif.																						
6S/22E-35M1	2- 7-62	295-310		OA	Dom	8	57	20	207		250	181	199			797	224	19	1,490	8.00	67	Y
35R1	1960?	302-326		OA	Ind	24	76	28	157		268	170	177	0.1		770	306	86	1,200	8.00	53	?
35R2	10-23-62		26		Ind	19	79	28	150		259	170	175	.5		752	310	100	1,320	7.40	51	Y
6S/23E-29R1	2- 7-61	264-368	25	OA	PS	20	133	28	113	3.6	269	302	114	.4	0.5	847	448	228	1,290	7.60	35	A
	10-23-62			OA	PS	17	124	30	101		246	275	115	.5		786	432	230	1,290	7.45	34	Y
31J1	2- 6-62	350-380		OA	PS	7	40	11	129		218	100	102			498	146	0	852	7.95	66	Y
32J1	9-14-60	342-366		OA	PS		46	11	120	2	223	90	110	.2		491	161	0	817	7.80	62	Calif
32M1	1960	310-335		OA	PS		44	10	120	2.5	218	92	110	1.1		489	151	0		8.20	63	Calif
	2- 7-61				PS		44	12	126	2.6	223	94	111	.6	.5	522	160	0	881	7.70	63	A
32P1	3-11-60	245-324		OA	PS		68	11	100	5	229	90	117	.1		525	216	28	900	7.80	78	P
	2- 7-61	245-324	26	OA	PS	21	91	22	122	3.0	249	153	153	.4	3.1	691	316	112	1,150	7.50	45	A
	10-23-62	245-324	26	OA	PS	18	104	27	136		264	192	177	.5		787	372	156	1,370	7.35	44	Y
33G1	1958?	500-600		OA	PS		58	16	106	15	224	87	112	.3	0	493	210	27		7.50	52	Calif
	2- 7-62	500-600		OA	PS	12	80	17	118		248	155	115			621	271	68	997	7.70	48	Y
33K1	2- 7-62	351-408		OA	PS	11	63	17	87		230	92	93			478	226	38	874	8.00	46	Y
33M1	6-16-58	70-306		YA, OA	Dom		70	17	96	0	232	99	112	.2		510	246	54		7.70	46	Calif
	2- 7-62	70-306		YA, OA	Dom	11	78	19	122		249	165	115			634	272	68	1,010	7.70	49	Y
7S/22E-11Q1	2-14-62				Dom	12	44	12	167		239	135	133			623	161	0	1,080	7.90	69	Y
34Z1					Dom		80	29	178	4.8	258	134	250		1.0	856	319	106	1,290	7.90	54	Calif
7S/23E-5E1	2-15-62				Dom	16	63	17	125		228	133	124			592	228	41	997	7.80	54	Y
18A1	2-14-62	465-486		OA	S	12	120	34	179		218	231	291			976	440	261	1,700	7.70	47	Y
21H1	2-15-62				Dom	11	36	9	174		242	140	113			604	125	0	1,020	8.10	75	Y
29D1					Dom	19	156	37	279	6.3	277	342	398	.2	3.0	1,380	540	313	2,250	7.50	53	A
32M1	2-14-62				Dom	15	68	19	88		241	100	97			507	246	48	897	7.80	44	Y
8S/21E-13A1	8-14-63	395-430	28	OA	T (LCRP 16)	28	256	43	2,430		184	1,600	3,040			7,490	815	664	11,700	7.60	87	Y
8S/23E-6P1	2- 8-62	362-370		OA	Dom	10	71	18	95		224	129	99			534	250	66	887	7.80	45	Y
8S/23E-7B1	2-14-62	370-382		OA	Dom	11	89	26	96		217	190	115			635	328	150	1,040	7.60	39	Y
9S/21E-2J1	3-27-62	229-231	24	OA	T	20	510	153	4,640		426	4,150	5,190			14,900	1,900	1,550	21,100	8.20	84	Y
3Z1	5-11-50				(?)		178	73	3,800		180	1,740	5,010			11,000	744	596	16,800		92	Calif

Although most of the water obtained from the deep zone in the Parker Valley and vicinity can be characterized by the tailed-vane pattern, some waters are distinctly different types. Thus, an analysis of water bailed from LCRP 27 at a depth of 200 feet from the Bouse Formation is characterized by the hourglass pattern which is characteristic of water from the unit B of the older alluviums in the deep zone near Blythe (p. 88). This chemical analysis was the only one from any depth in the Parker Valley which plotted as the typical hourglass Stiff pattern, although several analyses from the Parker Mesa also did. A bailed sample obtained from Tertiary sandstone at 900 feet in LCRP 27 was a typical gypsum water, high in calcium and sulfate, low in other constituents, and unlike any other water found in test-well sampling in the Parker-Blythe-Cibola area. The analyses from LCRP 27 (pl. 2*H*) indicate vertical separation of water of different concentrations and types in the deep zone in the central part of Parker Valley.

Moderately saline mixed sodium chloride-sulfate water containing 3,000–5,000 mg/l dissolved solids was obtained from several samples bailed from the deep zone during the drilling of LCRP 4 in the narrower southern part of Parker Valley. The well was completed by perforating the casing only between depths of 120 and 130 feet, thereby tapping only the principal gravel zone. The water pumped from the well was very similar in character to, but less highly mineralized, than the samples obtained from the deep zone.

Later LCRP 4 was perforated in the interval 200–300 feet below land surface, a mechanical packer was installed to shut off the 120- to 130-foot perforated interval, and the well was again pumped. The water obtained during the later test contained less than 2,000 mg/l dissolved solids at the beginning of the test, but as pumping continued the concentration slowly increased, possibly owing to failure of the packer. The water obtained during the test was similar to water from wells on the piedmont slope near Ehrenberg that are perforated opposite the upper part of the deep zone.

Analyses of water samples bailed from LCRP 5, which is on the terrace bordering the flood plain about 5 miles northeast of Ehrenberg, indicated that water from unit B of the older alluviums contained 1,000–1,500 mg/l dissolved solids, but that at a depth of 471 feet, also in the same unit, the concentration (dominantly sodium chloride) reached nearly 4,000 mg/l. The well was not completed suitably to permit pumping and sampling the better water separately, so it was not determined whether practical quantities of the low salinity water are available in this area.

A single sample from the Bouse Formation at a depth of 420 feet obtained by bailing LCRP 22, which is on the piedmont slope 6½ miles south of Ehrenberg, indicated the presence of low salinity water characterized by the tailed-vane Stiff pattern. All other samples obtained during construction and testing of this well, which was drilled to a depth of 998 feet, indicated the presence of sodium chloride water containing 3,000–4,000 mg/l dissolved solids.

The Palo Verde Valley includes the only part of the Parker-Blythe-Cibola area where a sufficient number of wells have been sampled to permit generalization about water-quality variations in the deep zone. Here, most of the known deep-zone wells are within 2 or 3 miles of Blythe, but some are in an area that extends southward as far as Ripley, westward to the Palo Verde Mesa, and eastward to within about 2 miles of the Colorado River. Thus, the zone is used as a source of domestic and municipal water in about one-third of the Palo Verde Valley.

Two general water-quality patterns characterize the developed deep-zone water in this part of the Palo Verde Valley. Most of the deep-zone wells yield water containing 500–700 mg/l dissolved solids with sulfate concentrations of 150 mg/l or less, which is less than one-half that in present Colorado River water (300–350 mg/l). The bicarbonate and chloride concentrations are, however, about equal to those in the Colorado River water. The low proportion of sulfate results in Stiff patterns that somewhat resemble the shape of an hourglass and which in this area indicates water from unit B of the older alluviums. A few wells, mostly those that are heavily pumped and that tap the upper part of the deep zone, yield water that contains 800–1,200 mg/l dissolved solids and has sufficient sulfate so that Stiff diagrams have the pennant pattern that is characteristic of present Colorado River water. Several deep-zone wells yield water whose Stiff diagram patterns are intermediate between the hourglass and the pennant. The distribution of the various Stiff diagram patterns suggests that in the vicinity of Blythe probably all the deep-zone water was originally of the hourglass type and that, as a result of sustained pumping, this water was slowly replaced by Colorado River water that infiltrated from the irrigation canals to the principal gravel zone and thence into the deep zone.

Quality of water conditions in the deep zone in southern Palo Verde Valley and in Cibola Valley are largely unknown because few wells have been drilled into the zone and because the available well records generally do not include information on the chemical quality of the water. However, the very fact that information on the deep zone is almost absent suggests that water in the deep zone has proved unsatisfactory for common uses.

Numerous samples obtained from the mud scow during the drilling of the 800-foot LCRP 16, about 4 miles north of Palo Verde in the southern Palo Verde Valley, indicated the presence of mineralized water containing 5,000–8,000 mg/l dissolved solids throughout the deep zone. An analysis of a sample obtained from the interval 395–430 feet during testing of the completed well contained 7,490 mg/l dissolved solids consisting mostly of sodium chloride. Sulfate concentration was somewhat less than half the chloride concentration.

An analysis of a sample of water obtained from a sandpoint in the bottom of an auger hole 231 feet deep, near Palo Verde, indicated 14,900 mg/l dissolved solids of sodium chloride-sulfate water. Another analysis reported by the State of California in 1950 as having been obtained from a well of unknown depth contained 11,000 mg/l dissolved solids, and was relatively higher in chloride than the sample first mentioned.

No records of analyses of water positively known to be from the deep zone in Cibola Valley were obtained during project investigations. A single analysis representing water first reported to have been obtained from the deep zone and later reported possibly to have come from above the zone indicated the presence of water too saline for irrigation.

THE PIEDMONT AREAS

On both sides of the Colorado River flood plain in the Parker-Blythe-Cibola area are piedmont slopes where appreciable ground water has been developed. Study of the chemical analyses of water obtained from wells in the piedmont areas indicates that the quality of the water is significantly affected by local geologic and hydrologic conditions. Accordingly, the piedmont areas have been divided into several principal subareas to facilitate discussion of the chemical quality of the water underlying them.

Analyses of water samples from the piedmont areas, grouped according to the principal subareas are given in table 10. Stiff diagrams of analyses selected as representative of water beneath the various principal piedmont subareas are shown on plate 6, along with diagrams for analyses of water samples from the deep zone under the flood plain.

PARKER MESA

Parker Mesa is a rather indefinitely bounded part of the Colorado River terrace on the Arizona side of the Colorado River south of Headgate Rock Dam, which is generally about 70 feet higher than the adjacent Colorado River flood plain. The town of Parker is at its northwest corner. Information obtained during the present investigation indicates that there have been many changes in the number, depth, and location of the Parker public supply wells. However, quality-of-water considerations do not seem to have been responsible for any of the changes. Comparison of analyses of samples of water taken many years ago from public and private wells in Parker with analyses of samples taken recently from the public supply wells indicates that there have been no changes in water composition that cannot be explained either as differences resulting from changes in analytical procedure or as differences resulting from the samples not being obtained from identical strata.

Although the surface of the Parker Mesa is alluvium from the Colorado River, well logs and other geologic information indicate that the water produced from the present wells on Parker Mesa comes from the fanglomerate. Generally, the water contains 500–850 mg/l dissolved solids, the chloride and sulfate concentrations being approximately equal. It has been considered satisfactory for domestic use, except in those instances where it contains more fluoride than is recommended for drinking water.

The water from the public supply wells is comparable in concentration to recent Colorado River water (600–900 mg/l) but is always softer and contains less magnesium compared to calcium, and more chloride compared to sulfate, than the river water. Water of similar composition is produced from wells in Vidal Valley, on the Palo Verde Mesa, and from piedmont areas outside the Parker-Blythe-Cibola area. Water from two newly completed wells near Headgate Rock Dam when sampled in 1964 also was very much like the water at Parker.

In order to investigate the aquifers beneath other parts of the mesa, the U.S. Geological Survey drilled two test wells, LCRP 15 and LCRP 21. Test well LCRP 15, which is 2 miles east of Parker, showed a definite change in the chemical character of the water with depth. Water pumped from deposits in the older alluviums 175–199 feet deep contained 616 mg/l dissolved solids and was sufficiently similar in composition to present-day Colorado River water to suggest some hydraulic connection between the well and the river. Water pumped from deposits in the fanglomerate, 285–520 feet deep, contained 733 mg/l dissolved solids and was similar to the deep-zone water from the Parker Valley previously designated the tailed-vane type water.

TABLE 10.—*Chemical analyses of water from wells from the piedmont slopes, Parker-Blythe-Cibola area, Arizona and California*

[Analyses are in milligrams per liter, except as indicated]

Water temperature: Temperature, in degrees Celsius (°C). Temperatures taken with a Fahrenheit thermometer.
Geologic sources: OA, older alluviums; B, Bouse Formation; F, fanglomerate.
Use of water: Irr, irrigation; PS, public supply; Dom, domestic; Ind, industrial or mining; T, test hole or well; Un, unused; Des, destroyed or filled in above water table; S, stock.

Remarks: Analyses by following laboratories A, U.S. Geological Survey, Albuquerque, N. Mex.; Y, U.S. Geological Survey, Yuma, Ariz.; T, U.S. Geological Survey, Tucson, Ariz.; W, U.S. Geological Survey, Washington, D.C.; USSAL, U.S. Salinity Laboratory, Riverside, Calif.; Ariz, State of Arizona; Calif, State of California; P, private.

Well	Date sampled	Perforated interval (feet below land-surface datum)	Temperature (°C.)	Geologic source	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium	Remarks
								PARKER MESA, ARIZ.														
(B- 8-19)5bba	7-13-64	At 300	...	B	T (LCRP 21).	4	102	19	455		78	725	350	4.0	...	1,700	332	268	2,730	7.80	75	Y
	7-14-64	At 335	...	B	T (LCRP 21).	5	46	5.4	316		70	400	240	4.8	...	1,050	137	80	1,750	8.10	83	Y
	7-16-64	At 510	...	B	T (LCRP 21).	2	17	.4	254		76	258	177	6.0	...	752	44	0	1,300	8.10	93	Y
	7-30-64	At 650	...	F	T (LCRP 21).	21	23	1.1	242		91	275	149	6.8	...	764	62	0	1,230	8.10	90	Y
	9- 1-64	At 835	...	F(?)	T (LCRP 21).	24	27	.4	217		87	242	141	7.5	...	703	69	0	1,210	7.80	87	Y
	9-11-64	At 846	...	F(?)	T (LCRP 21).	15	24	0	255		84	258	177	10	...	781	60	0	1,290	8.40	90	Y
	9-18-64	815-1,000	...	F(?)	T (LCRP 21).	23	24	.5	222		80	242	149	6.7	...	707	62	0	1,190	8.15	89	Y
	9-18-64	815-1,000	...	F(?)	T (LCRP 21).	15	36	.5	224	3.9	117	248	152	6.3	2.7	747	92	0	1,240	8.20	83	A, Boron=1.0
	1-12-65	636-1,000	...	F, F(?)	T (LCRP 21).	24	18	.7	226		76	238	153	5.5	...	703	48	0	1,210	8.30	91	Y
(B- 9-19)5ddd	6-25-63	At 168	...	OA	T (LCRP 15).	20	39	16	168		117	200	157	1.7	...	660	164	68	1,130	7.60	69	Y
	7- 8-63	At 280	...	F	T (LCRP 15).	16	27	1.8	179		152	150	127	2.0	...	579	75	0	981	7.90	84	Y
	7-10-63	340-430	...	F	T (LCRP 15).	19	25	1.8	228		92	258	149	4.5	...	731	70	0	1,210	7.90	88	Y
	9-13-63	175-199	28	OA	T (LCRP 15).	25	78	22	101		140	242	97	.3	...	635	284	169	1,010	7.45	44	Y
	9-13-63	175-199	28	OA	T (LCRP 15).	26	70	22	99	4.6	114	240	98	.3	.0	616	264	170	958	7.80	44	A, Boron=0.16
	9- 6-63	285-520	35	F	T (LCRP 15).	20	23	.6	213		78	233	145	5.0	...	679	60	0	1,160	7.95	88	Y
	9- 6-63	285-520	35	F	T (LCRP 15).	21	34	.7	220	3.1	110	249	146	4.8	.1	733	88	0	1,190	8.10	84	A, Boron=0.52
6ccc	8- 8-57	162-280	...	F	T (LCRP 15).	...	18	1	240		185	110	214	4.3	...	679	51	0	...	...	91	Ariz
	1961?	162-280	...	F	T (LCRP 15).	...	23	<1	265		94	230	231	4.2	...	806	61	0	...	...	90	Ariz
	2- 8-61	162-280	...	F	T (LCRP 15).	25	21	2.8	260	3.0	102	218	220	4.0	2.9	807	64	0	1,360	8.20	89	A
(B- 9-19)7ccb	1966	187-320	...	OA, F	Irr	...	67	14	155		147	250	124	2.0	...	697	224	104	1,000	...	60	Ariz
18cbb	8-10-66	100-145	...	OA	Irr	...	30	8	232		181	296	108	...	.1	764	108	0	...	...	82	P
18ccb	9- 7-66	100-130	...	OA	Irr	...	82	0	154		166	254	98	...	0	671	204	68	...	...	62	P

(B- 9-20)1dbd	8-19-55	165-186		F	PS		64	12		189		144	195	210	2.4		644	209	91			66	P
							83	14		200		140	215	285	2.2		875	265	150			62	Ariz
1dbc1	8-19-55	90-148		F	PS		43	9		183		134	180	170	2.8		655	144	34			73	P
	1961?	90-235		F	PS		44	9		190		124	205	214	3.2	2	729	147	44			74	Ariz
	2- 8-61	90-235		F	PS	25	47	7.9	184		4.6	136	173	183	2.9	3.9	698	150	38	1,170	7.40	72	A
	10-24-62	90-235	27	F	PS	21	49	7.2		175		130	160	178	3.0		658	152	46	1,190	7.40	71	Y
1dbc2	7-16-63	263-400	29	F	PS	18	24	.5		205		89	183	169	1.9		646	62	0	1,120	8.10	88	Y
	7-17-63	263-400	29	F	PS	17	25	0		200		88	175	166	3.0		630	62	0	1,100	7.95	88	Y
	7-17-63	263-400	29	F	PS	21	24	1.5	202		3.2	91	191	167	2.8	.9	658	66	0	1,100	8.20	86	A, Boron=0.41
	10-19-66	263-400		F	PS	18	22	.2		201		96	158	173	2.5		623	56	0	1,110	8.10	89	Y
1bdb	2-22-62		24		Dom	16	268	50		334		243	700	478			1,970	875	676	3,490	7.30	45	Y
1dda	3-25-19	110-225		F	Ind	22	52	5.2		318		114	221	363			1,040	151	58			82	W
	8-19-55	110-225		F			90	10		459		139	400	516			1,550	226	152			79	P
(B- 9-20)1Z1	9-26-17				Dom	29	61	19		94		175	119	118			527	230	86			47	W
1Z2	9-26-17				PS	24	21	2.1		249		116	166	236			756	61	0			90	W
1Z3	1930				PS		22	7.0		279		131	195	264			835	84	0			88	Ariz
2dac1	8-19-55				PS		40	8		187		129	225	140	4.0		668	133	27			75	P
2dac2	1961	89-180		F	PS		42	7		130		134	98	145	4.5		494	134	24			68	Ariz
(B-10-19)31ada	6-30-64				I S, Dom	24	71	2.2		175		176	192	154	1.7		708	186	42	1,140	7.85	67	Y
31bdd	6-30-64				PS	25	95	4.6		145		204	208	130	1.4		711	256	88	1,130	7.40	55	Y
EHRENBERG SLOPE, ARIZ.																							
(B-2-22)16bba	8-24-64	At 420		B	T (LCRP 22).	1	44	10		285		82	350	238	2.0		971	152	85	1,620	7.80	80	Y
	8-26-64	At 520		B	T (LCRP 22).	11	234	14		1,040		246	625	1,440	5.0		3,490	640	438	5,660	7.30	78	Y
	9- 4-64	797-802		B	T (LCRP 22).	10	166	23		825		56	575	1,170	3.5		2,890	510	464	4,910	7.40	78	Y
	9- 9-64	At 841		F	T (LCRP 22).	9	194	18		811		60	550	1,200	3.5		2,820	560	511	4,830	7.40	76	Y
	9-11-64	At 945		F	T (LCRP 22).	30	326	6.4		1,190		23	700	1,890	4.5		4,160	840	821	7,020	7.50	76	Y
	9-14-64	993-997		F	T (LCRP 22).	32	318	8.9		1,170		22	650	1,900	4.0		4,090	830	812	6,910	7.80	76	Y
	9-28-64	820-985	44	F	T (LCRP 22).	50	326	.2	1,200		10	28	648	1,930	3.5	0.2	4,180	815	792	6,910	7.30	76	A
(B-3-21)4cda	2- 5-62			OA(?)	Dom, S	10	32	5		193		204	231	78			651	99	0	1,000	7.90	81	Y
7db	6- 7-63	423-443	33	OA(?)	Ind	18	40	4.9		229		90	275	182	.5		794	120	46	1,330	7.40	81	Y
(B-3-22)15bac	2- 6-62	225-250		OA	Dom	1	106	60		931		48	825	1,160			3,110	510	470	5,010	7.20	80	Y
15bcc	5- -61			OA	PS		54	11		306		305	313	192	.9		1,030	180	0	1,700		79	Ariz
	2- 5-62		21	OA		18	54	11		327		318	350	188			1,110	180	0	1,700	7.80	80	Y
15bcd1	2- 5-62		27	OA	PS	24	178	34		559		268	662	632			2,220	585	365	3,520	7.70	68	Y
15bcd2	2- 5-62		28	OA	PS	16	215	37		609		236	775	720			2,490	690	496	3,800	7.40	66	Y
15bcd3	2- 5-62	160-200	23	OA	Dom	16	250	43		610		736	700	855			2,590	800	606	4,150	7.40	62	Y
16daa	1960	242-270		OA	Ind		80	17		390		314	390	341	1.2		1,380	270	12			76	Ariz
	2- 5-62	242-270	26	OA	Ind	15	116	33		491		320	588	438			1,840	425	116	2,840	7.50	72	Y
(B-4-22)36bab	11-18-61	132-140		OA	T (LCRP 5).	37	254	26	638		15	116	668	955	1.9	5.0	2,660	740	645	4,220	7.70	65	A, Boron=1.1
	11-16-61	466-471		OA	T (LCRP 5).	25	405	66	764		15	144	940	1,330	1.0	5.1	3,620	1,280	1,160	5,590	7.50	56	A, Boron=1.0
	6- 7-62	132-140	27	OA	T (LCRP 5).	20	262	34		621		117	675	955			2,620	795	699	4,380	7.40	63	Y
36ccb	8-15-63			OA	Dom	31	209	25		694		122	725	908			2,650	625	525	4,270	7.40	71	Y
VIDAL VALLEY, CALIF. **Vidal Junction**																							
[1]N/23E-5P1	4-19-33	312-600		B(?)	Ind		[1]21	[1]5		[1]198		[1]100	218	139			[2]660	74	0				(?)
8D1	9-16-33	296-603		B(?)	Ind		[1]16	[1]4		[1]192		[1]60	206	148			[2]610	55	0				(?)
9E1	12-13-50	630-670		B(?)	PS		7	2		158		166	85	112		3.5	450	26	0	800	8.00	93	Calif
9E2	5-11-54			B(?)	Dom		28	3	179		3.2	77	176	149	0.8	19	595	80	11	1,020	8.10	82	Calif
	12-12-61			B(?)	Dom	23	21	5		193		81	200	154			637	73	7	1,060	8.15	85	Y

See footnotes at end of table.

TABLE 10.—*Chemical analyses of water from wells from the piedmont slopes, Parker-Blythe-Cibola area, Arizona and California*—Continued

Well	Date sampled	Perforated interval (feet below land-surface datum)	Temperature (°C)	Geologic source	Use	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Percent sodium	Remarks
VIDAL VALLEY, CALIF—Continued																						
Vidal Vicinity																						
1S/23E-1A1	4-2-27	205-605		B					203			180	159			[2] 622						
	5-24-55	205-605		B			13	3	205	2	58	175	167			604	45	0			90	Calif
	12-13-61	205-605		B			32	5	107		42	92	144			411	100		765	8.25	70	Y
1A2	8-11-10	320-412		B	PS		[1] 16	[1] 4	216		132	176	164			[2] 643	50	0			90	(?)
1S/24E-9K1	12-13-61			OA	Irr	32	15	.9	125		164	69	69	1.9	4.7	399	41	0	651	8.10	87	A
	6-17-64		32	OA		27	14	2.2	119		154	72	67	2.2		380	44	0	661	7.60	85	Y
10F1	10-19-60	160-198		OA	Irr		44	12	180	4.0	156	161	178	1.5	18.6	677	162	34			70	Calif
	6-17-64	160-198	29	OA	Irr	25	129	38	264		148	308	432	1.3		1,270	480	358	2,100	7.20	54	Y
10N1	8-1-62	100-306	30	OA	Irr	29	123	27	335		173	425	398	1.1		1,420	420	278	2,430	7.45	63	Y
10N2	8-1-62		30	OA	Irr	30	99	20	265		183	362	265	1.7		1,130	328	178	1,850	7.25	64	Y
10Q1	6-17-64	142-222	28	OA	Irr	29	103	31	317		196	425	332	1.4		1,340	384	224	2,230	7.20	64	Y
10R1	8-1-62			OA	S	22	173	44	215		173	500	295	.6		1,340	612	470	2,090	7.45	43	Y
15B2	12-14-61				Dom	29	22	3.6	256		193	194	180	4.1	2.2	787	70	0	1,300	8.30	89	A
15B3	5-9-66	775-1,000		F	Irr		9	1	268		67	284	178	10	0	774	26	0	1,330	8.75	96	P
	10-18-66	775-1,000		F	Irr	22	95	30	282		172	425	268	5.0		1,210	360	219	2,020	7.50	63	Y
15C1	8-1-62	120-205	27	OA	Irr	24	182	59	174		197	425	332	.7		1,300	696	534	2,280	7.25	35	Y
16B1	1960?	130-200		OA	Irr		101	7	348	4.2	95	334	430	2.9	35	1,350	282	204			72	USSAL
	2-9-61	130-200		OA	Irr	31	71	7.1	298		90	277	350		20	1,100	206	132	1,870	7.60	76	A, Boron=0.82
	12-13-61	130-200		OA	Irr	26	88	8	330		88	333	390			1,220	252	180	2,130	7.80	74	Y
	5-24-61	130-200	42	OA	Irr	26	73	7.3	297		90	248	356		22	1,070	212	138	1,830	7.50	75	A, Boron=0.74
	6-16-64	130-200		OA	Irr	28	52	3.0	267		88	225	291	2.2		912	142	70	1,640	7.70	80	Y
	10-18-66	130-200		OA	Irr	21	146	9.8	399		84	425	535	2.5		1,580	405	336	2,770	7.50	68	Y
17C1	5-20-52	210-220		B(?)	Dom		33	1.1	396		86	274	399	16.0	5.0	1,170	87	16	2,010	8.40	91	Calif
	4-7-61	210-220		B(?)	Dom	26	29	2.7	381		79	282	401		.0	1,160	83	18	2,030	8.20	91	Calif
	2-20-62	210-220	28	B(?)	Dom	20	28	3	398		82	317	392			1,200	83	16	2,090	8.00	91	Y
29G1	12-2-60	120-230		B(?)	Dom	25	55	0	422		79	407	410			1,360	137	72		7.82	87	P
	2-20-62	120-230		B(?)	Dom	18	44	2.2	446		70	462	390			1,400	119	62	2,270	7.80	89	Y
29J1	2-20-62				Dom	17	35	3	329		90	275	322			1,030	98	24	1,770	8.10	88	Y
PALO VERDE MESA, CALIF.																						
5S/22E-28C1	2-8-62	270-601	32	OA	Irr	11	255	12	457		22	1,020	425			2,190	685	667	3,160	7.70	59	Y
	10-25-62	270-601	32	OA	Irr	16	268	8.9	439		38	972	435		3.8	2,160	705	674	3,090			A, Boron=1.2
33J1	3-16-62	260-380	31	OA	Irr	29	128	2.1	316		58	380	395	2.2	9.7	1,290	328	280	2,090	7.20	68	A, Boron=0.48
	10-26-62	260-380		OA	Irr	24	122	7.4	302		50	375	395	1.7		1,250	335	294	2,200	7.35	66	Y
35A1	2-10-66	200-450	31	OA	Irr	18	68	5	376		122	330	405	1.8		1,300	190	90	2,160	7.40	82	T, Boron=1.2
35M1	1-27-64		31	OA	Irr	19	84	2.1	315		82	338	340	1.9		1,140	218	151	1,940	7.60	76	Y
	2-10-66		31	OA	Irr	20	110	1.8	376		80	365	415	1.7		1,300	282	217	2,150	7.60	79	T, Boron=1.3
6S/21E-36R1	7-15-54	520-620	33	OA(?)	Irr, Dom		[1] 108	[1] 24	927		104	1,060	845	4.0		3,020	368	283	4,700	7.60	85	USSAL
36R2	5-23-61	250-380		OA	Dom	33	35	7.9	445	6.2	120	404	396	2.4	7.9	1,400	120	22	2,310	7.70	88	A
	6-13-61	250-380		OA	Dom	32	36	8.5	439	5.5	116	414	401	1.1	14	1,410	125	30	2,350	7.80	88	Calif
6S/22E-1N1	2-9-66	410-426		OA	Irr	16	20	8.8	230		244	150	161	1.2		709	86	0	1,210	7.70	85	A, Boron=0.29
2P1	5-14-64	150-250		OA	Irr		21	6	210	4	201	120	178			640	76	0	1,150	8.20	85	P
	7-1-64	150-250		OA	Irr		21	5	229		214	145	174		.6	681	72	0	1,190	8.90	87	USSAL
	2-10-66	150-250		OA	Irr	15	16	5.8	239		208	150	179	1.7		711	64	0	1,220	8.20	89	Y, Boron=0.34
	2-10-66	150-250		OA	Irr		17	6.4			216	146	185	1.9		732	69	0	1,220	8.20	88	T
9P1	6-13-67	230-250	32	OA	T (LCRP 31).	16	154	9.4	422		34	475	578			1,670	430	392	2,920	7.50	69	Y

11H1	6-19-64	165-235	27	OA	Irr	22	108	39	253		224	312	332	1.0		1,180	428	244	2,060	7.20	56	Y
12E1	10-22-60	160-220		OA	Irr		[1]106	[1]37	334		238	404	373			1,370	415	220	2,300		64	USSAL
12F1	1-5-61			OA	Irr		100	35	308	4.8	255	404	324	.8		1,300	395	184		8.00	63	Calif.
15M1	1960?	168-315		OA	Irr		32	9.8	244		198	187	209	3.2	1.2	785	122	0	1,370	8.00	81	USSAL
	2-6-62	168-315	27	OA	Irr	10	35	8	268		200	225	217			863	122	0	1,440	8.00	83	Y
	6-20-62	168-315	27	OA	Irr	20	33	10	250		191	192	215	3.8		820	125	0	1,400	7.45	81	Y
	6-12-63	168-315		OA	Irr	19	35	8.9	251		196	189	222		.2	822	124	0	1,400	8.10	81	A, Boron=0.45
15Q1	9-16-63	346-572	33	OA	Irr	17	23	.1	257		240	150	183	2.3		752	58	0	1,320	7.90	91	Y
20A1	6-15-67	230-250	31	OA	T (LCRP 32).	30	55	10	223		76	212	268	1.8		838	180	118	1,510	8.00	73	Y
28G1	2-9-66		31	OA	Irr	18	38	8.5	268		217	220	245	2.9		930	130	0	1,550	7.70	64	T, Boron=0.63
31Z1	10-17-17			OA	Irr, Dom	39	38	64	365		111	324	343		.7	1,170	121	30			87	W
32F1	5-23-61			OA	Ind	32	24	11	244	3.8	116	220	207	2.5	11	813	104	9	1,340	18.10	83	A
32K1	1954			OA	Irr				283		101		296				174	92	1,670			USSAL
	5-23-61			OA	Irr	24	62	17	324		86	374	330			1,180	224	154	1,960		76	A, Boron=1.2
32R1	6-11-63	120-488	31	OA	Un	27	55	20	388		256	575	177	2.0		1,370	220	10	2,140	7.70	79	Y
	6-11-63	120-488	31	OA	Un	27	65	19	397		214	534	260		8.1	1,420	240	65	2,200	8.30	78	A, Boron=1.3
	6-11-63	120-488	31	OA	Un	22	67	24	427		204	575	301	1.7		1,520	266	98	2,310	7.60	78	Y
33R1	1960?			OA	Des		86	17	341		127	366	391	1.7	1.0	1,270	284	180	2,150	7.70	72	USSAL
34L1	5-25-61	350-360		OA	Dom	16	81	26	371	4.8	270	354	368	.6	.3	1,350	310	88	2,220	7.80	72	A
7S/21E-14B1	2-8-66				Un	24	85	29	893		59	460	1,150	6.4		2,650	224	176	4,490	7.90	90	T
14H1	3-1-66	700-900	45	F	Un	45	150	14	1,510		65	800	1,990	5.2		4,550	430	376	7,680	7.50	88	Y
7S/22E-4P1	8-13-59	118-136		OA(?)	Irr	25	41	14	280	5.1	178	230	274	1.5		959	158	13	1,750	7.90	79	Calif
	2-29-60	118-136		OA(?)	Irr		53	18	351		198	295	346	2.2	1.8	1,170	204	42	1,950	7.00	79	USSAL
	5-25-61	118-136		OA(?)	Irr	30	108	29	500		176	515	522		5.2	1,840	388	244	2,950	7.40	74	A
	10-22-62	118-136	28	OA(?)	Irr	25	124	46	559		168	700	602			2,140	500	362	3,790	7.30	71	Y
OUTLYING UPLAND AREAS																						
Milpitas Wash (Arroyo Seco), Calif.																						
10S/21E-29D1	5-14-62	136-138		B	T	4	64	31	129		49	350	115			717	286	246	1,150	7.75	50	Y
11S/20E-15Z1	12-7-17			Br	Dom, Ind	64	80	12	18		300	13	13		12	362	249	3			14	W
	1-9-62			Br		32	86	5.5	17		292	13	11	0.3	4.6	313	237	0	503	7.70	13	A, Boron=0.08
11S/21E-5H1	9-17-63	283-752, open hole	31	F	Un	20	20	.2	181		272	48	121	.0		526	51	0	896	7.75	88	Y
Bouse Wash Basin, Ariz.																						
(B-8-19)34daa	12-3-63			B	S	20	58	4.3	21		168	23	29	1.7		241	162	24	495		22	Ariz
Tyson Wash Basin, Ariz.																						
(B-4-19)28b	5- -61				PS		44	7	72		146	129	27	0.8		353	138	19	600		53	Ariz
	2-7-63					38	47	4.5	78		151	131	28	.8	5.6	407	136	12	606		56	A
(B-5-19)31a	3-29-62				S	27	84	1.1	29		290	13	18	.0		317	214	0	520	7.75	23	Y
(B-5-20)29bcc	5- -50				Des		68	11	152		390	136	58			620	210	0	1,200		67	Ariz
Mohave Wash Basin, Ariz.																						
(B-1-21)23d	5- -61			YAw	Wildlife		115	20	7		315	23	65	0	13	401	369	110	800		4	Ariz
	3-19-63			YAw	Wildlife		116	12	9.4		323	29	46	.2		415	340	75	715		6	Y

[1] Estimated.

[2] Dissolved solids.

Test well LCRP 21, about 6 miles southeast of Parker, was sampled intermittently during drilling in the Bouse Formation after the well was completed in three zones in the fanglomerate between 636 and 1,000 feet. Except for the uppermost samples, which were somewhat more concentrated, all samples of water from this well were similar in chemical composition, the dissolved solids being between 700 and 800 mg/l, and the fluoride concentrations high. All were characterized by tailed-vane Stiff patterns.

Following the completion of the two Geological Survey test wells, private interest in using ground water for irrigation on the mesa resulted in the drilling of three production wells. These wells yielded water having a chemical composition intermediate between the pennant type of the Colorado River and the tailed-vane type of water from the Bouse Formation. This may indicate that water from the private wells, which were rather close to the edge of the mesa, included some ground-water recharge from irrigation in the adjacent flood plain.

Thus, the limited information available indicates that water high in fluoride content but otherwise suitable for many purposes can be obtained within a mile or two eastward from the west escarpment of the Parker Mesa. It is not known, however, how far southward or eastward usable water might be obtained.

EHRENBERG SLOPE

The only piedmont area east of the Colorado River and south of the Parker Mesa where a considerable number of wells have been located is the dissected piedmont slope that reaches almost to the river at Ehrenberg and that is close to the river for a few miles both north and south of Ehrenberg. Most of the wells on the slope near Ehrenberg have been drilled only into the older alluviums, but farther away, some may penetrate the Bouse Formation. Water from the older alluviums produced from wells 200–300 feet deep within a mile of Ehrenberg generally has contained moderately high concentrations of both chloride and sulfate and has had dissolved solids of between 2,000 and 3,000 mg/l. However, water from one well at the Arizona State inspection station, reported to have been drilled to 600 feet but producing from an unknown depth, was better than the water from other wells in and near Ehrenberg. This water contained only about 1,000 mg/l dissolved solids, was low in fluoride, and its analysis produced the tailed-vane Stiff pattern, a possible indication that it may have been water from the Bouse Formation.

Two wells near U.S. Highway 60–70, about 5 and 3 miles northeast of Ehrenberg, both of which produce water from deposits slightly above sea level, probably the older alluviums, yielded samples containing 651 and 794 mg/l dissolved solids, respectively, and both analyses plotted as tailed-vane Stiff patterns.

Analyses of samples from all selected depths in 471-foot deep LCRP 5, and 4 miles northeast of Ehrenberg, and from depths of 500 feet and greater in LCRP 22, 6½ miles south of Ehrenberg, were somewhat alike and indicated the general presence of moderately saline chloride-sulfate water containing between 1,800 and 4,500 mg/l dissolved solids, and generally having moderately high fluoride concentrations. However, a single sample bailed from LCRP 22 at 420 feet contained only 971 mg/l dissolved solids, and the analysis plotted as a tailed-vane pattern.

It seems from the available data that waters of two rather diverse concentration levels are present beneath the Ehrenberg slope. Near Ehrenberg the more saline water is generally present, although better quality water may underlie it. Data are not sufficient to outline the areal extent of either type of water.

VIDAL VALLEY

Vidal Valley, the alluvial upland drained by Vidal Wash and several shorter unnamed washes parallel to it, is the northernmost piedmont area west of the Colorado River in the Parker-Blythe-Cibola area where development of ground water has been significant. Development has occurred in three subareas: the Vidal Junction subarea, the Vidal subarea, and the lower valley subarea. Near Vidal Junction (elev 920 ft) and Vidal (elev 630 ft), about 11 and 5 miles, respectively, from the Colorado River, domestic and commercial wells as much as several hundred feet deep have yielded water containing 400–600 mg/l dissolved solids. In both areas the waters are solutions of mixed sodium salts; but near Vidal Junction the sulfate concentrations generally exceed the chloride concentrations, whereas near Vidal the reverse is true. However, neither of the two constituents approaches the 250 mg/l limits recommended as maximums by the U.S. Public Health Service.

Yield of wells in and near the two trading points has been so low that irrigation by pumping has not been attempted, although the water in either subarea would be suitable for irrigation. The low salinity of the water indicates that this up-valley water was derived mostly from local rainfall and infiltration of runoff in the washes and has not moved very far through deposits containing appreciable amounts of readily soluble minerals. The observed increase of chloride relative to sulfate between Vidal Junction and Vidal may indicate sulfate reduction.

All or parts of several sections of land in the lower part of Vidal Valley within 3 or 4 miles of the Colorado River and near Vidal Wash are now irrigated with water pumped from wells. Several domestic wells a little farther from the river are also in use. The irrigation and domestic wells are usually perforated at depths a few tens of feet below the average level of the Colorado River, so pumping from them may be inducing movement of water from the river.

The water pumped from most of the wells in the lower valley subarea generally contains 1,000–1,500 mg/l dissolved solids. Sodium is the principal cation, and chloride, the principal anion. Generally, the sulfate exceeds the bicarbonate, but the relative concentration of sulfate compared to chloride varies from well to well so the shape of the Stiff patterns also vary. Two analyses of samples of water from well 1S/24E-9K1, an irrigation well of unknown depth, are anomalously low in dissolved solids which suggests that water produced from this well has come mainly from local recharge.

PALO VERDE MESA

The most extensive ground-water development in the Parker-Blythe-Cibola area has been on the Palo Verde Mesa west of Blythe, where at least 48 large-diameter wells have been drilled. Several of the wells served the former Blythe Air Base and nearby housing developments, but most were drilled for irrigation, more than half of them since 1960. Analyses of water samples collected from wells on the mesa show that the best quality water has been obtained within a mile or two of the flood plain and that there is a gradual increase in mineral content westward and northwestward from the flood plain.

Wells within about 2 miles of the Palo Verde Mesa escarpment and north of U.S. Highway 60–70 have produced water mainly from depths between 150 and 350 feet. In this area the water contains 700–900 mg/l dissolved solids with the chloride concentration generally being in the range 150–250 mg/l and somewhat greater than the sulfate concentration. Two or three miles farther west, concentrations are commonly greater, the dissolved solids being in the range 1,000–1,500 mg/l and the sulfate concentrations being about the same as, or moderately exceeding, the chloride concentrations. Water of this character is found closer to the flood plain south of U.S. Highway 60–70.

Two wells about 3 miles southwest of Blythe airport indicate the presence of a body of deep water more mineralized than other water developed in the rest of the Palo Verde Mesa area. One of the wells, perforated from 700–900 feet below the land surface, yielded water containing 4,550 mg/l dissolved solids, mostly made up of a mixture of sodium chloride and sodium sulfate, with the chloride concentration being about double the sulfate concentration. The second well, perforations unknown, yielded water of the same type but containing only 2,800 mg/l dissolved solids.

The irrigated acreage on the Palo Verde Mesa is being expanded, and judging by the number of wells drilled in 1966, the acreage can be expected to increase considerably in the next few years. Increased pumping for irrigation likely will result in a gradual lowering of the water table on the mesa and may result in increases in concentrations of some constituents dissolved in the water being pumped. Comparisons of analyses of samples obtained from the few wells sampled more than once and of analyses of samples from neighboring wells taken during different years suggest that slow increases in concentrations already are occurring.

OUTLYING UPLANDS

Other unnamed outlying areas in the mountains and high on the piedmont slopes are drained intermittently by desert washes that may flow for short distances after major rainstorms but which very rarely flow sufficiently to discharge directly into the Colorado River. During the past hundred and more years that the Lower Colorado River Basin has been occupied and developed, numerous wells have been dug or drilled in these outlying areas by mine operators, cattlemen, game conservators, and others. Occasionally, chemical analyses have been made of water samples collected from these wells. Although the analytical coverage is too scanty to justify generalizations about water-quality variation by specific areas or individual drainage basins, considering all the known analyses together makes possible some general statements.

Without exception, reported analyses of water from wells in the outlying uplands indicate that the water contained less dissolved solids than the present Colorado River water. Generally, the main dissolved constituent is calcium bicarbonate; however, a few samples mostly from deeper wells indicate sodium bicarbonate as the main dissolved constituent. On the basis of the above analytical data it is inferred that rainwater and storm runoff, being nearly saturated with carbon dioxide, first dissolves limy materials present in almost all rocks, thereby producing the calcium bicarbonate water. The sodium bicarbonate water probably is then formed by base exchange as the calcium bicarbonate water seeps through silts and clays that locally underlie some of the washes.

The concentrations of chloride and sulfate reported for water from the remote areas have generally been less than 50 mg/l each, although occasionally one or the other has been reported to be somewhat more than 100 mg/l. Probably the higher concentrations of these two constituents mostly reflect some concentration by evapotranspiration.

The fluoride concentrations have been mostly low (0.0–0.8 mg/l), but one sample contained 1.7 mg/l. The higher fluoride concentration may be related to the presence of volcanic materials in the water-bearing sediments.

It is unlikely that ground-water at any point in the outlying areas changes greatly in concentration from year to year or over a period of years. Some support for the latter statement is the fact that two analyses of samples taken 45 years apart from Midway well (11S/20E–15Z1), a landmark well in the middle of Milpitas Wash drainage in California, are very similar.

CHEMICAL CHANGES IN THE GROUND WATER

The analyses of ground waters from beneath the flood plain in the Parker-Blythe-Cibola area show that some of the wells yield water that is very similar in composition to average Colorado River water, whereas others yield water of very different character. Almost certainly, nearly all the ground water beneath the flood plain, at least in the shallow and principal gravel zones, originated as Colorado River water. Questions then arise as to what chemical processes could have changed the composition of the river water to that of the well waters. Defining all the possible chemical changes is difficult because various kinds of change probably occur at different rates under different environmental conditions, so that waters of similar composition may have been produced in different ways. However, explanations of common patterns of ground-water composition can be developed if one chemical change is considered at a time, and if several of the more important changes are considered in a prescribed order.

The composition of water obtained from many wells in the Parker-Blythe-Cibola area can be explained if the ground water is assumed to have originated as shallow infiltration from the Colorado River, from irrigation canals, or from irrigated fields, and to have been altered mainly by three primary processes: concentration by evapotranspiration, precipitation of insoluble calcium and magnesium carbonates, and reduction of sulfate.

Table 11 is a series of hypothetical analyses which would result if average Colorado River water, as represented by the weighted average analysis of water released from Hoover Dam in 1965, should be altered by only one, two, or all three of the primary processes. In the table, and in figure 36, evaporation is assumed to have reduced the volume of water from an original

TABLE 11.—*Hypothetical chemical analyses of Colorado River water chemically altered in the alluvial aquifer*

[Results in milligrams per liter, except as indicated]

Description	Analysis No.	Volume (milliliters)	Concentration factor	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (sum)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Percent sodium
Original water	1	1,000	1	101	29	119		156	335	108	770	371	242	1,210	41.1
Concentrated by evaporation only.	2	667	1.5	151	44	178		234	502	162	1,150	556	364	1,820	41.1
	3	500	2	202	58	238		312	670	216	1,540	742	485	2,420	41.1
	4	333	3	303	87	357		468	1,005	324	2,310	1,110	726	3,630	41.1
	5	250	4	404	116	476		624	1,340	432	3,080	1,470	967	4,840	41.1
	6	200	5	505	145	595		780	1,675	540	3,850	1,860	1,210	6,050	41.1
Concentrated by evaporation and precipitation of $CaCO_3$ and $MgCO_3$ when HCO_3 is more than 312 mg/l.	7	333	3	268	76	357		312	1,005	324	2,190	982	726	3,660	44.2
	8	250	4	333	95	476		312	1,340	432	2,830	1,220	967	4,700	45.8
	9	200	5	399	114	595		312	1,675	540	3,480	1,470	1,210	5,740	46.9
Concentrated by evaporation and precipitation of $CaCO_3$ and $MgCO_3$ when HCO_3 is more than 312 mg/l, plus SO_4 reduction of 25 percent.	10	667	1.5	131	37	178		234	430	162	1,060	480	288	1,800	44.6
	11	500	2	154	44	238		312	502	216	1,310	565	309	2,250	47.8
	12	333	3	160	46	357		312	625	324	1,670	586	330	2,840	57.0
	13	250	4	167	48	476		312	753	432	2,030	612	356	3,430	62.8
	14	200	5	166	47	595		312	850	540	2,350	608	352	3,960	68.1
Concentrated by evaporation and precipitation of $CaCO_3$ and $MgCO_3$ when HCO_3 is more than 312 mg/l, plus SO_4 reduction of 33⅓ percent.	15	667	1.5	126	36	178		234	412	162	1,030	462	270	1,760	45.6
	16	500	2	138	40	238		312	447	216	1,240	508	252	2,130	50.5
	17	333	3	131	38	357		312	525	324	1,530	482	227	2,620	61.7
	18	250	4	122	35	476		312	596	432	1,820	450	194	3,090	69.7
	19	200	5	102	29	595		312	625	540	2,050	374	118	3,470	77.6
Concentrated by evaporation and precipitation of $CaCO_3$ and $MgCO_3$ when HCO_3 is more than 312 mg/l, plus SO_4 reduction of 40 percent.	20	667	1.5	115	33	178		234	375	162	980	424	232	1,690	47.7
	21	500	2	126	36	238		312	402	216	1,170	461	205	2,040	52.9
	22	333	3	110	31	333		312	450	324	1,400	404	148	2,460	65.7
	23	250	4	90	26	476		312	482	432	1,660	331	75	2,840	75.8
	24	200	5	74	21	595		352	525	540	1,910	270	14	3,250	82.8
	25	167	6	49	14	714		312	540	648	2,120	0	0	3,600	89.7
	26	125	8	1.2	.4	952		312	578	864	2,550	0	0	4,320	99.7

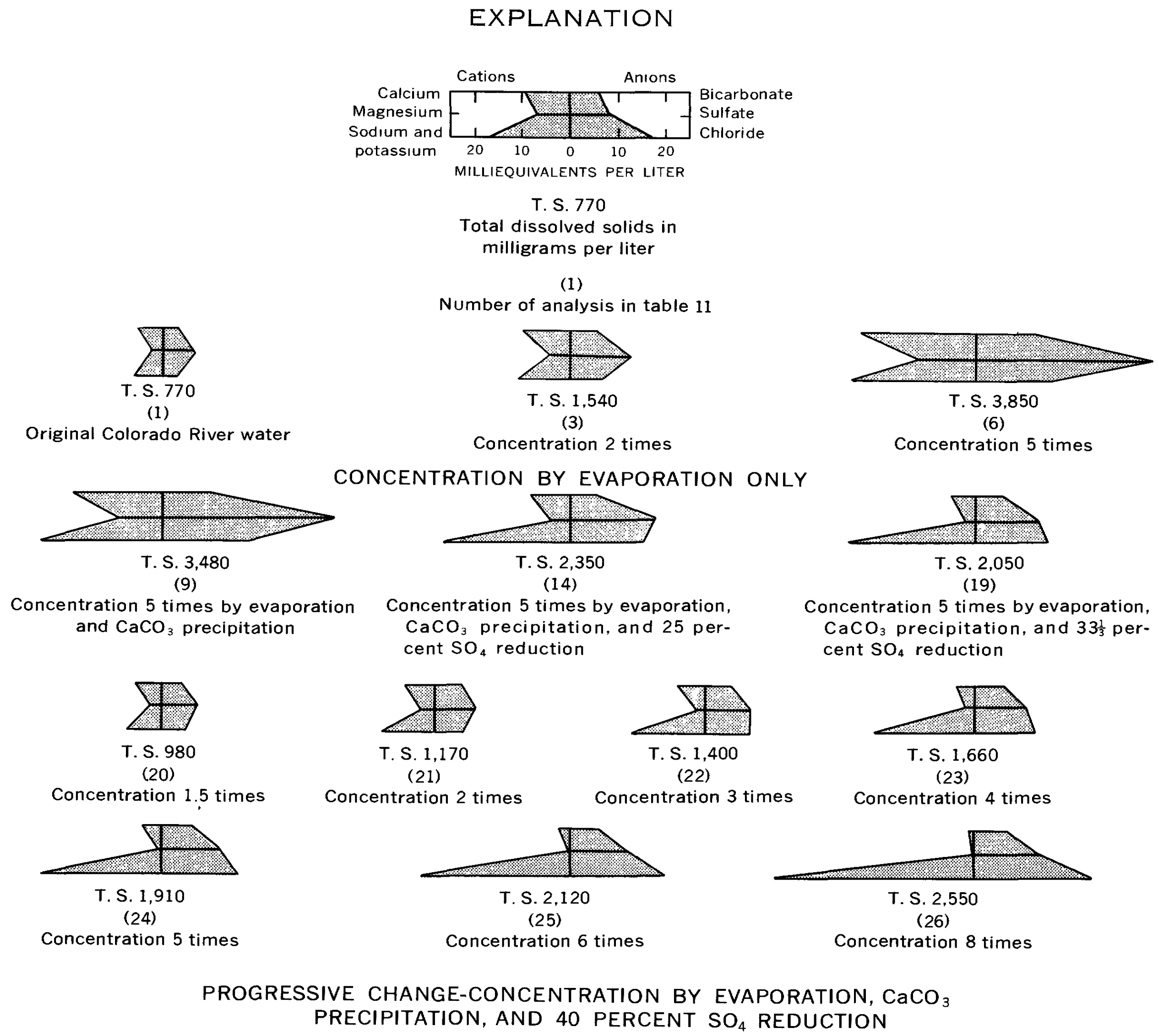

FIGURE 36.—Diagrams of hypothetical chemical analyses of Colorado River water shown in table 11.

1,000 ml to the volumes shown for the analyses. A concentration factor based on the amount of reduction of volume is also shown as an aid to the explanations.

Analyses 2–6 in table 11 represent concentration levels which would be reached if the Colorado River water (analysis 1) were concentrated by evaporation from 1.5 to 5 times. Comparison of these analyses with actual analyses from the Parker-Blythe-Cibola area (tables 7–10) shows that the hypothetical analyses produced by evaporation alone become less like the analyses of actual ground waters as concentrations increase and that the bicarbonate concentrations attain levels not found in the real analyses. Thus, the composition of most of the ground waters cannot be accounted for on the basis of evaporation alone.

Next, assume that chemical precipitation of calcium and magnesium carbonates begins whenever bicarbonate concentrations reach some specific level, hereinafter referred to as the stability level, and that as bicarbonate concentrations exceed the stability level, precipitation becomes more and more pronounced. Only a few analyses would then indicate bicarbonate concentrations far above the stability level, although a considerable number might moderately exceed it. Also, concentrations above the stability level would represent water likely to be changing in composition.

Fixing the exact stability level for Colorado River water would require careful experimentation. The level would undoubtedly be found to vary with temperature and pressure, and probably would also vary somewhat with different sulfate and chloride concentrations and their ratio. Laboratory determinations of stability level, therefore, might not give useful average field values. However, the true stability level does not have to be known to model chemical changes which may occur as Colorado River water moves underground because, for any selected level, the predicted chemical changes will parallel the changes occurring at the true level.

To explain changes in water quality in the Parker-Blythe-Cibola area, it is arbitrarily assumed that doubling the 156 mg/l bicarbonate content of Colorado River water is the maximum change that can occur without loss of calcium, magnesium, and bicarbonate by chemical precipitation. Analyses 7–9 in table 11 indicate the chemical character of the water which results from this assumption. The assumed bicarbonate stability level (312 mg/l) seems to be reasonably close to the unknown true value because the median bicarbonate concentration for 55 analyses of water from the shallow zone (table 7) is 304 mg/l, and the median concentration for 104 analyses of water from the principal gravel zone (table 8) is 303 mg/l. In both zones the bicarbonate concentrations of individual samples generally are near the median, and only a small number of concentrations are above 400 mg/l.

Precipitation of insoluble carbonates results in reduced calcium and magnesium concentrations which together are chemically equivalent to the reduction of bicarbonate. It also results in lowered dissolved solids, lowered specific conductances, and increased values for percent sodium. The extent of these effects can be noted from table 11 by comparing analysis 7 with analysis 4, analysis 8 with analysis 5, and analysis 9 with analysis 6. Comparing analyses 7–9 in table 11 with actual analyses in tables 7 and 8 indicates that the precipitation hypothesis results in a water that contains relatively more sulfate compared to chloride than is commonly found for water samples from the shallow and principal gravel zones. Also, analyses 7–9 indicate sulfate concentrations in excess of 1,000 mg/l, whereas most of the actual ground waters in the upper two flood-plain zones contain less than 800 mg/l sulfate. Thus, the two processes of evaporation and chemical precipitation of themselves do not provide satisfactory explanations for the general pattern of ground-water composition in the zones most likely to contain altered Colorado River water.

In order for Colorado River water that has been subjected to the aforementioned evaporation to attain the general compositional pattern of the ground waters of the Parker-Blythe-Cibola area, either precipitation of insoluble calcium sulfate, or reduction of sulfate ions, or both, must also occur. But before calcium sulfate will precipitate, calcium concentrations must reach about 600 mg/l and sulfate concentrations must reach about 2,000 mg/l. Such concentrations might be reached as water evaporates in irrigated soils, but it is unlikely that they would be reached as a result of processes occurring below the water table. Therefore, it is concluded that precipitation of calcium sulfate is unlikely to be an important factor in producing the chemical constitution of much of the ground water.

Sulfate reduction is a well-recognized geochemical process reported as occurring rather extensively in ground water and in special environments, such as in the new deltaic sediments in Lake Mead. The process is, in effect, substitution of a chemically equivalent quantity of dissolved bicarbonate for dissolved sulfate. The sulfate is changed to colloidal elemental sulfur, to sulfide ion, or to gaseous hydrogen sulfide 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. Generally, the end products that contain sulfur are removed from the water by other reactions, but, occasionally, water in which sulfate reduction has occurred has a distinct rotten-egg odor, indicating the presence of retained hydrogen sulfide.

Evidence for sulfate reduction was not specifically sought out as a part of the Parker-Blythe-Cibola area study, although there were reports from time to time that some well waters smelled of hydrogen sulfide. However, a sulfate-reduction hypothesis seems to offer the most reasonable explanation for the variation in the chemical composition of the ground waters, particularly those in the shallow and principal gravel zones under the flood plain. The problem then becomes that of investigating how the reduction occurs.

Sulfate reduction conceivably can occur continuously or intermittently, and at variable rates relative to volume reduction. However, for investigation of the process by use of model chemical analyses, it is convenient to assume sulfate reduction at a constant rate. The principal complication of this assumption is that the increase of bicarbonate resulting from the sulfate reduction must be included in the computation of quantities of calcium and magnesium carbonate that are precipitated as a result of evaporation.

For illustrative purposes, it is assumed that sulfate is reduced 25 percent, 33⅓ percent, and 40 percent. In table 11, analyses 10–14 give successive concentrations of Colorado River water, assuming that the original volume has been evaporated to the volume indicated, that insoluble carbonates have precipitated, and that sulfate has been reduced by 25 percent. Analyses 15–19 are similar, except that the sulfate has been reduced by 33⅓ percent. In analyses 20–26 the sulfate has been reduced 40 percent, and the three processes have been continued until the final volume is one-eighth of the original volume.

Comparison of the three groups of hypothetical analyses with actual analyses of ground waters, particularly shallow ground waters from the Parker-Blythe-Cibola area, indicates a close similarity between one or more of the hypothetical analyses and certain of the actual analyses. Furthermore, each set of increasing sulfate-reduction rate shows a pattern of increasing dissolved-solids concentration which is characteristic of the ground waters. Furthermore, as the dissolved-solids concentrations increase, the sulfate to chloride ratio decreases. Also, the percent sodium generally increases as chloride concentrations increase. It is concluded, therefore, that the processes of concentration by evaporation, precipitation of insoluble carbonates, and sulfate reduction account for most of the chemical changes that Colorado River water undergoes as it becomes part of the ground-water supply.

Although the reasoning followed in preparing the table of hypothetical chemical analyses results in analyses that are similar to a majority of the analyses of actual ground waters from the Parker-Blythe-Cibola area, there are some analyses of ground waters that are quite different from any of the hypothetical analyses. Very possibly the assumption that precipitation would begin at a bicarbonate concentration of about 312 mg/l was conservative. A value of about 450 mg/l as the threshold for precipitation might be better. Furthermore, it appears that some analyses of water containing several thousand milligrams per liter dissolved solids may have resulted from more evaporation and less sulfate reduction than indicated in table 11. Also, base exchange of calcium or magnesium for sodium, or of sodium for calcium or magnesium, seems to have occurred during the transformation of some of the ground waters.

One group of analyses that is exceptional includes those referred to as having the hourglass pattern. Waters producing this pattern have been found mostly at considerable depths, and the suggestion has been made that they represent past flood waters or fossil waters. However, to produce the hourglass pattern a water must contain less sulfate than chloride. In 40 years of sampling Colorado River water at Grand Canyon, the sulfate was never less than the chloride. So, for the hourglass water to be fossil water, the chemical character of the river water would have had to be materially different in the years preceding the period of record. It seems more logical to assume that the hourglass pattern indicates a nearly complete sulfate reduction as a result of the long-term presence of the water in a sulfate-reducing environment.

POTENTIAL FOR DEVELOPMENT OF GROUND WATER

The Parker-Blythe-Cibola area has been subdivided into 12 subareas (fig. 37) for the discussion of the potential for well development. Although many ground-water data were collected and many test wells were drilled, the available data still are meager for many parts of the area. Nevertheless, based primarily on the geology of the area, some speculations are warranted as to the potential for development of ground water supplies from wells.

The 12 areas include 3 in the flood plain, 5 in the western part of the valley, and 4 in the eastern part. The areas along the flood plain are (1) Parker Valley, (2) Palo Verde Valley, and (3) Cibola Valley. The areas in the western part of the valley are (4) Vidal, (5) Big Maria–Riverside, (6) Palo Verde Mesa, (7) Mule, and (8) Milpitas Wash. Those in the eastern part are (9) Parker Mesa, (10) La Posa, (11) Tyson, (12) Ehrenberg.

The potential for well development is in the fanglomerate, the Bouse Formation, and the alluviums of the Colorado River and its tributaries. The bedrock is not considered because its potential for development

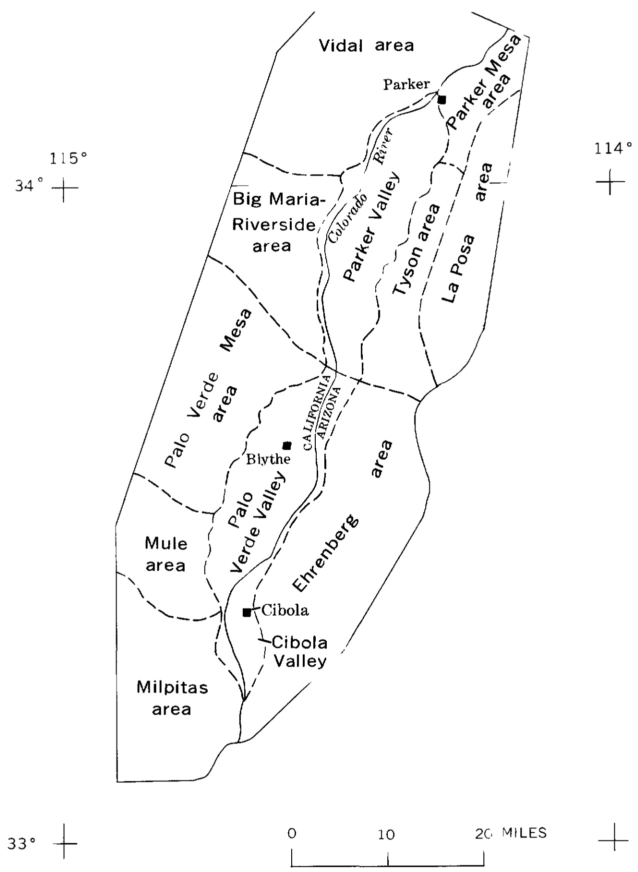

FIGURE 37.—Potential ground-water development subdivisions.

is very poor. Therefore, even though most of the areas include outcrops of bedrock, this discussion does not pertain to the bedrock, unless otherwise so stated.

The discussion for each area will include location, subsurface geology, and potential for well development. The location, in most places, will have arbitrary boundaries. The subsurface geology, in contrast to the discussion primarily on the geology, will be discussed from the youngest to the oldest, that is, from the surface downward. The geology will be summarized with emphasis on the estimates of the water-bearing characteristics. Future drilling will demonstrate how good the speculations are.

PARKER VALLEY

LOCATION

The Parker Valley area (fig. 37), as herein defined, includes the flood plain of the Colorado River and extends from near Parker southwest to an indefinite line from the Big Maria Mountains through the Palo Verde Dam to an extension of the Dome Rock Mountains in T. 4 N., R. 21 W.

SUBSURFACE GEOLOGY

The subsurface units are the younger alluvium of the Colorado River, Bouse Formation, fanglomerate, and bedrock (pl. 1; fig. 14). The younger alluvium is 90–125 feet thick and contains a basal gravel as much as 20 feet thick. The younger alluvium is as wide as the flood plain.

The Bouse Formation occurs throughout this area and underlies the younger alluvium. The Bouse Formation is composed of a basal limestone and clay, silt, and sand. In the northern part of the area, the formation acts as an aquitard. In the southern part of the area, as is shown by the log of LCRP 27, the upper 175 feet contains much sand. A pumping test indicated that these sands are very permeable. The sand is also present at LCRP 4, about 5 miles south. The extent of this sand can only be determined by further drilling. Both at LCRP 27 and 4, the water-bearing characteristics of the material below the sand were similar to those determined from other wells. The subdivision, northern and southern, is arbitrary because all that is known is that the sand is absent at LCRP 20, which is about 10 miles northeast of LCRP 27.

The fanglomerate underlies the Bouse Formation. The only information on the formation in this area is at LCRP 20, where it was 73 feet thick, and at LCRP 27, where it was absent. Nevertheless, it may be expected that the fanglomerate occurs in the subsurface in other parts of the area and that it will be penetrated in future drilling.

Although the bedrock generally is not considered as a source of ground water, an exception is the basalt encountered at LCRP 20. The results of a pumping test on the basalt indicated that there were openings in the basalt that were not fully penetrated during test drilling. The occurrence of the basalt may be an isolated case and may be a part of a buried hill or mountain.

Isolated outcrops of bedrock occur at several places in Parker Valley. Two of these outcrops are along the eastern edge of the flood plain at the points of the large cusps in T. 6 and 7 N., R. 21 W. (pl. 1). Another outcrop occurs in sec. 3, T. 8 N., R. 20 W. From these few scattered outcrops, it may be concluded that there are other places where the bedrock is at shallow depth, which, of course, would restrict the development of ground water.

POTENTIAL FOR WELL DEVELOPMENT

The best opportunity for the development of ground water by wells in the Parker Valley is from the younger alluvium. Many sandpoints have been driven only a few feet below the water table, yet they furnish adequate water for domestic use. Whether these supplies are considered successful depends on the quality of the shallow water. Sandpoints installed near the main canals or laterals obtain their water from seepage from the canals, and therefore, the chemical quality is generally near that of the Colorado River.

Wells developed in the highly permeable basal gravel of the younger alluvium may be expected to have specific capacities that are roughly proportional to the thickness of the gravel. Perforating casing opposite 10 feet of some 15 feet of gravel in LCRP 4 resulted in the well having a specific capacity of 35 gpm per ft of drawdown. Not everywhere, however, will the gravel be this thick, and in some parts of the flood plain it is absent.

Another limiting factor on whether a satisfactory well can be developed in the gravel is the chemical quality of water. Water of satisfactory quality can be found near the Colorado River, but, in general, the quality deteriorates progressively away from the river. Water from sandpoints installed in this gravel produced water having total dissolved solids ranging from about 700 near the river to 13,000 mg/l near the terrace on the east side of the flood plain.

Water in the first 200–300 feet of the Bouse Formation is of better quality than the water in the basal gravel of the younger alluvium. In the northern part of the valley, the amount of water that could be produced from the Bouse is very small because of the fine-grained material. Specific capacities may be 1 gpm per ft of drawdown or less. Even this limited amount is of importance because water containing less than 1,000 mg/l could be obtained where unsuitable water occurs in the basal gravel. In the southern part of the area where the first 200 or 300 feet of the drilled section of the Bouse contains much sand, specific capacities as high as 15 gpm per ft of drawdown may be obtained. As was shown by LCRP 4 and 27, the chemical quality of this water is much better than the quality of the water in the basal gravel.

The dissolved-solids content of the water in the fanglomerate in the northern part of the area can be expected to be between 700 and 1,000 mg/l, and the fluorides, more than 1.5 mg/l. The specific capacities of wells perforated in the fanglomerate may range from less than 1 to as much as 15 gpm per ft of drawdown. This was demonstrated by the test wells: (1) 0.3 in LCRP 20, and (2) 15 in LCRP 15 and 21.

Although the basalt penetrated in LCRP 20 produced water, it is not likely that there will be many wells that drill into basalt. However, if basalt is encountered in wells that do not have the desired production from overlying materials, additional production may be obtained by drilling deeper into the basalt.

PALO VERDE VALLEY

LOCATION

The Palo Verde Valley (fig. 37), as herein defined, includes the flood plain of the Colorado River and extends from an indefinite line from the Big Maria Mountains through the Palo Verde Dam to an extension of the Dome Rock Mountains in T. 4 N., R. 21 W., southwestward to the middle of T. 1 N., R. 23 W., then along the Colorado River westward and southward to the boundary between T. 8 and 9 S., R. 21 W., then west to the bedrock of the Palo Verde Mountains.

SUBSURFACE GEOLOGY

The subsurface units are the Colorado River younger and older alluviums, Bouse Formation, fanglomerate, and bedrock (pls. 1, 3).

The thickness of the alluviums of the Colorado River ranges from about 130 feet near the Palo Verde Weir to about 600 feet in the vicinity of Blythe, and to about 200 feet where the Colorado River flows west between Palo Verde and Cibola Valleys. The alluviums are composed of sand, silt, and clay with lenses of gravels.

Only two wells in this area have been drilled into the Bouse Formation. These are Blythe city well 11 where the top of the Bouse Formation is at a depth of 506 feet (other wells near Blythe were as deep as 600 feet and were still in Colorado River alluvium) and LCRP 16, at a depth of 445 feet. The Bouse Formation in these two wells is composed of interbedded clay, silt, and sand. The Bouse Formation probably underlies the alluviums of the Colorado River throughout this area at depths ranging from about 130 to more than 600 feet.

No wells have been drilled into the fanglomerate in this area. Nevertheless, on the basis of two wells drilled outside the flood plain, the fanglomerate probably underlies the Bouse Formation in this area, although it may be considerably deeper than the depths at which it has been encountered in other areas in the test wells. The depth to the fanglomerate at LCRP 22, 6½ miles south of Ehrenberg and about a quarter of a mile east of the flood plain, is 811 feet. On the other side of the valley on the Palo Verde Mesa, the depth to the fanglomerate at well 7S/21E–14H1, as determined from an electric log, is 845 feet. Because the contact between the Bouse Formation and the fanglomerate dips away from the mountains, it is probable that the fanglomerate is much deeper in the center of the valley near Blythe.

Bedrock has been reported in the log of only one well in this area, well (B–4–22)3aca (Arizona numbering system, although the well is on the west side of the Colorado River in California). The well is about 1 mile south of the Palo Verde Weir and about 1 mile from the exposed bedrock of the Big Maria Mountains. The depth to bedrock was reported as 65 feet.

POTENTIAL FOR WELL DEVELOPMENT

The discussion given under Parker Valley on shallow water (p. 100) also applies to the Palo Verde Valley area.

Wells developed in the highly permeable gravel of the alluviums of the Colorado River can be expected to have large specific capacities, providing, of course, that sufficient gravel is penetrated. Some of the present wells, for example, well (B–4–22)2bca, have specific capacities of more than 100 gpm per ft of drawdown. Wells that penetrate mostly sand and that are gravel packed may have specific capacities as high as 80 gpm per ft of drawdown.

In the northern part of this valley, in particular in the vicinity of Blythe, the chemical quality of water in the alluviums of the Colorado River is good. In fact, one of the least dissolved-solids content in the Parker-Blythe-Cibola area was reported for a sample of water obtained from well 6S/23E–31J1 in Blythe.

In the southern part of the area, however, the chemical quality of the water in the alluviums of the Colorado River is poor. The boundaries between the strata containing water of good and of poor chemical quality are indefinite because of the wide spacing of the data, and also because the chemical quality of the water deteriorates with depth. As examples, three sandpoints were installed near Palo Verde at depths of 52, 95, and 231 feet; the total dissolved solids of the water from these wells were 3,100, 4,400, and 14,900 mg/l, respectively.

The first 150 feet of the Bouse Formation penetrated by LCRP 16 contained much sand. Based on the results obtained from LCRP 4 and 27, it is possible that a well developed in the sand penetrated by LCRP 16 may have a specific capacity of 15 gpm per ft of drawdown. However, the chemical quality of the water obtained from the Bouse Formation at LCRP 16 was poor, the total dissolved-solids content exceeding 7,500 mg/l.

Wells in the Palo Verde Valley have not been drilled into the fanglomerate. The two nearby wells that penetrated the fanglomerate, LCRP 22 to the east and well 7S/21E–14H1 to the west, had specific capacities of 4 and 7 gpm per ft of drawdown, respectively. However, the chemical quality of the water was poor. Analyses of water from LCRP 22 showed 4,190 mg/l, and for 7S/21E–14H1, 4,550 mg/l. Only further drilling will determine whether satisfactory wells can be developed in the fanglomerate.

CIBOLA VALLEY

LOCATION

The Cibola Valley (fig. 37), as herein defined, includes the flood plain of the Colorado River and extends southward from the northern boundary, which begins on the east side of the flood plain in the middle of T. 1 N., R 23 W., then westward and southward along the Colorado River to the township line between T. 9 and 10 S., R. 21 E., then westward to the edge of the flood plain. From this northern boundary, the valley extends southward to the bedrock narrows below Cibola.

SUBSURFACE GEOLOGY

The subsurface units are the younger and older alluviums of the Colorado River, Bouse Formation, fanglomerate, and bedrock (pl. 1).

The thickness of the alluviums is about 200 feet at the northern boundary of the area in the middle of T. 1 N., R. 23 W. The older alluviums thin southward, and in the southern part of the area in well (C–1–24)36bbb1, only the younger alluvium is present. The younger and older alluviums are composed of gravel, sand, silt, and clay.

The Bouse Formation underlies the alluviums of the Colorado River and is composed of a basal limestone, overlain by interbedded clay, silt, and sand.

The fanglomerate underlies the Bouse Formation, except in the southern part of the area where the Bouse Formation has been completely eroded away. Here, the younger alluvium rests directly on the fanglomerate. This is the natural discharge area for the ground water in the fanglomerate. Throughout most of the Parker-Blythe-Cibola area, the ground water in the fanglomerate is confined beneath the Bouse Formation.

POTENTIAL FOR WELL DEVELOPMENT

The yield of wells perforated in the gravels of the alluviums of the Colorado River is roughly proportional to the amount of gravel penetrated. An example of yield from a gravel is from well (C–1–24)36bbb1 which contained 18 feet of gravel and has a specific capacity of 34 gpm per ft of drawdown.

Probably a limiting factor on the usefulness of a well in this area will be the chemical quality of ground water. An example of poor quality ground water is that from well (C–1–24)36bbb1, which contained 3,830 mg/l of total dissolved solids. An analysis of good quality of ground water is that from a shallow well (C–1–23)30aca, which shows a total dissolved-solids content of 672 mg/l. This good water may be indicative of recharge from the area to the east.

VIDAL AREA

LOCATION

The Vidal area (fig. 37), as herein defined, extends from the Whipple Mountains on the north to the Riverside Mountains on the south. The southeastern boundary is the flood plain of the Colorado River. The area extends northwest and includes the drainage area of Vidal Wash.

SUBSURFACE GEOLOGY

The subsurface units that occur below the water table are the older alluviums of the Colorado River, Bouse Formation, fanglomerate, and bedrock (fig. 14).

The older alluviums are saturated in a narrow band that extends only about 2 miles from the edge of the flood plain to the flood plain. Logs from other wells together with depth-to-water measurements indicate that the saturated older alluviums are from 50 to 110 feet thick. The older alluviums are made up of gravel, sand, silt, and clay.

The Bouse Formation is 570 feet thick at well 1S/24E–15B3. Logs of deep wells drilled near Vidal Junction indicate that most of the material penetrated was the Bouse Formation.

The available logs of wells for the Vidal area indicate that only two wells penetrated into the fanglomerate. Both wells were in sec. 15, T. 1 S., R. 24 E. One of them, well 1S/24E–15B3, penetrated fanglomerate from 570 to 1,360 feet, the bottom of the well.

POTENTIAL FOR WELL DEVELOPMENT

Only in a narrow band paralleling the edge of the flood plain can wells be developed in the Colorado River deposits. If a sufficient thickness of gravel is penetrated, specific capacities from 50 to as high as 100 gpm per ft of drawdown may be expected. Most of the chemical analyses of water from wells pumping from the older alluvium show from 1,000 to 1,400 mg/l total dissolved solids.

Throughout the rest of the Vidal area, the only possibilities for development of ground water from deposits underlying the older alluviums are from the Bouse Formation and the fanglomerate. None of the wells perforated in the Bouse Formation have specific capacities greater than about 1 gpm per ft of drawdown. From this, it would not be expected that wells to be used for irrigation could be developed in the Bouse Formation. Wells satisfactory for domestic use may be developed throughout the area.

The fanglomerate may be a usable source of water in the area, but this speculation can be verified only by drilling. Neither the yield nor the quality of the water that is likely to be obtained from the fanglomerate is known; however, the possibility of developing water from the fanglomerate should not be overlooked if yields greater than those which can be obtained from the Bouse Formation are needed.

BIG MARIA-RIVERSIDE AREA

LOCATION

The Big Maria—Riverside area (fig. 37), as herein defined, is bounded on the east by the flood plain of the Colorado River. It is bounded on the north by the Riverside Mountains; on the west, by the surface divide between Rice Valley and the Colorado River Valley; and on the southeast and south, by the Big Maria Mountains. The area is bisected by a bedrock ridge extending from the Big Maria Mountains to the flood plain.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The subsurface units that occur below the water table are the older alluviums of the Colorado River, Bouse Formation, fanglomerate, and bedrock.

The older alluviums occur in a manner similar to that discussed under Vidal area. They form a narrow band parallel to the edge of the flood plain. Because no wells are in this area, the limits or water-bearing characteristics of the older alluviums are unknown, but they probably would be similar to those of the Vidal area.

The Bouse Formation is probably extensive in the subsurface of this area. The unit was 667 feet thick in LCRP 27, about 3 miles from the edge of the flood plain. If the thick section of sand that was penetrated in the flood plain in the first 200 feet of the Bouse Formation extends westward under the terrace, the section would be a good aquifer. Wells developed in it may have specific capacities as much as 15 gpm per ft of drawdown. Lower sections of the Bouse Formation have much lower hydraulic conductivities, and therefore, the specific capacities of wells perforated in the lower section probably will be 1 gpm per ft of drawdown or less. Analysis of samples of water from LCRP 27 indicated that the quality of water was satisfactory for most uses. Only drilling will verify whether similar conditions exist in this area.

Although the fanglomerate was absent in LCRP 27, it is exposed nearby in the mountains. Therefore, the fanglomerate probably is present in the subsurface in some parts of the area and is likely to be saturated.

PALO VERDE MESA AREA

LOCATION

The Palo Verde Mesa area (fig. 37), as herein defined, extends from the Palo Verde Dam northwestward along the crest of the Big Maria Mountains and along the surface divide of the drainage for McCoy Wash to the McCoy Mountains, then southward along the drainage divide between Chuckwalla Valley and the Colorado River valley to the township line between T. 7 and 8 S., R. 21 E., then east to the edge of the flood plain, then northward along the edge of the flood plain to the Palo Verde Weir.

SUBSURFACE GEOLOGY

The older alluviums of the Colorado River and its tributaries include unit B, the piedmont gravel, and units D and E. Because these alluviums cannot readily be separated from subsurface data, they are considered as one water-bearing unit, the alluviums of the Colorado River.

The alluviums of the Colorado River that occur beneath the water table contain much gravel in the part of the area that roughly parallels and borders the edge of the flood plain and has a width of about 1 mile. Lenses of Colorado River gravel interbedded with sand, silt, and clay occur in this area. The rest of the alluviums beneath the water table are composed almost entirely of sand, silt, and clay, which thin towards the bedrock. The saturated thickness of the alluviums at well 6S/22E–15Q1, which bottomed in the alluviums, is at least 445 feet.

Two wells, 5S/22E–28C1 and 7S/21E–14H1 on the Palo Verde Mesa, penetrated into the Bouse Formation. An electric log of the first well indicates that the Bouse Formation occurred from 605 to the total depth of the well at 1,118 feet. An electric log of the second well indicates that the Bouse Formation was 330 feet thick, and the base was 845 feet. The electric logs from both wells indicated much clay and silt in the sequence.

Only one well, 7S/21E–14H1, has been drilled into the fanglomerate, which occurs from 845 to 1,368 feet. The lithologies as reported by the driller for the fanglomerate were medium sand, rocks, decomposed granite, and clay. The casing was perforated from 700 to 900 feet, and the well had a specific capacity of 5 gpm per ft of drawdown.

POTENTIAL FOR WELL DEVELOPMENT

Large specific capacities may be expected for properly developed wells that are drilled near the edge of the flood plain, and that tap a large thickness of gravel. Specific capacity as high as 70 gpm per ft of drawdown has been reported, and some as high as 100 are possible.

In the rest of the area in which sand is the dominant lithology of the alluviums of the Colorado River, specific capacities range from 30 to 70 gpm per ft of drawdown and in exceptional cases may approach 100. Where sand is the water-bearing lithology, it is necessary to gravel pack the wells to get the maximum yield. Analyses of samples of water from wells in this area indicate a range of 730–3,100 mg/l total dissolved solids. A generalization on the basis of meager data is that the better quality water occurs near the edge of the flood plain, and the total dissolved solids increase away from the flood plain.

The only ground-water information on the Bouse Formation and the fanglomerate comes from well 7S/21E–14H1. This well was perforated from 700 to 900 feet. It had a specific capacity of 5 gpm per ft of drawdown, and an analysis of a water sample indicated a total dissolved content of 4,550 mg/l.

Based on an inspection of the electric logs from the two wells that have been drilled into the Bouse Formation, it may be expected that the yield from this unit will be small, probably 1 gpm per ft of drawdown or less.

Although the one well that was drilled into the fanglomerate indicated poor yield and poor quality, these results do not necessarily apply to the entire Palo Verde Mesa area. This well is in the southern part of the area, which leaves a large area to the north in which nothing is known about the water-bearing characteristics of the fanglomerate. The potential of the fanglomerate as an aquifer cannot be determined until more wells are drilled into it.

MULE AREA

LOCATION

The Mule area (fig. 37), as herein defined, extends from the edge of flood plain west along the township line between T. 7 and 8 S., R. 21 E., to the Mule Mountains, then southward and eastward along the crests of the Mule and Palo Verde Mountains to the flood plain, and then northward along the edge of the flood plain.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The units that occur beneath the water table are the older alluviums, Bouse Formation, and fanglomerate.

The older alluviums that are saturated probably thin to the south in a manner similar to that discussed under Palo Verde Valley. Based on an interpretation of the well logs in the valley, the saturated older alluviums may be as thick as 400 feet along the edge of the flood plain in the northern part of the area, but they thin and wedge out to the south where the Bouse Formation is exposed at the surface.

The Bouse Formation and the fanglomerate are exposed along the north flanks of the Palo Verde Mountains, and they can be expected to occur extensively in the subsurface.

Probably the limiting factor on the usefulness of wells in the area will be the chemical quality of the ground water. The data collected during the drilling and testing of LCRP 16 indicated that the water contained more than 7,000 mg/l dissolved solids below a depth of 400 feet. Water from the sandpoints near Palo Verde was also of poor quality. At both sites the data suggested a deterioration of the quality with depth. If this poor quality of ground water extends into the Mule area, it would offer little encouragement for the development of wells.

MILPITAS AREA

LOCATION

The Milpitas area (fig. 37), as herein defined, is bounded on the north by the Palo Verde Mountains; on the west, by the range line between R. 19 and 20 E.; on the south, by a line through the middle of T. 11 S.; and on the east, by the flood plain of the Colorado River.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The subsurface units that occur below the water table are the Bouse Formation, fanglomerate, and bedrock. Some of the alluviums of the Colorado River may be saturated near the flood plain, but this is probably insignificant.

Wells developed in the interbedded clay, silt, and sand of the Bouse Formation may yield sufficient water for domestic purposes. The basal limestone may be a potential aquifer because of its thickness and the gravel lenses it contains. As yet, no wells have been drilled into the limestone.

The bailer test of well 11S/21E-5F1 indicates that the fanglomerate at that site has a very low hydraulic conductivity. In this well, however, 283 feet of the fanglomerate was above the water table, so the water-bearing characteristics of this section are not known. A comparable section will be saturated under Milpitas Wash to the north. A well drilled near Milpitas Wash could therefore be used to determine the water-bearing characteristics of this section of the fanglomerate.

PARKER MESA AREA

LOCATION

The Parker Mesa area (fig. 37), as herein defined, is bounded on the east by the Colorado River Indian Reservation boundary; on the south, by Bouse Wash; and on the west and northwest, by the flood plain of the Colorado River.

SUBSURFACE GEOLOGY

The subsurface units that occur beneath the water table are Colorado River gravel of the older alluviums, Bouse Formation, fanglomerate, and bedrock.

The Colorado River gravel occurs in a channel bounded on the west by outcrops of the Bouse Formation west of Parker, and on the east, by Black Peak. This old channel leaves the present Colorado River channel near the mouth of Osborne Wash and trends southward to the flood plain. The gravel ranges from pebbles to cobbles, and much of it is rounded to well rounded.

The Bouse Formation penetrated by LCRP 15 was mostly clay and silt. It is doubtful that the formation could produce sufficient water even for domestic use.

Variations in cementation in the fanglomerate were evident during the drilling of LCRP 15. From 275 to 399 feet, the fanglomerate was well cemented and difficult to drill. Bailer tests in this interval indicated specific capacities that ranged from almost nothing to 1 gpm per ft of drawdown. From 399 to 465 feet, the drilling was much easier, and a bailer test indicated a specific capacity of about 8 gpm per ft of drawdown. A test of the fanglomerate between depths of 275 and 520 feet indicated that a well tapping the fanglomerate would have a specific capacity of 15 gpm per ft of drawdown.

Some of the bedrock in this area may be a potential source of ground water, although no wells are known to have been drilled into it. Underlying the basalts of Black Peak is a thick series of sandstones. These sandstones were strongly tilted and folded prior to the outpourings of the basalt. Because of their structural attitude, it would be difficult to interpret the sequence if encountered in wells, and it may be difficult to distinguish the lithology from that of the fanglomerate.

POTENTIAL FOR WELL DEVELOPMENT

Wells having large specific capacities may be developed in the Colorado River gravel if a sufficient thickness of gravel is saturated. At LCRP 15, tapping 46 feet of saturated gravel resulted in a well having a specific capacity of 124 gpm per ft of drawdown. The total dissolved-solids content of water from the gravel in LCRP 15 was 635 mg/l.

Wells perforated in the fanglomerate may have specific capacities as high as 15 gpm per ft of drawdown. However, in order to test fully the fanglomerate, at least 200 feet should be drilled, because in LCRP 15, the upper 124 feet of fanglomerate was well cemented and would not yield much water. Analyses of water samples from the fanglomerate in LCRP 15 and 21 indicated 679 and 703 mg/l total dissolved solids, respectively. Although this water is satisfactory for irrigation, the high fluoride content (4.8 mg/l in LCRP 15 and 5.5 mg/l in LCRP 21) makes it unsuitable for domestic use.

LA POSA AREA

LOCATION

The La Posa area (fig. 37), as herein defined, extends from Black Peak eastward to the range line between

R. 17 and 18 W., then south along the Plomosa Mountains to U.S. Highways 60–70, then westward along this highway through Quartzsite to the bedrock of the Dome Rock Mountains, then northwestward along the crest of the mountains in T. 4 and 5 N., R. 20 W., to the boundary of the Colorado River Indian Reservation, then northeastward along the boundary to Black Peak.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The subsurface units are the older alluviums, Bouse Formation, fanglomerate, and bedrock.

The older alluviums, containing Colorado River gravels, are exposed in the slopes bordering Bouse Wash, which indicates that the Colorado River at one time flowed to the east of the unnamed mountain in T. 7 and 8 N., R. 20 W., thence southward through the gap in the Dome Rock Mountains, now occupied by Tyson Wash, to the Blythe area.

One of the purposes of LCRP 21 was to determine the thickness of the Colorado River deposits below the water table. Because all the Colorado River deposits were above the water table in LCRP 21, it is concluded that there is little possibility of Colorado River deposits occurring beneath the water table in the La Posa area.

Other possibilities for well development in the La Posa area are in the Bouse Formation and the fanglomerate. Of these, based on data from wells outside this area, the Bouse Formation probably is not capable of anything but small yields.

A well drilled about 900 feet into the fanglomerate at Quartzsite had a poor yield. As has been discussed under some of the other areas, this fact would not necessarily rule out the fanglomerate as a potential aquifer in other parts of the area.

A perched water table occurs at Quartzsite and extends northward along Tyson Wash for about 5 miles. This perched water table supplies sufficient water of good quality for domestic use. It is probably restricted to Tyson Wash.

TYSON AREA

LOCATION

The Tyson area (fig. 37), as herein defined, is bordered on the north by Bouse Wash; on the east and south, by the boundary of the Colorado River Indian Reservation; and on the west, by the flood plain of the Colorado River.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The subsurface units that may occur beneath the water table are the older alluviums, Bouse Formation, and fanglomerate.

The older alluviums are likely to be saturated only near the edge of the flood plain. The saturated thickness will not exceed about 100 feet and will thin away from the flood plain. As was discussed under "Parker Valley area," the Bouse Formation underlies the younger alluvium at depths of 95–125 feet beneath the flood plain and forms the sides of the trough. Thus, in the terraces bordering the flood plain, the older alluviums could not be saturated beyond those depths.

The Bouse Formation and the fanglomerate may both be potential aquifers in this area, but there are no wells to verify this. If the sand that was penetrated in the upper part of the Bouse Formation in LCRP 4 and 27 extends into this area, it would be a potential aquifer for the development of ground water.

EHRENBERG AREA

LOCATION

The Ehrenberg area (fig. 37), as herein defined, is bounded on the west by the flood plain of the Colorado River; on the north, by the boundary of the Colorado River Indian Reservation in T. 4 N., R. 21 W.; on the east, by the bedrock of the Dome Rock and Chocolate Mountains; and on the south, at the point where the bedrock touches the edge of the flood plain.

SUBSURFACE GEOLOGY AND POTENTIAL FOR WELL DEVELOPMENT

The subsurface units that occur beneath the water table are the older alluviums, Bouse Formation, fanglomerate, and bedrock.

Although the data are meager, it may be that the older alluviums in this area is similar to that of the Palo Verde Mesa area—that is, the gravel would occur only near the flood plain, whereas the rest of the area would be mostly sand.

The log of LCRP 22, 6½ miles south of Ehrenberg, shows 37 feet of Colorado River gravel from 223 to 254 feet. Although this gravel was not tested, it is possible that a good yield could be obtained. The logs of LCRP 5 and well (B–3–21)7db show mostly sand. The saturated thickness of the older alluviums in LCRP 5 is at least 436 feet, because the well bottomed in the older alluviums. The saturated thickness in well (B–3–21)7db is about 250 feet. Because the alluviums are mostly sand, wells drilled in this area will have to be gravel packed to get maximum yields.

Only one well in this area, LCRP 22, has been drilled into the Bouse Formation and the fanglomerate. The Bouse Formation was penetrated between depths of 254 to 811 feet and was composed of the basal limestone overlain by interbedded clay, silt, and sand. It is doubtful that much yield can be obtained from a well perforated in this unit.

The fanglomerate was 811–998 feet below land surface and was composed of cemented gravel. A pumping test indicated a specific capacity of 7 gpm per ft of drawdown. The quality of water was poor, and an analysis of a water sample indicated 4,190 mg/l total dissolved solids.

Information on test and selected wells in the Parker-Blythe-Cibola area is given in table 12. The well numbers, as used in the table, are described in the section on well-numbering systems.

TABLE 12.—*Records of test and selected water wells, Parker-Blythe-Cibola area, Arizona-California*

Well number: 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 U.S. Geological Survey; number assigned to wells of irrigation districts; informal number assigned to some wells privately owned.
Owner or user: Owner or user reported to the U.S. Geological Survey at the time the well was inventoried, not necessarily the original or present owner or user. USGS, U.S. Geological Survey; USBLM, U.S. Bureau of Land Management; USBIA, U.S. Bureau of Indian Affairs; M.W.D., Metropolitan Water Districts of California.
Year completed: Known or reported year of completion of well.
Elevation of land surface: Average elevation of land surface at well above mean-sea-level datum. Elevations given to nearest foot are approximate and were obtained from topographic maps; elevations given to decimal fractions of 1 foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Log information and water-level data are referred to land-surface datum.
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.
Method 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; RR, drilled with reverse-circulation rotary equipment; A, drilled with power or hand auger; G, gravel packed.
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 or well screen and base of lowest perforations or well screen. Where more than one major aquifer or water-yielding zone is perforated or screened, figures refer to top and bottom of perforated or screened intervals in each aquifer, in downward sequence.
Water level: Date measured by the U.S. Geological Survey, or reported 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 and horsepower: Source of power and pump type. 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 airlift pump used to obtain water samples, then hose was removed.
Use: The use of the water is indicated by the following symbols: Irr, irrigation; PS, public supply; Dom, domestic; Ind, industrial or mining; Dr, drainage; O, observation; 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 U.S. 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: D, driller's log; L, lithologic log; E, electric log; G, gamma-ray log; T, temperature log; P, paleontologic studies of drill cuttings; PT, pumping test; PTp, pumping tests with packers; PTc, pumping tests with down-hole current meter.

Well No.	Other No.	Owner or user	Year completed	Elevation of land surface (ft above m.s.l.)	Total depth (feet)	Completed depth (feet)	Method of construction	Casing diameter (inches, ID)	Depth of perforated interval (feet)	Water level: Date of measurement	Water level: Depth to water (feet)	Type of pump	Use	Discharge (gpm)	Drawdown (feet)	Water quality: Date	Water quality: Sum of solids (mg/l)	Water temperature (°C)	Other data available
(B-1-21)23d [1]		Arizona Game and Fish Comm.						10				W, L	Wildlife			3-19-63	415		
(B-1-23)21bc [2]		K. E. Harvey	1959		209	209		12	189-209			E, T	Dom			2-14-62	1,220		
28abb		W. Sprawls	1964	240	1,009	1,009	C	20,16	800-1,009	10-29-64	18.4	D, T	Irr	2,800	135				D
28bdc		do	1964	240	227	227	C	20,16					Irr			12-21-64	2,800		
31cdc		Mortensen & Sons.		235	600		C	8,6	127-140	2- 8-62	5.0		Un			2-13-62	6,720		D
(B-2-22)9cba		J. Wells	1958		30	30	D	1¼				H, P	Dom			2- 9-62	789		
16bba	LCRP 22	USGS	1964	300	998	998	C	12	820-985	10- 5-64	8.9	G, T	T	925	126	9-28-64	4,180	44	D, L, PT
(B-3-21)4cda		J. Wells	1949		600			4				Ga, L	Dom			2- 5-62	651		
7db		USBLM	1963		454	454	C	12	423-443	2-20-64	193.2	Ga, T	Ind	100	150	6- 7-63	794	33	D, PT
(B-3-22)15bac		E. P. Gregory	1951		260	260	C	12	225-250			E, T	Dom			2- 6-62	3,110		
15bcc		Arizona Highway Dept.			600			12				E, L	Dom			2- 5-62	1,110	21	
15bcd1		A-1 Motel			350		C	12				E, T	PS			2- 5-62	2,220	27	
15bcd2		do			350		C	12				E, T	PS			2- 5-62	2,490	28	
15bcd3		J. E. Davis	1954		200	200	C	8	160-200			E, S	PS			2- 5-62	2,590	23	
16daa		El Paso Natural Gas Co.	1948		273	273	C	8	242-270	2- 5-62	48.6	E, T	Dom			2- 5-62	1,840	26	D
22bbb		USGS	1961		12	12	A	1¼	11-12	7-27-61	6.4	H	T			4-24-62	3,060		
27bbb		USGS	1961		18	18	A	1¼	17-18	7-27-61	10.0	H	T			4-24-62	1,730		
(B-4-19)28b [1]												E, S	PS			2- 7-63	407		
(B-4-21)6abb		USGS	1963		119	115	A	1¼	114-115			G, J	T, Des	6		3-13-63	1,820	23	D
19bbb1		La Paz 1						14		3-16-61	18.0		Un						
19bbb2		La Paz 2						14		3-16-61	17.0		Un						
19bbb3		La Paz 3						16		3-16-61	16.8		Un						
(B-4-22)1dbc		USGS	1961		18	18	A	1¼	17-18	8- 2-61	13.6	H	T			4-25-62	1,110	23	
2bca [2]		Riverview Farms	1948		136		C	20	112-130	6-18-64	11.4	T	Irr	2,200	21	6-18-64	1,100	22	PT
3aca [2]		do			65		C	6						10					
22aaa		USGS	1962		26	18	A	1¼	17-18	4-25-62	15.2	H	T			4-25-62	854	22	
25bda		USGS	1961		18	18	A	1¼	17-18	7-31-61	9.5	H	T			4-25-62	3,930	22	
25ccd		USGS	1963		24		A					G, J	T, Des						D
34aaa		USGS	1962		18	18	A	1¼	17-18	4-25-62	10.2	H	T			4-25-62	636	21	
35cba		USGS	1961		18	18	A	1¼	17-18	7-31-61	9.7	H	T			4-25-62	1,770	22	
35cdb		USGS	1963		109	105	A	1¼	104-105			G, J	T, Des	6		3-19-63	2,080	22	D
36bab	LCRP 5	USGS	1961	295	471	466	C	8	132-140	11-19-61	34.6	G, T	T	190	37	6- 7-62	2,620	27	D, L, PT
36ccb		Colorado River Tribal Council.			150		C	6				E, J	Dom			8-15-63	2,650		
(B-5-19)31a				725	44		Dug	36×36		3-29-62	35.2	W, L	S			3-29-62	317		

(B-5-20)8dcc1		USGS	1962		77		A						T, Des						D
8dcc2		USGS	1962		167	162	A	1¼	161–162	3-26-62	Dry		T, Des						D
18cab1		USGS	1962		57		A						T, Des						D
18cab2		USGS	1962		28		A						T, Des						D
18cab3		USGS	1962		33		A						T, Des						D
18cab4		USGS	1962		32		A						T, Des						D
18cab5		USGS	1962		43		A						T, Des						D
29bcc													Des			5- -50	620		
(B-5-21)3dab					31			5		4-13-61	14.5		Un						
8ccc		USGS	1961		18	18	A	1¼	17–18	8- 2-61	12.1	H	T			4-27-62	3,150		
9ccc		USGS	1962		152	126	A	1¼	125–126			G, J	T, Des			3-28-63	8,000	23	D
15dda		USGS	1962		177	149	A	1¼	148–149			G, J	T, Des						D
18aaa		USGS	1963		118	114	A	1¼	113–114			G, J	T, Des			3-12-63	2,360	23	D
20ccc		USGS	1961		18	18	A	1¼	17–18	8- 2-61	12.3	H	T			4-27-62	5,780		
21abb		USGS	1962		97	82	A	1¼	81–82			G, J	T, Des						D
21bbb		USGS	1963		132	128	A	1¼	127–128			G, J	T, Des			3-28-63	5,010	24	D
29ccc		USGS	1961		18	18	A	1¼	17–18	8- 1-61	10.2	H	T			4-25-62	4,280	22	
29ddd		USGS	1961		18	18	A	1¼	17–18	8- 1-61	9.5	H	T			4-25-62	1,160	22	
30ccc		USGS	1961		18	18	A	1¼	17–18	8- 1-61	12.0	H	T			4-25-62	1,390	22	
31bbc		USGS	1963		127	126	A	1¼	125–126			G, J	T, Des						D
(B-5-22)11dcd		USGS	1961		18	18	A	1¼	17–18	8- 3-61	9.9	H	T			4-25-62	621	21	
24ccc		USGS	1961		18	18	A	1¼	17–18	8- 3-61	9.9	H	T			4-25-62	761		
25ccc		USGS	1961		18	18	A	1¼	17–18	8- 1-61	12.0	H	T			4-25-62	1,230	21	
26ddd		USGS	1963		118	115	A	1¼	114–115			G, J	T, Des			3-14-63	672	21	D
(B-6-21)2bab		USGS	1963		117	114	A	1¼	113–114			G, J	T, Des			2-28-63	6,050	24	D
16bdd [1]		USBIA	1915		98	98	C	16	0–98				Des	825	25	11- -15	3,540		
18ccd		USGS	1963		123	120	A	1¼	119–120			G, J	T, Des			3- 7-63	1,010	23	D
20bbb		USGS	1963		118	114	A	1¼	113–114			G, J	T, Des			3- 4-63	2,080	23	D
20ccc		USGS	1961		18	18	A	1¼	17–18	8- 2-61	11.6	H	T			8- 2-61	1,800		
20ddd1	LCRP4	USGS	1961		584	584	C	8	120–130	10-27-61	12.7	G, T	T	500	15	10-27-61	5,220	24	D, L, PT
									200–300			G, T	T	375	32	6-16-65	1,910	26	PT
20ddd2		USGS	1962		120	120	A	1¼	119–120							5-18-62	5,610		
21ddd		USGS	1961		18	18	A	1¼	17–18	8- 3-61	11.7	H	T			4-27-62	7,610		
32ccc		USGS	1961		18	18	A	1¼	17–18	8- 2-61	12.6	H	T			4-27-62	7,220		
34ccd		USGS	1961		18	18	A	1¼	17–18	8- 2-61	12.8	H	T			4-27-62	2,540		
(B-6-22)1abb		USGS	1963		102	80	A	1¼	79–80			G, J	T, Des			2- 6-63	794	23	D
12cdc		USGS	1961		18	18	A	1¼	17–18	8- 4-61	11.6	H	T			4-25-62	1,080		
23baa1		USGS	1963		97	85	A	1¼	84–85			G, J	T, Des			2- 6-63	662	22	D
23baa2		USGS	1963		111	111	A	1¼	110–111			G, J	T, Des			3-11-63	1,170	23	D
24ddd		USGS	1961		18	18	A	1¼	17–18	8- 3-61	9.8	H	T			4-25-62	1,180	23	
26baa		USGS	1961		23	23	A	1¼	22–23	8- 3-61	14.2	H	T			4-25-62	1,120		
35dcc		USGS	1963		112	105	A	1¼	104–105			G, J	T, Des			3-18-63	1,110	22	D
35ddd		USGS	1961		23	23	A	1¼	22–23	8- 3-61	15.1	H	T			4-25-62	1,560		
(B-7-21)4aaa		USGS	1961		18	18	A	1¼	17–18	8- 6-61	12.7	H	T			4-26-62	2,210		
5baa		USGS	1961		18	18	A	1¼	17–18	8- 6-61	13.1	H	T			4-26-62	1,230	22	
8ddd		USGS	1962		25	25	A	1¼	24–25	4-26-62	13.8	H	T			4-26-62	1,560	23	
13aba		USGS	1963		115	105	A	1¼	104–105			G, J	T, Des			2-27-63	1,730	23	D
14acd	Well 7	USBIA	1952		201			20	25–187			E, T	Dr	1,560	35	10-24-62	1,920	23	D, PT
14dcd	Well 8	USBIA	1952		165			20	25–153			E, T	Dr	1,400	10	7-31-62	2,840	21	D, PT
15caa	Poston 2, well 1.	USBIA	1942		360		C	12	175–205	2-14-63	10.7		Un	450	86				D
15cba	Poston 2, well 2.	USBIA			252		C	12	180–210	2- 9-61	10.2		Un						D
15ccd	Poston 2, well 3.	USBIA	1942		246		C	12	110–218			E, T	PS	800	56	2- 9-61	1,540		D
16aaa		USGS	1961		13	13	A	1¼	12–13	8- 6-61	8.4	H	T			4-26-62	1,520	22	
16z1[1]		USBIA	1915		72	72	C	16	0–72					450	25	16	1,170		
18aaa		USGS	1961		23	23	A	1¼	22–23	8- 6-61	16.1	H	T			4-26-62	1,200	25	
19ddd		USGS	1961		18	18	A	1¼	17–18	8- 5-61	13.8	H	T			4-26-62	2,270	22	
20ddd		USGS	1961		18	18	A	1¼	17–18	8- 5-61	11.3	H	T			4-26-62	1,410	22	
22bcb		USBIA											Des						
23acd	Well 9	USBIA			160							E, T	Dr	1,050	14	11- 2-62	3,260	22	D, PT
23dcd	Well 10	USBIA			160							E, T	Dr	885	12	10-25-62	4,540	22	D, PT
31aaa	LCRP 27	USGS	1965	312	961	915	C	12	194–722	6- 7-65	12.8	G, T	T	630	43	6- 4-65	891	26	D, L, PT
31cdd		USGS	1961		18	18	A	1¼	17–18	8- 5-61	14.0	H	T			4-26-62	3,170	24	
32daa	Poston 3, well 1.	USBIA			282			12	180–220	2-14-63	10.8		Un	125		8-10-42	888		D, PT
33cbb	Poston 3, well 3.	USBIA			262			14	184–208	1-25-61	10.5		Un	125	91	6-13-63	2,290		D, PT
33ccd	Poston 3, well 2.	USBIA	1942		144			12	100–124			T	Un	925	20			26	D
(B-7-22)12ddb		USGS	1963		115	92	A	1¼	91–92			G, J	T, Des	6		2- 7-63	827	22	D
					115	114	A	1¼	113–114			G, J	T, Des	6		2- 7-63	769	22	D
14aad		USGS	1961		23	23	A	1¼	22–23	8- 4-61	16.0	H	T			4-26-62	1,280	22	
23ccc		USGS	1961		18	18	A	1¼	17–18	8- 4-61	11.3	H	T			4-26-62	820	22	
23ddd1		USGS	1961		23	23	A	1¼	22–23	8- 4-61	13.9	H	T			4-26-62	1,370		
23ddd2		USGS	1963		87	83	A	1¼	82–83			G, J	T, Des			5-10-63	1,260	23	D
24ddd		USGS	1961		18	18	A	1¼	17–18	8- 5-61	14.3	H	T			4-26-62	1,690		
35ddd		USGS	1961		19	19	A	1¼	18–19	8- 4-61	13.9	H	T			4-25-62	1,070		

See footnotes at end of table.

TABLE 12.—*Records of test and selected water wells, Parker-Blythe-Cibola area, Arizona-California*—Continued

Well No.	Other No.	Owner or user	Year completed	Elevation of land surface (ft above m.s.l.)	Total depth (feet)	Completed depth (feet)	Method of construction	Casing diameter (inches, ID)	Depth of perforated interval (feet)	Water level: Date of measurement	Water level: Depth to water (feet)	Type of pump	Use	Discharge (gpm)	Drawdown (feet)	Water quality: Date	Water quality: Sum of solids (mg/L)	Water temperature (°C)	Other data available
(B-8-19) 5 bba	LCRP 21	USGS	1964	530	1,000	847	C	12	635-1,000	9-18-64	183.8	G, J	T	600	40	1-12-65	703	34	D, L, PT
34daa			1963				C	6				W, L	S			12-3-63	241		
(B-8-20) 4baa		USGS	1963		157	95	A	1¼	94-95			G, J	T, Des	5		2-15-63	1,110	23	D
19bbb		USGS	1963		137		A						T, Des						D
20aaa		USGS	1963		122		A						T, Des						D
20bbb		USGS	1963		124	100	A	1¼	99-100			G, J	T, Des	4		1-28-63	2,810	22	D
21acc		USGS	1963		129		A						T, Des						D
22cbb		USGS	1963		105		A						T, Des						D
29baa	LCRP 20	USGS	1964	332	763	665	C	12	688-763	6-24-64	10.4	G, T	T	264	65	6-24-64	1,050	29	D, L, PT
(B-8-21) 1baa	Valley School.	USBIA	1959		178	178	C		122-138			E, T	PS			2-10-61	1,170		D
1cbc	Well 11	USBIA			76		C	20					Dom						
3cbb		USGS	1963		49		A						T, Des						D
4ddd		USGS	1963		41		A						T, Des						D
10ccc		USGS	1963		105		A						T, Des						D
11ccc		USGS	1963		87	79	A	1¼	78-79			G, J	T, Des			5-11-63	1,570	23	D
12ccc		USGS	1963		98		A						T, Des						D
13bdd		USGS	1963		109		A						T, Des						D
14bbb		USGS	1963		84	74	A	1¼	73-74			G, J	T, Des			1-28-63	1,580	23	D
28cdd		USGS	1963		97	83	A	1¼	82-83			G, J	T, Des			2-13-63	1,130	21	D
					97	90	A	1¼	89-90			G, J	T, Des			2-13-63	1,590	21	D
35aaa	Poston 1, well 1.	USBIA	1942		136			12	100-124				Des	925	9				D
35add	Poston 1, well 2.	USBIA	1942		136			12	100-124	2-9-61	10.0		Un	925	11				D
35bab	Poston 1, well 5.	USBIA											Des						
35dcd	Poston 1, well 3.	USBIA	1942		216			12	102-170	2-9-61	10.5	E, T	PS	820	17				D
36bc	Job Corps, well 4.		1966		467	467	C	8, 6	340-467							10-12-66	902		D
36bdc	Poston 1, well 4.	USBIA	1942		165			12	90-125	2-9-61	9.7	E, T	PS	925	11	2-9-61	884		D
(B-9-19) 5ddd	LCRP 15	USGS	1963		520	520	C	12, 10	175-199		152.5	G, T	T	930	7.5	9-13-63	635	28	D, L, PT
									285-520		151.7	G, T	T	605	40	9-6-63	679	35	D, L, PT
6ccb		Parker Ice Plant			140			6				E, S	Ind						
6ccc	Well 6	City of Parker	1956		281			16, 14	162-280	2-8-61	68.8	E, T	PS			2-8-61	807		D
7ba	Cemetery well.	do			91					2-8-61	87.2		Un						
7ca	Parker well warehouse 9.	USBIA								2-15-63	67.2		Un						D
7ccb		Sunny Valley Citrus Co.	1966		320	205	C	16	187-320							- -66	697		D
18cbb		do	1966		145	145	RR, G	16	100-145		63					8-10-66	764		D
18ccb		do	1966		130	130	RR, G	20	100-130		70					9-7-66	671		D
(B-9-20) 1bdb		J. Powers	1961					8				E, S	Dom			2-22-62	1,970	24	
1dbc1	Well 5	City of Parker	1950		240		C	16	90-235			E, T	PS	200		10-24-62	658	27	D, PT
1dbc2	Well 7	do	1963		400	400	C	16, 14	263-400	7-16-63	77	E, T	PS	900	127	7-16-63	646	29	D, PT
1dbd	Well 4	do	1942		190			12	165-185			E, S	PS			8-19-55	644		D
1dda		AT&SF RR	1916		225	225		16, 13	110-225				Un						D
1z1 [1]			1911		70			12, 6		9-26-17	68			60		9-26-17	527		
1z2 [1]			1915		105			10		9-26-17	60			20		9-26-17	756		
1z3 [1]		City of Parker			134											30(?)	835		
2dac1	Well 1		1937		215			10				E, T	PS	96	20	8-19-55	668		D
2dac2	Well 2	USBIA	1939		220	220		10	89-180			E, T	PS			61	494		D
11acb		USBIA	1934				C	20					Un	887	82				PT
11dbc		USBIA	1934		140		C	20	28-118	6-14-63	10.8		Un	780	48	6-14-63	919	21	D
12aa		Parker High School			180		C	12				E, T	PS						
14ab		Colorado River Tribal Council.	1965		166	166	C	12	177-132					1,050	58				D
14cdd	Well 4	USBIA	1934		176		C	20	50-138	6-14-63	12.0		Un	1,600	52	6-17-63	1,180	23	D, PT
14dab		USGS	1963		87	53	A	1¼	52-53			G, J	T, Des	6		2-15-63	971	22	D
14z1 [1]																30(?)	954		
20cbd		Parker Land & Cattle Co.	1962		137		C	8		8-15-63	5	E, T	S			8-15-63	1,010	24	
24cba		USGS	1963		90	64	A	1¼	63-64			G, J	T, Des	7		2-13-63	1,210	23	D
						87	A	1¼	86-87			G, J	T, Des	9		2-13-63	1,080	24	D
24daa		USGS	1963		64		A						T, Des						D
25caa		USGS	1963		96	85	A	1¼	84-85			G, J	T, Des			2-15-63	594	23	D
36aba		USGS	1963				A	1¼	62-63			G, J	T, Des	1		3-6-63	638		D

(B- 9-21)35baa		USGS	1963	87	54	A	1¼	53-54			G, J	T, Des			2- 5-63	1,480	22	D
(B-10-19)1z1 [1]		Marina Village Development Co.	1961	400	82	C	10	26-40		14		PS, Dom	60	.5		1,090		
28cdc		USGS	1963	84								T, Des						D
31ada		USBIA	1963	306	306	C	10				E, T	PS	70	4	6-30-64	708	22	D
31bdd		USBIA	1963	192	192	C	10				E, S	PS	25	3	6-30-64	711	22	
32bcb		USGS	1963	18		A						T, Des						D
(B-11-18)21adc [1]		B. Catterlin	1956	111		C	11				E, S	PS			8-29-63	1,740		
(C- 1-23)7dba		R. Bishop	1917	70		D	10		12-13-61	14.0		Un						
7dbc		Dick Young	1918	21		Dug			12-14-61	15.7		Un						
19caa		J. A. Woods	1954	30		Dug			12-14-61	19.0	W, L	Dom			12-14-61	1,230		
19ccb		R. Bishop	1924	180		D	8				G, C	Irr						
30aca		do	1917	40		D	10, 6				W, L	Dom			12-14-61	672		
32bdd		H. M. Arnett	1962	200		D	6					Un						D
(C- 1-24)36bbb1		Arizona Game and Fish Comm.		123		D	20	102-117	12-14-61	11.0	D, T	Irr	2,300	74	6-14-63	3,830	22	D, PT
36bbb2		do		300		D	6		12-14-61	11.0		Un						D
(C- 2-23)19adc		Brasher & Waller	1960	155		C	8		12-14-61	29.0	W, L				12-14-61	3,930		
19dcd		K. C. Gibson	1959	32		D	14	24-32			E, J	Dom			11-19-62	1,560		
1N/23E-5N1		M. W. D.				D						Un						
5P1	Well 13	do	1933	785		D	8	312-600				Un	100	130	4-19-33	660		D
8D1	Well 14	do	1933	629		D	16	296-603	3-16-62	268.5		Un			9-16-33	610		D
8D2		do				D	9											
9E1		State of California	1948	670		C	8, 6	630-670			L	Un			12-13-50	450		D
9E2		F. Talbot	1952	300		D	6				E, S	PS			12-12-61	637		
1N/24E-35L1		Mitchell	1915(?)			D	12		12-13-61	132.8	L	Un						
35R1			1964	535		C	20					Un						
1N/25E-24N1		Sterling Pipe Line	1964	162		C	14	72-142	6- 4-64	14.0		PS			6- 4-64	1,290		D
33L1		do	1964	250		C	14	40-78	6- 4-64	18.0		PS						
1N/26E-18N1	Well 15A	M. W. D.	1935	60		D	16	16-58										
2N/27E-10z1 [1]		do	1933	103	101		16	28-97	33	7.5		Ind	450	4.5	6- 8-33	1,740		D
1S/23E-1A1	Well 2	AT&SF RR	1924	685	614	D	16	205-605	12-13-61	239.3	E, T	PS			12-13-61	411		D
1A2	Well 1	do		412		D		320-412	12-13-61	240.8		Un			8-11-10	643		D
1A3		H. Oxnevad	1933			D	12	288-308	12-13-61	246.5		Un						
1S/24E-6E1	Millsite well					D	6					Un						
9B1		Zoff		365	365	C	14		12-13-61	159.3		Un						D
9K1		Ruzicka				R	6		6-17-64	151.8	E, T	Irr	210	50	6-17-64	380	32	PT
9Q1			1966			C	12											
10F1		Ruzicka, Deahring, & Fortner.	1959	290	290	C	14	160-198	6-17-64	141.6	E, T	Irr	705	26.5	6-17-64	1,270	29	D, PT
10N1	Well 2	Rio Mesa Ranch		332	306		16	100-306	12-14-61	135.1	E, T	Irr			8- 1-62	1,420	30	D
10N2	Well 1	do									E, T	Irr			8- 1-62	1,130	30	
10Q1		do	1964	247	234	R	16	142-222	6-17-64	117.5	E, T	Irr	1,800	23	6-17-64	1,340	28	D, PT
10R1	Well 5	do				D	6		12-14-61	93.7	E, S	S			8- 1-62	1,340		
15B1	Well 4	do		335		D			12-14-61	110.7	E, T	Irr					27	D
15B2	Domestic well.	do	1958	1,386	400	R	6		12-14-61	110	E, S	Dom			12-14-61	787		D
15B3		do	1966	1,360		R		775-1,000				Irr	250	100	10-18-66	1,210		
15C1	Well 3	do	1957	205	205			120-205	12-14-61	115.3	E, T	Irr			8- 1-62	1,300	27	D
15C2		do	1964	450	214	R	16	128-214	6-16-64	122.1	E, T	Irr	1,650	13				D
16B1		V. Ruzicka	1959	225	225	C	14, 10	130-200			E, T	Irr	265	14	5-24-61	1,070	42	D, PT
17C1		C. Taylor	1950	220	220	C	8	210-220			E, J	Dom	10		2-20-62	1,200	28	
29G1		G. Brome	1959	230		D	10, 8	120-230			E, S	Dom			2-20-62	1,400		D
29G2		do	1934	106	106	D	6	89-106				Un						
29J1		W. Sutton		150			5				E, S	Dom			2-20-62	1,030		
34N1		USGS	1962	32	32	A	1¼	31-32	5- 3-62	19.8	H	T			5- 3-62	1,260	24	
3S/23E-14B1		W. Townsend			60?							Dom			11-13-62	780		
5S/22E-26M1		Handcock and Holly.	1953	790	790	C	16	745-780	2-14-62	197.5		Irr, Un						
26R1		C. Cheely	1957	770		D	12		2-14-62	175.8		Irr, Un						
28C1		U.S. Citrus Corp.	1960	1,118	600	R, G	14	270-601	2-13-62	233.8	D, T	Irr	1,450	27	10-25-62	2,160	32	D, E, PT
28C2		do	1957	410	400	R, G	16	256-400	2-13-62	226.3		Irr, Un						D
28Q1		do	1910	300		Dug	14		2-13-62	195.4		Irr, Un						
31D1		J. Erkeneff		214		D	12		2-13-62	Dry		Un						
31E1		V. Ruzicka	1965	484	484	C	14	291-467	2- 8-66	218.5		Irr						D
33J1		L. C. Winters	1962	380	310	R, G	12	260-380			E, T	Irr	1,050	70	3-16-62	1,290	31	
35A1		C. Cheely	1965	450	450	R, G	14	200-450	2- 8-66	176.2	E, T	Irr	1,950	38	2-10-66	1,300	31	
35D1		V. Ruzicka					14		1-28-66	178.6	E, T	Irr						
35M1		E. Fortner	1964	405							E, T	Irr	500	18.5	1-27-64	1,140	31	
6S/21E-25A1		Riverside County		272			14					Des						D
36M1		State of California		186			12					Des						D
36R1		Nicholls Warm Springs.	1946	638			14	520-620			E, T	Irr	1,500	40	7-15-54	3,020	33	D
36R2		do	1952	400	398	C	16	250-380			E, T	Dom			5-23-61	1,400		

See footnotes at end of table.

TABLE 12.—*Records of test and selected water wells, Parker-Blythe-Cibola area, Arizona-California*—Continued

Well No.	Other No.	Owner or user	Year completed	Elevation of land surface (ft above m.s.l.)	Total depth (feet)	Completed depth (feet)	Method of construction	Casing diameter (inches, ID)	Depth of perforated interval (feet)	Water level: Date of measurement	Water level: Depth to water (feet)	Type of pump	Use	Discharge (gpm)	Drawdown (feet)	Water quality: Date	Water quality: Sum of solids (mg/l)	Water temperature (°C)	Other data available
6S/22E-1F1		S. F. Curtis	1966		350	350	R, G	16	150-350			E, T	Irr	2,275	38				D
1H1		P. A. Dansie	1960			320	R, G	10, 8	180-320	2-13-62	143		Un						D
1L1		N. Weeks	1966		346	340	R, G	10	200-340			E, T	Irr						D
1N1		J. L. Johston			452	452	C	12	410-426	2-15-62	143.0	E, T	Ind			2- 9-66		21	D
1N2		do											Des						
2J1		J. Erkeneff	1965		528		C	12	406-514	2-10-66	142.8		Un						
2P1		W. C. Reeder	1964		313	250	R, G	12	150-250	2-10-66	141.2	E, T	Irr	1,270	38	2-10-66	732		D
2R1		J. Erkeneff	1965		518		C	12	406-514	2-10-66	142.2		Un						D
3B1		W. C. Reeder	1964		420									1,500	37				
3J1											Dry		Des						
3R1		J. Mortensen	1966		360	355	R, G	16	180-355			E, T	Irr	2,000	45				D
3R2		do	1966		350	350	R, G	16	170-350			E, T	Irr	2,500	41				D
8J1		J. Bradbury	1966		302	302	RR, G	16	172-302			E, T	Irr	1,700	50				D
8L1		R. Backman	1966		406	400	R, G	16	180-400			E, T	Irr						D
9L1		L. Meyers	1966		332	332	R, G	16	172-332			E, T	Irr						D
9M1		do	1966		292	292	RR, G	16	162-292			E, T	Irr	1,750	64				D
9P1	LCRP 31	USGS	1967		276	252	R, G	6	230-250				T			6-13-67	1,670	32	
9Q1		M. Bradbury	1966		302	302	RR, G	16	172-302			E, T	Irr	2,000	55				D
10H1		V. Smith	1966		304	304	RR, G	16	174-304			E, T	Irr	2,000	62				D
11H1		H. M. Neighbour	1955		252	250	C	10	165-235			E, T	Irr	665	9	6-19-64	1,180	27	PT
11R1		USGS	1967		101	77	A	1½	75-77	3-27-67	18.3	G, J	T			3-27-67	1,470	24	
11R2		USGS	1967		26	21	A	1½	18-21	3-21-67	16.4	G, J	T			3-21-67	1,510	24	
12E1		W. Miller	1925		230	230		16	160-220			E, T	Irr	2,400	14	10-22-60	1,370		
12F1		do	1920		252	252		14				E, T	Irr	1,275	9	1- 5-61	1,300		
13Q1		USGS	1967		121	116	A	1½	114-116	3-23-67	8.0	G, J	T			3-23-67	867	22	
13Q2		USGS	1967		26	22	A	1½	20-22	3-23-67	7.7	G, J	T			3-23-67	1,730	21	
14L1		USGS	1967		121	94	A	1½	90-94	3-31-67	32.9	G, J	T			3-31-67	1,540	24	
14L2		USGS	1967		41	34	A	1½	30-34	3-31-67	32.2	G, J	T			3-31-67	1,540	24	
15M1		E. Weeks	1955		315	315	R, G	12, 10	168-315	2- 6-62	139.1	E, T	Irr	475	21	2- 6-62	863	27	D, PT
15Q1		do	1963		585	585	C	12	346-572			E, T	Irr	712	12	4-16-63	752	33	D, L, PT
16A1		D. McMillan	1966		364	364	RR, G	16, 12	170-359			E, T	Irr	2,750	40				D
16D1		do	1966		645	428	C, G	20, 12	235-420			E, T	Irr	1,900	58				D
17B1		do	1966		302	302	RR, G	16	181-302			E, T	Irr	1,400	56				D
17L1		J. Meyers	1966		445	445	R, G	16	180-445			E, T	Irr	2,500	66				D
17L2		do	1966		323	323	RR, G	12	171-323			E, T	Irr	2,350	55				D
18A1		L. Nichols	1966		298	298	RR, G	16	168-298			E, T	Irr	1,600	53				D
18J1		do	1966		302	302	RR, G	16	172-302			E, T	Irr	1,500	44				D
19N1		Riverside County						12					Des						
20A1	LCRP 32	USGS	1967		276	250	R, G	6	230-250							6-15-67	838	31	
21B1		A. Peterson	1966		378	378	R, G	16	178-378			E, T	Irr	2,600	45				D
21K1		do	1966		323	323	RR, G	16	182-323			E, T	Irr	2,700	43				D
22B1		L. Hunt	1966		380	378	RR, G	16, 12	192-372			E, T	Irr	2,700	27				D
26E1		USGS	1967		121	64	A	1½	62-64	3-28-67	15.6	G, J	T			3-28-67	1,020	23	
26E2		USGS	1967		26	21	A	1½	19-21	3-28-67	15.2	G, J	T			3-28-67	857	24	
26G1		USGS	1967		121	79	A	1½	77-79	3-28-67	9.0	G, J	T			3-28-67	1,290	22	
26G2		USGS	1967		26	21	A	1½	19-21	3-28-67	8.5	G, J	T			3-28-67	1,180	22	
28G1	Well 1	Basha	1965					16				E, T	Irr	2,225		2- 9-66	930	31	E
29D1		Riverside County	1942		268			14	173-193	4- 4-61	141.5		Un	470	38				D
29G1		do	1943		375			14		4- 4-61	138.8		Un						D
29J1		do	1943		246			14		6- 9-61	135.0	E, T	Un						D
31Z1 [1]			1913		156		Dug			10-17-17	149					10-17-17	1,170		
32F1		do	1943		252			14		2- 7-61	135.9	E, T	Ind			5-23-61		27	D
32K1		J. Aiello	1953		500	500	C	16				E, T	Irr	1,350	20	5-23-61	1,180		

32R1		Bill Passey	1947		560		C	14	120-488	5-23-61	82.7		Un.	500	82	6-11-63	1,520	31	PT
33Q1		Roy Gast			232			14	100-145				Des.						
33R1		do			560								Des.			-60	1,270		D
34L1		F. Olson	1960		384	384	C	10	350-360			E, S	Dom.			5-25-61	1,350		
35M1		G. W. McBride	1953		328		C	8	295-310			E, J	Dom.	250	10	2- 7-62	797		
35R1		South Counties Gas Co.	1947		402	402		12	302-326	5-25-61	7.0	E, T	Ind.	425	11	-60	770		D
35R2		do	1947		350	350		12		5-25-61	6.3	E, T	Ind.	520	15	10-23-62	752	26	D, PT
6S/23E-24J1 [3]		Clayton Ranch	1964		170	170	C	20		7- 7-64	12.4			2,180	50	7- 8-64	921	23	PT
25G1 [3]		USGS	1962		16	16	A	1¼	15-16	4-24-62	5.9	H	T.			4-24-62	3,740	21	
29R1	Well 8	City of Blythe	1960		382	382	C	12	264-368	2- 7-61	11.4	E, T	PS.	360	33	10-23-62	786	25	D, PT
31J1		Ramada Inn	1957		390		C	8	350-380			E, T	PS.	460	8	2- 6-62	498		D
32C1	Well 5	City of Blythe	1947		168	168	C	12	125-152	2- 7-61	10.0	E, T	PS.	646	85				D
32D1	Well 9	do	1953		316		C	14	122-286			E, T	PS.	520	31	10-23-62	1,050	24	D, PT
32E1	Well 11	do	1965		725	712	C	16	421-505				PS.	2,000	46.5				D
32F1	Well 2	do	1937		188	188	C	14	128-168			E, C	PS.	780	19				D
32F2	Well 3	do	1939		263		C	14				E, T	PS.	357	10.5				
32G1	Well 1	Palo Verde Hospital.	1961		190	190	C	10	112-144				Un.						
32G2	Well 2	do	1961		590	590	C	10	544-560	12-15-61	8.1	E, T	PS.						D
32J1	Well 10	City of Blythe	1958		400	400	C	14	342-366			E, T	PS.	547	27	9-14-60	491		D
32L1	Well 4	do	1943		176	176	C	16		2- 7-61	8.5	E, T	PS.	627	13				
32M1	Well 7	do	1956		350	350	C	14	310-335	2- 7-61	7.3	E, T	PS.	515	10.5	2- 7-61	522		D
32P1	Well 1	do	1960		450	450	C	16	245-324			G, T	PS.	470	12	10-23-62	787	26	D, PT
32Z1 [1]																10-16-17	530		
32Z1 [1]																10-16-17	535		
32Z3 [1]																10-16-17	532		
33E1	Well 6	City of Blythe			368	368	C	12	290-324	2- 7-61	10.7	E, T	PS.	455	19				D
33G1	Well 2	County Water District.	1958		600	600	C	12	500-600			E, C	PS.	450	11.5	2- 7-62	621		D
33K1	Well 3	do	1959		426	426	C	12	351-408			E, C	PS.	450	13	2- 7-62	478		D
33M1	Well 1	do	1949		306	306	R	12,8	70-306			E, C	PS.	250	5	2- 7-62	634		
36N1		State of California.	1960		250	250	C	12	110-177			E, T	PS.	370	8.5	2- 6-62	872		D
36N2		do	1951		350	350	C	8	235-248				Des.			2-14-52	3,460		D
7S/21E-12D1	Well 2	Basha	1966				R	16		1-28-66	139.2		Un.						E
14A1		Gudzunas								2-15-62	139.2	T	Un.						
14B1		do								2-15-62	138.0	E, T	Un.			2- 8-66	2,650		
14H1	Well 3	Basha	1966		1,368		R		700-900	3- 1-66	130.			750	160	3- 1-66	4,550	45	E
7S/22E-3D1		USGS	1967		121	49	A	1½	45-49	3-30-67	5.4	G, J	T.			3-30-67	1,090	26	
3D2		USGS	1967		26	20	A	1½	18-20	3-30-67	5.1	G, J	T.			3-30-67	1,600	25	
3H1		USGS	1967		121	118	A	1½	114-118	3-30-67	9.2	G, J	T.			3-30-67	2,390	23	
3H2		USGS	1967		26	22	A	1½	20-22	3-30-67	9.8	G, J	T.			3-30-67	969	23	
4P1		J. E. Mason	1959		156	156		10	118-136			E, T	Dom.	100	2	10-22-62	2,140	28	PT
4Q1		E. Williams			40			4		5-25-61	22.4	H, P	Des.						
11Q1		G. Scott			460	460	C	8		2-14-62	7.8	E, J	Dom.			2-14-62	623		
17P1		D. N. Nowland	1959		260		C	8		1-24-61	6.8		Un.						
34Z1																3-24-51	856		
7S/23E-5D1		Blythe Ice Co.	1955		200		C	16	104-190			E, T	Ind.	1,500	6	2- 7-62	806		
5D2		do	1942		142		C	16					Un.						
5E1		M.L.T. Enterprise.	1957		382	350	C	8				E, T	Dom.			2-15-62	592		
17D1		Union Feed Yards.	1951		176	176	C	12	112-147			E, T	S.			2-14-62	1,200		D
17E1		do	1956									E, T	S.			2-14-62	1,640		
18A1		do	1960		510	510	C	12	465-486			E, T	S.			2-14-62	976		
21H1		J. Ulmer	1955		400	400	C	8				E, J	Dom.			2-15-62	604		
29D1 •		Ivey			353			6				E, J	Dom.			5-25-61	1,380		
32M1		J. Norton	1961		400							E, T	Dom.			2-14-62	507		
8S/21E-13A1	LCRP 16	USGS	1963	240	800	800	C	12	39-115	8-28-63	10.56	G, T	T.	670	32	8-28-63	2,200	24	D, L, PT
									395-430	8-14-63	8.8	G, T		515	140	8-14-63	7,490	28	PT
24A1		N. Hyduke	1962		14			1½				E, J	Dom.			2-13-63	1,440		
8S/22E-8D1		C. Whitlock	1953		21			2				E, J	Dom.			2-15-63	1,330		
17Z1 [1]					100	100		2								11- 6-17	665		
19A1		L. Perry	1959		18			2				E, J	Dom.			3- -63	1,110		
8S/23E-6P1		Knappenberger	1953		390	390	C	8	362-370	2- 8-62	10.3	E, J	Dom.			2- 8-62	534		
7B1		do	1956		390	390	C	8	370-382			E, J	Dom.			2-14-62	635		

See footnotes at end of table.

TABLE 12.—*Records of test and selected water wells, Parker-Blythe-Cibola area, Arizona-California*—Continued

Well No.	Other No.	Owner or user	Year completed	Elevation of land surface (ft above m.s.l.)	Total depth (feet)	Completed depth (feet)	Method of construction	Casing diameter (inches, ID)	Depth of perforated interval (feet)	Water level: Date of measurement	Water level: Depth to water (feet)	Type of pump	Use	Discharge (gpm)	Drawdown (feet)	Water quality: Date	Water quality: Sum of solids (mg/l)	Water temperature (°C)	Other data available
9S/21E-1N1		Burwood Inv. Co.	1962			25										2- 7-63	5,160		
2J1		USGS	1962		232	231	A	1¼	229-231			G, J	T, Des			3- 27-62	14,900	24	D
2J2		USGS	1962		152	147	A	1¼	145-147			G	T, Des						D
2J3		USGS	1962		97	95	A	1¼	93-95			G, J	T, Des			3-27-62	4,400	24	D
2J4		USGS	1962		57	52	A	1¼	50-52				T, Des			5-15-62	3,100		D
2P1		USGS	1963		112	104	A	1¼	103-104			G, J	T, Des			5- 7-63	14,400	24	D
2Z1 [1]					100(?)								Dom			11- 6-17	726		
2Z2 [1]		Al's Trading Post											Dom			5-11-50	1,020		
2Z3 [1]		Capt. Anderson Yard.											Dom			3- 9-54	975		
2Z4 [1]																3- 9-54	4,620		
2Z5 [1]		Dunlap's Trailer Park.														3- 9-54	2,180		
2Z6 [1]		Spencer's Cafe														10-14-58	1,984		
2Z7 [1]		Howbuck Ranch														8- 2-59	2,240		
2Z8 [1]		Dunlap's Trailer Park.														4- 6-61	2,180		
2Z9 [1]		do														6- 9-61	1,700		
3H1					55		C	6		2- 7-61	10.3		Un	3					
3N1		USGS	1963		147	110	A	1¼	109-110			G, J	T, Des			3-15-63	4,040	26	D
3Z1 [1]		Vincent			280											5-11-50	11,000		
11A1		USGS	1963		139	105	A	1¼	104-105			G, J	T, Des			3-27-63	8,040	23	D
						120			119-120							3-27-63	10,300	22	D
11A2		USGS	1963		107	100		1¼	99-100			G, J	T, Des			5- 8-63	3,110	23	D
11K1		USGS	1963		147	110	A	1¼	109-110			G, J	T, Des			3-26-63	920	21	D
23C1		Rancho Del Rio	1963		100			30, 20	15-100				Un			7-29-63	20,800		
24D1		USGS	1963		112	105	A	1¼	104-105			G, J	T, Des			5- 9-63	1,040	22	D
9S/22E-2B1		USGS	1962			21	A	5	21	1-17-62	9.7		Obs						
10S/21E-14P1		USGS	1962			6	A	5	6	1-18-62	3.8		Obs						
14P2		Jack Rye	1963		18			1½			13					6- -63	980		
29D1		USGS	1962		232	138	A	1¼	136-138	3-19-62	45.7		T			5-14-62	717		D
29H1		USGS	1962		84	84	A	1¼	82-84	5-24-62	57.4		T						D
30B1		USGS	1962		74	74	A	1¼	72-74	5-24-62	43.4		T						D
11S/20E-15z1					35		Dug									12- 7-17	362		
11S/21E-5F1		Southern Pacific Co.			752			Open		9-26-62	283.2		Un	1	100	9-17-63	526	31	PT

[1] Not on map showing well locations. [2] Well in California. [3] Well in Arizona.

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SELECTED LOGS OF WELLS

The following pages contain selected logs from 16 wells in the Parker-Blythe-Cibola area. The logs labeled "Modified drillers' logs of wells" (table 13) are modified from the original terms used by the drillers only by giving the lithology first. The logs labeled "Lithologic logs of wells" (table 14) are based on an examination of the drill cuttings by the senior author. The geologic units for both types of logs are by the senior author.

TABLE 13.—*Modified drillers' logs of wells*

	Thickness (feet)	Depth (feet)
City of Parker well 7 ((B-9-20)1dbc2) [SW¼NW¼SE¼ sec. 1, T. 9 N., R. 20 W., Gila and Salt River base line and meridian]		
Colorado River alluvium:		
Sand, loose; boulders	22	22
Sand, loose	13	35
Sand, loose; gravel	10	45
Gravel, loose	11	56
Bouse Formation:		
Clay	22	78
Sand and gravel	9	87
Clay, blue	17	104
Sandstone	31	135
Clay, blue	55	190
Fanglomerate:		
Sand and gravel, red-clay binder	75	265
Basalt	15	280
Gravel and sand, cemented	120	400
Arizona Game and Fish well (C-1-24) 36bbb2 [NW¼NW¼NW¼ sec. 36, T. 1 S., R. 24 W., Gila and Salt River base line and meridian]		
Younger alluvium:		
Soil, top	3	3
Sand, fine; heaving	75	78
Sand, fine; with gravel	5	83
Sand, fine; with clay	23	106
Conglomerate, clay, rock, and sand	3	109
Sand, coarse; rock and gravel	19	128
Bouse Formation:		
Clay, blue-shale	16	144
Shale, brown	1	145
Conglomerate, blue, and brown shale	16	161
Shale, blue	10	171
Shale, blue; caving	94	265
Shale, green-pea colored	30	295
Clay and shale, yellow	5	300
Rio Mesa Ranch well 1S/24E-15B2 [NW¼NW¼NE¼ sec. 15, T. 1 S., R. 24 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Gravel and clay	3	3
Sand and gravel, packed	12	15
Sand	4	19
Gravel, cemented	6	25
Boulders and gravel	55	80
Clay	5	85
Sand	15	100
Sand and gravel	15	115
Sand	9	124
Clay with rock embedded	18	142
Clay with gravel embedded	10	152
Rock	18	170
Bouse Formation:		
Clay, hard	75	245
Sand	35	280
Clay, sandy	20	300

TABLE 13.—*Modified drillers' logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Rio Mesa Ranch well 1S/24E-15B2—Continued		
Bouse Formation—Continued		
Sand and gravel	28	328
Clay, hard	17	345
Gravel, fine	15	360
Clay, sandy	8	368
Sand	2	370
Clay, hard	32	402
Sand, fine	8	410
Clay	4	414
Sand	2	416
Clay	4	420
Sand	7	427
Clay	3	430
Clay, sandy	7	437
Clay	4	441
Sand	4	445
Clay	7	452
Clay, sandy	6	458
Sand	2	460
Clay	3	463
Sand	7	470
Clay	40	510
Sand	10	520
Clay, hard	60	580
Sand	5	585
Clay, sandy	45	630
Sand	8	638
Clay, hard	32	670
Sand	7	677
Clay	23	700
Sand	5	705
Clay, hard	25	730
Sand	5	735
Clay, sandy	65	800
Clay, hard	30	830
Fanglomerate:		
Gravel, coarse, brown	60	890
Clay, hard	65	955
Conglomerate	55	1,010
Rock	10	1,020
Clay, hard	30	1,050
Sand, brown	5	1,055
Clay, hard	20	1,075
Clay, sandy	5	1,080
Clay, hard, red	5	1,085
Clay with gravel embedded	15	1,100
Conglomerate	50	1,150
Clay with gravel and sand embedded	30	1,180
Conglomerate, brown	40	1,220
Clay with gravel embedded	30	1,250
Sand	5	1,255
Clay	15	1,270
Sand, coarse, brown	28	1,298
Clay, hard	17	1,315
Sand, coarse	8	1,323
Conglomerate, hard	37	1,360

TABLE 13.—*Modified drillers' logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Rio Mesa Ranch well 1S/24E-15B2—Continued		
Fanglomerate—Continued		
Clay with gravel embedded	8	1,368
Clay, sandy	7	1,375
Clay, hard	11	1,386
U.S. Citrus Corp. well 5S/22E-28C1		
[SW¼NE¼NW¼ sec. 28, T. 5 S., R. 22 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Sand, tight and fine, and gravel mixed	79	79
Sand, fine; with sandy clay streaks	78	157
Sand, fine tight	80	237
Sand, fine to coarse, and some gravel	5	242
Sand, fine to medium	5	247
Sand, fine and tight	21	268
Sand, fine, and small gravel, mixed	89	357
Clay, sandy; with gravel streaks	11	368
Clay, sandy, and fine sand	23	391
Gravel	3	394
Sand, coarse to fine; with clay streaks	64	458
Sand, fine to coarse; with clay and shale streaks	44	502
Sand, fine to coarse, and gravel mixed	16	518
Bouse Formation:		
Clay with mixed gravel and sand streaks	45	563
Gravel and fine sand (tight) with shale streaks	21	584
Sand, fine, to gravel (fine) with shale streaks	23	607
Clay, gray, and shale	22	629
Clay, gray	36	665
Shale	4	669
Shale with gravel streaks	14	683
Clay, blue, and shale	26	709
Clay, blue, and shale with blue sandstone streaks	46	755
Gravel	2	757
Clay, blue, and shale	35	792
Clay, soft and sandy (blue)	10	802
Clay, blue, and shale	24	826
Clay, blue; with fine sand streaks	14	840
Clay, blue; with gravel streaks	9	849
Clay, soft sandy	19	868
Clay, blue, and shale	27	895
Sand, medium and fine	6	901
Clay, gray; with shale streaks	38	939
Clay, gray	45	984
Clay, gray, and shale	19	1,003
Shale, hard, with a metallic color	3	1,006
Shale, gray	15	1,021
Shale, hard	7	1,028
Shale and clay	23	1,051
Shale, hard (brown)	17	1,068
Clay, sandy (brown)	6	1,074
Shale and clay (brown)	12	1,086
Shale, hard (brown)	10	1,096
Shale, greenish; with thin white quartz streaks	22	1,118

TABLE 13.—*Modified drillers' logs of wells*—Continued

	Thickness (feet)	Depth (feet)
City of Blythe well 11 (6S/23E-32E1)		
[NE¼SW¼NW¼ sec. 32, T. 6 S., R. 23 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Soil	4	4
Sand, fine, brown	38	42
Sand, fine, gray	32	74
Sand, fine, gray; with trace of clay	28	102
Clay and sand, fine; with trace of gravel	4	106
Sand, fine, to 4-in. rock	12	118
Sand, coarse, to 6-in. rock	32	150
Sand, coarse, to 1-in. gravel	8	158
Sand, fine, gray	8	166
Sand, coarse, to 1-in. gravel	16	182
Sand, fine, cemented	26	208
Clay, soft, blue	2	210
Clay, blue, and fine sand	4	214
Sand, fine, gray	28	242
Gravel, 1-in. to fine sand	4	246
Clay, brown, very hard	4	250
Sand, fine, gray	77	327
Sand, fine, gray, to ¾-in. gravel	2	329
Sand, fine, gray	25	354
Gravel, 1-in., to coarse sand	10	364
Sand, fine, gray; with trace of pea gravel	12	376
Sand, fine, gray	10	386
Sand, fine, gray; with broken gravel	7	393
Clay, brown	4	397
Silt, fine, and ¾-in. gravel	13	410
Sand, fine, to ¾-in. gravel 10 percent	1	411
Clay, hard, gray	8	419
Gravel, 1-in., clean; with coarse sand	3	422
Sand, fine, gray, to ¾-in. gravel 10 percent	28	450
Sand, fine, gray, to 1-in. gravel 20 percent; (wood)	5	455
Clay, blue, soft	4	459
Sand, fine, gray, to pea gravel 5 percent	35	494
Sand, fine, gray, to 1-in. gravel	12	506
Bouse Formation:		
Clay, blue, hard	13	519
Sand, fine, to ¾-in. gravel	3	522
Clay, blue, hard	30	552
Sandstone, soft	2	554
Clay, blue; with brittle streaks	30	584
Sandstone with trace of ¾-in. gravel	6	590
Clay, blue, hard	52	642
Sand, soft	9	651
Clay, blue, very hard	59	710
Clay, blue, very hard; with small sea shells	10	720
Clay, blue, very hard, brittle	5	725
Palo Verde Hospital well 2 (6S/23E-32G2)		
[NW¼SW¼NE¼ sec. 32, T. 6 S., R. 23 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Soil, sandy	4	4
Sand	50	54
Sand, clay, gravel	8	62

TABLE 13.—*Modified drillers' logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Palo Verde Hospital well 2(6S/23E-32G2)—Continued		
Colorado River alluvium—Continued		
Sand with trace of gravel	8	70
Sand, gravel, and wood	6	76
Sand and clay	24	100
Sand, fine, and pea gravel to 3-in. rock	4	104
Sand to 3-in. rock	12	116
Rock, 5-in., to coarse sand	48	164
Sand, coarse, and pea gravel	9	173
Sand, coarse, to 6-in. gravel	6	179
Sand	5	184
Sand and pea gravel	8	192
Sand, fine	24	216
Sand, coarse, and pea gravel to 2-in. gravel	20	236
Sand, coarse; with trace of pea gravel	12	248
Sand, fine, clay layers	22	270
Sand, fine, to 1½-in. gravel	10	280
Sand, coarse; pea gravel to 3-in. rock	8	288
Sand, coarse, and pea gravel	14	302
Sand, medium	35	337
Sand, coarse, to pea gravel (wood)	19	356
Clay, sand, and 1-in. gravel	48	404
Clay, fine sand; some gravel	88	492
Sand to 1½-in. gravel	8	500
Sand to 1-in. gravel	14	514
Gravel, cemented (hard-tight)	8	522
Gravel, pea, to 1½-in. gravel	6	528
Sand, coarse, to pea gravel	4	532
Gravel, 2-in., to sand; very good water gravel	28	560
Hard clay streaks with sand to 1-in. gravel	10	570
Clay, hard sandy	4	574
Sand to pea gravel	4	578
Sand to ¾-in. gravel	6	584
Sand, coarse, to 1½-in. gravel	4	588
Sand with trace of gravel	2	590
Bashas's well 3 (7S/21E-14H1)		
[SW¼SE¼NE¼ sec. 14, T. 7 S., R. 21 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Sand, fine; with clay streaks	88	88
Sand, medium to coarse, and gravel; with clay streaks	43	131
Sand, medium to coarse; with clay streaks	42	173
Sand, medium to fine; with clay	22	195
Sand, medium to fine; with clay streaks	90	285
Sand, medium to coarse	43	328
Sand, fine to medium	110	438
Sand, medium to coarse; with clay streaks	45	483
Sand, medium, and gravel; with clay streaks	44	527
Bouse Formation:		
Clay with sand	56	583
Clay with coarse sand streaks	23	606
Clay	79	685
Rock	21	706
Sand, coarse; with clay streaks	23	729
Clay and coarse sand	11	740

TABLE 13.—*Modified drillers' logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Bashas's well 3(7S/21E-14H1)—Continued		
Bouse Formation—Continued		
Sand, coarse; some clay streaks	54	794
Sand, medium; with clay streaks	51	845
Fanglomerate:		
Sand, medium, black; with red clay streaks	13	858
Sand, medium, and granite rocks	24	882
Sand, medium; with rock streaks	22	904
Sand, coarse; with clay streaks and rock	26	930
Sand, coarse; with clay streaks	10	940
Granite, decomposed; with small clay streaks	96	1, 036
Granite, decomposed; with clay streaks	42	1, 078
Clay and decomposed granite	22	1, 100
Granite, decomposed; with clay streaks	66	1, 166
Clay, red, and medium sand streaks	22	1, 188
Clay with streaks of fine sand	179	1, 367

TABLE 14.—*Lithologic logs of wells*

	Thickness (feet)	Depth (feet)
Well LCRP 22 ((B-2-22)16bba)		
[NE¼NW¼NW¼ sec. 16, T. 2 N., R. 22 W., Gila and Salt River base line and meridian]		
Younger alluvium:		
Gravel as much as 6 in. in diameter, commonly 1–3 in. in diameter, mostly subangular, some well-rounded; with 20 percent sand	48	48
Unit B of older alluviums:		
Sand, medium to fine, grayish-orange, fairly well sorted, round to well-rounded; few ½ to 1-in. thick sandstone streaks; few well-indurated clayballs	28	76
Sand, medium to fine, grayish-orange; about 20 percent, ¼–½ in. in diameter, rounded to well-rounded, and 2–3 in. in diameter, subangular gravel; few ½- to 1-in. thick sandstone streaks	12	88
Sand, medium to fine, grayish-orange; few ½–1-in. in diameter, subangular to rounded pebbles; few ½- to 1-in. thick sandstone streaks; few well-indurated clayballs	77	165
Sand, medium to coarse, grayish-orange; few light-green clayballs; subrounded gravel as much as 3 in. in diameter; few cemented streaks	18	183
Conglomerate, pebbles and cobbles subangular; pea-size well-rounded well-indurated yellow clayballs as much as 12 in. in diameter; fine to medium grayish-orange sand	16	199
Sand, fine to coarse, grayish-orange; 35 percent subangular to well-rounded gravel as much as 4 in. in diameter	14	213

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 22 ((B-2-22) 16bba)—Continued		
Unit B of older alluviums—Continued		
Sand, medium to coarse, grayish-orange, fairly well sorted; scattered pebbles as much as 2 in. in diameter	10	223
Gravel as much as 8 in. in diameter, subrounded to well-rounded; sand; some cementation; few clayballs	31	254
Bouse Formation:		
Claystone, pale-yellowish-green, and clayey pale-orange limestone	3	257
Claystone and clay, yellowish-gray; some very light-gray siltstone between depths of 299 and 309 ft	76	333
Claystone and clay, yellowish-gray and light-olive-gray; scattered subrounded to well-rounded pebbles; some fine to coarse sand between depths of 339 and 342 ft	40	373
Claystone, yellowish-gray; interbedded with fine yellowish-gray sand	36	409
Claystone, yellowish-gray; some yellowish-gray siltstone	40	449
Clay, yellowish-gray; interbedded with fine light-olive-gray sand; fossils	70	519
Sand, fine, light-olive-gray; some yellowish-gray claystone; some carbonized wood fragments; some pyrite in claystone	61	580
Claystone, yellowish-gray and pale-olive; some fine light-olive-gray sand	13	593
Sand, fine, pale-yellowish brown	16	609
Clay and claystone, light-greenish-gray; interbedded with fine pale-yellowish-brown sand	20	629
Claystone, yellowish-gray; some fine pale-yellowish-brown sand	10	639
Sand, fine, pale-yellowish-brown; some yellowish-gray and light-greenish-gray claystone; fossils; carbonized wood fragments	44	683
Claystone, light-greenish-gray to light-olive-gray, very fossiliferous; very fine medium-gray calcareous sandstone; very small pyrite crystals	10	693
Claystone, greenish-gray; fossils	21	714
Sand, fine to very fine, pale-yellowish-brown, very fossiliferous; some light-greenish-gray claystone	21	735
Claystone, light-yellowish-gray; interbedded with very fine light-olive-gray sand	7	742
Sand, fine to very fine, light-olive-gray; fossils	11	753
Claystone, light-greenish-gray; interbedded with fine to very fine light-olive-gray sand and sandstone; fossils	41	794
Sand, fine to very fine, light-olive-gray; fossils	7	801
Claystone, light-greenish-gray; interbedded with fine to very fine light-olive-gray sand and sandstone; fossils	5	806
Limestone, marly, white; porous yellowish-gray "coquina-like" limestone	5	811
Fanglomerate:		
Gravel, cemented, subangular to rounded, as much as 7 in. in diameter; 20–30 percent silty poorly sorted sand	187	998

	Thickness (feet)	Depth (feet)
Well LCRP 5 ((B-4-22)36bab)		
[NW¼NE¼NW¼ sec. 36, T. 4 N., R. 22 W., Gila and Salt River base line and meridian]		
Piedmont gravel:		
Sand, gravelly, grayish-orange, poorly sorted	45	45
Unit B of older alluviums:		
Sand, very fine to fine, silty, grayish-orange, poorly sorted	10	55
Sand, fine to coarse, grayish-orange, poorly sorted; 10–15 percent pebbles	38	93
Sand, medium, pale-yellowish-brown, fairly well sorted; with few pebbles	22	115
Sand, medium, pale-yellowish-brown, fairly well sorted; 25 percent gravel	2	117
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; 15–20 percent gravel	15	132
Gravel, sandy, well-sorted	8	140
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; 10 percent gravel	10	150
Sand, fine to medium, silty, pale-yellowish-brown, poorly sorted	10	160
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; 5–10 percent gravel	20	180
Sand, medium, pale-yellowish-brown, fairly well sorted; 5–10 percent gravel	30	210
Sand, medium to coarse, pale-yellowish-brown, fairly well sorted; 20 percent gravel	5	215
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; 15–20 percent gravel	5	220
Sand, fine to medium, pale-yellowish-brown, poorly sorted; 20 percent gravel	5	225
Sand, medium, pale-yellowish-brown, fairly well sorted; 5–10 percent gravel	20	245
Sand, fine to medium, pale-yellowish-brown, poorly sorted	10	255
Sand, fine to medium, pale-yellowish-brown; 30 percent gravel	5	260
Sand, fine to medium, pale-yellowish-brown, poorly sorted	20	280
Sand, fine to medium, grayish-orange, poorly sorted; some pebbles	5	285
Sand, fine to medium, pale-yellowish-brown, poorly sorted; with few granules and pebbles	15	300
Sand, fine to medium, pale-yellowish-brown; 10 percent gravel	20	320
Sand, very fine to fine, pale-yellowish-brown, poorly sorted; with some granules and pebbles	15	335

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 5((B-4-22)36bab)—Continued		
Unit B of older alluviums—Continued		
Sand, very fine to fine, pale-yellowish-brown, poorly sorted; 15–20 percent small pebbles	35	370
Sand, very fine to fine, pale-yellowish-brown, poorly sorted; 25 percent gravel	75	375
Sand, very fine to fine, pale-yellowish-brown, poorly sorted	5	380
Sand, fine, dark-yellowish-brown; 25 percent gravel; some fragments of silicified wood	5	385
Sand, fine, dark-yellowish-brown; 40–50 percent gravel; some fragments of silicified wood	5	390
Sand, fine, dark-yellowish-brown; 30 percent gravel; some fragments of silicified wood	5	395
Clay, silty, pale-yellowish-brown	5	400
Sand, very fine to fine, pale-yellowish-brown; with some granules	10	410
Sand, fine to medium, pale-yellowish-brown, fairly well sorted	40	450
Sandstone, siltstone and clay	5	455
Sand, fine to medium, pale-yellowish-brown, poorly sorted	16	471
Well LCRP 4((B-6-21)20ddd)		
[SE¼SE¼SE¼ sec. 20, T. 6 N., R. 21 W., Gila and Salt River base line and meridian]		
Younger alluvium:		
Sand, fine to medium, grayish-orange, poorly sorted; scattered pebbles	110	110
Sand, medium, grayish-orange; 20–30 percent gravel	5	115
Gravel; some sand	15	130
Bouse Formation:		
Clay, silty, moderate-yellowish-brown; some small pebbles	6	136
Sand, fine to medium, grayish-orange	4	140
Clay, moderate-yellowish-brown; embedded pebbles	10	150
Sand, very fine to medium, pale-yellowish-brown, poorly sorted; some granules and some pebbles	5	155
Sand, very fine to medium, pale-yellowish-brown, poorly sorted; very pale orange sandstone	5	160
Sand, fine to medium, pale-yellowish-brown, poorly sorted; grayish-yellow-green fossiliferous clayballs	8	168
Sand, very fine to fine, grayish-orange, poorly sorted	7	175
Sand, very fine to fine, grayish-orange, poorly sorted; grayish-yellow-green fossiliferous clayballs	65	240
Sand, fine, pale-yellowish-brown, poorly sorted; numerous clayballs	10	250

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 4((B-6-21)20ddd)—Continued		
Bouse Formation—Continued		
Sand, very fine to fine, pale-yellowish-brown, poorly sorted; some clayballs	20	270
Sand, medium to coarse, pale-yellowish-brown, fairly well sorted; 10–20 percent gravel; some clayballs	7	277
Sand, medium to coarse, pale-yellowish-brown; some granules and pebbles	22	299
Sand, pale-yellowish-brown, poorly sorted; 20 percent gravel	11	310
Sand, very fine to very coarse, pale-yellowish-brown, poorly sorted; 5–10 percent gravel	15	325
Sand, fine to medium, pale-yellowish-brown, poorly sorted; 5–10 percent gravel	15	340
Sand, medium, pale-yellowish-brown; 5–10 percent gravel; clayballs	10	350
Sand, fine to medium, pale-yellowish-brown, poorly sorted; fossiliferous clayballs	10	360
Sand, pale-yellowish-brown, poorly sorted; clayballs	5	365
Sand, fine, pale-yellowish-brown, poorly sorted; clayballs	55	420
Sand, fine, light-olive-gray, poorly sorted; clayballs	20	440
Clay, silty, light-olive-gray	25	465
Sand, silty, very fine to fine, yellowish-gray; some clayballs	20	485
Clay, silty, light-olive-gray; some fine to medium sand	25	510
Clay, siltstone, and sandstone	6	516
Clay, silty, light-olive-gray; some medium sand	19	535
Sand, silty, very fine to fine, light-olive-gray, poorly sorted; with light-olive-gray clayey siltstone	45	580
Siltstone, sandy, light-olive-gray	5	585
Well LCRP 27((B-7-21)31aaa)		
[NE¼NE¼NE¼ sec. 31, T. 7 N., R. 21 W., Gila and Salt River base line and meridian]		
Younger alluvium:		
Silt, pale-yellowish-brown	4	4
Sand, medium, grayish-orange; pale-yellowish-brown clay between depths of 30 and 31 ft; scattered rounded to subrounded pebbles between depths of 31 and 91 ft	87	91
Gravel as much as 5 in. in diameter; rounded to well-rounded; 25 percent medium sand	23	114
Bouse Formation:		
Silt, yellowish-gray	4	118
Clay, light-brown, very pale green streaks; with fine to very fine yellowish-gray sand; scattered small pebbles	11	129
Sand, very fine to medium; few grains to very coarse; few scattered small pebbles	36	165

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 27((B-7-21)31aaa)—Continued		
Bouse Formation—Continued		
Sand, very fine to medium; few grains to very coarse; with numerous hard white and moderate-orange-pink limestone balls, as much as 3 in. in diameter	26	191
Silt, pale-yellowish-brown and grayish-orange-pink; pale-olive and pale-reddish-brown clay	3	194
Sand, fine, yellowish-gray, dusky-yellow streaks	6	200
Sand, medium to fine, moderate-greenish-yellow; scattered small rounded pebbles	8	208
Sand, coarse to fine, pale-olive and light-olive-gray; scattered pebbles of greenish-gray limestone	27	235
Gravel and sand, medium-gray; some gravel as much as 4 in. in diameter, mostly pebble size, subrounded to rounded; also armored balls composed of dense, hard light-olive-gray limestone	15	250
Sand, coarse to fine, light-olive-gray; few granules	6	256
Sand, fine to very fine, light-olive-gray; few scattered small pebbles	4	260
Clay, greenish-gray, and light-gray silt	11	271
Sand, fine to medium, light-gray; scattered small pebbles and armored pebbles of dense, hard light-olive-gray limestone	18	289
Silt, sandy, light-olive-gray; greenish-gray clay, fragments of carbonized wood, and few scattered small pebbles	23	312
Sand, fine to very fine, light-olive-gray and very light-gray; few small pebbles between depths of 312 and 316 ft	14	326
Clay, silty, greenish-gray	2	328
Sand, very fine, light-olive-gray	10	338
Clay, greenish-gray; and fine to very fine sand, interbedded with thin hard sandstone and hard limestone	5	343
Sand, fine, light-olive-gray	33	376
Sand, fine light-olive-gray; light-olive-gray silt and clay	9	385
Clay and silt, greenish-gray and light-olive-gray; some siltstone and claystone; some fine yellowish-gray sand between depths of 410 and 415 ft	30	415
Sand, fine, yellowish-gray; some thin beds of light-olive-gray clay and a 6-in. bed of light-olive-gray claystone at 455-ft depth	53	468
Clay, greenish-gray; some fine yellowish-gray sand and light-olive-gray claystone	5	473
Sand, fine, yellowish-gray	11	484
Clay, greenish-gray	1	485
Sand, fine, yellowish-gray	11	496
Clay and claystone, greenish-gray; fragments of carbonized wood	4	500
Sand, fine, yellowish-gray	3	503
Clay and claystone, greenish-gray	7	510
Sand, fine, yellowish-gray	6	516
Clay and claystone, light-olive-gray and greenish-gray	8	524
Sand, fine, yellowish-gray	9	533
Clay, greenish-gray; some light-olive-gray silt and fine yellowish-gray sand	6	539
Sand, fine to medium, yellowish-gray	15	554
Clay, greenish-gray, and fine to very fine yellowish-gray silty sand	41	595
Claystone, light-olive-gray; thin streaks of siltstone and sandstone and fragments of carbonized wood	14	609
Sand, very fine to fine, light-olive-gray; some medium, silty sand	45	654
Claystone, light-olive-gray, and fine silty light-olive-gray sand	16	670
Clay, greenish-gray, and fine silty light-olive-gray sand	23	693
Claystone and clay, light-olive-gray, and fine silty light-olive-gray sand with thin streaks of very hard greenish-gray limestone between depths of 708 and 722 ft	29	722
Clay, greenish-gray, and fine to very fine light-olive-gray sand	40	762
Clay and claystone, greenish-gray; interbedded with fine light-olive-gray sand and light-olive-gray silt	95	857
Marl, light-yellowish-gray, almost white	8	865
Marl, light-greenish-gray	5	870
Marl, yellowish-gray, containing granules and pea gravel	11	881
Tertiary sedimentary rocks:		
Sand, clayey, light-brown; few granules	22	903
Sandstone, clayey, light-brown; gypsum pods	58	961
Well LCRP 21((B-8-19)5bba)		
[NE¼NW¼NW¼ sec. 5, T. 8 N., R. 19 W., Gila and Salt River base line and meridian]		
Unit D of older alluviums:		
Silt, clayey, grayish-orange, slightly cemented	10	10
Sand, medium to fine, grayish-orange, fairly well sorted	35	45
Sand, very fine; grayish-orange silt and clay	20	65
Gravel as much as 3 in. in diameter, subangular to subrounded; sand	80	145
Gravel as much as 12 in. in diameter, rounded to well-rounded; sand; few clayballs	5	150
Clay, light-brown	3	153
Bouse Formation:		
Claystone, light-olive-gray, light-greenish-gray, and yellowish-gray; with grayish-yellow and light-olive-gray very fine sand and silt	52	205

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 21((B-8-19)5bba)—Continued		
Bouse Formation—Continued		
Same, but with dusky-yellow claystone and 1 thin light-olive-gray limestone	35	240
Claystone, light-olive-gray; light-olive gray fossiliferous silt and very fine sand	108	348
Sand, fine to very fine, light-olive-gray, poorly sorted	26	374
Clay, light-olive-gray and light-greenish-gray	6	380
Sand, fine to very fine, light-olive-gray; some light-olive-gray claystone	22	402
Clay, silty, light-olive-gray	8	410
Sand, silty, very fine, light-olive-gray	15	425
Sand, fine to medium, light-olive-gray	21	446
Claystone, light-olive-gray and greenish-gray; light-olive-gray siltstone and very fine to fine sand	94	540
Sand, fine to very fine, light-olive-gray; some light-olive-gray claystone	25	565
Claystone, light-olive-gray; light-olive-gray siltstone and fine to very fine sand; fossils	58	623
Limestone, clayey, white to light-yellowish-gray	10	633
Fanglomerate:		
Gravel, cemented, as much as 2 in. in diameter, subrounded to rounded; pebbles are rounded to well-rounded between depths of 655 and 657 ft	24	657
Sand, silty, fine to medium, cemented, pale-yellowish-brown, poorly sorted; few small pebbles	88	745
Tertiary sedimentary rocks:		
Silt, clayey, cemented, pale-yellowish-brown; few small pebbles; some fine sand	55	800
Clay, pale-reddish-brown and light-brown	4	804
Sand and gravel, pale-yellowish-brown, cemented, poorly sorted; subrounded pebbles as much as 4 in. in diameter	48	852
Sand, silty, cemented, pale-yellowish-brown poorly sorted; few small pebbles; some clay	48	900
Claystone, grayish-orange-pink; interbedded with fine to medium poorly sorted grayish-orange sandstone	35	935
Same, but few pebbles	35	970
Claystone, white and pinkish-gray; may be tuffaceous; interbedded with fine to medium grayish-orange poorly sorted sandstone	30	1,000
Well LCRP 20((B-8-20)29baa)		
[NE¼NE¼NW¼ sec. 29, T. 8 N., R. 20 W., Gila and Salt River base line and meridian]		
Younger alluvium:		
Clay, silty, pale-yellowish-brown; thin streaks of fine to medium sand	26	26
Sand, fine to medium, grayish-orange, fairly well sorted	10	36

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 20((B-8-20)29baa)—Continued		
Younger alluvium—Continued		
Sand, medium, light-brownish-gray, fairly well sorted	10	46
Sand, medium, light-brownish-gray, fairly well sorted; about 5 percent mostly subangular gravel	63	109
Gravel as much as 5 in. in diameter, subrounded to well-rounded	21	130
Bouse Formation:		
Claystone, light-olive-gray, fossiliferous; few wood fragments; few rounded pebbles; thin light-gray siltstone layers	35	165
Sand, fine, light-olive-gray, poorly sorted, fossiliferous; few thin clay beds	31	196
Claystone and siltstone, interbedded, greenish-gray, fossiliferous	2	198
Sand, very fine, light-olive-gray, poorly sorted, fossiliferous; some light-olive-gray siltstone	25	223
Sand, fine, siltstone and claystone, interbedded, light-olive-gray, fossiliferous	50	273
Claystone, light-olive-gray; few pebbles	15	288
Sand, fine, poorly sorted, siltstone and claystone, interbedded, light-olive-gray; some wood fragments between depths of 353 and 363 ft	125	413
Claystone, light-olive-gray, fossiliferous; with embedded rounded pebbles	5	418
Sand, fine, poorly sorted, siltstone and claystone, interbedded, light-olive-gray	30	448
Claystone, light-olive-gray; rounded pebbles	5	453
Sand, fine, poorly sorted, siltstone and claystone, interbedded, light-olive-gray	9	462
Sand, fine, light-olive-gray, poorly sorted	30	492
Claystone, light-olive-gray	20	512
Limestone, light-olive-gray, fossiliferous	1	513
Claystone, light-olive-gray; few rounded pebbles	10	523
Sand, fine, light-olive-gray, poorly sorted	10	533
Sand, fine, and claystone, interbedded, light-olive-gray; few rounded pebbles; few thin well-indurated sandstone streaks	30	563
Claystone, light-olive-gray, and yellowish-gray siltstone, interbedded	5	568
Sand, fine, yellowish-gray, poorly sorted	10	578
Sand, fine, and claystone, interbedded, light-olive-gray; one 2-in.-thick white fossiliferous limestone stratum	10	588
Claystone, light-olive-gray, fossiliferous; few rounded pebbles	20	608
Limestone, clayey, white, fossiliferous	7	615
Fanglomerate:		
Gravel, pebble, sandy, cemented, poorly sorted, subangular	73	688
Basalt	75	763

TABLE 14.—*Lithologic logs of wells*

	Thickness (feet)	Depth (feet)
Well LCRP 15((B-9-19)5ddd)		
[SE¼SE¼SE¼ sec. 5, T. 9 N., R. 19 W., Gila and Salt River base line and meridian]		
Unit D of older alluviums:		
Sand, medium, grayish-orange, fairly well sorted	27	27
Clay, light-brown	1	28
Sand, medium, grayish-orange, fairly well sorted	14	42
Sand, medium to fine, grayish-orange, fairly well sorted	19	61
Sand, medium to fine, grayish-orange, fairly well sorted; with 10 percent gravel as much as 2 in. in diameter	3	64
Sand, medium to fine, grayish-orange, fairly well sorted; few pebbles; some cemented streaks a quarter of an inch thick	8	72
Sand, fine to very coarse, grayish-orange, poorly sorted; with 10 percent gravel; some cemented streaks a quarter of an inch thick	8	80
Sand, fine to medium, grayish-orange, fairly well sorted; few subangular to rounded gravel as much as 3 in. in diameter	8	88
Sand, fine, grayish-orange, fairly well sorted	4	92
Sand, fine to coarse, grayish-orange, poorly sorted; about 20 percent subangular to rounded gravel as much as 3 in. in diameter	4	96
Sand, fine, grayish-orange, fairly well sorted; with occasional pebble	4	100
Gravel as much as 6 in. in diameter, subangular to rounded; some clayballs; about 10 percent sand	6	106
Sand, medium to fine, grayish-orange; with 20 percent granules and pebbles	2	108
Gravel as much as 9 in. in diameter, subrounded; some clayballs as much as 4 in. in diameter; 10 percent sand	34	142
Sand, very coarse, grayish-orange; about 20 percent gravel as much as 2 in. in diameter	3	145
Gravel as much as 7 in. in diameter, rounded to well-rounded; 10 percent sand	8	153
Clay, grayish-orange; embedded small pebbles; iron streaks throughout	5	158
Sand, coarse to very coarse, fairly well sorted; 30 percent granules and small pebbles	7	165
Gravel as much as 9 in. in diameter, rounded to well-rounded; 30 percent sand	11	176
Gravel as much as 11 in. in diameter, subrounded to well-rounded; some greenish-gray clayballs; 10 percent sand	23	199
Bouse Formation:		
Claystone, banded, greenish-gray, grayish-yellow, and very light gray	9	208
Claystone, light-olive-gray with some moderate-yellow; embedded small pebbles	4	212

TABLE 14.—*Lithologic logs of wells*

	Thickness (feet)	Depth (feet)
Well LCRP 15((B-9-19)5ddd)—Continued		
Bouse Formation—Continued		
Claystone, light-olive-gray, fossiliferous; some siltstone; scattered embedded well-rounded pebbles as much as 2 in. in diameter	54	266
Marl, yellowish-gray, fossiliferous	9	275
Fanglomerate:		
Gravel as much as 6 in. in diameter, cemented, poorly sorted, reddish-brown, subrounded to subangular; 40 percent sand	61	336
Conglomerate, gray, subangular to subrounded	63	399
Sand, cemented, reddish-brown, poorly sorted; some granules and small pebbles	66	465
Sand, cemented, reddish-brown, poorly sorted; 40 percent subangular gravel	11	476
Sand, cemented, reddish-brown, poorly sorted; some granules and small pebbles	19	495
Sand, cemented, reddish-brown, poorly sorted; subangular to subrounded gravel as much as 1 in. in diameter	25	520
Well LCRP 16 (8S/21E-13A1)		
[SE¼NE¼NE¼ sec. 13, T. 8 S., R. 21 E., San Bernardino base line and meridian]		
Younger alluvium:		
Silt, sandy, light-brown	5	5
Sand, medium, light-brown, fairly well sorted	10	15
Sand, medium, pale-yellowish-brown; few pebbles as much as 2 in. in diameter	21	36
Gravel as much as 4 in. in diameter, rounded to well-rounded; 20–40 percent medium to very coarse sand	19	55
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; few pebbles and light-brown clayballs; wood fragments between depths of 65 and 70 ft	20	75
Sand, fine, silty, pale-yellowish-brown	5	80
Sand, fine to medium, pale-yellowish-brown, fairly well sorted	5	85
Gravel as much as 7 in. in diameter, subrounded to well-rounded; 40 percent sand	7	92
Sand, fine to coarse; 30 percent rounded to well-rounded gravel as much as 6 in. in diameter	13	105
Gravel, rounded to well-rounded; 50 percent sand	10	115
Sand, medium; 30 percent rounded to well-rounded gravel	9	124
Sand, medium, pale-yellowish-brown, fairly well sorted	3	127
Unit B of older alluviums:		
Caliche, yellowish-gray	3	130
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; few pebbles and clayballs	22	152

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 16 (8S/21E-13A1)—Continued		
Unit B of older alluviums—Continued		
Silt, sandy and clayey, pale-yellowish-brown	4	156
Sand, medium, pale-yellowish-brown; 15 percent well-rounded gravel	24	180
Sand, medium to coarse, pale-yellowish-brown; few small pebbles and some clayballs	20	200
Sand, medium to coarse, pale-yellowish-brown; 20 percent gravel as much as 1½ in. in diameter; few clayballs	10	210
Sand, medium to coarse, pale-yellowish-brown; cemented streaks	16	226
Sand, medium, pale-yellowish-brown; some clayballs	17	243
Clay, silty, pale-yellowish-brown	2	245
Sand, medium, pale-yellowish-brown, fairly well sorted	14	259
Sand, medium, pale-yellowish-brown, fairly well sorted; 10 percent gravel as much as 3 in. in diameter; some wood fragments and clayballs	19	278
Sand, medium, pale-yellowish-brown; few small pebbles	30	308
Siltstone, pale-yellowish-brown; clayballs	2	310
Sand, fine to coarse, poorly sorted; 10 percent small pebble gravel	17	327
Sand, fine to medium, pale-yellowish-brown, poorly sorted; some clay and silt	12	339
Sand, fine to coarse, pale-yellowish-brown, fairly well sorted	14	355
Sand, medium to coarse, pale-yellowish-brown; 30–40 percent small pebble gravel	35	390
Claystone, pale-brown and pale-yellowish-brown	2	392
Gravel, subrounded to well-rounded, pebble and cobble gravel; 40 percent sand	23	415
Sand, medium to coarse, pale-yellowish-brown; 10 percent gravel; few clayballs containing wood fragments	6	421
Gravel, subrounded to rounded, pebble and cobble; 30 percent sand	9	430
Sand, medium to coarse, pale-yellowish-brown; 35 percent gravel as much as 4 in. in diameter; few clayballs	15	445
Bouse Formation:		
Sand, medium, pale-yellowish-brown, fairly well sorted; few small pebbles	18	463
Clay, greenish-gray	2	465
Sand, fine, silty, pale-yellowish-brown	40	505
Sand, medium, pale-yellowish-brown; few pebbles and clayballs	10	515
Sand, medium to coarse, pale-yellowish-brown	10	525
Sand, fine to medium, pale-yellowish-brown; few clayballs and small pebbles	10	535

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Well LCRP 16 (8S/21E-13A1)—Continued		
Bouse Formation—Continued		
Sand, fine to medium, pale-yellowish-brown; large light-olive-gray clayballs and shell fragments	10	545
Sand, fine, pale-yellowish-brown; clayballs	5	550
Clay, light-olive-gray and light-gray	2	552
Sand, fine, pale-yellowish-brown, poorly sorted; shell fragments	8	560
Sand, fine, silty, pale-yellowish-brown, poorly sorted; light-olive-gray and light-gray clay; shell fragments	30	590
Clay, light-olive-gray and light-gray; some silt and fine sand	35	625
Clay, light-olive-gray; light-gray silt and fine sand	10	635
Clay, light-olive-gray; light-gray silt and fine sand; light-brown clay and fine sand	5	640
Clay, light-olive-gray; light-gray silt and fine sand; wood fragments in sand	5	645
Clay, light-olive-gray; light-gray silt and fine sand	30	675
Clay, light-olive-gray; light-gray silt and fine sand; light-brown clay and fine sand	10	685
Clay, light-olive-gray; light-gray silt and fine sand	55	740
Sand, fine, silty, light-gray; fossils	10	750
Clay, light-olive-gray; light-gray silt and fine sand	50	800
Weeks well 6S/22E-15Q1		
[NE¼SW¼SE¼ sec. 15, T. 6 S., R. 22 E., San Bernardino base line and meridian]		
Colorado River alluvium:		
Sand, fine, silty, grayish-orange; caliche nodules	9	9
Sand, medium to coarse, grayish-orange; cemented streaks; subangular to subrounded gravel; few clayballs	37	46
Sand, fine to medium, grayish-orange; some light-brown clay	17	63
Sand, medium to coarse, grayish-orange; 5–10 percent well-rounded gravel as much as 6 in. in diameter; light-brown clayballs	29	92
Gravel as much as 7 in. in diameter, subrounded to well-rounded; with 20–40 percent sand; 1 moderate-reddish-brown clayball; few light-brown clayballs	21	113
Sand, medium, grayish-orange; some granules and small pebbles; clayballs; cemented streaks	196	309
Sand, medium, light-gray; few gravels as much as 1½ in. in diameter; clayballs	20	329
Sand, medium, light-gray; 30 percent gravel as much as 1½ in. in diameter; clayballs	12	341

TABLE 14.—*Lithologic logs of wells*—Continued

	Thickness (feet)	Depth (feet)
Weeks well 6S/22E-15Q1—Continued		
Colorado River alluvium—Continued		
Gravel as much as 3 in. in diameter, subangular to subrounded, few well-rounded; 30 percent sand; 1-in. diameter clayballs	16	357
Sand, medium, light-gray; 30 percent caliche nodules as much as 2 in. in diameter; some gravel as much as ½ in. in diameter	12	369
Sand, medium, light-gray; few well-rounded pebbles as much as 1 in. in diameter; few caliche nodules	16	385
Sand, medium, light-gray; 40 percent caliche nodules	4	389
Sand, fine to medium, light-gray; some caliche nodules; some small pebbles	36	425
Sand, medium to coarse, light-gray; 30 percent small pebble and granule gravel	12	437
Sand, medium, light-gray; few small pebbles and clayballs	83	520
Gravel as much as 4 in. in diameter, subangular to well-rounded; 25 percent sand	29	549
Sand, medium to coarse, light-gray; 10 percent gravel; few clayballs	5	554
Gravel, subangular to well-rounded; 40 percent sand	19	573
Sand, medium to coarse, light-gray; 10 percent gravel; few clayballs	4	577
Gravel as much as 4 in. in diameter, mostly small pebble; 40 percent sand	8	585

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