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WATER RESOURCES OF LOWER COLORADO RIVER–SALTON SEA AREA

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# GEOHYDROLOGY OF THE YUMA AREA, ARIZONA AND CALIFORNIA

By F. H. Olmsted, O. J. Loeltz, and Burdge Irelan

## ABSTRACT

The Yuma area includes the upstream part of the Colorado River delta within the United States, in one of the driest desert regions of North America. Except for very minor irrigation by the Indians and the Spanish before about 1850, irrigation with Colorado River water began in the late 19th century. By 1966, about 100,000 acres was being irrigated, chiefly in the river valleys (flood plains) and on Yuma Mesa (a river terrace). Ground water has been the source of supply only in South Gila Valley east of Yuma and in small areas outside the established irrigation districts in the other river valleys and on Yuma Mesa.

The valley lands were the first to be irrigated, and only a very small acreage was irrigated on Yuma Mesa before 1923. After the middle 1940's the irrigated area on Yuma Mesa expanded rapidly so that by 1966 more than 20,000 acres was under irrigation. About two-thirds to three-fourths of the total of more than 5 million acre-feet of Colorado River water imported for irrigation on the mesa from 1922 through 1966 either went into ground-water storage to build a widespread ground-water mound or induced ground-water movement into the valleys west and north of the mesa. Drainage wells were installed in the 1950's and 1960's in eastern Yuma Valley and in the 1960's in South Gila Valley in order to alleviate drainage problems aggravated by the growth of the ground-water mound.

Irrigation with Colorado River water in Mexicali Valley, the northern part of the Colorado delta in Mexico, began shortly after the turn of the century. By 1955, more than 500,000 acres in the valley was irrigated. This area required more water than the 1.5 million acre-feet of Colorado River water guaranteed annually to Mexico under a 1944 treaty plus the small supplementary supply pumped from private wells. Accordingly, the Mexican Government authorized the drilling of several hundred wells to augment the total supply. Pumpage of ground water increased during the next decade, so that by 1965 nearly 1 million acre-feet was pumped, of which about two-thirds came from Government wells. Ground-water pumpage is now carefully controlled by the Mexican Government, and the total area irrigated with ground water and surface water is restricted to about 415,000 acres—substantially less than the maximum area irrigated in the 1950's.

The Yuma area straddles the dividing line between the Sonoran Desert section and the Salton Trough section of the Basin and Range physiographic province and is characterized geomorphically by low north-northwest-trending mountains separated by much more extensive desert plains through which are cut the present valleys (flood plains) of the Colorado and Gila Rivers. The landforms include seven major types: (1) Mountains and hills, (2) dissected old river deposits, (3) dissected piedmont slopes, (4) undissected piedmont slopes, (5) river terraces and mesas, (6) sand dunes, and (7) river valleys.

Mountains and hills composed of dense pre-Tertiary crystalline rocks and hard volcanic rocks of Tertiary age form the higher, more rugged exposures; less consolidated sedimentary and volcanic rocks of Tertiary age form the lower, more rounded hills. Some of the mountain blocks are buried or nearly buried by alluvium, particularly those in the southern and western parts of the area.

Dissected old river deposits lie at some distance from the mountains; the chief example of this landform type is the "Upper Mesa," a generally westward-sloping desert plain southeast of Yuma Mesa.

Dissected piedmont slopes characterized by broad desert pavements cut by numerous washes lie along the margins of the hills and mountains.

The undissected piedmont slopes, also near the hills and mountains, are distinguished from the older, dissected piedmont slopes by the general absence of desert pavement and by the shallow depth of incision of the most recent washes.

The river terraces and mesas are remnants of an extensive former valley and delta plain of the Colorado River and its major tributary, the Gila. The surfaces of the terraces and mesas lie about 60–80 feet above the present river valleys except in the extreme western part of the area, where the terrace surfaces slope west or southwest toward the axis of the Salton Trough at gradients steeper than those of the river valleys. Yuma Mesa represents the principal river terrace in the area. Others are Imperial East Mesa, Wellton Mesa, and several distinct smaller terraces that extend upstream along both the Gila and the Colorado Rivers.

Windblown sand is extensive in the Yuma area, although in only two sizable areas has the sand accumulated to form dunes more than 10 feet thick. The larger area, known as the Sand Hills or the "Algodones Dunes," lies northwest of Yuma between the Imperial East Mesa and Pilot Knob Mesa; the smaller tract of dunes—the "Fortuna Dunes"—is in the southeastern part of the area, near the international boundary.

The river valleys (Holocene flood plains of the Colorado and Gila Rivers) were flooded periodically before dams and reservoirs were constructed upstream on both the Colorado

and the Gila Rivers. The principal valleys within the area of intensive investigation are Yuma Valley, "Bard Valley," South Gila Valley, and North Gila Valley.

The earth materials of the Yuma area range from dense crystalline rocks to unconsolidated alluvium and windblown sand. These materials are grouped in 10 generalized stratigraphy units: (1) Crystalline rocks (pre-Tertiary), (2) nonmarine sedimentary rocks (Tertiary) including a new formation, the Kinter, of Miocene age; (3) volcanic rocks (Tertiary) (4) older marine sedimentary rocks (Tertiary), (5) Bouse Formation (Pliocene), (6) transition zone (Pliocene), (7) conglomerate of Chocolate Mountains (Tertiary and Quaternary), (8) older alluvium (Pliocene and Pleistocene), (9) younger alluvium (Quaternary), and (10) windblown sand (Quaternary).

The crystalline rocks, which form a large part of the mountains and hills and unconformably underlie the Tertiary and Quaternary rocks, comprise a wide variety of metamorphic, plutonic, and dike rocks, of which granite and quartz monzonite and various kinds of gneiss and schist are the most abundant. The ages of most of these rocks have not been established, although all of them appear to antedate the Laramide orogeny (Late Cretaceous to early Tertiary).

The nonmarine sedimentary rocks (Tertiary) consist of strongly to weakly indurated clastic rocks ranging from mudstone and shale, in part of lacustrine origin, to megabreccia and boulder conglomerate. For the purpose of this report all these rocks are grouped in one major unit, although detailed mapping in the Laguna Mountains and northernmost Gila Mountains resulted in the delineation of three mappable units: red beds, breccia and conglomerate, and the Kinter Formation (chiefly fanglomerate, with subordinate breccia, arkosic sandstone and mudstone, and tuffaceous beds). Stratigraphic relations with radiometrically dated volcanic rocks indicate that the red beds and the breccia and conglomerate are pre-Miocene; the Kinter Formation is designated Miocene on the basis of a potassium-argon date of 23 $\pm 2$ million years for an interbedded bentonitic ash and of stratigraphic relations with overlying units.

Associated with the nonmarine sedimentary rocks is a suite of volcanic rocks that includes an older andesitic sequence (flows and tuffs), pyroclastic rocks of silicic to intermediate composition ranging from soft pumiceous ash-fall tuff to densely welded ash-flow tuff (ignimbrite), basaltic andesite or basalt of the Chocolate Mountains (a sequence of dark-gray flows and flow breccias), flows and vent tuff of the Laguna Mountains, and scattered masses of basalt or basaltic andesite of uncertain stratigraphic position and age. Potassium-argon dates for several of the volcanic rocks range from about 25 to 26 million years, indicating a probable middle Tertiary age for the unit.

The older marine sedimentary rocks consist of more or less indurated fine sandstone and interbedded gray siltstone and claystone which occur entirely in the subsurface in the Yuma area. Fossils include foraminifers and mollusks indicative of a marine environment but not diagnostic as to age. The age of these beds and their correlation with units of other areas are uncertain, but their stratigraphic position suggests that they probably intertongue with the Kinter Formation in the upper part of the nonmarine sedimentary rocks.

The Bouse Formation, a younger marine unit which probably is unconformable on the older marine sedimentary rocks, includes fossiliferous silt and clay, subordinate fine sand, hard calcareous claystone, and, locally in the basal part, calcareous sandstone or sandy limestone, tuff, and possibly conglomerate of local derivation. The fine-grained clastic beds are predominantly greenish to bluish gray and contain small gastropods, pelecypods, and ostracodes, as well as several species of Foraminifera which indicate brackish to marine environments but are not diagnostic as to age. Other evidence, in part from the Parker-Blythe-Cibola area, indicates a Pliocene age, although a definite assignment within the Pliocene is not yet possible. Except for one small area of exposures 2–3 miles southeast of Imperial Dam, the Bouse Formation occurs entirely in the subsurface in the Yuma area.

Throughout much of the Yuma area, the Bouse Formation is overlain by a transition zone in which marine strata like those of the Bouse alternate or intertongue with nonmarine strata like those in the overlying older alluvium. The transition zone reflects the fact that marine or estuarine conditions did not cease abruptly but recurred at intervals for some time after the ancestral Colorado River entered the area.

The conglomerate of the Chocolate Mountains occurs only in the northern part of the area, on the flanks of the Chocolate Mountains. This unit, which is composed predominantly of volcanic detritus from nearby exposures of Tertiary volcanic rocks, includes strata probably equivalent in age to the upper part of the nonmarine sedimentary rocks (Kinter Formation) but also in part equivalent in age to the lower part of the older alluvium.

The older alluvium is composed of basin-filling fluvial deposits of the Colorado and Gila Rivers and of local ephemeral streams. The unit is actually a complex of alluvial fills separated by unconformities representing degradational cycles that resulted in extensive scouring. It is the most widely exposed unit in the Yuma area and reaches a maximum thickness of more than 2,000 feet in the southwestern part of the area. Its age ranges from Pliocene to late Pleistocene.

The older alluvium comprises a great variety of granular materials ranging from clay to cobble and boulder gravel; sand is predominant at most places. These materials are classified by primary source as deposits of local origin, deposits of the old Colorado and Gila Rivers, and deposits of mixed origin. In addition, relatively thin stream-terrace and piedmont deposits cap the older, thicker fills at many places. The deposits of local origin occupy the margins of the area and consist of poorly sorted, obscurely bedded gravel, sand, silt, and clay which were deposited probably as alluvial fans. The stream–terrace and piedmont deposits are similar to the deposits of local origin, which they cap near the mountains, and are characterized by broad surfaces of so-called desert pavement. The deposits of mixed origin consist of intergradational or intertonguing deposits of local origin and old river deposits. The deposits of the old Colorado and Gila Rivers, which constitute the greatest bulk of the older alluvium, consist of relatively well sorted sand and subordinate silt and clay, at many places containing anastomosing tonguelike and ribbonlike bodies of gravel. The gravel includes abundant well-rounded pebbles and cobbles of siliceous rocks, chiefly quartzite and chert, which appear to have been derived from the Grand Canyon region and even farther upstream.

The younger alluvium comprises all the alluvial deposits of the most recent cycle of deposition. These deposits are classified in three categories according to the dominant agent of deposition: (1) Deposits of the Colorado and Gila Rivers, (2) alluvial-fan deposits, and (3) wash and sheetwash deposits. The river deposits consist predominantly of sand and silt and underlie the present river flood plains; locally a basal gravel may be present at depths exceeding 100 feet. The alluvial-fan deposits, which consist of poorly sorted detritus derived from nearby exposures of granitic rocks, occur only near the southeastern and northwestern corners of the area. The wash deposits are thin, occur in channels cut into the older alluvium and prealluvial rocks, and consist of sand and gravel and thin lenses of silt. The sheet-wash deposits are similar to the wash deposits but occupy broader, less well defined areas.

The windblown sand occurs as dunes, principally in the Sand Hills and in the "Fortuna Dunes," and as relatively thin sheets on Yuma Mesa and "Upper Mesa." Small dunes occur also in Yuma Valley and "Bard Valley." The windblown deposits consist of well-sorted fine to medium sand which is probably derived from nearby sandy alluvium or, for the deposits of the Sand Hills, from old lacustrine or marine beaches.

Structurally, the Yuma area is characterized by north-northwest-trending mountains separated by broader basins filled with Cenozoic deposits possibly as much as 16,000 feet thick in the "Fortuna basin" west of the southern Gila Mountains and Butler Mountains. Some of the mountain masses, especially in the western Sonoran Desert and eastern Salton Trough, are buried or nearly buried by the Cenozoic deposits. Presumably the mountains and basins are separated by faults, but most of the present mountain fronts are fault-line scarps rather than fault scarps; the faults lie basinward and are concealed by alluvial fill.

Early deformational episodes, which were Laramide and probably pre-Laramide (pre-Tertiary), resulted in faulting (including thrust faulting), folding, and metamorphism. In the Sonoran Desert—the eastern part of the Yuma area—structural activity continued into the Tertiary, and by middle Tertiary time the mountains and basins assumed approximately their present configuration. Subsequent deformation has involved only minor warping and normal faulting, probably associated with regional subsidence along the southwest margin, adjacent to the Salton Trough.

In the Salton Trough in the southwestern part of the area, deformation has continued to the present, especially on and near the faults of the San Andreas system. Movement on these faults has involved large right-lateral components as well as apparently sizable vertical displacements. A major fault in this system, herein named the Algodones fault, has been delineated in the present study from topographic, geophysical, and hydrologic evidence. In the southeastern part of the area this fault forms a partial to nearly complete barrier to ground-water movement and is a feature to major hydrologic significance. Other faults, parallel or en echelon to the Algodones fault, have been identified from seismic and temperature data.

The ground-water reservoir consists of two major subdivisions: (1) poorly water-bearing rocks of Tertiary age, and (2) water-bearing deposits of Pliocene to Holocene age. The first subdivision constitutes the lower part of the reservoir and includes (1) the nonmarine sedimentary rocks, (2) the volcanic rocks, (3) the older marine sedimentary rocks, (4) the Bouse Formation, (5) the transition zone, and (6) the conglomerate of the Chocolate Mountains. These units contain some water, but much of it is highly mineralized, and the rocks are too poorly permeable or lie at too great a depth beneath most of the area to be significant sources of ground water. Local exceptions include fresh-water-bearing nonmarine sedimentary rocks, in the northern part of the area, and a conglomerate in the basal part of the Bouse Formation, also in the northern part of the area. (Fresh water is defined herein as water containing not more than 1,800 mg/l (milligrams per liter) of dissolved solids or having a specific conductance of not more than 3,000 micromhos.)

The units of the second subdivision, which form the upper, principal part of the ground-water reservoir, include (1) the older alluvium, (2) the younger alluvium, and (3) the windblown sand. However, beneath the river valleys and Yuma Mesa, the upper part of the reservoir is most conveniently subdivided into three zones, two of which cross stratigraphic boundaries. In ascending order, these zones are (1) the wedge zone (lower, major part of the older alluvium), (2) the coarse-gravel zone (uppermost gravel strata of the older alluvium and possibly a basal gravel of the younger alluvium), (3) the upper, fine-grained zone (uppermost strata of the older alluvium beneath Yuma Mesa, the upper, major part of the younger alluvium beneath the river valleys, and small masses of windblown sand). Outside the river valleys and Yuma Mesa the alluvial deposits (almost entirely older alluvium below the water table) are not subdivided and are classified instead as older alluvium, undivided.

The wedge zone, which extends to depths of about 2,500 feet in the south-central and southwestern parts of the area, constitutes the major part of the fresh-water-bearing deposits of Pliocene to Holocene age beneath the river valleys and Yuha Mesa. The average grain size and probably the average porosity and permeability of the wedge zone decrease with depth. The lower part of the zone contains more silt and clay than the upper part, but in general, the fine-grained strata are not sufficiently extensive or thick to cause significant hydraulic separation. The upper part of the zone locally contains coarse-gravel strata similar to those in the overlying coarse-gravel zone.

Except in two small areas, one beneath the city of Yuma and the other west of the northern Gila Mountains, the water in the wedge zone contains less than 1,800 mg/l dissolved solids. In both areas of more highly mineralized water, the overlying coarse-gravel zone is thin or absent and the wedge zone is thinner and probably less permeable than it is at most other places. In most of the northern part of the Yuma area, water in the wedge zone appears to be substantially fresher than that in the overlying coarse-gravel zone. Beneath the southern part of the area the chemical quality of the water in the wedge zone is virtually indistinguishable from that of the water in the coarse-gravel zone.

Relatively little is known about the chemical quality of the water in the older alluvium, undivided. Some of the water is undoubtedly similar to that in the adjacent wedge zone. Mineralized water in which the dissolved-solids content exceeds 1,800 mg/l exists west of the northern Gila Mountains, beneath "Fortuna Plain" at the southerly international boundary, and possibly between these two places.

The coarse-gravel zone, which is the principal aquifer beneath the river valleys and Yuma Mesa, is a complex of gravel bodies of different ages deposited by the Colorado and Gila Rivers. The zone ranges in thickness from 0 to possibly more than 150 feet; the top lies at an average depth of 100 feet beneath the valleys and 170–180 feet beneath Yuma Mesa in the central part of the area.

Under natural conditions, the Colorado and Gila Rivers were the sources of almost all ground-water recharge in the Yuma area, but with the development of irrigation and the construction of upstream reservoirs on both rivers, irrigation water diverted from the Colorado River became the principal source. Local runoff and precipitation are very minor sources of ground-water recharge.

The chemical regimen of the Colorado River has been materially affected by man's control of the river. Before the impounding of water in Lake Mead in 1935 the chemical composition of the water in the lower reaches of the river was highly variable, both seasonally and annually. Since 1935 the composition has varied much less; during the period 1941–65 the concentration of dissolved solids at Imperial Dam generally was between 700 and 800 mg/l. Sulfate was the major dissolved constituent, and calcium was the most abundant cation, although sodium was slightly more abundant than calcium when the dissolved-solids concentration was highest.

Precipitation and local runoff furnish ground-water recharge of excellent chemical quality. In most places the overall effect of these sources on the quality of ground water is negligible; however, in several places, such as along Fortuna Wash near the northwest margin of the Gila Mountains, fresh ground water derived from storm runoff occurs as a thin lens or lenses not far below and above the water table.

The connate water is likely to be rather highly mineralized; sodium and chloride are the chief ionic constituents.

The coarse-gravel zone and the wedge zone are the principal aquifers in the Yuma area. Subordinate aquifers of only local significance include the nonmarine sedimentary rocks, the conglomerate in the basal part of the Bouse Formation, and a few relatively coarse grained beds in the upper, fine-grained zone. Outside the river valleys and Yuma Mesa, the older alluvium, undivided, is regarded as the principal single, heterogeneous aquifer.

Transmissivity values for the principal aquifers were estimated on the basis of one or more of the following: (1) Step-drawdown tests, (2) short-term pumping tests, (3) specific-capacity data, (4) lithologic logs, (5) electric and sonic logs, and (6) seismic data. The studies of previous investigators also were utilized.

Critical evaluations of the reliability of computed values of transmissivity obtained from pumping tests made during the present investigation indicated that three of the values were within 10 percent of true values, 33 within 25 percent, 27 within 50 percent, and 10 more than 50 percent.

Transmissivity values of the wedge zone generally increase in a southwestward direction from zero along the relatively thin east and north margins of the zone to values of more than 500,000 gpd (gallons per day) per foot beyond a northwestward-trending line about 4 miles southwest of the Algodones fault, where the wedge zone is more than 2,000 feet thick.

Transmissivity values for the coarse-gravel zone range from zero to about 1,000,000 gpd per foot. Maximum values of transmissivity for the coarse-gravel zone occur in the South Gila Valley, south of the confluence of the Colorado and Gila Rivers. Transmissivity values exceed 500,000 gpd per foot beneath The Island, north of the area just cited, and they also persist for about 6 miles southward beneath Yuma Mesa from the area of maximum transmissivity. Transmissivities of more than 500,000 gpd per foot occur also beneath the west edge of Yuma Valley and southwestward from a line 3–5 miles southwest of the Algodones fault, about along the boundary between southern Yuma Mesa and the "Upper Mesa."

Storage characteristics of the material saturated by the large ground-water mound built up beneath Yuma Mesa after 1947 were estimated on the basis of soil-moisture data obtained with a neutron moisture probe lowered into access tubes driven into the zone of saturation. The difference between the moisture content above the capillary fringe and that below the water table was considered to be a valid estimate of the amount of water that would be stored as water levels rose. The storage coefficient at 10 sites in South Gila Valley averaged 38 percent; at six sites in Yuma Valley, 43 percent; and at 10 sites on Yuma Mesa, 28 percent. Storage coefficients for the material penetrated by drainage wells along the east edge of Yuma Valley as computed by earlier investigators ranged from $5.8 \times 10^{-4}$ to $3.6 \times 10^{-3}$ and averaged $1.2 \times 10^{-3}$— values which indicate confined or artesian conditions for at least the periods of the tests. Data for computing storage coefficients under similar conditions were not obtained during the present investigation.

Under natural conditions both the Colorado and the Gila Rivers were losing streams in the Yuma area. Infiltration from these streams was the principal source of ground-water recharge. Much of the infiltration replenished the draft on ground-water supplies caused by evapotranspiration, but some of the infiltration provided a source for the ground water moving out of the area. Movement of ground water through the alluvial section between Pilot Knob and the Cargo Muchacho Mountains under natural conditions was about 4,500 acre-feet per year. The movement of ground water westward from the limitrophe (International Boundary) section of the Colorado River is estimated to have been as much as 110,000 acre-feet per year. As much as 90,000 acre-feet of water that infiltrated from the Colorado River is estimated to have been discharged by evapotranspiration in Yuma Valley.

The Colorado River continued to be a losing stream until the early 1940's, at which time the channel near Yuma was deepened 5 feet or more by erosion, and ground-water levels rose as a result of irrigation and leakage from the All-American Canal. These conditions caused the Colorado above the limitrophe section to change from a losing to a gaining stream. For a distance of 25 miles west of Pilot Knob the ground-water ridge resulting from leakage of the All-American Canal was 30 feet or more high, with the result that the direction of ground-water movement south of the canal changed from westward to southward, and the gradient steepened from that existing under natural conditions.

By 1960 many changes in rates of movement had occurred and the pattern of movement was more complex than it was under natural conditions. In the alluvial section between Pilot Knob and the Cargo Muchacho Mountains the westward flow is estimated to have been only three-eighths of the flow under natural conditions. The westward movement of ground water to Mexicali Valley adjacent to the limitrophe section is estimated to have been 36,000 acre-feet in 1960. This estimate is corroborated by an estimate of

20,000 acre-feet of outflow from Yuma Valley opposite the limitrophe section plus about 15,000 acre-feet for unaccounted depletion of the river in the limitrophe section during periods of low flow. In addition to the outflow from Yuma Valley to the limitrophe section, 7,250 acre-feet of ground water moved northward to the Colorado River and 5,000 acre-feet flowed across the southerly international boundary, making the total ground-water outflow from Yuma Valley about 33,000 acre-feet.

After 1960 the principal changes in ground-water movement were a moderate increase in the size of the ground-water mound beneath Yuma Mesa and a lowering of water levels in Mexicali Valley. Water levels beneath Yuma Mesa continued to rise until 1962, but subsequent to that year, water levels northward and westward from the apex of the mound began a moderate decline, owing to increased pumping for drainage near the toe of the mesa in Yuma and South Gila Valleys. However, water levels continued to rise at greater distances eastward and southward from the apex of the mound. The generally lower water levels in Mexicali Valley resulted from the large-scale pumping for irrigation in that valley. Pumping by private interests for irrigation on Yuma Mesa, which began in 1962, caused only a moderate lowering of water levels through 1966.

Average yearly water budgets for the period 1960–63, inclusive which were prepared for seven subareas designated for the Yuma area, had a net imbalance of 20,000 acre-feet out of a total inflow to the subareas of 1,192,000 acre-feet. The imbalance for individual subareas expressed as a percent of the inflow to the subarea ranged from zero for the Yuma Mesa subarea to about 7 percent for the Reservation and Bard subarea. Consumptive use in the subareas is 488,000 acre-feet, or about 40 percent of the total inflow.

A water budget for the entire Yuma area for the 4-year period 1960–63 shows an imbalance of only 7,000 acre-feet—an imbalance that is well within the limits of accuracy for measuring inflow and outflow, each of which exceeds 6 million acre-feet per year.

During the 1950–65 period the average yearly discharge of ground water to the Colorado River is estimated to have averaged about 21,000 acre-feet in the reach, Imperial Dam to Yuma, and 17,000 acre-feet in the reach, Yuma to northerly international boundary. For the 4-year period 1960–63, comparable estimates are 45,000 and 27,000 acre-feet, respectively.

Two electrical analog models of the hydrologic system of the delta region were constructed during the present investigation for the purpose of verifying the estimates of hydrologic parameters that had been made as the result of geologic and hydrologic studies.

The first model, built in 1964, simulated a single transmissive layer connected to a constant-head surface throughout the flood-plain area in the United States by a vertical-hydraulic-conductivity parameter. It was abandoned because satisfactory correlation between model responses and historical changes was not achieved. However, the study did demonstrate that the model failed to simulate one or more significant hydrologic parameters beneath Yuma Mesa.

Later, a more sophisticated model was constructed. The hydrologic system was simulated as a three-dimensional flow field idealized as two two-dimensional transmissive layers and two layers of solely vertical flow, one of which served as the hydraulic connection between the two two-dimensional transmissive layers and the other as the hydraulic connection to constant-head boundaries. This second model incorporated the newly discovered hydrologic-barrier effects of the Algodones fault and satisfactorily reproduced historical changes in water level.

In the Yuma area, variations in ground-water temperature are useful in corroborating vertical movement of water inferred from other evidence. Also, abnormally high temperatures at some places furnish supporting evidence for the presence of fault barriers or zones of low permeability. At many places, especially on Yuma Mesa, geothermal gradients have been modified greatly from natural conditions, owing to vertical movements of ground water induced by heavy applications of irrigation water or by large-scale pumping from wells. Faults, such as the Algodones fault and the inferred buried faults near the west margins of the Gila Mountains and the "Yuma Hills," have produced warm anomalies which are caused by upward movement of deep water near the fault barriers. Upward movement of warm water along the east margin of Yuma Valley has been accelerated by pumping from drainage wells.

The chemical quality of ground water in the Yuma area varies markedly, both areally and vertically. Differences in chemical characteristics of the recharge from several sources account for part of these variations, but the most important factors appear to be the chemical changes in the ground water that take place as a result of such processes as concentration by evaporation or evapotranspiration, softening by ion exchange, precipitation of insoluble carbonates, sulfate reduction, and hardening by ion exchange. Other processes probably include re-solution of precipitated salts, oxidation of dissolved organic substances, and mixing of waters of different chemical composition.

It is possible to summarize the chemical characteristics of the ground water in the area by regarding it as chemically altered recent Colorado River water, using a hypothetical-model approach in which the river water is assumed to have been evaporated and subjected to the chemical processes cited above. Most of the chemical characteristics of the ground water can be accounted for by these hypotheses, although not all the ground water is actually derived from recent Colorado River water. Among the various processes, concentration by evaporation or evapotranspiration and sulfate reduction appear to be especially important at most places.

The mineral content of the ground water in the coarse-gravel zone in the South Gila Valley and eastern North Gila Valley is greater, on the average, than it is in most other places, the sum of determined constituents generally exceeding 1,800 mg/l. However, information on the preirrigation chemical quality of the water is lacking, so that it is not possible to estimated how much of the present salinity has resulted from long-continued irrigation without drainage. Most of the water is of the sodium chloride type, and the proportions of sodium and chloride tend to increase with increasing dissolved-solids content. Two places, one near the east end of South Gila Valley, the other near the west end, have the most concentrated water, the dissolved-solids content exceeding 3,600 mg/l. The water in the wedge zone is much fresher than that in the coarse-gravel zone, as it generally contains substantially less than 1,800 mg/l dissolved solids.

In "Bard Valley," "Laguna Valley," and western North Gila Valley the water in the coarse-gravel zone appears to contain less than 1,800 mg/l dissolved solids at most places, and the water in the wedge zone is even fresher. The upper, fine-grained zone in these valleys locally contains more highly mineralized water, especially where the water table is shallow.

Water-quality variation is not well defined in most of Yuma Valley because of the sparsity of the data. Variations in the upper, fine-grained zone and the coarse-gravel zone appear to be erratic, although the freshest water—commonly containing less than 900 mg/l—occurs near the Colorado River.

On Yuma Mesa the chemical quality of the ground water beneath the irrigated area has been affected by infiltrated Colorado River water, somewhat concentrated by evapotranspiration. Sulfate is the major anion in most of this water. Outside the irrigated area the ratio of chloride to sulfate is higher, chloride generally exceeding sulfate in equivalent concentration. The dissolved-solids content of the water at most places is less than 1,800 mg/l, except in the area west of the northern Gila Mountains, and beneath the city of Yuma at the northwest corner of the mesa, where somewhat brackish water occurs.

Pumping-test data for five Geological Survey test wells are presented in an appendix. Possible explanations are offered for some of the observed anomalies. The probable large differences that may exist between measured drawdown and drawdown in the aquifers are illustrated by the data collected using different pumping equipment. The movement of water between strata is offered as an explanation for some of the anomalies. The reasons for some of the other anomalies are not known. The practical value of a deep-well current meter for determining the rates at which various strata yield water when a well is pumped is shown. Its value in connection with other geophysical logs for disclosing strata that are still sealed with drilling mud is also indicated.

Soil-moisture data are presented in another appendix. The relation between counting rate and actual soil moisture of material in place for use with the neutron probe and access tubes is difficult to determine for material whose moisture content is half or more of the moisture content of the material when it is saturated. Because of the small variations in absolute specific gravity of the material for which moisture determinations were made, moisture content of saturated material in place was determined on the basis of the bulk density of the material and its absolute specific gravity. The absolute specific gravity of 25 samples of material as determined in the laboratory ranged from 2.66 for a sandy loam to 2.81 for a loamy clay. The absolute specific gravity for 14 samples of sand ranged from 2.66 to 2.70 and averaged 2.68; for five samples of silt, from 2.69 to 2.75 and averaged 2.72; for six samples classified as clay or clayey silt, from 2.72 to 2.81 and averaged 2.76. The relation between counting rate and moisture content for moisture contents of more than 10 percent was interpolated between the relation determined for low moisture content and moisture content when saturated. The soil-moisture studies indicated the need for improved methods of constructing access holes, especially to depths greater than 20 feet. Minor differences in the relation between counting rate and soil moisture were found to be due to differences in the construction of the access holes and in the material used for casing the holes.

# INTRODUCTION

## LOCATION OF AREA

The area investigated is near the downstream end of the Colorado River basin, in one of the driest desert regions in North America. The southwestern part of the Yuma area is within the Salton Trough, a lowland extension of the Gulf of California which includes the delta of the Colorado River; the northeastern part is in the Sonoran Desert, a region of barren, low, generally northwestward-trending ranges separated by extensive desert basins (fig. 1). The city of Yuma, at the confluence of the Colorado and Gila Rivers, is 70 airline miles north of the mouth of the Colorado at the Gulf of California.

## HISTORY OF WATER-RESOURCES DEVELOPMENT

The Yuma area is part of a very arid region where crops are entirely dependent on irrigation for their water supply. The dry climate, with its hot summers, mild winters, and practically yearlong growing season, together with the availability of the Colorado River as a source of water supply, have encouraged the development of intensive irrigated agriculture. Since irrigation began, before the turn of the century, the acreage under cultivation has increased so that, by 1966, about 100,000 acres was being irrigated (fig. 2).

The first irrigation developments were in the river valleys (flood plains of the Colorado and Gila Rivers); the broad river terrace known as Yuma Mesa (fig. 6) was developed later—principally after the end of World War II—when citrus orchards were planted extensively on the favorable sandy soils. The Colorado River has been the source of supply except in the South Gila Valley (fig. 6) and in small areas in the other valleys and on Yuma Mesa, where ground water has been developed by means of wells of generally large capacity.

### YUMA VALLEY

The first irrigation in Yuma Valley (fig. 6) began about 1897. By 1902, four privately owned canal systems were in operation. In 1904, Congress authorized the Yuma Project, the first Federal irrigation project on the main stem of the Colorado River. At that time more than 10,000 acre-feet of water was being diverted annually from the Colorado River by pumps and gravity for irrigation. However, the supply was very undependable owing to the large fluctuations in stage of the river.

Between 1904 and 1912 about 50,000 acre-feet per year was being pumped from the river to irrigate Valley Division (Yuma Valley) lands (fig. 2). In 1912 the Colorado River siphon was completed and thereafter until 1945 water was diverted at Laguna

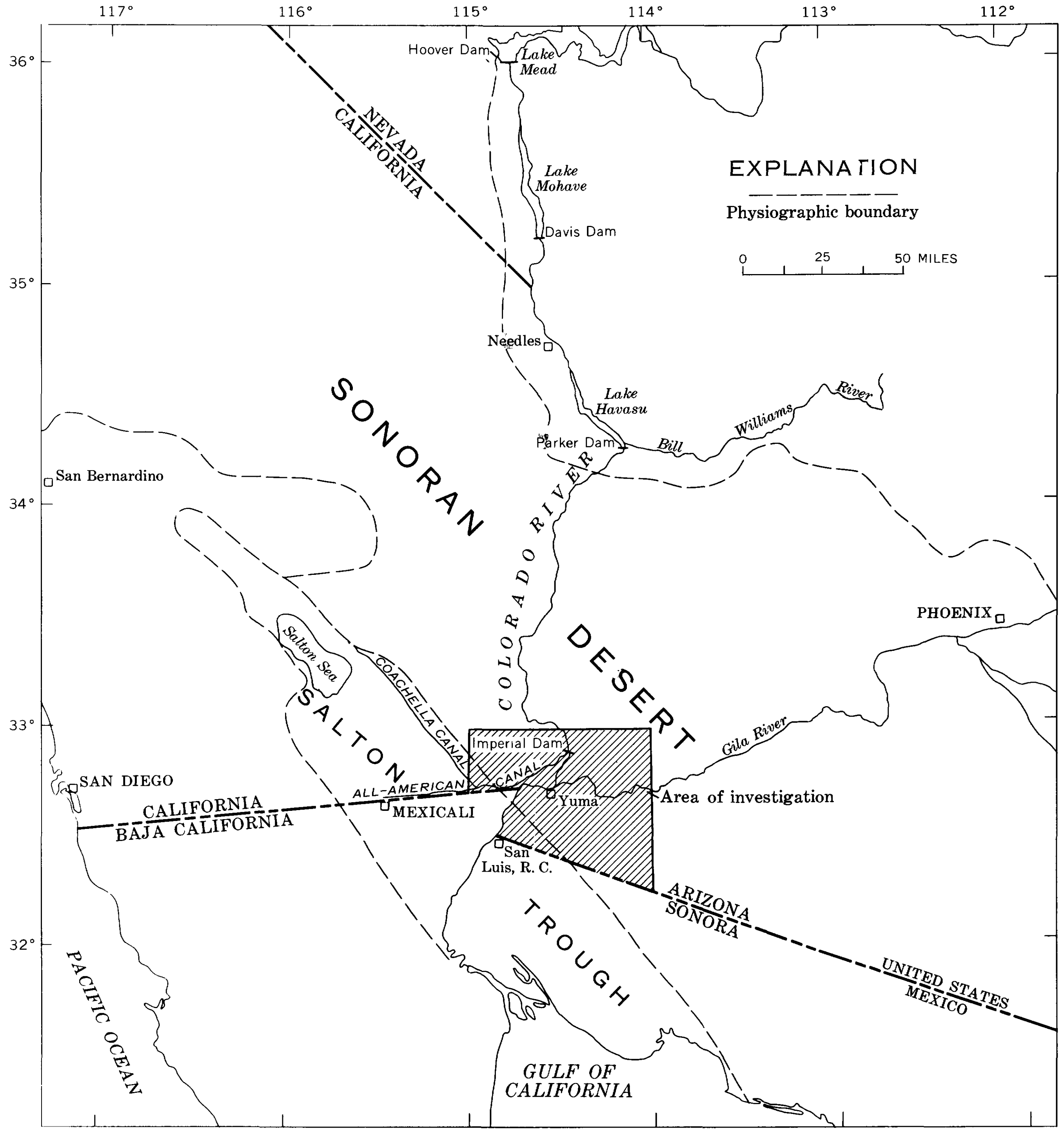


FIGURE 1.—Map of the lower Colorado River region showing location of the Yuma area.

Dam (pl. 3), and it flowed by gravity to the lands of the Valley Division of the Yuma Project.

Continued irrigation resulted in a rise in ground-water levels and consequent drainage problems; construction of gravity drainage ditches began in 1916. The system generally was expanded to meet drainage problems as they arose. The Main Drain (pl. 3) extending southward down the middle of the valley carries the drainage to the southerly international boundary where the boundary pumping plant (fig. 2) lifts the drainage water 12–15 feet and discharges it into Mexico.

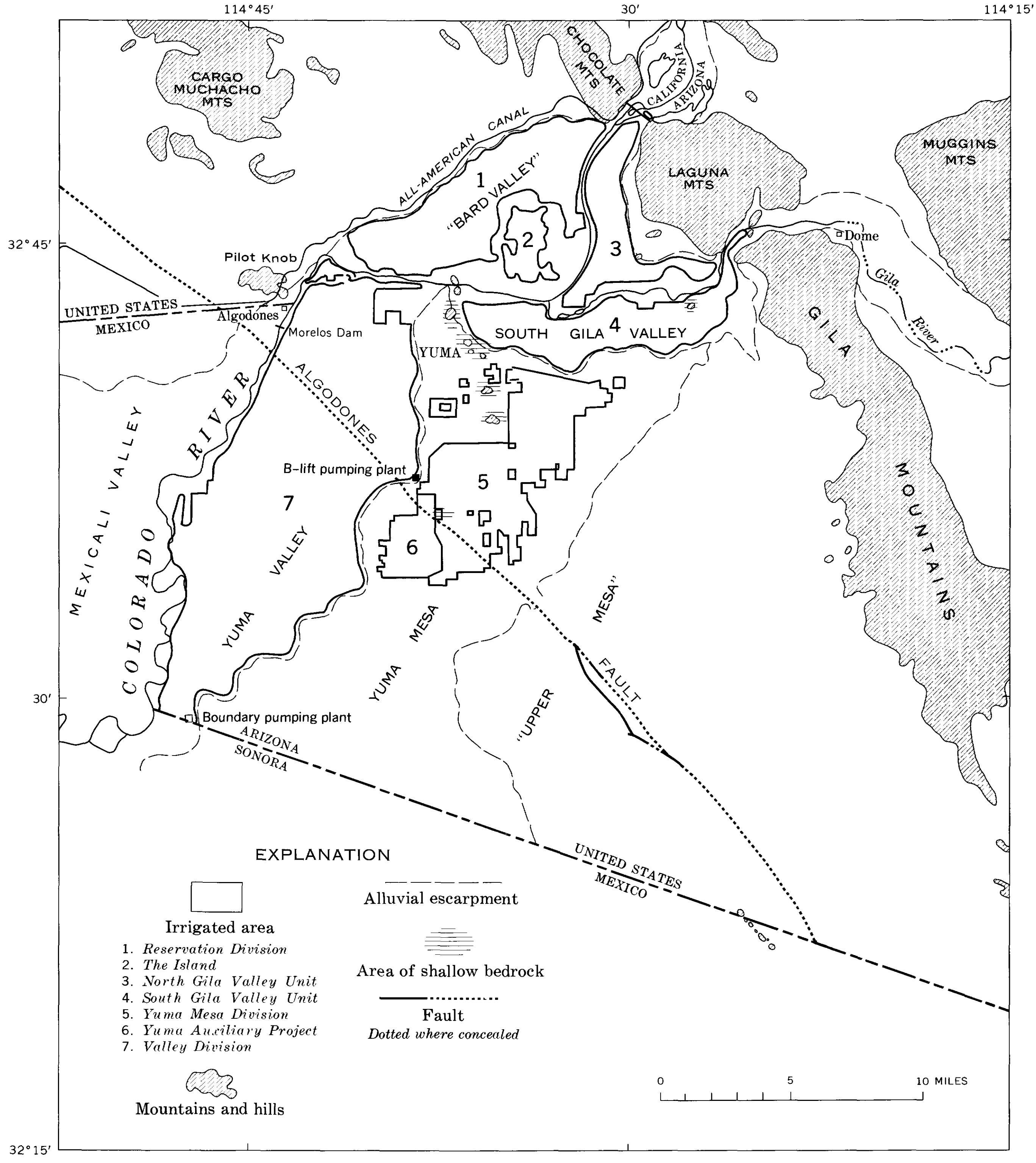


FIGURE 2.—Areas irrigated in 1966.

The yearly pumpage of drainage water at the boundary pumping plant at 5-year intervals is listed in the following table. Much of the increased pumpage after 1945 is derived from drainage wells along the east side of Yuma Valley. The pumpage discharges into the drainage system.

*Drainage water pumped at boundary pumping plant*

[Amounts rounded to nearest 5,000 acre-feet]

| Year | Amount | Year | Amount |
|---|---|---|---|
| 1920 | 20,000 | 1945 | 55,000 |
| 1925 | 50,000 | 1950 | 90,000 |
| 1930 | 45,000 | 1955 | 105,000 |
| 1935 | 25,000 | 1960 | 135,000 |
| 1940 | 65,000 | 1965 | 130,000 |

Between October 1940 and June 1945 diversion of water for the Valley Division lands was shifted from Laguna Dam to Imperial Dam (pl. 3) with its desilting works and thence into the newly completed All-American Canal (fig. 2) from which it was diverted into the Yuma Main Canal (pl. 3). This conveyance plan has remained in effect to the present time.

### YUMA MESA

Only a small acreage was irrigated on Yuma Mesa prior to 1923. Then about 650 acres, an increase of more than 400 acres over that irrigated in 1922, was irrigated by lifting Colorado River water at the B-lift pumping plant (fig. 2) and distributing it to land east of the plant. This development, known as the Yuma Auxiliary Project (fig. 2), was authorized by Congress in 1917. Records of the acreage irrigated and the amount of water diverted under this project are shown in table 1. The B-lift pumping plant was abandoned in July 1953 when water became available to the project from an extension of the Yuma Mesa Division of the Gila Project.

TABLE 1.—*Irrigated acreage and water diverted to Yuma Mesa*[1]

[Diversions in thousands of acre-feet]

| Year | Yuma Auxiliary Project | | Year | Yuma Auxiliary Project | | Yuma Mesa division of Gila Project | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | Acres | Diversions | | Acres | Diversions | Acres | Diversions | Acres | Diversions |
| 1922 | 220 | 1 | 1943 | 1,600 | 20 | 200 | 1 | 1,800 | 21 |
| 1923 | 660 | 7 | 1944 | 1,500 | 17 | 1,000 | 15 | 2,500 | 32 |
| 1924 | 640 | 5 | 1945 | 1,550 | 20 | 5,100 | 55 | 6,650 | 75 |
| 1925 | 540 | 5 | 1946 | 2,100 | 25 | 5,500 | 109 | 7,600 | 134 |
| 1926 | 720 | 3 | 1947 | 1,950 | 33 | 5,900 | 118 | 7,850 | 151 |
| 1927 | 880 | 4 | 1948 | 2,050 | 34 | 6,300 | 124 | 8,350 | 158 |
| 1928 | 1,040 | 6 | 1949 | 2,100 | 33 | 6,300 | 99 | 8,400 | 132 |
| 1929 | 1,160 | 7 | 1950 | 2,150 | 31 | 7,100 | 104 | 9,250 | 135 |
| 1930 | 1,190 | 9 | 1951 | 2,150 | 32 | 8,200 | 138 | 10,350 | 170 |
| 1931 | 1,240 | 8 | 1952 | 2,250 | 33 | 10,400 | 176 | 12,650 | 209 |
| 1932 | 1,260 | 8 | 1953 | 2,100 | 32 | 14,100 | 195 | 16,200 | 227 |
| 1933 | 1,240 | 9 | 1954 | 2,350 | 37 | 14,200 | 235 | 16,550 | 272 |
| 1934 | 1,210 | 10 | 1955 | 2,500 | 35 | 14,600 | 214 | 17,100 | 249 |
| 1935 | 1,220 | 10 | 1956 | 2,600 | 37 | 13,500 | 196 | 16,100 | 233 |
| 1936 | 1,210 | 11 | 1957 | 2,850 | 35 | 14,700 | 187 | 17,550 | 222 |
| 1937 | 1,240 | 12 | 1958 | 2,900 | 37 | 14,200 | 208 | 17,100 | 245 |
| 1938 | 1,260 | 13 | 1959 | 2,950 | 41 | 17,200 | 230 | 20,150 | 271 |
| 1939 | 1,270 | 13 | 1960 | 2,950 | 42 | 16,900 | 253 | 19,850 | 295 |
| 1940 | 1,250 | 14 | 1961 | 3,100 | 42 | 16,000 | 248 | 19,100 | 290 |
| 1941 | 1,250 | 14 | 1962 | 3,150 | 45 | 16,300 | 282 | 19,450 | 327 |
| 1942 | 1,400 | 15 | 1963 | 3,150 | 42 | 16,600 | 275 | 19,750 | 317 |
| ------ | ---- | ---- | 1964 | 3,200 | 40 | 17,100 | 259 | 20,300 | 299 |
| ------ | ---- | ---- | 1965 | 3,200 | 36 | 17,000 | 229 | 20,200 | 265 |
| ------ | ---- | ---- | 1966 | 3,300 | 39 | 16,800 | 236 | 20,100 | 275 |

[1] Quantities (rounded) obtained from U.S. Bureau of Reclamation yearly project history reports.

A substantial increase in irrigated acreage followed the initial development work done under the Yuma Mesa Division of the Gila Project. Under this project water diverted at Imperial Dam into the Gila Gravity Main Canal (pl. 3) is pumped to the mesa at a point about 9 miles east of Yuma. The irrigated acreage increased from about 1,000 acres in 1944 to about 17,000 acres by 1959, after which it stabilized (table 1).

Because the project lands generally were about 90 feet above the water table when development began, drainage of these lands was not an immediate problem. However, the drainage of these lands was of early concern to the ranchers and farmers of the Valley Division, who feared that their existing drainage facilities would be overtaxed by any substantial increase of inflow from the mesa. Consequently, they immediately began to improve and augment their drainage system. Additional drainage wells were drilled near the foot of the mesa escarpment to control the rise of water levels in that area. As a result of this improvement program, very little, if any, land in the valley was lost to agriculture because of waterlogging. Several investigations (p. H16) resulted from the development of the Yuma Mesa Division of the Gila Project (fig. 2). Most of the studies attempted to determine the extent of the adverse effect that the mesa development had on the valley lands adjacent to the mesa. Complete agreement as to the extent of the effects has not yet been reached.

It is generally agreed that two-thirds to three-fourths of the total of more than 5 million acre-feet of water imported for irrigation of mesa land from 1922 through 1966 either went into ground-water storage to build a widespread ground-water mound or induced ground-water movement in the valley lands west and north of the mesa. The distribution of unused irrigation water among these three categories is also controversial.

### OTHER AREAS

The other principal areas where the hydrologic regimen has changed as a result of development are the lands of the Reservation Division, the North Gila Valley Unit of the Yuma Project, and the South Gila Valley Unit of the Gila Project (fig. 2).

The Reservation Division of the Yuma Project generally is that part of the Colorado River flood plain lying north of Yuma and on the right side of the river or on the right side of an abandoned channel of the river where the channel formed the western boundary of The Island (fig. 2). Since the early 1900's the irrigated acreage has ranged from about 5,000 to about 12,000 acres and has averaged about 9,000 acres. About 10,960 acres was irrigated in 1961.

A system of drains, begun in 1912, keeps water levels far enough below the land surface to prevent waterlogging. Leakage from the All-American Canal, beginning about 1939, made necessary the construction of additional drains whose principal function was to remove this leakage and discharge it into the river.

The North Gila Valley Unit, now a part of the Yuma Mesa Division of the Gila Project, lies along the left side of the Colorado River north of its confluence with the Gila River (fig. 2). This unit, too, has had a long history of irrigation with Colorado River water. Since 1955, it has been served from a turnout on the Gila Gravity Main Canal; before that time water was diverted from Laguna Dam. About 6,080 acres was irrigated in 1961.

Water levels rose because of irrigation, so new drains were constructed to keep the land from becoming waterlogged. Leakage from the Gila Gravity Main Canal, which was completed in 1943, added to the drainage problems of the eastern part of the unit.

South Gila Valley lies between Yuma and the narrows of the Gila River near Dome (fig. 2). It is bounded on the north by the Colorado and Gila Rivers and on the south by the Yuma Mesa escarpment. The South Gila Valley Unit is part of the Yuma Mesa Division of the Gila Project. Until 1965, irrigation was dependent largely upon pumping ground water. An exception was the authorization under the Warren Act of 1947 to divert surface water from the Gila Gravity Main Canal onto about 850 acres adjoining the canal.

The first irrigation well in the valley was drilled in 1915. By 1925 about 1,000 acres was being irrigated with ground water; by 1943 the acreage had increased to about 4,500, and by 1948, to almost 9,000 acres. The irrigated acreage increased at a slower rate through the fifties and the first half of the sixties, In 1955, 9,700 acres reportedly was irrigated with pumped water.

In 1965, surface water from the Colorado River became available to all the unit. Drainage wells were installed at the same time to keep water levels from rising to the point where the agricultural lands would become waterlogged. A substantial quantity of ground water continued to be pumped for irrigation.

In contrast to all the other areas, ground-water levels in the developed part of South Gila Valley declined from the levels of the early 1920's, which probably represented natural levels, to the levels of 1946 and 1947, which were 10–15 feet lower. About 1947, levels began to rise, probably owing in part to recharge of leakage from the newly completed Gila Gravity Main Canal and in part to lessened outflow to Yuma Mesa because of the growing ground-water mound beneath the mesa.

As the ground-water mound continued to grow, the historic southward gradient in South Gila Valley was gradually decreased until in the 1950's it was reversed and became northward. Waterlogging of lands near the mesa was widespread. In 1961 and 1962, nine large-capacity drainage wells were drilled near the foot of the mesa to reclaim the land that had become waterlogged and to prevent further waterlogging as the result of inflow from the mound beneath Yuma Mesa. The wells were drilled to the base of the coarse gravel zone, which is about 200 feet below land surface. The system was successful and was expanded in later years as the need for more drainage became apparent. Also three supply wells were drilled to depths of about 600 feet to obtain water of better quality which was used to augment the surface supply.

### MEXICALI VALLEY

Irrigation with Colorado River water began in Mexicali Valley (fig. 2) about 1901. In 1915 about 40,000 acres was irrigated out of a total valley area of some 700,000 acres. By 1925 about 200,000 acres was irrigated, but in 1932 the total irrigated area was only 70,000 acres. From this low point the irrigated area increased to more than 330,000 acres in 1949, and to about 540,000 acres in 1955.

Realizing that this amount of land would require water in excess of the 1.5 million acre-feet of Colorado River water guaranteed to Mexico annually under the treaty of February 3, 1944, the Mexican Government in late 1955 authorized the drilling of 281 deep wells for augmenting the surface-water supply. In 1957 the Government authorized the drilling of an additional 100 irrigation wells. These wells were in addition to some 230 privately owned irrigation wells which had been drilled by that time. Since 1957, the total number of pumped wells has been limited to 495 upon recommendation of the Ministry of Hydraulic Resources. Notwithstanding the increased pumping for irrigation, the total acreage irrigated was reduced in the early 1960's from the 540,000 acres irrigated in 1955 to about 415,000 acres.

The early history of pumping for irrigation is not well documented. Most of the wells were drilled by United States interests to furnish a supplemental supply to lands normally irrigated with Colorado River water. As early as 1934 a tract of 800 acres near Algodones (fig. 2), at the northeast corner of

Mexicali Valley, was receiving a supplemental supply of ground water.

The history of irrigation pumping can be inferred from records of well completions. Of more than 140 logs of private wells drilled in Mexicali Valley by United States drilling firms (made available to the U.S. Geological Survey by Frank E. Leidendeker of Yuma), only the logs of three large-capacity irrigation wells showed drilling dates prior to 1950; all the other logs showed drilling dates from 1950 to 1957, inclusive, the latter being the year when the well-limiting decree was enacted by the Mexican Government. Because these logs represent about half the privately owned irrigation wells in Mexicali Valley, the completion rate of these wells probably is indicative of the completion rate of all the privately owned irrigation wells.

If this is true, and if it is further assumed that pumpage was proportional to the number of wells drilled, then from 1930 (the first year of record of a large-capacity irrigation well, drilled by Mr. Leidendeker's firm) until 1950 the annual pumpage for irrigation was small relative to the pumpage from private wells in 1957—probably ranging from a few thousand acre-feet in 1930 to a few tens of thousands of acre-feet a year by 1950. From 1950 to 1956 the pumpage probably increased at an annual rate of about 25,000 acre-feet to about 200,000 acre-feet annually by 1956. With the beginning of pumping from Government wells in 1956, the total pumpage increased to about 300,000 acre-feet annually by the end of 1956. With the installation of additional Government wells, the pumpage more than doubled from 1956 to 1957, and thereafter continued to increase, so that by 1965 the pumpage amounted to 940,000 acre-feet. (See table below.)

| Calendar year | Pumpage (1,000 acre-feet) | | |
|---|---|---|---|
| | Private wells | Government wells | All wells |
| 1956 | 200 | 100 | 300 |
| 1957 | [1] 180 | [1] 455 | 635 |
| 1958 | [1] 250 | [1] 310 | 560 |
| 1959 | [1] 175 | [1] 460 | 635 |
| 1960 | [1] 230 | [1] 470 | 700 |
| 1961 | [1] 185 | [1] 680 | 865 |
| 1962 | ---- | ---- | 845 |
| 1963 | ---- | ---- | 845 |
| 1964 | 225 | 710 | 935 |
| 1965 | 255 | 685 | 940 |

[1] Figure adjusted on basis of ratios of earlier figures of total pumpage furnished by Mexican Government in 1962 to figures for total pumpage furnished by Mexican Government in 1966.

According to Paredes (1963) land irrigated principally with Colorado River water averaged about 256,000 acres during the period 1961 to 1963, inclusive; much of the 1.5 million acre-feet per year of surface water guaranteed to Mexico under the 1944 treaty was applied to this acreage. This implies an average annual diversion rate of 5.9 feet (5.9 acre-ft per acre) for surface water. Paredes (1963) further estimated that land designated as being irrigated principally by water pumped from private wells averaged about 60,000 acres, and that land designated as being irrigated principally by water pumped from Government wells averaged about 100,000 acres. Based on the average total pumpage for each year of the period, the average rate at which pumped water was diverted was 5.3 feet. The average rate of diversion to all the irrigated land (415,000 acres) was 5.6 feet per year for the years 1961 to 1963, inclusive.

In 1964, approximately 49,000 acres were irrigated with water pumped from private wells, and 107,000 acres with water from Government wells; in 1965, figures for these same categories are 54,000 and 100,000 acres, respectively (Eduardo Arguelles and Eduardo Paredes, written commun., 1966).

The figures for 1964 and 1965 indicate an average annual rate of pumpage of 4.7 feet from private wells and 6.7 feet from Government wells. A similar lesser rate of pumpage from private wells is indicated by figures furnished by Paredes (1963); his data suggest that pumpage from private wells in the 3-year period ending December 1963 averaged between 3 and 3½ feet annually and that pumpage from Government wells averaged more than 6½ feet annually.

The reason for these apparent differences in withdrawal rates is not known. Part of the difference may be due to the fact that a larger percentage of the pumpage from private wells is basically a supplemental supply than is the pumpage from Government wells. Part of the difference also may be due to pumping some water from Government wells into canals and transferring it to other areas to supplement supplies on land that is designated as being irrigated principally with surface water.

## OBJECTIVES OF PRESENT INVESTIGATION AND SCOPE OF REPORT

This report is one of a series of chapters of Geological Survey Professional Paper 486, on the water resources of the lower Colorado River-Salton Sea area. The broad objectives of the study of the Yuma area were to (1) define the geology sufficiently to delineate the ground-water reservoir or aquifer system, (2) determine the sources of the ground water and the relations between ground water and surface water, (3) define the hydrologic characteristics (transmissivity and storage coefficient) of the aquifer system, (4) determine the movement of ground water in different parts of the area, (5) calculate ground-water budgets for both past and present conditions, and (6) describe the chemical quality of the ground water and relate variations in chemical quality to sources of recharge and to processes of chemical change.

The report is divided into two principal sections: The first section describes the geology, with emphasis on the younger, water-bearing rocks and deposits; the second section describes the various aspects of the ground-water hydrology enumerated above. The geology is described in somewhat greater detail than usual for a report of this type, because relatively little previous detailed geologic investigation had been done in the area. Basic data consisting of well records, well logs, and chemical analyses of ground water, and detailed descriptions of several pumping tests and of soil-moisture measurements, are given in five appendixes at the end of the report.

The investigation, which was under the direction of C. C. McDonald, project hydrologist, was started in 1961 by G. E. Hendrickson and carried on from 1962 to 1968 by the present writers. Other members of the Geological Survey who assisted materially in the investigation were F. J. Frank, G. R. Vaughan, R. H. Westphal, and F. L. Doyle. Geophysical work was done by the Regional Geophysics Branch of the Survey, under the direction of D. R. Mabey. Assistance in well logging, sample analysis, and shallow test drilling was provided by the Hydrologic Laboratory and the Ground-Water Equipment Pool of the Survey, both headquartered at Denver, Colo.

## METHODS OF INVESTIGATION

The study of the geohydrology of the Yuma area included geologic mapping, extensive geophysical exploration and test drilling by the U.S. Geological Survey and the U.S. Bureau of Reclamation, inventory of existing wells and well records, quantitative determinations of aquifer characteristics, calculations of ground-water budgets, and determinations of the chemical character and temperature of water in many wells. Major emphasis was placed on study of the Cenozoic deposits, which contain virtually all the ground water of usable quality, and on the delineation of geologic structures that affect the movement of ground water. Toward the end of the investigation, an electrical analog model was constructed by the Geological Survey which incorporated an idealized geohydrologic framework based on the results of the several types of studies. The various methods of investigation are summarized in the following paragraphs.

### GEOLOGIC MAPPING

The geologic mapping, done chiefly in 1962–65, included detailed coverage of the north-central part of the area: the Laguna Mountains, southeastern Chocolate Mountains, northern Gila Mountains, southeastern Cargo Muchacho Mountains, and intervening piedmont, mesa, and valley areas. Some of this geology is shown on the geologic map of the Laguna Dam 7½-minute quadrangle (Olmsted, 1972). The Cenozoic geology of the northwestern Gila Mountains and adjacent piedmont area was also studied in detail by F. L. Doyle in 1963.

The remainder of the area was covered by a geologic reconnaissance, relying heavily on photogeologic techniques, with field checks along variously spaced traverses, mostly by vehicle. Reconnaissance of the southeastern part of the area was done chiefly by F. J. Frank; that of the northern part, by F. H. Olmsted.

### GEOPHYSICAL EXPLORATION

Geophysical surveys were made beginning in 1963 and continuing into 1967 to obtain subsurface information in support of the geohydrologic investigation. The work, which was done by the Regional Geophysics Branch of the U.S. Geological Survey under the direction of D. R. Mabey, included: (1) a gravity survey of about 900 square miles (most of the area shown on plates 3 and 9), (2) an aeromagnetic survey of an area of about 300 square miles in Yuma Valley and western Yuma Mesa, (3) nine seismic-refraction profiles in the northern part of the area, and (4) 14 resistivity profiles and lines of electrical soundings at several places throughout the area. In addition, four seismic-reflection profiles were made by a commercial firm under contract to the U.S. Bureau of Reclamation.

The gravity and magnetic surveys furnished valuable information about the gross distribution and thickness of the Cenozoic sediments forming the ground-water reservoir. The seismic and resistivity surveys yielded more detailed information on the thickness and structure of sediments along local profiles. Many of the interpretations of the geology in this report are based in part on the geophysical data.

### TEST DRILLING

Test drilling by the U.S. Geological Survey and the U.S. Bureau of Reclamation provided the primary basis for the interpretation of the subsurface geology and hydrology. For shallow-depth information, 134 test holes were bored with a truck-mounted power auger to depths ranging from 4 feet to more than 200 feet (fig. 3). Most of these test holes were completed as observation wells with 1¼-inch or 1½-inch pipes fitted with well points. Similar shallow wells were installed in the 1940's and

FIGURE 3.—Boring a test well with a power auger, 3½ miles south of Somerton, Ariz.

later by the U.S. Bureau of Reclamation, particularly on Yuma Mesa, where few other well data were available. In addition, more than 100 wells were installed by the Yuma County Water Users' Association in the 1950's by jetting pipes into the upper part of the coarse-gravel zone in Yuma Valley.

Deeper test drilling was done by private contractors for the U.S. Geological Survey (fig. 4) and the U.S. Bureau of Reclamation and by Bureau equipment. Twelve U.S. Geological Survey test wells were drilled to depths ranging from 328 to 2,946 feet; one private well and one U.S. Bureau of Reclamation test well were deepened for additional information. The U.S. Bureau of Reclamation drilled or had drilled about 70 test wells from 1957 to 1967. Depths of these wells range from 64 to 1,427 feet. All these test wells were drilled by either the percussion (cable-tool) method or the mud-rotary method; drill cuttings and a few cores were collected for study; and most of the wells were logged by various wire-line-logging methods. Ten of the U.S. Geological Survey test wells and several of the U.S. Bureau of Reclamation test wells were test pumped for information about transmissivity of the materials and chemical quality and temperature of the water.

### STUDIES OF FORMATION SAMPLES

In addition to megascopic identification of well cuttings made during drilling, several kinds of laboratory analyses of formation samples were made. Heavy-mineral analyses of alluvial sands and

FIGURE 4.—Drilling of test well LCRP 26 with mud-rotary equipment 1½ miles west of Winterhaven, Calif.

X-ray diffraction analyses of clays were made by the Hydrologic Laboratory of the Geological Survey in Denver, Colo. Grain-size analyses were made of samples from several of its test wells by the Bureau of Reclamation. Pebble counts and studies of general lithology of alluvial sands and gravels and a few petrographic studies of older rocks were made by the Geological Survey in Yuma. Also, cuttings from several oil-test wells were examined at the Arizona Bureau of Mines office in Tucson, Ariz., by F. J. Frank and F. H. Olmsted. Paleontological studies of cuttings from marine deposits were made by Mrs. P. B. Smith, Branch of Paleontology and Stratigraphy of the U.S. Geological Survey, in Menlo Park, Calif.

### WIRELINE LOGGING

Wireline logs were used extensively to supplement and refine the information obtained from drillers' logs, geologists' logs, and sample studies. Logs were made of most of the test wells and also of as many private wells and drainage wells as possible. The logs included the following types: Gamma-ray (natural gamma radiation), electric (resistivity and spontaneous potential), temperature, fluid-resistivity, caliper, contact-caliper (microresistivity-caliper), dip, and sonic (acoustic-velocity). Logging was done by three commercial logging companies and by the U.S. Geological Survey and the U.S. Bureau of Reclamation.

### INVENTORY OF EXISTING WELLS AND WELL RECORDS

The bulk of the geologic and hydrologic information about the upper water-yielding zones was provided by records of existing water wells, test wells, and observation wells. These data included descriptions of the wells and their locations, logs, production figures (pumping rates and drawdowns), chemical quality and temperature of the water, and water-level records. Many of these data were obtained from files of the U.S. Bureau of Reclamation, irrigation districts, and other government agencies; other information was obtained from drillers and private individuals during a field canvass of the area. All wells except for a few that had been destroyed were inventoried in the field and their locations plotted on the latest Geological Survey topographic maps. The information thus obtained is summarized in appendix A, tables 16–20; the locations of the wells are shown on plates 13–17.

### QUANTITATIVE DETERMINATIONS OF AQUIFER CHARACTERISTICS

Transmissivity at specific sites was computed on the basis of results of short-term pumping tests of practically all the large-capacity wells in the area. The tests of private wells commonly were limited to observing rates of change of water level during and after pumping periods and to determining specific capacity (yield per unit of waterlevel drawdown). Collection of data was limited to the pumped well because satisfactory observation wells were not available. Observation wells were utilized, however, for a few of the large drainage wells owned by the U.S. Bureau of Reclamation or the Yuma County Water Users' Association.

Step-drawdown and recovery tests were made for all the U.S. Geological Survey test wells that were pumped, for several U.S. Bureau of Reclamation drainage wells, and for a few newly drilled private irrigation wells. In addition to the tests made during the present investigation, previous pumping tests by others were utilized. Especially helpful were pumping tests made by the U.S. Bureau of Reclamation and by the Yuma County Water Users' Association (Jacob, 1960). Where pumping-test data were lacking, transmissivity was computed on the basis of specific capacity or of lithologic logs.

Storage coefficients were determined on the basis of soil moisture as indicated by a neutron probe. Soil-moisture profiles which commonly included both the zone of aeration and the zone of saturation were obtained at some 30 sites. None of the pumping tests during the present investigation provided useful data for computing long-term storage coefficients. As with transmissivity values, the work of earlier investigators was utilized in estimating storage coefficients. Studies by Jacob (1960) were used as a basis for estimating storage coefficients under artesian conditions; these studies were also the basis for estimating values for vertical hydraulic conductivity and leakage (leakance as defined by Jacob).

### CHEMICAL ANALYSES OF GROUND-WATER SAMPLES

Variations in the chemical quality of the ground water were determined primarily by comparisons of analyses of samples obtained during the present investigation; only a few earlier analyses assembled from other sources were used. Samples of water were collected from existing wells equipped with turbine pumps; from test wells by bailing, airlift pumping, or pumping by turbine; and from unused wells and observation wells by airlift pumping, bailing, or sampling with a thief sampler. Many of the wells were sampled several times in order to determine chemical changes occurring with the passage of time.

Most of the chemical analyses listed in the present report (appendix C) made in a field laboratory at Yuma, using rapid analytical methods. A few analyses were made in the U.S. Geological Survey's permanent water-quality laboratory at Albuquerque, N. Mex., using customary procedures. Most of the earlier analyses were obtained from the files or publications of the U.S. Geological Survey, the U.S. Bureau of Reclamation, other Federal or State agencies, or individuals. Some of these analyses were recomputed from originally reported values in order to agree with the format of the U.S. Geological Survey analyses.

The analytical data were supplemented by field observations made with a conductivity meter and by electric logs of test holes.

### MEASUREMENTS OF GROUND-WATER TEMPERATURE

Temperature of ground water was among the data collected in the routine inventory of well information. After the study was underway, it became apparent that water temperatures furnished useful evidence on the sources and movement of the ground water and the nature of the geologic framework through which it moves. Accordingly, a special study was made of vertical, and particularly areal, variations in temperature, using thermistors as well as maximum thermometers and a standard mercury thermometer.

### ANALOG-MODEL STUDIES

Two electrical analog models of the hydrologic system of the delta region (including both the Yuma area and the part of Mexicali Valley where much ground water is pumped for irrigation) were constructed. The first model, begun in 1964, was a relatively simple simulation of the hydrologic system. In 1966 it was replaced by a more complex model which took into account the barrier effect of a fault (Algodones fault) that was not recognized as a barrier to ground-water movement when the first model was built. The second model not only reproduces in generalized form the present and past hydrologic conditions but can be used to predict future changes in directions and rates of ground-water movement and changes in water level under various assumed schemes of ground-water development.

## EARLIER INVESTIGATIONS

### GEOLOGIC STUDIES

Previous geologic studies of the Yuma area consisted primarily of regional geologic reconnaissances by Wilson (1933, 1960) in Arizona and by Morton (1962) in California; more detailed studies of smaller areas such as the study of the Cargo Muchacho Mountains by Henshaw (1942), or of special problems such as the origin of the "Algodones Dunes" by Norris and Norris (1961) and McCoy, Nokleberg, and Norris (1967); and geophysical studies such as those by Biehler, Kovach, and Allen (1964) in the Salton Trough, and of private oil companies (unpub. data) in Yuma Valley and adjacent parts of Yuma Mesa in connection with wildcat drilling in search for oil or gas. The earlier geologic study having the most direct application to ground-water geology, or geohydrology, is that by R. H. Brown and others (1956). In a sense, the present report updates and expands the work of Brown and others (1956), although some of their geologic interpretations are modified substantially herein.

In addition to the reports and data cited above, many papers have dealt with the general region that includes the Yuma area, or have discussed problems that relate to certain aspects of the local geology. Among these are papers describing the geology and geomorphic features of the Salton Trough by J. S. Brown (1920, 1923), Kniffen (1932), MacDougal and others (1914) (a particularly exhaustive treatment), McKee (1939), and Sykes (1914, 1937). Reports describing the sediments of the Colorado River delta include those by Merriam (1965), Merriam and Bandy (1965), and van Andel (1964). The geologic history of the lower Colorado River has long been a subject of much interest and speculation. A few of the papers discussing this problem are those by Longwell (1946, 1954), Lovejoy (1963b), Cooley and Davidson (1963), and McKee, Hamblin, and Damon (1968).

Other papers describing previous work are cited in the section on geology and are listed in the bibliography.

### HYDROLOGIC STUDIES

Most of the hydrologic studies have been made for or by agencies concerned with the management or use of water. The U.S. Bureau of Reclamation not only has collected a large amount of hydrologic data during the years but has made many hydrologic studies to appraise the results of its management practices and the probable results of proposed changes in these practices. The U.S. Bureau of Reclamation report by Sweet (1952), the report on on the water supply of the Lower Colorado River basin (U.S. Bureau Reclamation, 1953), and the report on the Lower Colorado River water salvage and phreatophyte control (U.S. Bureau Reclamation, 1963) were especially helpful in the present study.

In 1956, the U.S. Geological Survey, as a result of a recommendation from the Assistant Commissioner of Reclamation to the Secretary of the Interior, reviewed the problem of high water levels in Yuma Valley and studied the need for additional information to define and control the problem. The results of that study were reported by R. H. Brown and others (1956).

As a result of the preceding study, in September 1956 the Secretary of the Interior entered into a contract with the consulting firm of Tipton and Kalmbach, Inc., and C. E. Jacob, consultant, which called for an investigation of the ground-water and drainage conditions in the Yuma Valley and a study of the relation between these conditions and the irrigation on Yuma Mesa. The report of this investigation (Tipton and Kalmbach, Inc., and Jacob, 1956) was the first attempt to estimate quantitatively the underground flow of water from the Yuma Mesa to the adjacent flood plains.

In 1960, C. E. Jacob, consultant, completed a study for the Yuma County Water Users' Association (Jacob, 1960) for the purpose of obtaining a more accurate inventory of water use on Yuma Mesa and in Yuma Valley and to better evaluate aquifer characteristics.

In 1966, C. E. Jacob, at the request of the Commissioner, United States Section, International Boundary and Water Commission, made additional studies of the ground-water regimen of the Yuma area, which included estimates of the flow of ground water across international boundaries (Jacob, 1966).

## ACKNOWLEDGMENTS

Many agencies, groups, and individuals provided substantial assistance to the U.S. Geological Survey in the present investigation. The U.S. Bureau of Reclamation, Yuma Projects Office, furnished information from its files, did exploratory drilling, contributed financial assistance toward the construction of an electrical analog model, financed two reflection seismic surveys, and worked closely with the writers in all phases of the investigation. Both the United States Section and the Mexican Section of the International Boundary and Water Commission gave freely of information from their files and of their general knowledge of the area. The United States Section also provided funds to assist in the construction of the analog model. The Yuma County Water Users' Association furnished valuable infor-

mation from its files, such as well logs and water-level records, and the results of hydrologic studies.

Several water-well drilling companies and drillers, notably Hamilton and Hood, Arizona Machine and Welding Works, Frank H. Leidendeker, and L. P. Cromer, provided well logs and other pertinent information. Many farmers and other landowners generously permitted access to their lands and wells, furnished various kinds of information, and cooperated in the scheduling of pumping tests. Information such as pumping-test data, well logs, chemical data, and geophysical data was made available from private consultants, including C. E. Jacob and Associates, General Atomic Division of General Dynamics Corp., S. F. Turner and Associates, and Water Development Corp. Radiometric dating of several rock samples was done by the Geochemistry and Petrology Branch of the U.S. Geological Survey; Geochron Laboratories, Inc., of Cambridge, Mass.; and the Geochronology Laboratories of the University of Arizona.

## WELL-NUMBERING SYSTEMS

The well-numbering systems used in this report are based on the rectangular system of land subdivision used by the U.S. Bureau of Land Management. Two systems are used because part of the Yuma area is in California and part is in Arizona.

In the Arizona system, the wells are assigned numbers according to their locations in the land survey based on the Gila and Salt River base line and meridian which divide 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. All wells in the Yuma area are in the southwest quadrant—the C quadrant. For example, the first well inventoried in the NE¼NE¼SW¼ sec. 35, T. 8 S., R. 22 W., is given the number (C–8–22)35caa1. The part of the well number in parentheses indicates the township and range in the southwest quadrant (T. 8 S., R. 22 W.), the digits following the parentheses indicate the section (sec. 35), and the lowercase letters indicate the location within the section (fig. 5, graph A). The first letter (c) indicates the 160-acre tract (SW¼ sec.), the second (a) the 40-acre tract (NE¼SW¼ sec.), and the third (a) the 10-acre tract (NE¼NE¼SW¼ sec.). These tracts are designated counterclockwise beginning in the northeast quarter (fig. 5, graph A). Where more than one well is inventoried within a 10-acre tract, the wells are distinguished by adding consecutive numbers beginning with 1 after the lowercase letters.

In the California system, the wells are assigned numbers according to their locations in the land survey based on the San Bernardino base line and meridian. A modification of the system used by the California Department of Water Resources and by the California District of the Water Resources Division of the U.S. Geological Survey is employed in which the 40-acre tracts are further subdivided into 10-acre and 2½-acre tracts. For example, the second well inventoried in the NE¼SW¼SW¼NE¼ sec. 29, T. 16 S., R. 22 E., is given the number 16S/22E–29Gca2. The part of the well number preceding the slash (16S) indicates the township (T. 16 S.); the number following the slash indicates the range (R. 22 E.); the digits following the en dash indicate the section (sec. 29); the letter (G) following the section number indicates the 40-acre tract within the section (SW¼NE¼); and the lowercase letters (ca) indicate the 10-acre and 2½-acre tracts (NE¼SW¼) according to a subdivision similar to that used in the Arizona system (fig. 5, graph B). Within each 2½-acre tract, the wells are numbered consecutively starting with 1.

A small area in Arizona west of Yuma and south of the Colorado River is subdivided according to the California system. Also, in The Island area north of Yuma, the California system is used in part of what is now Arizona, and the Arizona system is used in part of what is now California. In all these areas, State boundaries have been changed since they were originally established.

In addition to the U.S. land-net well-location systems just described, the location of each well is described according to a system of grid coordinates used by the U.S. Bureau of Reclamation. The Bureau of Reclamation coordinates are based on a zero point located at the Southern Pacific Co. railroad bridge across the Colorado River at Yuma. The grid utilizes section lines of the U.S. Bureau of Land Management net as mileage increments north or south and east or west of the zero point. For example, well (C–8–22)35caa1 has the coordinates 2½S–7½E, which indicate that the well is half a mile south of the section line approximately 2 miles south of the zero point and half a mile east of the section line approximately 7 miles east of the zero point (fig. 5). Coordinates for each well are given to the nearest one-sixteenth of a mile, as measured on the 1:24,000-scale 7½-minute series quadrangles of the U.S. Geological Survey published from 1955 to 1965. In some places these coordinates differ slightly from those assigned earlier by the U.S. Bureau of Reclamation using approximate locations shown on older maps.

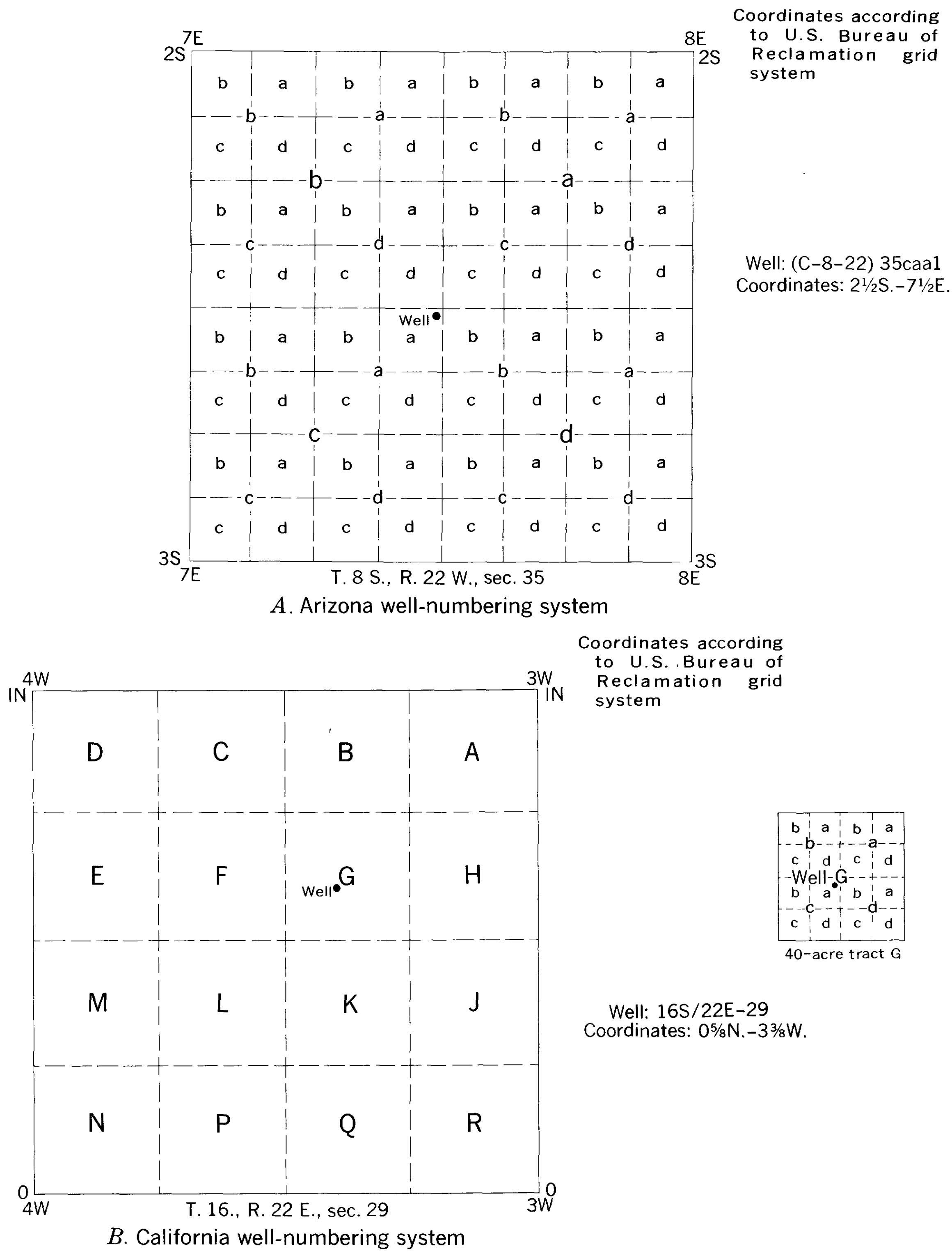


FIGURE 5.—Subdivision of land-net sections for assignment of well numbers and locations of wells by grid coordinates.

## GEOLOGY

### GEOMORPHOLOGY

#### REGIONAL SETTING

The Yuma area includes the upstream part of the delta of the Colorado River, near the downstream end of the Colorado River basin, within the United States. The northeastern part of the area lies within the Sonoran Desert section, the southwestern part within the Salton Trough section of the Basin and Range province, according to the widely adopted physiographic (geomorphic) classification of Fenneman (1931, 1946). (See fig. 1.)

The Sonoran Desert east of Yuma is characterized by generally elongate, low, rugged mountains separated by much more extensive desert plains. Many of the mountains trend about north-northwest (N. 20°–40° W.). The Colorado River flows across the region in an alternating series of narrow valleys or canyons through the mountains and much broader alluvial valleys through the desert plains. The Gila River, which is the principal southern tributary of the Colorado River, flows generally west-southwest across the mountains and desert plains of the Sonoran Desert to join the Colorado just east of Yuma.

The southernmost valley in the Yuma area, Yuma Valley, merges with Mexicali Valley on the west and southwest, the latter broadens southwestward to form the present delta plain of the Colorado River. The delta plain, and some of the low-lying desert plains to the east, lie within the Salton Trough, a northwestward lowland extension of the Gulf of California (fig. 1). The lowest part of the trough is occupied by Salton Sea, a large saline lake, the surface of which was about 232 feet below mean sea level in 1968. The northeast boundary of the Salton Trough section, where it adjoins the Sonoran Desert section, is rather vague geomorphically but may be considered structurally as being formed by the Algodones fault, the major fault of the San Andreas system in the Yuma area. The Salton Trough is bordered on the southwest by the Lower California (or Lower Californian) province (Fenneman, 1931, 1946).

## CLASSIFICATION OF LANDFORMS

Apart from the regional geomorphic classification of Fenneman (1931) just described, the landforms of the Yuma area are divided in this report into seven major types: (1) mountains and hills, (2) dissected old river deposits, (3) dissected piedmont slopes, (4) undissected piedmont slopes, (5) river terraces and mesas, (6) sand dunes, and (7) river valleys. Each landform type occurs in several subareas shown on the geomorphic map (fig. 6); a few subareas include more than one type of landform.

Several subareas have no formal geographic designation and are given informal names from some geographic feature; these informal names are designated by quotation marks. The term "mesa" has been given to some of the terraces, and to other surfaces—some terraced, some not—which stand a few feet to several tens of feet above adjacent valleys and plains. Other subareas have been called "plains," and still another, "desert." This local usage is carried on in the assignment of informal names to some of the subareas; the terms have no geomorphic significance. Several subareas beyond the limits of the principal geohydrologic study were not investigated in detail, and their landforms are described only briefly.

### MOUNTAINS AND HILLS

The mountains and hills are composed of the older, more consolidated rocks of the region—rocks of Tertiary and pre-Tertiary age. The higher, more rugged parts of the ranges consist of dense pre-Tertiary crystalline rocks, or, in places, of hard volcanic rocks of Tertiary age. The lower, more rounded hills are exposures of less consolidated volcanic and nonmarine sedimentary rocks of Tertiary age.

Where the mountains are composed of hard crystalline rocks, the topographic contrast between the mountains and the adjacent desert plains and river valleys generally is abrupt. Slopes of the hard-rock exposures are governed by joints and other physical characteristics of the rocks and are ordinarily much steeper than the slopes in the adjacent unconsolidated deposits of the plains and valleys. Slopes in exposures of metamorphic and plutonic rocks average about 1,000 feet per mile (11°) and locally exceed 4,000 feet per mile (37°). Geophysical data indicate that many buried surfaces of the crystalline rocks are equally steep. Some exposures of hard volcanic rocks—lava flows and beds of welded tuff—are even more rugged than those of the crystalline rocks; nearly vertical cliffs several hundred feet in height occur at several places in the volcanic rocks of the Chocolate and Muggins Mountains.

In contrast, the exposures of slightly to moderately consolidated nonmarine sedimentary rocks and volcanic rocks of Tertiary age are dissected or rounded hills of comparatively gentle slope. Instead of the sharp break in slope characteristic of the margins of the hard-volcanic-rock and crystalline-rock masses, a gradual transition from foothills to piedmont plains occurs where semiconsolidated nonmarine sedimentary rocks or soft volcanic rocks (tuff and ash) border unconsolidated alluvial deposits. Local relief in exposures of Tertiary sedimentary rocks or soft volcanic rocks rarely exceeds 400 feet, whereas that in exposures of crystalline rocks or hard volanic rocks commonly is 1,000 feet or more.

The principal chain of mountains in the Yuma area comprises the Chocolate, Laguna, Gila, Butler, and Tinajas Altas Mountains (fig. 6). This chain

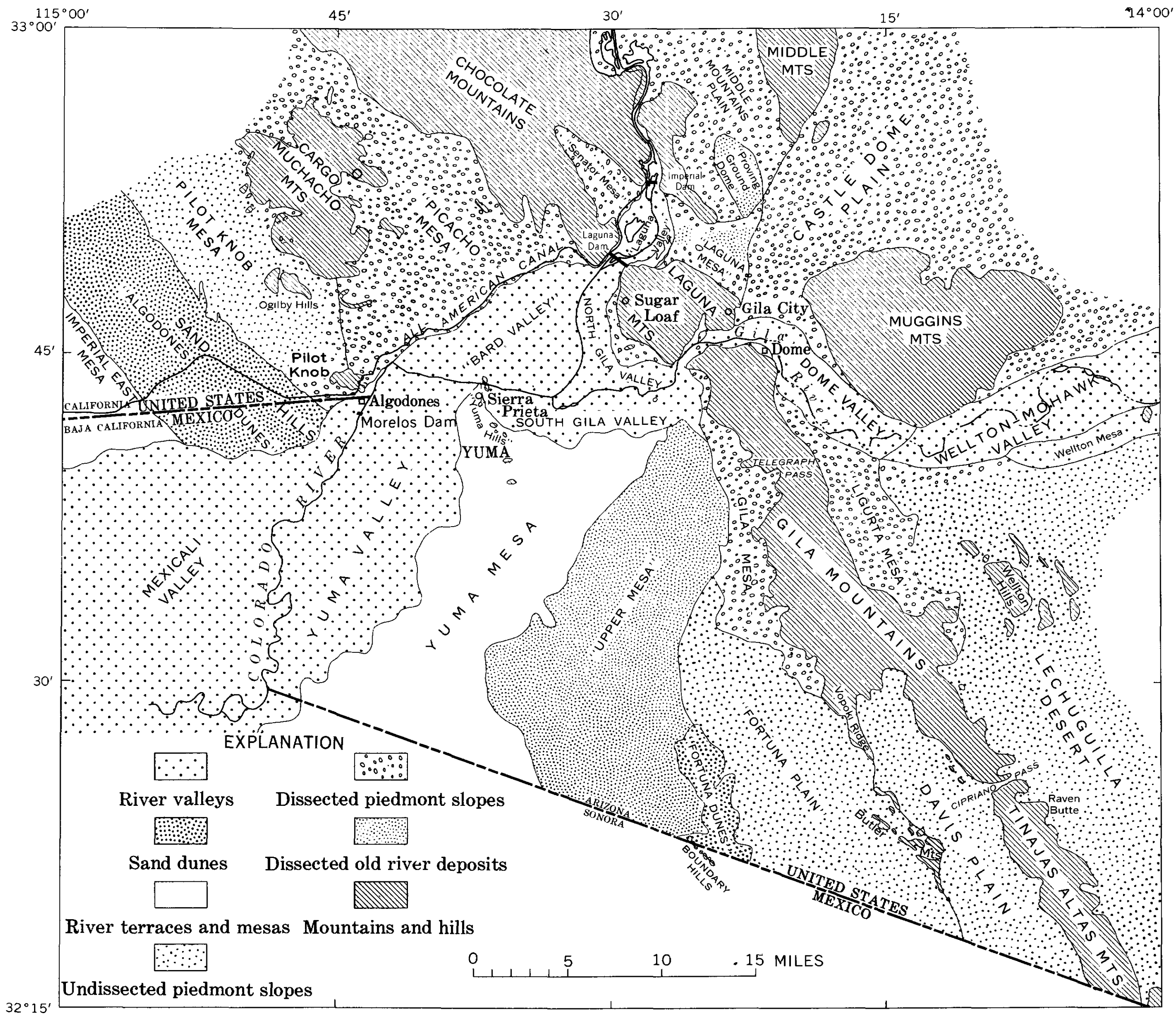


FIGURE 6.—Geomorphic map of the Yuma area.

trends about N. 35° W.—roughly parallel with several other ranges in the Sonoran Desert farther east and forms the northeastern bedrock border of the area of the main geohydrologic investigation.

The Chocolate Mountains, structurally and topographically the most complex of the chain, are largely a series of southwestward-tilted fault blocks of exposed Tertiary volcanic rocks. The higher ridges, which reach altitudes of 1,500 feet in the southwest part, are capped by flows of basaltic andesite or basalt (fig. 7) ; farther east, the lower ridges are of predominantly more silicic pyroclastic rocks. Exposures of pre-Tertiary crystalline rocks, not as extensive as in most of the other mountains of the Yuma area, are relatively low and are chiefly near the southeast end of the mountains, adjacent to Laguna and Imperial Dams. In some of the lower parts of the Chocolate Mountains, dissected hills composed of semiconsolidated sedimentary or volcanic rocks of Tertiary age merge on one side with more rugged exposures of hard volcanic or crystalline rocks, and on the other side, with more gently dissected exposures of late Tertiary and Quaternary alluvial deposits.

The Laguna Mountains occupy a roughly equidimensional area about 6 miles across lying between the Colorado and Gila Rivers. The rugged northern and eastern parts of the mountains are underlain by pre-Tertiary crystalline rocks. The rest of the exposures are chiefly semiconsolidated, coarse-

FIGURE 7.—Westward view of a ridge in the southeastern Chocolate Mountains, Calif. The ridge on the skyline is composed of pre-Tertiary crystalline rocks and Tertiary nonmarine conglomerate and breccia, capped by dark basaltic andesite or basalt. Surfaces in foreground and middle distance are underlain by piedmont gravel deposits of local origin.

grained nonmarine sedimentary rocks of Tertiary age. Sugarloaf, a volcanic knob near the west margin of the mountains about 2 miles south of Laguna Dam, rises to an altitude of 668 feet; the highest point in the eastern exposures of crystalline rocks is the summit designated as Gila City, 1,080 feet above sea level.

The drainage pattern of the Laguna Mountains is roughly radial. The northwestward-trending ridges characteristic of the Chocolate Mountains to the northwest are absent. Along the southwest margin of the Laguna Mountains, the dissected hills underlain by Tertiary nonmarine sedimentary rocks are flanked by only slightly less dissected exposures of gravelly alluvium of local origin, which in turn are bordered by southwestward-sloping alluvial terraces.

The Gila Mountains are fairly straight and elongate, trend north-northwest, and are about 27 miles long by 2–7 miles wide. Toward the south, the mountains divide into two ridges about 5 miles apart; farther south, the eastern ridge becomes the Tinajas Altas Mountains, and the western ridge (Vopoki Ridge) becomes the Butler Mountains (fig. 6).

The Gila Mountains contain some of the most rugged topography in the Yuma area. Only at the north end, and in a small area west of Telegraph

Pass, are there significant exposures of Tertiary nonmarine sedimentary rocks with their characteristic smoothly dissected hilly outcrop forms; the bulk of the range consists of much steeper, more jagged exposures of pre-Tertiary crystalline rocks (gneiss, schist, and granitic rocks). Local relief is greater than 2,000 feet in the southeastern part of the mountains, which attain a maximum altitude of 3,150 feet above sea level. The central and northwestern parts of the range are not as high; the highest summits are about 2,700 feet in the central part, south of Telegraph Pass, and 1,500–1,700 feet northwest of Telegraph Pass.

The Butler Mountains consist of low ridges of pre-Tertiary crystalline rock (granite). The granite outcrops are crudely linear in plan, and oriented about N. 30°–50° W. They are nearly buried by rock waste (local alluvium) that forms the piedmont slope along the southwest flank of the Tinajas Altas Mountains to the east (Davis Plain). The ridges rise to a maximum of only 400 feet above the plain, but their slopes are as steep as most of the slopes in the higher mountains to the north and east.

The Tinajas Altas Mountains are separated from the southeastern Gila Mountains by a low alluvium-filled gap known as Cipriano Pass. The highest peak has an altitude of 2,764 feet above sea level—about 1,700 feet above the adjacent desert plains. Except for Raven Butte, the mountains are composed entirely of buff-weathering, light-gray granite—the same as that in the Butler Mountains and the southern Gila Mountains. Raven Butte, near the north end of the mountains on their east flank, is a double-crested mass of nearly black basalt or basaltic andesite, crudely pentagonal in plan, about 1 mile in diameter, and rising about 700 feet above the Lechuguilla Desert.

The Tinajas Altas Mountains derive their name, Spanish for High Tanks, from the natural tanks near the east base of the mountains. The tanks, which are plunge pools beneath usually dry waterfalls or cascades, have provided water to wildlife, and also to men traveling the historic Camino del Diablo (Devils Road) into Mexico.

Southwest of the mountain chain just described is another, more crudely alined chain of mountains and hills comprising the Cargo Muchacho Mountains, Ogilby Hills, Pilot Knob, "Yuma Hills," and "Boundary Hills." The last two groups of hills are nearly buried by alluvium, and an intervening crystalline-rock mass beneath Yuma Mesa is completely buried. The hills and mountains in this chain not only are less well alined than the mountains to the northeast, they are also separated by substantial gaps in which the alluvial fill attains thicknesses ranging from 1,000 to more than 2,000 feet. Except for the Cargo Muchacho Mountains, they are generally lower than the mountains to the northeast.

The Cargo Muchacho Mountains are an irregular, deeply embayed mass about 10 miles long in a northwest direction by about 6 miles wide. Granitic rocks predominate, but there are sizable exposures of metamorphic rocks and associated dikes in the northern and western parts of the mountains. Several small hills, some of which are capped by basalt or basaltic andesite, lie as much as 2 miles beyond the margins of the main mass. The terrain in the main part of the mountains is rugged, like that in exposures of similar rocks elsewhere in the Yuma area. Highest altitudes are 2,100–2,200 feet—about 1,200 feet above the desert plains at the foot of the mountains. The northeastern part is generally much lower and less rugged than the rest of the mountains; the highest summits in that area are less than 1,200 feet above sea level and some of the intervening bedrock exposures are nearly reduced to pediments.

Two small hill masses 1 to 2 miles south of the Cargo Muchacho Mountains are named the Ogilby Hills from the former settlement of that name on the Southern Pacific Railroad about 2 miles west of the hills. The hills are composed of pre-Tertiary crystalline rocks, capped by basalt or basaltic andesite which forms extensive talus on the slopes.

Pilot Knob, so named because of its use as a landmark during early steamboat navigation on the lower Colorado River, is a low but rugged hill of pre-Tertiary crystalline rocks (chiefly gneiss) rising to an altitude of nearly 900 feet—600–750 feet above the adjacent valleys and desert plains.

"Yuma Hills" is the informal designation applied to a chain of low hills or knobs of pre-Tertiary and Tertiary rocks in and adjacent to Yuma. The Colorado River flows between the northernmost two hills, which are exposures of granite fanglomerate and breccia of Tertiary age (fig. 12). The remaining six outcrops to the south all are coarse-textured porphyritic granite or quartz monzonite similar to that occurring as detritus in the fanglomerate and breccia. The outcrops of granite are about a mile apart and are alined N. 20° W.—roughly parallel with the Gila Mountains to the east. The two hills of fanglomerate are slightly east of the axis of this trend. All the hills are the summits of a nearly buried ridge which is almost completely engulfed by the alluvium of the Colorado and Gila Rivers. The southernmost highest hill is about 320 feet above sea level and 120 feet above Yuma Mesa; the northernmost granite outcrop, known as Sierra Prieta, rises to nearly 300 feet above sea level—160 feet above South Gila Valley to the east and 100 feet above Yuma Mesa to the west.

The seemingly anomalous present position of the Colorado River between the northern two outcrops of Tertiary fanglomerate and breccia probably results from superposition from a higher level, perhaps at a time when the flood plain was the present Yuma Mesa. At that time, the hills of Tertiary rock much have been buried or nearly so. The river presumably exhumed these older rocks as it cut into this old flood plain, then backfilled to its present level. At other times as the river cut down, it flowed north of its present course; young river deposits extend from the northernmost hill of Tertiary rocks about 3½ miles northward to the edge of the flood plain ("Bard Valley").

The "Boundary Hills" consist of a northwest-trending small chain of outcrops of pre-Tertiary crystalline rock (porphyritic granite or quartz monzonite) near the southerly international boundary. Like the "Yuma Hills," these low hills are the tops of a nearly buried ridge projecting only about 100 feet above the adjacent desert plains. The northernmost and largest of the hills attains an altitude of 529 feet above sea level just north of the international boundary; the other hills are in Mexico.

East of the area of principal investigation are the Middle and Muggins Mountains and the Wellton Hills. The Middle Mountains are underlain chiefly by volcanic rocks and are low, rising to a maximum of about 500 feet above the adjacent desert plains. The Muggins Mountains, a notable exception to the narrow, elongate, north-northwest-trending ranges in the southwest part of the Sonoran Desert (fig. 6), are underlain by pre-Tertiary crystalline rocks, hard volcanic rocks (Tertiary?), and nonmarine sedimentary rocks of Tertiary age. The Wellton Hills are a small group of northwestward-trending ridges of gneiss several miles east of the Gila Mountains, rising a maximum of 600 feet above the Lechuguilla Desert.

### DISSECTED OLD RIVER DEPOSITS

Somewhat dissected exposures of predominantly old river alluvium are represented by "Upper Mesa," "Proving Ground Dome," and the central part of "Laguna Mesa" (fig. 6). The old river deposits are at many places blanketed with thin reworked deposits left by local ephemeral streams.

The informally named "Upper Mesa," a generally westward-sloping area between Yuma Mesa and the piedmont surfaces at the west base of the Gila Mountains, is the largest area of dissected old river deposits. The materials underlying "Upper Mesa" are composed of older alluvium of the Colorado and Gila Rivers and admixed alluvium of local origin. Near the land surface at many places are reworked materials deposited by local runoff after heavy storms and modified by wind erosion and deposition. A poorly formed desert pavement is preserved on remnants of some of the older river-formed surfaces but is lacking in most of the mesa. Parts of the mesa lie above intervening broad, shallow, stream-cut depressions, which are mantled with thin deposits of windblown sand and sheet-wash sand and gravel.

The general westward slope of the land surface is interrupted by a northeast-facing escarpment 50–60 feet in height which traverses "Upper Mesa" from "Fortuna Dunes" on the southeast to the edge of Yuma Mesa on the northwest (pl. 1). Southwest of the escarpment the slope of the dissected surface is about 40 feet per mile toward the west-southwest— somewhat steeper than the average slope of the land surface northeast of the escarpment, which is about 30 feet per mile. The drainage from the east is diverted toward the northwest along the foot of the escarpment—an obviously anomalous direction for the mesa as a whole. This unique feature is the trace of the Algodones fault, described in a later section (p. H61), an important member of the well-known San Andreas fault system.

"Proving Ground Dome," partly enclosed within the southern part of "Middle Mountains Plain" in the northeastern part of the Yuma area, is a low dome-shaped hill, roughly ellipsoidal in plan, about 4½ miles long by 2 miles wide. The summit of the hill is 562 feet above sea level, about 100 feet above "Middle Mountains Plain." "Proving Ground Dome" probably is primarily an erosional feature, a remnant of once more extensive Colorado River alluvium which filled the area to a level somewhat higher than the present summit of the dome. (The altitude and form of the dome may result in part from warping, however.) The dome is similar in origin and form to classic desert domes (for example, see Sharp, 1957); but, unlike most desert domes, it is formed on unconsolidated sand, silt, and gravel, rather than on consolidated rocks. Desert pavement, like that on adjacent "Middle Mountains Plain," is absent; instead, a thin colluvium of pebbly sand and silt and eolian sand blankets most of the dome.

"Laguna Mesa," which is south of "Proving Ground Dome," also includes dissected exposures of old river deposits. The mesa is a broad arch sloping westward toward the Colorado River flood plain ("Laguna Valley") and eastward toward Castle Dome Plain from a central area 320–340 feet above sea level.

### DISSECTED PIEDMONT SLOPES

The third and fourth types of landforms in the Yuma area, which occur along the margins of the mountains and hills, are dissected and undissected piedmont slopes. In places, one type grades into the other, but in general, the dissected piedmont slopes represent areas where erosion is the dominant process today and probably has been dominant for at least the past several thousand years. In contrast, undissected piedmont slopes represent areas where either deposition is occurring or a rough balance exists between erosion and deposition.

Many of the dissected piedmont slopes could be classified as dissected pediments under the broad meaning of the term "pediment." However, unlike classic pediments in desert regions, the surfaces are cut chiefly on unconsolidated to semiconsolidated alluvium rather than on consolidated bedrock. The deposits, chiefly coarse grained older alluvium of local origin, are generally mantled with thin stream-terrace and piedmont deposits (gravel).

The dissected piedmont slopes occur in "Picacho Mesa," "Senator Mesa," Middle Mountains Plain," Castle Dome Plain, "Gila Mesa," and "Ligurta Mesa" and in parts of Pilot Knob Mesa and "Laguna Mesa" (fig. 6). In all these subareas, desert pavement is generally conspicuous on the broad gravel surfaces and also conspicuous on the narrow terraces below the main piedmont levels. Several piedmont levels are present at most places. The most extensive of these appears to be graded to the level of Yuma Mesa. The narrow terraces are not paired, are generally adjacent to present washes, and represent abandoned washes left behind as the ephemeral streams cut down to their present levels.

"Picacho Mesa," the broad piedmont between the Cargo Muchacho Mountains and the Chocolate Mountains, is drained by subparallel southeast- to south-trending washes, of which Picacho Wash near the center of the area is the largest. The floors of the washes are incised as much as 80 feet below the adjacent piedmont surfaces near the Colorado River flood plain ("Bard Valley"), but the depths of incision become progressively less toward the northwest (fig. 8). The average slope of the piedmont surface is about 50 to 60 feet per mile. Near its north end, "Picacho Mesa" becomes more intricately dissected and merges gradually with low, hilly exposures of conglomerate of the Chocolate Mountains and nonmarine sedimentary rocks along the southwest flank of the Chocolate Mountains.

"Senator Mesa," on the east side of the Chocolate Mountains, comprises several piedmont and terrace levels, all sloping about 70–120 feet per mile toward the east and southeast. The underlying materials are alluvial gravel deposits of local derivation which thin eastward and southeastward, where they overlie relatively fine grained older Colorado River alluvium.

"Middle Mountains Plain" and the western margin of "Laguna Mesa" are similar in most respects to "Senator Mesa," except that the piedmont surfaces and terraces slope westward rather than eastward or southeastward and generally are not quite as deeply incised as in "Senator Mesa." Average slopes of "Middle Mountains Plain" range from more than 100 feet per mile at the foot of Middle Mountains to about 60 feet per mile near the Colorado River.

Castle Dome Plain, a gently sloping desert surface traversed by a network of shallow washes, slopes southwestward at gradients ranging from 100 feet per mile in the northeast to 45 feet per mile in the southwest. Dark-brown desert pavement is well developed on the surfaces between the present washes, which are generally incised only a few inches to 4 feet below the pavement surfaces, except in the eastern part of the plain, where depth of incision is locally as much as 40 feet. Much of Castle Dome plain is in some respects transitional between the relatively undissected and the dissected piedmont slopes. The chief difference between Castle Dome Plain and the Lechuguilla Desert farther south is the absence of dark desert pavement in the latter area.

"Gila Mesa" and its homolog on the east side of the Gila Mountains, "Ligurta Mesa," include some of the steepest and most deeply dissected piedmont slopes in the Yuma area. Slopes of desert pavement surfaces in the "Ligurta Mesa" area range from 160 feet per mile (1°45′) near the mountains to about 100 feet per mile (1°05′) at the lower ends. In "Gila Mesa," slopes are somewhat flatter (55–120 feet per mile). Both areas contain deeply dissected older alluvial deposits of local origin on which desert pavement is generally lacking (fig. 9). Slopes of ridges in these exposures are as much as 300–350 feet per mile, and near the mountains some of the present washes are incised as much as 150 feet below the ridges.

### UNDISSECTED PIEDMONT SLOPES

The undissected piedmont slopes are distinguished

FIGURE 8.—Dissected piedmont surfaces of reentrant of "Picacho Mesa" in eastern Cargo Muchacho Mountains, Calif. Present wash crosses picture from right to left in foreground. Granitic detritus in this area forms poorly developed desert pavement.

from the older, dissected piedmont slopes by the general absence of desert pavement and by the very shallow depths of incision of the most recent washes. Most of the deposits underlying the undissected piedmont slopes are classified as alluvial-fan deposits (younger alluvium) (pl. 3); these deposits are being aggraded slowly in most places, and in some places, a rough balance appears to exist between aggradation and degradation.

The subareas representing undissected piedmont slopes are the Lechuguilla Desert, Davis Plain, "Fortuna Plain," and part of Pilot Knob Mesa (fig. 6). The first three subareas are adjacent to the southern Gila Mountains and their southerly extensions, the Butler and Tinajas Altas Mountains. Light-colored fairly coarse grained granitic rock predominates in these mountains and furnishes the coarse granitic sand and fine gravel that constitute the alluvial-fan deposits. As mentioned earlier, desert pavement is either poorly developed or absent; moreover, desert varnish has not formed to an appreciable extent on the larger fragments. In part, the absence of varnish may reflect the fact that deposition is the dominant process. However, it probably is also a consequence of the tendency of varnish to form very slowly on the light-colored granitic rocks.

Land-surface slopes in the Lechuguilla Desert, Davis Plain, and "Fortuna Plain" range from 70 to 100 feet per mile at the foot of the mountains to about 40 feet per mile at the lower edges of the piedmonts—substantially flatter than the slopes in the dissected piedmont areas ("Ligurta Mesa" and "Gila Mesa") farther north. Present washes are poorly defined and entrenched only a few inches to

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FIGURE 9.—Northern Gila Mountains from Fortuna Wash. Beyond Fortuna Wash in the foreground are dark desert pavement surfaces; the light-colored exposures in the middle distance, and the somewhat darker smooth exposures near the center of the mountains beyond, are deeply dissected older alluvial deposits (chiefly coarse gravel of local origin). The high, rough exposures are of pre-Tertiary crystalline rocks.

a few feet below the general surface of the piedmont areas. In some areas, particularly in the southern part of the Lechuguilla Desert and in parts of Davis Plain, a distinctive rhomboidal pattern of shallow rills may indicate sheetflooding as the primary geomorphic process.

Except for its southeastern part, where it adjoins "Picacho Mesa," Pilot Knob Mesa consists of a relatively undissected piedmont slope like the areas just described. Also, as in those areas, the detritus beneath Pilot Knob Mesa is largely granitic, sheetflooding probably is common, and the present washes are poorly defined and very shallowly incised. The Southern Pacific Co. has had to protect its railroad tracks from washouts and inundation by a continuous line of revetments having a zigzag pattern, to concentrate the runoff through culverts.

## RIVER TERRACES AND MESAS

The river terraces and mesas are the remnants of former valleys and the delta plain of the Colorado and Gila Rivers. Yuma Mesa, Wellton Mesa, and Imperial East Mesa are the subareas of this type (fig. 6). All these surfaces are nearly flat and lie above the present valleys (flood plains) of the rivers. The old valleys and delta plain were abandoned when the rivers began to cut their present, narrower valleys.

Wellton Mesa and northeastern Yuma Mesa lie respectively 60–70 and 70–80 feet above the adjacent Wellton-Mohawk and South Gila Valleys. Extensive river terraces at similar heights occur farther upstream on both the Colorado and the Gila Rivers. In places—for example at Laguna Dam, Imperial Dam, and the Gila River narrows between the Gila and Laguna Mountains—the terraces are cut on pre-Tertiary crystalline rocks or on Tertiary sedimentary or volcanic rocks. Extensive piedmont surfaces formed by local runoff also are graded to this terrace level (fig. 10).

FIGURE 10.—Terraces in southern Laguna Mountains. The higher of the two prominent levels appears to be graded to the level of the Yuma Mesa terrace 70 to 80 feet above the present flood plains.

The time when the streams were at the level 60–80 feet above the present flood plains is not indicated by direct evidence. However, the terraces may have been formed at the time of the last major higher sea-level stand during the Sangamon Interglaciation. According to Broecker (1966) and Veeh (1966), the last sea-level stand significantly above the present level occurred about 120,000 years ago.

Not all the Yuma Mesa represents the terrace just described. In the southwestern part of the mesa, one or two much-eroded terraces lie below the main surface of the mesa and 30–50 feet above adjacent Yuma Valley. These surfaces may be correlative with similar levels in the piedmont areas.

The general slope of Yuma Mesa is much flatter than that of the "Upper Mesa" to the southeast and not greatly different from the slope of the present river valleys (flood plains). Northeastern Yuma Mesa has a southward gradient of about 2 feet per mile, but farther southwest the slope changes in direction to westward and steepens to about 6–8 feet per mile (pl. 2). The westward slope appears to be chiefly erosional in origin, although in part it results from downwarp along the east margin of the Salton Trough. Farther southwest, in Mexico, westward downwarp causes the mesa surface to intersect the surface of the present river flood plain at a point about 18 miles southwest of San Luis, Rio Colorado.

The Imperial East Mesa is similarly downwarped toward the axis of the Salton Trough, although the direction of tilt may be somewhat different from that of Yuma Mesa. The East Mesa surface has a westward slope of less than 2 feet per mile—substantially flatter than the slope of southwestern Yuma Mesa.

The northeast margin of East Mesa is occupied by an old shoreline, either of an ancestral lake or of an arm of the Gulf of California. In the southeastern part of the mesa the shoreline is about 160 feet above sea level, but 55 miles northwest of the international boundary it is only 70 feet above sea level (Loeltz and others, 1972). This tilt probably results from the westward (or northwestward) downwarp described above. The west margin of the mesa is occupied by another shoreline—that of ancient Lake Cahuilla at about 45 feet above sea level (Stanley, 1962). Unlike the higher, older shoreline, the Lake Cahuilla shoreline is virtually undeformed.

The lacustrine origin of the 45-foot shoreline is unequivocal, but the origin of the higher shoreline is uncertain. Fresh-water shells dated at 37,100± 2,000 years before present have been described from this shoreline (Hubbs and others, 1963, p. 262), but evidence of the barrier across the delta required to contain the lake and exclude the Gulf of California is lacking (Robison, 1965). Unless significant warping has occurred in the Yuma area more recently than indicated by present evidence, remnants of this higher shoreline should be found elsewhere at altitudes similar to those along the southeastern Imperial East Mesa (140–160 feet above sea level). The widespread tufa "gravel" that occurs in the Yuma Mesa and even on parts of the "Upper Mesa" may be indicative of shorelines, but no other evidence has been found in those areas.

Since the time the rivers began to cut their present narrower valleys, the older flood-plain surfaces represented by Wellton, Yuma, and Imperial East Mesas have been modified by erosion and deposition, chiefly by wind but also by water. The southeastern and eastern parts of Yuma Mesa, adjacent to the "Upper Mesa," are occupied by thin blankets of windblown sand, and the areas farther west by broad, wind-scoured depressions. Undrained depressions as much as 10 feet in depth are common in the areas of wind scour and deposition. One particularly large depression (whose origin may not be entirely wind scour), about 15 feet in depth and 2 miles in width, occurs in the northern part of the mesa, just west of the southernmost two outcrops of pre-Tertiary crystalline rocks of the "Yuma Hills" (pl. 2). On the Imperial East Mesa, low dunes are extensive in places; in other places, sand accumulates around the bases of the larger shrubs, particularly the creosote bush (*Larrea tridentata*).

Notwithstanding the modification of the mesa surfaces by wind, traces of old river-formed features remain. On Yuma Mesa, the most noticeable of these features is a low ridge, perhaps a natural levee or channel ridge, which trends southwestward in the south-central part of the mesa (pl. 2).

### SAND DUNES

Although windblown sand is extensive in the Yuma area, in only two sizable areas has the sand accumulated to form dunes more than 10 feet thick. One of these tracts—the Sand Hills, or, as they have been informally designated, the "Algodones Dunes"—is on the northeast side of the Imperial East Mesa, chiefly in California. See also Norris and Norris (1961). The other tract informally called "Fortuna Dunes," is in Arizona, near the southerly international boundary (fig. 6).

The "Algodones Dunes" form an elongate northwest-trending belt about 45 miles long by 6 miles wide on the northeast side of the Imperial East Mesa. The surface on which the dunes rest is continuous with the East Mesa and with the Pilot Knob Mesa to the northeast; this surface is exposed at several places in the southeastern part of the dunes.

The southeastern part of the "Algodones Dunes" comprises three longitudinal belts: (1) A narrow southwestern belt generally less than a mile wide, (2) a main central belt averaging about 2½ miles in width, and (3) a northeastern belt about 2–2½ miles wide. Each belt is characterized by a distinctive type of dune topography.

The southwestern belt is composed of narrow parallel longitudinal ridges. The higher ridges rise 60–100 feet above the East Mesa. Their remarkably straight southwestern edge has led some observers to believe that they are fault controlled, possibly by a branch or parallel branches of the San Andreas fault system. Loeltz, Robison, Irelan, and Olmsted (1972) have shown that the southwest edge of the dunes is adjacent to an old shoreline, of either an ancestral lake created by the Colorado River or an arm of the Gulf of California (p. H27).

The main central belt is composed of high transverse ridges and intervening depressions having a remarkably uniform spacing—the average distance between the ridge crests is about a mile. Smaller barchan crescent or quasi-barchan dunes are superimposed on the general form of the transverse ridges, which rise 150–300 feet above the depressions. According to Norris and Norris (1961), the transverse ridges are related to an earlier wind regime, the barchan dunes to a later one. The southeast, leeward sides of the ridges are linear, steep slip slopes of about 32° inclination—the angle of repose for the dry fine to medium sand. The barchans are on the gentler, windward slopes of the ridges; these dunes are modified in shape during the summer when the prevailing winds are from the south-southeast rather than from the north and west, as they are during the rest of the year (U.S. Weather Bureau unpub. data for Yuma, Ariz.). The depressions between the transverse ridges are generally semicircular in plan, with the straight side on the northwest, and many are scoured free of sand.

The northeastern belt consists of low, irregular dunes and small barchans. The dunes are much lower than the dunes in the other two belts; they range in height from about 5 to 15 feet. They appear to shift and change form more than the other, higher dunes, although no measurements are available to document this general observation.

The informal name "Fortuna Dunes" is given to an area of windblown sand between "Upper Mesa" and "Fortuna Plain," just north of the southerly international boundary. These dunes are merely the northwestern prong of a much more extensive dune area largely in Sonora, Mexico. The thicker sand deposits occur as closely spaced small transverse dunes as much as 30 feet high. The long axes of the dunes are all uniformly oriented N. 60° E., presumably perpendicular to the strongest winds that formed them. It is not known whether the dunes are moving at present.

### RIVER VALLEYS

The river valleys are the Holocene flood plains of the Colorado and Gila Rivers. Most of the flood plains are now farmed and are no longer subject to flooding since dams were constructed upstream and levees built along the Colorado River in the Yuma area. The flood plains are bordered by terraces and other higher desert surfaces into which the rivers cut down before starting the aggradational cycle that produced the present flood plains.

"Laguna Valley" is the informal name given to the flood plain of the Colorado River between Laguna and Imperial Dams. It is the first broad flood plain along the river downstream from the Parker-Blythe-Cibola area. In its present form it is not a natural feature but is a surface of aggradation caused by Laguna Dam, which was constructed in the early 1900's. An estimated 14 feet of aggradation has occurred behind Laguna Dam; the postdam fill probably thins upstream toward Imperial Dam. Most of "Laguna Valley" is occupied by phreatophytes and hydrophytes, and much is covered by shallow water. Mittry Lake (pl. 3) at the southeast edge of the valley is the largest water body.

The flood plain of the Gila River between the town of Wellton (pl. 3) and the site of Mohawk 25 miles to the east is usually referred to as the Wellton-Mohawk Valley. The present channel of the Gila River follows a somewhat meandering course down the valley, which ranges in width from 2 to 4 miles within the area shown in figure 6. The flood plain is bounded by higher lands underlain by older, dissected alluvial deposits. Within the area shown in figure 6, the Wellton-Mohawk Valley slopes westward from an altitude of 255 feet above sea level to 205 feet above sea level in a distance of about 14 miles—an average gradient of about 3½ feet per mile. Like most of the other valleys in the Yuma area, nearly all the area is presently irrigated.

The flood plain of the Gila River between the North and South Gila Valleys and the Wellton-Mohawk Valley is referred to locally as Dome Valley. Dome Valley is somewhat narrower than Wellton-Mohawk Valley and ranges in width from 3 miles near its upper end to less than 1 mile at the lower end, where the Gila River flows between the Gila and Laguna Mountains. The average altitude of the flood plain decreases from 205 feet above sea level at the upper end to 150 feet above sea level at the lower end, in a distance of 15 miles. This gradient—3⅔ feet per mile—is slightly steeper than that of the lower end of Wellton-Mohawk Valley to the east.

The part of the valley of the Colorado River in California downstream from Laguna Dam is informally designated "Bard Valley" from the community of Bard in the upper part of the valley (pl. 3). "Bard Valley" is a broad, flat area, the southeastern part of which was traversed by a meander loop of the Colorado River within historic time. The abandoned meander is now occupied by two oxbow lakes: Haughtelin Lake (pl. 3) and Bard Lake about a mile to the east. Until August 1966, the meander channel formed the disputed boundary between California and Arizona. The area between the present channel of the Colorado River and the abandoned meander is known as The Island. The eastern part of The Island and the adjacent area to the east is covered by a thin sheet of windblown sand and a few low dunes (not shown in fig. 6 but shown on pl. 3).

"Bard Valley" is an unusually flat segment of the Colorado River flood plain. It slopes southwestward from about 140 feet above sea level at Laguna Dam to 125 feet above sea level along the Colorado River west of Yuma—an average gradient of about 1½ feet per mile. The reason for the anomalously flat gradient is not fully understood; the presence of the nearly buried bedrock ridge ("Yuma Hills") near the downstream end of the valley may be a contributing factor.

The North Gila Valley is an L-shaped flood-plain area downstream from Laguna Dam, bounded on the east and north by the Laguna Mountains, on the west by the Colorado River, and on the south by the Gila River. The northern arm of the L is thus the eastern part of the Colorado River flood plain above the confluence of the Gila River; the eastern arm is the northern part of the lower Gila River flood plain. The northern arm is nearly flat, but the eastern arm slopes westward from 160 feet above sea level to 135 feet above sea level at the confluence of the Colorado and Gila Rivers—a gradient of 3⅞ feet per mile.

The South Gila Valley is south of the Gila River and of the Colorado River below the mouth of the Gila River. It extends westward from the Gila Mountains to the nearly buried "Yuma Hills." The valley is about 12 miles long by 2 miles wide and slopes westward at an average gradient of about 3 feet per mile. The valley surface is not perfectly flat but consists of a series of low terraces decreasing in altitude northward toward the Gila River. (Similar terraces occur on the north side of the Gila River in North Gila Valley.) Old meander scars mark the edge of these terraces, the lowest of which is 10–15 feet below the southern margin of the flood plain. In places the form and outline of the terraces have been modified greatly by land leveling for farming and roadbuilding.

The flood plain east of the Colorado River downstream from Yuma is called the Yuma Valley. Yuma Valley is about 19 miles long by 2–9 miles wide. It slopes south-southwestward from 125 feet above sea level west of Yuma to 90 feet above sea level at the southerly international boundary—an average gradient of 1.8 feet per mile.

Small, sinuous sand dunes 5–20 feet high are scattered throughout the central and eastern parts of the valley; these dunes have formed on the leeward (southeast) side of abandoned meanders. Many of these old meander scars can be discerned from the air, even where the land has been farmed intensively for several decades. The soil is sandier and of a lighter color in the old channels than in the adjacent flood plain. The Yuma Main Drain, the principal surface drain in the valley, occupies an old river channel along most of its length.

The present channel of the Colorado River is 15–20 feet below the adjacent flood plain. Much of this cutting occurred since the construction of the upstream dams and the desilting works at Imperial Dam in the 1930's and 1940's, when the sediment load of the river decreased markedly. (See fig. 26.) The terraces along the Gila River in the South and North Gila Valleys may reflect the recent degradation by the Colorado River below Yuma.

The Mexican part of the flood plain of the Colorado River downstream from Pilot Knob is generally called the Mexicali Valley. Mexicali Valley widens toward the south and west; together with Yuma Valley, it forms part of the delta of the Colorado River. The surface form of the delta is that of a large, flat fan having its apex near Pilot Knob and Yuma. The axis trends west-southwestward toward the Cucupas Mountains in Baja California; south of the axis, the surface slopes gradually toward the Gulf of California; to the north, toward the Salton Sea. The lowest point on the axis of the delta, near the Cucupas Mountains, is about 47 feet above sea level (Arnal, 1961). At times during the Holocene and latest Pleistocene, the Colorado River flowed westward rather than southward and maintained large fresh-water lakes about 42–48 feet above sea level north of the delta axis.

The average land-surface gradient along the east side of Mexicali Valley from Pilot Knob to the head of tidewater (Gulf of California) is about 2.2 feet per mile. The river has wandered back and forth across the valley frequently in historic time; because of its meandering course, the gradient of the river itself has averaged only about 1 foot per mile in this reach.

## STRATIGRAPHY

### CLASSIFICATION OF ROCKS

The geologic materials of the Yuma area range from hard, dense crystalline rocks, such as gneiss, schist, and granite, to unconsolidated alluvium and windblown sand. For the purposes of this report these materials are grouped in 10 generalized stratigraphic units. The inferred stratigraphic relations of these units are shown in figure 11, the extent of their outcrops on plate 3, and their probable subsurface extent and configuration on plate 10.

The oldest unit—the crystalline rocks—is separated from the overlying units by a major unconformity (nonconformity); less significant unconformities are present throughout the Tertiary and Quaternary units. The amount of deformation of the various units decreases with decreasing age. Deposits younger than the nonmarine sedimentary rocks and older marine sedimentary rocks of Tertiary age are only broadly warped and locally faulted.

The only fossils diagnostic as to age found within the area mapped in the present investigation were some bones of *Equus* sp. (a horse) and *Odocoileus* sp. (a deer) reported by Bryan (1923, p. 30–31) from a terrace near Ligurta (pl. 3). The bones indicate a Pleistocene age for the enclosing deposits of older alluvium. Lower Miocene vertebrate fossils have been reported from a locality about 10 miles east of the mapped area, in the eastern Muggins Mountains (Lance and Wood, 1958; Lance, 1960). In addition to the scanty fossil data, several radiometric dates have been obtained for material collected in the Yuma area and, together with inferred correlations with units in adjacent regions, have been used to establish the general stratigraphic sequence.

Most of the stratigraphic units (fig. 11 and pls. 3, 10) are useful subdivisions of the ground-water reservoir for describing the occurrence and movement of ground water. However, beneath the river valleys and Yuma Mesa, the alluvial and minor windblown deposits are subdivided into zones that differ in part from the stratigraphic units, as is explained in the section of the report on occurrence of ground water. The different geohydrologic classification of these deposits is required because the boundaries of the water-bearing zones cross the stratigraphic boundaries.

### CRYSTALLINE ROCKS (PRE-TERTIARY)

Crystalline rocks of pre-Tertiary age form a large part of the mountains and underlie the Tertiary and Quaternary rocks throughout the area. The crystalline rocks comprise a wide variety of metamorphic and plutonic rocks. For the purposes of this report all these rocks are grouped in one unit, as they are uniformly devoid of sizable supplies of ground water.

The metamorphic rocks range from weakly metamorphosed sedimentary and volcanic rocks to strongly metamorphosed gneiss and schist. In the Cargo Muchacho Mountains, Henshaw (1942) divided the metamorphic rocks into two formations: the Vitrefrax Formation, composed of quartzite, quartz-sericite schist, kyanite-quartz-sericite schist, sericite schist, biotite-hornblende schist, and a few other less extensive types; and the Tumco Formation, composed largely of feldspar-quartz-biotite-hornblende rock, hornblende schist, and metamorphosed arkose.

Elsewhere in the Yuma area, the metamorphic

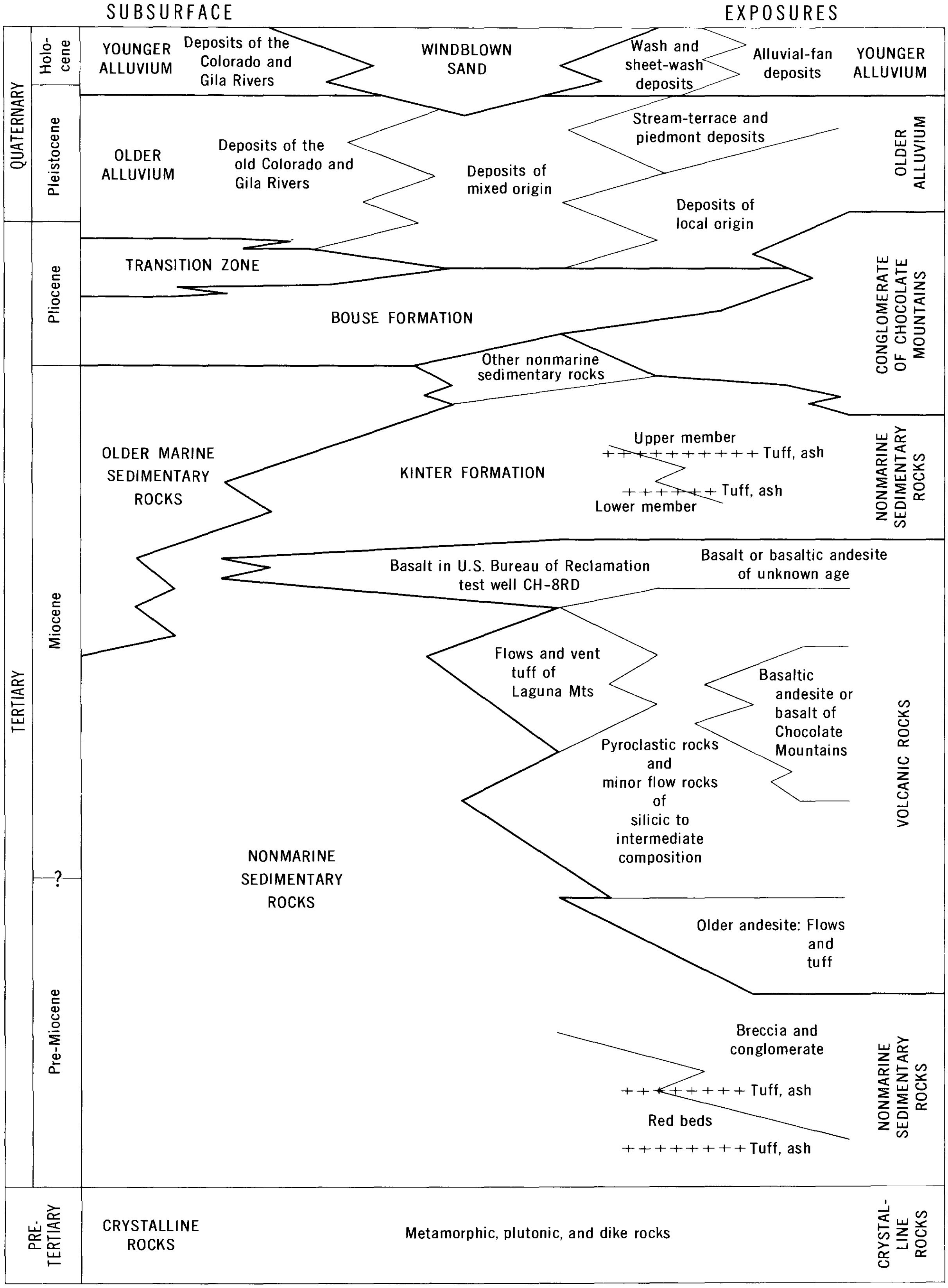


FIGURE 11.—Stratigraphic column.

rocks have not been named, although they have been described in a general way by Wilson (1933) in the Laguna, Gila, Butler, and Tinajas Altas Mountains, and they have been examined briefly in the Chocolate Mountains by F. H. Olmsted. The most extensive types in all these mountains are various kinds of biotite-bearing and hornblende-bearing gneiss, some of which is migmatitic and highly contorted. At the north end of the Gila Mountains, crystalline limestone, not known elsewhere in the Yuma area, is intercalated with schist. Gneiss of granitic to quartz monzonitic composition is abundant in the eastern Laguna Mountains; some of this rock appears to grade into porphyritic granite and quartz monzonite of probable plutonic origin.

In the Chocolate Mountains, a suite of weakly metamorphosed rocks includes slate and phyllite of epiclastic and probable pyroclastic origin, sheared sandstone and arkose, metaconglomerate, sheared tuff breccia, and greenstone derived from mafic lava flows and shallow intrusive bodies. These rocks are similar to the McCoy Mountains Formation of Miller (1944) farther north, with which they may be at least in part correlative. Also present in the Chocolate Mountains are several types of schist similar to the Orocopia Schist of Miller (1944) in the Orocopia Mountains to the northwest.

The plutonic rocks include a wide variety of types, although quartz monzonite and granite are the most extensive. Other plutonic rocks include granodiorite, quartz diorite, diorite, and gabbro. Dikes of aplite, alaskite, pegmatite, and various fine-grained dark rocks, of which distinctive dark-green altered diabase and basalt are most conspicuous, are abundant at many places.

Most of the plutonic rocks clearly intrude metamorphic rocks, but in places the relations of the two types are gradational. For example, in the Cargo Muchacho Mountains, some of the granite appears to grade into meta-arkose, from which it may have been derived (Henshaw, 1942); the gradational relations of some of the gneiss and the porphyritic granite and quartz monzonite in the Laguna Mountains were cited above.

The ages of most of the metamorphic and plutonic rocks in the Yuma area have not been established, although all these rocks appear to be no younger than the Laramide orogeny, which took place during the Late Cretaceous and the early Tertiary (Damon and Mauger, 1966). Some of the youngest plutonic and dike rocks might be of Tertiary age (Wilson, 1933, p. 185; 1960). For convenience, these rocks are grouped with the pre-Tertiary crystalline rocks in this report.

Ironically, the only two radiometric dates, which are for a coarse porphyritic quartz monzonite in Yuma, are widely disparate. Wasserburg and Lanphere (1965) report a rubidium-strontium age of 73 million years for the biotite in a sample obtained in the Highway 95 cut just east of the railroad overpass in Yuma. However, L. T. Silver (written commun., 1968) obtained a uranium-lead age of 1,440 million years for crystals of zircon in the same rock. The zircon age (Precambrian) presumably indicates the time of original crystallization; the biotite age (Late Cretaceous) may reflect a Laramide metamorphic event.

The dated porphyritic quartz monzonite is widespread in the Yuma area and makes up almost all the detritus in some of the breccia and conglomerate of Tertiary age described in a later section (p. H33). The rock is generally coarse grained, contains ovoid to irregular phenocrysts (or porphyroblasts) of white to pale-pink microcline as much as 50 mm (millimeters) in diameter, and smaller grains of plagioclase, quartz, biotite, and minor accessory minerals (chiefly magnetite and zircon). In places the rock is gneissose, and in ancient (pre-Laramide) fault and shear zones it is schistose and locally mylonitic. It is cut by younger plutonic and dike rocks whose ages are unknown. The porphyritic quartz monzonite grades into porphyritic granite and has been found in almost all wells that penetrate the pre-Tertiary crystalline rocks in the Yuma area.

### NONMARINE SEDIMENTARY ROCKS (TERTIARY)

Unconformably overlying the crystalline rocks of pre-Tertiary age is a suite of sedimentary rocks and associated volcanic rocks of Tertiary age. This suite comprises several mappable units, all of which appear to have been deposited before the Colorado River entered the Yuma area. For convenience, all the predominantly nonmarine sedimentary rocks, except conglomerate of volcanic composition in the Chocolate Mountains are included in one major unit, the volcanic rocks in another. Marine sedimentary rocks of Tertiary age comprise two additional units; the younger marine unit is overlain by a transition zone of marine and nonmarine deposits of late Tertiary age (fig. 11). All these other units are discussed in a later section.

The nonmarine sedimentary rocks consist of strongly to weakly indurated clastic rocks ranging from mudstone and shale, in part of lacustrine origin, to megabreccia and boulder conglomerate. Fanglomerate is most abundant, at least in the outcrop areas. Detailed mapping done during the present investigation resulted in the delineation of several mappable units in the Laguna Mountains, southeastern Chocolate Mountains, and northern Gila Mountains. These units, one of which has been named the Kinter Formation, are described briefly in the following paragraphs. Exposures in a critical area in the southeastern Laguna Mountains and northernmost Gila Mountains are shown on plate 4.

#### RED BEDS

The basal part of the nonmarine sedimentary rocks exposed in the Laguna Mountains area is composed of arkose, conglomerate, mudstone, fine-grained tuffaceous beds, and bentonitic ash, all referred to herein as red beds from the predominant color in the exposures near McPhaul Bridge (pl. 4).

The coarser beds are red, brownish red, brown, and yellow and contain subangular to rounded fragments of quartz and feldspar, hornblende, biotite and other heavy minerals, and various kinds of plutonic and metamorphic rocks, including abundant slightly metamorphosed volcanic rocks. These beds are of fluvial origin; the well-rounded character of many of the pebbles indicates transport for a considerable distance, probably by a fairly well integrated drainage system. Tongues of coarse breccia and conglomerate in the upper part of the sequence suggest local high relief and rapid erosion toward the close of deposition of the red beds.

The finer beds, generally more abundant in the lower part of the sequence, are mostly green, pale yellow, or gray and locally contain abundant thin seams of gypsum. These finer grained gypsiferous sediments probably are of lacustrine origin (no marine fossils have been observed) any may indicate the presence of local basins of interior drainage in the early stages of deposition of the red-bed sequence. Intermittent volcanic activity is reflected by the presence of tuffaceous mudstone and a few thin beds of white bentonitic ash.

In the Yuma area, the red beds are exposed only near McPhaul Bridge in the southeastern Laguna Mountains and at the north end of the Gila Mountains (pl. 4). The total exposed thickness in the Laguna Mountains is difficult to estimate because of faulting; probably it is on the order of 2,000–2,500 feet. The subsurface extent and thickness are largely unknown; varicolored sandstone, shale, and conglomerate penetrated between depths of 4,937 and 6,007 feet in oil-test well Colorado Basin Associates Federal 1 may be at least in part correlative with the red beds exposed near McPhaul Bridge.

Beds similar to those near McPhaul Bridge are exposed extensively in the Muggins Mountains 10–20 miles to the east, but fossil and radiometric evidence indicates that the Muggins Mountains beds probably are younger, as discussed on page H37.

#### BRECCIA AND CONGLOMERATE

The uppermost red beds in the southern Laguna Mountains intertongue with a thick sequence of generally coarse grained, poorly sorted breccia and conglomerate. These strata are made up of predominantly angular and subangular fragments of all sizes up to boulders and blocks many feet across in a semiconsolidated matrix of clayey sand and silt. Thin interbeds of arkose, sandy siltstone, and felsic tuff occur locally.

In the Laguna Mountains the lower part of this sequence consists of breccia and conglomerate composed entirely of the distinctive pre-Tertiary porphyritic granite and quartz monzonite and associated dike rocks found in nearby exposures. This monolithologic granite breccia and conglomerate sequence is obscurely bedded and very coarse—blocks as much as 50 feet across have been observed. Some of this material appears to have formed as mudflows, talus, and colluvium, although most of it probably is fanglomerate. Obscure bedding and faults make estimates of thickness uncertain, but probably at least 4,000 feet is exposed in the southern Laguna Mountains. The granite breccia-conglomerate sequence is exposed also in Yuma, where the Colorado River has cut its present channel through a low hill of this material (fig. 12).

The upper part of the breccia-conglomerate sequence is composed of more heterogeneous material but is otherwise similar to the underlying granite breccia and conglomerate. The two types intertongue in the southern Laguna Mountains (pl. 4); in the southeastern Chocolate Mountains, the heterogeneous type predominates. Typically the heterogeneous breccia and conglomerate has an earthy greenish-gray matrix in which are embedded fragments of all sizes as much as many feet across composed chiefly of fine-grained varicolored metasedimentary and metavolcanic rocks. The nearest exposures of similar low-grade metamorphic rocks in the pre-Tertiary crystalline-rock complex are in the Chocolate Mountains near the north edge of plate 3. Maximum exposed thickness of heterogeneous breccia and conglomerate near the southeast end of the Chocolate Mountains is probably more than 5,000 feet, although poorly exposed faults of unknown displacement make this estimate somewhat uncertain.

Both the red beds and the overlying breccia and conglomerate have been moderately deformed; bedding generally dips 30°–60°, most commonly in a

FIGURE 12.—Granite breccia and conglomerate exposed in north bank of Colorado River at Yuma.

westerly or southwesterly direction. Good exposures reveal high-angle reverse, or thrust, faults, as well as low to high-angle normal faults. In the southern Laguna Mountains, pre-Tertiary crystalline rocks in places are in contact with the red beds along high-angle reverse faults.

### KINTER FORMATION

The name Kinter Formation is proposed in this report for a sequence of predominantly coarse grained nonmarine sedimentary rocks and minor intercalated beds of tuff and ash exposed principally in the Laguna Mountains and at the north end of the Gila Mountains. The name is taken from a railroad siding of the Southern Pacific Co. at the north end of the Gila Mountains, along which the formation is typically exposed. The type section, designated *A–B–C* on plate 4, is in secs. 3, 9, 10, and 11, T. 8 S., R. 21 W., Gila and Salt River base line and meridian, directly south of the Wellton-Mohawk Canal, 1.8 miles east to 0.8 of a mile south of McPhaul Bridge, and about 7 miles southeast of Laguna Dam. The Kinter Formation is divided into two unnamed members: the lower, composed of coarse unsorted breccia and tongues of brown and gray arkosic sandstone and gray to pink tuffaceous mudstone and the upper, composed of yellowish-gray conglomerate (fanglomerate) and some soft arkosic sandstone and mudstone. The type section is described below.

*Type section*

| | *Thickness (feet)* |
|---|---|
| Top of section concealed by Quaternary alluvium. | |
| Upper member: | |
| Arkosic sandstone and pebbly sandstone, soft, yellowish-gray (5Y 7/2); interbedded pale-yellowish-brown (10YR 6/2) soft silty sandstone | 280 |
| Mudstone, sandy, moderately hard, obscurely bedded, pale-brown (5YR 6/2); thin interbeds of pale-yellowship-brown (10YR 6/2) very fine to fine-grained sandstone. Mudstone has subconchoidal fractures; contains a few poorly preserved small gastropods | 120 |
| Arkosic, tuffaceous sandstone, soft, yellowish-gray (5Y 7/2; 5Y 8/1) to pinkish-gray (5YR 8/1); lenses of pebbly sandstone containing granules and small pebbles of metamorphic and granitic rocks and pale-pink pumice; a few interbeds of pale-yellowish-brown (10YR 6/2) soft silty sandstone and sandy siltstone | 700 |

| | Thickness (feet) |
|---|---|
| Upper member—Continued | |
| Pumice tuff, soft, pale-pink (5RP 8/2) to pinkish-gray (5YR 8/1) | 5 |
| Arkosic sandstone, soft, yellowish-gray to pinkish-gray; thick, lenticular interbeds of yellowish-gray to gray conglomerate and pebbly sandstone | 120 |
| Conglomerate, obscurely bedded to moderately well bedded, yellowish-gray to gray; composed chiefly of angular to subrounded clasts, as much as 3 ft across, of gneiss, schist, granite, and scattered pumice tuff; thin, lenticular interbeds of yellowish-gray (5Y 7/2; 5Y 8/1) arkosic sandstone. Lower part traversed by vertical fractures filled with grayish-brown sandy clay and silt | 950 |
| Tuffaceous sandstone or sandy tuff, soft, fine- to medium-grained, pinkish-gray (5YR 8/1); lens of conglomerate in upper part | 5 |
| Exposed thickness of upper member | 2,180 |
| Lower member: | |
| Breccia, unsorted, obscurely bedded; contains angular to subangular fragments of metamorphic and granitic rocks as much as 5 ft in diameter in a light-brown (5YR 5/6) earthy matrix | 250 |
| Breccia, earthy, light-brown (5YR 5/6) to pale-olive (10Y 6/2); interbedded gray (N 7) to grayish-orange-pink (10R 8/2) sandy tuff or tuffaceous sand | 40 |
| Breccia, coarse, earthy, greenish-gray (5GY 6/1); crude bedding indicated mainly by alinement of larger slabs of gneiss and schist | 150 |
| Interval poorly exposed; probably similar to material above and below | 450 |
| Breccia, fine to coarse, earthy, obscurely bedded and poorly sorted, light-brown (5YR 5/6), pale-olive (10Y 6/2), and yellowish-gray (5Y 7/2). Larger clasts include tuff as well as metamorphic and granitic rocks | 510 |
| Fault contact with upper member. | |
| Exposed thickness of lower member | 1,400 |
| Total exposed thickness of Kinter Formation | 3,580 |

The two members designated in the type section can be traced northward into the southern Laguna Mountains, but the coarse, unsorted breccia characteristic of the lower member has not been identified in the central and northwestern parts of these mountains. In places in the northern Gila Mountains the lower member contains brown and gray arkosic sandstone and gray to pale-pink tuffaceous mudstone. The sandstone is generally more indurated than that in the upper member. The coarse, unsorted, and virtually unbedded nature of the breccia that constitutes most of the lower member suggests a mudflow origin in a region of strong local relief.

The upper member of the Kinter Formation is generally better sorted than the lower member. In exposures near Dome, east of the type section, conglomerate makes up the entire exposed thickness of the upper member, and in most exposures in the Laguna Mountains, conglomerate seems to predominate over finer grained deposits. The conglomerate (fanglomerate) was deposited on alluvial fans from local sources, as indicated by the angularity of most of the clasts and their similarity to pre-Tertiary rocks presently exposed in the area. The alluvial fans were bounded by flood plains on which were deposited the finer sands and muds.

Both the upper and the lower members of the Kinter Formation contains beds of ash-fall tuff, some of which have been reworked by streams. The most widespread of these beds is a biotite-bearing tuff and altered ash at or near the base of the upper member (fig. 13). This bed is only a few feet thick and is locally missing, probably because of subsequent erosion.

In addition to the extensive outcrops in the Laguna Mountains and northern Gila Mountains, the Kinter Formation is exposed in a narrow belt along the south flank of the hills southeast of Imperial Dam and also in the southwestern Chocolate Mountains just northeast of "Picacho Mesa." Probable equivalents occur on the east side of the Chocolate Mountains as well, but these last exposures (mapped as conglomerate of Chocolate Mountains) consist chiefly of conglomerate composed of volcanic detritus rather than the predominantly metamorphic and granitic clasts typical of the Kinter.

In the subsurface the Kinter Formation appears to have been penetrated in several test wells where it underlies fine-grained marine deposits of the Bouse Formation. The contact probably is an angular unconformity, at least near the mountain blocks on the margins of the basins, as indicated by the discordance of several degrees observed in exposures southeast of Imperial Dam and by the relatively mild deformation of the Bouse Formation at most places in the subsurface (fig. 15). Metzger (1965) reports a similar angular discordance between the Bouse Formation and an underlying Miocene(?) fanglomerate in the Parker-Blythe-Cibola area. The Miocene(?) fanglomerate appears to be at least in part equivalent to the Kinter Formation.

In the Laguna Mountains the Kinter Formation locally overlies pyroclastic rocks (chiefly silicic ash-flow tuffs) mapped as volcanic rocks of Tertiary age (fig. 11 and pls. 3, 4). No angular discordance between these two units has been observed, although the abundance of clasts of silicic tuff in parts of the Kinter suggest at least local unconformity. On the southwest flank of the Chocolate Mountains, just northeast of "Picacho Mesa," the Kinter overlies basaltic andesite or basalt and contains abund-


FIGURE 13.—Exposure of Kinter Formation in railroad cut along Kinter siding at north end of Gila Mountains. Poorly consolidated fanglomerate overlies thin bed of pale-purplish-gray tuffaceous sand (**ts**) at base of upper member; unbedded mudflow breccia (**br**) below the tuffaceous sand at lower right corner of exposure is typical of much of the lower member of the formation.

ant clasts of that rock in places. The basaltic andesite or basalt also is part of the main sequence of Tertiary volcanic rocks (fig. 11).

Both the Kinter Formation and the underlying volcanic rocks unconformably overlie the red beds and the breccia-conglomerate sequence. The unconformity has several hundred feet of local relief. The angular discordance between the bedding of the Kinter Formation and that of the red beds is as much as 60° in a highly faulted area about 1½ miles north of McPhaul Bridge (pl. 4). The volcanic rocks and the Kinter Formation have generally been deformed by normal faulting and tilting or folding with bedding dips of less than 35°. This comparatively mild deformation contracts with the high-angle reverse faulting and moderate to steep tilting and folding characteristic of the red beds, breccia, and conglomerate of the older sedimentary sequence. However, in places in the central Laguna Mountains, the Kinter Formation appears to rest conformably on, or even intertongue with, heterogeneous breccia and conglomerate presumed to be part of the older sequence. Evidently, deformation varied in time and intensity through the Laguna Mountains.

The age of the Kinter Formation is well established as Miocene on the basis of radiometric dating and stratigraphic evidence. Biotite from a bed of bentonitic ash at locality VAW–60:29 near the base of the upper member in the southern Laguna Mountains (pl. 4) has been dated by the potassium-argon method as 23±2 million years (U.S. Geological Survey, written commun. 1963). (See table 2.) If the apparent age is correct, the ash and the enclosing fanglomerate can be assigned an early Miocene age according to the widely accepted time scales of Holmes (1960) and Kulp (1961).

Beds similar to those in the lower member of the Kinter Formation and also resembling some of the underlying red beds occur in the Muggins Mountains 10–20 miles east of the Laguna and northern Gila Mountains. Lance and Wood (1958) assigned an early Miocene age to camel teeth from the Muggins Mountains beds; in a subsequent paper, Lance (1960, p. 156) stated that the fossils are "certainly no older than Upper Oligocene or younger than Middle Miocene." P. E. Damon (written commun., 1968) reports a potassium-argon age of 21.9±0.9 m.y. (million years) for biotite in a tuff determined by F. H. Olmsted to be 350–400 feet stratigraphically below the fossiliferous bed; this corresponds to a late Arikaree age according to the Cenozoic mammalian chronology of Evernden and James (1964), which supports the interpretations of Lance and Wood (1958) and Lance (1960).

The Bouse Formation, which unconformably overlies the Kinter Formation, is considered to be Pliocene (p. H44). The volcanic rocks underlying the Kinter in the Chocolate and Laguna Mountains have yielded potassium-argon dates ranging from about 25 to 26 m.y. (table 2).

All the evidence cited above suggests a Miocene age for the Kinter Formation. The probable time equivalent of the Kinter in the western Salton Trough is the Split Mountain Formation of Tarbet and Holman (1944), a predominantly nonmarine fanglomerate and sandstone containing intercalated marine sandstone and shale. Marine beds have not been definitely identified in the Kinter Formation in the Yuma area, although in the subsurface the older marine sedimentary rocks underlying the Bouse Formation may be at least in part contemporary with the Kinter (fig. 11).

#### OTHER NONMARINE SEDIMENTARY ROCKS

In addition to the units described above, unnamed nonmarine sedimentary rocks of probable Tertiary age—chiefly coarse breccia and conglomerate—occur in the east-central Cargo Muchacho Mountains and at scattered localities in the Gila Mountains. The stratigraphic assignment of these deposits is uncertain. In the Cargo Muchacho Mounains, coarse, loosely indurated conglomerate underlies basalt or basaltic andesite of uncertain age and alluvium of probable Quaternary age and unconformably overlies crystalline rocks of pre-Tertiary age. In the Gila Mountains, similar coarse deposits composed of detritus similar to nearby exposed crystalline rocks unconformably rest on the crystalline rocks and are overlain unconformably by coarse alluvial-fan deposits of probable Quaternary age.

### VOLCANIC ROCKS (TERTIARY)

Volcanism took place intermittently throughout much of the time the nonmarine sediments of Tertiary age were accumulating. The volcanic activity was most extensive after the deposition of the red beds, breccia, and conglomerate and before that of the Kinter Formation and the unnamed conglomerate of the Chocolate Mountains. The thickest accumulation of these volcanic rocks within the area mapped (pl. 3) is in the Chocolate Mountains; farther southeast, in the Laguna Mountains, the volcanic sequence is much thinner. Comparatively thick sections of volcanic rocks occur outside the mapped area, in the Muggins Mountains, Castle Dome Mountains, Middle Mountains, and several other ranges east and northeast of the Yuma area, but some of these rocks may be older than middle Tertiary.

#### OLDER ANDESITE

The oldest rocks in the main volcanic sequence are exposed chiefly in the easternmost part of the Chocolate Mountains near the Colorado River and in the adjacent area across the river in Arizona. These rocks consist of flows, pumiceous tuff, and some shallow intrusive bodies, agglomerate, and flow breccia, all apparently of andesitic composition. The flows are dull gray to dull red, are cut by closely spaced irregular fractures, and lack pronounced flow banding or other primary structures. Most of the flows are very fine grained and partly glassy; small phenocrysts of plagioclase, pyroxene, or hornblende are present but not abundant. The tuff is light gray, soft, and pumiceous and contains scattered crystals of biotite, hornblende, pyroxene (mostly augite), and plagioclase, as well as scattered fragments of fine-grained andesite and abundant glass shards. The thickness of this sequence of andesitic flows and tuffs is difficult to estimate but is probably less than 1,000 feet.

#### PYROCLASTIC ROCKS OF SILICIC TO INTERMEDIATE COMPOSITION

Predominantly pyroclastic rocks overlie the older andesite in the eastern Chocolate Mountains, in places unconformably. These younger rocks range from light-colored soft, pumiceous ash-full tuff to red densely welded ash-flow tuff (ignimbrite). Several beds of water-laid tuff and tuff breccia also are present. A few flows of light- to medium-gray andesite or dacite occur in the upper part of the sequence near Picacho Peak. A hard pink trachyte is reported at Senator Wash about 2 miles northwest of Imperial Dam (U.S. Bureau of Reclamation, written commun., 1963). Associated with these rocks are widely scattered dikes and, near Picacho Peak, a circular vent filled with a dull-gray aphanitic rock (probably welded tuff).

The softer beds of tuff form valleys, commonly mantled with thin gravel deposits of Quaternary age; the more resistant beds of welded tuff and the flows form ridges. The valleys and ridges are generally oriented northwest, parallel with the strike of the beds.

The tuffs, both welded and nonwelded, are composed chiefly of glass shards, with scattered crystals and small fragments of fine-grained to glassy volcanic rocks. The low refractive indices of the glass and the abundance of biotite, sanidine, and quartz in some of the tuffs indicate probable rhyolitic or rhyodacitic (quartz-latitic) composition. Other tuffs contain more plagioclase, little or no sanidine and quartz, and augite or hornblende rather than biotite as the chief ferromagnesian constituent; these rocks probably are of andesitic or dacitic composition.

The predominantly pyroclastic sequence appears to reach a maximum thickness of about 1,500 feet in the eastern Chocolate Mountains, although unknown displacements on poorly exposed faults make this estimate somewhat uncertain. A section about 1,100–1,200 feet thick was observed in upper Senator Wash, but the base is not exposed at this locality.

In the Laguna Mountains the older andesite is missing, and the younger pyroclastic rocks are much thinner than they are in the Chocolate Mountains. The pyroclastic rocks are chiefly welded to nonwelded ash flows locally containing a small amount of black vitrophyre in the basal part. The sequence ranges in thickness from a few feet in the southern part of the mountains, northwest of McPhaul Bridge, to nearly 400 feet in the northern part, east of Laguna Dam. The pyroclastic rocks overlie coarse breccia and conglomerate with angular unconformity and are overlain by the Kinter Formation without significant angular discordance.

#### BASALTIC ANDESITE OR BASALT OF CHOCOLATE MOUNTAINS

The most prominent ridges in the southeastern Chocolate Mountains are formed of dark basaltic andesite or basalt (fig. 7). This rock comprises several distinct flows or flow units, some of which are brecciated, probably from flowage after the lava had begun to solidify. Most of the rock is medium gray to dark brownish gray, is more or less vesicular, and on weathered surfaces is coated with dark-brown desert varnish. It breaks up into small-boulder-sized subangular fragments but on the whole is very resistant to erosion and forms long, prominent ridges.

The rock typically has a groundmass composed of tiny laths of plagioclase and pyroxene (chiefly augite) and some brownish glass and opaque grains (probably magnetite), and it contains scattered phenocrysts of olivine (partly altered to iddingsite), augite, and plagioclase (labradorite). The potassium content of 1.4 percent, determined in a potassium-argon analysis for dating (Geochron Laboratories, written commun., 1963), is considerably higher than that in most basalt (Nockolds and Allen, 1954) and suggests that the rock is more likely a basaltic andesite or potassic basalt rather than a normal basalt.

The flows of basaltic andesite or basalt overlie coarse breccia and conglomerate with angular discordance and locally rest unconformably on the older andesitic sequence. At a few places the basaltic andesite or basalt is overlain by tuff of silicic to intermediate composition, but most contacts of these two rocks are faults; their age relations are therefore uncertain. The maximum exposed thickness of the basaltic andesite or basalt in the southeastern Chocolate Mountains is about 1,000 feet.

#### FLOWS AND VENT TUFF OF LAGUNA MOUNTAINS

Flows and vent tuff of uncertain stratigraphic position occur at a few scattered localities in the Laguna Mountains. A sizable exposure of very fine grained rocks of undertermined composition occurs near the west margin of the mountains, south of Laguna Dam. The concentric, steeply dipping structure of the rocks in this exposure suggests an eroded volcanic neck or plug. The neck or plug appears to be capped by remnants of flows that issued from the central part.

Other small remnants of flows or possibly shallow intrusive bodies occur at several scattered localities in the southern Laguna Mountains. The relations of these rocks to the other volcanic rocks in the area are not known.

#### BASALT OR BASALTIC ANDESITE OF UNKNOWN AGE

Basalt or basaltic andesite of unknown age and stratigraphic position occurs at several localities scattered throughout the Yuma area. All the masses are small, and one was penetrated in U.S. Bureau of Reclamation test well CH–8 about 2 miles north of Yuma—the only known subsurface occurrence of volcanic rock in the Yuma area. Four of the exposures are in the northwestern part of the area: two on the east flank of the Cargo Muchacho Mountains, one on the west flank of those mountains, and one in the Ogilby Hills. A fifth exposure occurs at Raven Butte on the east flank of the Tinajas Altas Mountains in the southeastern part of the area. The exposed bodies are either flat lying or gently tilted. The overlie crystalline rocks of pre-Tertiary age or, in places, conglomerate of uncertain age. The basalt penetrated in the well 2 miles north of Yuma is overlain by possibly a few feet of the Bouse Formation and then by alluvium of the Colorado River.

#### AGE OF VOLCANIC ROCKS

The main masses of volcanic rocks in the Chocolate and Laguna Mountains have been dated with reasonable certainty by the potassium-argon method. The results of the determinations for five samples, and for a sixth sample from an ash bed in the overlying Kinter Formation, are given in table 2. The samples are listed in approximate stratigraphic order, with the youngest at the top. The stragraphic position of the basaltic andesite or basalt is uncertain; it may be below rather than above most of the tuffs of silicic to intermediate composition, but it definitely overlies the older andeside (represented by the lowermost two samples in table 2).

TABLE 2.—*Potassium-argon ages of volcanic rocks in the Yuma area*

| Location, description, and stratigraphic position of sample | Apparent age (million years) |
|---|---|
| Lat 32°45′58″ N., long 114°26′10″ W., Laguna Mountains, Ariz. Sample from bed 2–4 ft thick composed of pink altered bentonitic ash in lower part of upper member of Kinter Formation. Locally Kinter Formation overlies breccia and conglomerate of heterogeneous composition. Sample VAW–60:29; USGS lab, 471–B. K-Ar age of biotite | 23±1.2 |
| Lat 32°49′53″ N., long 114°31′39″ W., Chocolate Mountains, Calif. Sample from base of a sequence of flows of basaltic andesite or basalt that unconformably overlies breccia and conglomerate of heterogeneous composition. Sample HC2–15:35B; Univ. Arizona lab. (P. E. Damon, written commun., 1970). K-Ar whole-rock age | 25.1±1.6 |
| Lat 32°48′13″ N., long 114°28′50″ W., Laguna Mountains, Ariz. Sample from top of a bed of pale-purple porous soft vitric crystal tuff at top of section at least 200 ft thick composed of vitric tuff, welded tuff, vitrophyre, and possible flow rock of felsic to intermediate composition. Volcanic rocks unconformably overlie granite breccia and conglomerate and are overlain (unconformably?) by fanglomerate of the Kinter Formation. Sample 5–15:55A; Univ. Arizona lab. PED 4–65. K-Ar age of biotite | 26.3±1.0 |
| Lat 32°55′15″ N., long 114°31′12″ W., Chocolate Mountains, Calif. Sample from a bed of hard grayish-purple slightly welded felsic tuff within a sequence of tuff and welded tuff of felsic to intermediate composition. Sample COL 2–35:1A; Geochron lab. FO 448. K-Ar age of sanidine | 26.2±1.6 |
| Lat 32°56′56″ N., long 114°33′12″ W., Chocolate Mountains, Calif. Sample from a flow of hornblende andesite that overlies dated pumiceous andesite tuff (sample COL 2–7:38A). Sample COL 2–7:41A; Univ. Arizona lab. PED 1–67. K-Ar age of hornblende phenocrysts | 24.7±2.1 |
| Lat 32°56′37″ N., long 114°32′52″ W., Chocolate Mountains, Calif. Sample from a bed of pumiceous andesite(?) tuff that underlies dated hornblende andesite flow (sample COL 2–7:41A). Both the flow and the tuff appear to be stratigraphically below the dated felsic tuff and welded tuff and probably below the dated basaltic andesite or basalt. Sample COL 2–7:38A; Geochron lab. BO 514. K-Ar age of biotite | 25.9±0.9 |

The apparent ages of the volcanic rocks have remarkably little spread and suggest that the entire sequence was erupted within a relatively short time. The precision of the age determinations is not sufficient to corroborate the inferred stratigraphic sequence. The potassium-argon dates all indicate a late Oligocene or early Miocene age for the volcanic rocks according to the widely used time scales of Holmes (1960) and Kulp (1961). However, until the problems of interpreting apparent radiometric ages and correlating them with standard Tertiary sedimentary sequences are worked out more thoroughly than they are at present, it seems best to say only that the main volcanic sequence in the Yuma area is middle Tertiary. Volcanic rocks of similar age have been described from many other places in the Basin and Range province; Damon and Bikerman (1964, 1965) and Bikerman and Damon (1966) have described a middle Tertiary pulse of hypabyssal plutonism and volcanism which reached a peak between 25 and 30 million years ago in southeastern Arizona and adjacent areas.

The age and correlation of the flows and vent tuff of the Laguna Mountains, and of the scattered masses of basalt or basaltic andesite, are uncertain. Stratigraphic relations indicate that these rocks also are middle Tertiary. These scattered masses may be in part correlative with the basaltic andesite or basalt of the southeastern Chocolate Mountains, but some might be younger.

### OLDER MARINE SEDIMENTARY ROCKS (TERTIARY)

Predominantly fine grained deposits that contain invertebrate faunas representing marine and possible brackish-water environments have been penetrated in several oil-test wells and water-test wells in the Yuma area. Data from U.S. Geological Survey test well LCRP 29 and two oil-test wells indicate that the marine sedimentary rocks in much of the area are divisible into two units: (1) An older, more indurated, and probably more deformed sequence, herein designated the older marine sedimentary rocks, and (2) a younger, generally finer grained sequence which is assigned to the Bouse Formation, a name given by Metzger (1968) to equivalent strata in the Parker-Blythe-Cibola area.

A dip log of one of the oil-test wells—Colorado Basin Associates Federal 1 in the south-central part of the Yuma Mesa—indicates the presence of an angular unconformity between the two marine units and that the older sequence may be essentially conformable on underlying nonmarine rocks. In contrast to the Bouse Formation, which is mostly silt and clay with subordinate thin layers of sand, the older marine sedimentary rocks contain much more sand and are also more indurated. In test well LCRP 29 the greater degree of induration of the older sequence is shown by a caliper log made just after the pilot hole was completed (fig. 14). The log shows that the hole remained at or near the diameter of the drilling bit throughout the thickness of the older marine sedimentary rocks, even though the sequence is very sandy; whereas in the Bouse Formation, almost all the thin strata of sand, and much of the clay and silt as well, washed out or sloughed, enlarging the hole.

The older marine sedimentary rocks consist of more or less indurated light-gray fine-grained sandstone and interbedded medium- to dark-gray siltstone and claystone. The sandy strata make up about half the total thickness in all three test wells (LCRP 29, Colorado Basin Associates Federal 1, and Yuma Valley Oil and Gas Co. Musgrove 1). Beds of ash or tuff are reported in the two oil-test wells, and at least one bed of altered soft tuff or ash was penetrated in the lower part of the section in well LCRP 29 (fig. 14).

Fossils in the older marine sedimentary rocks include foraminifers and mollusks indicative of a marine environment but not diagnostic as to age. In well LCRP 29, Smith (1968) reports the presence of two foraminiferal faunas: the older (which occurs in what are herein designated the older marine sedimentary rocks) consists of abundant globigerinids, mainly *Globigerinita uvula* with few to common *Globquaderina hexagona* and *Sphaerhoidinella dehiscens*, plus a good shelf benthonic fauna including *Planulina* sp., *Uvigerina* sp., *Hanzawayai* sp., and *Bolivina interjuncta*. The younger fauna occurs in the overlying Bouse Formation and indicates much shallower, more restricted waters.

The age of the older marine sedimentary rocks and their correlation with stratigraphic units of other areas are not known with certainty. The stratigraphic position of these beds suggests that they probably intertongue with nonmarine beds of the Kinter Formation of Miocene age.

Mrs. P. B. Smith (written commun., Oct. 12, 1969) reports that the planktonic foraminifer *Sphaeroidinella dehiscens* in the sample of older marine sedimentary rocks from well LCRP 29 is now regarded as post-Miocene and is, in fact, considered to be a guide fossil to the Miocene-Pliocene boundary. The older marine sedimentary rocks therefore would be Pliocene, rather than Miocene. However, because of the apparent conflict with other lines of evidence, it seems best to defer assigning a definite age to the older marine sedimentary rocks until additional information becomes available.

On the west side of Imperial Valley the Split Mountain Formation of Tarbet and Holman (1944) contains a poorly preserved, meager foraminiferal fauna of Miocene age in the middle part (Tarbet and Holman, 1944), or in the upper part (Durham and Allison, 1961). The Split Mountain is overlain unconformably by the marine Imperial Formation (Durham and Allison, 1961; Woodard, 1961). Because of their similar structural and stratigraphic relations, the older marine sedimentary rocks and the Bouse Formation of the Yuma area may be correlative, respectively, with the marine part of the Split Mountain Formation of Tarbet and Holman (1944) and with the Imperial Formation. However, in both places the faunas are somewhat different in the presumably equivalent units, and it has not yet proved possible to trace the units from one area to the other beneath the intervening Imperial Valley.

The maximum thickness of the older marine sedimentary rocks in the Yuma area may exceed 1,000 feet. A vertical interval of 1,135 feet was penetrated in Colorado Basin Associates Federal 1 oil test; however, if the average dip of 30° indicated by the dip log is correct, the stratigraphic thickness in this well is a little less than 1,000 feet. According to an interpretation of seismic-reflection data and the record of test well LCRP 29, the thickness may be somewhat greater near that well; it may be greater also near well LCRP 25, which, however, did not penetrate these rocks.

### BOUSE FORMATION (PLIOCENE)

The Bouse Formation was named and described by Metzger (1968) in the Parker-Blythe-Cibola area along the Colorado River north of the Yuma area. The younger sequence of marine sedimentary rocks in the Yuma area is assigned to the Bouse on the basis of similar lithology and stratigraphic posi-

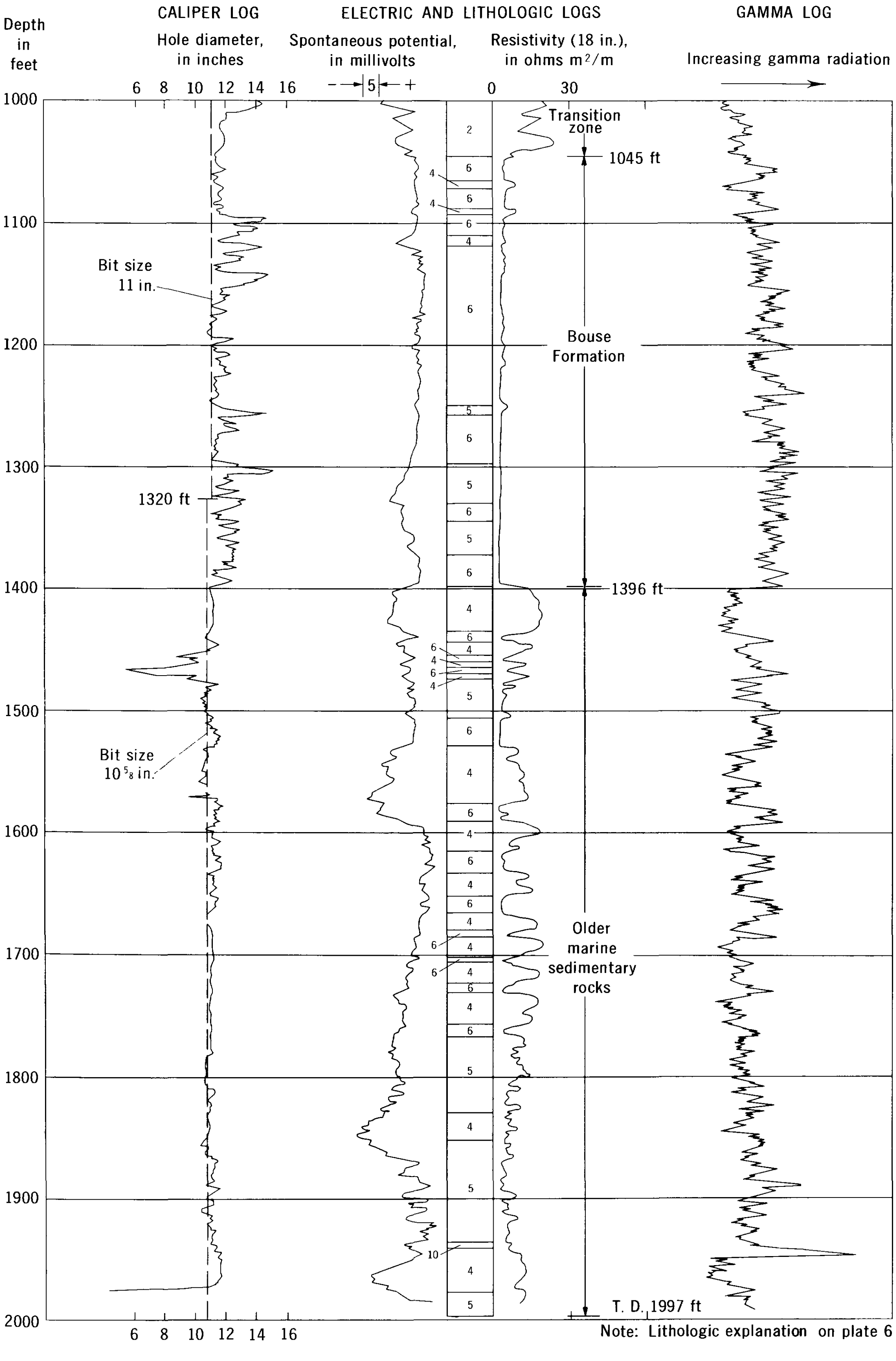


**FIGURE 14.**—Selected logs of test well LCRP 29 below a depth of 1,000 feet.

tion and of an identical foraminiferal fauna (Smith, 1968).

The Bouse Formation is widespread in the subsurface, but the only known exposure in the Yuma area is 2 miles southeast of Imperial Dam, just east of the Colorado River flood plain (pl. 3). The Bouse appears to be more extensive than the older marine sedimentary rocks and is probably absent only in the mountains, in most of the foothills, and on the tops and upper flanks of buried ridges of pre-Tertiary and early to middle Tertiary rocks (fig. 15).

Although it has been broadly warped and locally faulted (fig. 15), the Bouse Formation appears to be substantially less deformed than the nonmarine sedimentary rocks and the older marine sedimentary rocks, and it probably was deposited after the principal mountain masses in the Yuma area had assumed approximately their present configuration but not their present altitude.

The thickness of the Bouse ranges from zero where it pinches out or is overlapped by alluvium to a maximum of about 950 feet in Yuma Valley Oil and Gas Co. Musgrove 1 test well near the southwest corner of the area. Except at some places in the northeastern part of the area where the contact with overlying older alluvium is sharp and may be an unconformity, the Bouse Formation is overlain by a transition zone in which marine clay and silt are interbedded with nonmarine alluvial deposits like those in the older alluvium.

The Bouse Formation consists predominantly of silt and clay, with subordinate very fine to fine sand, hard calcareous claystone, and—locally in the basal part—calcareous sandstone or sandy limestone, tuff, and possibly conglomerate of local derivation. In the subsurface the clay and silt are pale-greenish gray to bluish gray (dark green to dark blue when wet); some strata are pink and brown. The very fine to fine sand is light gray and is well sorted. In the exposures southeast of Imperial Dam the predominant color of the fine-grained beds is pale-greenish gray, but pale-yellowish-gray, light-brown, and pink beds are conspicuous in the upper part, which is transitional into grayish-brown and reddish-brown clay and silt characteristic of the overlying older alluvium. Organic remains, both plant and animal, are abundant in some zones. Small gastropods, pelecypods, and ostracodes can be seen with the unaided eye. Plant remains consist of molds of twigs and roots, partly filled with brown ferric oxides or hydroxides. The microscope reveals also several species of Foraminifera, consisting of *Ammonia beccarii, Elphidium* cf. *E. gunteri, Eponidella palmerae,* and *Rosalina columbiense.* (P. B. Smith, written commun., 1969). The faunas are said to indicate brackish to marine environments but are not diagnostic as to age (Metzger, 1968).

The sandy limestone or calcareous sandstone locally present at the base of the Bouse Formation is very pale gray to grayish yellow and in places contains an abundant marine fauna, including corals as well as mollusks. This calcareous bed is equivalent to the basal limestone described by Metzger (1968) in the Parker-Blythe-Cibola area. In the Yuma area, this limestone was penetrated in test wells LCRP 26 and 23, in a private well (C–9–21)14bdb, and probably in oil-test well Sinclair Oil Co. Kryger 1, but in other wells penetrating the base of the Bouse Formation it is either absent or unrecognized. In gamma-ray logs this basal limestone is a prominent zone of abnormally low natural gamma radiation. In test well LCRP 26 it unconformably overlies a nonmarine coarse fanglomerate, the top few feet of which appears to be weathered, probably representing a fossil soil zone. The weathered zone is characterized by high natural gamma radiation (probably owing to its clay content), which contrasts vividly with the very low gamma radiation of the overlying basal limestone (or calcareous sandstone) of the Bouse Formation (fig. 16). In well LCRP 26 the basal limestone is 28 feet thick and is overlain by a bed about 9 feet thick that has abnormally high gamma radiation and is probably a tuff or altered tuff (fig. 16). Unfortunately, only a very few cuttings of this bed were recovered during drilling, so its exact nature is not known, and it could not be dated radiometrically.

In test well LCRP 23 the clay, silt, and fine sand of the upper part of the Bouse Formation are underlain by conglomerate and arkosic sandstone composed of granitic and metamorphic rocks containing a 3-foot bed of bluish-gray claystone similar to that higher in the section. These beds overlie a 6-foot stratum of sandy limestone, which in turn rests on conglomerate (fanglomerate?) much like that above. The stratigraphic position of the conglomerate, the interbed of claystone, and the sandy limestone are uncertain; no fossils were collected from these beds. Lithologically, the conglomerate resembles that in the Kinter Formation, which unconformably underlies the Bouse Formation southeast of Imperial Dam and probably also at test well LCRP 14 at Laguna Dam. However, the presence of the bluish-gray claystone in the middle of the section and of the sandy limestone at the base suggests that the entire sequence belongs to the Bouse Formation. The conglomerate and sandstone beds may represent beach

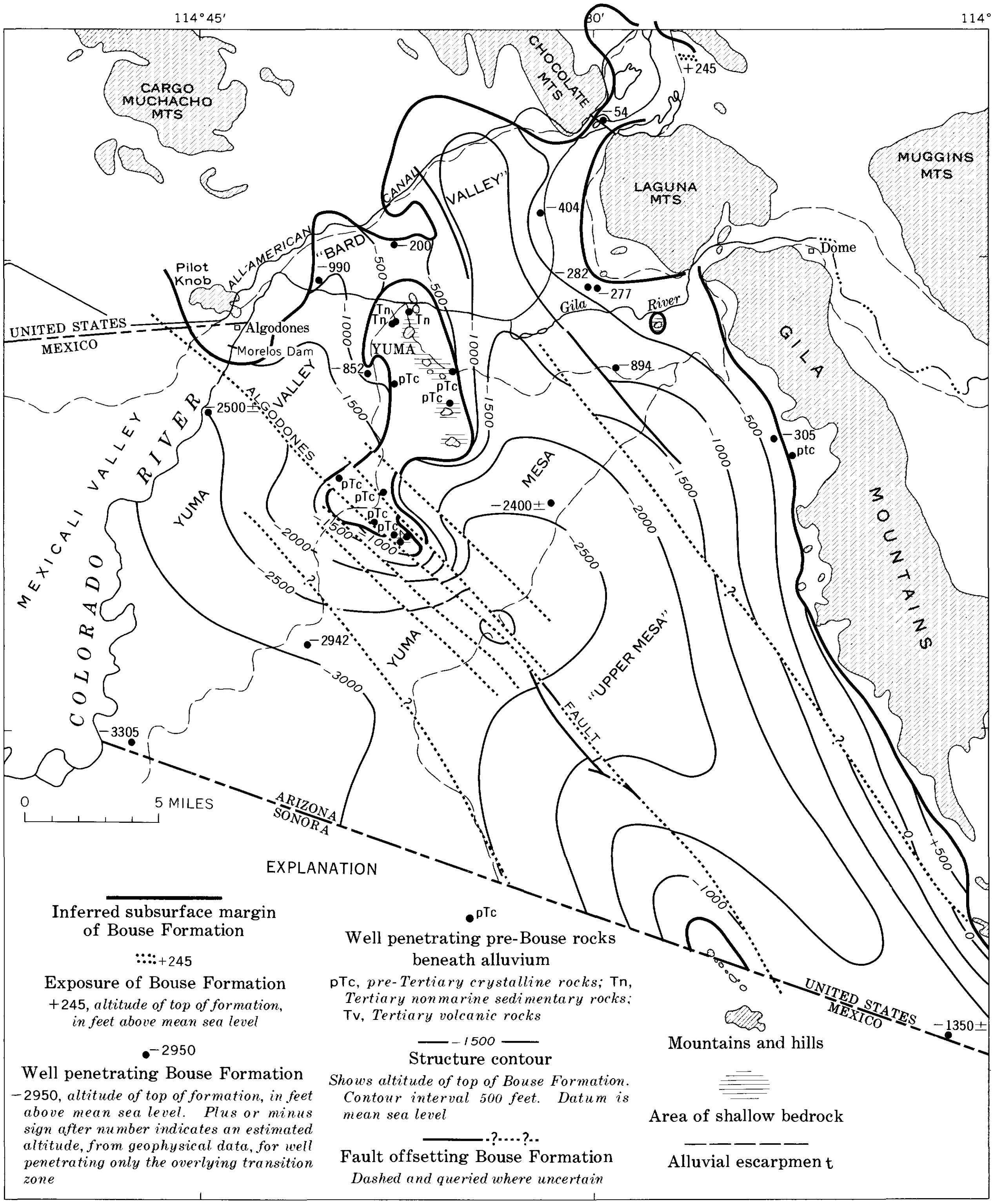


FIGURE 15.—Inferred extent and configuration of the Bouse Formation.

gravels or offshore bars similar to those described by Metzger (1968) in the basal limestone of the Bouse Formation in the Parker-Blythe-Cibola area to the north.

The invertebrate fossils in the Bouse Formation are useful as indicators of a marine to brackish-water environment, but none so far identified is diagnostic as to age except within broad limits.

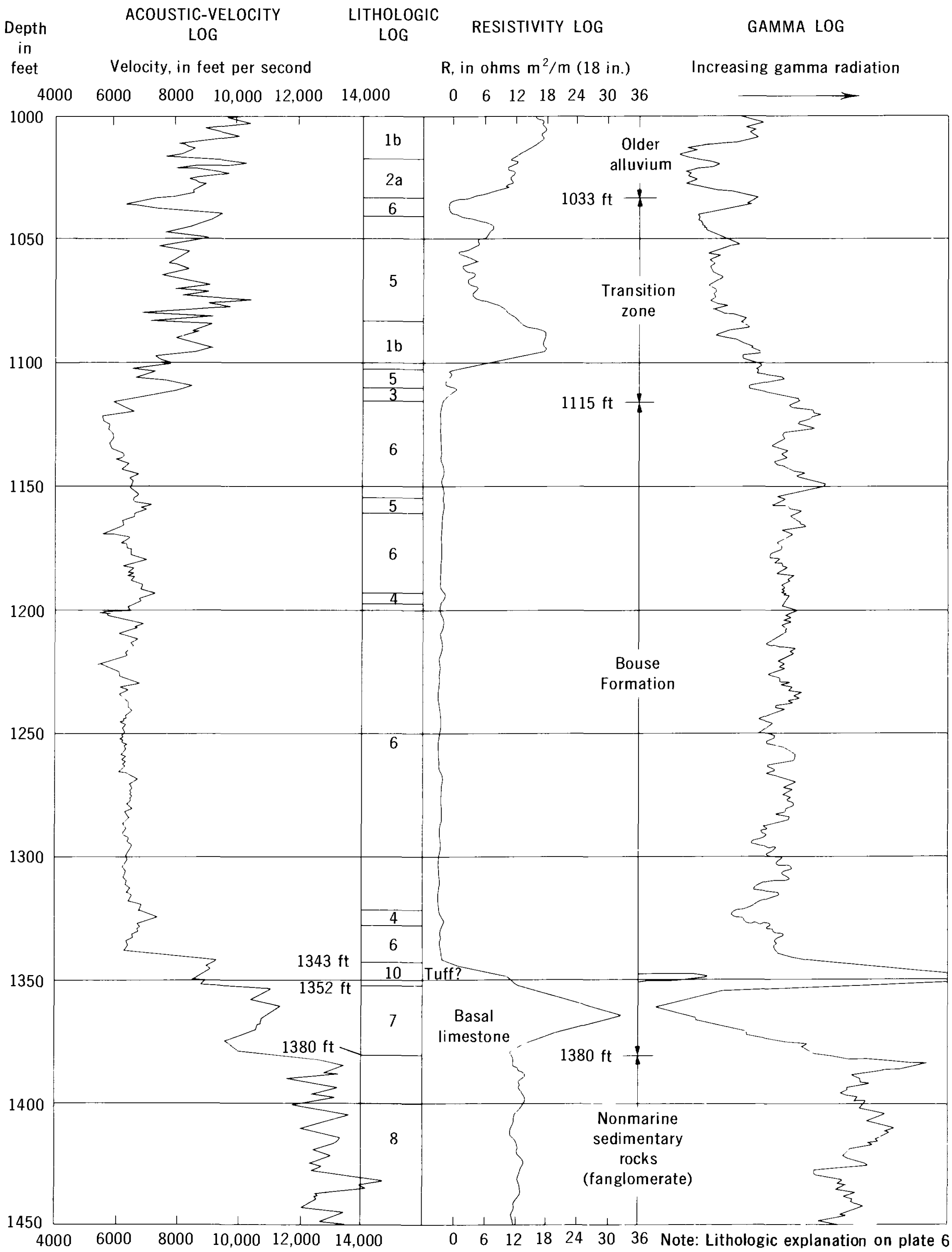


FIGURE 16.—Selected logs of test well LCRP 26 between depths of 1,000 and 1,450 feet.

P. B. Smith (written commun., 1966) reports that the foraminifers range from Miocene to Holocene, though none is living on the Pacific coast today.

Metzger (1968) reviews other evidence for the age of the Bouse and concludes that it belongs within the Pliocene, although a more definite age assignment is not yet possible. Metzger (1968) describes a thin tuff within the basal limestone of the Bouse Formation between the Parker-Blythe-Cibola area and Imperial Valley which was dated by the potassium-argon method as 8.1±4.4 m.y. (P. E. Damon, written commun., 1969). This tuff may be correlative with that just above the basal limestone in test well LCRP 26 (fig. 16).

Little additional evidence for the age of the Bouse Formation is available in the Yuma area. As mentioned earlier, the Bouse overlies the Kinter Forma- (Miocene) with at least local angular discordance; a lower limit of Miocene (probably late Miocene) is therefore reasonably well established. As in the Parker-Blythe-Cibola area, none of the distinctive well-rounded siliceous gravel characteristic of Colorado River alluvium occurs within or below the Bouse Formation, so the Bouse antedates the establishment of the Colorado River as a through-flowing stream within the present lower Colorado River region. In the Yuma area, the Bouse Formation is overlain gradationally by alluvium of the Colorado River; Metzger (1968) cites evidence that the earliest deposits of the lower Colorado River are no younger than late Pliocene.

### TRANSITION ZONE (PLIOCENE)

Throughout most of the Yuma area, the Bouse Formation appears to be overlain conformably by alluvium deposited by the Colorado River and possibly the Gila River. In much of the area, marine deposition did not cease abruptly, however, and the marine deposits are overlain by alternating or intertonguing marine and nonmarine (alluvial) strata. For convenience this interval, which is as much as several hundred feet thick in the southwestern part of the area, is designated the transition zone. The top of the transition zone is defined by the uppermost bed of fossiliferous gray clay or silt, the base by the lowermost bed of recognizable sand or gravelly sand of fluvial origin just above the predominantly fine grained marine beds of the Bouse Formation. In a few wells, thin beds of bluish- or greenish-gray clay have been reported within the alluvium as much as 1,000 feet above the top of the deposits assigned to the transition zone. These beds, generally less than 2 feet thick, may indicate later brief recurrences of marine conditions, but more likely they are not beds at all but are boulders of the marine clay reworked into the alluvium by the ancestral Colorado River. Such boulders have been observed in exposures of the older alluvium at many places.

### CONGLOMERATE OF CHOCOLATE MOUNTAINS (TERTIARY AND QUATERNARY)

On the flanks of the southern Chocolate Mountains, the nonmarine sedimentary rocks and volcanic rocks of Tertiary age are overlain by a slightly to moderately indurated conglomerate composed chiefly of volcanic detritus derived from nearby exposures of the volcanic rocks. In places the contact of the conglomerate and the older rocks is an angular unconformity with a discordance of as much as 15°, but in other places the discordance is slight or absent. Small angular unconformities have been observed within the conglomerate and probably record uplift of the Chocolate Mountains mass while deposition was going on. On the west flank of the mountains the conglomerate is overlain unconformably by older alluvium (old deposits of the Colorado River), but farther west the contact of these two units may be conformable or gradational. From the field relations it appears that the older parts of the conglomerate of the Chocolate Mountains may be equivalent in age to the upper part of the nonmarine sedimentary rocks (Kinter Formation of Miocene age), but that the younger parts are equivalent in age to the older alluvium (Pliocene and Pleistocene). (See fig. 11.)

The conglomerate of the Chocolate Mountains is typically pale pink when viewed from a distance and is composed chiefly of pink and gray fragments of ash-flow tuff and welded tuff. Most of the fragments, which range in size from granules to occasional slabs and blocks several feet across, are subangular or angular. Beds of pale-brown soft sandstone are locally conspicuous. The upper part of the unit contains abundant soft brown siltstone.

The conglomerate generally is only mildly deformed; the bedding dips less than 5° at most places but bedding as steep as 45° has been observed near normal faults. Small high-angle normal faults are abundant, especially in the more indurated parts of the unit and where the bedding dips more than about 4°.

### OLDER ALLUVIUM (PLIOCENE AND PLEISTOCENE)

The older alluvium consists of basin-filling fluvial and deltaic sediments deposited by the Colorado and Gila Rivers and by local ephemeral streams. The unit does not represent a single cycle of aggradation but rather is a complex of fills separated by degradational cycles during which extensive scouring occurred. The degradational and aggradational cycles probably were caused in part by fluctuations in sea level amounting to several hundred feet related to glacial and interglacial stages and in part by both regional and local warping of the land surface. Erosion by the river probably occurred during times of lowered sea level or upwarping; deposition took place when sea level rose or downwarp occurred. The southwestern part of the Yuma area, on the margin of the Salton Trough, subsided continually under the load of the fluvial and deltaic deposits so that not all the deposits of the aggradational episodes were removed during the ensuing degradational episodes. Farther northeast and adjacent to the mountain blocks, however, many if not most of the earlier fills were removed and replaced by later fills.

Although different alluvial fills separated by unconformities have been identified in outcrop areas, subsurface delineation of all the fills has not been possible with present data. Accordingly, all the alluvial and deltaic deposits older than the most recent fill are grouped in one unit designated as older alluvium. The older alluvium occupies the stratigraphic interval between the transition zone (or the Bouse Formation where the transition zone is absent) and the younger alluvium (the most recent fill).

#### DISTRIBUTION AND THICKNESS

The older alluvium is the most widely exposed stratigraphic unit in the Yuma area. It is exposed in mesas, stream terraces, and piedmont areas and underlies the younger alluvium of the present flood plains of the Colorado and Gila Rivers and the young alluvial fans in the southeastern part of the area (pl. 3). At some places the older alluvium is concealed by a blanket of windblown sand. Exposures of older alluvium commonly are dissected, and many are characterized by desert pavement that formed on poorly sorted gravelly deposits (pl. 3). On the flanks of some of the mountains, coarse older alluvium of local origin forms low hills and dissected uplands similar to some of the exposures of coarse nonmarine sedimentary rocks of Tertiary age (fig. 9).

The thickness of the older alluvium ranges from zero to as much as 2,500 feet in the southwestern part of the area, near San Luis, Ariz.; if the underlying transition zone is included, the maximum thickness is about 3,400 feet (fig. 15 and pl. 10). This thickness is much greater than that attained by equivalent deposits north of the Yuma area; Metzger, Loeltz, and Irelan report that the maximum depth to the base of the older alluvium in the Parker-Blythe-Cibola area is about 600 feet. The great thickness in the Yuma area, and the much greater thickness of equivalent deposits of the Colorado River in Imperial Valley, indicate subsidence during deposition. The oldest alluvial deposits (at the base of the transition zone), which are now more than 3,000 feet below sea level near San Luis (fig. 15), must have been deposited above or at least not far below sea level by the ancestral Colorado River.

#### AGE AND CORRELATION

The age of the older alluvium ranges from Pliocene to late Pleistocene, according to several lines of evidence. The underlying Bouse Formation is considered Pliocene (p. H44), and the overlying younger alluvium is Holocene and possibly latest Pleistocene. Recent studies of the erosional history of the Grand Canyon, summarized in McKee, Wilson, Breed, and Breed (1967), show that the canyon was cut to nearly its present depth by the middle Pleistocene. This seems to require an inauguration of the canyon cutting well before the beginning of the Pleistocene and would imply that the Colorado River had entered the downstream region including the Yuma area at least as early as some time in the Pliocene. The Gila River may not have entered the Yuma area until long after the advent of the Colorado River, but the scanty evidence is inconclusive as to the history of the ancestral Gila River downstream from the Phoenix basin (M. E. Cooley, written commun., 1969).

Three samples of carbonized wood from the upper part of the older alluvium in the Yuma area have been analyzed by the radiocarbon ($C^{14}$) method. The results are listed below:

| | *Age in years before present* |
|---|---|
| (C–10–23)31bbb1. U.S. Geological Survey test well LCRP 1. Lignite from a depth of 472–474 ft. USGS lab. W–1428 | >42,000 |
| (C–10–24)12ccc2. U.S. Bureau of Reclamation drainage well YVI–28. Carbonized wood from a depth of 128–130 ft. Geochron lab. GXO–661 | >33,600 |
| 16S/23E–10Rcc. U.S. Geological Survey test well LCRP 23. Carbonized wood from a depth of 224–234 ft. USGS lab. W–1538 | >36,000 |

All three samples are older than the limits of the radiocarbon method of measurement, and the differences in the minimum ages shown are not significant. The unconformably overlying younger alluvium has yielded radiocarbon ages of less than 10,000 years in the Parker-Blythe-Cibola area (Metzger and others, 1972). Thus, the radiocarbon evidence indicates that the upper part of the older alluvium can be no younger late Pleistocene.

The older alluvium of the Yuma area probably is correlative with the older alluvium of the Parker-Blythe-Cibola area (Metzger and others, 1973). Deposits near Gila Bend 120 miles east of Yuma, called older alluvial fill by Heindl and Armstrong (1963), probably are correlative with the older alluvium in the Yuma area. In the Imperial Valley region, units equivalent or partly equivalent to the older alluvium of the Yuma area include the Palm Spring Formation, the Canebrake Conglomerate of Dibblee (1954), and the Borrego Formation of Tarbet and Holman (1944); the Ocotillo Conglomerate and the Brawley Formation (both of Dibblee, 1954) may be equivalent to the uppermost part of the older alluvium.

### CLASSIFICATION OF DEPOSITS BY SOURCE

The older alluvium comprises a great variety of granular materials ranging from clay to cobble and boulder gravel. On the geologic map (pl. 3) these materials are classified according to their primary source into deposits of local origin, deposits of the old Colorado and Gila Rivers, and deposits of mixed origin. In addition, many of the areas adjacent to the mountains are mantled with relatively thin sheets and ribbonlike bodies of gravelly deposits left behind as these areas were dissected. These deposits, referred to as stream-terrace and piedmont deposits, are included with the older deposits of local origin on the geologic map; their extent is indicated in a general way by the pattern representing desert pavement, which is characteristic of the exposures (pl. 3).

### DEPOSITS OF LOCAL ORIGIN

The deposits of local origin occupy the margins of the area, adjacent to the mountains and exposures of older rocks, and were laid down by ephemeral streams and sheetfloods. Because most of the materials were deposited as flood-swollen, muddy masses of debris from nearby sources, they are obscurely bedded and poorly sorted. Typically they consist of angular to subangular gravel in a matrix of silty or clayey sand (fig. 17). Scour and fill are common, and individual strata are poorly defined and lenticular. The composition of the gravel is closely related to the kinds of older rocks in the drainage area. Farther from the source, the deposits become finer grained and better sorted and the gravel more rounded.

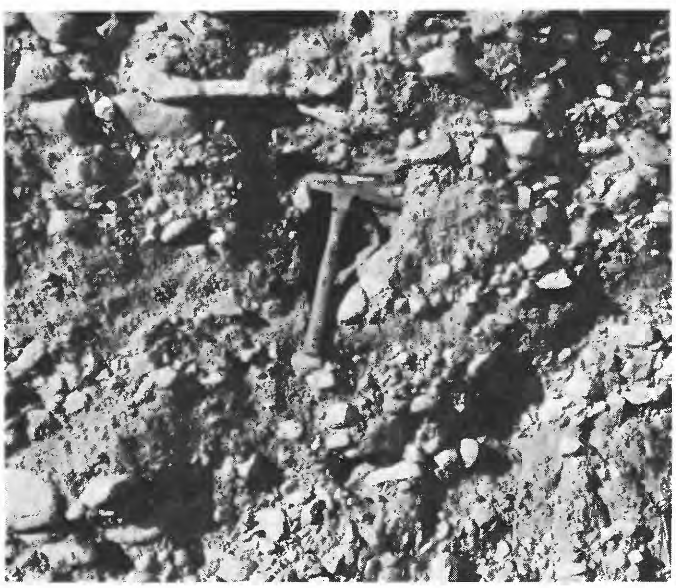

FIGURE 17.—Poorly sorted gravelly deposits of local origin exposed in west bank of Fortuna Wash 0.4 of a mile north of U.S. Interstate Highway 8.

Most of the older alluvium of local origin probably was deposited as alluvial fans. The oldest exposed local deposits are comparatively thick masses of coarse ill-sorted gravel which characteristically form low hills and dissected uplands mantled with a blanket of coarse colluvium (fig. 9).

### STREAM-TERRACE AND PIEDMONT DEPOSITS

Except for the scattered low hills and dissected uplands mentioned above, the older fills in the older alluvium are capped by relatively thin stream-terrace and piedmont deposits left behind as the older deposits were progressively dissected by local streams and sheetfloods. The stream-terrace and piedmont deposits consist largely of ill-sorted gravel associated with much sand, silt, and clay. At most places they overlie similar older fill from which they are often difficult to distinguish. According to F. L. Doyle (written commun., 1963), who intensively studied the piedmont area at the northwest corner of the Gila Mountains, the gravelly piedmont deposits represent the bedloads of ephemeral streams that dissected the older rocks and alluvial fills.

As their name implies, the stream-terrace and piedmont deposits occur in two principal environments which, however, tend to intergrade. The stream-terrace deposits are found at different levels along the larger washes and also along abandoned washes, where they reach a maximum thickness of more than 50 feet. The terraces are not paired and are most extensive on the concave sides of large bends. The deposits undoubtedly are analogous to those now accumulating in the larger washes. The piedmont deposits underlie extensive piedmont surfaces formed by a combination of sheetfloods and shifting ephemeral streams. These deposits are less than 10 feet thick at most places.

Most exposures of stream-terrace and piedmont deposits are characterized by an armor of closely spaced pebbles or small cobbles which is called "desert pavement." In many places these stones form a mosaic so that little sand or silt is visible. The stones are generally coated with a dark stain called "desert varnish," which gives the pavement a dark aspect, like asphalt. Not all pavement is dark, however. Pebbles and cobbles of the lighter colored granitic and quartzose rocks commonly lack a good coating of desert varnish (fig. 8).

Most desert pavement contains a layer of silty sand and silt 2–4 inches thick just below the armor of pebbles and cobbles. The layer is impoverished in gravel and nearly everywhere contains some clay as a binder. It is underlain by a darker mixture of silty sand and gravel in a zone as much as 8 inches thick. The darker third layer contains seams of calcium carbonate (caliche) and may represent the B soil horizon. Owing to their clay and silt content, the second and third layers are not very permeable, and the dense mosaic of stones in the top layer does not allow water to penetrate rapidly from the surface. Infiltration rates from precipitation are low, and much of the water runs off pavement surfaces during storms. Infiltration rates are higher in the areas of light-colored granitic and quartzose pavement, which have thinner silty and clayey substrata.

The desert varnish on desert pavement consists of oxides of manganese and iron brought to the surface by capillary action assisted by acid secretions of lichens (Laudermilk, 1931). Hunt (1954) cites archeological evidence that most coatings of desert varnish are at least 2,000 years old, although Engel and Sharp (1958) state that varnish is not necessarily an indicator of antiquity. If Hunt's conclusions (1954) are correct, the widespread presence of varnish on even the lower stream terraces and on bedrock exposures attests to the general slowness of the processes of weathering and erosion in the region.

#### DEPOSITS OF MIXED ORIGIN

Where the deposits of local origin intertongue or grade laterally into old deposits of the Colorado and Gila Rivers, the materials are classified on the geologic map (pl. 3) as deposits of mixed origin. Much of this unit consists of river deposits that have been reworked by local ephemeral streams and sheetfloods and mixed with deposits of local origin. At many places, good exposures reveal a broad zone of distinctive buff silt and fine sand which grades away from the mountains into well-sorted fine to medium river sand, and toward the mountains into ill-sorted gravelly deposits of local origin. From this relationship it is inferred that the old Colorado and Gila Rivers were bordered by broad flood plains into which discharged, during brief periods, local runoff carrying detritus from the adjacent hills and mountains. However, at some places the flood-plain silt and fine sand abut directly against older rocks and contain very little coarse detritus of strictly local derivation. This relationship has been observed on the flanks of the Chocolate Mountains (fig. 18) and the almost-buried "Yuma Hills."

#### DEPOSITS OF THE OLD COLORADO AND GILA RIVERS

The greatest bulk of the older alluvium in the Yuma area consists of deposits of the old Colorado and Gila Rivers. These deposits are noticeably different from those of local origin. They are better sorted and stratified and less heterogeneous on a small scale than the local deposits; the river gravel is much more rounded than the local gravel and contains types of rocks derived from the middle and upper parts of the Colorado River drainage basin. In contrast with the local deposits, which are extremely variable, both areally and vertically, the river deposits contain some beds or zones that can be traced for several miles.

Sand is the most abundant material in the old river deposits. The river sand is much better sorted than the local sand and is more commonly crossbedded (fig. 19). Also, the grains of river sand are generally more rounded than those of local sand. River sand is typically gray to pinkish gray, whereas local sand is yellowish to reddish brown.

Crude analyses of several samples of fine to medium river sand from the older alluvium near Yuma indicate the following approximate composition: Quartz, 65–75 percent; feldspar (not differentiated), 10–20 percent; rock fragments, 5–15 percent; calcite and dolomite (in part as cement), 2–5 percent; and heavy minerals, 1–8 percent. The quartz is clear to translucent, mostly subrounded to subangular but occasionally rounded; feldspar is white, pink, or grayish-yellow and subangular to subrounded; rock fragments are chiefly small, angular to subrounded, and composed of chert, quartzite, granitic, metamorphic, and volcanic rocks. Most of the river sand is feldspathic, according to the classification of Krumbein and Sloss (1951).

Results of heavy-mineral analyses of alluvial sand (chiefly older alluvium but including some younger alluvium) are summarized in table 3. Most of the samples represent river deposits; the two samples from well (C–8–23)33cdd (test well LCRP 13) represent local sand and are quite different in composition from the other samples. Amphiboles (chiefly green hornblende), pyroxenes (chiefly augite), and opaque minerals (magnetite, ilmenite, and pyrite) typically compose about three-fourths of the total; garnet and zircon are the other important heavy minerals. No significant variation in heavy-mineral composition with depth has been noted, with the possible exception that the orthorhombic pyroxenes (hypersthene and enstatite) are scarce or absent below depths of about 350 feet in the Yuma Mesa.

FIGURE 18.—View in southeastern Chocolate Mountains, Calif., showing predominantly fine-grained older alluvium abutting basaltic andesite or basalt of Tertiary age.

Other investigators in the region have reported similar conclusions. R. W. Thompson (written commun., 1963) states that amphiboles, pyroxenes, and opaque minerals compose more than 80 percent of the heavy-mineral total in sand of the lower Colorado River delta and Gulf of California; epidote, titanite, garnet, and zircon also are present in significant amounts. Imbrie and van Andel (1964) describe the north end of the Gulf of California as an amphibole-augite-garnet heavy-mineral province in which the Colorado River is the probable source of the sediments.

After sand, gravel probably is the most abundant material in the deposits of the old Colorado and Gila Rivers, especially in the upper several hundred feet of these deposits. Some of the gravel is coarse and contains many rounded cobbles and small boulders.

River gravel is exposed at many places throughout the Yuma area. Along the southeast margin of "Picacho Mesa" a gravel tongue can be traced for a distance of about 10 miles. Similar tongues occur farther north as much as 560 feet above sea level and also in the "Upper Mesa" as much as 580 feet above sea level. The highest known occurrences of river gravel in the Yuma area are at 740 feet above sea level on the southwest flanks of the Chocolate Mountains.

In the subsurface, river gravel occurs throughout the entire thickness of older alluvium and underlying transition zone to depths as great as 3,400 feet near the southwest corner of the area, although the coarse cobble-gravel strata probably extend no deeper than about 750 feet (pl. 6). The uppermost coarse-gravel strata beneath the river valleys and

FIGURE 19.—Crossbedded coarse sand and fine gravel in exposure of older alluvium 6 miles west of Yuma. The more resistant sand laminae in these old deposits of the Colorado River have a slightly higher content of calcareous cementing material than the rest of the sand.

Yuma Mesa constitute the principal aquifer in the Yuma area and are referred to collectively as the coarse-gravel zone (p. H67). Brown and others (1956), who named the coarse-gravel zone, described it as a widespread blanketlike deposit underlying at least part of their "upper terrace" ("Picacho Mesa" and "Upper Mesa"), as well as the intervening Yuma Mesa and river valleys. However, detailed studies by both the U.S. Bureau of Reclamation (J. W. Julian, written and oral commun., 1967) and the U.S. Geological Survey have shown that the coarse river gravel in the older alluvium occurs as a complex of several gravel bodies of different ages, although it has not yet proved possible to determine the boundaries of all these bodies. The top and bottom of the coarse-gravel zone are therefore at different horizons and altitudes from place to place (pl. 7). Some of the irregularities in the zone are shown also in the geologic sections of the area (pls. 5, 6, 8). The coarse-gravel bodies, including those below the coarse-gravel zone, probably were deposited during the glacial stages of the Pleistocene, when the Colorado River was swollen by glacial melt water from the Rocky Mountains, and each gravel body fills a trench or valley scoured in older fills.

The top of the coarse-gravel zone slopes generally southwestward from altitudes of about 90 feet above sea level at the east end of South Gila Valley and 40 feet above sea level at Laguna Dam to about 80 feet below sea level at the southwest corner of the area (pl. 7). Corresponding depths below valley surfaces are about 70 feet in eastern South Gila Valley, 100 feet at Laguna Dam, and 170 feet at the southwest corner of the area. The increasing depth toward the southwest results chiefly from southwestward gradation of the uppermost coarse-gravel strata into finer deposits, so that the top of the coarse-gravel zone is at a lower horizon in the southwest than in the northeast.

Areas where the coarse-gravel zone does not appear to be present include the southeast margin of northern Yuma Mesa, "Picacho Mesa" and adjacent parts of "Bard Valley," most of the "Upper Mesa," and the northwest corner of Yuma Mesa and the adjacent northeast corner of Yuma Valley (pl. 7). The older alluvium of these areas is predominantly sandy, with only minor, apparently discontinuous streaks of fine gravel.

The river gravel differs markedly in several respects from the local gravel of the older alluvium. Unlike local gravel, in which bedding is indistinct and crossbedding rare, river gravel commonly is crossbedded; foreset bedding dips about 20°–30° and is conspicuous in many exposures. Cementation, generally calcium carbonate, is a widespread characteristic of the river gravel, both in exposures and in the subsurface. Compared to the local gravel, the river gravel is better sorted, and the clasts are more rounded and include a large proportion of hard, siliceous rocks (fig. 20). Gray and tan quartzite are generally the most abundant types of siliceous rocks; other types include red and brown jasper, gray and black chert, and a distinctive crosslaminated tan and maroon quartzite very similar to some of the Tapeats Sandstone of Cambrian age in the Grand Canyon. Except for a few pebbles of brown jasper, these hard siliceous rocks are completely absent in the gravel of entirely local origin.

In places the river gravel contains as much as 80 percent siliceous rocks, but the usual proportion is 30–60 percent (table 4). Other types of rocks include a variety of felsic plutonic (granitic) rocks; felsic to intermediate volcanic rocks (including abundant hard red welded tuff); various kinds of schist, gneiss, and fine-grained metamorphic rocks; vein quartz; pegmatite, aplite, and other dike rocks; and in places some limestone and dolomite. Worn, rounded fragments of silicified wood (probably desert iron-wood) also occur locally. Like the siliceous rocks, some of the plutonic, metamorphic, and volcanic rocks, especially the most resistant, well-rounded clasts, probably came from regions far upstream from Yuma, but others probably were con-

TABLE 3.—*Summary of heavy-mineral analyses of alluvial sand (deposits of the Colorado River of the Yuma area)*

[Analyses by U.S. Geol. Survey, Hydrologic Laboratory]

| Well | Number of samples | Range in depth of samples (feet) | Percentage of total heavy minerals [1] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Amphiboles | Pyroxenes | Opaques | Garnet | Zircon |
| (C-10-23)31bbb1 | 3 | 195-955 | 31 | 14 | 21 | 9 | 7 |
| (C-10-23)15aab | 2 | 400-851 | 32 | 18 | 16 | 9½ | 12 |
| (C-10-23)5ddd | 14 | 0-500 | 44 | 34 | 11 | 5 | 1½ |
| (C-8-22)35ccb | 10 | 85-600 | 40 | 34 | 16 | 4 | 2 |
| 16S/22E-23Caa | 2 | 100-248 | 28 | 16 | 28 | 10 | 8 |
| (C-11-24)23bcb | 7 | 39-1,038 | 33 | 21 | 16 | 12 | 7 |
| (C-8-23)33cdd [2] | 2 | 705-1,080 | 12 | 2½ | 22 | 20 | 11 |
| (C-7-22)14bcd | 3 | 77-209 | 30 | 14 | 33 | 9½ | 5 |
| (C-10-25)35bbd | 10 | 51-2,823 | 30 | 18 | 23 | 9 | 5 |
| Average for eight wells | | | 34 | 21 | 20 | 8½ | 6 |

[1] Other heavy minerals present in significant amounts include epidote, biotite, tourmalne, apatite, and titanite.
[2] Samples from (C-8-23)33cdd not included in averages; probably represent deposits of local origin.

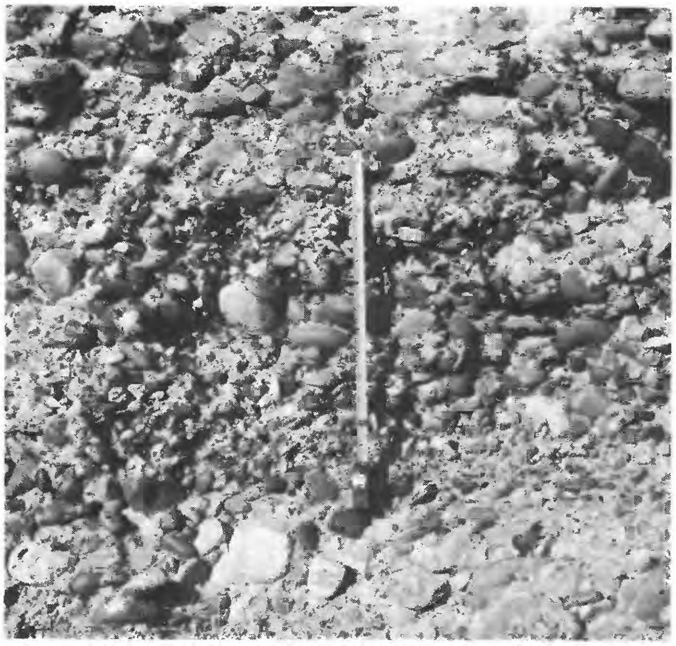

FIGURE 20.—Well-rounded to subrounded Colorado River gravel in an exposure of older alluvium southwest of Pilot Knob. Pebbles and cobbles are chiefly quartzite and chert in a matrix of lime-cemented coarse sand. Steel tape (extended to a little more than a foot) gives scale.

tributed from local sources. Welded tuff derived from the local Tertiary volcanic sequence is locally abundant, and some of the granitic clasts undoubtedly had local sources.

A few of the most significant characteristics of the gravel penetrated in test wells and deep private wells are summarized in table 4. Each sample consisted of 100 pebbles and small cobbles selected at random from the bulk sample obtained from the depth interval indicated. Clasts ranged in size from about ½ inch to 4 inches; most were in the range of 1–2 inches. Identifications were made by hand lens.

Most of the samples appear to be river gravel, although in some of the samples the angularity of the clasts and the relatively low percentage of quartzite and chert suggest local origin.

Possibly the most significant parameter in the gravel analyses is the percentage of black chert. Recent studies of the south-central Yuma area by the U.S. Bureau of Reclamation (J. W. Julian and Earl Burnett, oral commun., 1966–67) have shown that the deeper, older gravel strata in the older alluvium have a noticeably higher concentration of black chert than the shallower, younger gravel strata. The figures in table 4 tend to substantiate that conclusion, although admittedly the data are too few to indicate more than a general trend. The source or sources of the black chert have not yet been identified with certainty; M. E. Cooley (oral commun., 1967) reports that similar black chert in the Grand-Glen Canyon region was probably derived originally from the Mescal Limestone (upper unit of the Precambrian Apache Group) of central Arizona, from which it was deposited in the Shinarump Member and other conglomeratic sandstone units of the Chinle Formation (Upper Triassic), and whence reworked later by the Colorado River. M. E. Cooley (written commun., 1969) reports also that no black chert has been observed in the terrace gravel of the Gila River between Hyder and Phoenix, Ariz., although black chert is present in the Mescal Limestone in the canyon of the Salt River, a tributary of the Gila near Phoenix. The paleogeographic significance of the relative abundance of black chert in the river gravel of different ages and different sources may be a fruitful subject for future investigation.

Although generally less abundant in the older alluvium than sand and gravel, clay and silt strata are locally conspicuous, especially below depths of

TABLE 4.—*Selected data from analyses of gravel from wells in older and younger alluviums*

[Analyses by F. J. Frank. Average roundness (Wadell, 1932; Krumbein and Sloss, 1951) derived by assigning the following roundness values to each of four categories described by visual inspection: Well rounded, 0.875; subrounded, 0.625; subangular, 0.375; angular, 0.125]

| Well | Depth of sample (feet) | Average roundness | Percentage | |
|---|---|---|---|---|
| | | | Quartzite and chert | Black chert |
| (C–7–22) 14bcd | 111–125 | 0.70 | 52 | ([1]) |
| | 177–183 | .60 | 36 | ([1]) |
| (C–8–22) 15bdd | 109–120 | .54 | 45 | 6 |
| | 135 | .70 | 43 | 2 |
| | 145–150 | .53 | 41 | 10 |
| | 260–280 | .50 | 34 | 15 |
| | 285–290 | .43 | 47 | 21 |
| | 415–420 | .40 | 42 | 11 |
| (C–8–22) 19ccc | 225–235 | .44 | 37 | ([1]) |
| | 355–375 | .47 | 41 | 9 |
| | 390–400 | .58 | 36 | 16 |
| | 440–465 | .49 | 30 | 12 |
| (C–8–22) 33cbb | 109–120 | .58 | 35 | 5 |
| (C–8–22) 35caa1 | 89 | .60 | 43 | 0 |
| | 122 | .59 | 22 | 2 |
| | 548–556 | .56 | 32 | 11 |
| (C–8–22) 35ccb | 150–185 | .70 | 56 | 0 |
| | 190–240 | .68 | 50 | 0 |
| | 240–245 | .54 | 45 | 3 |
| | 273–300 | .42 | 54 | 20 |
| | 415–425 | .38 | 43 | 13 |
| | 495–515 | .36 | 55 | 20 |
| | 560–570 | .37 | 51 | 15 |
| (C–10–23) 11ccb | 131–163 | .68 | 59 | 12 |
| | 332–336 | .66 | 56 | 11 |
| (C–10–23) 15aab | (?) | [2] .44 | 72 | 27 |
| | 615–670 | .61 | 72 | 22 |
| | 730–754 | .55 | 59 | 23 |
| | 754–798 | .48 | 62 | 19 |
| | 848–856 | .49 | 57 | 22 |
| (C–10–23) 31bbb1 | 137–150 | .66 | 39 | 3 |
| | 178–190 | .60 | 41 | 7 |
| | 395–407 | .49 | 56 | 28 |
| | 545–560 | .49 | 62 | 26 |
| (C–11–24) 23bcb | 186–196 | .72 | 38 | 9 |
| | 211–226 | .62 | 46 | 10 |
| | 370–379 | .74 | 87 | 25 |
| | 381–394 | .77 | 79 | 26 |
| | 398–410 | .75 | 77 | 14 |
| | 472–490 | .74 | 80 | 30 |
| | 523–540 | .70 | 70 | 20 |
| | 627–630 | .74 | 76 | 27 |
| | 682–685 | .64 | 64 | 17 |
| | 850–866 | .69 | 65 | 24 |
| | 987–990 | .60 | 62 | 18 |
| | 1,004–1,006 | .59 | 57 | 11 |
| 16S/23E–10Rcc | 110–155 | .56 | 28 | 6 |
| | 224–264 | .58 | 43 | 13 |
| | 334–364 | .47 | 26 | 13 |
| | 495–515 | .45 | 51 | 8 |

[1] Black chert not differentiated in count.

[2] Roundness probably too low; many pebbles in sample were broken by drill.

1,000–1,500 feet in the southern part of the area (pl. 6) and in the uppermost deposits, above the coarse-gravel zone (pls. 5 and 8). These fine-grained strata can be identified readily on electric logs by their low resistivity and on gamma logs by their relatively high natural gamma radiation. The high gamma intensity of most beds suggests a substantial clay content, although most samples from wells, together with evidence of at least moderate permeability, indicate the presence of much sand and silt. Brown and others (1956, p. 20) report that particle-size analyses of samples from U.S. Bureau of Reclamation observation wells drilled on Yuma Mesa showed that pure clay is uncommon; particle-size analysis of a representative bed described by the driller as "silty clay with sand streaks" or "silty sand with clay streaks" might show about 55 percent clay, 30 percent silt, and 15 percent sand.

The clay and silt strata of the older alluvium are typically brown to gray, in contrast with the greenish- to bluish-gray marine clay and silt of the underlying transition zone and Bouse Formation. A nonmarine origin for the fine-grained strata of the older alluvium is suggested by the abundance of fossil twigs, roots, and root fillings, the scarcity or absence of marine fossils, the close association with coarser strata of obviously fluvial origin, and the similarity to flood-plain clay and silt at the top of the younger alluvium. Slack-water deposition on broad flood plans is the most likely origin.

Little work has been done on the determination of the mineral composition of the clay and silt in the Yuma area. Two samples of clay and silt from U.S. Geological Survey test well (C–10–23) 31bbb1 (LCRP 1) were analyzed by X-ray diffraction in the Hydrologic Laboratory of the U.S. Geological Survey at Denver, Colo., with the following results:

| | *Approximate mineral content (percent)* | |
|---|---|---|
| | *115–120 ft* | *735–736 ft* |
| Clay minerals: | | |
| Illite | 7.5 | 6.3 |
| Kaolinite | 7.5 | 4.9 |
| Montmorillonite | 45.0 | 51.8 |
| Mixed-layer | 15.0 | 7.0 |
| Quartz | 13 | 13 |
| Calcite | 9 | 10 |
| Dolomite | Trace | 5 |
| Potassium feldspar | 2 | -- |

Montmorillonite, the dominant clay mineral in both samples, is common in arid environments, especially where source rocks include volcanic ash or tuff. Montmorillonite has the property of expanding its crystal structure to accommodate variable amounts of water, and a body of it moistened with water tends to thus swell and become impermeable. Montmorillonite has a considerable capacity for base (cation) exchange.

Seismic-reflection data indicate that some of the deeper beds of clay and silt extend several miles laterally. Extensiveness is suggested also by somewhat uncertain correlation of several of the thicker fine-grained beds between wells (C–11–25) 11ab and (C–10–25) 35cab, which are about 2 miles apart (pl. 6).

Some of the clay and silt strata in the uppermost part of the older alluvium beneath Yuma Mesa can be traced several miles in wells and good exposures. One prominent bed 5–15 feet thick of fine sandy silt and clay is exposed in the escarpment along the northern and western edges of Yuma Mesa, where it extends, with some interruptions, more than 15 miles.

Two fine-grained beds in the top part of the older alluvium have been identified in wells beneath sizable areas of eastern Yuma Valley and western Yuma Mesa. The lower bed, informally designated clay A (fig. 21 and pl. 5), is not far above the coarse-gravel zone beneath Yuma Valley and adjacent parts of Yuma Mesa. This bed ranges in thickness from a few inches to about 35 feet. Parts of clay A appear to grade laterally into coarser materials at different places, so it is difficult if not impossible to trace a single horizon far enough to determine the precise attitude of the bedding beneath a large area. In general, however, the middle of the bed seems to have approximately the same slope toward the southwest as the present surface of Yuma Valley.

Southeast of Somerton, where clay A is thickest and least sandy, its middle part lies about at sea level (pl. 5, geologic section *E–E′* and fig. 21). In places along the margins of the bed the clay and silt grade laterally into pebbly clay and other ill-sorted gravelly deposits which, like the clay and silt, are characterized by high gamma radiation. Clay A underlies an area of at least 33 square miles.

Clay B is the informal designation applied to another, higher fine-grained bed that occurs beneath western Yuma Mesa at an average altitude of about 100 feet above sea level (fig. 22 and pl. 5). Clay B is even more extensive than clay A, underlying an area of at least 42 square miles, and it probably extended farther west before it was removed by erosion when Yuma Valley was cut (fig. 22). Clay B is 10–15 feet thick at most places; more than half the thickness is clay and silty clay, the remainder is silt, fine sand, and scattered pebbles. Toward the northwest the bed is difficult to distinguish from other strata of clay and silt above and below; possibly clay B underlies much of he city of Yuma. Like clay A, clay B grades laterally into pebbly clay and other heterogeneous gravelly deposits, particularly toward the southwest (fig. 22). Along its southeastern margin, clay B may abut older deposits that are exposed in the "Upper Mesa" farther southeast.

### YOUNGER ALLUVIUM (QUATERNARY)

The younger alluvium comprises all the alluvial deposits of the most recent major cycle of deposition. These deposits underlie the present river flood plains, the washes, and the alluvial fans. At these places, aggradation has been the dominant process during the last several thousand years, although locally degradation seems to have occurred most recently. Soils on the younger alluvium are immature and lack the profile development characteristic of the exposures of older alluvium.

The younger alluvium has been classified in three categories according to the dominant agent of deposition: (1) Deposits of the Colorado and Gila Rivers, (2) alluvial-fan deposits, and (3) wash and sheetwash deposits (fig. 11). Each of these three categories or subunits is described briefly below.

#### DEPOSITS OF THE COLORADO AND GILA RIVERS

The deposits of the Colorado and Gila Rivers underlie the present river flood plains. Until Hoover Dam and other large dams were constructed on both the Colorado and the Gila Rivers, floods added increments of predominantly fine-grained deposits to the flood plains. The rivers continually shifted their courses across the flood plains in meandering channels. In Yuma Valley the sites of many of the old meanders are marked by long, narrow, arcuate or sinuous sand dunes which accumulated on the leeward sides of the channels.

The river deposits consist predominantly of sand and silt. Pebbly sand and silt are abundant in places, especially in the lower part, and beds of clay and silty clay, which are rarely more than a few feet thick, are locally extensive. One extensive bed of silt and clay lies immediately beneath the flood plains of the Colorado and Gila Rivers. It is not present everywhere, having been replaced by scour and fill of sand along channels occupied by the rivers during relatively recent times, probably within the last few hundred years. In northern and central Yuma Valley the silt and clay range in thickness from a few feet to as much as 30 feet (pl. 5). Deposition on the flood plain during times of overbank flow is the most likely origin.

The river sand of the younger alluvium is generally similar to that of the older alluvium, except that it is commonly looser. Van Andel (1964, p. 236) gives the following composition for a sand from the Colorado River near Yuma: Quartz, 73.3 percent; feldspar (chiefly potassium feldspar), 18.8 percent; and rock fragments, 7.9 percent.

A gravel occurs at the base of the younger alluvium of the Colorado River at depths of about 100–130 feet in the Parker-Blythe-Cibola area 30–100 miles north of Yuma, where it has been dated

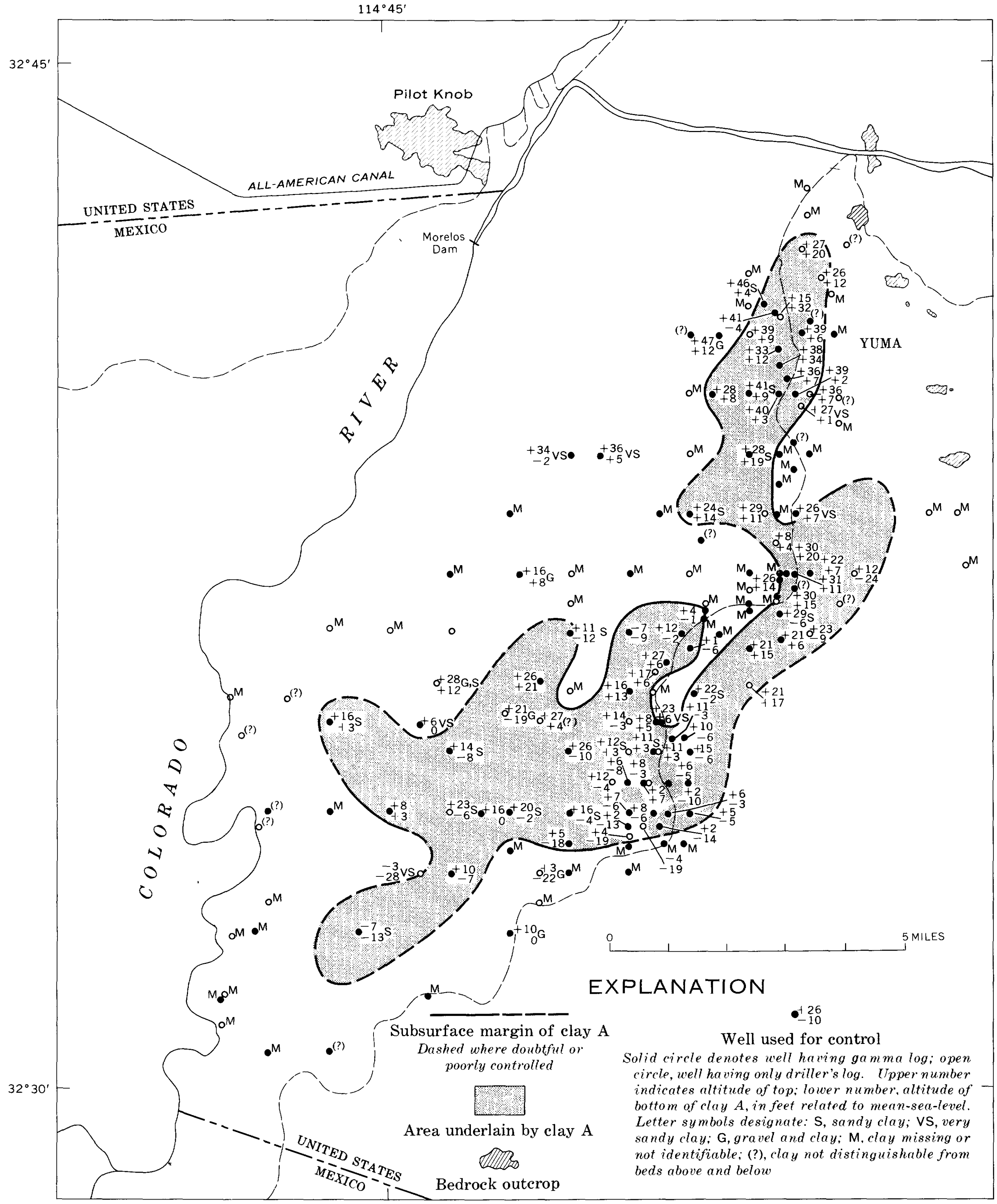


**Figure 21.**—Extent and altitude of top and bottom of clay A beneath Yuma Valley and northwest margin of Yuma Mesa.

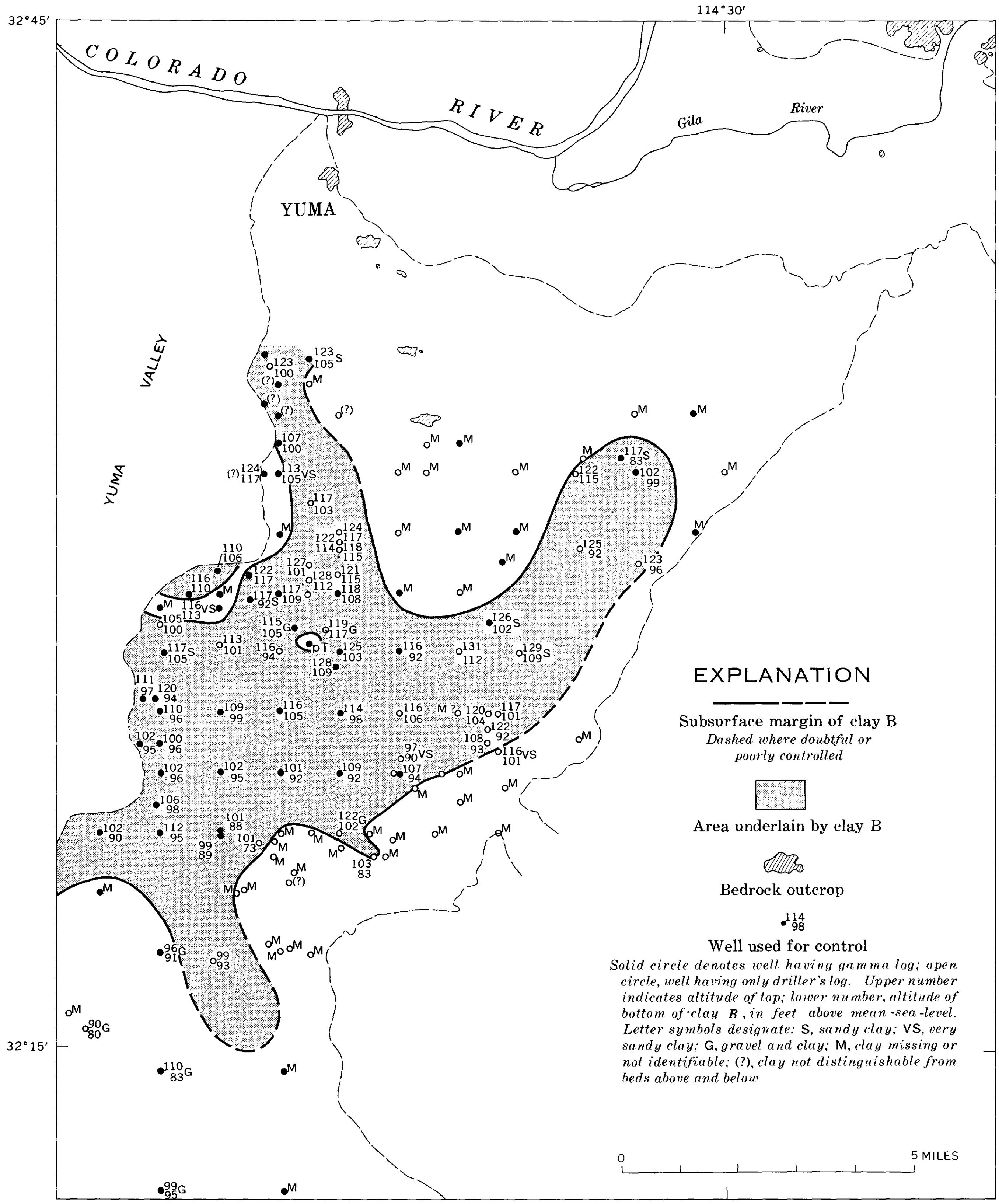


**Figure 22.**—Extent and altitude of top and bottom of clay B beneath Yuma Mesa.

by the radiocarbon method as less than 10,000 years old (Metzger and others, 1973). This gravel probably was the first material deposited during the most recent aggradation by the Colorado River as sea levels rose with the retreat of the last glaciers of the Wisconsin stage. Two samples of carbonized wood from overlying fine-grained younger alluvium in the same area gave radiocarbon ages of 5,380 and 6,250 years (Metzger and others, 1973).

The basal gravel of the younger alluvium of the Colorado and Gila Rivers has not been dated or positively identified in the Yuma area; accordingly, the younger alluvium and older alluvium are not differentiated in the geologic sections (pls. 5, 6, 8). If present in Yuma Valley, this gravel must occur in the western part; no significant gravel strata overlie clay A of the older alluvium in eastern Yuma Valley, which is at a depth of 80–90 feet below the land surface (pls. 5 and 8). In South Gila Valley, likewise, a basal gravel of the younger alluvium has not been definitely identified; if present, such a gravel must be nested in gravel of the older alluvium which extends southwest of the valley, beneath Yuma Mesa (coarse-gravel zone on pl. 8).

#### ALLUVIAL-FAN DEPOSITS

Although surfaces somewhat similar to alluvial fans are common in the Yuma area, true young alluvial fans—that is, thick accumulations of young deposits having fan-shaped aggradational surfaces—occur only in the southeastern part of the area, adjacent to the Tinajas Altas and Butler Mountains and at the northwest corner of the area, on the west flank of the Cargo Muchacho Mountains. In both these areas the deposits consist of poorly sorted granitic detritus derived from the exposures of granitic rocks in the mountains. U.S. Bureau of Reclamation test well CH–28YM on the southerly international boundary about 30 miles east of San Luis, Rio Colorado, Mexico, penetrated 310 feet of ill-sorted arkosic sand and silt with thin interbeds of calcareous clay, overlying older alluvium consisting of interbedded river deposits and local deposits, probably also of alluvial-fan origin. (See log of well (C–13–20)2abd1 in appendix B.) The scattered shallow exposures in this area reveal granitic (arkosic) sand and fine gravel (chiefly angular clasts of granite, felsic dike rocks, quartz, and feldspar), and interbedded silt and clay. The fan surfaces are characterized by a network of broad, shallow channels having a dendritic pattern where degradation has been the dominant recent process, and a distinctive rhomboidal pattern where aggradation (perhaps by sheetfloods) has been dominant most recently.

#### WASH AND SHEET-WASH DEPOSITS

The wash deposits occur in washes and channels cut into the older alluvium and prealluvial rocks. The deposits are generally thin and consist of sand and gravel and thin, lenticular beds of silt. In many washes, degradation rather than aggradation is the dominant process at present, and even the most recent wash deposits have been subject to extensive scour during floods.

The sheet-wash deposits are similar to the wash deposits but occupy broader, less well defined areas. They also resemble the alluvial-fan deposits. However, instead of forming fairly thick wedges like the alluvial-fan deposits, the sheet-wash deposits are thin blankets on older rocks and deposits, and are probably formed by sheetfloods and thin mudflows. Their most extensive development is in the "Laguna Mesa" north of the Laguna Mountains, where they consist of sand and silt reworked from the underlying older alluvium.

#### WINDBLOWN SAND (QUATERNARY)

The thickest and most extensive deposits of windblown sand are the Sand Hills ("Algodones Dunes") on the East Mesa of Imperial Valley, northwest of the Yuma area, proper. The less extensive "Fortuna Dunes" occur on the "Upper Mesa" and "Fortuna Plain" in the southeastern part of the Yuma area (fig. 6). These two dune areas are alined northwest and may once have been part of a continuous belt before the Colorado River formed what is now the Yuma Mesa and, later, the Yuma and Mexicali Valleys. The belt appears to extend southeastward into Mexico, where dunes are large and extensive. The "Algodones Dunes" and "Fortuna Dunes" are described earlier, in the section "Geomorphology" (p. H28).

Other, smaller dunes, as well as thin sheets of windblown sand, occur at many places throughout the area. One small area of low dunes and sand sheets is on the east side of The Island in Bard Valley, 3–4 miles northeast of Yuma. These deposits are adjacent to a meander channel of the Colorado River that was cut off within historic time. In Yuma Valley, long sinuous or arcuate dunes are widespread; they occur on the leeward sides of abandoned meanders. Most of these dunes (or perhaps more properly, sand ridges) are less than 20 feet high and 500 feet wide. Some are long in proportion to their width; one ridge just east of Somerton is more than a mile long. On Yuma Mesa, the windblown sand occurs in somewhat discontinuous thin sheets rather than in discrete dunes; most of this sand is on the inner margin of the Yuma Mesa, adjacent to the "Upper Mesa." Other small masses of windblown sand occur on the north flank of the Laguna Mountains and in scattered windrows on the "Upper Mesa."

The windblown deposits consist almost entirely of well-sorted fine to medium sand which is probably derived from nearby sandy alluvium or, with the "Algodones Dunes," from old lacustrine or marine beaches. The sand grains are subrounded to rounded, include many frosted grains, and are composed chiefly of quartz, with subordinate feldspar, rock fragments, and heavy minerals.

## STRUCTURE

### REGIONAL STRUCTURAL PATTERNS

The Yuma area lies at the southwest edge of the Sonoran Desert section and the northeast edge of the Salton Trough section of the Basin and Range province of Fenneman (1931, 1946). (See fig. 1.) The structural features of these two physiographic sections are somewhat different, both in pattern and in time of most actve development.

The Sonoran Desert east of Yuma is characterized by subparallel, narrow, low but rugged mountain ranges trending generally north-northwest, separated by much more extensive desert plains underlain by Cenozoic fill. The mountains probably owe their configuration at least in part to block faulting (Davis, 1903; Gilbert, 1928; Gilluly, 1946; Thornbury, 1965), although most of the marginal faults are concealed by the Cenozoic fill of the plains and must be inferred from geophysical and other indirect evidence (pl. 9). Some of the mountain masses, especially those adjacent to the Salton Trough, are buried or nearly buried by fill. The mountains and basins assumed approximately their present configuration by middle Tertiary time; subsequent deformation has involved only broad-scale warping and minor normal faulting, probably associated with regional subsidence along the southwest margin of the Sonoran Desert.

The Salton Trough, by contrast, has been tectonically active to the present time, especially west of the Yuma area, where movement on faults is still going on. The faults are part of the well-known San Andreas system. Along this major fault system, aggregate right slip (blocks southwest of the fault displaced northwestward relative to blocks northeast of the fault) in southern California has amounted to about 160 miles since earliest Miocene time, according to Crowell (1962). The faults of the San Andreas system in the Salton Trough trend somewhat more northwesterly than the mountains of the Sonoran Desert and their inferred bounding faults, although the two trends appear to converge to the southeast, in Mexico.

The Salton Trough has sunk rapidly during Cenozoic time and has accumulated as much as 20,000 feet of fill (Biehler and others, 1964). Much of this fill in the southern part of the trough consists of alluvial and deltaic deposits of the Colorado River.

### PRE-TERTIARY STRUCTURAL FEATURES

The structural features of the Yuma area may be classified according to the time of their principal development. Some deformation has affected only the pre-Tertiary crystalline rocks; other features probably had their maximum development during Tertiary time; and still others such as the faults of the San Andreas system have been active throughout late Tertiary and Quaternary time, although most of these faults originally formed earlier.

The structural features that affect only the crystalline rocks of pre-Teriary age did not all originate at the same time, but no attempt was made in the present study to decipher the sequence of the older deformational episodes. The pre-Tertiary structural features include old faults, metamorphic foliation and lineation, and joint systems. Most of the old faults are mineralized and filled with dikes and quartz veins.

The last major deformation affecting only the crystalline rocks was the Laramide orogeny, which occurred at the end of the Cretaceous period and extended, in its waning phases, into the early Tertiary (Damon and Mauger, 1966). The Laramide orogeny resulted in extensive folding, reverse and normal faulting, igneous intrusion and extrusion, and recrystallization of many of the older rocks. The rubidium-strontium date of 73 million years reported by Wasserburg and Lanphere (1965) for biotite in a porphyritic quartz monzonite at Yuma probably indicates a Laramide metamorphic event. Abundant evidence of Laramide plutonism and volcanism farther east in southern Arizona has been reported (Richard and Courtright, 1960; Creasey and Kistler, 1962; Lootens, 1966; Bikerman and Damon, 1966).

Laramide and pre-Laramide structural features are expressed topographically where rocks of different resistance to erosion are juxtaposed along faults, where faulting has formed easily eroded crushed or sheared rocks, and where extensive and conspicuous joint systems and metamorphic foliation have controlled patterns of erosion. The southeastern Laguna Mountains afford good examples of

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the effects of probable Laramide faults on topography. Joint systems and foliation have profoundly affected the topography of the Gila, Butler, and Tinajas Altas Mountains.

The present outlines of some of the ranges and basins in the Yuma area may be related to faulting and domal uplift that began during the Laramide orogeny and continued, at intervals, throughout much of the Tertiary, but present evidence on this question is inconclusive. Farther north, in the Great Basin section of the Basin and Range province, the block faulting that resulted in the present pattern of the basins and ranges is generally regarded as post-Laramide (Gilbert, 1928; Nolan, 1943; Mackin, 1960). However, some students of the basin-range problem have questioned this interpretation; Lovejoy (1963a) has ascribed the product of so-called basin-range faulting of classical theory to normal erosional processes acting on Laramide structures. Later workers have generally agreed with the interpretation of Gilluly (1946) that the faulting in southern Arizona (Ajo area) began earlier than it did farther north. In the Yuma area the outlines of the present basins and ranges resulted chiefly from Tertiary faulting, accompanied by domal uplift and basin subsidence, but some faults, particularly in the southeastern part of the area, date from the Laramide orogeny. Some of the Laramide faults thus became the loci of later activity.

### BASIN AND RANGE STRUCTURAL FEATURES (TERTIARY)

The so-called Basin and Range structural features, as apart from Laramide and earlier structural features, are not well understood in the Yuma area. Except for parts of the Chocolate Mountains and possibly the southern part of the Tinajas Altas Mountains, the present form of the mountains and intervening basins seems to be only indirectly related to faulting, uplift of the mountain blocks, and subsidence of the basins. The present mountain fronts are in most places erosional in origin. The faults that may determine the general pattern of the basins and ranges are mostly buried beneath alluvium and lie basinward from the mountain fronts, although a few faults within the Gila Mountains have helped to determine the general outline of those mountains.

The clearest evidence of Basin and Range block faulting in the Yuma area is found in the southeastern Chocolate Mountains, where middle Tertiary volcanic rocks are offset by antithetical faults, with southwesterly to westerly tilting of the fault blocks and steep northeasterly dips of fault planes. The sequence of volcanic rocks is probably repeated several times from northeast to southwest, although the actual throw on the faults and even some of their positions are uncertain. At some of the faults near Senator Wash Dam and Imperial Dam, nearly horizontal slickensides record strike-slip movement where the faults cut welded tuff or other hard volcanic rocks. The fault pattern in part of the exposures of basaltic andesite or basalt farther west indicate left-lateral displacement on north-northwestward-trending faults; intervening tension faults and fractures trend west-northwestward. The predominant trend of faults in the southeastern Chocolate Mountains is northwest, but another important set has a north-south trend.

In the Cargo Muchacho Mountains to the west, the exposed faults strike northwest to west. Henshaw (1942) suggests that the range may be an elevated block between two now-buried strike-slip faults which are approximately parallel to the San Andreas fault system (northwest). In the north-central part of the mountains, Henshaw (1942) mapped a thrust fault on which the upper plate was thrust from the south. Most of the other faults within the range are normal faults, however. The quaquaversal attitude of several flows of basalt on the margins of the mountains suggests domal uplift as well as faulting.

In the Laguna Mountains, the straight northeast margin of the exposures of crystalline rocks, and seismic-refraction data as well suggests a high-angle fault trending about N. 60° W., downthrown to the northeast. South of this probable fault is a set of normal(?) faults trending about northward; the youngest rocks affected are middle Tertiary volcanic and sedimentary rocks.

In the southeastern part of the Laguna Mountains is a set of concentric arcuate faults bending from an easterly strike on the west to northeasterly farther east. These faults are roughly parallel to the foliation and joints in the pre-Tertiary gneiss and probably developed before Tertiary time. At least one of the faults extends westward across exposures of early to middle Tertiary sedimentary rocks (pl. 4). Where the fault planes are clearly exposed they dip about 50°–80° north to northwest. Direction of net slip is generally unknown, but on two of the more southerly faults, pre-Tertiary gneiss is thrust over Tertiary nonmarine sedimentary rocks (red beds). Similar faults may extend beneath the alluvium between the Laguna and the Gila Mountains. In the southeastern Laguna Mountains are several small northwestward-trending normal faults. The throw on these faults is generally no more than 100 feet.

Bedding in the nonmarine sedimentary rocks in the Laguna Mountains dips generally west to southwest at angles ranging from a few degrees to more than 40°. The older part of the sequence, the red beds, dips west to north in an arcuate pattern; the attitudes of the bedding are generally similar to those of the foliation in the adjacent pre-Tertiary gneiss, but the dips are flatter. Evidently middle Tertiary deformation in this area had a pattern governed in large part by Laramide or older structures and merely accentuated these structural features in the pre-Tertiary rocks.

The Kinter Formation and the volcanic rocks in the southern part of the mountains overlie the older nonmarine sequence with marked angular discordance; dips of the Kinter are gentle toward the west and northwest where it fills an old valley trending west-northwest cut into the older rocks. In the northern part of the mountains the beds of the Kinter Formation have low, irregular dips and strikes indicating broad folding and warping.

In the southwestern part of the Laguna Mountains, alluvium of local origin unconformably overlying the Kinter Formation is very gently deformed. Bedding dips westward to southwestward at angles ranging from 1° or less to as much as 4°—not much more than the probable initial dips.

The easterly to northeasterly trending fault pattern of the southeastern Laguna Mountains continues southward into the northern Gila Mountains. A steep normal fault having a throw of more than 2,000 feet extends northeastward across the northern Gila Mountains, the Kinter Formation on the northwest being faulted against pre-Tertiary crystalline rocks on the southeast along the eastern part of its exposed length (pl. 4). Aeromagnetic data suggest that this fault continues southwestward beneath the alluvium of the South Gila Valley. The Kinter Formation is titled about 15°–30° toward the northwest along the northern margin of the Gila Mountains; foliation in the metamorphic rocks south of the fault dips southward to southeastward at about 40°–50°.

In the central and southern parts of the Gila Mountains several large faults near the margins of the range trend northwest to west-northwest. Probably other parallel faults exist farther out from the margins, where they are now buried by alluvium. The foliation and prominent joints in the crystalline rocks in this area dip 30°–60° southeast to south-southeast; another joint set dips northwest. These trends are athwart the long axis of the range and perpendicular to the margins. This pattern suggests that the margins of the mountains, which are fairly straight in most places, may be controlled at least indirectly by faults parallel or nearly parallel to the exposed faults. The western edge of the Tinajas Altas Mountains near the Mexican border is controlled in large part by such a fault (pl. 3). Farther northwest the parallel ridges of the Butler Mountains may result from en echelon faults trending about N. 50°–60° W. (pl. 9).

Between the Cargo Muchacho Mountains and the Chocolate Mountains, and farther south, between the "Yuma Hills" and the Laguna and Northern Gila Mountains, is a basin informally designated the "Picacho-Bard basin." The depth to the pre-Tertiary crystalline rocks along the axis of the basin increases southward from about 1,500 feet to about 3,500 feet, according to an interpretation of gravity data. The presence of a few outliers of crystalline rocks near the margins of the basin and the complexity of the gravity and magnetic patterns suggest that the bedrock surface has considerable local relief.

South of the Gila River the trough west of the Gila Mountains—essentially a continuation of the "Picacho-Bard basin" called the "Fortuna basin"—deepens rapidly and attains a depth estimated from gravity data to be about 16,000 feet. (See pl. 9.) As indicated by the log of well (C–9–22)28cbb (test well LCRP 25), only the upper one-eighth of the basin-filling deposits consists of alluvium of the Colorado and Gila Rivers; the lower seven-eighths probably is composed of marine and nonmarine deposits older than the Colorado River (Bouse Formation and older units).

Farther south, the "Fortuna basin" does not appear to be quite as deep. Estimates from gravity data and electrical soundings indicate that the basement (pre-Tertiary crystalline rocks) surface is 10,000–13,000 feet below the land surface in the middle of the basin just north of the southerly international boundary. Information from test well (C–13–20) 2 abd1 (USBR CH–28YM) and from a profile of electrical soundings indicates that only the upper 1,200 or 1,300 feet of the overlying fill is alluvium; the bulk of the basin-filling deposits probably are semiconsolidated marine and nonmarine sedimentary rocks of Tertiary age (pl. 10).

On the west side of the trough formed by the "Picacho-Bard basin" and the "Fortuna basin" is an irregular chain of basement highs composed of, from north to south, the Cargo Muchacho Mountains (described earlier), the "Yuma Hills," a buried ridge south of the "Yuma Hills" referred to informally as the "Mesa basement high," and a southeast-trending basement high culminating in the row of low hills, known as the "Boundary Hills," straddling the southerly international boundary (fig. 6).

The north-northwesterly alinement of outcrops of the "Yuma Hills" and various kinds of geophysical data indicate that these hills are the summits of a nearly buried ridge approximately parallel to the Gila Mountains and other ranges of the Sonoran Desert farther east. The "Yuma Hills" basement ridge probably is bounded on both sides by faults whose precise location and attitude can be only a matter of speculation at present.

The "Mesa basement high" is separated from the "Yuma Hills" to the north by a saddle in which the basement surface is estimated on the basis of geophysical data to be at a depth between 1,000 and 1,500 feet. Shallow test drilling by the U.S. Bureau of Reclamation and the U.S. Geological Survey, and geophysical exploration by the Geological Survey, have established that the highest part of the buried basement ridge, which is oriented northwest, is less than 100 feet below the surface of Yuma Mesa; well (C–9–23) 33cdd (USBR CH–20YM) penetrated porphyritic quartz monzonite at a depth of only 47 feet. The "Mesa basement high" is bounded on both northeast and southwest sides by faults (pls. 9, 10). The large fault on the southwest is the Algodones fault which is described on pages H61–H63; the other faults probably are parallel or en echelon to the Algodones fault.

Geophysical data suggest that southeast of the "Mesa basement high" and on the southwest side of the Algodones fault, the surface of the crystalline rocks slopes steeply southward into a broad saddle and thence rises southeastward to the line of low outcrops straddling the southerly international boundary—the "Boundary Hills." The "Boundary Hills" are composed of the same porphyritic quartz monzonite as that penetrated in test wells on the "Mesa basement high" and exposed in the "Yuma Hills" farther north.

Between the "Yuma Hills" and Pilot Knob is a basement trough oriented north-northeast referred to informally as the "Yuma trough." Geophysical data, supplemented by information from test wells 16S/22E–29Gca2 (USGS LCRP 26) and (C–8–23)32caa1 (Sinclair Oil Co. Kryger 1) and from water well 16S/21E–36Fca, show that the basement surface is deepest in the eastern part of the trough, where the sedimentary fill includes the Tertiary nonmarine sedimentary rocks below the less deformed Bouse Formation, transition zone, and older and younger alluviums. Farther west, within 2 or 3 miles of Pilot Knob, the crystalline basement is shallower and is overlain only by the older and younger alluviums or, in places, the transition zone and Bouse Formation.

Gravity and magnetic data indicate a deep basin between the "Boundary Hills" and San Luis which is given the informal name "San Luis basin." (See pl. 9.) The axis of the "San Luis basin" trends west-northwest along the southerly international boundary. Estimates indicate that the depth to basement in the middle of the basin is about 13,500 feet. Oil-test well (C–10–24)24cbb (Colorado Basin Associates Federal 1) on the north side of the basin bottomed in Tertiary nonmarine sedimentary rocks at a depth of 6,007 feet (pl. 10).

### LATE TERTIARY AND QUATERNARY STRUCTURAL FEATURES

The older and younger alluvium, the underlying transition zone, and the Bouse Formation, which range in age from late Tertiary (Pliocene) to Quaternary (Holocene), are substantially less deformed than the pre-Bouse rocks, from which they are separated by significant angular unconformities. Nevertheless, except for the younger alluvium and possibly the upper parts of the older alluvium, these late Tertiary and Quaternary units are affected by broad-scale warping and local faulting.

Deformation of the older alluvium on the flanks of the mountains consists chiefly of slight tilting with dips as much as 6° away from the mountains, and, locally, of small-scale high-angle normal faulting. Uplift of the mountains in post-older alluvial time is indicated by the presence of Colorado River deposits as high as 740 feet above sea level on the flanks of the southeastern Chocolate Mountains and about 580 feet above sea level on the west flank of the northern Gila Mountains. Even greater uplift since the deposition of the Bouse Formation is indicated by the presence of basal limestone and tuff of the Bouse at an altitude of about 1,000 feet above sea level in a gap in the Chocolate Mountains 10 miles beyond the north edge of plate 3 (Metzger, 1968).

In the subsurface, a measure of the maximum deformation since the late Tertiary is provided by the configuration of the top of the Bouse Formation (fig. 15). The Bouse, being marine, presumably was nearly horizontal at the time of deposition; the basal beds of the overlying transition zone are the earliest deposits of the Colorado River, which must have been laid down not far above sea level. The maximum dip of the top of the Bouse Formation is about 9°–10°. These deposits have been downwarped in the basins such as "Fortuna basin" and differentially upwarped along the margins of the mountain blocks (pl. 10). The top of the Bouse Formation is more than 3,000 feet below sea level in the southwest corner of the Yuma area, near San Luis (fig. 15 and pl. 10). This probably reflects broad-scale downwarp or subsidence in the Colorado delta region as well as more local downwarp or down faulting in the basins. At least part of the downwarp results from differential compaction in the fine-grained deposits. Farther west, in the central part of the Salton Trough, probably nonmarine deposits (possibly of the Colorado River?) have been penetrated in oil-test wells at depths exceeding 13,000 feet (Muffler and Doe, 1968), which indicates much greater downwarp or subsidence there.

Structural activity has generally occurred more recently in the Salton Trough than it has farther northeast, in most of the Yuma area. The trough is crossed at acute angles by northwest-trending faults of the well-known San Andreas system. Many members of this system are well delineated by seismic and gravity data in the delta region (Biehler and others, 1964). One of these faults and several other probably related faults that cross the Yuma area are described in the following section.

### ALGODONES FAULT AND RELATED FAULTS

The San Andreas fault system is a major crustal feature along the northeast margin of the Pacific Ocean. The Gulf of California—a southern extension of the Salton Trough—was probably formed by oblique rifting across the system (Hamilton, 1961) and probably also by ocean-floor spreading (Larson and others, 1968). Displacements on the faults have been right lateral and, in southern California, may have amounted to as much as 160 miles since early Miocene time (Crowell, 1962). An earlier date has been postulated for some of the faults by Hill (1965), who believes that possibly several hundred miles of right slip has occurred since the Cretaceous.

One of the main branches of the San Andreas system extends along the northeast side of Coachella Valley southeastward to the northeast shore of Salton Sea. Allen (1957) calls this branch the Banning-Mission Creek fault; Dibblee (1954) considers it the San Andreas, itself. Southeast of Salton Sea the trace of the fault is concealed by unaffected alluvium and windblown sand, so its precise trend is not known. Biehler (unpub. Ph. D. thesis, 1964; oral commun., 1967) interprets a strong alinement of gravity lows as indicating the trace of the fault where it is concealed by the Sand Hills ("Algodones Dunes"). On the basis of this evdence and of further evidence from seismic data (Kovach and others, 1962), the fault appears to extend beneath the Sand Hills to a point on the Colorado River south of Pilot Knob; the exact location is uncertain.

The fault just described (or possibly a parallel fault) appears to continue southeastward across the Yuma area from a point on the Colorado River about a mile south of Morelos Dam to the southerly international boundary 26 miles east of the Colorado River at San Luis (pls. 3 and 9). It is herein named the Algodones fault from the village of Algodones just northeast of the trace of the fault in the northeastern corner of Baja California, Mexico. The evidence for the Algodones fault is summarized:

1. *Anomalous topography on the "Upper Mesa."*—The existence of the Algodones fault was first inferred from a topographic anomaly on the "Upper Mesa," in the southeast part of the area of investigation. The anomaly consists of a northwestward trending drainage system approximately perpendicular to the normal, consequent streams draining southwestward from the Gila Mountains. The inferred fault trace is along this system, at the foot of an eroded northeast-facing alluvial escarpment. The mesa surface southwest of the fault is 30–60 feet higher than the surface to the northeast and slopes toward the west-southwest at about 30–40 feet per mile (pl. 1). Lineaments apparent on vertical aerial photographs suggest that the fault has a branching pattern in the central part of the "Upper Mesa."
2. *Offset of the water table and ground-water barrier effect.*—Test wells in the "Upper Mesa" indicate an abrupt offset in the water table along the inferred fault trace. Water levels northeast of the fault are more than 30 feet higher than those southwest of the fault near the northwest edge of the "Upper Mesa" and about 7 or 8 feet higher near the southerly international boundary (pl. 1). Measurements in private irrigation wells and government observation wells indicate that the water-table offset continues about 3 miles northwestward beneath Yuma Mesa, although this part of the fault trace is concealed.

   The water-table offset results from the function of the fault as a barrier to ground-water movement. The barrier effects of faults in alluvial materials are well known and are commonly attributed to: (a) Pulverization of earth materials along the fault, (b) offset of bedding so that impermeable beds are juxtaposed against permeable beds, (c) rotation of flat or elongate clasts parallel to the fault, thereby decreasing permeability normal to the fault plane, and (d) deposition of minerals along the fault surface (Davis and De Wiest, 1966, p. 396). The first and fourth factors listed above are probably most significant at the Algodones fault. Electrical-analog data, described on page H108, indicate that observed changes in water level on both sides of the fault are best modeled by assuming that the transmissivity of the fault barrier is less than one-thousandth of that of the alluvial deposits on either side. The configuration of the water table-water-level contours on both sides of the fault are nearly perpendicular to the fault trace—also supports the conclusion that very little ground water moves across the fault.

3. *Magnetic gradients.*—A steep magnetic gradient along the southwest side of the buried "Mesa basement high" suggests a fault or series of step faults on which the basement is downthrown to the southwest. The zone of steep gradient extends across Yuma Valley to the northwest and indicates that the inferred fault or fault zone crosses the Colorado River somewhere between 1½ and 4 miles south of Pilot Knob.
4. *Gravity patterns.*—Gravity data generally corroborate the magnetic data. Also, the gravity data indicate a very steep gradient on the northeast flank of the "Boundary Hills" basement high, which suggests downthrow of the basement surface toward "Fortuna basin" along a fault about in the position of the fault inferred from topographic and hydrologic evidence.
5. *Seismic-reflection data.*—Seismic-reflection profiles made by a commercial firm under contract to the U.S. Bureau of Reclamation revealed several faults including what is interpreted herein as the main Algodones fault. The faults offset reflecting horizons such as the top and bottom of the Bouse Formation and the top of the transition zone, and locally are associated with steep dips of the reflecting horizons (Snodgrass, 1965, 1966). On a profile along the limitrophe section of the Colorado River, the top of the Bouse Formation was determined to be downthrown 500 feet to the south or southwest along a fault that is probably the main Algodones fault about 2½ miles south of Pilot Knob (Snodgrass, 1966). (See pl. 10.) The faults inferred to be parallel to the Algodones fault near the "Mesa basement high" (pls. 9 and 10) all were determined from seismic-reflection data.
6. *Seismic-refraction data.*—A seismic-refraction profile extending southward from the crest of the "Mesa basement high" revealed that the basement surface is downthrown 350 feet toward the south or southwest along a steeply dipping fault in alinement with the projected extension of the ground-water barrier to the southeast. This fault is interpreted as being the main Algodones fault (pl. 10).
7. *Ground-water-temperature anomalies.*—Although the Algodones fault is concealed beneath Yuma Mesa and Yuma Valley, its position throughout much of its extent across these features is revealed by an elongate body of anomalously warm ground water, mostly on the northeast side of the inferred fault trace (fig. 47). Similar temperature anomalies farther southwest probably reflect parallel or en echelon faults. The elevated temperatures of these anomalies are probably the result of upward movement of deep warm water induced by the barrier effects of the faults. However, the effect of the buried basement ridge at the "Mesa basement high" may in part account for the temperature anomaly along the Algodones fault.

In addition to the methods of investigation described above, attempts were made to delineate the Algodones fault beneath Yuma Mesa by use of resistivity profiles and electrical soundings. Unfortunately, the resistivity surveys did not provide the expected information as to the location and nature of the fault or fault zone. Information on the attitude and width of the fault, and on whether the barrier effect results primarily from pulverized material (gouge) or from cemented material, must await detailed exploration by test drilling or excavation.

Likewise, unambiguous information on the direction and amount of movement on the Algodones fault is not yet available. Analogy with other, better known faults in the San Andreas system suggests chiefly right-lateral movement; this inference is substantiated to some extent by gravity and magnetic patterns. However, vertical components of movement also are indicated by some of the evidence summarized above. Northwestward from the vicinity of the "Mesa basement high" the southwest side is downthrown, but to the southeast, across the "Upper Mesa," the throw is opposite. Such reversals in throw along the strike are common along other faults in the San Andreas system which have had predominantly strike-slip movements.

The last significant movement on the Algodones fault can be dated approximately by geology and topography. The fault is exposed on the "Upper Mesa" but is concealed beneath apparently unaffected alluvial deposits in both the Yuma Mesa and Yuma Valley. The uppermost coarse-gravel strata of the older alluvium (coarse-gravel zone) are not offset, at least vertically, beneath western Yuma Mesa and eastern Yuma Valley (pls. 5 and 8). The age of the Yuma Mesa surface is late Pleistocene—perhaps Sangamon (p. H27)—and the presumably unaffected gravel strata are somewhat older. The age of the "Upper Mesa" surface, which is offset, has not been established but almost certainly is older than latest Pleistocene. It is therefore inferred that significant movement on the Algodones fault ceased before the latest Pleistocene. Movement on the parallel or en echelon faults probably ceased even earlier; this is indicated by the lack of topographic expression of these faults on the "Upper Mesa" and from the apparent absence of significant hydrologic effects (other than thermal effects) caused by these faults. By contrast, many faults of the San Andreas system crossing the Salton Trough farther west are still active, which indicates the more recent deformation of that region as compared to the Sonoran Desert.

## GROUND-WATER HYDROLOGY

### THE GROUND-WATER RESERVOIR

The limits of the ground-water reservoir in the Yuma area are considered as being formed by the crystalline rocks of pre-Tertiary age. These rocks include many types, but all are dense and contain only small quantities of water in open fractures and weathered zones within a few tens of feet of the land surface and possibly to greater depths in faults and shear zones. In the arid environment of Yuma, most of the small quantity of water in the crystalline rocks near the mountains and hills occurs far above the regional water table as small, discontinuous perched bodies.

The ground-water reservoir is therefore composed of the Cenozoic basin-fill deposits overlying the pre-Tertiary crystalline rocks. The general configuration of the basins was discussed in the preceding section on structure. The thickness of fill in the deepest parts of some of the basins probably exceeds 16,000 but only the upper 2,000–2,500 feet at these places is composed of fresh-water-bearing alluvial deposits. For this reason, the ground-water reservoir is considered as being composed of two parts, which are discussed separately below.

#### MAJOR SUBDIVISIONS OF THE RESERVOIR

The ground-water reservoir consists of two major subdivisions: (1) Poorly water-bearing rocks of Tertiary age and (2) water-bearing deposits of Pliocene to Holocene age. The first subdivision constitutes the lower part of the reservoir and includes the following stratigraphic units: (1) The nonmarine sedimentary rocks, (2) the volcanic rocks, (3) the older marine sedimentary rocks, (4) the Bouse Formation, (5) the transition zone, and (6) the conglomerate of the Chocolate Mountains. The volcanic rocks and the conglomerate of the Chocolate Mountains appear to be of very minor subsurface extent within the area of principal hydrologic investigation and are not considered further in this section of the report. The stratigraphic units of the second subdivision include: (1) The older alluvium, (2) the younger alluvium, and (3) the windblown sand. These units contain most of the fresh ground water. For convenience, the water-bearing deposits of the second subdivision are further subdivided into water-bearing zones that cross stratigraphic boundaries, as discussed on pages H66–H69.

#### DEFINITION OF FRESH WATER

In describing the fresh-water part of the ground-water reservoir, the term "fresh water" requires definition. Fresh water is an imprecise term probably best defined as water that has a sufficiently low mineral content to be acceptable for ordinary uses. The Office of Saline Water defines fresh water as that containing not more than 3,000 mg/l of dissolved solids. In many reports of the U.S. Geological Survey, fresh water is defined as that containing not more than 1,000 mg/l of dissolved solids—a useful limit in most parts of the United States where such water is widely available. However, in the Yuma area, as in many other desert areas, more highly mineralized water is used extensively; not many wells yield water containing less than 1,000 mg/l dissolved solids. On the other hand, water containing as much as 3,000 mg/l dissolved solids is injurious to some of the local salt-sensitive crops and is not considered acceptable for general domestic use. Accordingly, a limit of 1,800 mg/l probably is applicable to local conditions and is used in this report. This limit corresponds approximately to a specific conductance of 3,000 micromhos per centimeter (hereinafter abbreviated to micromhos), which is used as the upper limit for fresh water in the interpretation of electric logs of wells.

## POORLY WATER-BEARING ROCKS OF TERTIARY AGE

Within the area of principal geohydrologic investigation, the lower part of the ground-water reservoir—the poorly water-bearing rocks of Tertiary age—includes, in ascending order: (1) The nonmarine sedimentary rocks, (2) the older marine sedimentary rocks, (3) the Bouse Formation, and (4) the transition zone. Inferences as to the subsurface extent and configuration of these units (pl. 10) are based primarily on records of 31 test wells and water wells (table 5) and on geophysical data. In parts of

TABLE 5.—*Depths of Tertiary and pre-Tertiary horizons in wells*

| Well | | Name of well or owner | Altitude of land surface (feet) | Total depth (feet) | Depth, in feet, to top of— | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Transition zone | Bouse Formation | Older marine sedimentary rocks | Non marine sedimentary rocks | Crystalline rocks | |
| (C–7–22) | 14bcd | USGS LCRP 14 | 155.1 | 505 | ---- | 209 | ---- | 471 | ---- | |
| (C–8–21) | 16bca | Tanner Paving Co. | 195 | 396 | ---- | ---- | ---- | 207(?) | ---- | |
| (C–8–22) | 15bdd | USBR CH–6 | 140.5 | 501 | ---- | 422 | ---- | 497 | ---- | |
| | 15dab | Gila Valley Oil & Gas Co Kamrath 1. | 145 | 2,140 | ---- | 422 | ---- | 482 | ---- | |
| | 35caa1 | USBR CH–704 USGS LCRP 29. | 150.8 | 1,997 | 794(?) | 1,045 | 1,396 | ---- | ---- | Top of transition zone may be at 885 ft. |
| (C–8–23) | 21caa | Yuma School District 1. | 175 | 404 | ---- | ---- | ---- | 280(?) | ---- | |
| | 21cac | Abe Marcus Pool | 175 | 478 | ---- | ---- | ---- | 300(?) | 470 | "Granite" at bottom. |
| | 32caa1 | Sinclair Oil Co. Kryger 1. | 120 | 1,400 | ---- | 972(?) | ---- | 1,243 | 1,398 | Do. |
| | 33cdd | Stardust Hotel USGS LCRP 13. | 197 | 1,090 | ---- | ---- | ---- | ---- | 1,085 | Porphyritic quartz monzonite at bottom. |
| | 35caa | S & W Ranches | 141 | 191 | ---- | ---- | ---- | ---- | 190 | "Granite" at bottom. |
| (C–9–21) | 13ccb | B. Palon | 423 | 603 | ---- | ---- | ---- | ---- | 563 | |
| | 14bac | do | 395 | 1,085 | ---- | 700 | ---- | ---- | 1,082 | Do. |
| (C–9–22) | 28cbb | USGS LCRP 25 | 204.6 | 2,318 | 2,101 | ---- | ---- | ---- | ---- | |
| (C–9–23) | 2cda | Yuma County Fairgrounds. | 212 | 306 | ---- | ---- | ---- | ---- | 292 | Do. |
| | 19bcd | Colorado Basin Associates Elliott 1. | 110 | 3,277 | ---- | ---- | ---- | ---- | 1,431 | Drilled 1,846 ft into granitic basement. |
| | 29aab | Old oil test | 118 | 730 | ---- | ---- | ---- | ---- | 730 | Reported in Kovach, Press, and Allen (1962). |
| | 32bad | USBR CH–21YM | 188.0 | 285 | ---- | ---- | ---- | ---- | 267 | Cored porphyritic quartz monzonite. |
| | 33cbd | USGS AH | 195 | 90 | ---- | ---- | ---- | ---- | 90 | |
| | 33cdd | USBR CH–20YM | 196.0 | 64 | ---- | ---- | ---- | ---- | 47 | Do. |
| | 33dab | USGS AH | 196 | 79 | ---- | ---- | ---- | ---- | 79 | |
| (C–9–24) | 8baa | USGS LCRP 28 | 118.7 | 2,466 | 1,927 | ---- | ---- | ---- | ---- | |
| (C–10–23) | 31aaa | M. P. Stewart Co. Federal 1. | 181 | 3,660 | 1,748(?) | 2,515(?) | (?) | ---- | ---- | |
| (C–10–24) | 24cbb | Colorado Basin Assoc. Federal 1. | 170 | 6,007 | 2,367 | 3,112 | 3,802 | 4,937(?) | ---- | Top of nonmarine sedimentary rocks may be at 4,302 ft. |
| (C–10–25) | 35bbd | USGS LCRP 17 | 94 | 2,946 | 2,514 | ---- | ---- | ---- | ---- | |
| (C–11–25) | 11ab | Yuma Valley Oil & Cas Co. Musgrove 1. | 90 | 4,868 | 2,525 | 3,395 | 4,350 | ---- | ---- | |
| (C–13–20) | 2abd1 | USBR CH–28YM | 577.5 | 1,427 | 1,285 | ---- | ---- | ---- | ---- | |
| 16S/21E | 36Fca | Arizona Public Service Co. | 117 | 978 | (?) | ---- | ---- | ---- | ---- | Bottom in alluvium or transition zone. |
| 16S/22E | 23Caa | USBR CH–8RD | 128.5 | 360 | ---- | 328(?) | ---- | ---- | ---- | Basalt 342–360 ft. |
| | 29Gca2 | USGS LCRP 26 | 125.4 | 1,777 | 1,033 | 1,115 | ---- | 1,380 | ---- | |
| | 35Hac | San Carlos Hotel | 145 | 173 | ---- | ---- | ---- | 173 | ---- | "Granite" boulder at bottom. |
| 16S/23E | 10Rcc | USGS LCRP 23 | 143.8 | 715 | ---- | 548 | ---- | 687 | 703(?) | May be breccia at bottom. |

the area these wells are far apart (pl. 3), and by no means all the wells penetrate the units below the transition zone. Interpretations shown in figure 15 and plate 10 are therefore in part uncertain and generalized. The poorly water-bearing rocks are relatively unimportant in the hydrology of the area, and each of the units listed above is discussed only briefly.

#### NONMARINE SEDIMENTARY ROCKS

The nonmarine sedimentary rocks of Tertiary age occupy the basal part of the ground-water reservoir throughout much of the Yuma area. In the southwestern part of the area, on the north flank of the "San Luis basin," varicolored sandstone and conglomerate of the nonmarine sedimentary rocks were penetrated in oil-test well (C–10–24)24cbb (Colorado Basin Associates Federal 1) from a depth of 4,937 feet to the bottom of the well at 6,007 feet; some nonmarine strata, possibly interbedded with marine strata (older marine sedimentary rocks) occur as high as 4,302 feet in this well (table 5). The electric log indicates very brackish-water—probably exceeding 15,000 micromhos specific conductance—throughout this interval.

Farther north, in the "Yuma trough" and "Picacho-Bard basin," several test wells penetrated coarse fanglomerate and breccia of the nonmarine sedimentary rocks. Electric logs and pumped water samples indicate much fresher water than that in well (C–10–24)24cbb—the specific conductance of most of this northern water is substantially less than 3,000 micromhos. However, at test well (C–7–22)14bcd (USGS LCRP 14) at Laguna Dam, analysis of a sample of water from fanglomerate (probably the Kinter Formation) indicated 3,420 mg/l dissolved solids and 5,610 micromhos specific conductance, which is too mineralized for most uses (appendix C, analysis 206b).

The extent and thickness of the nonmarine sedimentary rocks beneath "Fortuna basin" in the southeastern part of the area are unknown (no wells in this basin are deep enough to penetrate these rocks); however, the nonmarine sedimentary rocks probably are present in at least part of the basin. On the southerly international boundary, deep electrical soundings and an electric log of test well (C–13–20)2abd1 (USBR CH–28YM) indicated brackish to saline water in all the Tertiary deposits below the base of the older alluvium at depths of 1,200–1,300 feet.

In summary, the nonmarine sedimentary rocks probably contain brackish water in the southern part of the Yuma area but contain fresh water in much of the northern part of the area. These deposits are very coarse grained in places but are slightly to moderately indurated and therefore are generally less porous and permeable than the alluvial deposits in the upper part of the ground-water reservoir. Even the coarser phases, like the fanglomerate of the Kinter Formation, do not appear to be potentially very productive. In test wells (C–7–22)14bcd (USGS LCRP 14) and 16S/22E–29Gca2 (USGS LCRP 26) in the northern part of the area, the productivity of the fanglomerate was much less than that of the alluvium.

#### OLDER MARINE SEDIMENTARY ROCKS

The older marine sedimentary rocks have been penetrated in three test wells (table 5), where borehole geophysical logs and drilling characteristics indicate that these rocks are moderately indurated and therefore probably less porous and permeable than the overlying Bouse Formation, transition zone, and water-bearing deposits of Pliocene to Holocene age. Like the nonmarine sedimentary rocks, the extent of the older marine sedimentary rocks is not well known, but their absence below the Bouse Formation in several test wells in the northern part of the area suggests that they are less extensive than the Bouse Formation.

Although no samples of ground water from the older marine sedimentary rocks were obtained for chemical analysis, electric logs of the three wells penetrating the unit indicate brackish water (specific conductance 3,000–15,000 micromhos) unfit for most uses.

#### BOUSE FORMATION

The Bouse Formation appears to be widespread (fig. 15 and pl. 10), although it has not actually been penetrated by wells in the southern and southeastern parts of the area, where its subsurface extent and configuration are inferred from geophysical data. The unit consists chiefly of clay and silt having small hydraulic conductivity, but the interbedded very fine to fine sand probably would yield small amounts of somewhat mineralized water to wells. In places the basal part of the Bouse Formation contains sandy limestone or limy sandstone, conglomerate, and tuff; a conglomerate penetrated by test well 16S/23E–10Rcc (USGS LCRP 23) in the "Picacho-Bard basin" yielded large quantities of fresh water (1,180 mg/l dissolved solids) when that well was test pumped, but such coarse-grained productive strata have not been recorded elsewhere in the Yuma area.

In the "Picacho-Bard basin" and the "Yuma trough" the predominantly clay and silt of the

Bouse Formation form an aquiclude between the underlying nonmarine sedimentary rocks (which contain fresh to somewhat brackish water) and the overlying water-bearing deposits of Pliocene to Holocene age, which constitute the upper, main part of the ground-water reservoir. Farther south, the Bouse is underlain by the older marine sedimentary rocks, and both units contain brackish water.

#### TRANSITION ZONE

The transition zone overlies the Bouse Formation throughout most of the Yuma area but is missing in the northeast and perhaps elsewhere along the margins of the Bouse embayment (fig. 15), where the Bouse Formation is overlain by the older alluvium. The transition zone is as much as several hundred feet thick in the "San Luis basin" in the southwestern part of the area, where it is penetrated by several test wells (table 5). Electric logs of wells (C–10–24)24cbb and (C–11–25)11ab indicate that the specific conductance of the water in the zone increases from about 3,000 micromhos near the top to more than 8,000 micromhos near the base. Although the transition zone locally contains fresher water (less than 3,000 micromhos in some test wells) the unit is unimportant hydrologically because of the generally small hydraulic conductivity inferred from the abundance of clay and silt and from the slight to moderate induration of the coarser strata.

### WATER-BEARING DEPOSITS OF PLIOCENE TO HOLOCENE AGE

The upper, principal part of the ground-water reservoir—the water-bearing deposits of Pliocene to Holocene age—includes the following stratigraphic units: (1) The older alluvium, (2) the younger alluvium, and (3) the windblown sand. However, beneath the river valleys and Yuma Mesa—the areas of most intensive present and probable future water development—the upper part of the reservoir is more conviently subdivided into three zones, two of which cross stratigraphic boundaries, as shown below:

| *Zones* | *Stratigraphic units* |
|---|---|
| Upper, fine-grained zone | Windblown sand (small dunes in valleys, sheets of sand on Yuma Mesa). |
| | Younger alluvium (upper, major part). |
| | Older alluvium (uppermost strata beneath Yuma Mesa). |
| Coarse-gravel zone | Younger alluvium (basal gravel). |
| | Older alluvium (uppermost) coarse-gravel strata). |
| Wedge zone | Older alluvium (lower, major part). |

These zones are not everywhere well defined; for example, the coarse-gravel zone is thin or absent beneath the northwest corner of Yuma Mesa and the north-central part of "Bard Valley." However, at most places beneath the river valleys and Yuma Mesa, the zones are useful subdivisions of the upper part of the ground-water reservoir. The wedge zone, the coarse-gravel zone, and the upper, fine-grained zone correspond respectively to the lower sandy alluvium, the coarse-gravel zone, and the sandy and silty alluvium of Brown and others (1956, p. 15–22). Later writers have used classifications similar to that of Brown and others (1956), and it seems desirable to continue with this classification in the present report.

Outside the river valleys and Yuma Mesa, where the coarse-gravel zone is generally absent or unrecognized, the water-bearing deposits of Pliocene to Holocene age, which are almost entirely the older alluvium below the water table, are not subdivided and are classified instead as older alluvium, undivided. The older alluvium, undivided, is stratigraphically equivalent to the wedge zone and hydraulically continuous with it.

#### WEDGE ZONE

The wedge zone constitutes the major part of the water-bearing deposits of Pliocene to Holocene age beneath the river valleys and Yuma Mesa. Throughout most of its extent the wedge zone overlies the transition zone or the Bouse Formation and underlies the coarse-gravel zone; laterally, beneath "Picacho Mesa" and "Upper Mesa," the wedge zone is adjacent to the older alluvium, undivided, to which it is largely equivalent. The zone extends to depths of about 2,500 feet in the "San Luis basin" and the northern "Fortuna basin" but wedges out beneath the coarse-gravel zone against the Laguna and Gila Mountains to the northeast and also against the buried and nearly buried "Mesa basement high" and "Yuma Hills" farther southwest, hence its name. The top of the wedge zone ranges from about sea level (depth 160 ft) near Laguna Dam and eastern South Gila Valley to nearly 200 feet below sea level (depth nearly 300 ft) in southern Yuma Valley. However, where strata of coarse gravel are abundant in the upper part of the wedge zone, as they are at many places, the boundary between the wedge zone and the overlying coarse-gravel zone is vague and arbitrary and is not shown at a definite horizon in the geologic sections of the area. (See pls. 5, 6, 8.)

Scanty information indicates that the average grain size and probably the average porosity and hydraulic conductivity of the wedge zone decrease with depth. Clay and silt appear to be more abundant below depths of 1,000–1,500 feet than they are at shallower depths, especially in the "San Luis basin." However, except possibly for the lower 1,000 feet or so, fine-grained strata do not appear to be sufficiently extensive or thick to cause significant hydraulic separation. Thus, on a large scale, the wedge zone is considered to be a single heterogeneous hydrologic unit.

The chemical characteristics of the water in the wedge zone are not known in detail, owing to the small number and irregular spacing of wells from which samples have been collected (pl. 11). However, electric logs of several test wells supplement the chemical data and help to provide reasonably reliable estimates of the extent and general character of fresh water in the zone.

Except for two small areas, the water in the wedge zone is fresh, as defined in this report. The two areas where the concentration of dissolved solids exceeds 1,800 mg/l (and the specific conductance exceeds 3,000 micromhos) are roughly the city of Yuma at the northwest corner of Yuma Mesa and a strip along the west flank of the northern Gila Mountains (pl. 11). In these areas the overlying coarse-gravel zone is thin or absent and the deposits of the wedge zone are relatively thin and probably less permeable than they are at most other places. The body of somewhat brackish water along the west flank of the northern Gila Mountains, which is much more extensive farther south, in the older alluvium, undivided, may represent contamination from deeper water in the Bouse Formation and nonmarine sedimentary rocks of Tertiary age which has risen along faults.

Electric logs and a few chemical analyses indicate that in the northern part of the Yuma area the water in the wedge zone becomes fresher with depth. The wedge-zone water in this part of the area appears to be substantially fresher than that in the overlying coarse-gravel zone, except for the two occurrences of brackish water described above. The decrease in dissolved-solids content with depth probably indicates that some of the more concentrated water in the coarse-gravel zone has moved downward into the upper part of the wedge zone.

Farther south, beneath central and southern Yuma Mesa and Yuma Valley, vertical variations in concentration and chemical characteristics of water in most of the wedge zone appear to be relatively small. However, several electric logs in that part of the area indicate a gradual downward increase in specific conductance of the water below depths of 1,500–2,000 feet, where clay and silt are more abundant in the zone. South of the irrigated area on Yuma Mesa, the water in the wedge zone not only shows little vertical variation in concentration and chemical characteristics, but it is virtually indistinguishable from the water in the overlying coarse-gravel zone. (See pl. 11.) However, this condition may change when water from irrigation to the north moves farther southward, largely through the coarse-gravel zone.

Scattered sample and electric-log data suggest that the freshest water in the wedge zone occurs beneath a strip along the Colorado River. This water is considerably fresher than the present Colorado River; four samples had dissolved solids concentrations ranging from 451 to 624 mg/l (pl. 11).

Elsewhere, except in the two areas of brackish water described earlier, the concentration of dissolved solids in wedge-zone water generally ranges from about 700 to 1,500 mg/l. At most places below a depth of 500 feet, the concentration generally is less than 1,200 mg/l.

Expressed in chemical equivalents, wedge-zone water characteristically contains considerably less magnesium than calcium, and much of the water contains less sulfate than bicarbonate (pl. 11). Except for one sample (242c), for which the analysis represents a mixture of water from the coarse-gravel zone and the uppermost part of the wedge zone, the equivalent concentration of chloride exceeds that of sulfate. The equivalent concentrations of sodium and chloride are generally about equal, although a few wells have yielded water in which calcium seems to have replaced sodium by base exchange, so that the chloride substantially exceeds the sodium.

In general, the water in the wedge zone has a smaller range in concentration and chemical characteristics than that in the overlying coarse-gravel zone, and probably much less than that in the upper, fine-grained zone.

### COARSE-GRAVEL ZONE

The most permeable deposits in the Yuma area, and the ones that are tapped by nearly all the producing wells, are the coarse-gravel strata in the upper part of the older alluvium and locally, perhaps, at the base of the younger alluvium. These strata are herein referred to collectively as the coarse-gravel zone, which is the principal aquifer beneath the river valleys and Yuma Mesa. This zone, to which Wilcox and Scofield (1952) applied the term "deep aquifer," has long been recognized as the primary source of ground water pumped in the Yuma area. Brown and others (1956) suggested that "deep aquifer" is not an appropriate designation because of the presence of much deeper fresh-water-bearing deposits; instead, they used both "coarse-gravel zone" and "coarse-gravel aquifer." Usage of the term "coarse-gravel zone" is continued in the present report.

As described in the section, "Geology" (p. H50), the coarse-gravel zone consists of a complex of gravel bodies of different ages deposited by the Colorado and Gila Rivers; the top and bottom of the zone are at different altitudes and stratigraphic horizons from place to place (pl. 7). Delineation of the zone is necessarily arbitrary at many places; the upper part of the underlying wedge zone locally contains similar coarse gravel. The coarse-gravel zone generally ranges in thickness from 0 to more than 100 feet (or more than 150 ft, depending on which horizon is identified as the bottom). The zone generally dips southwestward at an angle somewhat steeper than the slopes of the valley surfaces and Yuma Mesa; in the central part of the area the depth to the top averages about 100 feet beneath the valleys and about 170–180 feet beneath Yuma Mesa.

Somewhat saline water, in which the sum of determined constituents exceeds 1,800 mg/l, occurs in the coarse-gravel zone beneath most of South Gila Valley, eastern North Gila Valley, northwestern Yuma Mesa, a U-shaped area in northern Yuma Valley, and scattered other areas of small extent (pl. 11). At all these places except the northwest corner of Yuma Mesa (city of Yuma) and the east end of South Gila Valley, the water in the underlying wedge zone is fresh.

Elsewhere, the concentration of dissolved solids of the ground water in the coarse-gravel zone ranges from about 900 to 1,500 mg/l, although scattered wells of small capacity have yielded water containing as little as 418 mg/l dissolved solids (pl. 11). As in the wedge zone, much of the fresher water in the coarse-gravel zone is near the Colorado River and presumably results from local recharge of river water. The scattered occurrences of fresher water at sites away from the river probably are due to local anomalous conditions such as excessive sulfate reduction.

Beneath most of Yuma Mesa the water in the coarse-gravel zone has a smaller range in concentration of dissolved solids than it has beneath the valleys: most analyses from the mesa range in concentration from 900 to 1,400 mg/l. As mentioned earlier, the water in the coarse-gravel zone in the southern part of the mesa is chemically about the same as that in the underlying wedge zone.

The water in the coarse-gravel zone is more variable in chemical character as well as in concentration of dissolved solids than that in the wedge zone. (See pl. 11.) In much of the coarse-gravel-zone water the concentration of sulfate (expressed in chemical equivalents) exceeds that of chloride, whereas in the wedge-zone water, chloride exceeds sulfate in equivalent concentration except for one analysis, and that analysis represents a strong admixture of coarse-gravel-zone water. The higher sulfate concentrations probably indicate that river water (chiefly, but not entirely, the Colorado River) is a more recent source of the water in the coarse-gravel zone, and that sulfate reduction (explained in the section "Chemical Quality," p. H127) has not generally proceeded as far as it has in wedge-zone water.

The water in the coarse-gravel zone is highly variable in proportions of the major dissolved constituents, and the variations are not necessarily correlative with the variations in concentration of dissolved solids (pl. 11). Because the coarse-gravel zone is the overwhelmingly predominant source of ground water pumped in the Yuma area, a more detailed description of the variations in the chemical characteristics of the water in the zone, and suggested explanations for the variations are given in the section, "Chemical Quality."

#### UPPER, FINE-GRAINED ZONE

The upper, fine-grained zone includes most of the younger alluvium, the uppermost deposits of the older alluvium, and the relatively minor deposits of windblown sand beneath the river valleys and Yuma Mesa. Although little water is pumped from these fine-grained deposits, the upper, fine-grained zone is significant hydrologically because most of the ground-water recharge and discharge within the Yuma area take place through it and because the water table beneath the irrigated areas lies within it.

The upper, fine-grained zone generally ranges in thickness from about 70 to 240 feet and averages about 100 feet beneath the valleys and 170–180 feet beneath Yuma Mesa. Sand and silt are the most abundant materials in the zone, although beds of silty and sandy clay and sandy gravel are extensive in places.

Because much ground water moves vertically through the upper, fine-grained zone, a special effort was made to determine the thickness and lateral extent of fine-grained beds that might impede or restrict vertical movement. Studies of geologic logs and gamma logs of numerous test wells and observation wells in Yuma Valley and on Yuma Mesa were supplemented by careful examination of exposures along the escarpment along the northern and western edges of Yuma Mesa.

Clay beds A and B of the older alluvium (p. H53) are two of the more extensive fine-grained beds mapped in the subsurface study, and other beds of clay and silt in both the older and younger alluviums in the upper, fine-grained zone may be extensive enough to be hydrologically significant. No attempt was made to trace these individual beds as was done with clays A and B. Instead, the aggregate thickness of clay, silty clay, and clayey silt in the upper 100 feet beneath three areas—Yuma Mesa, Yuma Valley, and South Gila Valley—was computed from well-log data (pl. 12). Because the thickness of the upper zone considered in each area is 100 feet, the aggregate thickness of the fine-grained materials is also equivalent to their percentage in this interval. The well-log data consist of drillers' or geologists' logs of many wells, supplemented by gamma logs or other borehole geophysical logs. Using the gamma logs, the drillers' or geologists' logs were modified so that the thickness of the clay-bearing strata could be computed more precisely than would have been possible otherwise.

The computations indicate that the average thickness of clay-bearing strata in the top 100 feet beneath the river valleys and Yuma Mesa is only about 15 feet; however, the range is from 0 to more than 50 feet (pl. 12). The clayey deposits are thickest in South Gila Valley (pl. 12). Somewhat lesser thicknesses occur beneath northern Yuma Mesa, west-central Yuma Mesa (in the vicinity of the apex of the large ground-water mound caused by irrigation), south-central Yuma Valley, and several other scattered localities. Beneath much of the Yuma area, the aggregate thickness of the fine-grained clayey deposits in the top 100 feet is less than 10 feet.

Most of the clayey strata in the upper, fine-grained zone contain a considerable amount of silt and sand. Consequently, the permeability of these strata is not sufficiently low to cause extensive perching of ground water, even where these fine-grained strata, such as clays A and B described earlier, are thick and extensive. However, although true perching is rare or absent, the fine-grained strata inhibit vertical movement of ground water, so that sizable differences in water levels exist at different depths where upward or downward movement occurs. One of the best examples is in the west-central Yuma Mesa. In this area, which has been irrigated for about 50 years and which is the apex of the ground-water mound beneath Yuma Mesa, the water table locally is more than 35 feet higher than the piezometric level for the top of the coarse-gravel zone.

Scattered chemical analyses suggest that the water in the upper, fine-grained zone is exceedingly variable in chemical characteristics and concentration of dissolved solids. The variations probably are related to several factors, among which are depth of the water table, proximity of canals, laterals, or surface drains, irrigation regimen, and upward or downward movement of water reflecting areal patterns of ground-water circulation. Not nearly enough wells tapping the upper zone are available to document adequately the pattern of chemical variation; wide differences exist between wells less than a mile apart. Where the water table is shallow, the dissolved solids are concentrated by evapotranspiration, and brackish water, generally high in sodium chloride, is the result. At some other places, where infiltration of canal water occurs, the shallow ground water is almost identical to the water in the canal (Colorado River water).

#### OLDER ALLUVIUM, UNDIVIDED

Outside the river valleys and Yuma Mesa, the coarse-gravel zone appears to be largely absent, and the older alluvium forms a single water-bearing unit which is stratigraphically equivalent to the adjacent wedge zone and hydraulically continuous with it. This unit, called older alluvium, undivided, consists chiefly of slightly to moderately indurated sand, silt, and a minor amount of gravel and clay of river origin, interbedded or mixed with deposits of local origin. Near the mountains, poorly sorted gravelly deposits of local origin predominate. As in the wedge zone, the permeability and porosity of the deposits probably decrease with depth, owing to compaction and cementation. However, because of the considerable thickness—as much as 2,000 feet beneath part of the "Upper Mesa"—the older alluvium, undivided, stores and transmits substantial amounts of water. In "Fortuna Plain" and Davis Plain in the southeastern part of the Yuma area, the older alluvium is overlain by younger alluvial-fan deposits, but these fan deposits are largely if not entirely above the water table and are not considered further here.

Relatively little is known about the chemical quality of the water in the older alluvium, undivided. Beneath the "Upper Mesa," three analyses indicate that the water is similar to that in the wedge zone beneath Yuma Mesa (pl. 11). Farther east, beneath "Gila Mesa," the water is brackish and probably contaminated by deeper water rising along fault barriers. The southern limits of the brackish water are not known. The electric log of U.S. Bureau of Reclamation test well CH–28YM on "Fortuna Plain" at the southerly international boundary indicated water having a specific conductance slightly exceeding 3,000 micromhos—the limit for fresh water in the Yuma area. However, there are no data to show whether or not the brackish water at test well CH–28YM extends all the way north to the body of brackish water beneath "Gila Mesa."

### ORIGIN OF GROUND WATER AND SOURCES OF RECHARGE

Almost all the ground water in the upper part of the ground-water reservoir in the Yuma area is infiltrated river water; precipitation and local runoff are very minor sources of ground-water recharge. The more highly mineralized water in the older rocks of the lower part of the reservoir may include some connate water which was not completely flushed out. Patterns of ground-water recharge have changed, both in geologic time and in historic time, so that the configuration of the water table and the chemical character of the ground water are in a state of flux. The relative importance and the chemical characteristics of each of the various sources of ground-water recharge are described in the following paragraphs.

#### COLORADO RIVER

Under natural conditions the Colorado River was the predominant source of ground-water recharge in the Yuma area, and it still is by way of diversions for irrigation. Water-level contours for 1925 (fig. 29) indicate that the Colorado River at that time was a source of ground-water recharge during low flows as well as high flows. The water table sloped away from the channel so that the river formed a ground-water ridge, and water moved away from the channel on both sides. Evapotranspiration, in large part by the phreatophytes growing on the flood plain, maintained the lower water levels away from the river. Considerable quantities of ground-water recharge occurred during floods, when most of the flood plain was covered with slow-moving sheets of water.

Discharge of ground water by evapotranspiration in the flood plain probably resulted in increased salinity at shallow depth. The rest of the ground water moved slowly southward and southwestward into Mexico to areas of discharge in the Colorado delta around the head of the Gulf of California. The underground flow was a very small fraction of the flow in the river itself.

After the construction of Hoover Dam, Imperial Dam, and other upstream dams, the Colorado River cut down, so that its channel now lies 10–20 feet below the adjacent flood plain from Laguna Dam to the southerly international boundary. The downcutting resulted from the clearer water in the river after its normal load of sediment was largely trapped by the dams. At the same time, irrigation has maintained a high water table beneath the flood plain, hence the lowered river channel now acts primarily as a drain rather than as a source of ground-water recharge. However, some recharge from the river still occurs, during occasional high flows, and also at other times along reaches where significant quantities of ground water are pumped from adjacent wells, such as along the limitrophe section between Pilot Knob and the southerly international boundary.

The chemical composition of ground-water recharge from the Colorado River has been materially affected by control of the river by the upstream dams. Before the impounding of water in Lake Mead behind Hoover Dam, beginning in 1935, the chemical composition of the river water in the lower reaches was highly variable, both seasonally and annually. Concentrations of dissolved solids were relatively low during seasons and years of high flow and relatively high during periods of low flow. Because of their longer duration, periods of low flow and high concentration may have affected the chemical quality of ground-water recharge more than periods of high flow and low concentration.

As shown by the summary below, the chemical characteristics of Colorado River water at Yuma were very similar to those at Grand Canyon during the two years of parallel sampling, 1927 and 1928.

*Constituent concentrations in Colorado River water prior to closure of Hoover Dam in 1935*

| Year | Constituent | Grand Canyon | | | Yuma | | |
|---|---|---|---|---|---|---|---|
| | | Minimum | Weighted average | Maximum | Minimum | Weighted average | Maximum |
| 1927 | Dissolved solids | 238 | 569 | 1,450 | 287 | 612 | 1,300 |
| 1927 | Bicarbonate | 121 | 162 | 289 | 133 | 169 | 256 |
| 1927 | Sulfate | 66 | 235 | 597 | 75 | 238 | 579 |
| 1927 | Chloride | 18 | 53 | 248 | 25 | 73 | 278 |
| 1928 | Dissolved solids | 233 | 491 | 1,180 | 285 | 513 | 1,180 |
| 1928 | Bicarbonate | 126 | 162 | 240 | 132 | 163 | 234 |
| 1928 | Sulfate | 66 | 187 | 525 | 79 | 195 | 557 |
| 1928 | Chloride | 10 | 48 | 165 | 23 | 55 | 157 |
| 1934 | Dissolved solids | 437 | 960 | 1,890 | --- | --- | --- |
| 1934 | Bicarbonate | 145 | 206 | 280 | --- | --- | --- |
| 1934 | Sulfate | 131 | 392 | 827 | --- | --- | --- |
| 1934 | Chloride | 51 | 136 | 310 | --- | --- | --- |

Concentrations were not determined at Yuma during 1934, the minimum annual flow year of record of the Colorado River prior to construction of Glen Canyon Dam, but were probably similar to those listed for Grand Canyon. Thus, the pre-Hoover Dam records indicate that the usual flow of the Colorado River water in the Yuma area contained less than 1,000 mg/l dissolved solids, with sulfate the major anion and with concentrations of bicarbonate exceeding chloride except during periods of low flow. During flood flows, bicarbonate was the major anion. Sulfate always exceeded the chloride, regardless of flow.

During the 25-year period 1941–65, the composition of Colorado River water downstream from Lake Mead, although still somewhat variable on a year-to-year basis, did not depart much from a characteristic concentration pattern. Thus, although the concentration of dissolved solids at Imperial Dam fluctuated between 600 and 900 mg/l, it was generally between 700 and 800 mg/l. The chloride concentration fluctuated between 70 and 140 mg/l. Sulfate, always the major dissolved constituent, usually ranged from 260 to 370 mg/l and amounted to about three-sevenths of the dissolved solids. The calcium concentration, ranging from 80 to 115 mg/l, was generally about three times the magnesium concentration and was also usually a little greater than the sodium concentration when the dissolved solids concentration was lowest (about 700 mg/l), and somewhat less than the sodium concentration when the dissolved solids concentration was highest about 900 mg/l). No consistent relation existed between the concentrations of any of the cations and anions, although the equivalent concentration of sodium was generally about twice the equivalent concentration of the chloride.

### GILA RIVER

Under natural conditions the Gila River was perennial to its mouth near Yuma, except during prolonged dry periods, when flow ceased during some months (Wells and others, 1954, p. 707–709). Regulation of the river began in 1911 with the construction of Roosevelt Dam on the Salt River, a major tributary near Phoenix. Thereafter, as irrigation increased east of the Yuma area, especially near Phoenix, the flow at the mouth generally decreased; after the late 1920's, only occasional floods produced flow near Yuma.

Water-level data for 1925 indicate the Gila River was a significant source of ground-water recharge to South Gila Valley at that time; by inference, the recharge under natural conditions was even greater. Ground water beneath South Gila Valley moved southward beneath eastern Yuma Mesa, eastern "Upper Mesa," and "Fortuna Plain"; therefore, under natural conditions, much of the ground water beneath the eastern part of the Yuma area was derived from the Gila River.

Unfortunately, no analytical records describe the natural variation of the chemical quality of the Gila River before the construction of upstream dams and the diversions for irrigation. Recent analytical records for the major tributaries above Phoenix indicate considerable differences in chemical characteristics among these tributaries, which are the former major sources of inflow to the lower Gila River. The natural chemical characteristics of water in the lower Gila River probably were quite variable, depending on the proportions of inflow from each of the major tributaries at any particular time.

The Gila River flowed at the mouth during the winter of 1966 as the result of release of low-salinity water from the new Painted Rock Reservoir, about 100 miles east of Yuma. The water was stored as a result of flooding on the Salt and Verde Rivers (two of the major tributaries) when runoff in December 1965 filled the storage reservoirs. Analyses of samples taken at various points from Painted Rock Dam downstream to Dome (12 miles upstream from the mouth) during release of the stored water showed that it flowed down the river without great change in composition. Similarity in chemical composition of this water to that produced from wells at many locations on Yuma Mesa supports the hypothesis that much of the original ground water beneath the mesa was derived from flood flows of the Gila River.

### IRRIGATION

Irrigation with diverted Colorado River water is now the source of almost all ground-water recharge in the Yuma area. The principal exception until 1965 was the South Gila Valley which was irrigated with ground water and therefore received much recirculated ground water as well as some water from adjacent areas irrigated with Colorado River water.

Water applied in excess of crop requirements and the amount evaporated from the soil penetrates to the water table. In addition, leakage occurs from the canals and distribution system; a considerable proportion of this leakage also reaches the water table. Much of the ground water derived from irrigation is discharged by surface drains or, in recent years, by drainage wells. Since the early 1920's, but especially since the late 1940's irrigation with Colorado River water on Yuma Mesa has resulted in the formation of a ground-water mound of considerable size. Because of the sandy soils of low water-holding capacity and the need to reduce salt accumulation in the soil zone, the amount of irrigation water applied has been several times as much as the amount evaporated and transpired, so that ground-water recharge from this source has been substantial.

As discussed in the quality of water section of this report, there has been a significant change in the quality of water obtained from domestic wells in the part of the Yuma Mesa irrigated with Colorado River water. Older analytical data indicate that formerly the quality of the water obtained from wells in this area was of rather uniform character with sodium and chloride the principal ionic constituents and with much less sulfate than chloride being present. Domestic wells in the area now generally yield water more like Colorado River water, with sulfate exceeding chloride, except that there apparently has been considerable softening as the water infiltrated from the land surface. Apparently surface application of large volumes of imported Colorado River water has resulted in a downward displacement of the original water accompanied by softening of the displacing water.

### LOCAL PRECIPITATION

In the Yuma area, as in most desert regions, precipitation is too scanty to allow deep penetration of moisture at most places. The mean annual precipitation in Yuma for the period 1931–60 was only 3 inches, and in the adjacent mountains, 4–6 inches (Hely and Peck, 1964, pl. 3). Even during relatively wet years and during periods of intensive rainfall, little or no water penetrates below the soil zone. Moisture measurements by the neutron-meter method made during the present study showed that the materials between the top few feet and the water table are nearly dry outside of the irrigated areas; moisture contents of less than 5 percent—far below field capacity—were recorded at most places. Deep penetration of precipitation, therefore, is a negligible source of ground water recharge in the Yuma area, except possibly in irrigated areas where the soil is wet before rains occur.

The addition from precipitation to the mineral content of ground water in the Yuma area is almost certainly negligible. Investigations by Feth (1967) have shown that the dissolved mineral content of bulk precipitation (rainwater and incorporated dry fallout from the atmosphere) in the Mojave Desert region is generally very low; the specific conductance of most samples is less than 100 micromhos, although in a few samples of fallout it ranged from 200 to 300 micromhos. Feth found that most of the samples having higher specific conductance came from locations where dry fallout might include dusts stirred up from the surface of desert playas. These more concentrated samples probably are not representative of bulk precipitation in the Yuma area because playas are absent. Otherwise, Feth's results appear applicable. It appears reasonable to assume, therefore, that the average mineral content of rainfall in the Yuma area has less than 100 micromhos specific conductance and contains 60 mg/l or less dissolved solids. Several of Feth's analytical results representing samples collected near the Yuma area, are given in table 6.

### LOCAL RUNOFF

Even the small amount of precipitation in the local mountains is enough to produce local runoff, especially during periods of intense storm rainfall. The mean annual runoff in the mountains near Yuma may exceed 1 inch (Hely and Peck, 1964, pl. 5). However, because of rapid infiltration in the sandy and gravelly washes, most of this locally generated runoff does not reach the Colorado and Gila Rivers. A major part of the infiltrated water is later evaporated and transpired, but a minor part eventually reaches the water table. Chemical-quality and water-level data from wells near Fortuna Wash show that local runoff has reached the water table and has also formed perched or semiperched bodies of ground water. Although no data have been gathered elsewhere, the large washes like Picacho Wash and Unnamed Wash north of Yuma are likely sources of local ground-water recharge. However, the flat water-table gradients adjacent to the mountains indicate that the total quantity of recharge from local runoff is very small.

Evidence that local runoff, particularly in the mountains, is low in mineral content is afforded by a number of analyses of samples collected from both natural and artificial tanks and one spring in mountainous areas near the Yuma area. An analysis of a sample from Little Picacho Wash, in California, and another from the Gila River near Texas Hill, Ariz., taken after a rain also show low mineral contents. (See table 6.)

## HYDROLOGIC CHARACTERISTICS OF AQUIFERS

### DEFINITION OF TERMS

The term "aquifer" commonly is applied to a water-bearing formation or rock unit that is capable of yielding appreciable quantities of water to wells. The term is flexible, in that it may denote a single bed, or it may refer to a relatively thick sequence of beds. The latter usage is especially

TABLE 6.—*Miscellaneous chemical analyses*

[Values in milligrams per liter, except for specific conductance]

| Sample source | Date | 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bulk precipitation-3-Slashes Ranch, lat 33°17′ N., long 114°43′ W. In California.) (Data from Feth, 1967, table 1.) | Mar. 17, to Apr. 18, 1965. | 0.2 | 10.0 | 1.0 | 4.6 | 3.8 | 10 | 13 | 4.8 | ---- | 8.7 | 51 | 29 | 21 | 111 |
| Bulk precipitation-3-Slashes Ranch Data from Feth, 1967, table 1.) | Apr. 4 to Nov. 23, 1965. | ---- | 18 | 1.7 | 12.0 | 11 | 94 | 16 | 16 | ---- | 2.5 | 124 | 50 | 0 | 259 |
| Bulk precipitation Singers, lat 33°03′ N., long 114°43′ W. (In California.) (Data from Feth, 1967, table 1.) | Mar. 17, 1965, to Mar. 21, 1966. | 1.0 | 4.8 | 0.0 | 1.0 | .8 | 8 | 4.0 | .8 | ---- | 1.5 | 26 | 12 | 5 | 44 |
| Bulk precipitation-Glamis, lat 33°00′ N., long 115°04′ W. (In California.) (Data from Feth, 1967 table 1.) | Mar. 17 to Apr. 4, 1965. | .6 | ---- | ---- | 5.0 | 2.0 | 29 | 18 | 4.1 | ---- | 4.5 | ---- | ---- | ---- | 99 |
| Bulk precipitation-Glamis (In California.) (Data from Feth, 1967, table 1.) | Apr. 4, 1965, to Jan. 20, 1966. | .3 | 8.8 | .5 | 1.0 | 1.8 | 2 | 8.0 | 3.8 | ---- | 12 | 37 | 24 | 22 | 72 |
| Owl Head Dam, Kofa Mountains, Ariz. | Aug. 11, 1965 | 11 | 45 | 4.7 | ---- | 8.7 | 152 | 6 | 14 | .3 | 0 | 166 | 132 | 8 | 295 |
| Budweiser Spring, Kofa Mountains, Ariz. | Jan. 14, 1965 | 25 | 25 | 5.7 | ---- | 14 | 102 | 17 | 9.5 | .3 | ---- | 148 | 86 | 2.5 | 216 |
| High tank No. 7, Kofa Mountains, Ariz. | Jan. 14, 1965 | 12 | 38 | 3.6 | ---- | 11 | 106 | 22 | 16 | .3 | ---- | 156 | 110 | 23 | 253 |
| Charley Died tank, Kofa Mountains, Ariz. | Feb. 3, 1965 | 14 | 23 | 4.3 | ---- | 19 | 70 | 35 | 16 | .2 | ---- | 146 | 75 | 18 | 219 |
| Horse tank, Castle Dome Mountains, Ariz. | Dec. 13, 1964 | 1 | 20 | 2.4 | ---- | 26 | 98 | 14 | 16 | ---- | ---- | 128 | 60 | 0 | 232 |
| Horse tank | Sept. 15, 1965 | 16 | 17 | .9 | ---- | 35 | 124 | 0 | 14 | ---- | ---- | 145 | 46 | 0 | 238 |
| Frenchman tank, Tank Mountains, Ariz. | Mar. 5, 1965 | 7 | 22 | 0 | ---- | 12 | 64 | 12 | 10 | .2 | 1.3 | 97 | 55 | 2.5 | 143 |
| Black tank, Castle Dome Mountains, Ariz. | Jan. 12, 1965 | 5 | 30 | 4.6 | ---- | 15 | 120 | 7 | 14 | .3 | ---- | 136 | 94 | 0 | 236 |
| Arch tank, Castle Dome Mountains, Ariz. | Mar. 23, 1965 | 6 | 26 | .7 | ---- | 8.7 | 56 | 19 | 9.5 | .2 | 8.8 | 107 | 68 | 22 | 166 |
| Bandy tank, Castle Dome Mountains, Ariz. | Mar. 23, 1965 | 1 | 34 | 5.6 | ---- | 13 | 110 | 19 | 18 | .2 | ---- | 146 | 108 | 18 | 242 |
| Saguaro tank, Castle Dome Mountains, Ariz. | Feb. 17, 1965 | 7 | 38 | 1.9 | ---- | 14 | 80 | 27 | 16 | .2 | 15 | 162 | 103 | 32 | 246 |
| Ladder tank, Castle Dome Mountains, Ariz. | Dec. 14, 1964 | 11 | 38 | 3.2 | ---- | 14 | 72 | 42 | 26 | ---- | ---- | 170 | 108 | 49 | 297 |
| Burnt Wagon tank, Castle Dome Mountains, Ariz. | July 15, 1965 | 6 | 37 | 2.8 | ---- | 6.9 | 116 | 9 | 10 | .1 | ---- | 130 | 104 | 9 | 226 |
| Salton tanks, Castle Dome Mountains, Ariz. | Feb. 18, 1965 | 6 | 29 | 2.3 | ---- | 7.1 | 65 | 13 | 6.5 | 26 | ---- | 122 | 82 | 28 | 190 |
| Carrizo tank, Chocolate Mountains, Calif. | Feb. 5, 1962 | 11 | 32 | 1 | ---- | 5 | 66 | 30 | 7.0 | ---- | ---- | 119 | 84 | 30 | 223 |
| Little Pichacho Wash., near Burro Wash., in Calif. | Jan. 31, 1962 | 27 | 31 | 4 | ---- | 73 | 177 | 63 | 31 | ---- | ---- | 317 | 96 | 0 | 513 |
| Gila River near Texas Hill, Ariz., after rain, barely flowing. | Aug. 15, 1963 | 7 | 30 | 4.4 | ---- | 26 | 86 | 34 | 30 | .3 | ---- | 175 | 93 | 22 | 291 |
| Gila River near Dome, Ariz. Flood water being released from Painted Rock reservoir. | Feb. 28, 1966 | 11 | 68 | 18 | ---- | 185 | 180 | 98 | 281 | .3 | ---- | 751 | 244 | 96 | 1,390 |
| Gila River near Dome, Ariz. Flood water being released from Painted Rock reservoir. | Mar. 18, 1966 | 10 | 70 | 16 | ---- | 191 | 186 | 115 | 272 | ---- | ---- | 767 | 240 | 88 | 1,360 |
| Well in nonmarine sedimentary rocks at North end of Gila Mountains, Ariz. | Apr. 24, 1963 | 1 | 964 | 651 | ---- | 5,450 | 29 | 792 | 11,400 | ---- | ---- | 19,300 | 5,080 | 5,060 | 31,300 |
| Mine shaft near well at North end of Gila Mountains, Ariz. | Apr. 24, 1963 | 25 | 230 | 264 | ---- | 6,680 | 696 | 367 | 10,800 | ---- | ---- | 18,700 | 1,660 | 1,090 | 31,300 |

applicable to alluvial deposits in the Yuma area where individual permeable beds are lenticular or vaguely bounded and are not generally separated by extensive relatively impermeable beds.

The principal aquifers in the Yuma area are the coarse-gravel zone and the wedge zone; subordinate aquifers of only local significance include the nonmarine sedimentary rocks, conglomerate in the basal part of the Bouse Formation, and a few relatively coarse grained beds in the upper, fine-grained zone. Outside the river valleys and Yuma Mesa, the older alluvium, undivided, is regarded as the principal single, heterogeneous aquifer. Further studies using more data than are presently available may indicate that the older alluvium, undivided, and the wedge zone actually comprise several distinct aquifers and interbedded relatively impermeable beds.

Because what is considered to be an appreciable water supply varies widely from place to place, aquifer is a relative term which depends in large part on the conditions that must be met. The adjectives excellent, good, fair, or poor are commonly used to

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denote the degree to which the supply is satisfactory. However, these general terms are inadequate for quantitative appraisal of an aquifer or aquifer system, or for comparing one supply with another. For these purposes, more specific terms are required.

The principal characteristics of an aquifer that permit a quantitative analysis of its response to changes in supply or withdrawal are designated by two terms: "transmissivity" and "storage coefficient."

The term "transmissivity," which is equivalent to the term "coefficient of transmissibility" introduced by Theis (1935), has been used by an increasing number of hydrologists in recent years because it is a more appropriate word than transmissibility for the property that is described. In units commonly used by the U.S. Geological Survey, transmissivity may be expressed as the rate of flow of water in gallons per day through a vertical strip 1 foot wide of the entire saturated thickness of the aquifer under a unit hydraulic gradient at the prevailing temperature of the water. In some applications it may be visualized more easily by expressing the width of the aquifer cross section in miles and the hydraulic gradient in feet per mile.

Hydraulic conductivity (formerly coefficient of permeability) is the term that expresses the flow of water in gallons per day that will occur through a 1-square-foot cross section of the aquifer under a unit hydraulic gradient at a water temperature of 60°F (15.6°C). If the flow is that occurring at the prevailing temperature of the water, the term is referred to as the field hydraulic conductivity. Thus, the field hydraulic conductivity is related to the transmissivity by the formula

$$Pm = T$$

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

Under certain conditions, especially in alluvial material, it is necessary to differentiate between the horizontal and vertical hydraulic conductivity. Generally, the horizontal hydraulic conductivity of a particular bed is substantially greater than the vertical hydraulic conductivity because of the size sorting and the alinement of platy and ellipsoidal grains that occur during the deposition of alluvial materials. The difference between average horizontal and average vertical hydraulic conductivity increases markedly with thickness if an aquifer is composed of a large number of thin beds whose conductivities cover a wide range, such as is common in the alluvial deposits of the Yuma area. Thus, an alluvial aquifer composed of many different strata ranging from clay or silt to sand or gravel may have a horizontal hydraulic conductivity that is hundreds or even thousands of times larger than the vertical conductivity. Values of horizontal hydraulic conductivity commonly range from a fraction of a gallon per day per square foot for clay and silt to 10,000 gallons per day per square foot for well-sorted gravel.

Determinations of hydraulic conductivity are among the principal objectives of an appraisal of a ground-water system. Reasonably close estimates of hydraulic conductivity can be obtained by proper sampling and laboratory procedures. However, the results thus obtained apply only to the samples analyzed. It is seldom feasible to obtain a sufficient number of samples to adequately define hydraulic conductivity throughout a ground-water system. Rather, the average horizontal hydraulic conductivity is computed on the basis of a known transmissivity and a known thickness of saturated material.

Vertical hydraulic conductivity can be computed from adequate pumping-test data for a leaky artesian system. It also can be computed for areas in which most of the flow is vertical, if data on vertical gradients, changes in water level with changes in rate of recharge or discharge, and storage coefficients are known or can be estimated with reasonable accuracy. The costs of obtaining the data necessary to compute vertical hydraulic conductivity often exceed the available funds, and thus in many investigations this parameter is not well defined. The inability to adequately define the vertical hydraulic conductivity will not of itself prevent a satisfactory appraisal of the total quantities of water involved in recharge, storage, and discharge. However, its absence will lessen the precision with which the response of the system to stresses placed on it by changes in rates of recharge or discharge can be predicted.

In the Yuma area, values of vertical hydraulic conductivity had been computed for limited areas by Jacob (1960). Most of the values were for the alluvial material above the coarse-gravel zone beneath the irrigated area of the Yuma Mesa and for the alluvial material both above and below the coarse-gravel zone for limited areas of the flood plain in Yuma Valley and the South Gila Valley that border the Yuma Mesa. These values were used as guidelines for determining values to be used in the electrical analog model of the Yuma area.

Transmissivity generally is determined from pumping or aquifer tests for areas where adequate data are available. However, the areas for which aquifer-test data are inadequate generally are much more widespread than the areas for which the data are adequate. For the areas where aquifer-test data are inadequate but the specific capacities of wells of known construction can be computed, the transmissivity for the materials tapped by the wells can be estimated on the basis of the theoretical relation between specific capacity and transmissivity that exists under a given set of conditions (Theis and others, 1963).

If data on specific capacity are lacking, transmissivity can be estimated for those areas where lithologic logs or good drillers' logs are available if the relation between hydraulic conductivity and median grain size is known. Such a relation has been established for alluvial material in the Arkansas River Valley, Ark., (Bedinger and Emmett, 1963).

To the extent that the relation found for the alluvial materials of the Arkansas River Valley are applicable to the materials of the area being investigated or that a new relation can be established, possibly on the basis of pumping tests or laboratory analyses, the transmissivity can be computed by summing the products of the various hydraulic conductivities and the thicknesses of the strata to which they apply.

Transmissivity can also be computed if the width of a vertical section through which ground water is moving at a known rate and the hydraulic gradient normal to that section are known or can be estimated with reasonable accuracy.

All the above methods were used in varying degrees during the current investigation for estimating transmissivity.

## TRANSMISSIVITY

### DETERMINATIONS BY PREVIOUS INVESTIGATORS

Prior to the present investigation, Jacob (1966) analyzed the results of interference tests for 10 deep drainage wells along the eastern side of Yuma Valley. Transmissivities obtained as a result of these tests are shown in figure 23. He also analyzed the results of step-drawdown tests on six of these wells to determine the characteristics of the wells themselves. Step-drawdown tests also were made on 10 other wells, of which three were in the Yuma Valley, three in the South Gila Valley, and four on the Yuma Mesa. The location of these tests and the transmissivities, where considered reliable by Jacob, are also shown in figure 23.

### DETERMINATIONS DURING PRESENT INVESTIGATION

In planning the phase of the investigation dealing with regional transmissivity values it was decided that, for the time and funds available, more representative information could be obtained by making short-term pumping tests of practically all the large capacity wells, even though some of the procedures might yield questionable data in some instances, than by making more detailed and much more expensive and time-consuming tests at only a limited number of sites. Consequently, advantage was taken of almost all opportunities to make pumping tests on existing large-capacity wells for which adequate tests had not been made. In most places, the procedure was limited to obtaining data on the rate of recovery of water level in the pumped well after it had been pumped at a constant rate for a known period of time. Although the reliability of this procedure was unpredictable it generally provided useful information for computing transmissivity for the material tapped by the well. When it was possible to obtain rate-of-drawdown data also, the transmissivity computed from that data was compared with the value computed from the recovery data. A substantial difference between the two values was considered an indication that one or both was unreliable. Other measures of transmissivity, such as specific capacity, were considered in checking the reasonableness of the values computed from drawdown or recovery data.

Step-drawdown tests were made for most of the test wells that were drilled and for a few other wells where it was practical to do so. Step-drawdown tests permit the separation of the observed drawdown into two components, one due to well losses and the other due to formation losses. A transmissivity computed on the basis of the specific capacity from which well losses have been excluded is likely to be closer to the true transmissivity than is a value that is based on the assumption that the well loss is average for the area.

The Thiem method for computing the transmissivity was used for several of the large drainage wells for which observation wells were available for computing the hydraulic gradient toward the pumped well. All the pumping tests, except those which were analyzed by the Thiem method, involved the use of the nonequilibrium formula of Theis (1935) or modifications thereof. The nonequilibrium formula is based on the following assumptions: (1) The aquifer is isotropic and homogenous, (2) the aquifer is of infinite areal extent, (3) the well taps the full thickness of the aquifer, (4) the well has an infinitesimal diameter, and (5) the release of water from storage with decline of head is instantaneous.

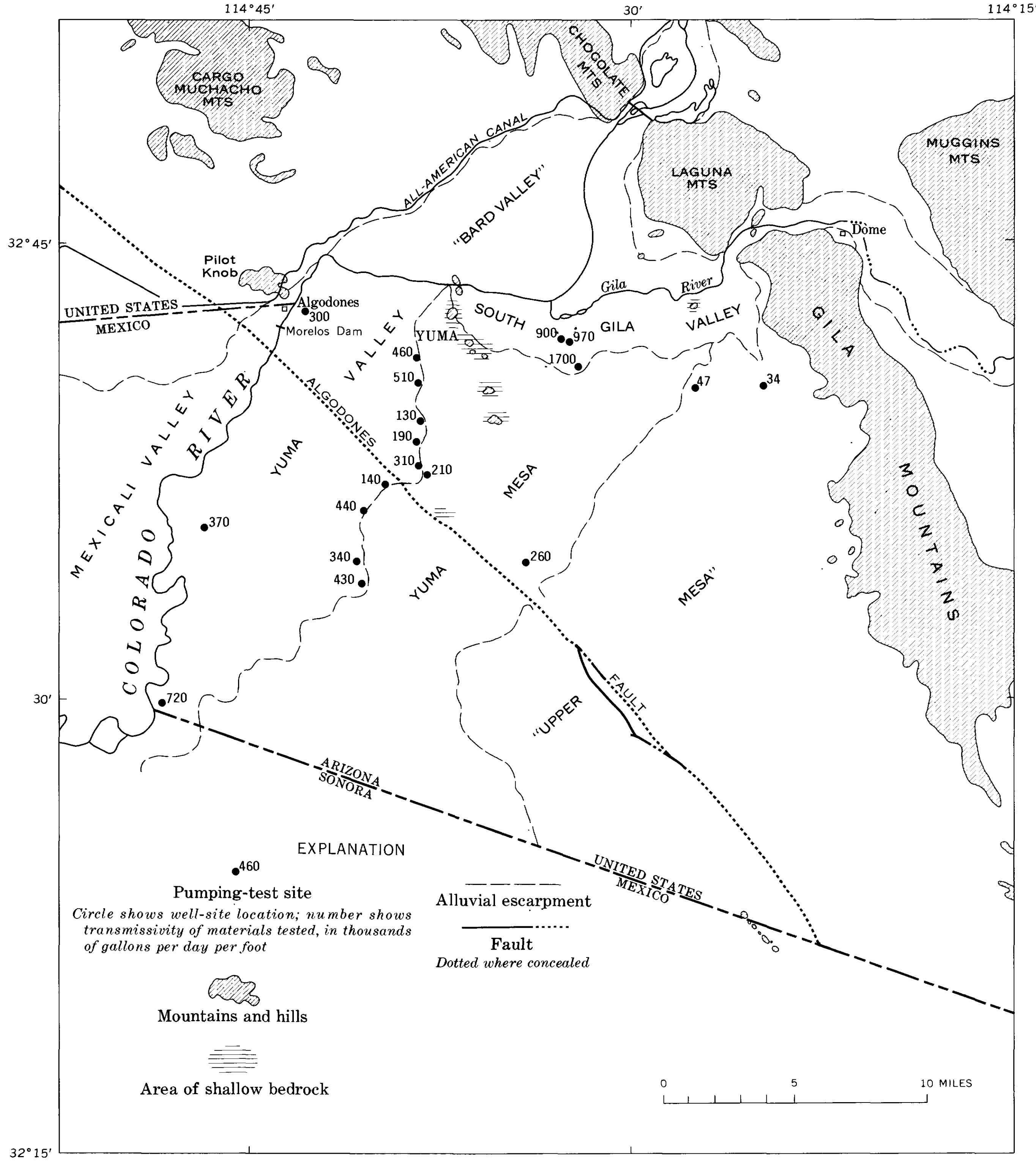


FIGURE 23.—Transmissivities computed from pumping tests made prior to the present investigation.

It was realized that the actual conditions differed substantially from the ideal conditions that were assumed in deriving the nonequilibrium formula. Nevertheless, the results of previous pumping tests throughout the country have demonstrated that meaningful results can be obtained if the tests are made and the results are analyzed in a way that minimizes the effects of any conditions that differ substantially from ideal conditions. Accordingly, pumping tests utilizing the nonequilibrium formula

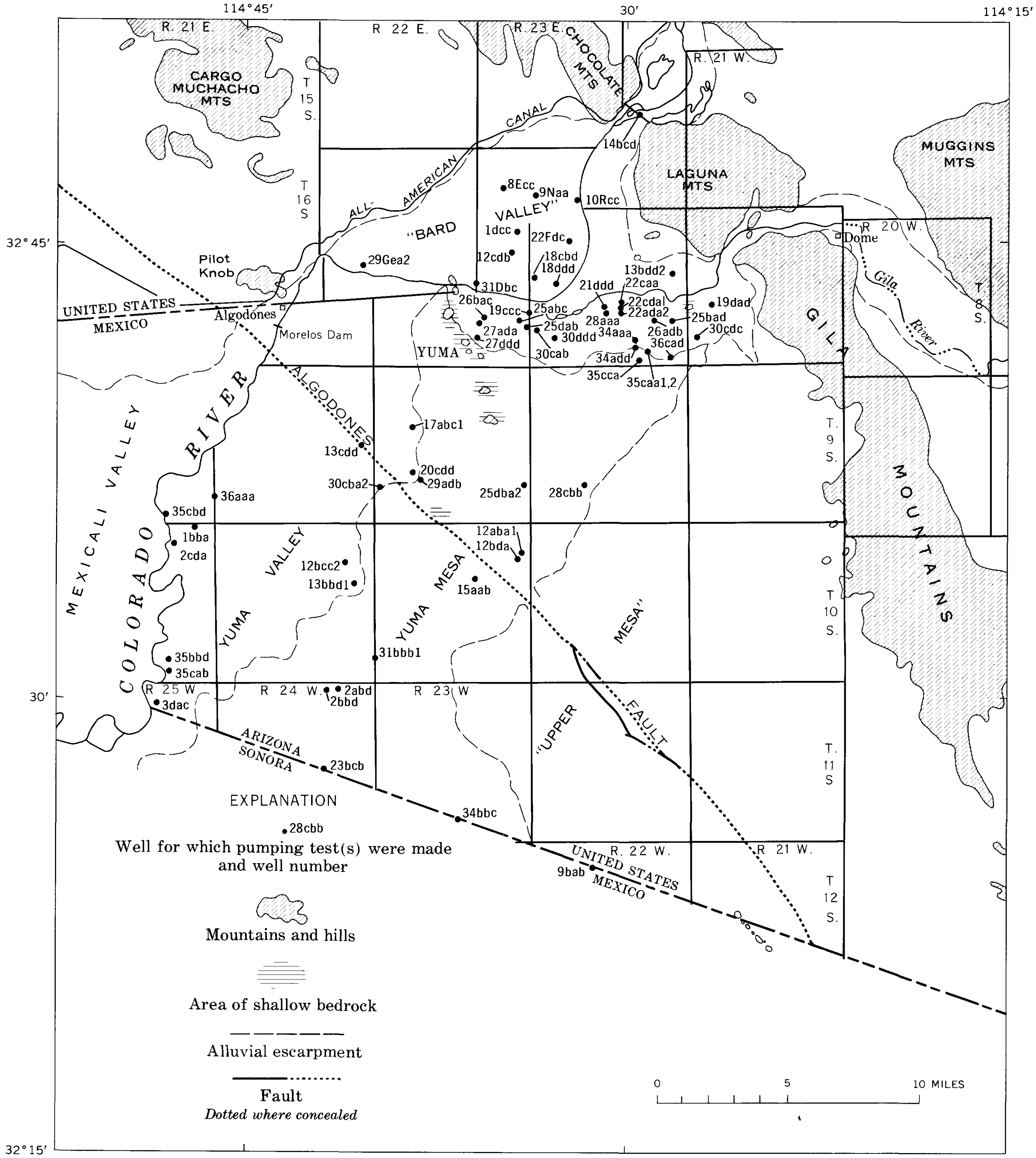


FIGURE 24.—Wells for which pumping tests were made during present investigation.

were made on practically all large-capacity wells on which pumping tests had not been made previous to the present investigation and for which satisfactory arrangements for a pumping test could be made, unless the geologic and hydrologic conditions obviously precluded obtaining meaningful results (fig. 24). Because of this practice, some of the pumping tests yielded data that were not satisfactory for analyses by the nonequilibrium formula.

Table 7 lists the results of the pumping tests that were made during the present investigation. Each of the values of transmissivity is designated as being considered an excellent, good, fair, or poor indicator of the transmissivity of the material tapped by the well. The classification takes into account the construction of the well, the possibility of leakage between strata tapped by the well either within the well casing or the gravel envelope outside the casing, the storage capacity of the well casing and the gravel envelope relative to the rate at which the well had been discharging, and other factors that might tend to invalidate the results. The degree to which changes in water level with time conformed with theory also was used to judge the reliability of the transmissivity. Another criterion was the ratio between the transmissivity and the specific capacity of the well, a method mentioned earlier in this report. For most of the wells that were tested, ratios of 2,000–3,000 were considered reasonable. Lower ratios were indicated when the drawdown used to compute specific capacity did not include well losses, when the specific capacity was considerably higher than it would be at the end of a 1-day pumping period, or when effective well diameters were considerably more than 24 inches.

Another criterion for evaluating the reliability of the indicated values of transmissivity was whether the hydraulic conductivity as computed by dividing the indicated transmissivity by the thickness of strata tapped by the well greatly exceeded the probable maximum hydraulic conductivity of the material tapped by the well. In the Yuma area the average maximum hydraulic conductivity of alluvial material several tens of feet thick probably is not more than 10,000 gallons per day per square foot. Thus, computed values of transmissivity that indicated hydraulic conductivities two or more times larger than the above figure were considered unreliable.

A classification of excellent for the reliability of the transmissivity was made where, taking into account all the aforementioned criteria, the computed transmissivity was thought to differ from the true value by less than 10 percent; good, if the difference was likely to be as much as 25 percent; fair, if as much as 50 percent; and poor, if more than 50 percent. Of the 73 evaluations of reliability of the computed values of transmissivity, three are classified as excellent; 33 as good; 28 as fair, and nine as poor.

To adequately evaluate the transmissivity of the full thickness of saturated material at a particular well site, one must also have knowledge of the hydraulic conductivity of all water-bearing strata not tapped by the well, or at least a general knowledge as to what percentage of the transmissivity of the fully saturated section is represented by the computed value. A good understanding of the various kinds of water-bearing material and their positions in the geologic framework in which the ground water occurs is necessary for this evaluation and was attained during the present investigation. This knowledge together with pumping-test data and drillers' logs of wells permitted the compilation of maps showing transmissivity (fig. 25 and others not shown), which were used as a basis for constructing the analog model of the Yuma area and for computing rates of ground-water movements.

### STORAGE COEFFICIENT

An important characteristic of an aquifer is its ability to store or to release water in response to changes in head. This characteristic commonly is designated by a dimensionless number called the storage coefficient (formerly coefficient of storage), which 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).

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

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

The volume of water involved in gravity drainage ordinarily is many hundreds or even thousands of times greater than the volume attributable to compressibility of the aquifer materials and of the water in the saturated zone; therefore, the volume of water resulting from compressibility can be ignored. The volume of water involved in gravity drainage divided by the volume through which the water table moves, has been defined as the specific yield. Under dewatering and unconfined conditions the storage coefficient therefore is sensibly equal to the specific yield. When water is going into storage, that is, when the water table is rising, the storage coefficients may exceed the specific yield if the material in which the water is being stored contains less moisture than it can retain against gravity drainage. The upper limit of the storage coefficient in the latter con-

TABLE 7.—*Results of pumping tests*

Type of test: D, drawdown; R, recovery; SD, step-drawdown.
Aquifers tested: B, Bouse Formation; C, coarse-gravel zone; N, nonmarine sedimentary rocks; O, older alluvium, undivided; W, wedge zone.

| Well | Owner or name | Depth interval tested, in feet below land-surface datum | Date of test | Type of test | Yield, in gpm | Drawdown, in feet | Specific capacity, in gpm per ft | Transmissivity (*T*), in gpd per ft | Conformance of test data to theoretical values | Reliability of *T* | Aquifers tested | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16S/22E-29Gca2 | USGS LCRP 26 | 125–1,127; 1,368–1,769 | 4–13–65 | R | 1,390 | 9.6 | 140 | 570,000 | Good | Fair | C, W, N | See page H211 for additional test data. |
| 16S/23E-8Ecc | USBR CH5 | 110–141 | 12–16–63 | D | 570 | 6 | 95 | 340,000 | do | do | C | |
| | | | 12–18–63 | R | 570 | 6 | 95 | 750,000 | do | do | C | |
| 22Fdc | H. Mitchell | (?) | 10–29–62 | R | 4,120 | 17 | 240 | 440,000 | Fair | do | C(?) | |
| 9Naa | M. E. Spencer | 124–225 | 4–20–63 | R | 3,900 | 19 | 200 | >300,000 | do | do | C, W | Only parts of aquifers tested. |
| 10Rcc | USGS LCRP 23 | 634–694 | 1–21–63 | D | 1,230 | 22 | 56 | 260,000 | Excellent | Good | B | See page H209 for additional data. |
| | | | 1–21–63 | R | 1,230 | 22 | 56 | 4,600,000 | Fair | Poor | B | |
| | | 120–548 | 4–6–65 | R | 650 | 4 | 160 | 240,000 | Excellent | Good | C, W | |
| 31Dbc | Dover and Webb | 100–144 | 4–30–63 | R | 3,000 | 21 | 140 | 420,000 | Fair | Fair | C | |
| (C–7–22) 14bcd | USGS LCRP 14 | 470–490 | 4–23–63 | R | 290 | 46 | 63 | 110,000 | Good | do | N | Only part of aquifer tested. |
| | | 118–128; 152–162 | 5–29–63 | R | 600 | 9 | 67 | 790,000 | Poor | Poor | C | |
| (C–8–21) 19dad | F. J. Hartman | 115–165 | 9–11–62 | R | 2,600 | 28 | 93 | 230,000 | Good | Good | C | |
| 30cdc | do | 120–140 | 10–9–62 | R | 2,050 | 11 | 190 | 1,800,000 | Excellent | Fair | C | Gravel reported 80–150 feet. Only part of aquifer tested. |
| (C–8–22) 13bdd2 | S. Sturges | 109–128 | 4–9–64 | R | 1,325 | 53 | 25 | 65,000 | Good | Good | C | In tight gravel. Only part of aquifer tested. |
| 18cbd | Powers | 110–160 | 10–16–62 | R | 4,400 | 9 | 490 | 610,000 | do | do | C | |
| 18ddd | do | 100–155 | 10–17–62 | R | 4,600 | 24 | 190 | 800,000 | Fair | Fair | C | |
| 19ccc | USBR CH702 | 370–390; 395–435; 455–463 | 11–13–63 | R | 1,060 | 35 | 30 | 68,000 | Good | Good | W | Only parts of aquifer tested. |
| 21ddd | B. Church | 105–150 | 10–10–62 | R | 2,820 | 16 | 180 | 390,000 | do | do | C | |
| 22caa | do | 100–165 | 10–5–62 | R | 3,200 | 15 | 210 | 430,000 | Excellent | do | C | |
| 22cda1 | do | <136 | 10–4–62 | R | 3,200 | 16 | 200 | 320,000 | do | Fair | C | *T* may be low by about 25 percent because well ¼ mile distant was shut off 10 minutes prior to recovery test. Only part of aquifer tested. |
| 22cda2 | do | 100–152 | 10–4–62 | R | 2,600 | 10 | 260 | 380,000 | Fair | do | C | |
| 25bad | F. J. Hartman | 100–114 | 9–20–62 | R | 2,600 | 14 | 190 | 400,000 | do | do | C | Only part of aquifer tested. |
| 26adb | S & W | (?) | 10–8–62 | R | 2,400 | 20 | 120 | 290,000 | Good | Good | C | |
| 28aaa | B. Church | 105–150 | 10–10–62 | R | 2,600 | 18 | 140 | 350,000 | Excellent | do | C | |
| 30cab | C. Lord | 115–170 | 10–4–62 | R | 3,100 | 12 | 260 | 380,000 | do | do | C | |
| 30ddd | do | 130–160 | 10–9–62 | R | 1,450 | 8 | 180 | 360,000 | Good | do | C | Do. |
| 34aaa | W. R. Whitman | 93–177 | 10–9–62 | R | 2,560 | 26 | 98 | 960,000 | Excellent | do | C | |
| 34add | USBR CH750 | 500–600 | 10–7–64 | R | 2,700 | 60 | 45 | 150,000 | Fair | Fair | W | |
| 35caa1 | USBR CH704 | 435–445; 480–490; 507–570 | 12–24–63 | R | 1,100 | 24 | 46 | 340,000 | do | do | W | Do. |
| | | 99–170 | 1–7–64 | R | 1,620 | 8 | 200 | 1,100,000 | Good | Good | C | |
| 35caa2 | USBR CH751 | 484–585 | 10–13–64 | R | 2,750 | 65 | 42 | 190,000 | Fair | Fair | W | Do. |
| 35cca | Arizona Western College. | 180–248 | 9–30–62 | R | 690 | 30 | 23 | 230,000 | do | do | C | |
| 36cad | USBR CH752 | 520–621 | 10–1–64 | R | 2,600 | 82 | 32 | 200,000 | do | do | W | Do. |
| (C–8–23) 1dcc | K. Easterday | 120–145 | 11–6–62 | R | 2,900 | 22 | 130 | 600,000 | Poor | do | C | |
| 12cdb | do | 115–171 | 11–8–62 | R | 4,500 | 27 | 170 | 480,000 | do | do | C | |
| 25acb | Gunther and Shirley. | 115–175 | 10–5–62 | R | 2,230 | 20 | 110 | 260,000 | Good | Good | C | |
| 25dab | do | 115–175 | 10–5–62 | R | 2,400 | 17 | 140 | 300,000 | Excellent | Excellent | C | |
| 26bac | G. Ogram | 142–180 | 10–10–62 | R | 1,960 | 22 | 89 | 180,000 | do | do | C | Only part of aquifer tested. |
| 27ada | USBR CH701 | 84–88; 125–160 | 12–3–63 | D | 1,250 | 20 | 62 | 330,000 | Fair | Fair | C | |
| | | | 12–3–63 | R | 1,300 | 19 | 68 | 230,000 | Excellent | Excellent | C | |
| 27ddd1 | Carter | 135–158 | 10–8–62 | R | 1,725 | 35 | 49 | 120,000 | Fair | Fair | C | Do. |
| (C–8–24) 22ccd | McLaren Produce Co. | 117–142 | 7–15–30 | D | 2,850 | 39 | 58 | 300,000 | Good | Good | C | Do. |
| (C–9–22) 28cbb | USGS LCRP 25 | 862–2,002 | 1–19–65 | SD, R | 600 | 11 | 54 | 200,000 | Poor | | W | See page H213 for additional test data. Upper 500 feet of aquifer not included in test. |
| (C–9–23) 17abc1 | YCWUA 3 | 130–170 | 4–29–63 | D | 4,700 | 42 | 110 | 230,000 | Fair | do | C | |
| 20cdd | YCWUA 5 | 130–203; 213–240 | 4–25–63 | D | 6,300 | 35 | 180 | 250,000 | Good | do | C, W | Only upper 27 feet of wedge zone included in test. |

TABLE 7.—*Results of pumping tests*—Continued

| Well | Owner or name | Depth interval tested, in feet below land-surface datum | Date of test | Type of test | Yield, in gpm | Drawdown, in feet | Specific capacity, in gpm per ft | Transmissivity (*T*), in gpd per ft | Conformance of test data to theoretical values | Reliability of *T* | Aquifers tested | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C–9–23) 25dba2 | USBR CH7B | 160–250 | 3–18–64 | R | 700 | 12 | 58 | 3,000,000 | Poor | Poor | C | |
| 29adb | Yuma Mesa Fruit Growers Unit B. | 156–207 | 12–23–55 | D | 3,700 | 20 | 180 | 600,000 | Fair | Fair | C | |
| 30cba2 | YCWUA 6 | 140–160 } 170–203 } | 4–25–63 | D | 4,000 | 40 | 100 | 200,000 | Good | Good | C | |
| (C–9–24) 13cdd | USBR CH3 | 139–170 | 12–31–63 | D | 520 | 22 | 24 | 300,000 | do | do | C | |
| | | | 12–31–63 | R | 520 | 22 | 24 | 300,000 | Excellent | do | C | |
| (C–9–25) 35cbd | USGS LCRP 9 | 436–1,108 | 11–28–62 | R | 100 | 71 | 1.4 | 300,000 | Good | Poor | W | Specific capacity is abnormally low because of high internal well losses. 120 feet of screen in the 672-foot interval tested. Only part of aquifer tested. |
| | | 436–560 | 12–11–62 | D | 92 | 79 | 1.2 | 18,000 | do | do | W | Only part of aquifer tested. |
| | | | 12–11–62 | R | 92 | 79 | 1.2 | 220,000 | do | do | W | Do. |
| 36aaa | McDaniel & Sons, Inc. | 130–180 | 11–19–62 | R | 3,620 | 44 | 82 | 160,000 | Fair | Good | C | |
| (C–10–23) 12aba1 | J. F. Nutt | 178–686 | 10–31–63 | D | 4,150 | 28 | 150 | 210,000 | Excellent | do | C, W | Only part of wedge zone tested. |
| | | | 10–31–63 | R | 4,150 | 28 | 150 | 260,000 | Fair | do | C, W | Do. |
| 12bda | do | 150–680 | 11–6–63 | R | 3,700 | 26 | 140 | 500,000 | do | do | C, W | Do. |
| 15aab | do | <890 | 11–18–61 | R | 1,940 | 19 | 100 | 270,000 | Good | do | W | Do. |
| 31bbb1 | USGS LCRP 1 | 220–280 | 6–20–62 | | 1,320 | 84 | 16 | 280,000 | Fair | Fair | C | Analyzed by using leaky artesian formula and observation wells. Only part of aquifer tested. |
| (C–10–24) 12bcc2 | YCWUA 8 | 150–178 | 1–18–65 | R | 4,940 | 33 | 150 | 260,000 | Good | Good | C | Only part of aquifer tested. |
| 13bbd1 | YCWUA 9 | 142–185 | 1–18–65 | R | 2,060 | 120 | 170 | 540,000 | Fair | Fair | C | Do. |
| (C–10–25 1bba | P. R. Sibley | 160–285 | 11–9–62 | R | 5,200 | 22 | 240 | 443,000 | Excellent | Good | C | |
| 2cda | F. Jeffries | 158–295 | 10–30–62 | R | 3,820 | 25 | 150 | 460,000 | Fair | Fair | C | |
| 35bbd | USGS LCRP 17 | 520–1,398 | 3–28–64 | R | 388 | 5 | 78 | 160.000 | Poor | do | W | See page H214 for additional data. Only part of aquifer tested. |
| 35cab | J. F. Barkley | 178–293 | 11–21–62 | R | 4,000 | 39 | 100 | 600,000 | Fair | Good | C | |
| (C–11–23) 34bbc | USGS LCRP 30 | 160–600 | 8–31–65 | SD, R | 1,340 | 11 | 120 | 1,300,000 | Excellent | Fair | C, W | Only part of wedge zone tested. |
| (C–11–24) 2abd | J. F. Nutt | 130–300 | 1–14–65 | D | 1,660 | 11 | 150 | 1,100,000 | do | Good | C | |
| | | | 1–14–65 | R | 1,620 | 11 | 150 | 1,100,000 | do | do | C | |
| 2bbd | do | 140–289 } 319–376 } | 5–3–65 | D | 3,700 | 19 | 190 | 1,600,000 | Good | Poor | C, W | Do. |
| | | | 5–3–65 | SD, R | 3,700 | 19 | 190 | 9,000,000 | do | do | C, W | *T* as indicated from recovery data, is 10 or more times larger than *T* based on formation specific capacity. Only part of wedge zone tested. |
| 23bcb | USGS LCRP 10 | 165–1,002 | 4–11–63 | R | 2,500 | 18 | 140 | 740,000 | do | Good | C, W | See page H216 for additional data. 231 feet of screen in the 837-foot interval tested. Only part of wedge zone tested. |
| (C–11–25) 3dac | E. Hughes | 188–282 | 10–31–62 | R | 4,560 | 29 | 160 | 730,000 | Fair | Fair | C | |
| (C–12–22) 9bab | USGS LCRP 24 | 318–346 | 3–16–65 | SD | 600 | 66 | 9.1 | 200,000 | do | Poor | O | 18 feet of casing perforated in the 28-foot interval tested. Only part of aquifer tested. |
| | | | 3–16–65 | R | 600 | 66 | 9.1 | 3,500,000 | Poor | do | O | Above remarks apply to this test also. |

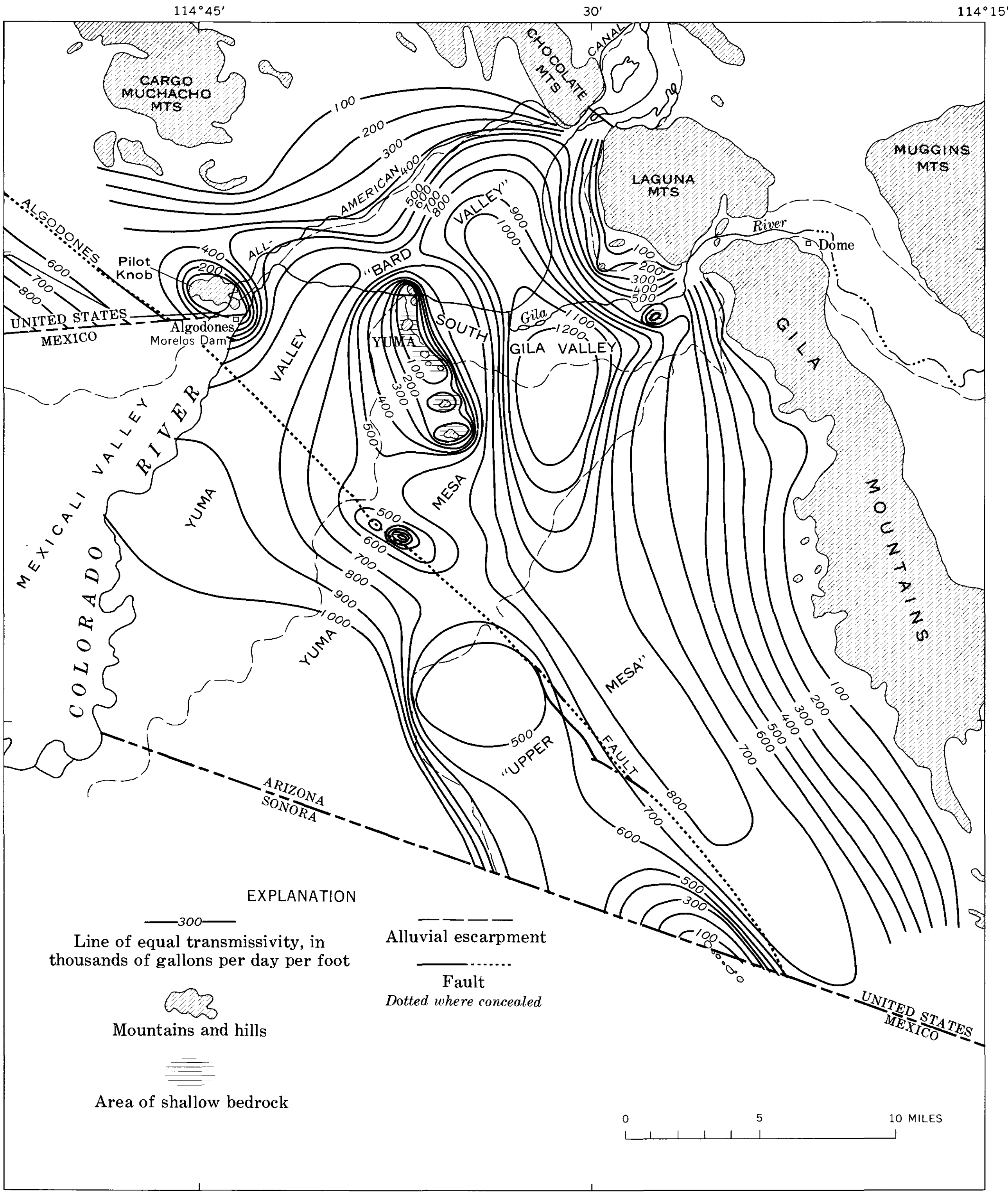


FIGURE 25.—Transmissivity of alluvium.

dition is the porosity of the material. Under water table conditions, the storage coefficient for clay and silt commonly ranges from almost zero to a few hundredths. Generally, as grain size, and sphericity of the aquifer material increase and (or) sorting improves, the storage coefficient commonly increases. For clean sand and gravel, it frequently ranges between 0.2 and 0.4

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

Storage coefficients used in conjunction with transmissivities enable one to determine for a given change in the ground-water supply in a given area the relative amounts of ground water that will be involved in storage changes and those that will be innvolved in movement of ground water toward or away from the area. In other words, using these two characteristics one is able to determine the change in position and change in shape of the water or piezometric surface that results from a given change in the supply of ground water.

Storage coefficients can be determined from pumping tests. Pumping tests are probably the most practical way for obtaining storage coefficients if artesian conditions exist, but many times they may be less practical than other methods where water-table conditions prevail. The failure of short-term pumping tests to provide valid data for computing a storage coefficient is due in most places to the slow rate at which many water-bearing materials drain.

The mathematical formulas used in this analysis of pumping tests assume an instantaneous change in storage with a change in head. Although this idealization is approached under artesian conditions, it is not approached under water-table conditions. Most storage coefficients computed from data obtained during pumping tests of unconfined aquifers are likely to be substantially less than the true storage coefficient unless the test is extended for several days and adjustments for the protracted drainage are made. In most tests, therefore, it is impractical to meet all the conditions that are necessary to obtain valid data. A more practical approach for determining storage coefficients under water-table conditions in the Yuma area appears to be the use of a neutron moisture probe in conjunction with access tubes driven to depths of several feet below the water table. The average difference between the moisture content of material above the capillary zone and that of material below the water table is then considered a reliable indicator of the amount of water that will go into storage as the water table rises.

This approach was used for estimating storage characteristics of the material saturated by the large ground-water mound that built up beneath Yuma Mesa after 1947. The details of the investigation of moisture content by means of the neutron probe are given in appendix E.

Storage coefficients for artesian conditions were not computed from any of the pumping tests that were made during the present investigation because the conditions for the pumping tests were not adequate for obtaining valid results. Artesian storage coefficients for drainage wells along the eastern boundary of Yuma Valley, as computed by Jacob (1960, appendix E, table E–1) ranged from $5.8 \times 10^{-4}$ to $3.6 \times 10^{-3}$ and averaged $1.2 \times 10^{-3}$.

In the Yuma area, the quantities of water that are involved in changes in storage under artesian conditions are very small relative to the quantities involved under water-table conditions. Thus, only a general knowledge of the storage coefficient under artesian conditions is needed to account for or predict the principal changes in ground-water movement or storage resulting from stresses imposed on the system.

## MOVEMENT OF GROUND WATER

As in surface flow, ground water moves in the direction of decreasing head, but its rate of movement through granular materials, such as those in the Yuma area, is only a small fraction of the rate of movement of surface water, and its path of movement is much more complex.

During the present study, water-level maps were prepared to show the direction of movement of ground water under natural conditions and at selected times during the historical development of the water resources of the area. Because the Colorado River and the ground-water system are connected hydraulically, important controls for preparing the water-level maps were the mean annual stages of the river (fig. 26).

A river-profile map and a series of topographic maps of the Colorado River flood plain were published in 1927 by the U.S. Geological Survey from surveys made in 1902. These maps together with the early records of river stage at Yuma were used to estimate mean annual river stages under natural conditions and also during the period of water-resources development until the rapid degradation of the river channel in the early 1940's. After 1940, considerable information regarding the river profile was inferred from river-channel-cross-section sur-

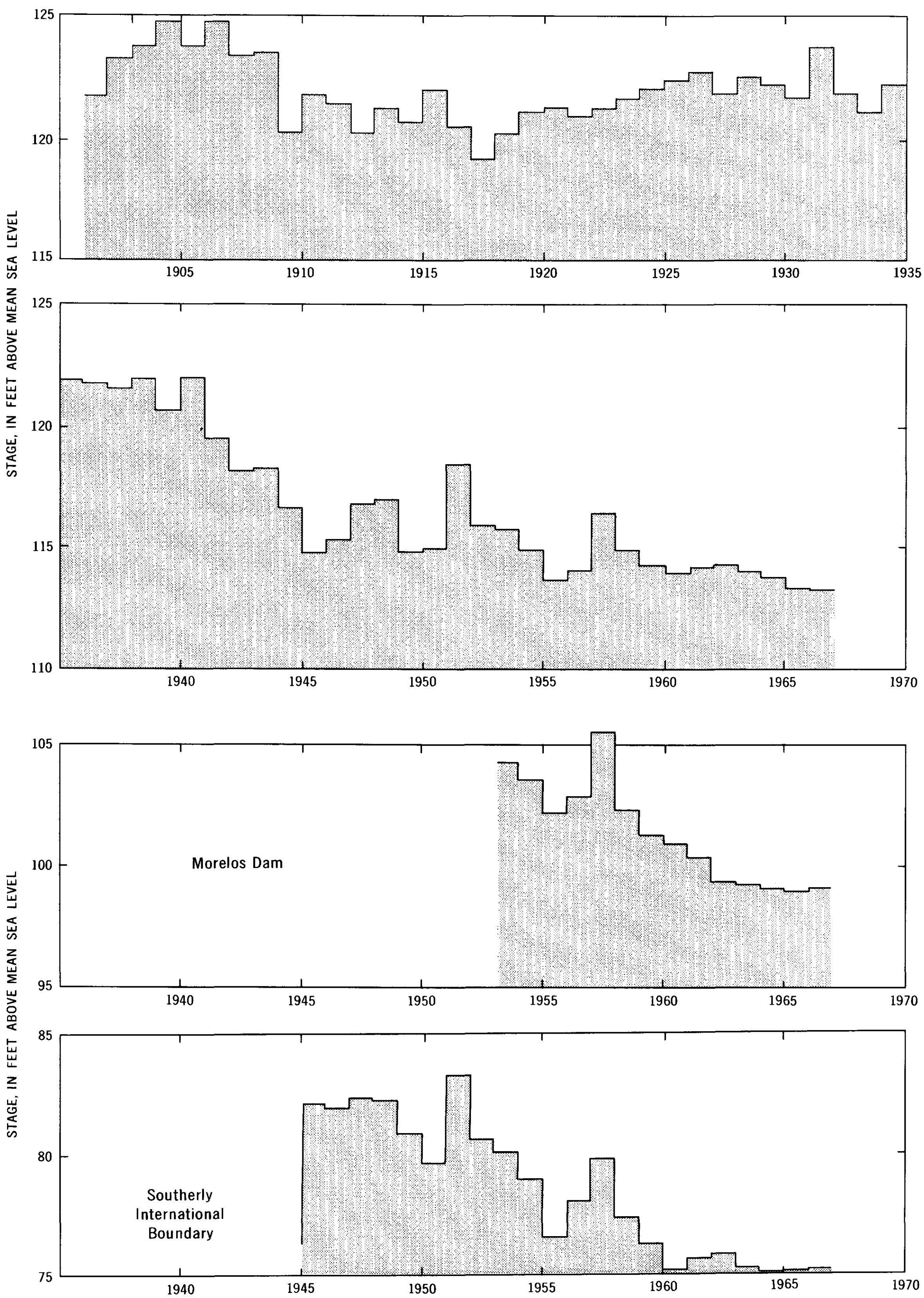


FIGURE 26.—Mean annual stages of Colorado River at Yuma, Ariz.

veys that were made periodically at selected sites by the U.S. Section of the International Boundary and Water Commission.

Before 1942 the mean annual stage of the Colorado River at Yuma ranged from 120 to 125 feet above mean sea level; during the next few years the stage dropped about 5 feet, then continued to drop, but at a lesser rate, to a stage of about 113 feet in 1966 (fig. 26). Although the lowering of stage was due in part to decreased flow of the river, the principal cause of the rapid lowering in the 1940's probably was the erosion of the channel by the clearer water that resulted from upriver storage.

Stages were also dropping at the Morelos gaging station and at the southerly international boundary, undoubtedly for the same reasons as at Yuma (fig. 26). In the 1960's a stage of about 74 feet indicated no measurable streamflow at the southerly international boundary.

### DIRECTION OF MOVEMENT UNDER NATURAL CONDITIONS

Adequate water-level data are not available for determining directly the configuration of the groundwater surface beneath Yuma Valley or Mexicali Valley under natural conditions. The earliest year for which sufficient data are available for drawing a water-level map for Yuma Valley is 1911. Although the valley had been irrigated with Colorado River water for several decades priod to 1911, the effects of irrigation on the configuration of the groundwater surface probably was small, partly because under natural conditions Yuma Valley had been subject to periodic flooding by the river and partly because only one-eighth of the valley land was being irrigated. Therefore, ground-water levels in Yuma Valley in 1911 probably were similar to those under natural conditions.

The inferred configuration of the water table in Yuma Valley in 1911 is based on widely scattered water-level data and estimated river stages (fig. 27). The water-level contours indicate that in 1911 and by inference, also under natural conditions, the Colorado River was a source of recharge to the ground-water body underlying Yuma Valley.

The earliest year for which similar information is available for any part of Mexicali Valley is 1939. Water-level data for 1939 for that part of Mexicali Valley lying north of the Alamo Canal, together with water-level data for 1958 for that part of Mexicali Valley lying south of the Alamo Canal, were used as a basis for drawing a water-level map showing the probable configuration of ground-water levels in Mexicali Valley in 1939 (fig. 28).

The irrigation of land with surface water in Mexicali Valley, without provisions for drainage, caused water levels to rise above the levels that existed under natural conditions. By 1939, several places had been noted in which irrigated lands had become so waterlogged that farming was no longer feasible.

Although the configuration of the water-level surface in Mexicali Valley in 1939 was similar to its configuration under natural conditions, its southwestward slope had decreased somewhat because its eastern boundary was hinged to the Colorado River and did not rise as did water levels beneath the irrigated lands farther westward from the river.

For these reasons a somewhat lesser rate of infiltration of Colorado River water to the ground-water system, both beneath Yuma Valley and Mexicali Valley, is indicated by this map (fig. 28) than existed under natural conditions. The map shows that as late as 1939 the Colorado River was a source of recharge to the ground-water body, although ground-water levels had risen as much as 5 feet as a result of irrigation with surface water. Under natural conditions, then, the movement of ground water easterly from the river to the Yuma Valley and westerly to Mexicali Valley was substantially greater than that indicated by the 1939 data.

In 1939 there was also a southward movement of water beneath Yuma Mesa and across the southerly international boundary (fig. 28). The available data for later years indicate that neither the direction nor the rate of movement across the southerly international boundary was greatly different from what it probably had been under natural conditions. Therefore, the movement of ground water across this boundary as shown by the 1939 water-level data is a good indication of the movement under natural conditions.

The westward movement of ground water through the alluvium between Pilot Knob and the Cargo Muchacho Mountains as shown in 1939 probably also is a good indication of the direction and rate movement under natural conditions. However, after 1939, leakage from the All-American Canal greatly changed the ground-water gradients in this area. (Compare figs. 28 and 30.)

In summary, the water-level data, for the delta area in 1939 also indicate the direction of groundwater movement under natural conditions. However, the rates of movement from the Colorado River to the ground-water system adjacent to the limitrophe section, as shown by gradients in figure 28, are less than under natural conditions.

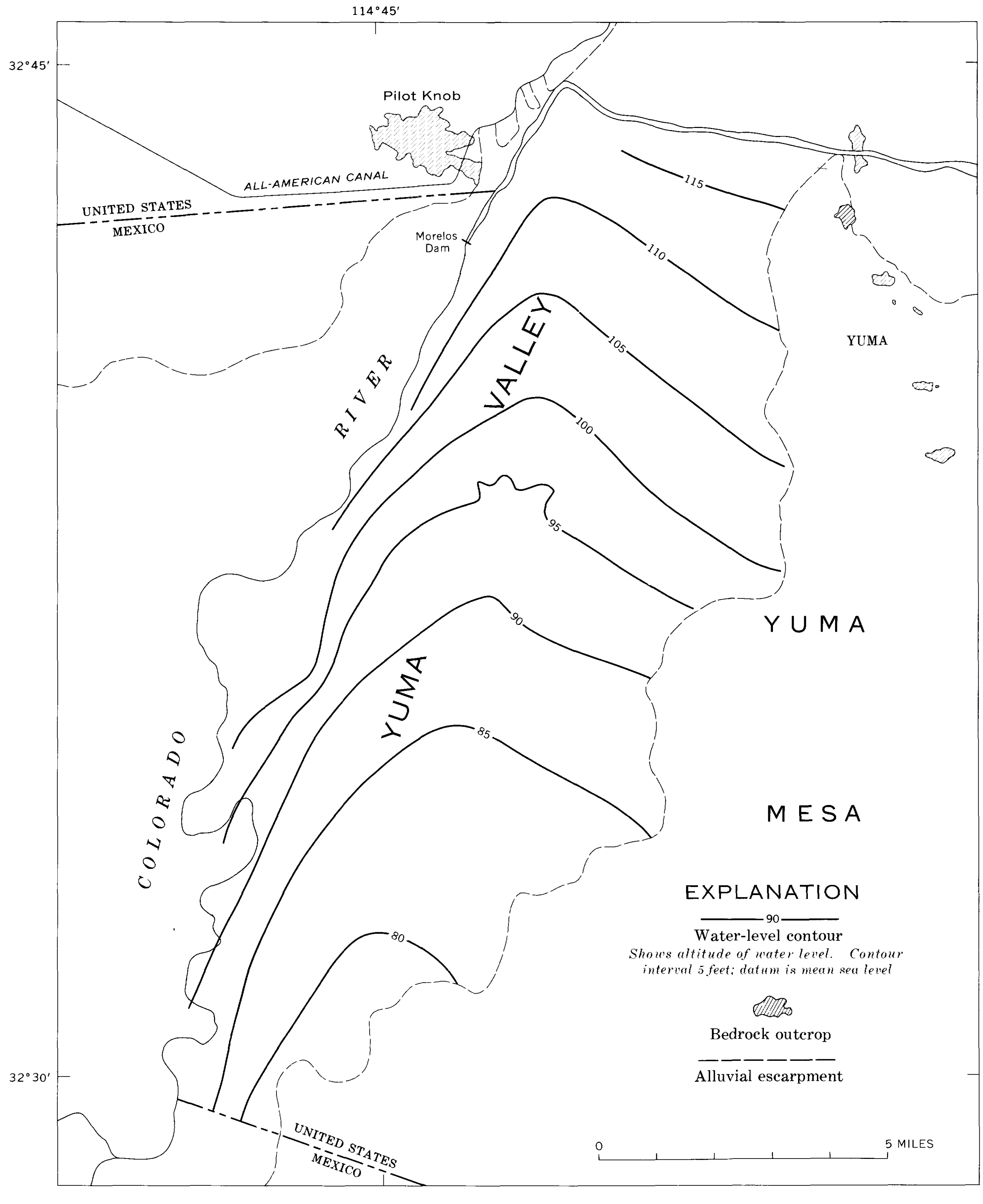


FIGURE 27.—Average water-level contours in 1911 in Yuma Valley.

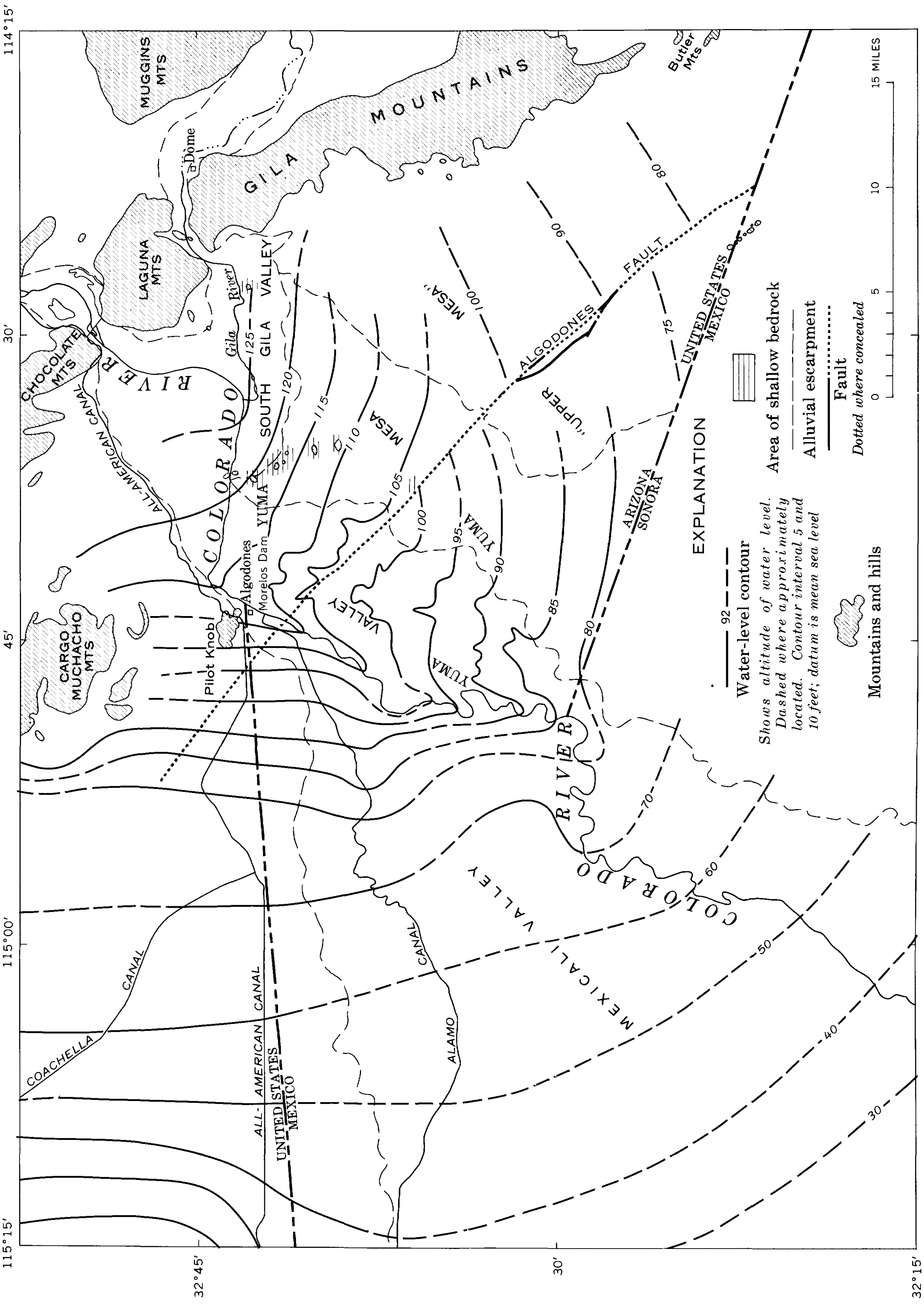


FIGURE 28.—Average water-level contours in 1939 in the delta region. Data for Mexicali Valley provided by the Mexican Section, International Boundary and Water Commission.

### RATE OF MOVEMENT UNDER NATURAL CONDITIONS

It is impractical to determine the rate of movement of ground water by direct measurement. However, an average rate of movement can be computed if the total quantity of ground water passing across a known section in a given period of time is known, or if the transmissivity of the material through which the water moves, the width normal to the direction of movement, and the hydraulic gradient causing the movement are known.

Rates of movement under natural conditions at selected sections necessarily must be computed or estimated by the latter method because there are no data on quantities that pased a known section during a given period of time.

#### ALLUVIAL SECTION BETWEEN PILOT KNOB AND CARGO MUCHACHO MOUNTAINS

On the basis of transmissivity values shown in figure 25, the transmissivity of the alluvial material through which ground water moved westward between Pilot Knob and the Cargo Muchacho Mountains is about 200,000 gpd per ft. The gradient probably was about 4 feet per mile in 1939 (fig. 28), and the width of the section is about 5 miles. The rate of movement under natural conditions based on the foregoing estimates then was about 4 mgd (million gallons per day) or about 4,500 acre-feet per year.

#### LIMITROPHE SECTION OF COLORADO RIVER

Computations of the rate of ground-water movement westward into Mexicali Valley from the limitrophe section of the Colorado River (the reach of the river forming the international boundary) under natural conditions are based on an average transmissivity value for the alluvium as determined during this study, and the estimated gradients that caused the movement. As stated in the foregoing section, the earliest date for which data on water levels in Mexico are available to the present study is 1939, at which time ground-water levels had risen in some areas as a result of irrigation. Using the gradients of 1939, therefore, will tend to make the estimates of ground-water movement under natural conditions somewhat too low.

The gradients under which the ground water moved westward from the Colorado River probably can be estimated within the limits warranted by the data by assuming that most of the water moved across a north-south alluvial section that originates at the northerly international boundary about 6 miles west of Pilot Knob, or near where the 90-foot contour crosses the northerly international boundary, and that extends southward to the southerly international boundary, a distance of about 15 miles. The gradient in the northern third of this section was less than that in the southern two-thirds of the section (fig. 28). The westward gradient across the northern third of the section is estimated to have been about 4 feet per mile, and that across the southern two-thirds to have been about 5 feet per mile.

The transmissivity is estimated to average about 800,000 gpd per ft for the northern third of the alluvial section and about 1,000,000 gpd per ft for the remainder of the section. Using the foregoing values, the flow of ground water westward into Mexicali Valley from the limitrophe section of the Colorado River in 1939 is estimated to have been about 66 mgd or about 74,000 acre-feet per year.

Under natural conditions the outflow was larger because by 1939 water levels in Mexicali Valley had risen as a result of irrigation, thereby decreasing the hydraulic gradient from the river. The extent to which the gradient was decreased is not known precisely, but if water levels in Mexicali Valley had risen 5–15 feet above their levels under natural conditions the westward flow of ground water in 1939 may have been only about three-fourths of the flow under natural conditions. On this basis the movement of ground water westward from the limitrophe section of the Colorado River under natural conditions may have been almost 100,000 acre-feet a year.

#### YUMA VALLEY

The movement of ground water from the Colorado River to Yuma Valley is postulated on the basis of river-stage records and early records of water level in Yuma Valley, plus the fact that such movement was necessary in order to meet the evapotranspiration requirements of the natural vegetation in Yuma Valley.

Under natural conditions Yuma Valley supported a rather heavy growth of water-loving vegetation over most of the valley. Mesquite was the dominant species, although willow, cottonwood, and arrowweed also thrived. The Colorado River annually overflowed its banks in early summer. In years of average or below-average floods most of the overflow was carried in the abandoned channels and sloughs that trended southward through the valley. In years of above-average floods however, the overflow spread over much of the valley.

The average annual rate of use of water by the natural vegetation is not known. However, an estimate can be made using as a basis the present rates of use by these plants in the flood plain of the river. The average density of the mesquite in the flood plain of the Colorado River in the reach between Davis Dam and the southerly international boundary as mapped by the U.S. Bureau of Reclamation in 1962 was about 50 percent, and the average annual rate of use was about 2 feet; the density of arrowweed was slightly less than 60 percent, and its annual rate of use was slightly less than 3 feet; tules used slightly more than 8 feet per year (U.S. Bureau of Reclamation, 1963, p. 26, 33).

It seems probable therefore that the average rate of use by mesquite in Yuma Valley under natural conditions was about 2 feet per year, and the rate of use by the other vegetation was slightly higher. The area of Yuma Valley is slightly more than 60,000 acres, so the total evapotranspiration probably was between 100,000 and 150,000 acre-feet annually.

Owing to the almost yearly flooding of large parts of Yuma Valley by the Colorado River, a substantial part of the transpiration requirements of the natural vegetation was supplied by the soil moisture resulting from the infiltration of the flood waters; the remainder, however, was supplied with ground water having a more remote source. The only remote sources of any significance were the Colorado and Gila Rivers.

Water-level contours in 1911 (fig. 27), which probably are fairly representative of the slopes and directions of ground-water movement that existed under natural conditions, show that ground water moved to Yuma Valley both from the Colorado River where it bordered the valley and from the Colorado and Gila Rivers in the South Gila Valley.

The quantity of the discharge originating along the reach of the Colorado River from Yuma to the west edge of the flood plain where the river abruptly changes its direction from westward to southward is computed on the basis of the average ground-water gradient southward, the length of the section, and the average transmissivity. The gradient is selected sufficiently far from the river and from the areas of substantial ground-water discharge to minimize the effect of vertical components of flow, and also the decrease in gradient that occurs in the area of discharge as more and more of the initial inflow is discharged.

The gradient is estimated to have averaged 3 feet per mile normal to a section 5 miles wide west of Yuma for which the transmissivity is estimated to be 600,000 gpd per ft. This gradient makes the inflows to the north end of Yuma Valley from the Colorado River before it turns southward about 9.0 mgd or about 10,000 acre-feet per year.

The quantity of the discharge originating along the reach from Pilot Knob to the southerly international boundary (limitrophe section) is estimated in a similar manner.

The gradients eastward from the river in this reach were much less uniform than the southward gradients in the reach between Yuma and Pilot Knob. However, gradients along flow lines some distance from the river, yet before points where substantial discharge occurred, appear to have averaged about 5 feet per mile. The section normal to these gradients is about 15 miles long, and the transmissivity of the section is estimated to be 900,000 gpd per ft. On this basis the eastward flow of ground water from the Colorado River in the reach between Pilot Knob and the southerly international boundary was 68 mgd or about 76,000 acre-feet per year.

Thus, in 1911, and also under natural conditions, the total ground-water flow from the Colorado River to Yuma Valley in the reach bordering the valley was about 86,000 acre-feet per year. This inflow plus the inflow from Yuma Mesa of ground-water originating in South Gila Valley was discharged by evapotranspiration in Yuma Valley.

The inflow to Yuma Valley from South Gila Valley is estimated on the basis of water-level contours in 1925 (fig. 29) and the transmissivities shown in figure 25. Water-level contours in 1925 are more typical of natural conditions than are those in 1939, especially in South Gila Valley, because pumping for irrigation was just beginning in 1925. The flow line that divides the ground water into segments that discharge to Yuma Valley from those that do not, is about 3 miles east of Yuma in the vicinity of the 120-foot water-level contour. Using the gradients and transmissivities west of this line, the discharge to Yuma Valley is computed to have been about 5,000 acre-feet per year in 1925, and by inference, also under natural conditions.

In summary, under natural conditions, the total amount of ground water that originated near the Colorado and Gila Rivers and that was discharged in Yuma Valley is estimated to have been about 90,000 acre-feet per year. This estimate is about six-tenths the maximum and about nine-tenths the estimated minimum total transpiration of the natural vegetation. In view of the almost yearly flooding of parts of Yuma Valley by the Colorado River, which undoubtedly supplied some of the transpiration requirement of the natural vegetation, the above estimated of ground-water inflow from the Colorado River appears reasonable, although somewhat high.

### DIRECTION OF MOVEMENT IN 1960

The configuration of the ground-water surface

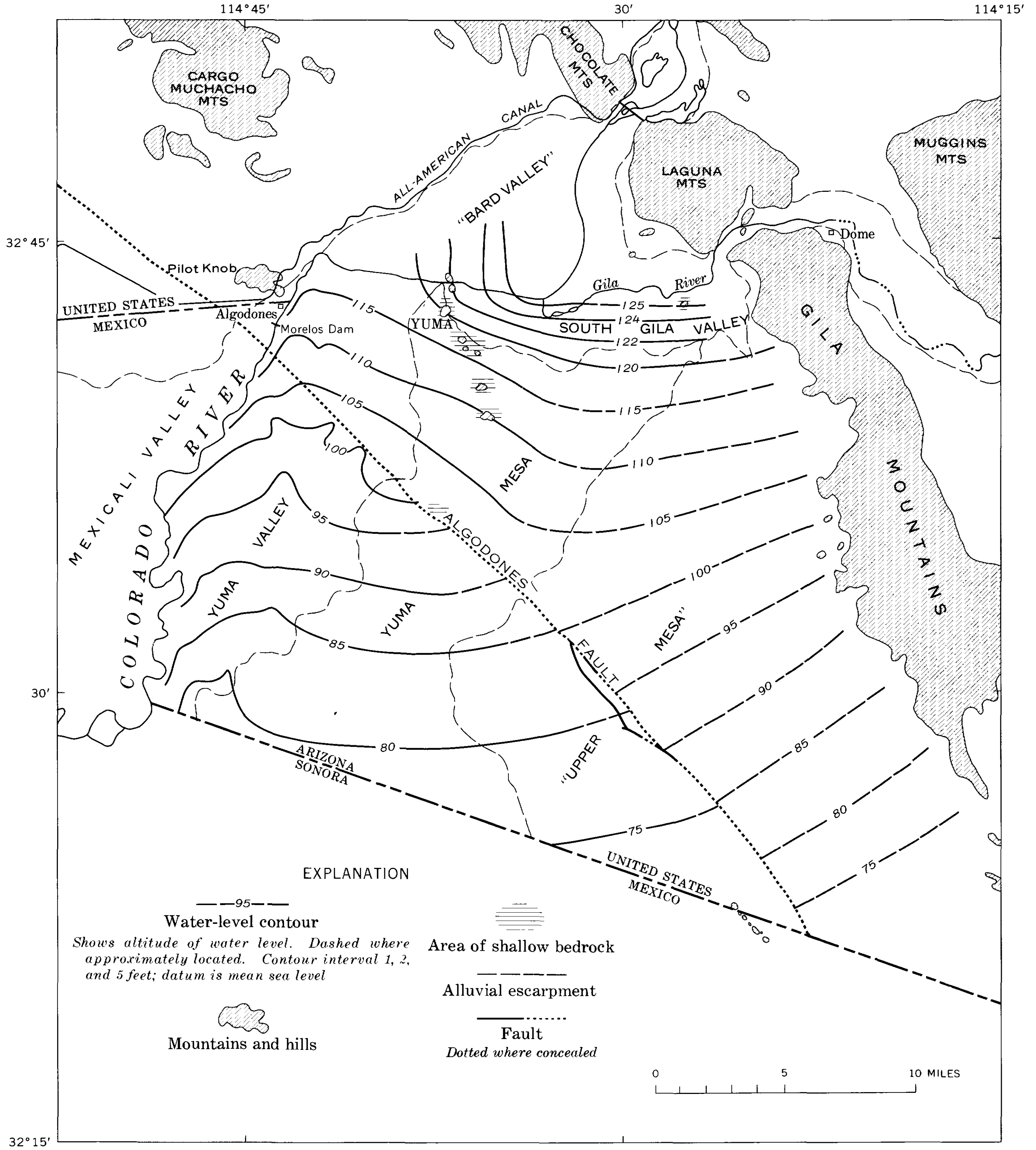


FIGURE 29.—Average water-level contours in 1925.

changed considerably between 1939 and 1960 (and also, by inference, between the time of natural conditions and 1960; see figs. 28 and 30). A significant change is the large ground-water mound beneath Yuma Mesa that had formed by 1960. The influence of the mound extends in all directions: eastward toward the Gila Mountains, southward toward Mexico, northward into South Gila Valley, and west-

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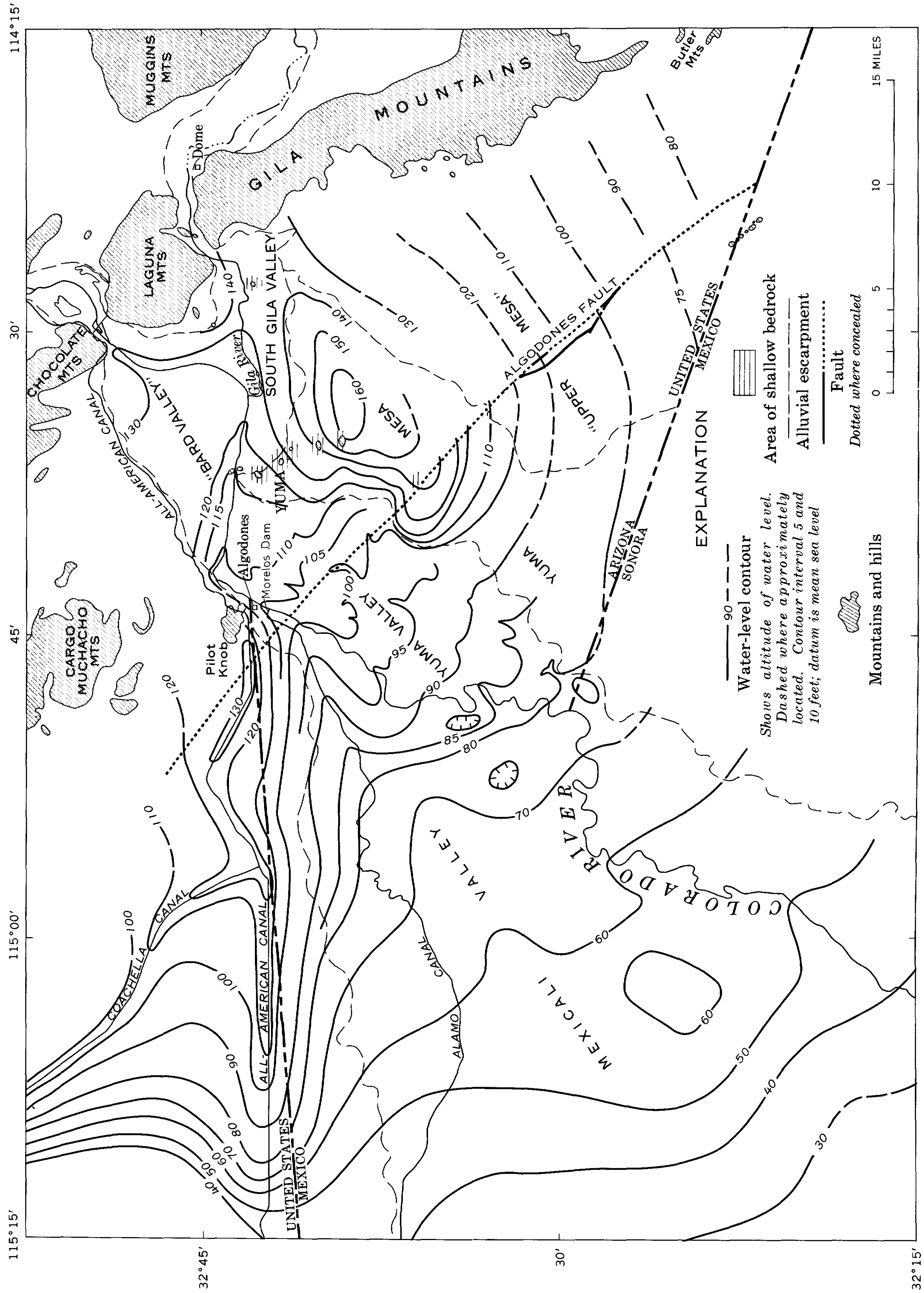


FIGURE 30.—Average water-level contours in 1960 in the delta region. Data for Mexicali Valley provided by the Mexican Section, International Boundary and Water Commission.

ward into Yuma Valley. The very steep gradients westward toward Yuma Valley result in large part from the lowering of head by drainage wells in Yuma Valley along the toe of the mesa. A more detailed discussion relative to the build up of the mound is given in the section on the analog model. (See p. H109.)

Also significant is the change in the character of the Colorado River upstream from the limitrophe section. Under natural conditions and as late as the early 1940's, the Colorado River was a losing stream. The mean annual stage of the river was higher than the mean annual water levels on either side of the river.

However, during the early 1940's the river channel was eroded 5 feet or more in the Yuma area (fig. 26). This degradation of the river channel, plus rising ground-water levels as the result of irrigation and leakage from the All-American Canal, all tended to raise ground-water levels upstream from the limitrophe section above the mean stage of the Colorado River, thereby making the river a gaining stream in the reach above the limitrophe section.

Marked changes also occurred in the limitrophe section area. Movement of ground water was still westward from the Colorado River into Mexico, but the direction of the movement in the northern part of the limitrophe section, principally as the result of leakage from the All-American Canal, had changed from westward to southward.

A marked change in the direction of the contours in Yuma Valley near the Colorado River also occurred between 1939 and 1960. Under natural conditions, and as late as the early 1940's, the mean stage of the river was above the adjacent ground-water levels in Yuma Valley.

In 1960, however, and for some 10 years prior thereto, ground-water levels in western Yuma Valley were higher than the adjacent mean river stages. As a result, ground water moved from Yuma Valley toward the river. To what extent the ground water discharged into the river rather than moved westward beneath the river is not known, but considering the westward gradient from the river to Mexicali Valley and the substantial thickness of predominantly fine-grained materials beneath the channel and above the coarse-gravel zone, which greatly inhibits interchange between the ground-water body and the river, it is doubtful that a large percentage of the outflow from Yuma Valley westward to Mexicali Valley was intercepted by the Colorado River.

An estimate of the outflow from Yuma Valley is made in a later section of this report. (See p. H103.)

Leakage from the All-American Canal is the principal cause for the changes in the direction and rate of movement of ground water relative to the course of the Colorado River. Leakage from the All-American Canal and the Coachella Canal branch of the canal obviously had built a sizable mound beneath these canals by 1960. For a distance of 25 miles west of Pilot Knob, the height of the mound averaged 30 feet or more. The net result is that in a 30-mile reach the direction of ground-water movement south of the All-American Canal had been changed from westward, or practically parallel to the United States-Mexico boundary which existed under natural conditions and until some years following the completion of the All-American Canal, to southward and at a gradient that was steeper than was the westward gradient before completion of the All-American Canal.

### RATE OF MOVEMENT IN 1960

Many of the same difficulties mentioned in the discussion of rates of movement under natural conditions also arise in making estimates of rates of ground-water movement after development of water resources by man. By 1960, many changes in rates of movement had occurred, and the pattern of movement was more complex than under natural conditions. Much of the complexity is due to the fact that many of the changes noted by 1960 were interim changes, which did not represent the ultimate response of the ground-water system to the development that had occurred.

#### ALLUVIAL SECTION BETWEEN PILOT KNOB AND CARGO MUCHACHO MOUNTAINS

The rate of movement westerly through the alluvial section between Pilot Knob and Cargo Muchacho Mountains is difficult to estimate, principally because of lack of knowledge of the westward gradient. Only two control points are available for defining the gradient. One indicates that the altitude of the water level in well 16S/22E–2Hac which is less than half a mile west of the All-American Canal, was about 135 feet. The other indicates that the altitude of the water level in a well 8 miles west was 123 feet. Thus a westward gradient of 1½ feet per mile is indicated.

If this figure is accepted as a reasonable value of the gradient, then the westward flow through the section in 1960 probably was only three-eighths of the flow under natural conditions, or somewhat less than 2,000 acre-feet per year.

#### LIMITROPHE SECTION OF COLORADO RIVER

In 1960, the movement of ground water in the 2-mile reach downstream from the northerly international boundary was toward the Colorado River both from Mexicali Valley and Yuma Valley (fig. 30). The eastward movement of ground water to the river was due principally, if not entirely, to the discharge of part of the leakage from the All-American Canal. South of this reach, or beginning at a point about where the 100-foot water-level contour crosses the river, to a point about 5 miles downstream, or where the 95-foot contour crosses the river, there was a westward gradient of about 3 feet per mile almost directly away from the river.

Using an average transmissivity of 80,000 gpd per ft and the foregoing data, the westward flow is indicated to have been 12 mgd, or 13,500 acre-feet per year.

Southward from this reach to the southerly international boundary, the contours are so irregular that it is difficult to determine the many gradients that are implied. Undoubtedly, much of the irregularity is caused by pumping of ground water for irrigating land west of the Colorado River.

However, in a gross sense, the contours in this reach leave the river at an angle of about 45°; the straight-line distance of the river reach is about 9 miles; and the contour difference is 20 feet. Using an average transmissivity of 1 mgd per ft and the foregoing data, the rate of movement of ground water southwestward into Mexicali Valley from the point where the 95-foot water-level contour crosses the river to the southerly international boundary is 20 mgd, or about 22,500 acre-feet per year. The total westward movement of ground water into Mexicali Valley adjacent to the limitrophe section, thus, was about 36,000 acre-feet in 1960.

The data on which the foregoing estimate is based are very meager. The principal value of the estimate is that it shows the order of magnitude of the movement of ground water westward from the Colorado River to Mexicali Valley in 1960. Some support for the reasonableness of the foregoing estimate is obtained by examining its value relative to estimated outflow from Yuma Valley in the limitrophe section and estimates of streamflow depletion and other losses in the limitrophe section.

The outflow from Yuma Valley in the limitrophe section is estimated to have been about 20,000 acre-feet in 1960 (p. H95). Estimates of streamflow depletion in the limitrophe section vary widely, depending on the magnitude of the flow and its relation to preceding flows and also the points between which the losses or gains are computed. Streamflow in the limitrophe section in 1960 was small relative to historical flows but somewhat larger than flows after 1960.

The streamflow depletion in 1960 and thereafter, therefore, probably is best estimated by noting the losses that occurred in years when the flows were near to and less than the 1960 flow.

Estimates of loss between the northerly international boundary and the southerly international boundary were computed by adding to the flow recorded at the northerly international boundary the wasteway water from the Yuma project, then subtracting (1) the diversions to Mexico made at Morelos Dam, (2) the pumpage in the limitrophe section of the river, and (3) the flow at the southerly international boundary.

Years of relatively low flow of the Colorado River and rates of depletion in the limitrophe section of the river since 1950 are as follows:

| *Year* | *Flow at northerly international boundary (acre-feet)* | *Loss between northerly and southerly international boundaries (acre-feet)* |
|---|---|---|
| 1956 | 1,640,000 | 9,000 |
| 1960 | 2,338,000 | 47,000 |
| 1961 | 1,672,000 | 31,000 |
| 1962 | 1,811,000 | 35,000 |
| 1963 | 1,834,000 | 72,000 |
| Average (rounded) | 1,860,000 | 39,000 |

From the foregoing, it appears that for a flow of about 1.9 million acre-feet per year at the northerly international boundary, the computed loss in the limitrophe section averages about 39,000 acre-feet. This loss is only about 2 percent of some of the measured flows, which is within the probable limits of error of the data.

Another evaluation can be made by computing the losses in the limitrophe section from Morelos gaging station to the southerly international boundary. Morelos gaging station is about 1.7 miles south of the northerly international boundary and about 0.5 mile south of Morelos Dam (fig. 30). The advantage of this evaluation is that the magnitude of the flows are much smaller than the flows at the northerly international boundary and the diversions to Mexico from Morelos Dam which were used in the preceding analysis.

According to water-level data for 1960 (fig. 30), the losses indicated for the reach between Morelos gaging station and the southerly international boundary should be a good indication of the net loss in the entire limitrophe section because northward from Morelos gaging station the Colorado River is a gaining stream.

Estimates of loss were obtained by adding to the measured flow at Morelos gaging station the inflows from Eleven-Mile and Twenty-One-Mile wasteways, which are 3¼ and 17½ miles respectively downstream from Morelos Dam, and subtracting therefrom the pumpage from the limitrophe section and the flow at southerly international boundary.

Years of relatively low flow and rates of unaccounted depletion since 1950 are as follows:

| *Year* | *Flow at Morelos gaging station (acre-feet)* | *Unaccounted depletion, Morelos gaging station to southerly international boundary (acre-feet)* |
|---|---|---|
| 1956 | 242,000 | 6,000 |
| 1960 | 540,000 | 18,000 |
| 1961 | 177,000 | 20,000 |
| 1962 | 313,000 | 23,000 |
| 1963 | 176,000 | 10,000 |
| Average (rounded) | 290,000 | 15,000 |

The yearly inflows from the wasteways were about 25,000 acre-feet, and pumpage from the river generally was about 4,000 acre-feet. The average unaccounted depletion of the gross flow therefore is about 5 percent of the average maximum flow. Five percent is outside the probable limits of error of the data, and therefore the indicated unaccounted depletion by the latter method is considered the more reliable of the two estimates. Therefore, the loss of Colorado River water in the limitrophe section in 1960 and thereafter probably averages about 15,000 acre-feet yearly.

The outflow of 20,000 acre-feet from Yuma Valley plus the unaccounted depletion of the riverflow of about 15,000 acre-feet suggests that in 1960 the outflow westward to Mexico opposite the limitrophe section of the Colorado River was about 35,000 acre-feet minus evaporation losses from the free water surface of the river. The latter probably is less than 2,000 acre-feet at low stages of the river.

This estimate of slightly less than 35,000 acre-feet per year, which is based largely on excess irrigation water and infiltration of river water, compares favorably with the estimate of 36,000 acre-feet per year, which was based wholly on ground-water parameters in Mexicali Valley.

#### YUMA VALLEY

Ground-water outflow from Yuma Valley can be analyzed as the sum of the flows that cross its northern, western, and southern boundaries. An estimate of the ground-water outflow northward and westward from Yuma Valley is made on the basis that part of the outflow is ground-water recharge from irrigated land lying between the northern and western boundaries of Yuma Valley and the ground-water divide southerly and easterly from these boundaries, less the use of ground water by phreatophytes and the pumpage of ground water from beneath these lands for irrigation, and that part is ground water moving westerly at depth.

Detailed water-level contour maps compiled by the United States section of the International Boundary and Water Commission (not shown) were used to determine the location of the divide for the ground-water recharge due to local irrigation. The contours were based on water-level altitudes in more than 200 shallow wells and on the altitude of the water surface in the drains. The ground-water divide that separates the area from which the outflow was principally northward coincided roughly with an easterly prolongation of the northerly international boundary. Most of the land north of the divide, about 2,500 acres, was irrigated.

Based on reports of the Yuma County Water Users' Association the diversion of water to land irrigated in Yuma Valley, including losses from laterals, averaged 6.5 feet for the years 1955 to 1960, inclusive. Estimates of consumptive use for crops was assumed to have been 3.6 feet, the same value as used throughout this study for crops grown in the flood plain. The recharge to ground water from irrigation thus averaged about 2.9 acre-feet per acre per year for lands that were irrigated. The outflow from Yuma Valley northward of an imaginary extension of the northerly international boundary therefore was about 7,300 acre-feet.

The area between the river, the ground-water divide, and the northerly and southerly international boundaries which contributed to the outflow was 15,000 acres. Of this acreage, 3,100 acres supported the growth of phreatophytes, and 11,900 acres supported irrigated crops. The recharge from irrigation, therefore, was 34,500 acre-feet per year, from which must be deducted the consumptive use by phreatophytes and pumpage for irrigation. The latter two items are 8,200 and 13,000 acre-feet, respectively, based on data in the U.S. Bureau of Reclamation (1963, p. 28 and 34) study. The net outflow from Yuma Valley to the limitrophe section as a result of local recharge from irrigation not diverted to drains, therefore, was about 13,000 acre-feet in 1960.

Outflow also occurred in the deeper aquifers. Contours based on water levels in wells penetrating the top of the coarse-gravel zone are considered to be representative of the head in the coarse-gravel zone and the underlying wedge zone. Therefore, the contours are useful for estimating gradients and for selecting width of sections through which water is transmitted to or across the limitrophe section.

Using the information shown in figure 31 and transmissivity values shown in figure 25 the flow to or across the limitrophe section through the coarse-gravel zone and the wedge zone is computed to have been about 6,400 acre-feet in 1960. The combined outflow of ground water from Yuma Valley to the

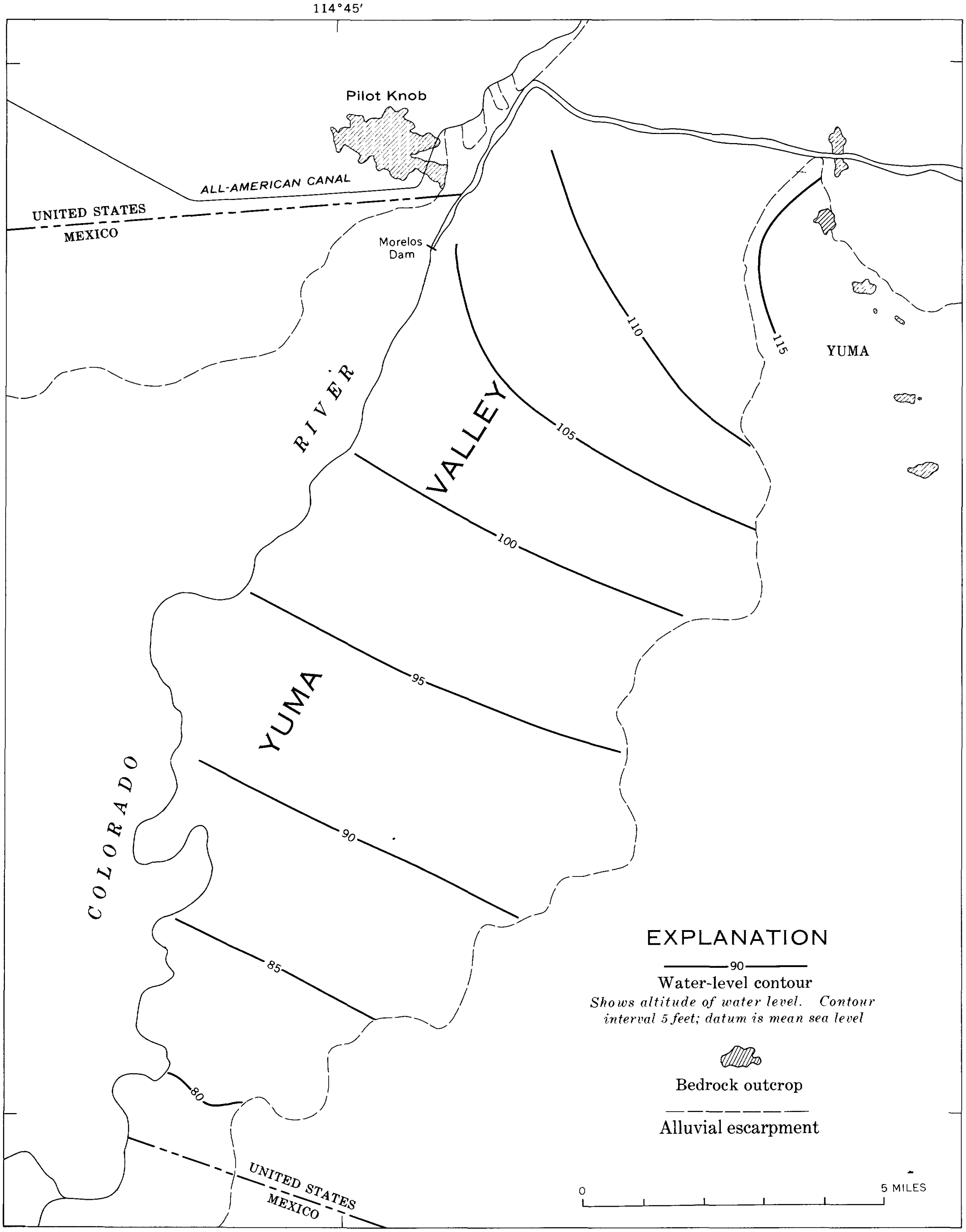


FIGURE 31.—Average water-level contours for upper part of coarse-gravel zone in 1960 in the Yuma Valley.

limitrophe section in 1960, therefore, is the above quantity plus the 13,000 acre-feet of local recharge from irrigation not diverted to drains, or about 20,000 acre-feet.

The outflow across the southerly international boundary based on a transmissivity of 1 mgd per ft, a width of section of 1¾ miles, and a gradient of about 3 feet per mile is about 6,000 acre-feet per year.

The total outflow from the valley in 1960 thus was the 20,000 acre-feet to the limitrophe section, plus the outflow northward of 7,300 acre-feet, plus the outflow across the southerly international boundary of 6,000 acre-feet, a total of about 33,000 acre-feet.

### MOVEMENT AFTER 1960

Both the direction and rate of movement of ground water continued to change after 1960. In general, the changes followed the pattern that was established prior to 1960. A comparison of water-level contours as of December 1965 (fig. 32), with the water-level contours as of December 1960 (fig. 30), illustrates the changes that occurred.

The principal changes were: a moderate increase in the size of the ground-water mound beneath the Yuma Mesa and a lowering of water levels in Mexicali Valley. Water levels beneath Yuma Mesa continued to rise until 1962. After 1962, owing to increased pumpage for drainage near the toe of the mesa in Yuma and South Gila Valleys, water levels northward and westward from the apex of the ground-water mound began a moderate decline. However, at greater distances eastward and southward from the apex, water levels continued to rise. More details on the areas and amounts of change of water level beneath Yuma Mesa are given in the section on the analog model (p. H107).

The other principal change is the generally lower water levels in Mexicali Valley, which resulted from pumpage for irrigation. These lower water levels together with generally unchanged levels for most of Yuma Valley resulted in an increased westward component of the water-level contours crossing the limitrophe section of the Colorado River. The increased westward component plus an increased ground-water gradient away from the river imply an increased outflow of ground water from the United States. More details about the lowering of water levels in Mexicali Valley is given in the section on the analog model (p. H107).

Movement of ground water in future years will depend on the changes in recharge to and discharge from the ground-water system. As long as ground-water levels in the United States remain relatively stable or continue to rise and water levels in Mexicali Valley continue to decline, the outflow from the United States will increase.

Water levels in the United States may be lowered by improving the irrigation efficiency to the point where only sufficient water is diverted for irrigation to satisfy evapotranspiration needs and to carry away the salts contained in the irrigation water.

Water levels also may be lowered by pumping. The marked increased pumpage of ground water for drainage beginning in 1961 illustrates the effectiveness of this method for lowering water levels. Pumping of ground water by private interests for the irrigation of land on Yuma Mesa outside designated irrigation districts, which began in 1962, also has resulted in lower water levels. As of 1968 the pumpage and consequent lowering has been only moderate, but if the present rapid pace of developing new land for pumping irrigation is maintained for only a few more years sufficient land will be developed in the southern part of Yuma Mesa to require the pumping of more ground water than presently is entering the area. Additional ground water will be diverted to the area because of the lowering of water levels, but if a ground-water sink is maintained, the chemical quality of the pumped ground water eventually will deteriorate because of the continued reuse of much of the water.

The extent to which the outflow of ground water from the United States eventually will be influenced by the control of water levels is likely to be governed not only by economic factors but also by international political considerations.

## WATER BUDGETS

Water budgets provide an accounting for the water resources of an area during a specific period of time. The budget may be for either the surface-water system or the ground-water system or both, depending on the objective of the analysis.

In the present study, the movement of ground water is of principal concern. Therefore, the budgets presented emphasize the disposition of the ground-water supply rather than the surface-water supply. The budget period was selected as the calendar years 1960–63, inclusive, because better-than-average data are available for most of the budget items during this period. The budget years also occurred near the end of a long period of continuous growth of the ground-water mound beneath Yuma Mesa.

In order to obtain a better understanding of the complex movement of the ground water, the Yuma area is divided into subareas, mainly on the basis

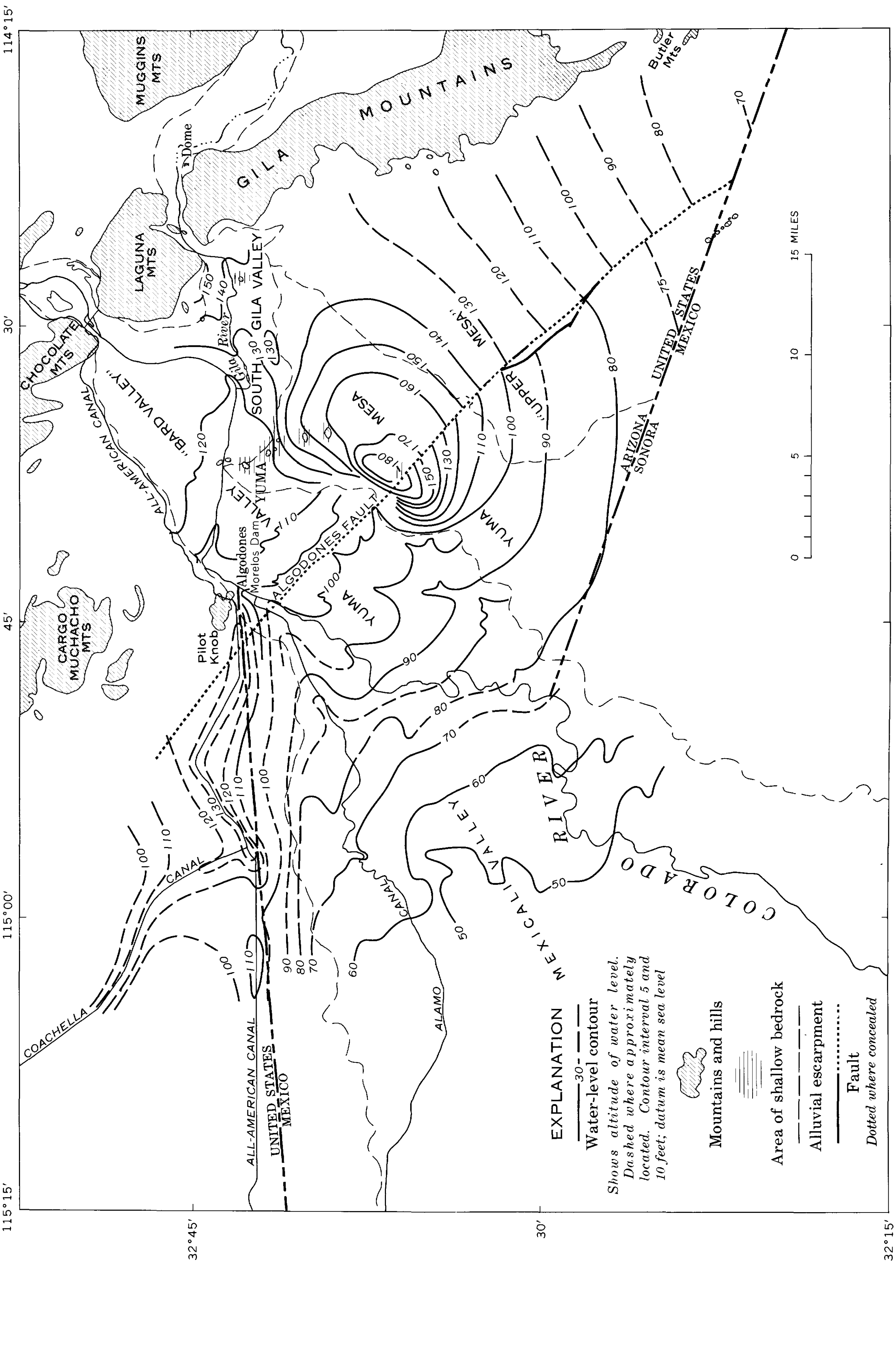


**Figure 32.**—Average water-level contours in December 1965 in the delta region. Data for Mexicali Valley provided by the International Boundary and Water Commission.

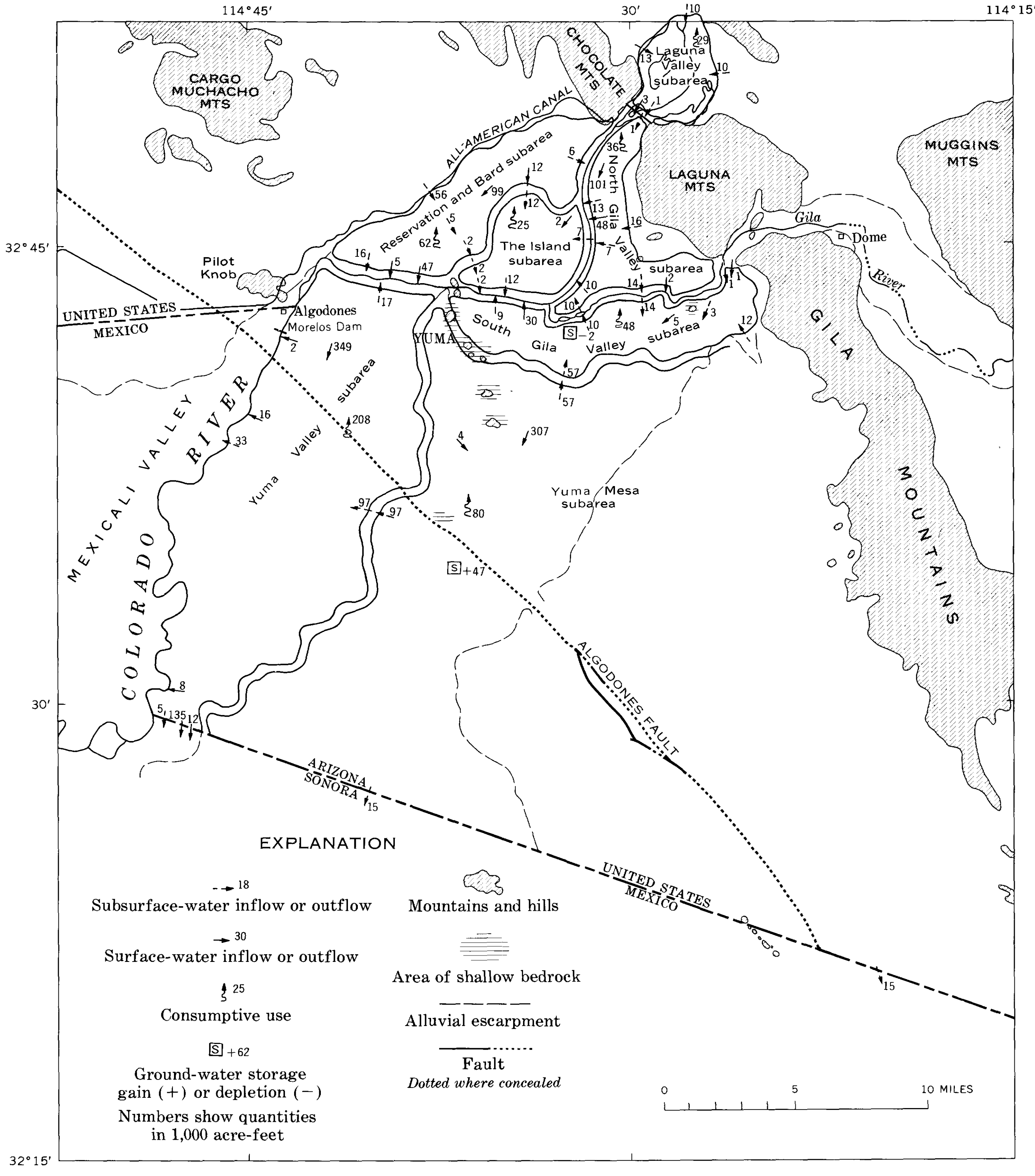


FIGURE 33.—Water budgets for subareas, 1960–63, inclusive.

of the principal irrigation districts (fig. 33). These subareas correspond to some of the subareas described in the section "Geomorphology" with the exception that The Island area of "Bard Valley" is herein made a subarea separate from the rest of that valley and that the Yuma Mesa subarea in this section of the report includes also the "Upper Mesa," "Fortuna Plain," and "Fortuna Dunes" subareas of the geomorphic classification.

Values for surface inflow and outflow items were determined from records published either by the U.S. Geological Survey, or from operational records maintained by the U.S. Bureau of Reclamation or the irrigation districts. Unmeasured runoff, estimated to average less than 1,000 acre-feet per year, was not considered large enough to be distributed among the various subareas. Values for subsurface inflow and outflow items were computed on the basis of transmissivity, width of section, and hydraulic gradient, as indicated by the map of the Yuma area showing transmissivity (fig. 25) and maps compiled quarterly by the U.S. Bureau of Reclamation showing water-level contours. The estimated average yearly recharge to ground water resulting from precipitation was negligible and therefore was not included in any of the budgets.

Estimates of leakage from the principal canals were in part based on unaccounted-for differences in flow between gaging stations and in part on transmissivity, hydraulic gradients, and length of canal. Ground-water storage change was considered significant only for Yuma Mesa subarea. The change was computed on the basis of increase in volume of the ground-water mound multiplied by storage coefficients of 31 per cent for the volume underlying Yuma Mesa and 18 percent for the volume underlying the "Upper Mesa" and "Fortuna Plain." Volume changes were determined from water-level contour maps for year end 1959 and 1963.

Values for consumptive use in the flood-plain areas, except where noted in a particular budget, were computed by multiplying the average net irrigated acreage for the years 1960–63 as listed in U.S. Bureau of Reclamation records by 3.6 feet and by multiplying the remaining area by an average consumptive use rate of 2.5 feet.

Consumptive use on Yuma Mesa was assumed to be the average of the annual consumptive use values for the years 1960–63 as shown in table 8. The consumptive use values were based on irrigated acreage of crop and noncropland and the following annual rates of use: (1) Alfalfa hay, 7 feet, (2) unharvested fields, 2.6 feet, (3) citrus and others, 3.9 feet, (4) urban and suburban, 2.5 feet, and (5) farmsteads and ditches, 2.5 feet.

Budgets for the individual subareas are based on the principle that inflow less consumptive use equals change in storage plus outflow. Because of practical limitations on the accuracy of flow measurements and of limited knowledge about values to be used for computing indirect estimates and estimates of consumptive use an equality is rarely achieved. This fact, of itself, does not lessen the reliability of the estimates as long as the imbalances are less than the probable error and the imbalances do not tend to be in the same direction. None of the imbalances are thought to be unreasonable in view of the uncertainties of many of the items to which they pertain.

TABLE 8.—*Diversions, consumptive use, and ground-water recharge for Yuma Mesa*

[Quantities in 1,000 acre-feet]

| Calendar year | Diversions [1] | Consumptive use | Ground-water recharge |
|---|---|---|---|
| 1941 | 14 | 6 | 8 |
| 1942 | 15 | 7 | 8 |
| 1943 | 21 | 8 | 13 |
| 1944 | 32 | 14 | 18 |
| 1945 | 75 | 38 | 37 |
| 1946 | 134 | 50 | 84 |
| 1947 | 151 | 47 | 104 |
| 1948 | 158 | 50 | 108 |
| 1949 | 132 | 52 | 80 |
| 1950 | 135 | 56 | 79 |
| 1951 | 170 | 62 | 108 |
| 1952 | 209 | 72 | 137 |
| 1953 | 227 | 84 | 143 |
| 1954 | 272 | 95 | 177 |
| 1955 | 249 | 90 | 159 |
| 1956 | 233 | 77 | 156 |
| 1957 | 222 | 72 | 150 |
| 1958 | 245 | 74 | 171 |
| 1959 | 271 | 81 | 190 |
| 1960 | 295 | 78 | 217 |
| 1961 | 290 | 77 | 213 |
| 1962 | 327 | 79 | 248 |
| 1963 | 317 | 78 | 239 |
| 1964 | 299 | 82 | 217 |
| 1965 | 265 | 82 | 183 |
| 1966 | 275 | 82 | 193 |

[1] Based on crop reports of the U.S. Bureau of Reclamation.

Average annual budgets for the period 1960–63, inclusive, for the subareas of the Yuma area are given in the following sections.

### "LAGUNA VALLEY" SUBAREA

The "Laguna Valley" subarea consists of the Colorado River flood plain between Laguna and Imperial Dams (fig. 33). Most of the subarea is covered by natural vegetation or shallow lakes and marshes (Mittry Lake is the principal water area); cropland is restricted to a small area immediately upstream from Laguna Dam. The water budget follows:

| | (Acre-feet) | |
|---|---|---|
| Inflow, subsurface water: | | |
| Leakage from All-American Canal [1] | 13,000 | |
| Leakage from Gila Gravity Main Canal [2] | 10,000 | |
| Leakage beneath Imperial Dam [3] | 10,000 | |
| Total | | 33,000 |
| Consumptive use: | | |
| Crops, 80 acres | 300 | |
| Natural vegetation | 22,000 | |
| Evaporation from free water surface other than river and canals [5] | 7,100 | |
| Total | | 29,400 |
| Inflow less consumptive use | | 3,600 |
| Change in storage | | Negligible |
| Outflow, subsurface water: | | |
| To North Gila Valley subarea [6] | | 700 |
| To Colorado River [7] | | 2,900 |
| Change in storage plus outflow | | 3,600 |
| Imbalance | | 0 |

[1] Estimated on basis of 3-mile length of canal and average rate of leakage of 4,300 acre-feet per year per mile of canal, the average rate of leakage computed from U.S. Geological Survey measurements of canal flows.

[2] Estimated on basis of 5-mile length of canal and average rate of leakage of 2,000 acre-feet per year per mile of canal.

[3] Unaccounted-for pickup in flow of river between Imperial Dam and gaging station 0.6 of a mile below dam is about 11 cubic feet per second or about 8,000 acre-feet per year. This pickup probably is due to leakage beneath the dam; an additional 1,000 to 2,000 acre-feet of leakage probably is still subsurface inflow 0.6 of a mile downstream from the dam, based on an estimated maximum coefficient of transmissivity of 500,000 gpd per ft, 1½ mile width of section, and hydraulic gradient of 2 feet per mile.

[4] Estimated on basis of acreages of natural vegetation and rates of use by various species as computed from data in U.S. Bureau of Reclamation (1963) study.

[5] Areas of open water as determined from U.S. Geological Survey topographic map Laguna Dam 7.5-minute series multiplied by a net annual rate of 6.2 feet.

[6] Computed on basis of transmissivity of 0.3 mgd per ft, hydraulic gradient of 2 feet per mile, and 1 mile width of section.

[7] Computed to balance budget.

The network of observation wells does not extend into the "Laguna Valley" subarea nor are the inflow and outflow of the Colorado River known. The available data therefore are insufficient for obtaining a check as to whether or not estimates of inflow less consumptive use equal estimates of change in storage plus outflow. Rather, the budget was balanced by assuming that the amount needed to balance the budget was subsurface inflow to the Colorado River.

The reasonableness of the various estimates therefore depends to a large extent on the reasonableness of similar types of estimates in other subareas where data or estimates for all budget items were available, because the basis for the estimates, other than the subsurface inflow to the Colorado River, is the same.

### RESERVATION AND BARD SUBAREA

The Reservation and Bard subarea includes all "Bard Valley" except for The Island, which is assigned to a separate subarea. More than half the subarea is in cropland, irrigated with water diverted or pumped from the Colorado River (a small tract in the northeastern part of the subarea is irrigated with ground water). The water budget follows:

| | Acre-feet | |
|---|---|---|
| Inflow: | | |
| Surface water: | | |
| Diversions to district lands | 95,100 | |
| Diversions to other lands [1] | 3,600 | |
| Total surface water | | 98,700 |
| Subsurface water: | | |
| Leakage from All-American Canal [2] | 56,000 | |
| Leakage from Yuma Main Canal [3] | 5,000 | |
| Total subsurface water | | 61,000 |
| Total inflow | | 159,700 |
| Consumptive use: | | |
| Irrigated cropland in district, 10,800 acres at 3.6 feet | 38,900 | |
| Other irrigated cropland, 630 acres at 3.6 feet | 2,300 | |
| Other land in subarea, 8,190 acres at 2.5 feet | 20,500 | |
| Total | | 61,700 |
| Inflow less consumptive use | | 98,000 |
| Change in storage | | Negligible |
| Outflow: | | |
| Surface water: | | |
| Araz Drain | 4,600 | |
| Reservation Central Main Drain | 46,600 | |
| Total surface water | | 51,200 |
| Subsurface water: | | |
| To The Island subarea [4] | 14,000 | |
| To Colorado River [5] | 22,000 | |
| Total subsurface water | | 36,000 |
| Change in storage plus outflow | | 87,200 |
| Imbalance: Inflow less consumptive use exceeds change in storage plus outflow | | 10,800 |

[1] Water pumped from river for irrigation at estimated rate of 6 feet on 600 acres.

[2] Based on average rate of leakage for the period 1958–64, inclusive, of about 4,300 acre-feet per year per mile length of All-American Canal bordering the subarea as computed from U.S. Geological Survey measurements of canal flows, multiplied by the 13-mile length of canal bordering the subarea.

[3] Based on rate of leakage of 2,000 acre-feet per year per mile length of canal.

[4] Computed on basis of transmissivity of 0.9 mgd per ft, hydraulic gradient of 4 feet per mile, and 3 mile length of section across northern part of The Island subarea boundary plus transmissivity of 0.7 mgd per ft, hydraulic gradient of 2 feet per mile, and 1½ mile length of section at southwestern boundary.

[5] In reach between Laguna Dam and The Island subarea, outflow is compupted as 6,000 acre-feet per year based on transmissivity at 0.6 mgd per ft, hydraulic gradient of 3 feet per mile, and length of reach of 3 miles; in reach between Yuma and All-American Canal, outflow is computed as 16,000 acre-feet per year based on transmissivity of 0.6 mgd per ft, hydraulic gradient of 6 feet per mile, and length of reach of 4 miles.

Minor items of inflow and outflow that were not included in the budget are: (1) Ground-water recharge from the tributary area west of the subarea, (2) unmeasured runoff to the subarea from the tributary area, and (3) subsurface outflow through the alluvial section between the Cargo Muchacho Mountains and Pilot Knob.

The latter item is estimated to be about equal to the two minor inflow items, so the omission of these minor items has no appreciable effect on the budget.

A substantial part of the imbalance of 10,800 acre-feet probably is due to an overestimate of the amount of water diverted for irrigation of district lands. Beginning in 1965, measurement procedures were improved, with the result that the average yearly diversion rate per acre irrigated apparently dropped 0.5 of a foot. An overestimate of 0.5 of a foot would account for about half of the imbalance.

The remaining imbalance is of the same magnitude but of opposite sense to the imbalance for The Island subarea. (See p. H100.) Part of the imbalance may be due to the use of the same rate of consumptive use for nonirrigated land (2.5 feet per year) for both subareas. The average depth to water in the Reservation and Bard subarea is several feet less than the average depth to water in the flood-plain subareas, whereas the depth to water in The Island subarea is several feet greater.

Rates of consumptive use commonly decrease as the depth to water increases. Thus it is reasonable to infer that the consumptive use estimate for nonirrigated land is somewhat too low for the Reservation and Bard subarea and somewhat too high for The Island subarea.

### THE ISLAND SUBAREA

The Island subarea is that part of "Bard Valley" south of an abandoned meander loop of the Colorado River (fig. 33). The subarea is outside the established irrigation district and the cropland (less than half of the total land area) is irrigated mainly with ground-water supplies. The water budget follows:

| | *Acre-feet* | |
|---|---|---|
| Inflow: | | |
| Surface water: | | |
| Diversions from river for irrigation | | 2,200 |
| Subsurface water: | | |
| Inflow from Reservation and Bard subarea [1] | 14,000 | |
| Inflow from North Gila subarea | 7,000 | |
| Total subsurface water | | 21,000 |
| Total inflow | | 23,200 |
| Consumptive use: | | |
| Irrigated cropland, 3,100 acres at 3.6 feet | 11,200 | |
| Other land in subarea, 5,470 acres at 2.5 feet | 13,700 | |
| Total | | 24,900 |
| Inflow less consumptive use | | –1,700 |
| Change in storage | | Negligible |
| Outflow, subsurface water to Colorado River [2] | | 4,000 |
| Change in storage plus outflow | | 4,000 |
| Imbalance: Amount by which inflow less consumptive use is less than change in storage plus outflow | | 5,700 |

[1] See footnote 4 of budget for Reservation and Bard subarea.
[2] Computed on basis of transmissivity of 0.7 mgd per ft, hydraulic gradient of 2 feet per mile, and 2½ mile length of reach east of Yuma.

Much of the imbalance probably is due to an overestimate of consumptive use on land that is not irrigated (p. H99).

### NORTH GILA VALLEY SUBAREA

The North Gila Valley subarea, an L-shaped area east of the Colorado River and north of the Gila River, is chiefly in cropland which is irrigated with Colorado River water except for the eastern arm of the subarea, which is now (1968) irrigated in large part with ground water. The water budget follows:

| | *Acre-feet* | |
|---|---|---|
| Inflow: | | |
| Surface water (Gila Gravity Main Canal): | | |
| Diversions at North Gila Main Canal turnout | 88,400 | |
| Diversions at other points (Warren Act contracts) | 11,600 | |
| Automatic canal spills | 1,000 | |
| Total surface water | | 101,000 |
| Subsurface water: | | |
| From South Gila Valley subarea [1] | 10,000 | |
| From "Laguna Valley" subarea and tributary areas eastward | 1,000 | |
| Leakage from Gila Gravity Main Canal [2] | 16,000 | |
| Total subsurface water | | 27,000 |
| Total inflow | | 128,000 |
| Consumptive use: | | |
| Irrigated cropland, 7,100 acres at 3.6 feet | 25,600 | |
| Other land in subarea, 4,300 acres at 2.5 feet | 10,800 | |
| Total | | 36,400 |
| Inflow less consumptive use | | 91,600 |
| Change in storage | | Negligible |
| Outflow: | | |
| Surface water: | | |
| Laguna Canal Wasteway | 7,700 | |
| Levee Canal Wasteway | 15,500 | |
| North Gila Main Canal Wasteway | 8,300 | |
| Bruce Church Wasteway | 9,400 | |
| North Gila Drain No. 1 | 7,300 | |
| North Gila Drain No. 3 | 600 | |
| Bruce Church Drain | 700 | |
| Total surface water | | 49,500 |
| Subsurface water: | | |
| To The Island subarea [3] | 7,000 | |
| To Colorado River [4] | 23,000 | |
| To South Gila Valley subarea [5] | 14,000 | |
| Total subsurface water | | 44,000 |
| Change in storage plus outflow | | 93,500 |
| Imbalance: Amount by which inflow less consumptive use is less than change in storage plus outflow | | 1,900 |

[1] Inflow across southwest corner of subarea computed on basis of transmissivity of 1 mgd per ft, hydraulic gradient of 6 feet per mile, and length of section of 1½ miles.
[2] Computed as average of 16,000 acre-feet per year based on average rate of leakage of 2,000 acre-feet per year per mile length of canal as indicated by measurements of flows and diversions.
[3] Computed on basis of transmissivity of 1.0 mgd per ft, hydraulic gradient of 4 feet per mile, and length of section of 1½ miles.
[4] Computed on basis of transmissivity of 0.6 mgd per ft, hydraulic gradient of 5 feet per mile, and 6-mile length of reach less 7,000 acre-feet to The Island subarea, plus outflow across southwest corner of subarea of 10,000 acre-feet.
[5] Computed on basis of transmissivity of 0.5 mgd per ft, hydraulic gradient of 8 feet per mile, and length of section of 3 miles.

The imbalance of 1,900 acre-feet per year is considered insignificant.

### SOUTH GILA VALLEY SUBAREA

The South Gila Valley subarea, which lies south of the Gila and Colorado Rivers and north of Yuma Mesa, was until 1965 irrigated principally with ground water. A minor part was irrigated with surface water diverted from the Gila Gravity Main Canal under Warren Act contracts. About two-thirds of the total area of nearly 15,000 acres is in irrigated cropland. The water budget follows:

| | *Acre-feet* | |
|---|---|---|
| Inflow: | | |
| Surface water (Gila Gravity Main Canal): | | |
| Diversions for irrigation, (Warren Act contracts) | 5,100 | |
| Automatic canal spills | 1,000 | |
| Total surface water | | 6,100 |
| Subsurface water: | | |
| Leakage from Gila Gravity Main Canal [1] | 12,000 | |
| Leakage from Wellton-Mohawk Main Outlet Drain [2] | 3,000 | |
| Inflow from Dome Valley [3] | 1,000 | |
| Inflow from North Gila Valley subarea [4] | 14,000 | |
| Inflow from Yuma Mesa subarea [5] | 57,000 | |
| Total subsurface water | | 87,000 |
| Total inflow | | 93,100 |

| | | |
|---|---|---|
| Consumptive use | | |
| Irrigated cropland,[6] 9,850 acres at 3.6 feet | 35,500 | |
| Other land in subarea, 4,850 acres at 2.5 feet | 12,100 | |
| Total | | 47,600 |
| Inflow less consumptive use | | 45,500 |
| Change in storage[7] | | −2,000 |
| Outflow: | | |
| Surface water: | | |
| Deep Pump Outflow Canal No. 1 | 17,000 | |
| Deep Pump Outflow Canal No. 2 | 13,000 | |
| Total surface water | | 30,000 |
| Subsurface water: | | |
| To North Gila Valley[8] | 10,000 | |
| To Colorado River[9] | 9,000 | |
| Total subsurface water | | 19,000 |
| Change in storage plus outflow | | 47,000 |
| Imbalance: Amount by which inflow less consumptive use is less than change in storage plus outflow | | 1,500 |

[1] Based on 2,000 acre-feet per year per mile length of canal and 6-mile length of canal in subarea.
[2] See discussion following budget.
[3] Computed on basis that transmissivity does not exceed 1 mgd per ft., hydraulic gradient of 2 feet per mile; and ½ mile-width of section.
[4] Computed on basis of transmissivity of 0.5 mgd per ft., hydraulic gradient of 8 feet per mile, and 3-mile length of section.
[5] See discussion following budget for Yuma Mesa subarea, p. H101.
[6] 9,420 acres in district plus 430 acres outside district.
[7] Computed from water-level maps for December 1959 and December 1963, assuming a specific yield of 20 percent.
[8] Computed on basis of transmissivity of 1 mgd per ft., hydraulic gradient of 6 feet per mile, and width of section of 1½ miles.
[9] Computed on basis of transmissivity of 0.7 mgd per ft., hydraulic gradient of 4 feet per mile, and width of section of 3 miles.

The budget item "Leakage from Wellton-Mohawk Main Outlet Drain" requires some additional explanation. Flow in this drain, or conveyance channel, began in February 1961. Therefore, for practical purposes, the drain was in operation for 3 of the 4 years of the budget period, 1960–63. The flow in the drain is measured at a point 8 miles above its outlet to the Gila River. Except at the measurement sections, the drain is unlined. Leakage from the drain during the budget period could not be computed because measurements were first made near the drain outlet beginning in October 1965, at which time the Main Outlet Drain Extension to Morelos Dam was completed. A comparison of flows between the two stations shows that in each of the years 1966, 1967, and 1968 the flow near the outlet to the Gila River is about 9,500 acre-feet less than the corresponding flow at the station where the flow was measured during the budget period. Allowing that some of the indicated loss represents evaporation and that the loss may be somewhat more than during the budget period because of a slightly higher stage due to the construction of the drain extension, a seepage loss of 8,000 acre-feet per year, or about 1,000 acre-feet per year per mile of channel is indicated. To the extent that the leakage does not discharge to the Gila River, whose channel generally is within half a mile of and north of the drain, the seepage is an inflow item to the South Gila subarea. The extent to which the above condition exists is not known, but on the basis of observations in the field and general ground-water conditions, at least half the leakage, or 4,000 acre-feet per year, is estimated to be inflow to the South Gila subarea. The rest of the inflow as measured at the station 8 miles above the drain outlet is considered a through flow, or return flow to the Colorado River via the Gila River, and as such need not be considered in the budget of the subarea.

The imbalance of less than 1,500 acre-feet is considered negligible in view of the uncertainty regarding true values for many of the budget items.

### YUMA MESA SUBAREA

The Yuma Mesa subarea includes the "Upper Mesa" and "Fortuna Plain" as well as Yuma Mesa. This subarea is underlain by most of the ground-water mound which has developed from irrigation of citrus orchards on Yuma Mesa, mostly since the mid 1940's. The water budget for the subarea follows:

| | *Acre-feet* | |
|---|---|---|
| Inflow: | | |
| Surface water: | | |
| Diversions for irrigation | 307,000 | |
| City of Yuma (diversions in excess of sewage returns) | 4,000 | |
| | | 311,000 |
| Consumptive use: | | |
| Crops[1] | 78,000 | |
| Lawns | 2,000 | |
| | | 80,000 |
| Inflow less consumptive use | | 231,000 |
| Change in storage[2] | | 47,000 |
| Outflow, subsurface: | | |
| To South Gila Valley[3] | 57,000 | |
| To Yuma Valley[3] | 97,000 | |
| Across international boundary east of San Luis | 30,000 | |
| Total | | 184,000 |
| Change in storage plus outflow | | 231,000 |
| Imbalance | | 0 |

[1] Average of values shown in table 8.
[2] Computed from map showing changes in water level, December 1959 to December 1963 and using coefficient of storage of 0.18 for changes beneath "Upper Mesa," 0.31 for changes beneath nonirrigated land of Yuma Mesa, and one-half of the foregoing coefficient for changes beneath irrigated land.
[3] See discussion following budget.

The outflow from the ground-water mound to the South Gila Valley subarea and to the Yuma Valley subarea was computed by determining the percentage of the ground-water recharge that moves toward each of these subareas and to the area east and southeast of the mound. A contour map showing the head in the coarse-gravel zone beneath the irrigated area of the Yuma Mesa as of December 1962 was used for establishing the position of the ground-water divides of the mound.

Although only a few data were available for controls as early as December 1962, by making use of all the data on water levels in both shallow and deep wells over a period of years, and of more complete data in deeps wells in later years, it was possible to draw contours showing the head in the coarse-gravel zone and also the ground-water divides. Then by assuming that the yearly rate of ground-water recharge per acre irrigated was uniform for blocks of several thousand acres or more, the yearly recharge that was diverted to the various subareas was computed by determining the percentages of the total irrigated areas that lay between specific divides. On the above basis it was found that about 25 percent of the irrigated acreage, and therefore of the recharge, or about 57,700 acre-feet, was within the divide diverting recharge to the South Gila Valley subarea. Of this amount, some 500 acre-feet went into storage beneath the mesa, leaving 57,000 (rounded) acre-feet as outflow to the South Gila Valley subarea. About 45 percent of the irrigated acreage, and thus 45 percent of the recharge, or 104,000 acre-feet, was in the sector where recharge was diverted westward toward the Yuma Valley subarea. Of this amount, about 7,000 acre-feet went into storage beneath the mesa leaving 97,000 acre-feet as outflow to the Yuma Valley subarea.

About 30 percent of the irrigated land was in the sector in which water moves eastward and southward from the mound. Of the 69,000 acre-feet of recharge to this sector, about 40,000 acre-feet went into storage beneath the mesa, and 29,000 acre-feet moved as outflow southward toward the international boundary.

A small eastward or westward shift of the divides causes a pronounced change in the relative quantities of recharge that are diverted to the Yuma Valley subarea and to the subarea eastward and southward of the divide, but the shift causes only a relatively small change in the recharge that is diverted northward to the South Gila Valley subarea. Although shifting the ground-water divides slightly westward would reduce the outflow to Yuma Valley and thus would reduce the rather large imbalance for that subarea, it would increase the recharge to the eastern and southern sector a similar amount. A balance presently exists between the recharge estimated on the basis of the ground-water divides and the recharge based on outflow and storage estimates in this sector, so any westward shift of the divides should be governed by the extent to which the outflow and storage estimates for the eastern sector might be too low.

The storage coefficients used for the budget may be too low. The coefficients used for the budget are those that were simulated by the analog model during the final stages of the vertification procedures. Although historical changes were verified to a better degree by using those coefficients than the larger coefficients of 0.25 for the material underlying the "Upper Mesa" and 0.35 for that underlying Yuma Mesa, the possibility that an excellent verification by using the larger coefficients and adjusting other parameters could be obtained was not fully explored because of a lack of both time and funds. The larger storage coefficients would increase the estimate of ground-water storage an additional 10,000 acre-feet per year. An increase of this magnitude would significantly reduce the imbalance of the Yuma Valley subarea, the algebraic sum of the imbalance of all the subareas (p. H105), and would change only the character of the imbalance for the whole Yuma area.

The above observations suggest that the estimate of yearly increase of ground-water storage beneath the Yuma Mesa subarea as computed for the budget may be too low by 10,000 acre-feet. Further studies of the storage characteristics of the materials underlying the Yuma Mesa subarea are needed in order to more reliably estimate the quantities of ground water represented by a given change in volume of saturated material.

Outflow from the Yuma Mesa subarea also would be lessened if the average yearly recharge were not as large as is shown in the budget. Some justification for the possibility that the estimate of average yearly recharge is too high may be had from the fact that the estimated yearly recharge during the 4-year budget period was the highest of record, that it exceeded the average of the 4 preceding years by 62,000 acre-feet, and the average of the 3 following years by 31,000 acre-feet, whereas the average irrigated acreages for these periods were only 1,800 acres less and 7,000 acres more, respectively, than the average acreage for the budget period. Average rate of ground-water recharge during the budget period was 11.7 feet per year, whereas for the periods preceding and following the budget period the rates were 9.4 and 9.8 feet per year, respectively. Part of the 2-foot lower rate of ground-water recharge following the budget period undoubtedly was due to a request by the U.S. Bureau of Reclamation to irrigation districts in the Yuma area to conserve water by diverting less water for irrigation.

The indicated 2.2 foot per year higher ground-water recharge rate during the budget period than the recharge rate preceding the budget period is not as easily explained.

### YUMA VALLEY SUBAREA

The Yuma Valley subarea includes about 62,000 acres, of which more than three-fourths is irrigated cropland. Except for a narrow strip adjacent to the Colorado River, which is outside the irrigation district and is irrigated chiefly with ground-water supplies, the subarea is irrigated with Colorado River water by way of the Yuma Main Canal. The water budget for the subarea follows:

| | Acre-feet | |
|---|---|---|
| Inflow: | | |
| Surface water: | | |
| Diversions for irrigation from Yuma Main Canal | 341,000 | |
| Diversions for irrigation by pumping from river, 1390 acres at 6 feet | 8,000 | |
| Subsurface water: | | |
| Inflow from Yuma Mesa | 97,000 | |
| Total inflow | | 446,000 |
| Consumptive use: | | |
| Irrigated cropland, 45,270 acres of district land and 2,220 acres of nondistrict land at 3.6 feet | 171,000 | |
| Other land in subarea, 14,810 acres at 2.5 feet | 37,000 | |
| Total | | 208,000 |
| Inflow less consumptive use | | 238,000 |
| Change in storage | | Negligible |
| Outflow: | | |
| Surface water: | | |
| Cooper Canal Wasteway | 2,000 | |
| Eleven Mile Wasteway | 16,000 | |
| Twenty-One Mile Wasteway | 8,000 | |
| East Main Canal Wasteway | 12,000 | |
| Main Drain | 135,000 | |
| Subsurface water [1] | 45,000 | |
| Change in storage plus outflow | | 218,000 |
| Imbalance: Amount by which inflow less consumptive use is more than change in storage plus outflow | | 20,000 |

[1] 5,000 acre-feet across southerly international boundary (p. H103); 13,000 acre-feet to limitrophe section, resulting from net excess irrigation (p. H93): 20,000 acre-feet to limitrophe section in main aquifers (p. H103): 7,000 acre-feet to Colorado River between Yuma and northerly international boundary (p. H93).

The estimates of subsurface outflow to the limitrophe section and across the southerly international boundary were computed on the following basis. It was assumed that the head in the top of the coarse-gravel zone in the western half of Yuma Valley is the same as the head in the underlying wedge zone. This assumption is based on limited evidence of little or no measurable differences of head with depth that was obtained during the present study. The head near the top of the coarse-gravel zone was computed from water-level measurements in the network of observation wells constructed and measured periodically by the Yuma County Water Users' Association. Water levels as of December 1962 (fig. 34) are assumed to be good indicators of average heads for the period 1960–63, inclusive.

The rate of ground-water movement toward the limitrophe section was computed as the product of the transmissivity, width of section, and hydraulic gradient. The transmissivity was that indicated in figure 25; the other parameters of width and hydraulic gradient were determined from the information shown in figure 34. A flow net was used to facilitate computations of the amounts of flow toward various segments of the limitrophe section.

The flow toward the limitrophe section as given for the budget contains some duplication to the extent that the flow in the coarse-gravel zone includes some of the excess irrigation water that originated between the Colorado River and the shallow ground-water divide east of the river. The amount of duplication is thought to be small, probably less than 5,000 acre-feet.

The subsurface flow across the southerly international boundary is the product of the transmissivity, width of Yuma Valley between the river and Yuma Mesa, and the hydraulic gradient as shown in or computed from figure 34.

The budget imbalance of 20,000 acre-feet is quite large relative to the budget items, being almost 5 percent of the total inflow, about 10 percent of the estimated consumptive use, and about 10 percent of the estimated outflow. A significant part of the imbalance may be due to an overestimate of the subsurface inflow from Yuma Mesa as was explained in the discussion of the budget for the Yuma Mesa subarea. Other causes of the imbalance are possible overestimates of the surface-water inflow and underestimates of the consumptive use, or the subsurface outflow. It seems quite unlikely, however, that the latter item is underestimated by much more than 5,000 acre-feet. Because of a lack of knowledge as to which estimates cause the imbalance, no adjustments of the estimates shown have been made to reduce the imbalance.

### SUMMARY OF SUBAREA BUDGETS

The water budgets for all the subareas are summarized in table 9. The algebraic sum of the imbalances of 19,000 acre-feet apparently is due in large part to the imbalance for the Yuma Valley subarea, the probable causes of which are discussed in the section on the budget of the Yuma Mesa subarea (p. H102). The interrelations of the budgets for the various subareas and the principal items of these budgets are shown in figure 33.

### YUMA AREA

A water budget for the entire Yuma area for the period 1960–63, inclusive, was also prepared. With the exception of consumptive use by evaporation from free water surfaces, the consumptive use values are the sum of the respective values given in the budgets of the subareas. Consumptive use by evaporation (total evaporation less precipitation) includes evaporation from the Colorado River and the All-American Canal in addition to evaporation within

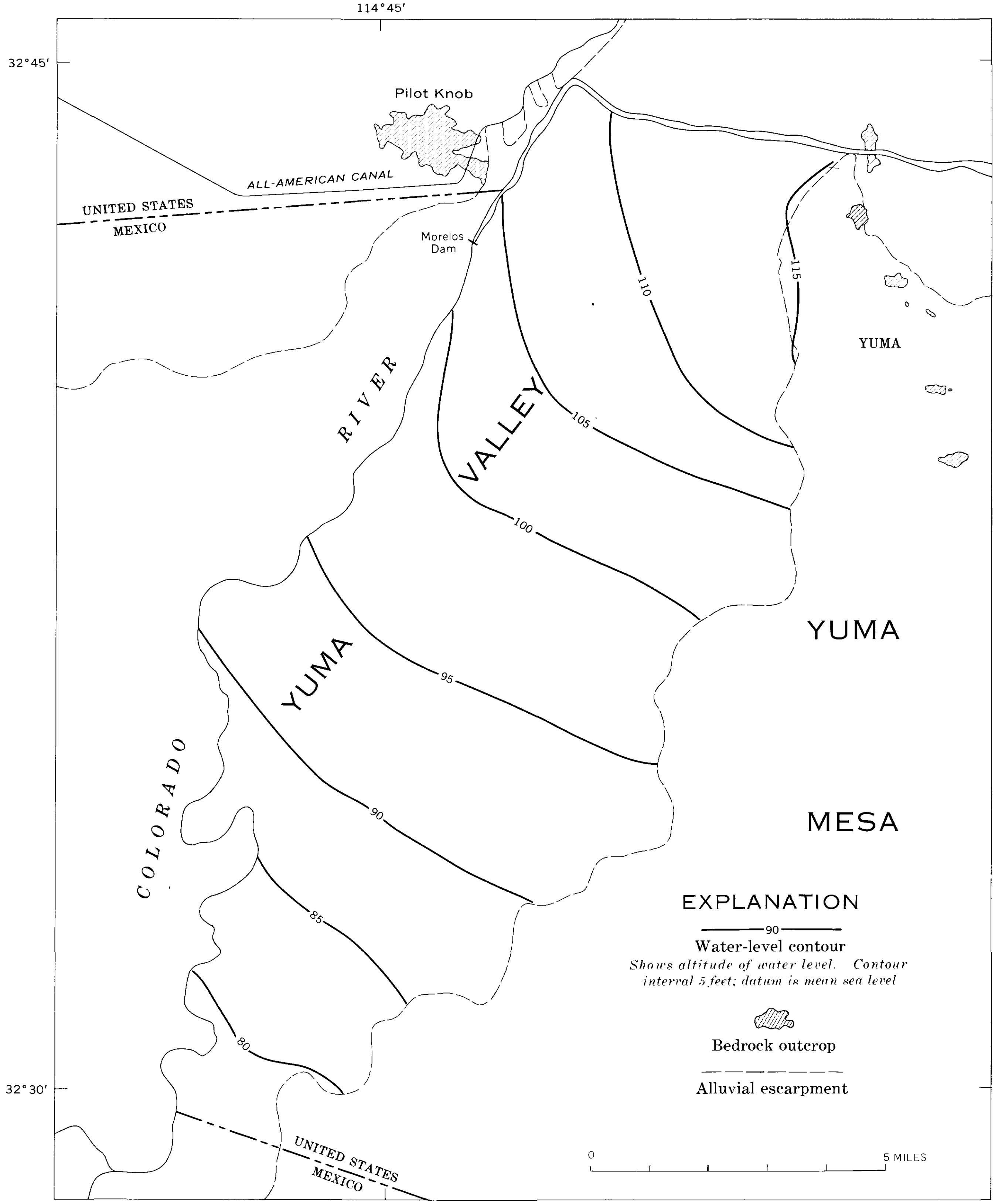


FIGURE 34.—Average water-level contours for upper part of coarse-gravel zone in 1962 in the Yuma Valley.

TABLE 9.—*Summary of ground-water budgets of Yuma subareas, 1960–63*
[Quantities in acre-feet per year]

| Subarea | Inflow | Consumptive use | Column 2 minus column 3 | Change in storage | Outflow | Column 5 plus column 6 | Imbalance, column 4 minus column 7 |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 3 | 5 | 6 | 7 | 8 |
| "Laguna Valley" | 33,000 | 29,400 | 3,600 | 0 | 3,600 | 3,600 | 0 |
| Reservation and Bard | 159,700 | 61,700 | 98,000 | 0 | 87,200 | 87,200 | 10,800 |
| The Island | 23,200 | 24,900 | −1,700 | 0 | 4,000 | 4,000 | −5,700 |
| North Gila Valley | 126,400 | 36,400 | 90,000 | 0 | 93,500 | 93,500 | −3,500 |
| South Gila Valley | 93,100 | 47,600 | 45,500 | −2,000 | 49,000 | 47,000 | −1,500 |
| Yuma Mesa | 311,000 | 80,000 | 231,000 | 47,000 | 184,000 | 231,000 | 0 |
| Yuma Valley | 446,000 | 208,000 | 238,000 | 0 | 218,000 | 218,000 | 20,000 |
| Total of subareas[1] | 1,192,000 | 488,000 | 704,000 | 45,000 | 639,000 | 684,000 | 20,000 |

[1] Column totals are rounded to nearest 1,000 acre-feet per year. The rounded column totals therefore do not necessarily check by row.

the subareas. Change in subsurface (ground water) storage is that indicated in the budgets of the subareas. The other items of inflow and outflow are based on surface-water measurements or are estimated as explained in the footnotes pertaining to individual items. The boundaries of the budget area are quite evident except in the limitrophe section of the river where the boundary is the left or easterly edge of the river.

*Water budget for Yuma area, 1960–63, inclusive*
[Mean annual quantities in 1,000 acre-feet]

| | | |
|---|---|---|
| Inflow: | | |
| Measured: Surface[1] | 6,719 | |
| Unmeasured: | | |
| Surface[2] | 2 | |
| Subsurface[3] | 11 | |
| Total inflow | | 6,732 |
| Consumptive use: | | |
| Irrigated cropland | 363 | |
| Natural vegetation and evaporation from other lands | 118 | |
| Evaporation from free water surfaces | 16 | |
| Total | | 497 |
| Inflow less consumptive use | | 6,235 |
| Change in storage (subsurface)[4] | | 45 |
| Outflow: | | |
| Measured: Surface[5] | 6,115 | |
| Unmeasured: Subsurface[6] | 68 | |
| Total | | 6,183 |
| Change in storage plus outflow | | 6,228 |
| Imbalance: Inflow less consumptive use exceeds change in storage plus outflow | | 7 |

[1] Sum of the average flows of the Colorado River at Imperial Dam, the Gila River near Dome, and the Wellton-Mohawk Main Outlet Drain.
[2] Estimate of average annual runoff from precipitation.
[3] Includes 10,000 acre-feet underflow below Imperial Dam; and 1,000 acre-feet underflow at the gap where the Gila River enters the area.
[4] Increase in storage beneath Yuma Mesa subarea of 47,000 acre-feet less decrease in storage in South Gila Valley subarea of 2,000 acre-feet.
[5] Sum of: flows of All-American Canal above Pilot Knob Power Plant and Wasteway less flows through Pilot Knob Power Plant and Wasteway (3,634,000 acre-feet); diversion to Wellton-Mohawk Irrigation District (399,000 acre-feet); and surface-water deliveries to Mexico (2,082,000 acre-feet).
[6] Sum of ground-water flow across southerly international boundary of 35,000 acre-feet, and ground-water flow across limitrophe section from Yuma Valley of 33,000 acre-feet.

The flows used to compute the average measured inflow are published flows except the flow of the Colorado River at Imperial Dam in 1960. The published flow for 1960 is adjusted downward 100,000 acre-feet to compensate for an overstatement of published flows at Imperial Dam prior to 1961 (Loeltz and McDonald, 1969, p. 67–69).

The outflow item "surface-water deliveries to Mexico" under footnote 5 consists of the same flows as those used in the administration of the Mexican Water Treaty of 1944, namely "the sum of the Colorado River at the northerly boundary, the drainage and waste waters which enter the limitrophe section and the southerly boundary from the United States, less the small (about 5,000 acre-feet annually) use within the United States in the limitrophe section." The drainage and waste waters that are included in the computations are those measured at Cooper, Eleven-Mile, Twenty-One Mile, and East Main Canal Wasteways, and at the boundary pumping plant of the Yuma Main Drain.

The small imbalance of 7,000 acre-feet has no significance because of the uncertainty of the true values of many of the budget items.

The budget compares favorably with a longer term (1951–66), slightly different, and less detailed budget which was prepared for Hely (1969).

## GROUND-WATER DISCHARGE TO THE COLORADO RIVER BETWEEN IMPERIAL DAM AND THE NORTHERLY INTERNATIONAL BOUNDARY

The water budgets for the various subareas of the Yuma area for the period 1960–63 indicate that ground water generally was being discharged to the Colorado River. The average yearly quantities of ground water discharged to the Colorado River or to the Gila River from each of the subareas between Imperial Dam and the northerly international boundary are listed in table 10.

Of the 72,000 acre-feet of ground-water discharge to the river, about 45,000 acre-feet is indicated to enter the river upstream from Yuma and 27,000 acre-feet downstream.

Surface-water records also indicate that ground water is being discharged to the river. However, because of the large volume of surface water relative to the discharge of ground water to the river, which is computed as the difference between surface inflow

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TABLE 10.—*Ground-water discharge to the Colorado or Gila Rivers between Imperial Dam and northerly international boundary, 1960–63*

| *Subarea* | *Average yearly quantity (acre-feet)* |
|---|---|
| Laguna Valley | 3,000 |
| Reservation and Bard: | |
| Eastern boundary | 6,000 |
| Southern boundary | 16,000 |
| The Island | 4,000 |
| North Gila Valley | 23,000 |
| South Gila Valley | 9,000 |
| Yuma Valley: | |
| Northern boundary | 7,000 |
| | 68,000 |
| Plus: Estimated leakage from All-American Canal to river between Reservation and Bard subarea boundary and northerly international boundary [1] | 4,000 |
| | 72,000 |

[1] Estimated on basis that only the leakage from about 1 mile of the 2-mile length of canal at rate of 4,300 acre-feet per year per mile reaches the river.

and outflow, the errors inherent in surface-water measurements may be the principal influence on the yearly differences of ground-water inflow indicated by surface-water measurements. Sufficient surface-water data are published so that computations can be made as to the indicated discharge of ground water to the Colorado River for the reach Imperial Dam to Yuma for the period 1961–65, inclusive, and for the reach Yuma to northerly international boundary for the period 1950–66.

The first computation involves the flow of the Colorado River, the Gila River, and 12 or more other inflows. The second involves the flow of the Colorado River and four other inflows. As many as four different agencies supply data for computing flows.

The yearly difference for the period 1961–65, inclusive, by which the flow of the Colorado River at Yuma exceeded the sum of the flow of the Colorado River at Imperial Dam and all the known surface-water inflows to the river in the reach between Imperial Dam and Yuma, including the flow of the Gila River, are shown in table 11.

TABLE 11.—*Flow of the Colorado River at Imperial Dam and at Yuma and differences between sum of all surface-water inflow items in the reach and flow of Colorado River at Yuma*

[All quantities in 1,000 acre-feet]

| Calendar year | Gaging station at— | | Surface-water outflow exceeds surface-water inflow [1] |
|---|---|---|---|
| | Imperial Dam | Yuma | |
| 1961 | 437 | 683 | 38 |
| 1962 | 510 | 860 | 32 |
| 1963 | 575 | 924 | 40 |
| 1964 | 440 | 712 | 20 |
| 1965 | 297 | 560 | 11 |
| Average | | | 28 |

[1] After adjusting published return flows to Gila River from Wellton-Mohawk Outlet Drain downward 4,000 acre-feet per year to compensate for estimated seepage loss in 8-mile unlined channel between measuring point and river that does not reach Colorado River.

For the period of record the yearly ground-water inflow less evaporation of river water (4,000 acre-feet) and water diverted for irrigation (6,000 acre-feet) ranges between 11,000 and 40,000 acre-feet and averages 28,000 acre-feet. Adding 10,000 acre-feet because of annual evaporation of river water and diversions for irrigation indicates an average annual inflow or discharge of ground water to the river of 38,000 acre-feet. This discharge of ground water to the Colorado River in the reach between Imperial Dam and Yuma computed on the basis of surface-water inflows and outflows thus averages only about 7,000 acre-feet less than the discharge of 45,000 acre-feet indicated by the water budgets of the various subareas (p. H105). Because of the uncertainty of the true values of many of the items in all the budgets the difference of 7,000 acre-feet between the two estimates is insignificant.

The difference by which the flow at the northerly international boundary exceeds the sum of the flow at Yuma and the other return flows is a measure of the discharge of ground water to the river in the reach, if to the difference is added about 2,000 acre-feet for average annual evaporation from the river and about 2,000 acre-feet because of pumpage from the river for irrigation. Table 12 shows a wide range in these annual differences—from an indicated loss of 85,000 acre-feet in 1952 to a gain of 74,000 acre-feet in 1954. It is quite apparent that the yearly differences are dominated to a large ex-

TABLE 12.—*Flow of the Colorado River at Yuma and at northerly international boundary, and differences between sum of all surface-water-inflow items in the reach and flow of Colorado River at northerly international boundary*

[All quantities in 1,000 acre-feet]

| Calendar year | Gaging station at— | | Surface-water outflow exceeds surface-water inflow | Surface-water outflow is less than surface-water inflow |
|---|---|---|---|---|
| | Yuma | Northerly international boundary | | |
| 1950 | 3,464 | 4,456 | 43 | |
| 1951 | 2,764 | 3,639 | | 48 |
| 1952 | 9,192 | 10,146 | | 85 |
| 1953 | 4,095 | 5,224 | 44 | |
| 1954 | 3,196 | 4,346 | 74 | |
| 1955 | 2,118 | 3,058 | 17 | |
| 1956 | 881 | 1,638 | 30 | |
| 1957 | 1,167 | 2,853 | | 2 |
| 1958 | 2,951 | 5,908 | | 68 |
| 1959 | 933 | 3,051 | 25 | |
| 1960 | 702 | 2,338 | 66 | |
| 1961 | 683 | 1,672 | 25 | |
| 1962 | 860 | 1,811 | 28 | |
| 1963 | 924 | 1,834 | 42 | |
| 1964 | 712 | 1,502 | 51 | |
| 1965 | 560 | 1,524 | 31 | |
| 1966 | 428 | 1,420 | 34 | |
| Total | | | 510 | 203 |

NOTE.—Surface-water outflow exceeds surface-water inflow:
For period of record 307
Yearly average 18

tent by errors of measurement. However, they also are influenced somewhat by the amount of flow in the preceding year. Generally, the ground-water discharge for a given year should be less than the ground-water discharge for the preceding year when the stream discharge for the given year is substantially larger than the stream discharge for the preceding year. A large annual increase of stream discharge for a given year ordinarily implies an increase of river stage. An increase of river stage in an area of ground-water discharge to the river decreases the gradient from the ground-water reservoir to the river and consequently the ground-water discharge to the river. Similar reasoning shows that ground-water discharge to the river should increase in a year in which the stream discharge, and presumably the stream stage, is lower than in the preceding year. The average annual amount by which the discharge at the northerly international boundary exceeds the sum of the measured inflows for the years listed in table 12 is 18,000 acre-feet.

The average annual discharge of ground water to the river is an additional 4,000 acre-feet because of evaporation and pumpage, or 22,000 acre-feet for the 17-year period 1950–66. For the period of the water budgets of the various subareas 1960–63 the discharge of ground water to the river is indicated to be about 44,000 acre-feet.

The true value probably is somewhere between these two values unless consistent errors of measurement are involved. Even in years of relatively low flow, the flow at the northerly international boundary is between 1.5 million and 3 million acre-feet, so a consistent error of only 1 percent would cause the computed discharge of ground water to the river to be in error 15,000–30,000 acre-feet. The indicated mean annual difference even for a 10-year or longer period therefore, may be reliable only to plus or minus 10,000–20,000 acre-feet.

As a basis for comparison, the average annual discharge to the Colorado River in the reach Yuma to the northerly international boundary as indicated by the water budgets of the various subareas was about 27,000 acre-feet for the period 1960–63 (p. H105). This estimate is based on the ground-water parameters of transmissivity, hydraulic gradient, and width of section. It is 17,000 acre-feet less than the estimate for the same period computed from surface-water measurements and 5,000 acre-feet more than the estimate computed from surface-water measurements for the period 1950–66.

In general, the estimates of ground-water discharge to the Colorado River computed on the basis of surface-water measurements and the estimates computed on the basis of ground-water parameters agree as well as can be expected in view of the uncertainties of the values of the items used to obtain the estimates.

## ANALOG-MODEL STUDIES

Because of the complex nature of the hydrologic system in the Yuma area and the continuing and varied development of the system, the use of mathematical formulas for directly computing the response of the system to this development becomes impractical. The electrical-analog method, however, is well adapted for solving the complex mathematics of the partial differential equations involved in describing the hydrologic system. The construction of an electrical analog model of the Yuma area that would simulate responses of the actual system to stresses imposed on it therefore was one of the objectives of the present investigation.

An initial attempt in 1964 to simulate observed changes of water level beneath Yuma Mesa by means of a one-layer model was not successful enough to warrant further work on the model. The model was useful, however, in demonstrating that some of the parameters of transmissivity, storage, and boundary effects in the southern and southeastern part of Yuma Mesa that were being simulated by the model were incorrect. In 1966, the barrier effect of the Algodones fault to the southward movement of ground water beneath Yuma Mesa was first recognized as the result of drilling exploratory wells on both sides of the fault. Discovery of this highly effective barrier appeared to provide the boundary parameter that would permit reasonable agreement between observed changes in water level and those indicated by an electrical analog model using values similar to those assumed for the initial study.

The United States Section of the International Boundary and Water Commission, and the U.S. Bureau of Reclamation were very much interested in obtaining a model that might be used in predicting the effect of future water development on the movement of ground water across international boundaries. As a consequence, both agencies cooperated with the Geological Survey in building a more representative electrical analog model of the Yuma area and in providing additional hydrologic data, principally from exploratory drilling in the southeastern part of the "Upper Mesa" and "Fortuna Plain." Also, these two agencies provided funds for additional geophysical exploration.

### MODEL CHARACTERISTICS

The analog model includes the Yuma area and contiguous parts of Sonora and Baja California, Mexico; a total area of some 2,000 square miles. The actual hydrologic system is simulated as a three-dimensional flow field idealized as two two-dimensional transmissive layers and two layers of solely vertical flow.

The upper transmissive layer generally corresponds to the coarse-gravel zone, but where that zone is missing, such as beneath the "Upper Mesa" and "Fortuna Plain," it includes the upper part of the older alluvium, undivided. Beneath southwestern Yuma Mesa and southern Yuma Valley the upper transmissive layer includes all the alluvial deposits in which most wells have been completed or are likely to be completed. Thus, in those areas the upper transmissive layer includes the uppermost part of the wedge zone as well as the coarse-gravel zone.

Overlying the materials modeled as the upper transmissive layer are much finer grained materials corresponding to the upper, fine-grained zone. In Yuma and South Gila Valleys these finer materials are modeled as a confining layer which allows vertical flow to or from the upper transmissive layer according to the hydraulic gradient between the constant-head surface assumed in these valleys and the head in the upper transmissive layer and the vertical hydraulic conductivity of the confining material. Elsewhere in the modeled area the upper confining layer is lumped with the upper transmissive layer.

The lower transmissive layer is hydraulically connected to the upper transmissive layer and is modeled as a single transmissive layer. Beneath the river valleys and Yuma Mesa the lower transmissive layer includes most of the wedge zone, and beneath the "Upper Mesa" and "Fortuna Plain" it includes the lower, major, part of the older alluvium, undivided. The average head loss resulting from vertical flow between the upper and lower transmissive layers at any site is simulated by a parameter representing the average vertical hydraulic conductivity and average flow distances between the two layers.

Wherever practicable, the model boundaries (partly shown in fig. 35) approximate natural hydrologic boundaries. The eastern boundary of the model coincides with the Gila Mountains and their southern continuation—the Butler Mountains; the northern boundary generally follows the Cargo Muchacho Mountains and a marked decrease in transmissivity in the alluvium about 9 miles north of the northerly international boundary; the western boundary is modeled as being about 30 miles west of Pilot Knob along a line that approximates the increasing clay content and consequent decreasing permeability of the deposits in Imperial and Mexicali Valleys; the southern boundary is arbitrarily modeled as being about 15 miles south of San Luis, Mexico, and is a constant-head boundary so as to yield or receive water in response to changes in ground-water gradients.

Also modelel as constant-head boundaries are the All-American Canal and the Colorado River. Their hydraulic connection with the upper transmissive layer is a parameter representing the hydraulic radius, the permeability of the deposits underlying the river or canal, and the distance through which the water moves in the interchange process. Values for this parameter were selected by trial and error until reasonable agreement between interflow rates computed from model response and best estimates of historical rates were obtained. For computational purposes, both the All-American Canal and the river are divided into two segments, one end of each terminating near Pilot Knob.

In the lower transmissive layer the Algodones fault is modeled as a partial barrier to the movement of water throughout its length, whereas in the upper transmissive layer, the fault's barrier effect was modeled only southeast of the apex of the ground-water mound. This difference in the two layers was modeled because barrier effects of the fault were not recognizable during the present investigation in wells bottoming in the coarse-gravel zone (principal part of upper transmissive layer) northwest of the apex of the ground-water mound.

### TRANSMISSIVITY VALUES

Ranges in transmissivity for the upper and lower transmissive layers as finally modeled are shown in figures 35 and 36. The transmissivity values were adapted by the analog-model-unit laboratory from more detailed maps submitted to the laboratory from the project office, which showed respective transmissivity values for the upper and the lower transmissive layers. These estimates were based on the results of pumping tests, specific capacity of wells, drillers' logs, lithologic logs, borehole geophysical logs, and probable thickness and permeability of sediments as interpreted from all the geologic, geophysical, and hydrologic studies in the area. Verification studies of the model showed that increasing the original estimates 25 percent resulted in an improved correlation between model response and observed changes of water level. This increase, therefore, was incorporated into the model and is included in the values shown in figures 35 and 36, and in figure 25, which shows the sum of the transmissivity values that were the basis for transmissivity values simulated by the analog model.

STORAGE-COEFFICIENT VALUES

The storage coeffcients for the upper transmissive layer that were actually modeled are shown in figure 37. They were arrived at in the following manner.

A first estimate of the storage coefficient for the nonirrigated areas of Yuma Mesa was 35 percent, based on soil-moisture studies with the neutron moisture probe (p. H219). Geologic studies indicated that the foregoing value was too large for the "Upper Mesa" and "Fortuna Plain," so a value of 25 percent was used for those areas. Subsequent verification studies, however, indicated that the smaller values shown in figure 37 resulted in model responses that correlated with observed changes much better than did the original estimates.

A storage coefficient of 20 percent was originally assumed for all the flood-plain land in Mexico and for land in the United States north and west of Pilot Knob. Verification studies indicated that a value of 18 percent as shown in figure 37 was as valid as the original 20 percent estimate. Construction of the model therefore was not modified to incorporate a simulation of the somewhat higher original value.

The storage coefficient for the upper transmissive layer beneath Yuma Valley is $5\times10^{-4}$, an artesian coefficient. In this area, the changes in water level are assumed to be small because of the extensive network of drains in most of the area. The specific value to be assigned to the storage coefficient is not critical because storage in the upper transmissive layer beneath the flood plain in the United States has little effect on the response of the system.

A storage coefficient of 0.31 was modeled for the flood-plain area north and northwest of Yuma Mesa. In addition, a constant head was modeled for North and South Gila Valley subareas. Modification of the model in the flood plain north of Yuma Mesa probably would better simulate actual conditions. However, the modifications were not essential to the principal objectives of the study and therefore they were not fully explored.

One modification, which involved using a constant head and artesian storage coefficient for the entire flood plain north and northwest of Yuma Mesa, gave poorer correlations between model response and historical changes than did the present model with the supposedly less realistic values.

A value of $5\times10^{-4}$ was modeled for the storage coefficient throughout the lower transmissive layer. Hydrologic data were not available for making an estimate of this parameter, so a reasonable value that would result in the shortest travel time for pressure waves was selected. Under this design, the movement of ground water across international boundaries as indicated by the model response is at a maximum rate.

STRESSES APPLIED TO THE MODELED SYSTEM

Recharge to the system was computed on the basis of imports to Yuma Mesa minus consumptive use, and was apportioned areally according to the acreage irrigated during specific periods (table 13). Discharge of ground water by pumps in the United States from the coarse-gravel zone began in 1948 and was apportioned according to the location of the principal drainage wells along the western and northern margins of Yuma Mesa and the pumpage for specific periods (table 1). Pumpage in Mexicali Valley was determined on the basis of the stress that had to be imposed on the system to cause historical declines in head in the coarse-gravel zone underlying the Mexicali Valley well field. (See last column of table 14.)

TABLE 13.—*Design stresses for analog model of Yuma area*

[Quantities in 1,000 acre-feet]

| Period | Yearly rate | Period | Accumulated |
|---|---|---|---|
| **Recharge** | | | |
| 1925–42 | -------- | 95 | 95 |
| 1943–47 | 51 | 256 | 351 |
| 1948–52 | 102 | 512 | 863 |
| 1953–57 | 147 | 785 | 1,648 |
| 1958–62 | 208 | 1,039 | 2,687 |
| 1963–64 | 228 | 456 | 3,143 |
| 1965–66 | 188 | 376 | 3,519 |
| **Drainage-well pumpage** | | | |
| 1948–52 | 19 | 95 | 95 |
| 1953–57 | 36 | 182 | 277 |
| 1958–62 | 80 | 400 | 677 |
| 1963–64 | 114 | 228 | 905 |
| 1965–66 | 126 | 251 | 1,156 |

TABLE 14.—*Effective yearend declines of water level, in feet, in Mexicali Valley at a site 12 miles west of the middle of the limitrophe section of the Colorado River*

| Period ending December | Average decline during irrigation season | Average additional decline due to drawdown at wells | Decline since December 1952 | Effective yearend decline |
|---|---|---|---|---|
| 1952 | 0 | 0 | 0 | 0 |
| 1957 | 1 | 3 | −2 | 2 |
| 1962 | 2 | 6 | 7 | 15 |
| 1964 | 3 | 7 | 11 | 21 |
| 1966 | 3 | 7 | 15 | 25 |

The average decline of water levels since December 1952 and the seasonal decline were based on water-level maps obtained by the United States Section of the International Boundary and Water Commission from the Mexican Section of the Commission. The average additional decline due to drawdown at wells was estimated to be about one-fourth of the average drawdown at the well sites. Points of stress were distributed uniformly throughout the Mexicali Valley well field.

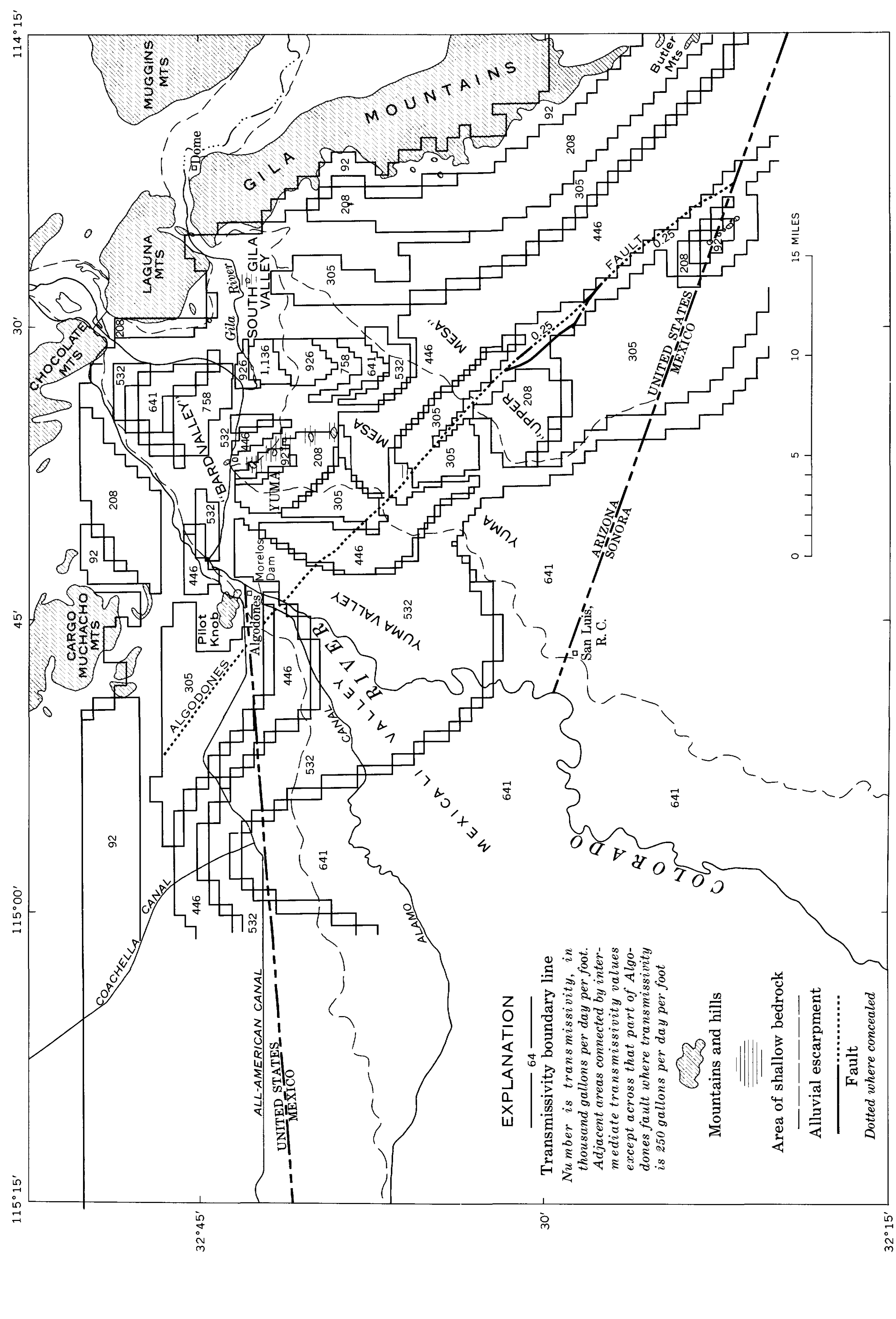


**Figure 35.**—Transmissivity of the upper transmissive layer simulated in the analog model in the delta region.

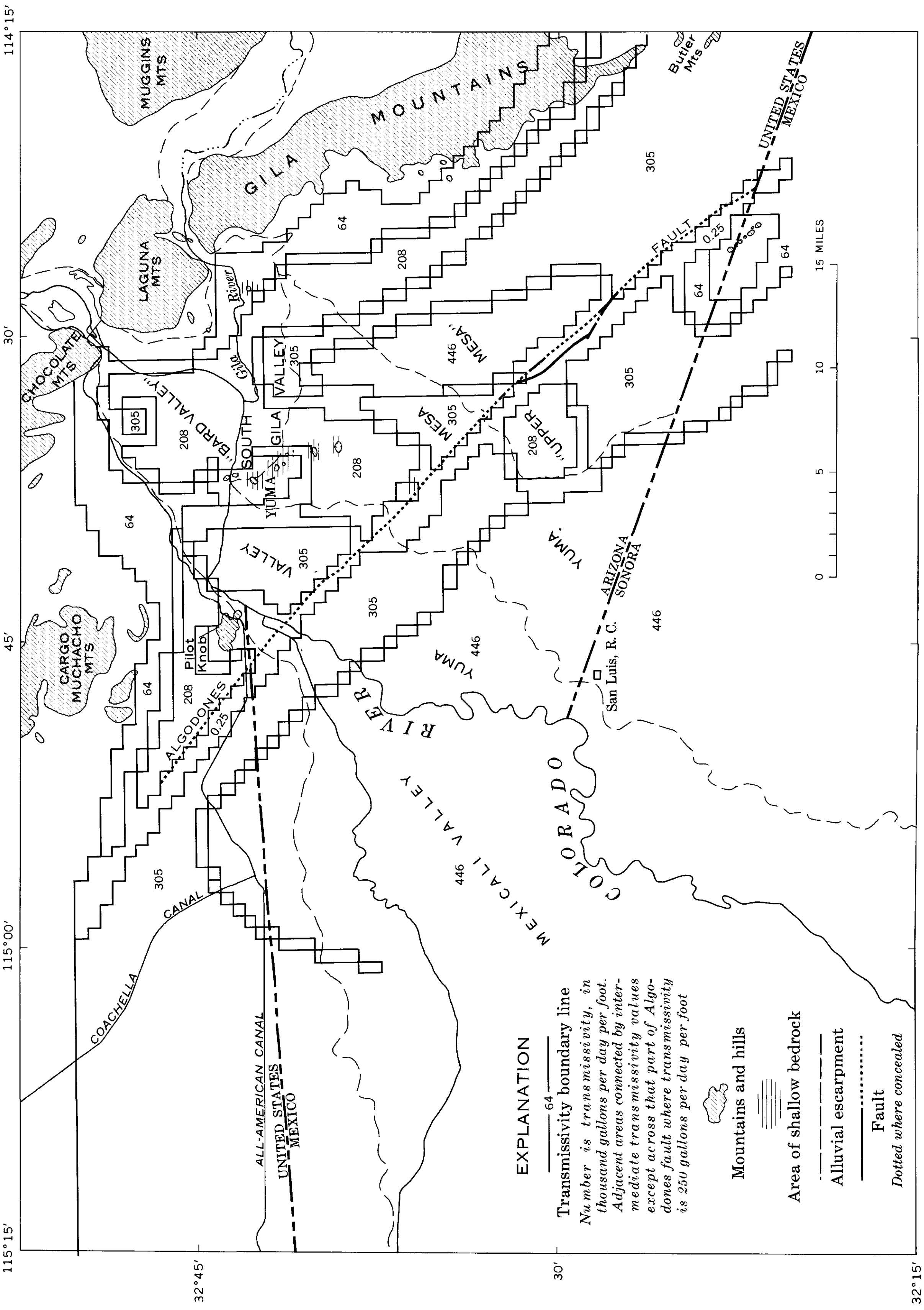


FIGURE 36.—Transmissivity of the lower transmissive layer simulated in the analog model in the delta region.

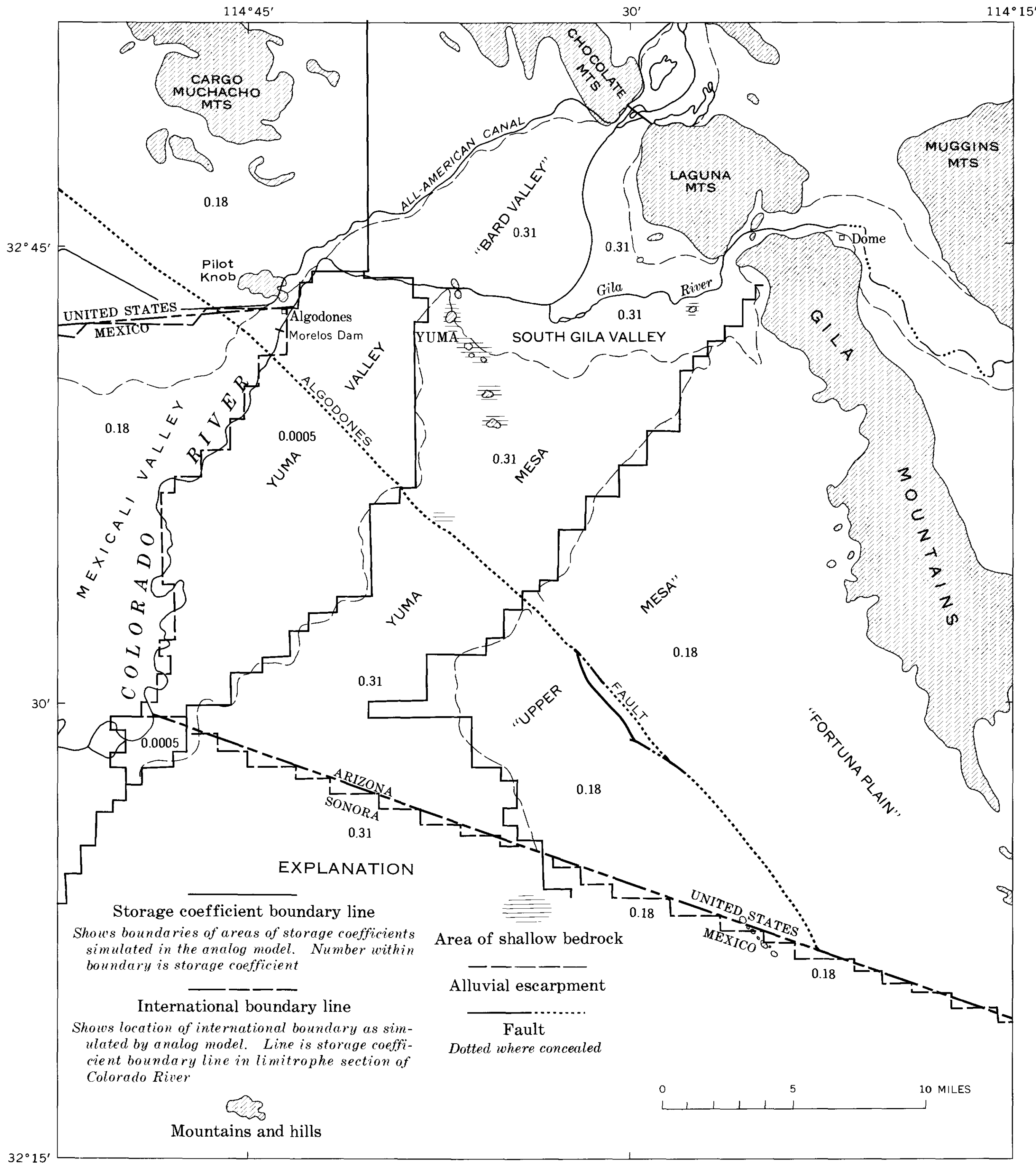


FIGURE 37.—Storage coefficients of the upper transmissive layer simulated in the analog model.

The resultant pumpage figures therefore were not indicative of the actual pumpage in Mexicali Valley because the stresses imposed on the model were only part of the stresses that were operative in Mexicali Valley. Recharge to the upper transmissive layer resulting from diversion of surface water for irrigation is a stress that would need to be imposed before a meaningful net pumpage figure could be expected.

However, the objectives of the model study—that is, an evaluation of the changes in the rate of movement of ground water across international boundaries, especially the limitrophe section of the Colorado River during a given time period—can be computed satisfactorily from transmissivity values and changes in gradients across international boundaries as shown by the analog model without regard to net pumpage in Mexicali Valley. The magnitude of the rate of ground-water movement across international boundaries at a given time can be computed from transmissivity values shown in figure 25 and hydraulic gradients computed from water-level contour maps of a given date, provided the gradients are adjusted for changes as indicated by the analog model that have occurred or will occur between the date of the water-level contour map and the time at which the rate of movement is desired.

### VERIFICATION STUDIES

Verification of the analog model involves a comparison of the model responses with historical responses. The respective responses for selected time intervals and the corresponding actual observed or estimated changes in water level are shown in figures 38–43.

The configuration of the change in water-level contours as inferred from field data and the response of the analog model are seen to be good in a general sense, although the changes in water level as determined from field data generally exceed the changes in water level computed on the basis of the model response. Differences are at a maximum for the heavily irrigated areas of the Yuma Mesa because the changes computed from field data include vertical head losses between the bottom of a well and the top of the coarse-gravel zone, whereas the model response excludes these losses. Differences of 30 feet and more between water levels in shallow wells and water levels in wells tapping the coarse-gravel zone beneath the principal recharge areas on the Yuma Mesa have been observed. However, with increasing distance from the irrigated areas, the differences in head between water levels in shallow wells and those in wells that tap the coarse-gravel zone decrease rapidly, so that at distances of a mile or more the differences are negligible.

The historical changes and the changes indicated by the model response for the periods 1957–62 and 1962–66 also agree reasonably well.

### RELIABILITY OF THE ANALOG MODEL

In view of the model's ability to duplicate reasonably well both the series of overall changes and the intermediate changes that have occurred, the model, with caution, can be used to predict the effect of other stresses that might be imposed on it. After the model is modified to obtain more realistic storage coefficients in the flood plain north of Yuma Mesa and after other small adjustments to lessen observed discrepancies between model response and historical changes are made, it should be a useful tool for predicting the changes in head that will result from future development of the ground-water resources of the area under any proposed plan. The changes in head can be readily converted to changes in gradient, which together with the transmissivity values can be used to compute changes in the direction and rate of ground-water movement.

## TEMPERATURE OF GROUND WATER

The temperature of ground water often provides clues to the sources of ground-water recharge, the direction and rate of ground-water movement, and the characteristics of the geologic framework that constitutes the ground-water reservoir. In the Yuma area, variations in temperature with place and depth have been particularly useful in corroborating vertical ground-water movement inferred from other evidence. In addition, local high-temperature anomalies furnish supporting evidence for the presence of faults affecting water-bearing materials and also for the presence of zones of low hydraulic conductivity in the alluvial deposits.

### VARIATIONS IN TEMPERATURE WITH TIME

Temperature of the ground water in the Yuma area fluctuates seasonally above depths of 30–60 feet. The amplitude of the fluctuation decreases with depth. At a depth of 4 feet, the seasonal range is about 12°–14°C—substantially less than the 20°C (36°F) range in average monthly air temperature at Yuma (Sellers, 1960). At a depth of 10 feet in well (C–9–24)11ccc, a representative observation well of the Yuma County Water Users' Association in central Yuma Valley, the difference in temperature from May to November 1967 amounted to a little more than 6°C. At depths greater than 55 feet, the seasonal differences for the same period were less than 0.2°C, and even these small differences probably were at least in part instrumental or observational error (fig. 44).

Trends in temperature that are not seasonal may be significant where heavy pumping or application of irrigation water have altered local patterns of ground-water movement. An example of this type of change is provided by the record of well (C–9–23) 20bdc, a U.S. Bureau of Reclamation drainage well in eastern Yuma Valley (fig. 45). The temperature

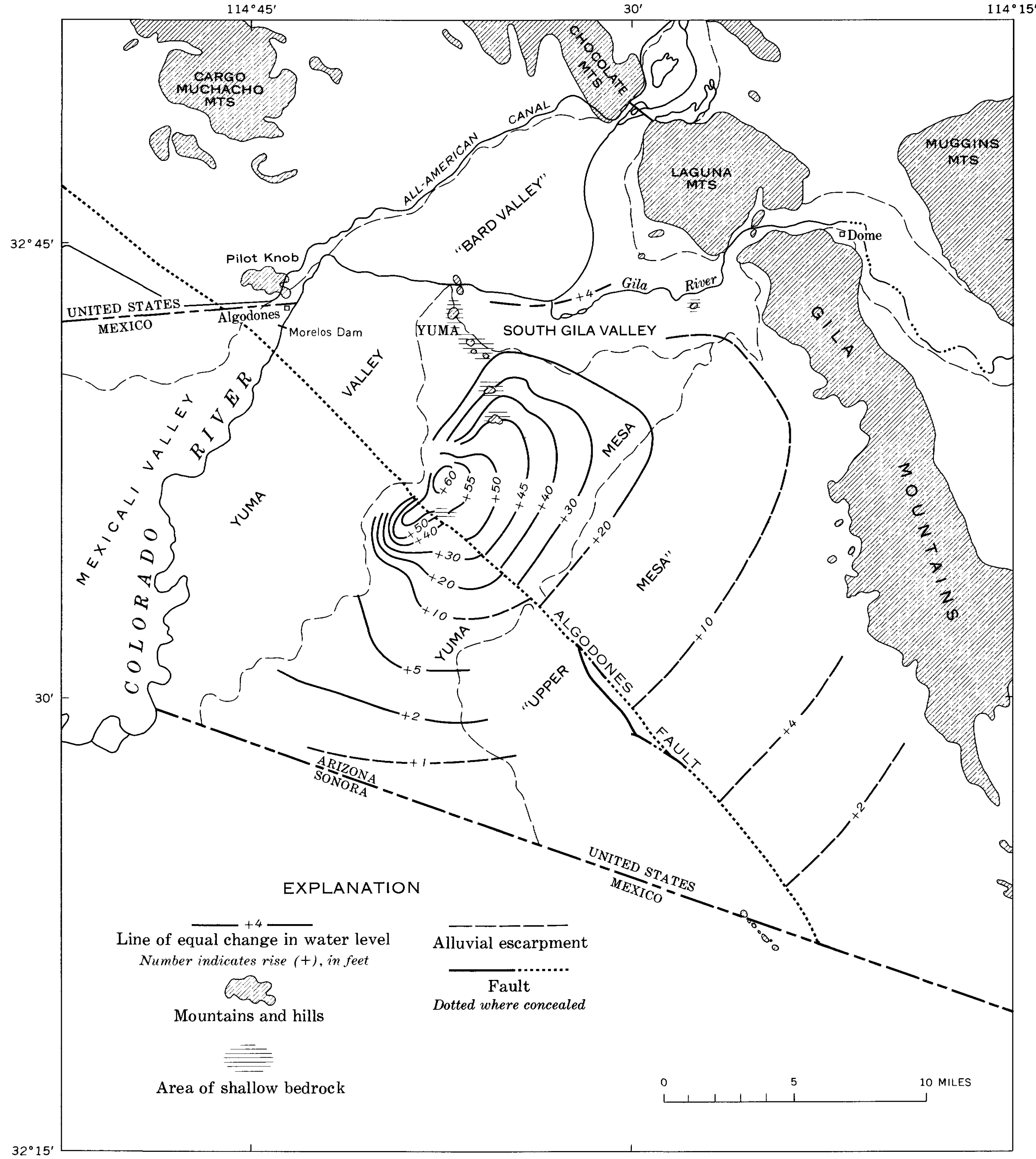


FIGURE 38.—Changes in water level, 1925 to December 1957, as indicated by field measurements or as estimated.

of the water pumped from this well, which is perforated in the coarse-gravel zone, has decreased at a diminishing rate from 28.9°C in late November 1966 when the pump was started to 27.8°C in early February 1968, 14 months later. Except for about a week in early December 1966, the well was pumped continuously during this period. The decrease in temperature probably resulted from increasing leakage

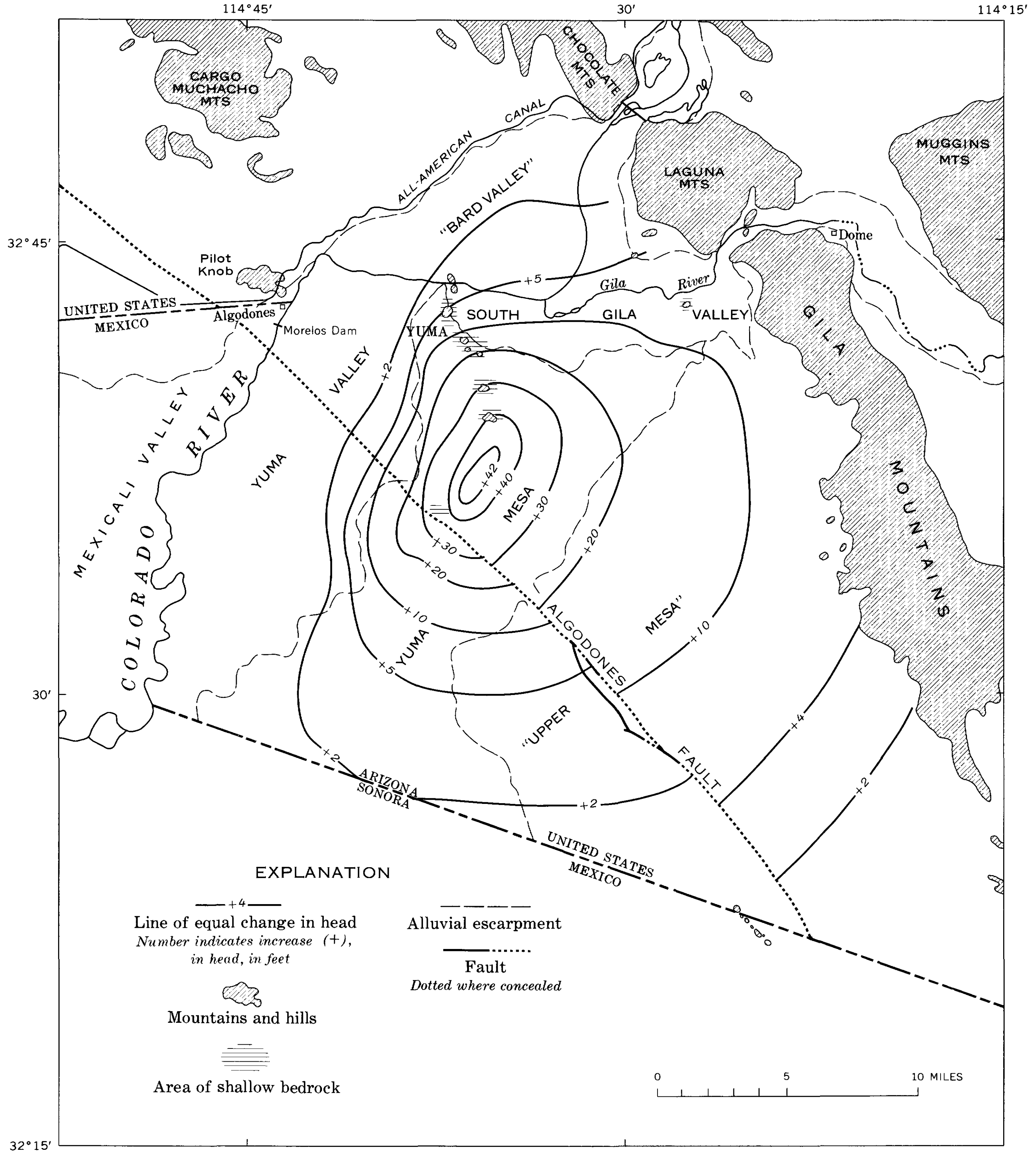


FIGURE 39.—Changes in head in the upper transmissive layer, 1925 to December 1957, as indicated by responses of the analog model.

of cooler water from the upper, fine-grained zone into the coarse-gravel zone as the pumping continued. Before the pumping began, the vertical component of ground-water movement was entirely upward, from the wedge zone through the coarse-gravel zone and into the upper zone. The water in the wedge zone in this area is substantially warmer than that in the overlying zones. Thus, the temperature record furnishes corroborative evidence that the drainage well is fulfilling its designed function,

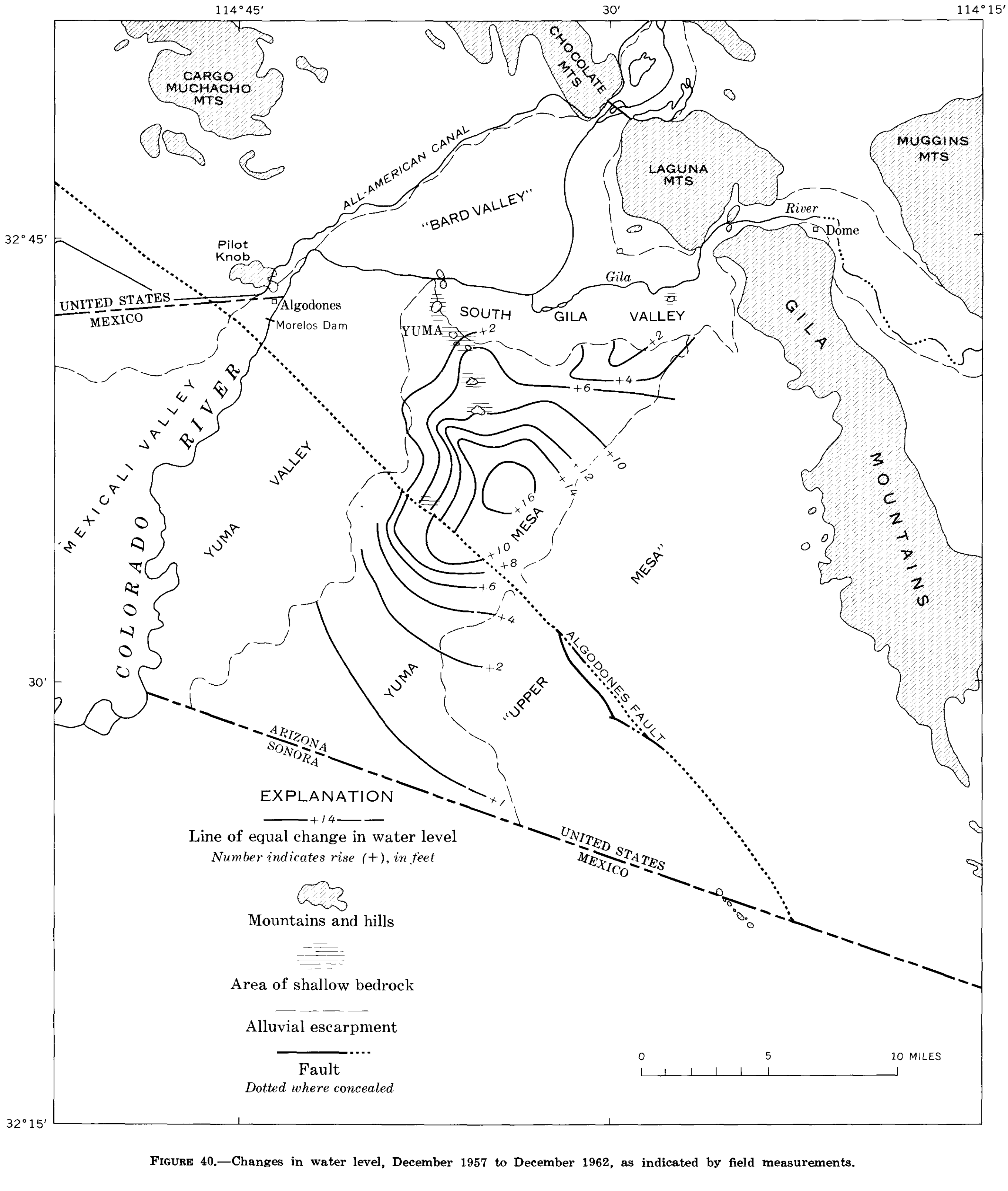


FIGURE 40.—Changes in water level, December 1957 to December 1962, as indicated by field measurements.

which is to lower the water table by causing downward leakage from the upper, fine-grained zone into the coarse-gravel zone.

## VERTICAL VARIATIONS IN TEMPERATURE

In dense rocks, where porosity is small and little ground-water movement occurs, the temperature

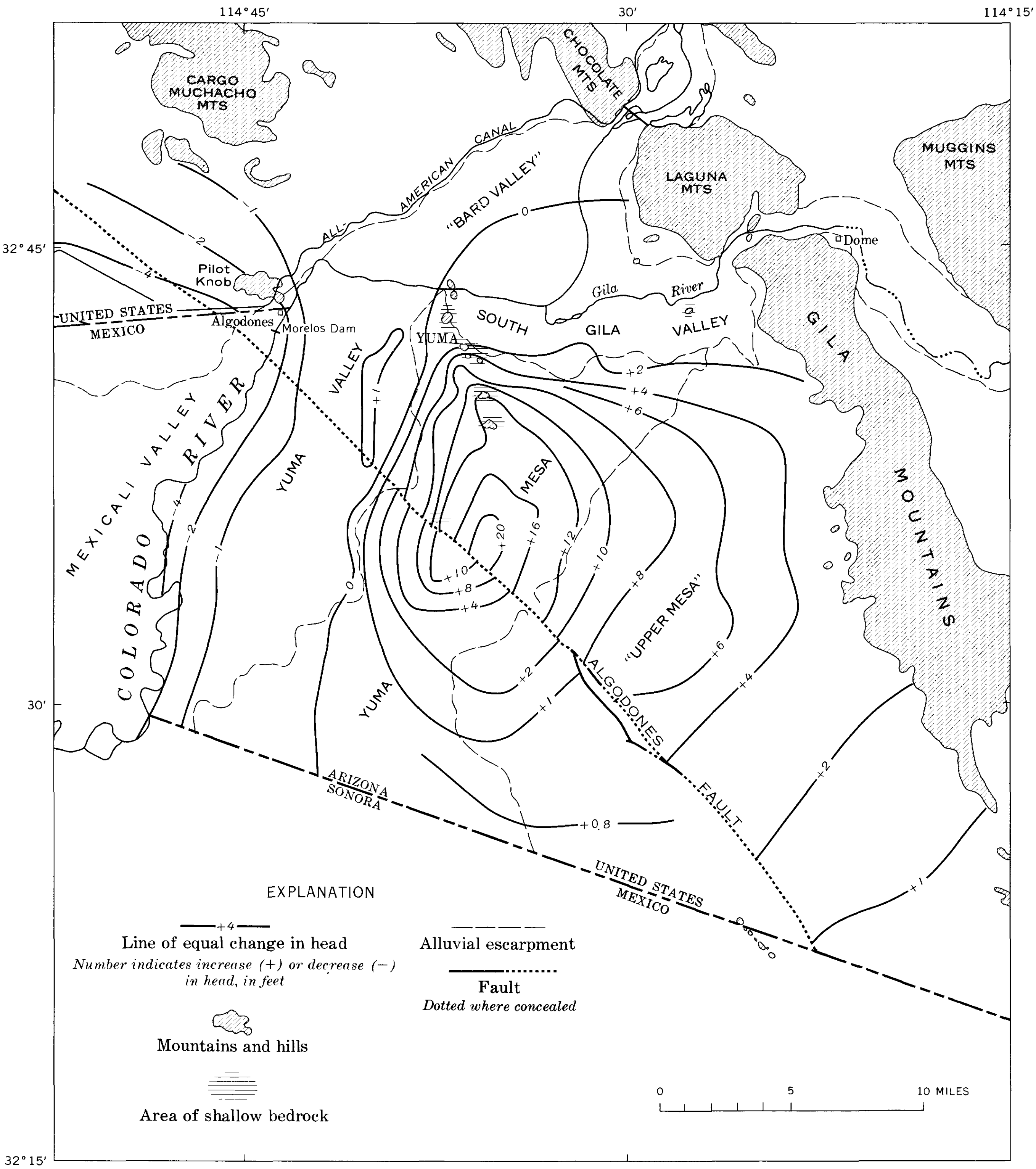


FIGURE 41.—Changes in head in the upper transmissive layer, December 1957 to December 1962, as indicated by responses of the analog model.

generally increases with depth. However, geothermal gradients are modified greatly or even reversed by significant circulation of ground water, such as occurs in most of the Yuma area.

Gradients are relatively large in fine-grained deposits of small to moderate permeability like those penetrated by U.C. Geological Survey test well (C–8–23)33cdd (LCRP 13) in Yuma (fig. 46). In

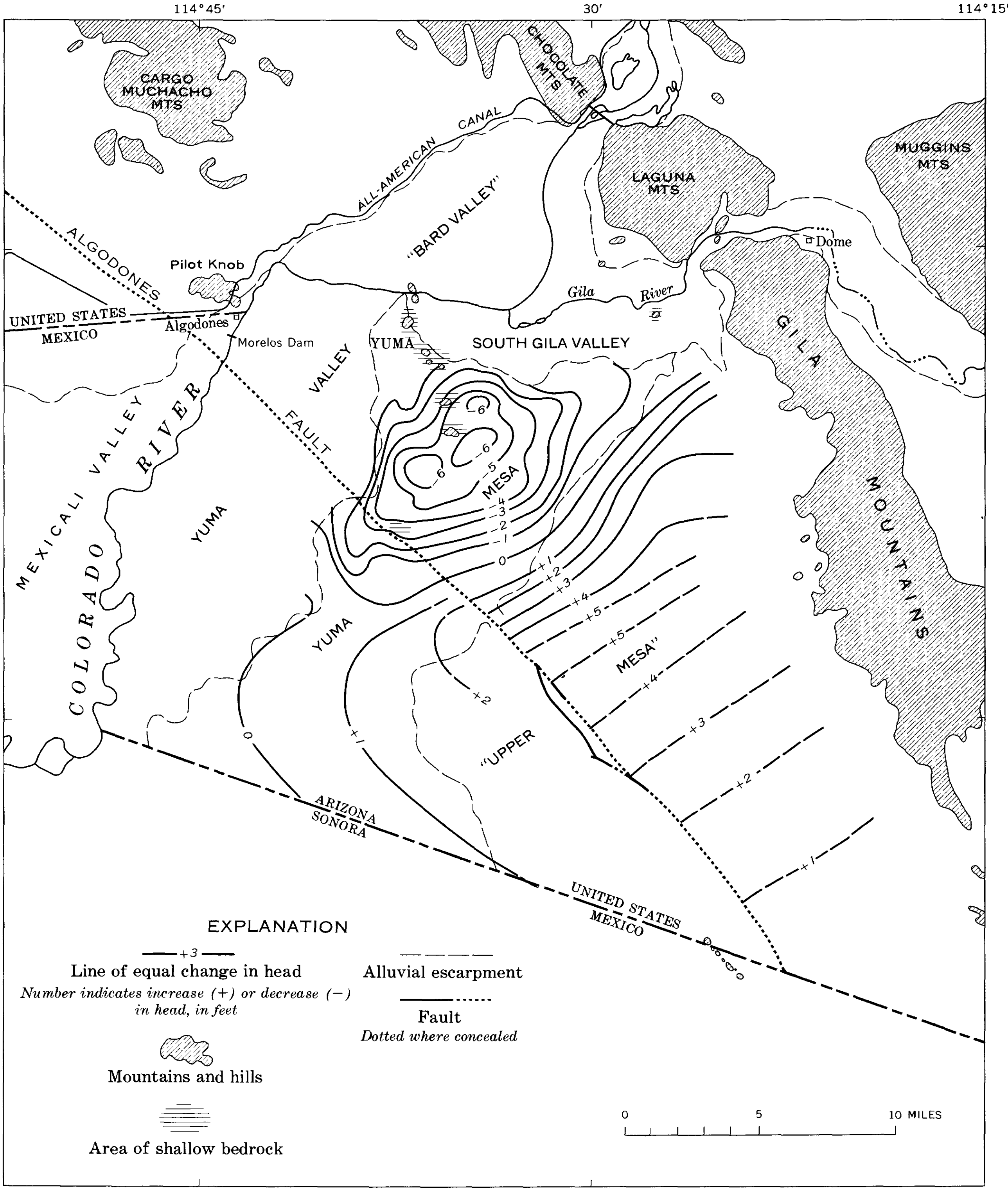


FIGURE 42.—Changes in water level, December 1962 to December 1966, as indicated by field measurements.

this well, the average gradient between depths of 80 and 730 feet is 1.3°C per 100 feet—not greatly different from the value of 1.0°C per 30 meters (about 100 ft) cited by Gutenberg (1959) as an average for many oil fields.

Gradients are usually smaller in permeable de-

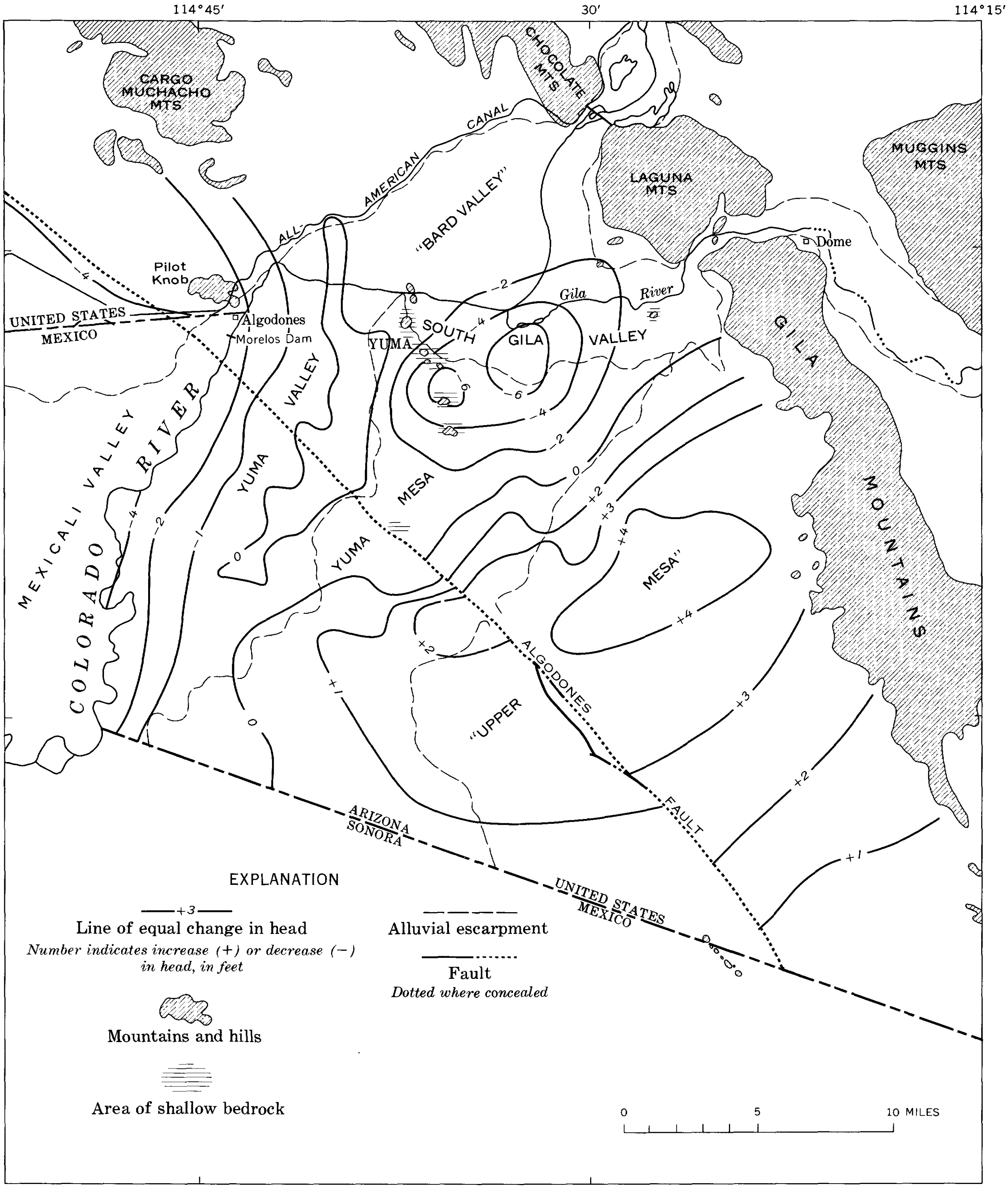


FIGURE 43.—Changes in head in the upper transmissive layer, December 1962 to December 1966, as indicated by responses of the analog model.

posits where ground-water circulation is more rapid and where few beds of clay and silt are present to impede vertical movement. For example, in U.S. Geological Survey test well (C–11–24)23bcb (LCRP 10), which penetrated mostly permeable sand and gravel, the range in temperature from the water

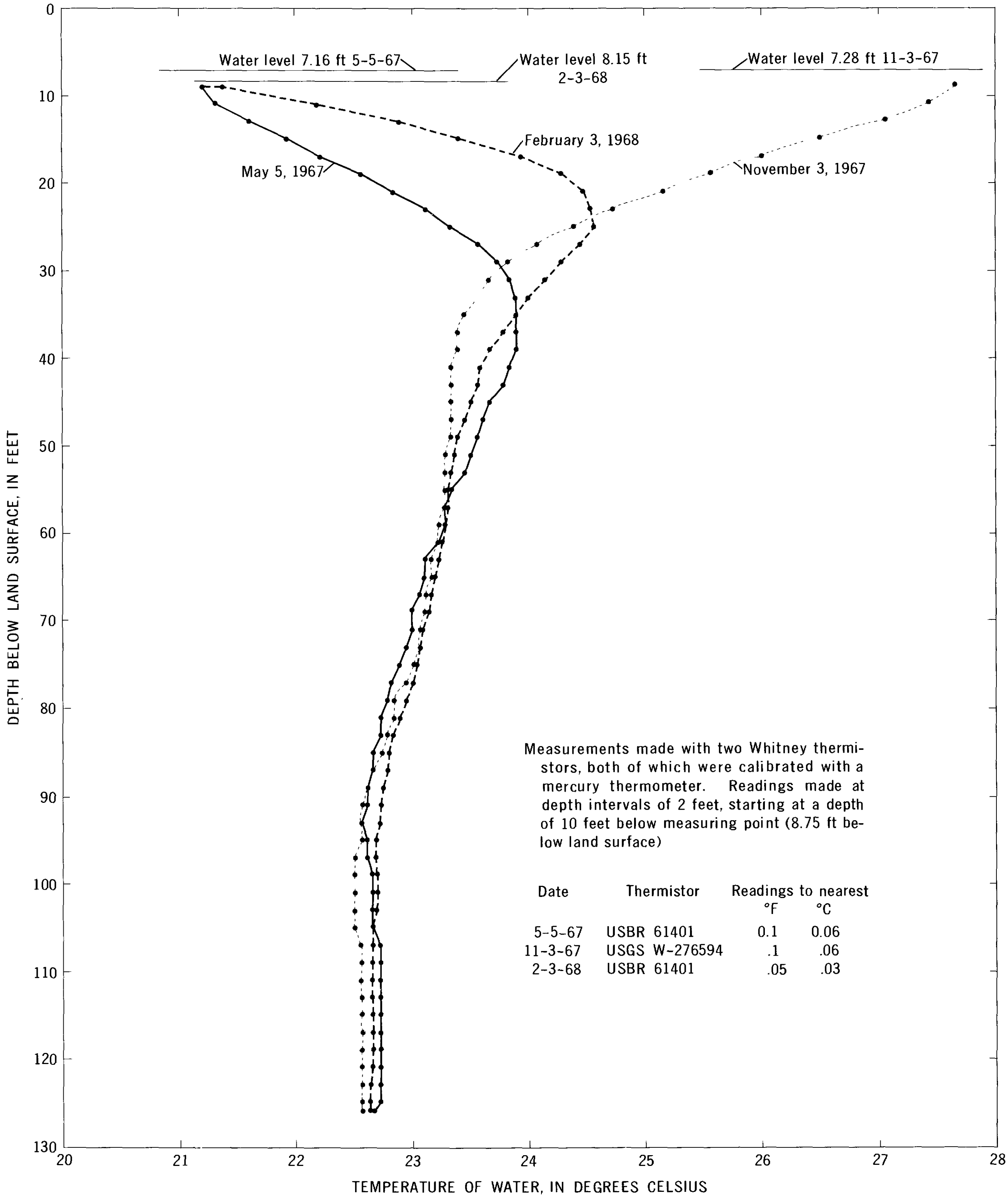


FIGURE 44.—Temperature profiles in well (C–9–24)11ccc for May and November 1956 and February 1968.

table at a depth of about 80 feet to the bottom of the well at a depth of more than 1,000 feet is no more than 0.3°C.

Reversed geothermal gradients occur seasonally within about 30 feet of the land surface, owing to summer warming of the shallow water. However,

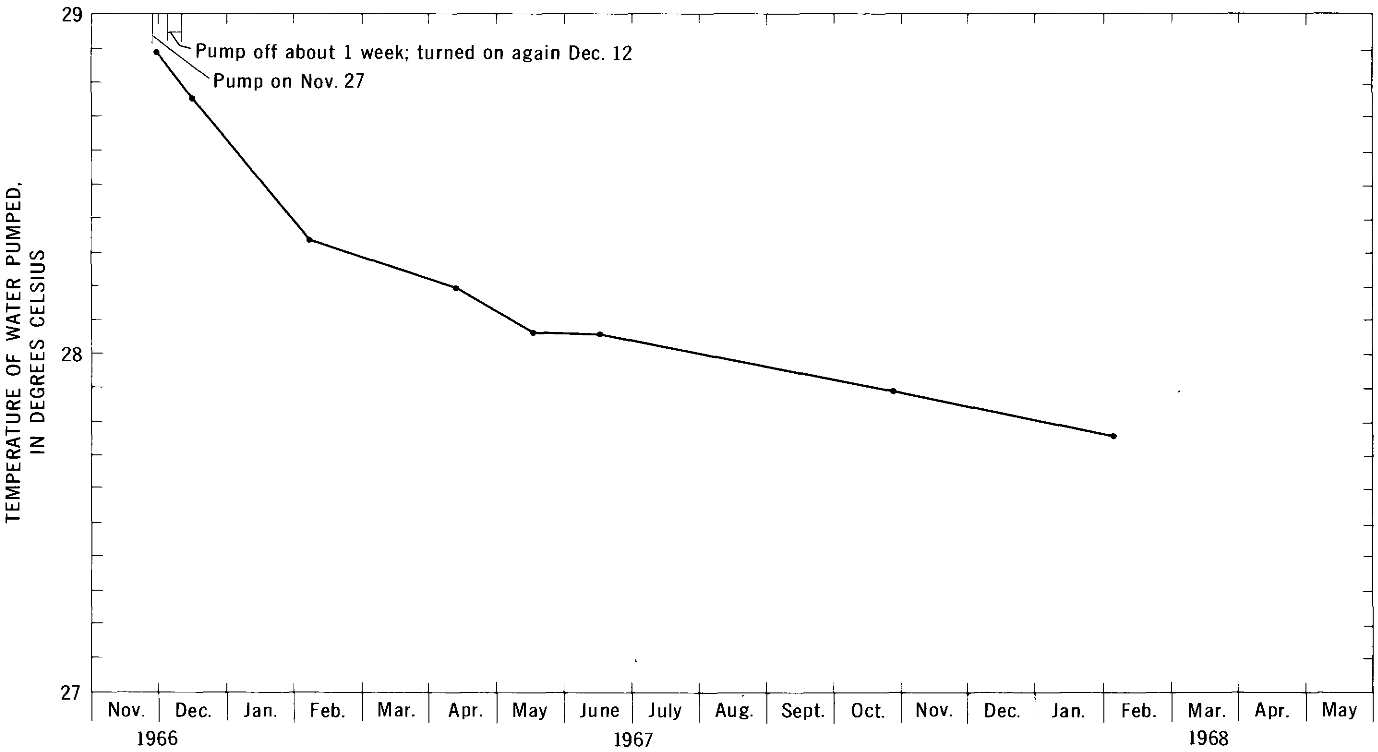


FIGURE 45.—Change in temperature of water pumped from well (C–9–23)20 bdc (USBR drainage well YV–13) from November 1966 to February 1968.

the reversed gradients locally extend to greater depths and persist throughout the year, as, for example, at well (C–9–24)11ccc cited earlier (fig. 44). These perennial reversed gradients indicate either that the deeper water has a cooler, more distant source than the shallower water, or that the ground at the well site is warmer on the average than that in most of the surrounding area. The latter situation commonly occurs where the well is in a bare, uncultivated, or paved area bordered by irrigated fields or orchards.

At many places, particularly in the irrigated part of Yuma Mesa and along the line of drainage wells in northeastern Yuma Valley, the geothermal gradients have been altered greatly from natural conditions, owing to vertical movement of ground water induced by heavy applications of irrigation water and by large-scale pumping from wells. Some of the observed conditions are described in the next section.

## AREAL VARIATIONS IN TEMPERATURE

The most useful and informative temperature data proved to be the areal variations in temperature of the water in the coarse-gravel zone (fig. 47). The zone is sufficiently deep so that seasonal fluctuations in temperature are negligible, yet shallow enough so that the temperature of the water would not be much different from the mean annual air temperature were it not affected by conduction or advection from various sources.

Temperatures representative of the coarse-gravel zone or, where that zone is missing, of materials at equivalent depths below the water table (about 100–150 ft) were measured in nearly 500 wells (appendix A). In roughly one-third of these wells—chiefly irrigation and drainage wells—the temperatures were measured at the discharge pipe with a mercury thermometer while the wells were pumping. In the rest of the wells the temperatures were measured with a thermistor or a maximum thermometer inside the casings at depths corresponding to the middle of the coarse-gravel zone. In some places, particularly on the "Upper Mesa" and "Fortuna Plain," temperatures at depths about 100–150 feet below the water table were estimated by extrapolation from water-table temperatures. Geothermal gradients observed in the nearest wells having such data were used. The configuration of the temperature lines is uncertain beneath most of the "Upper Mesa" because of the paucity of reliable data (fig. 47).

The coolest water in the coarse-gravel zone occurs beneath the river valleys. At most places in the valleys the temperature ranges from about 21°C to 23°C; a few areas underlain by somewhat warmer water are considered to be warm anomalies, as explained farther on. The usual temperatures are slightly higher than the mean annual air tempera-

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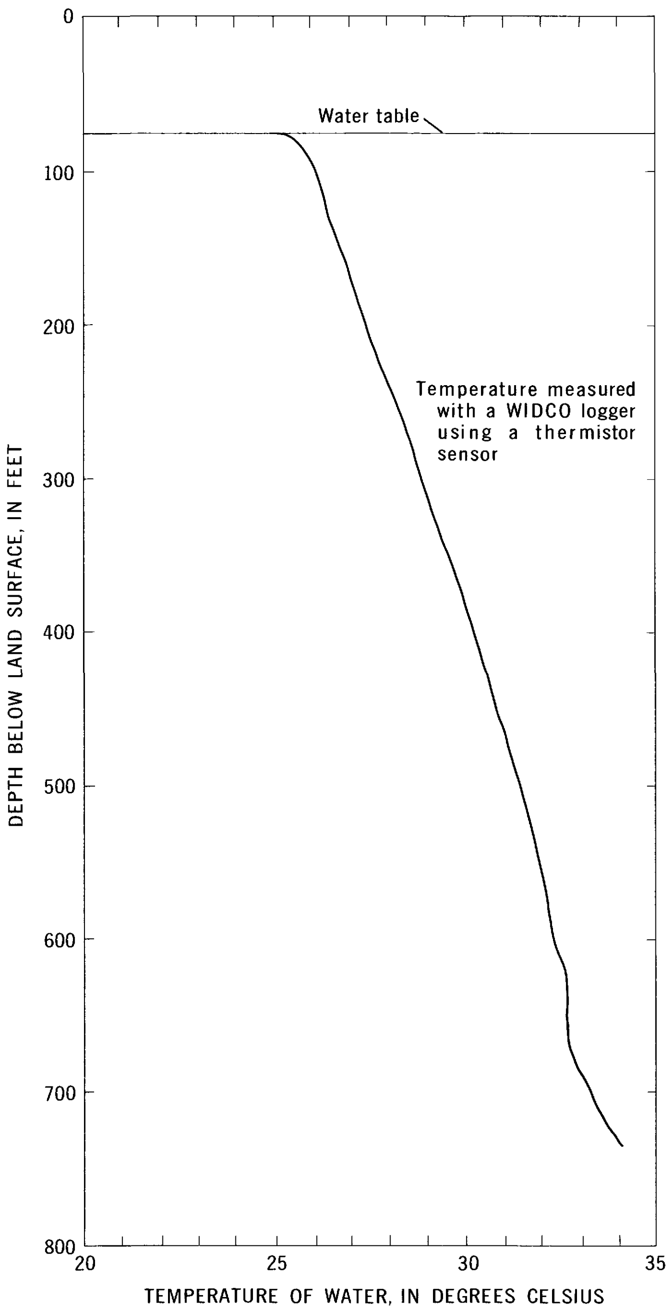


FIGURE 46.—Temperature profile in well (C–8–23)33cdd (LCRP 13) for March 12, 1963.

ture at the Yuma Valley weather station in northern Yuma Valley, which was 20.7°C for period 1906–53 (Sellers, 1960).

With certain exceptions, discussed later, the water in the coarse-gravel zone beneath Yuma Mesa is 2°–3°C warmer than that beneath the adjacent valleys. The higher temperatures beneath the mesa probably result from the greater average depth of the water table and the somewhat higher mean annual air temperature; the mean annual air temperature at Yuma (northwestern Yuma Mesa) for the period 1893–1957 was 22.4°C, as compared with 20.7°C for the Yuma Valley station for 1906–53 (Sellers, 1960). Beneath parts of Yuma Mesa, deep infiltration of irrigation water probably has cooled the water in the coarse-gravel zone to a temperature below what it was naturally. The close correspondence of the boundaries of the cooler water and the boundaries of the irrigated area at many places supports this inference. (Compare figs. 2 and 47).

In general, the warmest water in the Yuma area occurs beneath "Upper Mesa" and contiguous parts of "Fortuna Plain" and "Gila Mesa." The coarse-gravel zone is absent in most of those areas, but at equivalent depths below the water table the temperatures (which are largely extrapolated from temperatures at the water table and therefore somewhat uncertain) range from about 25°C along the northwest edge of "Upper Mesa" to more than 36°C at several places (fig. 47). In large part, these higher temperatures are a consequence of the fact that the water table is deeper beneath "Upper Mesa," "Fortuna Plain," and "Gila Mesa" than it is elsewhere in the Yuma area. The geothermal gradient in unsaturated material is generally greater than that in saturated material, so that depth to water has a pronounced effect on temperatures below the water table; the average geothermal gradient for dry materials beneath "Upper Mesa" is about 2.8°C per 100 feet.

After taking into account the effects of the variable depths of the water table and of recharge from irrigation, as described above, a number of warm anomalies can be delineated throughout the area (fig. 47). Most of these anomalies appear to be related to faults or fault zones such as the northwestward bulge of warm water beneath central Yuma Mesa and east-central Yuma Valley which is chiefly on the northeast side of the buried trace of the Algodones fault. Some anomalies may reflect hot zones in the pre-Tertiary crystalline rocks that are not related to faulting, but these possible sources of heat cannot be evaluated with the available data. Other anomalies related to faults or suspected faults are those west of the northern Gila Mountains, in north-central "Bard Valley," along the west edge of Yuma Mesa in Yuma, on Yuma Mesa about a mile west of the west edge of the "Upper Mesa," and on southern Yuma Mesa 1–3 miles north of the southerly international boundary. The warm water in these areas probably has resulted from upward movement from the wedge zone into the coarse-gravel zone induced by the partial damming effect of the faults. Where the anomaly is related to the

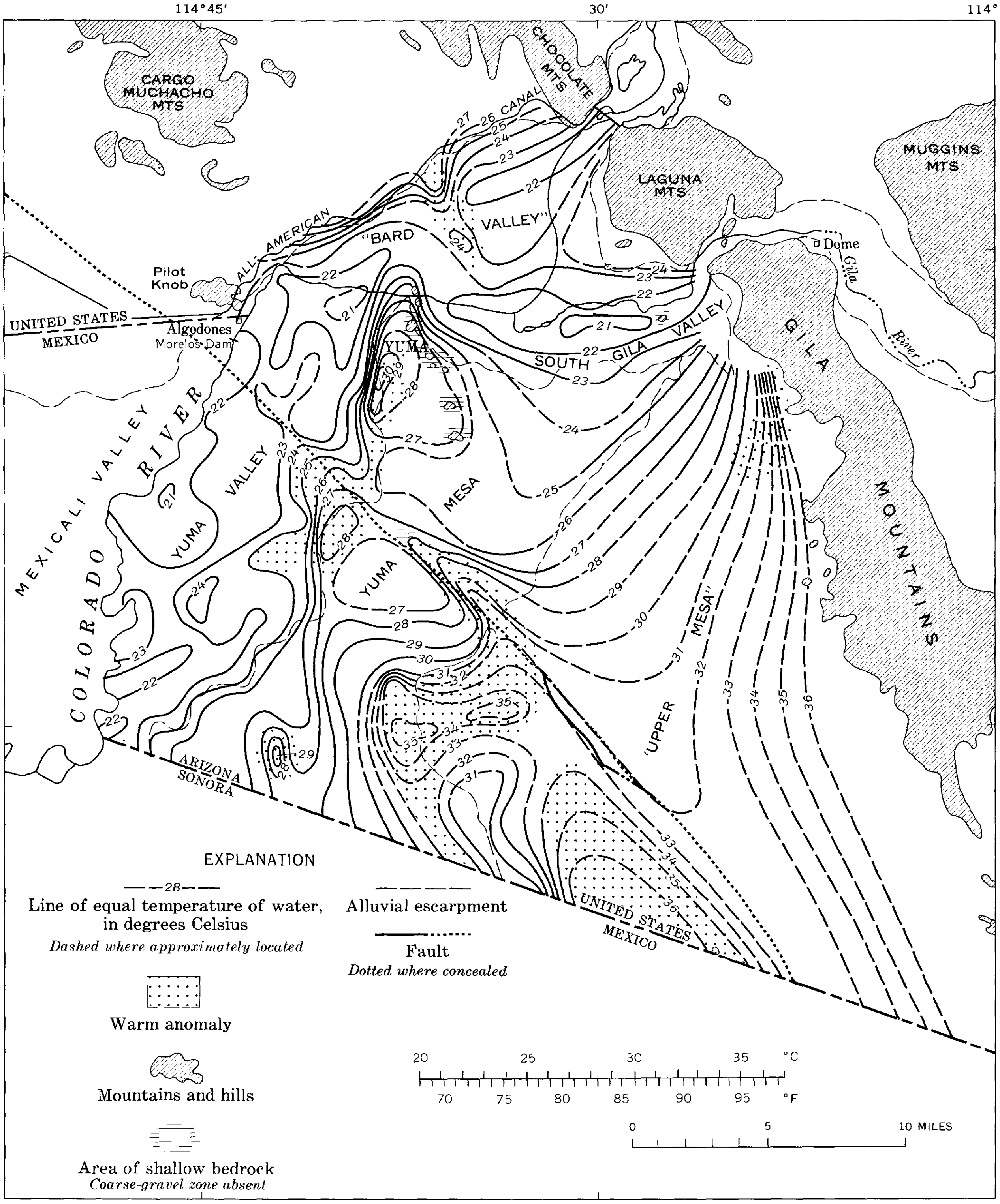


FIGURE 47.—Temperature of ground water in coarse-gravel zone or at equivalent depth below the water table, 1965–68.

Algodones fault, the temperature data indicate that the barrier effect of the fault extends farther northwest than can be demonstrated unequivocally from water-level and geologic data. However, the effect of the buried bedrock ridge may also account for the northwestern part of the anomaly.

Not all the warm anomalies are caused entirely or even partly by faults acting as ground-water barriers. Alluvium that is less transmissive than that in surrounding areas may account for the two anomalies in western "Upper Mesa," for the broad anomaly at the northwest corner of Yuma Mesa in Yuma, and possibly for the southwest-trending band of slightly warmer water in south-central Yuma Valley (fig. 47).

Another major anomaly is the elongate, somewhat irregular band of warm water that extends along the west margin of northern Yuma Mesa and the east margin of the adjacent Yuma Valley. Two thermal maxima occur within the band: a northern one in the southwest part of Yuma, where the maximum temperature exceeds 30°C and a southern one just south of the first major westward bend in the escarpment along the west edge of Yuma Mesa south of Yuma, where the maximum temperature is a little less than 29°C (fig. 47).

The higher temperatures in this band result from the upward movement of ground water from the wedge zone through the coarse-gravel zone and into the upper, fine-grained zone, from which it is discharged by evapotranspiration or by surface drains. This movement has taken place since irrigation began on Yuma Mesa and the associated ground-water mound began to form. However, the northern thermal maximum, in Yuma, probably results also from natural upward movement caused by a concealed fault barrier, as mentioned earlier.

Pumping of drainage wells along the east margin of Yuma Valley has accelerated the upward movement by providing additional discharge from the coarse-gravel zone with a consequent lowering of head in that zone, but the pumping has also induced downward leakage into the upper part of the coarse-gravel zone. The downward movement of relatively cool irrigation water from the upper, fine-grained zone has lowered the temperature in the coarse-gravel zone adjacent to the drainage wells, as illustrated by the record for well (C–9–23)20bdc (fig. 45) and by less-abundant data for some of the other wells.

### CHEMICAL QUALITY OF GROUND WATER

Chemical analyses of ground water in the Yuma area indicate marked differences from place to place in the percentage and concentration of the six ionic constituents that make up the bulk of the dissolved solids. (See appendix C; pl. 11). The chemical character of the ground water depends on (1) the chemical character of the source of recharge and (2) the chemical changes that have occurred since the water entered the ground. Separation of the effects of these two factors is ordinarily difficult. However, the interpretation of the second factor—the chemicall changes—is facilitated by the fact that the relatively shallow ground water beneath the irrigated areas is derived mainly from recent recharge from the Colorado River by way of diversions for irrigation. The following discussion considers the processes of chemical change that produce the types of ground water observed beneath the irrigated areas, starting with the Colorado River as the recent source of ground-water recharge.

#### CHEMICAL CHANGES IN GROUND WATER DERIVED FROM THE RECENT COLORADO RIVER

An appraisal of ground water beneath the irrigated areas as chemically altered recent Colorado River water requires consideration of the chemical processes capable of altering the river water to observed types of ground water, and also the establishment of criteria for recognition of the altered river water. In the approach used, recent Colorado River water is assumed to have been evaporated and subjected to specified chemical changes while it evaporated. Hypothetical chemical analyses computed from a 25-year weighted-average analysis of Colorado River water, and from two single-year weighted averages, then serve as examples that suggest how ground water represented by actual analyses might have been derived (table 15).

The assumption that the recent Colorado River (indicated by the chemical-quality records at Imperial Dam for 1941–65) is the source of ground-water recharge is most nearly valid for the relatively shallow ground water in the upper, fine-grained zone and the coarse-gravel zone beneath the irrigated areas of the valleys and Yuma Mesa. Deeper, older ground water beneath those areas and ground water outside the irrigated areas were derived from the Colorado River before regulation by upstream reservoirs and from the Gila River when it was still a live stream near Yuma. These sources of recharge may have differed substantially in chemical character from recent Colorado River water. The same chemical processes as those occurring in the younger ground water probably were operative in the older ground water, although the actual changes would have been different from those described below.

The chemical-change processes probably operative in ground water in the Yuma area include: (1) Concentration by evapotranspiration, (2) softening, (3) carbonate precipitation, (4) sulfate reduction, (5) hardening, (6) re-solution of precipitated salts, (7) oxidation of dissolved organic substances, and (8) mixing of waters of different chemical composition.

TABLE 15.—*Hypothetical analyses of ground water resulting from specified chemical changes in Colorado River water*

| No. | Description | Relative volume | Concentration factor | Calcium (Ca) | Magnesium (Mg) | Sodium plus potassium (Na+K) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Sum | Hardness Total | Hardness Noncarbonate | Specific conductance (micromhos at 25°C) | Percent sodium |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Milligrams per liter | | | | | | | | | | |
| | **Unchanged Colorado River water** | | | | | | | | | | | | | |
| 1 | [1]1941–65 | 1,000 | 1 | 94 | 28 | 110 | 165 | 309 | 93 | 730 | 350 | 214 | 1,120 | 40.6 |
| 2 | [1]1950 | 1,000 | 1 | 84 | 27 | 90 | 163 | 265 | 77 | 625 | 320 | 187 | 985 | 38.0 |
| 3 | [1]1956 | 1,000 | 1 | 106 | 34 | 142 | 173 | 375 | 128 | 872 | 404 | 262 | 1,340 | 43.4 |
| | **Concentrated by evaporation, no other change** | | | | | | | | | | | | | |
| 4 | 1941–65 | 667 | 1.5 | 141 | 42 | 165 | 248 | 464 | 140 | 1,090 | 525 | 321 | 1,680 | 40.6 |
| 5 | 1941–65 | 500 | 2.0 | 188 | 56 | 220 | 330 | 618 | 186 | 1,460 | 700 | 428 | 2,240 | 40.6 |
| 6 | 1941–65 | 333 | 3.0 | 282 | 84 | 330 | 495 | 927 | 279 | 2,190 | 1,050 | 642 | 3,360 | 40.6 |
| 7 | 1941–65 | 250 | 4.0 | 376 | 112 | 440 | 660 | 1,236 | 372 | 2,920 | 1,400 | 856 | 4,480 | 40.6 |
| 8 | 1950 | 250 | 4.0 | 336 | 108 | 360 | 652 | 1,060 | 308 | 2,500 | 1,280 | 748 | 3,940 | 38.0 |
| 9 | 1956 | 250 | 4.0 | 424 | 136 | 568 | 692 | 1,500 | 512 | 3,490 | 1,616 | 1,048 | 5,360 | 43.4 |
| | **Concentration by evaporation with 50 percent softening** | | | | | | | | | | | | | |
| 10 | 1941–65 | 667 | 1.5 | 117 | 35 | 205 | 248 | 464 | 140 | 1,080 | 437 | 234 | 1,680 | 50.5 |
| 11 | 1941–65 | 500 | 2.0 | 141 | 42 | 300 | 330 | 618 | 186 | 1,450 | 524 | 254 | 2,240 | 55.4 |
| 12 | 1941–65 | 333 | 3.0 | 188 | 56 | 491 | 495 | 927 | 279 | 2,190 | 699 | 292 | 3,360 | 60.4 |
| 13 | 1941–65 | 250 | 4.0 | 234 | 70 | 681 | 660 | 1,236 | 372 | 2,920 | 873 | 332 | 4,480 | 62.9 |
| 14 | 1950 | 250 | 4.0 | 210 | 68 | 583 | 652 | 1,060 | 308 | 2,560 | 803 | 269 | 3,940 | 61.2 |
| 15 | 1956 | 250 | 4.0 | 264 | 85 | 846 | 692 | 1,500 | 512 | 3,550 | 1,010 | 442 | 5,430 | 64.6 |
| | **Concentration by evaporation, precipitation of insoluble carbonates at 380 mg/l $HCO_3$** | | | | | | | | | | | | | |
| 16 | 1941–65 | 333 | 3 | 255 | 76 | 330 | 380 | 927 | 279 | 2,060 | 951 | 640 | 3,180 | 43.0 |
| 17 | 1941–65 | 250 | 4 | 313 | 93 | 440 | 380 | 1,236 | 372 | 2,640 | 1,160 | 853 | 4,040 | 45.1 |
| 18 | 1941–65 | 200 | 5 | 370 | 110 | 550 | 380 | 1,545 | 465 | 3,230 | 1,380 | 1,070 | 4,900 | 46.5 |
| 19 | 1950 | 200 | 5 | 328 | 106 | 450 | 380 | 1,325 | 385 | 2,780 | 1,250 | 942 | 4,250 | 43.8 |
| 20 | 1956 | 200 | 5 | 424 | 136 | 710 | 380 | 1,875 | 640 | 3,980 | 1,620 | 1,310 | 6,020 | 48.8 |
| | **Concentration by evaporation, bicarbonate ceiling 380 mg/l, 25 percent sulfate reduction** | | | | | | | | | | | | | |
| 21 | 1941–65 | 667 | 1.5 | 141 | 42 | 165 | 339 | 393 | 140 | 1,050 | 525 | 248 | 1,680 | 40.6 |
| 22 | 1941–65 | 500 | 2.0 | 155 | 46 | 220 | 380 | 464 | 186 | 1,260 | 576 | 266 | 2,010 | 45.3 |
| 23 | 1941–65 | 333 | 3.0 | 160 | 48 | 330 | 380 | 585 | 279 | 1,590 | 596 | 284 | 2,500 | 54.7 |
| 24 | 1941–65 | 250 | 4.0 | 162 | 48 | 440 | 380 | 696 | 372 | 1,910 | 603 | 292 | 2,970 | 61.3 |
| 25 | 1941–65 | 200 | 5.0 | 161 | 48 | 550 | 380 | 795 | 465 | 2,210 | 598 | 286 | 3,420 | 66.7 |
| 26 | 1941–65 | 125 | 8.0 | 142 | 42 | 880 | 380 | 1,040 | 744 | 3,040 | 528 | 216 | 4,650 | 78.4 |
| 27 | 1941–65 | 100 | 10.0 | 126 | 37 | 1,100 | 380 | 1,190 | 930 | 3,570 | 468 | 157 | 5,450 | 83.6 |
| 28 | 1950 | 100 | 10.0 | 134 | 43 | 900 | 380 | 1,030 | 770 | 3,070 | 510 | 199 | 4,700 | 79.3 |
| 29 | 1956 | 100 | 10.0 | 135 | 43 | 1,420 | 380 | 1,430 | 1,280 | 4,500 | 515 | 204 | 6,860 | 85.7 |
| | **As above but 33-1/3 percent sulfate reduction** | | | | | | | | | | | | | |
| 30 | 1941–65 | 667 | 1.5 | 141 | 42 | 165 | 371 | 367 | 140 | 1,040 | 524 | 220 | 1,680 | 40.6 |
| 31 | 1941–65 | 500 | 2.0 | 141 | 42 | 220 | 380 | 412 | 186 | 1,190 | 524 | 212 | 1,910 | 47.7 |
| 32 | 1941–65 | 333 | 3.0 | 133 | 40 | 330 | 380 | 489 | 279 | 1,460 | 496 | 184 | 2,310 | 59.2 |
| 33 | 1941–65 | 250 | 4.0 | 121 | 36 | 440 | 380 | 548 | 372 | 1,710 | 443 | 138 | 2,680 | 68.1 |
| 34 | 1941–65 | 200 | 5.0 | 106 | 32 | 550 | 380 | 600 | 465 | 1,940 | 395 | 84 | 3,030 | 75.2 |
| 35 | 1941–65 | 125 | 8.0 | 57 | 17 | 880 | 380 | 736 | 744 | 2,620 | 212 | 0 | 4,040 | 90.0 |
| 36 | 1941–65 | 100 | 10.0 | 17 | 5 | 1,100 | 380 | 800 | 930 | 3,040 | 62 | 0 | 4,680 | 97.5 |
| 37 | 1950 | 100 | 10.0 | 48 | 16 | 900 | 380 | 720 | 770 | 2,640 | 188 | 0 | 4,090 | 91.2 |
| 38 | 1956 | 100 | 10.0 | 18 | 6 | 1,420 | 380 | 1,000 | 1,280 | 3,910 | 68 | 0 | 6,010 | 97.8 |
| | **As above but 40 percent sulfate reduction** | | | | | | | | | | | | | |
| 39 | 1941–65 | 667 | 1.5 | 137 | 41 | 165 | 380 | 346 | 140 | 1,020 | 510 | 198 | 1,660 | 41.3 |
| 40 | 1941–65 | 500 | 2.0 | 129 | 39 | 220 | 380 | 371 | 186 | 1,140 | 482 | 170 | 1,830 | 49.8 |
| 41 | 1941–65 | 333 | 3.0 | 113 | 34 | 330 | 380 | 416 | 279 | 1,360 | 420 | 108 | 2,170 | 63.1 |
| 42 | 1941–65 | 250 | 4.0 | 92 | 27 | 440 | 380 | 445 | 372 | 1,570 | 342 | 30 | 2,470 | 73.9 |
| 43 | 1941–65 | 200 | 5.0 | 70 | 21 | 550 | 380 | 470 | 465 | 1,770 | 270 | 0 | 2,770 | 82.1 |
| 44 | 1941–65 | 125 | 8.0 | 0 | 0 | 880 | 380 | 533 | 744 | 2,350 | 5 | 0 | 3,650 | 100.0 |
| 45 | 1941–65 | 100 | 10.0 | 0 | 0 | 1,100 | 609 | 560 | 930 | 2,900 | 0 | 0 | 4,560 | 100.0 |
| 46 | 1950 | 200 | 5.0 | 78 | 25 | 450 | 380 | 405 | 385 | 1,530 | 296 | 0 | 2,430 | 76.8 |
| 47 | 1950 | 125 | 8.0 | 24 | 8 | 720 | 380 | 458 | 616 | 2,020 | 90 | 0 | 3,160 | 94.5 |
| 48 | 1950 | 100 | 10.0 | 0 | 0 | 900 | 442 | 490 | 770 | 2,380 | 0 | 0 | 3,730 | 100.0 |
| 49 | 1956 | 200 | 5.0 | 71 | 23 | 710 | 380 | 580 | 640 | 2,210 | 273 | 0 | 3,460 | 85.0 |
| 50 | 1956 | 125 | 8.0 | 0 | 0 | 1,136 | 431 | 648 | 1,024 | 3,020 | 0 | 0 | 4.710 | 100.0 |
| 51 | 1956 | 100 | 10.0 | 0 | 0 | 1,420 | 648 | 690 | 1,280 | 3,740 | 0 | 0 | 5,880 | 100.0 |
| | **Concentration by evaporation, bicarbonate ceiling 380 mg/l, 40 percent sulfate reduction, hardening equivalent to sulfate equivalents increase resulting from evaporation** | | | | | | | | | | | | | |
| 52 | 1941–65 | 667 | 1.5 | 147 | 44 | 147 | 380 | 346 | 140 | 1,010 | 548 | 237 | 1,660 | 36.9 |
| 53 | 1941–65 | 500 | 2.0 | 147 | 44 | 190 | 380 | 371 | 186 | 1,130 | 546 | 234 | 1,830 | 43.1 |
| 54 | 1941–65 | 333 | 3.0 | 142 | 42 | 279 | 380 | 416 | 279 | 1,350 | 530 | 219 | 2,170 | 53.4 |
| 55 | 1941–65 | 250 | 4.0 | 130 | 39 | 375 | 380 | 445 | 372 | 1,550 | 484 | 172 | 2,470 | 62.8 |
| 56 | 1941–65 | 200 | 5.0 | 115 | 34 | 473 | 380 | 470 | 465 | 1,750 | 428 | 116 | 2,770 | 70.6 |
| 57 | 1941–65 | 125 | 8.0 | 63 | 19 | 773 | 380 | 533 | 744 | 2,320 | 233 | 0 | 3,650 | 87.8 |
| 58 | 1941–65 | 100 | 10.0 | 20 | 6 | 980 | 380 | 560 | 930 | 2,690 | 74 | 0 | 4,200 | 96.7 |
| 59 | 1950 | 200 | 5.0 | 116 | 37 | 383 | 380 | 405 | 385 | 1,520 | 442 | 130 | 2,430 | 65.3 |
| 60 | 1950 | 125 | 8.0 | 76 | 25 | 628 | 380 | 458 | 616 | 1,990 | 292 | 0 | 3,160 | 82.4 |
| 61 | 1950 | 100 | 10.0 | 61 | 20 | 769 | 380 | 490 | 770 | 2,300 | 234 | 0 | 3,630 | 87.7 |
| 62 | 1956 | 200 | 5.0 | 127 | 41 | 612 | 380 | 580 | 640 | 2,190 | 486 | 174 | 3,460 | 73.3 |
| 63 | 1956 | 125 | 8.0 | 63 | 20 | 1,006 | 380 | 648 | 1,024 | 2,950 | 242 | 0 | 4,630 | 90.0 |
| 64 | 1956 | 100 | 10.0 | 19 | 6 | 1,270 | 380 | 690 | 1,280 | 3,460 | 73 | 0 | 5,400 | 97.4 |

TABLE 15.—*Hypothetical analyses of ground water resulting from specified chemical changes in Colorado River water*—Continued

| No. | Description | Relative volume | Concentration factor | Calcium (Ca) | Magnesium (Mg) | Sodium plus potassium (Na+K) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Sum | Hardness: Total | Hardness: Noncarbonate | Specific conductance (micromhos at 25°C) | Percent sodium |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Milligrams per liter | | | | | | | | | | |
| **Concentration by vaporation, bicarbonate ceiling 380 mg/l, 40 percent sulfate reduction, hardening until sodium equivalent concentration is reduced to chloride equivalent concentration** | | | | | | | | | | | | | | |
| 65 | 1941–65 | 667 | 1.5 | 180 | 54 | 91 | 380 | 346 | 140 | 1,000 | 672 | 360 | 1,660 | 22.8 |
| 66 | 1941–65 | 500 | 2.0 | 187 | 56 | 121 | 380 | 371 | 186 | 1,110 | 698 | 386 | 1,830 | 27.3 |
| 67 | 1941–65 | 333 | 3.0 | 200 | 60 | 181 | 380 | 416 | 279 | 1,330 | 744 | 432 | 2,170 | 34.6 |
| 68 | 1941–65 | 250 | 4.0 | 208 | 62 | 241 | 380 | 445 | 372 | 1,520 | 774 | 463 | 2,470 | 40.4 |
| 69 | 1941–65 | 200 | 5.0 | 215 | 64 | 302 | 380 | 470 | 465 | 1,710 | 800 | 489 | 2,770 | 45.0 |
| 70 | 1941–65 | 125 | 8.0 | 233 | 70 | 483 | 380 | 533 | 744 | 2,250 | 869 | 558 | 3,650 | 54.8 |
| 71 | 1941–65 | 100 | 10.0 | 240 | 72 | 603 | 380 | 560 | 930 | 2,600 | 894 | 582 | 4,200 | 59.5 |
| 72 | 1950 | 200 | 5.0 | 192 | 62 | 250 | 380 | 405 | 385 | 1,480 | 723 | 421 | 2,430 | 42.6 |
| 73 | 1950 | 125 | 8.0 | 206 | 66 | 400 | 380 | 458 | 616 | 1,940 | 788 | 476 | 3,160 | 52.4 |
| 74 | 1950 | 100 | 10.0 | 215 | 69 | 499 | 380 | 490 | 770 | 2,230 | 821 | 510 | 3,630 | 56.9 |
| 75 | 1956 | 200 | 5.0 | 239 | 77 | 415 | 880 | 580 | 640 | 2,140 | 914 | 603 | 3,460 | 49.7 |
| 76 | 1956 | 125 | 8.0 | 258 | 83 | 664 | 380 | 648 | 1,024 | 2,870 | 986 | 674 | 4,630 | 59.4 |
| 77 | 1956 | 100 | 10.0 | 269 | 87 | 830 | 380 | 690 | 1,280 | 3,350 | 1,030 | 718 | 5,400 | 63.9 |

[1] Weighted average.

The last three processes are not readily demonstrated from analytical evidence and are not readily demonstrated from analytical evidence and are not considered further here.

Several combinations of the first five processes, carried out to varying degrees, are listed in table 15, beginning with the weighted-average chemical analysis of the Colorado River at Imperial Dam for the period 1941–65. In addition, the effects of moderate annual variations in the chemical character of the river water are shown by listing the calculated analyses of substantially evaporated ground water derived from the weighted-average river water for 1950, when the concentration of dissolved solids was low, and the analyses for 1956, when the dissolved-solids concentration of the river was high.

Several series of hypothetical chemical analyses are given as illustrations of specified chemical processes, assuming that each process has operated continuously, and that the ground water it represents was sampled at specified evaporative volume reductions. Generally each series is ended when the specified chemical process results in hypothetical analyses with one or more ionic concentrations greater or less than those commonly observed in the many actual analyses of ground water from the irrigated areas. A few series are carried beyond these end points to illustrate particular hypothetical analyses.

### CONCENTRATION BY EVAPOTRANSPIRATION

Evaporation is loss of water to the atmosphere across an air-water interface. Transpiration is loss of water from plants by permeation through a cell membrane. In both processes (commonly lumped together as evapotranspiration) a more concentrated residual solution remains. Because of the prevailing high temperatures and low humidity and the presence of phreatophytes in the river valleys of the Yuma area, probably very little water infiltrates from the Colorado River without considerable concentration by evapotranspiration. Such concentration is indicated wherever all constituents in a well water are nearly the same multiple of river-water concentrations. If concentration by evapotranspiration is the only chemical change occurring, dissolved ionic concentrations increase by the same multiple, but the percent sodium, which depends on the ratio of sodium concentration to total cation concentration, both expressed in equivalents, does not increase. Thus, approximately equally increased ionic concentrations in ground water compared to concentrations of Colorado River water, and unchanged or nearly unchanged sodium percentage, are indicative of evapotranspirative change.

Bicarbonate concentrations greater than 500 mg/1 are extremely rare in Yuma area ground water and few analyses show bicarbonate concentrations as great as 450 mg/l. These limits probably indicate the level at which calcium carbonate precipitation begins. Recent Colorado River water has contained from 150 to about 175 mg/l bicarbonate, which suggests that evapotranspiration by itself seldom accounts for more than a threefold increase in ground-water concentrations as compared to river-water concentrations. In order to allow for all possible strictly evapotranspirative effects and not go beyond probable natural-process limits, the hypothetical analyses were computed for as much as a fourfold concentration by evapotranspiration but no further.

### SOFTENING

Softening, the replacement of the hardness-causing constituents calcium and magnesium by a chemically equivalent amount of sodium, commonly occurs wherever hard water, such as Colorado River water, seeps through beds containing a large number of clay-mineral particles. Softening is a particle-surface reaction between ions chemically attached to the clay-mineral particles and the ions dissolved in the water. Although it can continue so long as dissolved calcium and magnesium ions in the water are available for replacement, softening rarely removes all these constituents from the water. In the calculated analyses, softening is assumed to have resulted in replacement of half the increases in calcium and magnesium resulting from a 50 percent evaporation. However, softening may occur where there is little or no evaporation.

Softening and carbonate precipitation—the next change considered—both result in reduction in calcium and magnesium concentrations in water, but they are almost mutually exclusive and probably cannot go on simultaneously. They can be distinguished by the fact that carbonate precipitation results in decreases in calcium, magnesium, and bicarbonate, whereas softening results in decreases in calcium and magnesium but not of bicarbonate.

Softening is always accompanied by an increase in percent sodium. Because the equivalent weight of sodium is somewhat greater than that of calcium and substantially greater than that of magnesium, there is usually a somewhat greater increase in dissolved-solids concentration in water which is both concentrated by evaporation and softened than in water which is merely concentrated by evaporation.

### CARBONATE PRECIPITATION

Water containing appreciable quantities of bicarbonate and either of the alkaline earth ions calcium or magnesium precipitates the corresponding alkaline earth carbonate when sufficiently evaporated. Water containing both alkaline earths, such as Colorado River water, can precipitate mixed salts. The carbonate precipitation is indicated in pipes and boilers by the formation of scale. Carbonate precipitation is indicated wherever decreases in calcium and magnesium concentrations, in equivalents, are equalled by decreases in bicarbonates, in equivalents. However, because of temperature, pressure, and combination effects caused by other dissolved ions, the actual bicarbonate-concentration level at which insoluble carbonate precipitation begins is not readily predictable.

Analyses from frequently sampled wells suggest that individual ceilings on bicarbonate concentration do exist, depending in some manner on well environment, and that the concentration levels at which calcium and magnesism carbonate loss becomes an important control on dissolved-solids concentration may range from less than 200 mg/l to more than 450 mg/l. But after precipitation begins, the different bicarbonate-ceiling levels apparently have little effect on the general pattern of chemical change occurring with evaporation. Therefore, although other ceilings were considered and carried through the evaporation sequence, model analyses are given in table 15 only for the arbitrarily selected bicarbonate ceiling of 380 mg/l.

Precipitation of insoluble carbonates with or without concentration by evaporation is best indicated by an increase in percent sodium because, as calcium and magnesium are lost by precipitation and sodium is not, the relative amount of sodium increases. For the same reason, the ratio of chloride to bicarbonate increases.

Softening (described in the previous section) also results in an increase in percent sodium but not in an increase in the ratio of chloride to bicarbonate. Also, as the loss of dissolved solids caused by precipitation of insoluble carbonates is often considerable, and as there is always a small increase in dissolved-solids content resulting from softening, the two processes can ordinarily be separated by inspection of the chemical analyses.

### SULFATE REDUCTION

Most analyses of ground water from the irrigated areas indicated lower ratios of sulfate to chloride than those characteristic of recent Colorado River water. High-sulfate water is rare; even the analyses representing the greatest concentration by evapotranspiration do not indicate sulfate concentrations nearly high enough for precipitation of calcium sulfate to occur. Also, although hydrogen sulfide was not determined in the chemical analyses, hydrogen sulfide odor was reported when many wells were pumped. For these reasons, sulfate reduction is probably a major process occurring in Yuma area ground water.

Sulfate reduction is an incompletely understood process, which probably occurs in several ways under different conditions. Some may occur wherever organic matter is in long-continued anaerobic contact with water containing sulfate. The process is more likely associated with the natural metabolic processes of a widely distributed group of sulfate-reducing bacteria. These bacteria derive energy from oxidation of organic compounds and in the process obtain oxygen from the sulfate ions in water. Sulfate reduction by the bacteria probably involves a series of steps in which polysaccharides and other complex organic compounds are depolymerized, hydrolized, and oxidized simultaneously with the reduction of sulfate ion to sulfide ion or hydrogen sulfide.

Starting with cellulose, the organic substance (polysaccharide) making up most of the cell walls of plants, the complete process can be represented by the following steps:

1. Depolymerization of the cellulose to the monomer (sugar):
   $$(C_6H_{10}O)_x \rightarrow X \cdot C_6H_{10}O_5$$
2. Hydrolysis of the monomer to methane and carbon dioxide:
   $$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$$
3. Reduction of sulfate ion to give bisulfide ion or hydrogen sulfide:
   (a) $SO_4 + CH_4 \rightarrow HS + HCO_3 + H_2O$
   (b) $SO_4 + 2CH_4 \rightarrow H_2S + CO_3 + H_2O$

Other reactions have been written in which hydrogen is an intermediate decomposition product which reduces the sulfate.

An important point in considering sulfate reduction is that for each chemical equivalent of sulfate ion reduced, one chemical equivalent of carbonate or bicarbonate is formed. These newly formed ions must be allowed for in constructing model analyses of reduced waters. Generally the bicarbonate concentration is controlled as explained previously.

Although sulfate reduction undoubtedly takes place, its extent is variable and uncertain. Hypothetical analyses resembling a considerable number of Yuma area ground-water analyses are produced by imposing sulfate reduction at three rates in which 25 percent, 33⅓ percent, and 40 percent of the sulfate disappear each time the river water is evaporated by one half, with the reduction process being continued until the original volume is reduced by nine-tenths. Some actual analyses indicate even greater sulfate reduction. Thus, some show chloride concentrations similar to those in recent river water analyses but show sulfate concentrations much less than those in the river water. Other analyses indicate chloride concentrations substantially greater than those in recent river water and sulfate concentrations somewhat less than those of the river water. Although either of these water types might be explained by imposing large sulfate reduction rates on recently infiltrated river water, an environment that could produce rapid reduction on the large amounts of water pumped by some wells does not seem very likely. Thus it appears that the low-sulfate water may have been produced by slow sulfate reduction acting over a long period and may not be related to recent river water.

By comparing the sulfate and chloride concentrations in the Yuma area ground water with contrations that would have occurred if the original water was average Colorado River water, the apparent sulfate reduction in the ground water can be described as follows:

Slight: Sulfate reduction somewhat less than that shown by the 25-percent model analysis series.

Moderate: Sulfate reduction nearly the same as that shown by the 25-percent model analysis series.

Considerable: Sulfate reduction nearly the same as that shown by the 33-percent model-analysis series.

Substantial: Sulfate reduction nearly the same as that shown by the 40-percent model-analysis series.

High: Apparent sulfate reduction considerably more than 50 percent as indicated by sulfate concentrations less than 300 mg/l but greater than 100 mg/l.

Very high: Sulfate concentrations less than 100 mg/l with chloride concentrations equal to or greater than usual Colorado River concentrations.

The rate of sulfate reduction apparently is not often much less than 25 percent, because reduction at lesser rates would result in the presence of more sulfate relative to chloride than is indicated by any of the analyses of more concentrated ground water. A 50-percent reduction rate would result in a sulfate level unchanged as chloride increases during evaporation. A reduction rate greater than 50 percent would result in decreased sulfate concentrations as chloride concentrations increase.

In computing hypothetical analyses produced by sulfate reduction the calcium and magnesium concentrations are also lowered as the sulfate is reduced in amounts sufficient to maintain cation-anion balance, with the bicarbonate concentration maintained at 380 mg/l. Comparison of hypothetical analyses so produced with actual Yuma area ground-water analyses indicates many close resemblances up to about a fivefold evaporative concentration. Beyond that concentration the quantities of dissolved calcium and magnesium remaining in the water begin to be so lowered that the model analyses become softer than most Yuma area ground water. This difficulty disappears if hardening, explained in the next section, is also assumed.

### HARDENING

Hardening, the reverse of softening, is a base-exchange process in which sodium ions dissolved in water are replaced by calcium and magnesium ions attached to clay-mineral particles present in water-bearing materials. Montmorillonite, which constitutes more than half the clay minerals in two samples of older alluvium (p. H52), is noted for having the highest cation-exchange capacity of any of the common clay minerals (Robinson, 1962). Hardening, like softening, probably depends on clay-mineral particle saturation. For this reason the hardening reaction is likely to go to different completeness in different aquifer locations. Hardening is a hypothesis helpful in accounting for the presence of moderately high concentrations of calcium and magnesium in ground water in which sulfate reduction appears to have been considerable. Hardening is strongly suggested by so-called calcium or magnesium chloride water.

Two rates of hardening are considered in the series of hypothetical analyses (table 15). Sulfate reduction is assumed to be concurrent with evaporation, but the sulfate concentration increases if the reduction rate is less than 50 percent. In the first series of analyses computed so as to allow for hardening, the hardening is made chemically equivalent to the increase in sulfate concentration. The second series of analyses is calculated so that hardening occurs until sodium concentration is reduced to equivalence with chloride concentration. Both series of hypothetical analyses simulate some actual ground-water analyses, but the second series reproduces more actual analyses than the first.

#### SUMMARY OF HYPOTHETICAL ANALYSES

To summarize, the table of hypothetical analyses represents the quality of the ground water that would be obtained from wells assuming that the water infiltrated from the recent Colorado River and was evaporated to the degree indicated and subjected to the particular chemical processes described. Limits on concentration or process rates used in preparing the table were chosen for descriptive purposes and are not meant to imply that other limits or rates do not occur. Because of chemical considerations, some of the processes are terminated after less concentration by evaporation than others. Thus the evaporation process and the combination of evaporation and softening are terminated at the first step and produce bicarbonate concentrations above 500 mg/l, because that level represents about the maximum observed in Yuma area ground water.

To facilitate visual comparison of the model analyses with analyses indicated in other figures in the report, selected chemical analyses from table 15 are shown diagrammatically in figure 48.

The diagrams in figure 48 are arranged so that those in each row represent Colorado River water which has been subjected to uniform chemical processes and those in each column have been evaporated to the same extent. Consequently, comparing the diagrams by rows or columns emphasizes different environmental effects. Generally speaking the diagrams are not greatly different in shape up to a twofold concentration increase, regardless of the chemical processes assumed. Thereafter, the various combinations of chemical processes produce more and more individualistic chemical patterns as concentration increases.

A general conclusion is that a dissolved solids value (or specific conductance) by itself is not a very good guide as to how much the original volume may have been reduced by evaporation. For example, diagram 17 represents a reduction to one-fourth the original volume with 2,640 mg/l dissolved solids. In contrast, diagram 59 represents a volume reduction to one-tenth the original volume and 2,600 mg/l dissolved solids.

#### SUBDIVISION OF YUMA AREA FOR DESCRIPTION OF QUALITY OF WATER

Almost all information on chemical quality of ground water in the Yuma area is limited to the central part of the area, which includes the river valleys, Yuma Mesa, and the northern parts of "Upper Mesa" and "Gila Mesa." In order to facilitate detailed description of differences in water quality, this central part is divided into four subareas which are further subdivided into a total of 19 sectors (fig. 49). In the descriptions of the sectors, references are made to place names not shown in figure 49; these places are shown on the standard U.S. Geological Survey 7½-minute series topographic maps of the Yuma area. The four subareas correspond in a general way to some of the subareas described in the geomorphology section of the report (p. H18) and together constitute the part of the Yuma area investigated most intensively. A brief generalized description of the chemical characteristics of the ground water in each of the water-bearing units is given in the section on occurrence of ground water. The present discussion is more detailed and is concerned chiefly with water-quality differences in the coarse-gravel zone and, to a lesser degree, in the upper, fine-grained zone and wedge zone.

Selected chemical analyses of ground-water samples collected from wells in the Yuma area are given in appendix C, arranged according to the four subareas and 19 sectors. In the discussion below, comparisons are made between the ground water in the various sectors and present Colorado River water according to the hypothetical processes described earlier.

#### GILA VALLEY SUBAREA

The Gila Valley subarea consists of all South Gila Valley and the east leg of the L-shaped North Gila Valley (fig. 49). Because of the proximity of the relatively saline Gila River and Wellton-Mohawk conveyance channel, this subarea is the part of the Yuma area most likely to have the salinity of the

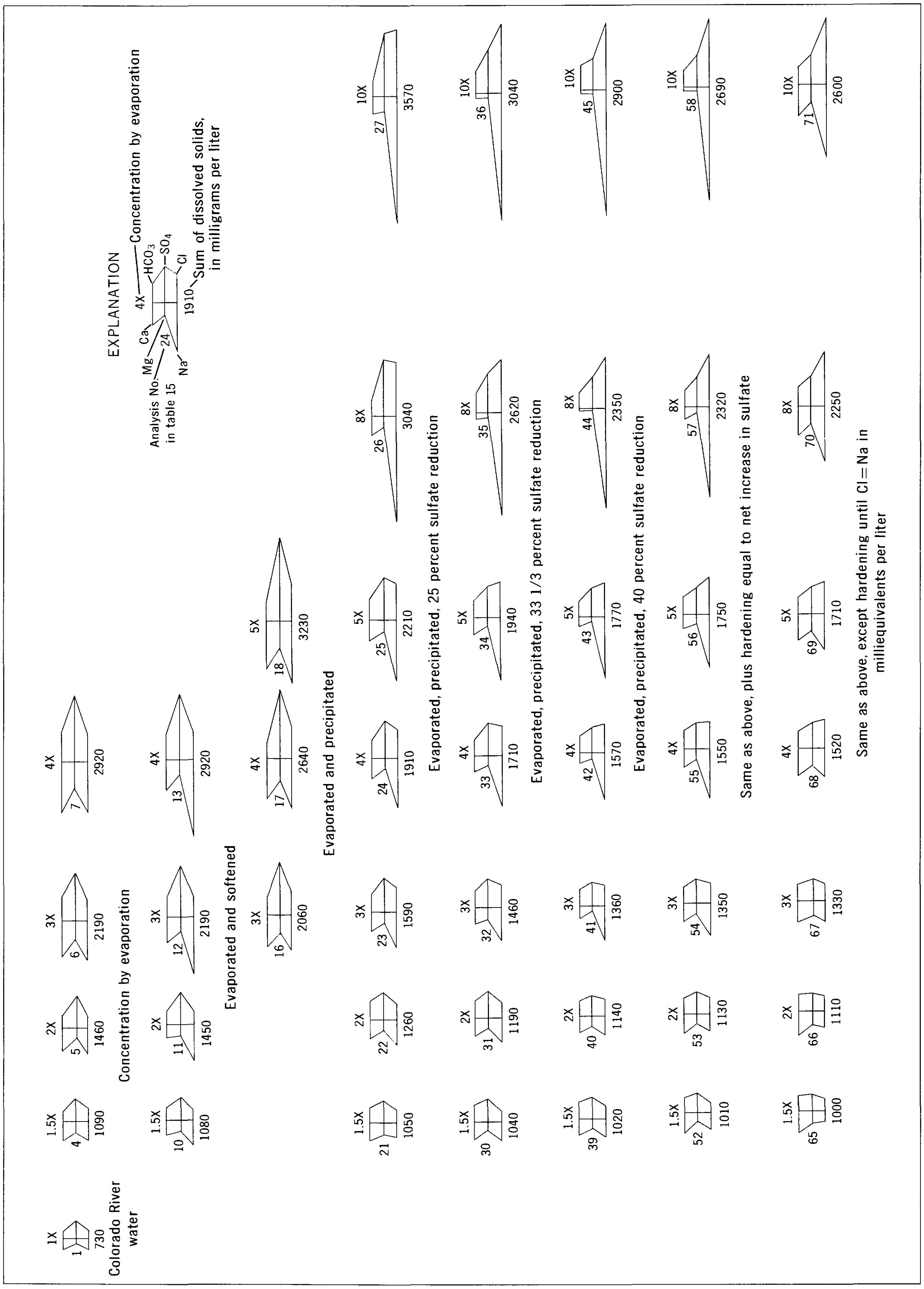


**FIGURE 48.**—Diagrams representative of chemical character of water represented by selected chemical analyses in table 15.

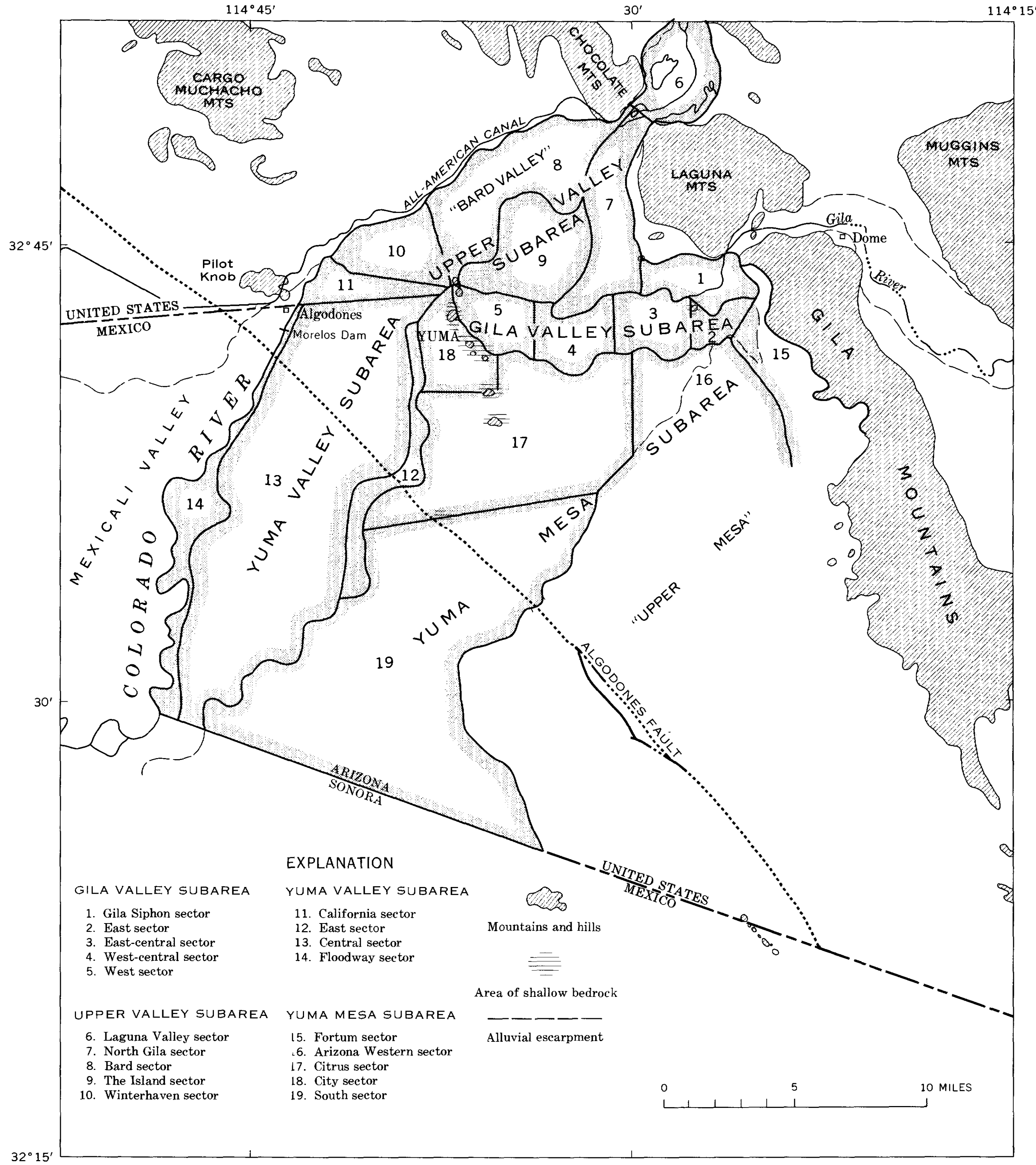


FIGURE 49.—Subareas and sectors described in section on quality of water and listed in appendix C.

ground water increased by induced infiltration. The natural drain of the subarea is the Gila River to its mouth and west of there the Colorado River. Until 1965 most of the subarea was irrigated with ground water pumped from wells perforated in the coarse-gravel zone. The pumping undoubtedly caused some infiltration of Gila River water and, since completion of the unlined part of the Wellton-Mohawk conveyance channel across the eastern part of the subarea, some infiltration from the conveyance channel. However, the hazard from induced infiltration was partly offset by the leakage from the unlined Gila gravity canal near the east end of the subarea, and by the fact that most of the South Gila Valley was converted in 1965 to irrigation with Colorado River water.

Although recent analytical data indicate that the mineral content of the ground water in the coarse-gravel zone in the Gila Valley subarea is greater, on the average, than in any of the other subareas, information on the preirrigation chemical quality of water is lacking so that it is not possible to estimate how much of the present salinity of the water has resulted from long-continued irrigation without drainage.

Emplacement of irrigation canals has greatly changed the ground-water quality in some parts of the Gila Valley subarea and has produced only small effects elsewhere. Also, irrigation developments in the South Gila Valley and adjacent parts of the Yuma Mesa produced effects which have extended to only part of the subarea. Consequently, the subarea is divided for detailed discussions into five sectors, each of which differs in some respects from neighboring sectors.

#### GILA SIPHON SECTOR

The east leg of the North Gila Valley and a small area east of the south-flowing reach of the Gila River immediately downstream from the Gila Gravity Main Canal Siphon are combined in the Gila Siphon sector of the Gila Valley subarea. The unlined Gila Gravity Main Canal, which carries Colorado River water, is at the north boundary of the sector and turns southward across the sector near its eastern boundary. The Gila River, which generally contains water three to four times as concentrated as the canal water and with relatively more chloride, is the natural drain and flows southward across the sector from the Gila Siphon, then bends west at the south edge of the sector. The Wellton-Mohawk Conveyance Channel, which was placed in use in 1961 and which is unlined across the sector, flows south from the siphon and turns west south of the bend in the Gila River. The salinity of the water in the conveyance channel is controlled almost entirely by selective pumping of drainage wells in the Wellton-Mohawk area to the east but is generally greater than that in the Gila River although of somewhat similar composition.

Formerly the North Gila Valley part of the sector was irrigated by diversion from the Gila Gravity Main Canal, but since 1965 it has mostly been irrigated by pumping from recently drilled irrigation wells. The South Gila Valley part of the sector has also mostly been irrigated from wells, although there has been some diversion from the Gila Gravity Main Canal.

Quality-of-water information for the sector is mostly limited to analyses of samples from the coarse-gravel zone. Chemical analyses of water samples obtained from a well at a gravel-washing plant at the east end of the sector, east of the Gila River, and from seven irrigation wells, of which two are east and five are west of the river, when arranged from east to west, do not suggest any composition pattern that can be related to well location alone. All the pumped water has been somewhat more mineralized than recommended for domestic use but has been less mineralized than water commonly used in the main part of South Gila Valley for many years to irrigate salt-tolerant crops. Several of the wells were sampled more than once, and it appears from successive analyses that there has been an erratic but generally upward change in concentration of the pumped water, particularly in chloride concentration. However, none of the sampled water has reached concentration levels recently prevalent in the lower Gila River or the Wellton-Mohawk Conveyance Channel.

In the future, water pumped from wells probably will contain increments derived from the Gila Gravity Main Canal, Gila River, and Wellton-Mohawk Conveyance Channel, and from recirculation of applied irrigation water. The proportions derived from these sources will vary with place and time, so that prediction of future water quality is not possible. However, the average concentration of dissolved solids and chloride probably will increase at sites near the Gila River.

#### EAST SECTOR

The east sector of the Gila Valley subarea lies east of County Avenue 10E and south of the Gila Siphon sector, in R. 21 W. of the Federal land net in Arizona. The sector is too far from the irrigated area on Yuma Mesa for the water quality to be affected by the water-table mound under the mesa. Water levels and water quality have been mainly affected by the transition from limited development on the east side of the sector to complete irrigation on the west. The Gila Gravity Main Canal, which traverses the sector diagonally from northeast to southwest, is a possible source of infiltrating water. Before the recent change to irrigation with surface supplies in the western part of the sector, pumpage of ground water was sufficient to prevent a shallow water table, and the recent expansion of irrigation east of the canal may keep the water table far enough below the land surface to prevent salinization of soils and ground water. There are no drainage wells in the area, although one is just outside of it on the southwest.

All chemical analyses from the sector represent water from the coarse-gravel zone. During the past few years the mineral content of the water has been higher than in most other parts of the Gila Valley subarea (pl. 11). In general, the water has been of the mixed chloride sulfate type in which the ratio of chloride to sulfate is greatest in the most concentrated samples.

#### EAST-CENTRAL SECTOR

The part of the South Gila Valley bounded by County Avenues 7E and 10E, the Gila River, and the escarpment at the north edge of Yuma Mesa constitutes the east-central sector of the Gila Valley subarea. Factors controlling quality of water in the sector are mostly like those in the east sector. However, infiltration of canal water probably has considerably less influence on the quality of the ground water because the Gila Gravity Main Canal bounds the sector for only about 1 mile along its southeast corner. The intensely irrigated part of Yuma Mesa begins about 1 mile southwest of the west edge of the sector. However, this irrigated area is sufficiently far away so that the deep seepage from the irrigation probably has not affected the water quality of the east-central sector as much as it has affected the sector immediately west.

The east-central sector, like most of the remainder of South Gila Valley, was irrigated for many years by pumping from wells perforated in the coarse-gravel zone but has been converted to primary dependence on Colorado River water. Therefore, recent ground-water-quality conditions are probably transient and may not closely resemble conditions which will exist after a few years.

Many analyses of water pumped from both irrigation wells and new drainage wells in the sector indicate a general southward increase in the mineral content of the water in the coarse-gravel zone (pl. 11). Sodium and chloride are invariably the dominant constituents, but their relative amounts increase as total salinity increases. Water from some of the wells has had fluctuating concentrations apparently caused by different duration of pumping periods and by simultaneous pumping from other wells.

Information about the wedge zone is limited, but near-uniformity of water-quality characteristics in one sample from a test well in the northern part of the sector, and samples from three deep supply wells at the south edge of the sector suggest the presence of water of relatively low salinity in the wedge zone under a considerable part, and perhaps all, of the sector.

#### WEST-CENTRAL SECTOR

The part of South Gila Valley bounded by County Avenues 4E and 7E, the Gila and Colorado Rivers, and the Yuma Mesa escarpment is called the west-central sector of the Gila Valley subarea. The sector is immediately north of the citrus sector of the Yuma Mesa subarea, and, as a result, both water levels and water quality have been considerably affected by irrigation on the mesa.

All the original nine drainage wells drilled for the U.S. Bureau of Reclamation to control water levels in South Gila Valley are in the southern part of the sector. Periodic analyses of water samples collected from these wells have indicated a pattern of slowly declining salinity with long-continued pumping. Analyses of samples obtained from irrigation wells suggest that usual concentrations north of the drainage wells may be less than those in the vicinity of the drainage wells. However, some of the irrigation wells appear to have produced water of slowly increasing salinity. Dissolved-solids concentrations throughout most of the sector have ranged from 1,800 to 3,600 mg/l, with fewer wells yielding concentrations above 3,600 mg/l than in the east-central sector. Samples obtained from a domestic well, a public-supply well, and a test well (appendix C, analyses 56a, 66, 87a, b, c) indicate that the water in the wedge zone is less mineralized than the water in the coarse-gravel zone.

#### WEST SECTOR

The part of South Gila Valley between County Avenue 4E and the city of Yuma, in R. 23 W. of the Federal land net for Arizona constitutes the west sector of the Gila Valley subarea. Several factors that influence the patterns of ground-water movement probably affect the water quality in the sector. The sector is south of the Colorado River and west of the mouth of the Gila River, so the local infiltration from the river channel probably is less saline than in the sectors farther east. Pumping of ground water for irrigation in The Island across the Colorado River to the north may reduce water movement south and southwest. The deposits flanking the buried slopes of "Yuma Hills" on the west side of the sector are less permeable than those to the north and east (fig. 25). The east half of the sector is north of the citrus sector of Yuma Mesa, but the west half is north of the urban area of Yuma.

Chemical analyses of water samples obtained from irrigation and drainage wells in the sector show the general southward increase in salinity that also occurs farther east (pl. 11). However, the analyses also indicate an increase in salinity toward the west and southwest, which suggests that recirculation of pumped water has been greater in the southwest corner of the sector than elsewhere in South Gila Valley.

### UPPER VALLEY SUBAREA

The upper valley subarea is the part of the Yuma area where water quality in both the upper, fine-grained zone and the coarse-gravel zone is most nearly related to the average quality of the Colorado River. The subarea comprises "Laguna Valley," "Bard Valley," and the western part of North Gila Valley. The Colorado River flows through the eastern part of the subarea and forms most of its southern boundary. The All-American and Gila Gravity Main Canals are emplaced mostly on cuts along the lower parts of the slopes at the sides of the valleys and are about 20–40 feet higher than the Colorado River. Consequently, ground-water movement is mainly away from the two canals toward the river.

Most of the subarea is irrigated with Colorado River water except for The Island sector, where irrigation is by pumping from wells screened in the coarse-gravel zone. Thus, most of the recharge in the subarea is Colorado River water infiltrating from the two principal canals or their diversions.

In order to describe local conditions, the upper valley subarea is subdivided into five sectors. The "Laguna Valley" and the North Gila Valley are treated as individual sectors, whereas "Bard Valley" is subdivided into three sectors termed the Bard sector, The Island sector, and the Winterhaven sector.

#### "LAGUNA VALLEY" SECTOR

The "Laguna Valley" sector, which is bisected by the Colorado River, includes the ovate part of the Colorado River flood plain between the All-American Canal and the Gila Gravity Main Canal above Laguna Dam and below Imperial Dam. Before the construction of Hoover Dam most of the sector probably was flooded every year. Mittry Lake, a permanent water body between the river and the Gila Gravity Main Canal, is continually fed by ground-water seepage. Analyses of several samples of outflow from Mittry Lake indicate that evapotranspiration has concentrated the lake water to two or three times as much as the river and that moderate sulfate reduction occurs in the lake.

Most of the remainder of "Laguna Valley" is low lying and swampy so that chemical processes just below the water table may be like those in Mittry Lake. Analyses of samples obtained from four hand-auger holes suggest that two patterns of chemical change occur in the shallow deposits on both sides of the Colorado River. Two of the analyses suggest concentration by evaporation, slight sulfate reduction, and considerable softening. The other two indicated greater concentration by evaporation, moderate sulfate reduction, and hardening instead of softening. Nevertheless all samples contained less than 1,600 mg/l dissolved solids.

A well at the Imperial Irrigation District's Imperial Camp, probably screened in the coarse-gravel zone, yields water very similar in composition and concentration to Colorado River water. Water obtained from the coarse-gravel zone at test well LCRP 14 just north of Laguna Dam is comparable to recent Colorado River water (appendix C, analysis 206a). Thus, water of the Colorado River type may be present in the coarse-gravel zone in much of the valley.

Analyses of samples obtained from the mud scow during drilling of LCRP 14 did not show the presence of water of better quality below the coarse-gravel zone like that found in "Bard Valley" to the southwest. Water pumped from the nonmarine sedimentary rocks perforated after the well was completed at depths of 470–490 feet was the most saline of any water sampled in the entire upper valley area, with 3,420 mg/l dissolved solids, 1,450 mg/l chloride, and 660 mg/l sulfate (appendix C, analysis 206b). Water of this character could not have been formed from recent Colorado River water without being concentrated by evaporation about 10 or 12 times and being subjected to substantial sulfate reduction. It is difficult to explain the quality of the water at this site except by assuming that the water has been in the sediments for a long time.

#### NORTH GILA SECTOR

The North Gila sector, which is east of the Colorado River across from the more comprehensively sampled Bard and The Island sectors and immediately downstream from the "Laguna Valley" sector, includes the part of North Gila Valley irrigated with Colorado River water. The sector contains no irrigation wells or other large-capacity wells in use. Consequently, appraisal of water-quality variation is based on analyses of samples of water obtained from small domestic and stock wells, auger-test wells, and a U.S. Bureau of Reclamation test well which may not have been pumped long enough for stabilization of water quality, and on the assumption that test wells LCRP 14 and 23, which are in adjacent sectors, indicate conditions in this sector.

The data indicate that ground water containing between 900 and 1,800 mg/l dissolved solids can be obtained in most of the sector, although water containing as much as 2,500 mg/l dissolved solids and relatively high in chloride may be present locally in the upper, fine-grained zone. Water of better quality than that represented by the analyses may be generally present in the wedge zone, and the best water is probably near the Colorado River. Most of the sampled water appears to be Colorado River water only moderately altered by concentration and softening.

#### BARD SECTOR

The Bard sector is the part of "Bard Valley" downstream from Laguna Dam, north of The Island, and east of the Yuma Main Canal. Chemical analyses of samples of water obtained from auger test wells drilled along washes outside the sector, a short distance north of the All-American Canal, are included in the tabulation (appendix C) because they indicate the presence of water similar to that obtained from auger test wells on the valley side of the canal. Most of the Bard sector is irrigated with Colorado River water, although strips of uncultivated land overgrown with phreatophytes are scattered along the All-American Canal and laterals.

Water quality along the east margin of the sector is probably similar to that indicated by test wells LCRP 14 and 23 which are close by but in other sectors. Water samples obtained from scattered farm wells and auger test wells mostly tapping the top of the coarse-gravel zone indicate only moderate variability of water-quality patterns. The composition ranges from water like Colorado River water to water from the river moderately evaporated and with somewhat reduced sulfate. Nine samples obtained from very shallow house wells used by Indians at uncertainly designated sites in the western part of the sector indicate that the shallow water is generally more mineralized than Colorado River water; this is likely to be true for shallow water throughout most of the sector.

A well drilled into the coarse-gravel zone a short distance east of the Yuma Main Canal near Indian Hill yielded water similar to recent Colorado River, which suggests that such water might be available in favorable areas close to many of the canals. U.S. Bureau of Reclamation test well CH–8, which penetrated a buried volcanic hill (basalt or basaltic andesite), yielded water containing 1,380 mg/l dissolved solids from 355 feet which was softened and also appeared to have undergone considerable sulfate reduction (appendix C, analysis 231a). A well at the San Pasqual Valley School was perforated from 120 to 204 feet and yielded water closely resembling 1950 Colorado River water which had been concentrated about four times, had undergone moderate sulfate reduction, and had been considerably hardened (appendix C, analysis 241).

#### THE ISLAND SECTOR

The Island sector includes the part of "Bard Valley" south and southeast of the Bard sector that is not supplied with Colorado River water by a canal system. The sector, somewhat larger than the abandoned Colorado River meander cutoff known as The Island, contains a considerable acreage irrigated from wells and scattered acreages which are either covered with small sand dunes or overgrown with phreatophytes and which are not irrigated. Information about shallow water is not available for the sector, but such water is probably variable in composition and more highly mineralized than the water in the coarse-gravel zone because of concentration by evapotranspiration and because there is no provision for drainage in the sector.

Chemical analyses of water samples obtained from 13 irrigation wells, probably all perforated entirely or mainly in the coarse-gravel zone, indicate that concentrations of dissolved solids in the pumped water ranges from about 900 to 1,900 mg/l. Some of the analyses indicate only moderately altered Colorado River water, slightly concentrated by evaporation, whereas others suggest more than 50 percent sulfate reduction and several times concentration.

Test well LCRP 23 at the northeast corner of The Island sector probably indicates the general variations in water quality with depth in parts of the Bard and North Gila sectors as well as in The Island sector. Water bailed from this well at 133 feet during drilling was somewhat like evaporated Colorado River water (appendix C, analysis 243a). Samples obtained when pumping from perforations extending from a depth of 120 to 548 feet represent a mixture of water from the wedge zone and the coarse-gravel zone. This water contained less than 600 mg/l dissolved solids and was like highly reduced Colorado River water (appendix C, analysis 243c). Water from the interval 634 to 694 feet. which came from the Bouse Formation (marine), was higher in concentration than the river water and contained much more chloride and somewhat less sulfate than the river water (appendix C, analysis 243b).

#### WINTERHAVEN SECTOR

The Winterhaven sector, most of which is in the

Yuma Indian Reservation, includes the part of "Bard Valley" west of the Yuma Main Canal. Most of the sector is accessible to a network of irrigation canals but not all the valley land has been cultivated; a considerable acreage of scattered low-lying tracts overgrown with phreatophytes has accumulated surface salts as a result of evapotranspiration.

Few wells have been drilled in the sector. Water-quality information is mainly limited to analyses of water samples obtained from auger test wells. Samples from most of these small-diameter wells indicate the presence of water about like recent Colorado River water or like river water concentrated two or three times but with its sulfate slightly to moderately reduced.

A water-quality problem exists at the village of Winterhaven, the only important trading point in the California part of the Yuma area. The chemical character of the water obtained from several wells drilled to supply the community is reported to have changed slowly from a water something like the recent river to water almost unacceptable for public supply. Hence, operators of the company supplying water have had to drill new wells and abandon old ones every few years. The latest well was drilled in September 1961 and by the spring of 1967 the water quality had deteriorated so that the well was considered questionable as a continuing source for public supply.

An auger test well southwest of Winterhaven between the Colorado River and a flood-protection levee produced water containing 3,450 mg/l dissolved solids with 1,160 mg/l chloride when sampled at 117 feet (appendix C, analysis 266). However, as very poor water originating upriver in the Wellton-Mohawk district constituted much of the river flow for many months prior to the time of sampling, the sample might represent local infiltration of mineralized water from the river.

A deep U.S. Geological Survey test well, LCRP 26, drilled by the mud-rotary method, cased, and gravel packed, yielded water containing only 712 mg/l dissolved solids (appendix C, analysis 269b). The well is perforated from 125 to 1,127 feet (throughout the coarse-gravel zone and the wedge zone) and also from 1,368 to 1,769 feet (in the nonmarine sedimentary rocks), so that the water sample represents a composite from three aquifers. Use of a flow meter in the well while making pumping tests indicated that relatively little water was yielded by the nonmarine sedimentary rocks, and electric and water-resistivity logs and thief samples showed that the water in these rocks was not quite as fresh as that in the wedge and coarse-gravel zones of the alluvium. The logs also indicated fairly uniform electrical conductivity for the water throughout the alluvium. Thus, it is inferred that the water yielded by the coarse-gravel and wedge zones alone would be slightly fresher than that actually pumped from the well and might contain less than 700 mg/l dissolved solids. A shallow well used to furnish water for drilling the test well yielded water containing 2,460 mg/l dissolved solids (appendix C, analysis 269a). This analysis indicates that the upper, fine-grained zone probably contains slightly to moderately saline water.

The only irrigation well in the Winterhaven sector, well 16S/22E–29Dba, less than a mile northwest of test well LCRP 26, obtains water of fair quality, though not as fresh as that in the test well (appendix C, analyses 267a, b). The irrigation well is perforated from 118 to 143 feet, entirely in the coarse-gravel zone.

### YUMA VALLEY SUBAREA

The Yuma Valley subarea, largest of the subareas, consists of all the Colorado River flood plain in Arizona south and west of the city of Yuma. The entire Yuma Valley except for a narrow strip adjacent to the river on the north and west is protected by a flood-control levee and is irrigated from the Yuma Main Canal system. The canal water enters the valley through an inverted siphon beneath the Colorado River at Yuma but is originally diverted from the river at Imperial Dam and therefore has the chemical characteristics of the Colorado River water at the dam rather than the somewhat greater concentrations that occur below the mouth of the Gila River.

Irrigation in Yuma Valley began before 1900, and most of the valley has been irrigated with river water for at least 50 years. Consequently, rather complete leaching of soluble salts present in the upper soil zones prior to initial irrigation probably has occurred. Nevertheless, some comparatively small areas are underlain by a high water table where white saline surface crusts appear from time to time as a result of evaporation from the capillary fringe.

An extensive network of canals and laterals begins at Yuma and interfingers with an equally extensive drain system which converges into a single main drain near the southerly international boundary. The drain water, although moderately variable in composition and concentration because it includes variable parts of irrigation wastes, is always considerably more mineralized than the applied Colorado River water. Nevertheless, it has been pumped across the southerly international boundary and used for irrigation in Mexico for many years.

The Yuma Valley subarea is not as easily divisible into sectors on the basis of topography, geology, or analytical data as the other three subareas. Numerous chemical analyses are available which represent sampling from drainage wells near the Yuma Mesa escarpment on the east side of the valley and also from irrigation and other wells in the floodway strip on the west side of the valley, but there are comparatively few analyses that represent sampling from the far larger area between the drainage wells and the floodway strip. Consequently, the subarea is divided into three relatively narrow sectors along the north, east, and west margins, and a fourth sector that includes the greatest part of the valley (fig. 49).

#### CALIFORNIA SECTOR

At the north end of Yuma Valley, west of Yuma, the Colorado River flows slightly north of west for about 5 miles, then turns abruptly toward the south-southwest. A small part of the valley near the river was once included in California and is still subdivided according to the California system of the Federal land net. For convenience in identifying wells this small area is designated the California sector of the Yuma Valley subarea. Part of the sector is not farmed, part is or has been irrigated by pumping directly from the Colorado River, and part has been irrigated by pumping from the Central Main and Cooper Canals of the Yuma Project. There is one irrigation well in the sector.

Analyses of water samples obtained from several domestic wells in the sector indicate the presence of an unusual body of shallow ground water containing only a few hundred to about 1,000 mg/l dissolved solids. This water is moderately low in chloride and unusually low in sulfate. Although the water may be residual flood water, more likely it is Colorado River water that has undergone great sulfate reduction. Water from two domestic wells and one observation well was considerably higher in dissolved solids. This fact indicates that part of the local ground water represents considerably evaporated and moderately reduced Colorado River water.

Two samples of water obtained 2 years apart from the irrigation well are so much like recent Colorado River water that they suggest a considerable part of the water pumped from this well is recently infiltrated Colorado River water, even though the well is perforated in the coarse-gravel zone (appendix C, analyses 308a, b). Two deep wells perforated in the wedge zone which have supplied water for a steam-electric plant for about 10 years have yielded water containing much less dissolved solids than any other regularly pumped large-capacity wells in the Yuma area (appendix C, analyses 303a, b, 304).

#### EAST SECTOR

Recent water quality in the coarse-gravel zone on the east side of Yuma Valley probably is rather well defined by chemical analyses of water samples collected from a line of drainage wells constructed near the eastern edge of the valley and west of the East Main Canal—the eastern distributary of Colorado River water in Yuma Valley. The drainage wells were constructed so that continuous pumping would relieve the high water table caused by the ground-water mound beneath Yuma Mesa to the east.

The first drainage wells, placed in operation in 1947, did not extend into the coarse-gravel zone, so that most of the water pumped from them actually came from the upper, fine-grained zone, although undoubtedly replaced by upward movement from the coarse-gravel zone. The capacity of the shallow wells proved inadequate to control water levels and they were replaced, beginning in 1954, by large-capacity wells screened in the coarse-gravel zone. Although the shallow drainage wells obtained water from the upper, fine-grained zone, the old analyses of samples obtained from them probably do not represent the quality of water in the upper zone near the well sites today. Consequently, the analyses of samples from the old wells are not included in appendix C.

Pumping from the high-capacity drainage wells screened in the coarse-gravel zone has generally been nearly continuous once a well has been placed in operation. Consequently, differences between chemical analyses of water samples taken at intervals from these wells can be interpreted as showing actual changes in water quality in the coarse-gravel zone resulting from the continued pumping. Nevertheless, some care must be taken in drawing conclusions about salinity changes in the ground water as the chemical analyses came from several sources and are not always strictly comparable owing to differences in analytical methods used by individual laboratories and because some analyses suggest possible chemical precipitation prior to analysis. None of the presently pumped wells yields water like the present Colorado River water. Yet each well tends to have a definite chemical pattern which is somewhat different from that for adjacent wells, probably because vertical and horizontal movement of water to the wells varies from well to well, and because part of the water pumped from some of the wells may have come from considerable depths in the wedge zone.

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The dissolved-solids content of water pumped from the drainage wells has ranged from about 1,100 to 2,300 mg/l and either has generally been rather constant for an individual well or has gradually decreased after several years of pumping; however, water from the northernmost drainage well has trended upward in concentration rather than downward. The most northerly wells, which are west of the built-up part of the city of Yuma and farther from the irrigated area of the mesa than those farther south, yield water that is like moderately evaporated and greatly reduced Colorado River water. The drainage wells in the central part of the group and west of the heavily irrigated part of the mesa yield water that contains more sulfate and less chloride. Wells at the south end of the group yield water having the lowest dissolved-solids content and containing less chloride and much less sulfate than farther north. The different changes in composition of the water with time apparently result from differential movement to the wells of an increment of Colorado River water applied as irrigation water on Yuma Mesa.

#### CENTRAL SECTOR

Water-quality variation in the central part of Yuma Valley is not very well defined, because there are only a few wells for which depth information, logs, and sampling all are available. Wells used to supply Somerton are the only ones in central Yuma Valley that have pumped substantial amounts of water. Information is also available on a few wells of moderate capacity constructed to supply labor camps, cotton gins, and feed yards. Most of the analytical information is on samples collected from auger test wells and small-capacity domestic wells of which many of the latter are of unknown depth. The auger test wells were sampled through well points at their base. Some of the domestic wells also obtain water through well points or open bottoms. Thus the auger-well and domestic-well samples mostly represent point rather than zone sampling and water of different quality might be obtained at their locations if wells of larger capacity perforated for lengthy intervals were constructed. Therefore, the central part of Yuma Valley must be appraised on a more tentative basis than the rest of the Yuma area, although the appraisal may not be far removed from describing average water-quality conditions.

Chemical analyses of water samples collected from auger test wells and domestic wells, chiefly from the northern one-third of the valley, indicate considerable erratic variation in the chemical quality of water in the upper and coarse-gravel zones. Apparently many of the canal reaches serve as line sources of recharge so that the chemical character of the water obtained from shallow sources near them is very similar to that of recent Colorado River water. In contrast, wells of similar depths but closer to drains rather commonly yield water with chemical characteristics indicating moderate concentration by evaporation and some sulfate reduction.

During 1962, the U.S. Bureau of Reclamation had two 500-foot test wells drilled in the valley. Analyses of water samples taken from the mud scow or with a thief sampler during drilling indicated irregular differences in water composition with depth. The wells were perforated in the coarse-gravel zone but not pumped and sampled until about 2 years later. The pumped samples agreed only in a general way with the samples obtained earlier. (See appendix C, analyses 360a–h, 376a–f).

In 1965 the city of Somerton had a deep test well drilled in order to prospect for water suitable for city use. Several samples (appendix C, analyses 375a–g) were obtained from the mud scow at depths ranging from 470 to 1,143 feet but they did not indicate the presence of the hoped-for good water, and the well was not completed at that time. It was completed later, however, and is now (1968) used for public supply.

#### FLOODWAY SECTOR

At the time the Yuma Project was developed by the U.S. Bureau of Reclamation a rather narrow strip along the Colorado River was separated from the rest of Yuma Valley by a flood-protection levee so that it did not receive canal water. Overgrown with bottom-land vegetation, the strip was mostly unused for many years. By 1940, however, some of it had been cleared and was irrigated by pumping directly from the river. Later the irrigated area was greatly expanded to cover most of the strip, and irrigation by pumping from wells replaced the pumping from the river.

Several analyses of samples from two wells near the West Main Canal in the north-central part of the sector have shown that these wells have always yielded water containing 1,200–1,400 mg/l dissolved solids which is similar to evaporated Colorado River water that has undergone slight sulfate reduction (appendix C, analyses 344a–e, 395a, b). All the irrigation wells farther south have yielded water that contains less dissolved solids, that appears to be less concentrated by evaporation, and to have undergone more sulfate reduction. Four analyses of samples taken from a cluster of auger test wells installed to determine differences in head (appendix C, analyses

402–405) indicate that the water in the upper, fine-grained zone is most like evaporated Colorado River water near the water table and that its dissolved-solids content decreases with depth, mainly because of increased sulfate reduction.

Several samples collected with packers from test well LCRP 9 (appendix C, analyses 399a–f) indicate that the quality of water obtained between depths of 310 and 1,108 feet (in the wedge zone) does not vary much with depth and that the wedge zone probably contains better water for an extended depth than that in the river.

Samples obtained from test well LCRP 17, several miles farther south (appendix C, analyses 410a–h) consistently indicated a little more chloride and a little less sulfate than in well LCRP 9.

All the analyses from irrigation wells represented by repeated samples showed small but definite increases in dissolved solids content after several years pumping, but the rate of increase was not sufficient to suggest that the water would become unsatisfactory for the general farming carried on in the area for many years.

### YUMA MESA SUBAREA

The Yuma Mesa subarea includes small parts of "Upper Mesa" and "Gila Mesa" as well as the entire Yuma Mesa. All the subarea lies above the river valleys (flood plains) and consequently has not been subject to geologically recent (Holocene) flooding by the rivers. The subarea includes a large central acreage irrigated by Colorado River water brought in by lined canal and scattered tracts where irrigation by pumping from wells has begun recently or is being planned. It also includes large sections where irrigation may be possible but where irrigation has not yet been planned.

The alluvium beneath the Yuma Mesa subarea is hydraulically continuous with the alluvium under the adjacent river valleys so that a continuous water table extends from the South Gila Valley southward and southwestward under the Yuma Mesa subarea to the southerly international boundary and Yuma Valley. Early chemical records suggest that most of the subarea may have had ground water of uniform chemical quality before irrigation began in the South Gila Valley and on Yuma Mesa, and that some of the old water was replaced by water more like recent Colorado River water. Irrigation on the mesa undoubtedly has altered the chemical quality of much of the ground water in the irrigated area so that the present patterns of ground-water-quality variation are best described by sectors.

#### FORTUNA SECTOR

The Fortuna sector, in the northeast corner of the Yuma Mesa subarea, is named for Fortuna Wash, an ephemeral stream which originates in the Gila Mountains several miles south of Telegraph Pass and extends northwestward, but nearly parallel to the mountains, to South Gila Valley. Except for the city sector in and adjacent to Yuma, the Fortuna sector is the only extensive part of the Yuma Mesa subarea where water of poor quality is widely present. The sector, a dissected upland 2–3 miles wide, lies chiefly within "Gila Mesa." Crossed by U.S. Highway Interstate 8, the sector has particularly good access from Yuma so that it has been attractive to picnickers and has been the site of several proposed desert homesite subdivisions. Land developers and purchasers of individual homesites have drilled more than a dozen wells in the sector.

Analyses of samples of water obtained from seven of the deeper wells during drilling and testing suggest the widespread presence of slightly to moderately saline sodium chloride type water which usually would not be considered suitable for domestic use because of its mineral and fluoride content. Analyses of samples obtained from three wells in the sector but west of Fortuna Wash, which penetrated only short distances below the water table, indicated the presence of water containing less than 300 mg/l dissolved solids with only a little fluoride.

The fresh water near Fortuna Wash, derived from the occasional flood flows of the wash. occurs in a lens or thin lenses, in part perched, overlying the more saline water in the main water body. The known thickness of the fresh-water body does not exceed 40 feet; the extent is less well known but probably does not exceed a few thousand acres. Development of this water of superior quality would have to be limited to domestic wells of small capacity, carefully spaced and pumped so as not to draw in the more saline water from below. The origin of the somewhat saline water of the main water body is uncertain; possibly it represents contamination by upward leakage along faults of brackish water from marine and nonmarine sedimentary rocks of Tertiary age. The abnormally warm temperatures of the water support such an inference (fig. 47).

#### ARIZONA WESTERN SECTOR

Extending south from the escarpment along the south edge of South Gila Valley between the Fortuna sector and the citrus sector is a tract of mostly undeveloped land which is designated the Arizona Western sector of the Yuma Mesa subarea. Two wells at Arizona Western College (from which the sector derives its name) are the only heavily pumped wells in the sector. Other wells are commercial wells of small capacity along U.S. Highway 80 (Interstate 8) and scattered exploratory wells drilled mainly to prove up land acquisition from the State of Arizona and generally not used after drilling.

Water samples obtained from 11 wells in the sector show similarly constituted sodium chloride water with dissolved solids ranging from 800 to 1,400 mg/l. The two wells at Arizona Western College are of different depth, and the water they produce is used for different purposes. The shallower well, perforated in the coarse-gravel zone and used mainly for irrigation (appendix C, analyses 517a, b), has produced water of higher concentration than that of the deeper well. The deeper well, perforated in the wedge zone and used for public supply, produces water like that pumped from the U.S. Bureau of Reclamation wells now supplying part of the water in nearby South Gila Valley (appendix C, analyses 518a–c).

Mud-rotary-drilled test well LCRP 25, about 5 miles southwest of Arizona Western College, is gravel packed and perforated from 862 to 2,002 feet (entirely in the wedge zone) and, when pumped during a test, yielded water similar to and only a little more concentrated than the water in the deeper college well (appendix C, analysis 521).

Although the number of wells in the Arizona Western sector represented by water analyses is small, the near uniformity of water-quality patterns and the general similarity to the patterns of water quality shown by the more numerous wells in the south sector of the Yuma Mesa subarea suggest that the general composition pattern of the deep supply well at Arizona Western College probably is representative of water that might be produced from any new wells drilled in the sector.

#### CITRUS SECTOR

The principal irrigated part of Yuma Mesa is designated the Citrus sector because most of it has been planted to citrus orchards. Analytical evidence indicates that the chemical characteristics of the ground water in the Citrus sector have been or are in process of being altered, owing to the infiltration of imported Colorado River water. Several older analyses, mostly from wells no longer in existence, indicate that formerly most of the ground water in the sector had the same chemical pattern as that occurring today in the Arizona Western sector. Concentration of dissolved solids generally ranged from 800 to 1,000 mg/l, with sodium and chloride the principal constituents.

Recent analyses of many samples collected from domestic wells scattered throughout the sector indicate the general presence of water that can be characterized as Colorado River water moderately evaporated and partly softened. The modified Colorado River water has sulfate, rather than chloride, as the principal anion constituent. However, because most of the sampled domestic wells in the Citrus sector are no deeper than about 200 feet, some of the water below that depth (upper part of the coarse-gravel zone) may still be of the sodium chloride type.

Analyses of samples obtained from a few wells in the northernmost part of the sector indicate water much like that produced from the coarse-gravel zone in South Gila Valley. The analytical evidence corroborates the water-level data which indicate that water moved southward from under South Gila Valley to under the mesa prior to the development of intensive irrigation on the mesa. After irrigation on the mesa, and particularly since drainage wells were drilled in South Gila Valley, the direction of movement of water in the northern part of the Citrus sector has been reversed and some reduction of salinity may have occurred.

#### CITY SECTOR

Most of the city of Yuma is on or immediately south of a peninsulalike extension of Yuma Mesa at its northwest corner. Only a few wells now pump water in this sector. A municipal water department (formerly a private company) supplies Colorado River water to residents of the city and a considerable quantity of this water is used to irrigate yards, trees, and shrubs, so that it must provide some local recharge. However, because of the rather high cost of the water, many of the larger grassy areas around some of the motels and public buildings and in parks and school yards are irrigated by pumping from wells. This pumped water, although considered satisfactory for irrigation of bermuda grass, has not been considered satisfactory for use on salt-sensitive trees and shrubs.

The parts of Yuma Mesa south of Yuma, and Yuma Valley to the west, are irrigated with Colorado River water. The part of South Gila Valley east of the city was long irrigated with ground water and has only recently been converted to irrigation with Colorado River water. The "Yuma Hills" on the east side of Yuma form a partial barrier to groundwater movement from South Gila Valley. However, the chemical character of the water pumped from most of the wells in Yuma is more like that beneath the South Gila Valley than that beneath Yuma Valley or the adjacent part of Yuma Mesa to the south.

Most of the wells in Yuma yield water containing between 1,800 and 3,600 mg/l dissolved solids which is like Colorado River water that has been concentrated several times by evaporation and has undergone substantial sulfate reduction and hardening. Other wells near the west edge of the mesa yield water which appears to have a considerable increment of infiltrated Colorado River water.

In 1962 a well was drilled to a depth of 830 feet at the Stardust Hotel near the center of the sector in an effort to obtain water suitable for cultivation of flowers and shrubs and other uses at the hotel. During the drilling, water-quality variation with depth was determined by frequent measurements of specific conductance of the water brought up with well cuttings in the mud scow. Both the quality of the water and the quantity obtained were disappointing and the hotel left the well unused. In 1963 an agreement was made for the U.S. Geological Survey to have the well deepened to bedrock (as LCRP 13) in order to further test water-quality variation with depth. Water of better quality was not found and the well was not completed as a production well and has since been filled in. It was concluded from this test well that there is little variation in water quality with depth under this part of Yuma Mesa (appendix C, analyses 573a–d).

#### SOUTH SECTOR

The largely undeveloped part of Yuma Mesa extending south and southwest from the citrus sector constitutes the south sector of the Yuma Mesa subarea. Most of the sector was once programed for irrigation with Colorado River water but was left out of the developed project because the Congress restricted the acreage that could be developed. However, as the south sector includes considerable land with soil characteristics similar to those in the most favorable part of the citrus sector, there has resulted much interest in developing farms irrigated with ground water. The development of a ground-water mound under the citrus sector, resulting from intensive irrigation there, and the continuing spread of this mound outside that sector, indicated that the ground water in the south sector was being recharged from the citrus sector and that this recharge would continue and replace water removed for irrigation. Consequently, well development and some irrigation farming in the south sector was begun by private developers about 1961 and has increased nearly every year since.

The analyses of water samples obtained from wells in the south sector indicate that the quality of the native ground water was as good as the recent Colorado River water, although it had chloride rather than sulfate as the chief anion constituent. Wells in the northern part of the south sector, adjacent to the citrus sector, have generally shown changing patterns of water quality with pumping. Commonly the first samples contain about 800 mg/l dissolved solids, mostly sodium and chloride; after pumping the relative amount of sulfate tends to increase and the dissolved solids also increase to 1,200–1,400 mg/l. This change is probably caused by admixture of water infiltrated from the citrus sector.

Farther south all the wells show the predominance of chloride over sulfate in a pattern that is so characteristic as to be recognizable as the original "Yuma Mesa pattern." The average mineral content appears to decrease in the southern part of the sector.

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# APPENDIXES A-E

## APPENDIX A. RECORDS OF WELLS

Appendix A represents records of 936 wells in the Yuma area inventoried by the U.S. Geological Survey during the period 1961–66. These wells provide much of the basis for the interpretation of the ground-water hydrology and the subsurface geology in the main part of this report. Logs of, and chemical analyses of water samples from, some of these wells are given in appendixes B and C, respectively.

Appendix A comprises five tables (16 through 20), in which the wells are grouped according to type or major use. Within each table, the wells are listed sequentially according to their location (well number) in the Federal land classification. A description of the well-numbering system is given in the introduction of the report (p. H17). Locations of the wells in tables 16–20 are shown on plates 13–17, respectively.

Not all wells in the Yuma area were inventoried in the present investigation; domestic wells, shallow observation wells, and destroyed wells were generally omitted except where special information was available for a well. The well inventory was terminated in the spring of 1966, but some well data were obtained as late as 1968.

## TABLE 16.—*Water-test wells and oil-test wells*

Well number: Location of well according to the Federal land classification. See text for description of well-numbering system.
Coordinates: Location of well according to grid system used by U.S. Bureau of Reclamation in Yuma area. See page H17 for explanation of grid system.
Owner or user: Government agency or company that drilled the well or had it drilled.
Other number: Number assigned to well by owner or user.
Year completed: Known or reported year of completion of well.
Altitude of land surface: Average altitude of land surface at well above mean sea-level datum. Altitudes given to nearest foot are approximate and were obtained from topographic maps; altitudes given to decimal fractions of a foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Log information, water-level data, and temperature 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—C, drilled with cable-tool or percussion equipment; R, drilled with rotary-mud equipment; 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.
Discharge: Measured or reported discharge of well in gallons per minute.
Drawdown: Measured or reported drawdown, in feet, accompanying discharge in previous column.
Water level: Date measured by the Geological Survey or reported by owner or other agency. Depth to water in feet below land-surface datum.
Water temperature: Date measured by the Geological Survey. Temperature, in degrees Celsius, of most recent sample of water pumped from well believed to represent water from the depth of the perforated interval in the coarse-gravel zone. In some wells, not equipped with pumps, temperature measured with a thermistor or a maximum thermometer at a depth believed to represent the middle of the coarse-gravel zone or an equivalent depth below land surface.
Other data available: Additional information about the well available in files of the Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the letter symbols—A, acoustic-velocity (sonic) log; C, caliper log; Cc, contact-caliper log (microresistivity-caliper log); D, driller's log; Dip, dip log; E, electric log (spontaneous potential and resistivity); G, gamma-ray log; L, lithologic log made by a geologist from drill cuttings and other information; R, fluid-resistivity log; T, temperature log; HA, heavy-minerals analyses of drill cuttings; MA, mechanical analyses of drill cuttings; P, paleontological studies of drill cutting; PC, pebble counts of drill cuttings; PT, pumping test or tests; PTc, pumping tests with down-hole current meter; PTp, pumping tests, pumping tests with packers; $C^{14}$, radiocarbon date of formation sample; Q, chemical quality-of-water data; W, periodic or continuous water-level records.

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-7-22)14bcd | 6 5/8 N-7 3/16 E | U.S. Geological Survey. | LCRP 14 | 1963 | 155.1 | 505 | [1]500 | C | 12 | 118–162, 470–490 | 600 | 8.43 | 11-1-66 | 14.08 | 2-27-68 | 19.9 | 150 | G, L, R, T, HA, P, PC, PT, Q |
| (C-8-21)17abb[2] | 1 N-10 9/16 E | U.S. Bureau of Reclamation. | Gila Siphon 9. | 1957 | 159 | 79 | | | | | | | | | | | | L |
| 17abd[2] | 0 15/16 N-10 5/8 E | do | Gila Siphon 10. | 1957 | 160 | 72 | | | | | | | | | | | | L |
| 17bab[2] | 0 15/16 N-10 1/4 E | do | Gila Siphon 4. | 1957 | 158 | 102 | | | | | | | | | | | | L |
| 17bac[2] | 0 15/16 N-10 3/8 E | do | Gila Siphon 6. | 1957 | 158 | 98 | | | | | | | | | | | | L |
| 17bad1[2] | 0 15/16 N-10 3/8 E | do | Gila Siphon 7. | 1957 | 158 | 105 | 105 | | 16 | 90–105 | 1,390 | 11 | | | | | | L, PT, Q |
| 17bad2[2] | 0 15/16 N-10 7/16 E | do | Gila Siphon 8. | 1957 | 159 | 102 | | | | | | | | | | | | L |
| 17bba1[2] | 1 N-10 3/16 E | do | Gila Siphon 1. | 1957 | 150 | 96 | | | | | | | | | | | | L |
| 17bba2[2] | 1 N-10 3/16 E | do | Gila Siphon 2. | 1957 | 151 | 96 | | | | | | | | | | | | L |
| (C-8-22)15bdd | 0 1/2 N-6 1/2 E | do | CH-6 | 1963 | 140.5 | 501 | 485 | C | 12 | 90–185 | | | 12-15-66 | 4.74 | 11-2-67 | 22.2 | 120 | G, L, R, T, PC, Q |
| 15dab[2] | 0 7/16 N-6 13/16E | Gila Valley Oil and Gas Co. | Kamrath 1 | 1958 | 145 | 2,140 | | R | | | | | | | | | | E, L |
| 15ddd[2] | 0 1/16 N-6 7/8 E | do | Kamrath 2 | 1958 | 147 | 400 | 372 | R | 13–10¾ | | | | | | | | | |
| 19ccc | 1 S-3 E | U.S. Bureau of Reclamation. | CH-702 | 1963 | 129.6 | 500 | 490 | C | 12 | 115–150, 370–463 | 1,060 | 35 | 12-11-66 | 10.29 | 11-2-67 | 21.2 | 120 | G, R, T, PC, PT, Q |
| 23dad | 0 3/4 S-8 E | do | CH-4 | 1962 | 152.4 | 500 | 500 | C | 8 | 100–130 334–354 | | | 3-31-67 | 16.10 | 11-2-67 | 21.5 | 120 | G, L, R, T, MA, Q |

See footnotes at end of table.

TABLE 16.—*Water-test wells and oil-test wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35caa1 | 2 1/2 S-7 1/2 E | do | [3]LCRP 29, CH-704. | 1965 | 150.8 | 1,997 | 600 | C, R | 12 | 99–170, 435–570 | 1,625 | 15.3 | 9-26-66 | 17.08 | 2-26-68 | 23.4 | 135 | C, E, G, L, T, P, PC, PT, Q |
| 36aaa | 2 S-9 E | do | CH-705 | 1963 | 152.7 | 250 | 250 | C | 12 | 88–169 | ---- | ---- | 11-30-66 | 18.37 | 2-26-68 | 22.8 | 120 | G, L, T |
| (C-8-23)27ada | 1 3/8 S-1 E | do | CH-701 | 1963 | 133.4 | 250 | 250 | C | 12 | 84–160 | 1,300 | 19 | 11-30-66 | 17.79 | 11-12-67 | 24.4 | 150 | G, L, R, T, PT, Q |
| 31daa | 2 1/2 S-2 W | do | YVI-2a(P) | 1965 | 113.6 | 182 | 152 | R | 1½ | 150–152 | ---- | ---- | 4-8-67 | 7.79 | 10-26-67 | 23.1 | 140.4 | G, L, T |
| 32bab | 2 S-1 3/4 W | do | YVI-1(P) | 1965 | 123.8 | 220 | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | L |
| 32bdc | 2 1/2 S-1 3/4 W | do | YVI-2b(P) | 1966 | 120.4 | 201 | 150 | R | 1½ | 148–150 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | G, L |
| 32caa1 | 2 5/8 S-1 5/8 W | Sinclair Oil Co. | Kryger 1 | 1925 | 120 | 1,400 | 1,400 | C | 16 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D, G, T |
| 33cdd | 3 S-0 5/8 W | Stardust Hotel. | [4]LCRP 13 | 1963 | 197 | 1,090 | 830 | C | 12–8 | 182–200 | ---- | ---- | 11-15-62 | 73.24 | 1963 | 27.8 | 182–200 | D, G, L, T, HA, Q |
| (C-9-22)28cbb | 7 1/2 S-5 E | U.S. Geological Survey. | LCRP 25 | 1964 | 204.6 | 2,318 | 2,002 | R, G | 12–8 | 862–2,002 | 595 | 10.8 | 12-3-66 | 53.95 | 11-7-67 | 24.8 | 158.6 | E, G, L, R, T, P, PT, Q, W |
| (C-9-23)5aab | 3 S-1 1/8 W | U.S. Bureau of Reclamation. | YM-1(P), CH-18YM. | 1966 | 190.4 | 391 | 230 | R | 1½ | 228–230 | ---- | ---- | 12-6-66 | 73.87 | 12-6-66 | 30.6 | 209.4 | G, L, T |
| 5abc | 3 1/4 S-1 1/2 W | do | YVI-4(P) | 1965 | 120.6 | 193 | 140 | R | 1½ | 138–140 | ---- | ---- | 12-8-66 | 6.65 | 11-2-67 | 29.5 | 139.6 | G, L, T |
| 5ddc2 | 4 S-1 1/4 W | do | CH-19YM | 1966 | 154.4 | 202 | 170 | R | 1½ | 168–170 | ---- | ---- | 12-6-66 | 37.73 | 11-29-67 | 29.0 | 168.4 | G, L, T |
| 6abb | 3 S-2 1/2 W | do | YVI-2(P) | 1965 | 120.7 | 203 | 140 | R | 1½ | 138–140 | ---- | ---- | 12-8-66 | 9.28 | 11-11-67 | 22.2 | 120.8 | G, L, T |
| 7baa | 4 S-2 5/8 W | do | YVI-5(P) | 1965 | 116.1 | 202 | 145 | R | 1½ | 143–145 | ---- | ---- | 12-22-66 | 5.72 | 10-26-67 | 23.1 | 143 | G, L, T |
| 8bdc1 | 4 7/16 S-1 5/8 W | do | YVI-7(P) | 1965 | 118.3 | 260 | 132 | R | 1½ | 130–132 | ---- | ---- | 12- -65 | 5.30 | ---- | ---- | ---- | L |
| 8dca | 4 13/16 S-1 1/4 W | do | YM-2(P) | 1966 | 155.1 | 232 | 180 | R | 1½ | 178–180 | ---- | ---- | 3-3-67 | 38.78 | 11-5-67 | 25.1 | 178.6 | G, L, T |
| 17dcd | 6 S-1 1/4 W | do | YM-3(P) | 1966 | 153.6 | 398 | 396.6 | R | 2 | 394.6–396.6 | ---- | ---- | 1-9-67 | 41.22 | 2-25-67 | 26.4 | 178.6 | G, L, T |
| 19bcd | 6 7/16 S-2 13/16 W | Colorado Basin Associates. | Newcomer and Pasquinelli[5]. | 1954 | 110 | 3,277 | 400 | R | 11 | ---- | ---- | ---- | 12-2-63 | 8.86 | 3-19-65 | 27.0 | 150 | G, L, T, P |
| 25dba1 | 7 1/2 S-2 3/4 E | U.S. Bureau of Reclamation. | CH-7A | 1964 | 204 | 710 | 650 | R | 4 | ---- | ---- | ---- | 2-26-64 | 37.50 | ---- | ---- | ---- | E, G, L |
| 25bda2 | 7 1/2 S-2 3/4 E | do | CH-7B | 1964 | 204 | 250 | 260 | R | 8 | 160–250 | 700 | 12.5 | 12-3-66 | 42.57 | 12-3-66 | 24.2 | 119 | PT, Q, T |
| 29aab | 7 S-1 1/4 W | Unknown[6] | ---- | 1920 | 118 | 730 | ---- | ---- | 6–4 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 29cad | 7 11/16 S-1 1/2 W | U.S Bureau of Reclamation. | YM-5(P) | 1967 | 185.3 | 416 | 257.6 | R | 2 | 255.6–257.6 | ---- | ---- | 2-25-67 | 71.71 | 2-25-67 | 26.4 | 213.5 | G, L, T |
| 30daa | 7 5/8 S-2 W | do | YM-5a(P) | 1967 | 183.6 | 392 | 247.5 | R | 2 | 245.5–247.5 | ---- | ---- | 2-25-67 | 79.33 | 11-5-67 | 27.3 | 250 | G, L, T |
| 31ada | 8 1/4 S-2 W | do | CH-16YM | 1966 | 183.4 | 492 | 230 | R | 1½ | 228–230 | ---- | ---- | 12-3-66 | 71.88 | 11-4-67 | 28.0 | 229.7 | G, L, T |
| 32bad | 8 1/8 S-1 1/2 W | do | CH-21YM | 1966 | 188 | 285 | 269½ | R | 1½ | 267½–269½ | ---- | ---- | 12-7-66 | 71.72 | 11-5-67 | 27.7 | 257.8 | G, L, T |
| 33cdd | 8 7/8 S-0 1/2 W | do | CH-20YM | 1966 | 196 | 64 | 49½ | R | 1½ | 47½–49½ | ---- | ---- | 8-30-66 | 29.16 | 3-7-67 | 23.3 | 49 | G, L, T |
| 35ccc | 9 S-1 E | do | CH-13YM | 1965 | 202.2 | 504 | 250 | R | 1½ | 248–250 | ---- | ---- | 12-3-66 | 34.85 | 11-4-67 | 26.7 | 238 | G, L, T |
| (C-9-24)8baa | 4 S-7 1/2 W | U.S. Geological Survey. | LCRP 28 | 1965 | 118.7 | 2,466 | 292 | R | 12 | ---- | ---- | ---- | 10-11-66 | 17.63 | 2-20-68 | 22.2 | 130 | C, E, G, L, T |
| 13cdd | 6 S-3 1/2 W | U.S. Bureau of Reclamation. | CH-3 | 1962 | 105 | 500 | 484 | C | 8 | 139–170 | 520 | 21.5 | 5-5-67 | 5.00 | 12-10-67 | 25.4 | 157 | G, L, T, MA, PT, Q, W |
| (C-9-25)24dcd1 | 7 S-9 3/8 W | do | CH-29VD | 1966 | 106.4 | 222 | 209.7 | R | 2 | 207.7–209.7 | ---- | ---- | 12-16-66 | 12.87 | 11-28-67 | 21.2 | 137.7 | G, L, T |
| 24dcd2 | 7 S-9 3/8 W | do | CH-29VD | 1966 | 106.4 | 210 | 149.3 | R | 1¼ | 147.3–149.3 | ---- | ---- | 12-16-66 | 12.92 | 3-3-67 | 22.8 | 147.3 | L, T |
| 24dcd3 | 7 S-9 3/8 W | do | CH-29VD | 1966 | 106.4 | 210 | 30.4 | R | 1¼ | 28.4–30.4 | ---- | ---- | 12-16-66 | 12.98 | 3-3-67 | 22.8 | 30 | L, T |
| 35cbd | 8 11/16 S-10 7/8 W | U.S. Geological Survey. | LCRP 9 | 1962 | 104 | 1,201 | 1,124 | R | 10–6 | 310–1,108 | ---- | ---- | 10-20-66 | 18.60 | 2-17-68 | 22.2 | 150 | C, D, E, L, T, PTp, Q, W |
| (C-10-23)6bbb | 9 S-2 15/16 W | U.S. Bureau of Reclamation | YM-7(P) | 1966 | 172.2 | 285 | 270 | R | 1½ | 268–270 | ---- | ---- | 12-3-66 | 69.72 | 3-23-68 | 27.3 | 210 | G, L, T |
| 31aaa | 14 1/8 S-2 1/8 W | M. P. Stewart Co. | Federal 1 | 1954 | 181 | 3,660 | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | L |
| 31bbb1 | 14 S-3 W | U.S. Geological Survey. | LCRP 1 | 1961 | 172.8 | 1,000 | 286 | C | 16 | 220–280 | 1,500 | 85 | 12-3-66 | 80.55 | 3-23-68 | 29.2 | 230 | G, L, R, T, HA, PC, PT, $C^{14}$, Q |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36ddd | 15 S-3 E | U.S. Bureau of Reclamation. | CH-22YM | 1966 | 285 | 211 | 211 | R | 2 | 209–211 | ---- | ---- | 12–14–66 | 188.42 | 12– 9–67 | 33.9 | 211.2 | G, L, T |
| (C–10–24)1bdd1 | 9 1/2 S-3 1/2 W | ---do | CH-1 | 1962 | 110 | 500 | 500 | C | 8 | 144–170 | ---- | ---- | 12–12–66 | 10.87 | 5– 5–67 | 28.0 | 177.6 | G, L, R, T, MA, Q |
| 1ccc | 10 S-4 W | ---do | CH-10VD | 1964 | 101 | 126 | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | L |
| 1cdd1 | 10 S-3 5/8 W | ---do | YVI-23(P) | 1966 | 103.4 | 197 | 160 | R | 1½ | 158–160 | ---- | ---- | 11– –65 | 4.70 | ---- | ---- | ---- | G, L |
| 1dad | 9 3/4 S-3 1/16 W | ---do | YM-8(P) | 1966 | 160 | 432 | 431.5 | R | ---- | 429.5–431.5 | ---- | ---- | 1– 9–67 | 55.10 | 11– 6–67 | 27.6 | 217.5 | G, L, T |
| 1dca | 9 3/4 S-3 5/16 W | ---do | YM-8a(P) | 1967 | 160.7 | 447 | 267.6 | R | 2 | 265.6–267.6 | ---- | ---- | 1–30–67 | 55.90 | 11– 6–67 | 27.4 | 238.3 | G, L, T, W |
| 5ddd | 10 S-7 W | ---do | CH-2 | 1962 | 100 | 500 | 500 | C | 8 | 170–215 | ---- | ---- | 12–11–66 | 9.30 | 11– 3–67 | 24.2 | 188 | G, L, R, T, HA, MA, Q |
| 12acd | 10 1/2 S-3 5/16 W | ---do | CH-14YM | 1965 | 140.3 | 257 | 182 | R | 1½ | 180–182 | ---- | ---- | 12– –65 | 41.0 | 3–23–68 | 26.1 | 180 | G, L, T |
| 12bdc | 10 1/2 S-3 11/16 W | ---do | YVI-24(P) | 1965 | 101.9 | 182 | 172 | R | 1½ | 170–172 | ---- | ---- | 11– –65 | 4.5 | ---- | ---- | ---- | L |
| 12ccc1 | 11 S-4 W | ---do | YVI-28(P) | 1966 | 101.5 | 183 | ---- | R | 1½ | ---- | ---- | ---- | ---- | ---- | 10–21–66 | 26.9 | 9.5 | L |
| 12cdd1 | 11 S-3 5/8 W | ---do | YVI-25(P) | 1965 | 101 | 182 | 150 | R | 1½ | 148–150 | ---- | ---- | 11– –65 | 2.40 | ---- | ---- | ---- | L |
| 12daa | 10 1/2 S-3 W | ---do | CH-15YM | 1965 | 163 | 240 | 212 | R | 1½ | 210–212 | ---- | ---- | 12–12–66 | 61.60 | 11– 6–67 | 25.2 | 212 | G, L, T |
| 13add | 11 1/2 S-3 1/16 W | ---do | YM-10(P) | 1967 | 171.6 | 347 | 347 | R | 2 | 345–347 | ---- | ---- | 2–25–67 | 75.55 | 2–25–67 | 26.1 | 208.6 | G, L, T |
| 13bcc1 | 11 7/16 S-4 W | ---do | YVI-27(P) | 1965 | 101 | 203 | 170 | R | 1½ | 168–170 | ---- | ---- | 10– –65 | 7.1 | ---- | ---- | ---- | L |
| 14aaa2 | 11 S-4 W | ---do | CH-12VD | 1965 | 101 | 153 | 60 | R | 1¼ | 58–60 | ---- | ---- | 10– –65 | 5.0 | 10–21–66 | 28.3 | ---- | L |
| 14ddd | 12 S-4 W | ---do | YM-11(P) | 1966 | 167.7 | 242 | 170 | R | 1½ | 168–170 | ---- | ---- | 12– 3–66 | 73.47 | 3–23–68 | 26.4 | 170 | G, L, T |
| 15dcc | 12 S-5 1/2 W | ---do | CH-11VD | 1964 | 98 | 186 | 166 | R | 1¼ | 164–166 | ---- | ---- | 12–11–66 | 5.94 | 4–16–67 | 23.9 | 165.5 | L, T, Q |
| 23ddd | 13 S-4 W | ---do | CH-17YM | 1966 | 166.9 | 462 | 200 | R | 1½ | 198–200 | ---- | ---- | 12– 3–66 | 74.35 | 3–23–68 | 26.3 | 200 | G, L, T |
| 24cbb | 12 9/16 S-3 15/16 W | Colorado Basin Associates. | Federal 1 | 1954 | 170 | 6,007 | 6,005 | R | 12–8 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D, E, L, P |
| 35bbb | 14 1/8 S-4 7/8 W | J. M. Hickey and Son. | Federal 1 | ---- | 161 | 880 | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | L |
| (C–10–25)26aba1 | 13 S-10 1/4 W | U.S Bureau of Reclamation. | CH-30VD | 1966 | 93 | 492 | 492 | R | 1¼–1 | 490–492 | ---- | ---- | 3– 7–67 | 11.92 | 11–28–67 | 23.2 | 162.4 | G, L, T |
| 26aba2 | 13 S-10 1/4 W | ---do | CH-30VD | 1966 | 93 | 492 | 440 | R | 1¼ | 438–440 | ---- | ---- | 3– 7–67 | 11.91 | 11–28–67 | 22.7 | 108 | G, L, T |
| 26aba3 | 13 S-10 1/4 W | ---do | CH-30VD | 1966 | 93 | 492 | 180.7 | R | 1¼ | 178.7–180.7 | ---- | ---- | 3– 7–67 | 12.21 | 11–28–67 | 22.8 | 48.7 | G, L, T |
| 26aba4 | 13 S-10 1/4 W | ---do | CH-30VD | 1966 | 93 | 492 | 21 | R | 1½ | 19–21 | ---- | ---- | 3– 7–67 | 12.16 | 11–28–67 | 24.6 | 19 | G, L, T |
| 35bbd | 14 1/8 S-10 13/16 W | U.S. Geological Survey. | LCRP 17 | 1964 | 94 | 2,946 | 1,998 | R, G | 14–8 | 520–1,998 | 388 | 4.9 | 2– 2–67 | 14.38 | 2–17–68 | 21.9 | 150 | C, E, L, HA, PTp, Q, W, T |
| (C–11–21)4ddc | 16 S-11 7/8 E | U.S. Bureau of Reclamation | CH-9YM | 1964 | 403.3 | 373 | 350 | R | 8–6 | 293.5–328.5 | ---- | ---- | 1–11–66 | 296.45 | 1–11–66 | 33.3 | 298.7 | L, T, W |
| (C–11–22)13acb | 17 5/16 S-8 9/16 E | ---do | CH-26YM | 1966 | 310.6 | 238 | 238 | R | 2 | 236–238 | ---- | ---- | 11– 3–66 | 201.0 | 11– 3–66 | 30.0 | 208.5 | G, L, T, W |
| 23dab | 18 9/16 S-7 7/8 E | U.S. Geological Survey. | LCRP 33 | 1967 | 381.6 | 328 | 328 | C, R | 6–2 | 326–328 | ---- | ---- | 2–21–67 | 303.21 | 2–20–67 | 30.6 | 310 | G, T, W |
| 24bab | 18 S-8 3/8 E | U.S. Bureau of Reclamation. | CH-27YM | 1966 | 322.3 | 270 | 270 | R | 2 | 268–270 | ---- | ---- | 11– 3–66 | 213.82 | 11– 3–66 | 30.0 | 231.0 | G, L, T, W |
| (C–11–23)34bbc | 20 3/16 S-0 1/16 E | U.S. Geological Survey. | LCRP 30 | 1965 | 163.0 | 623 | 600 | R, G | 12–10 | 160–600 | 1,340 | 10.0 | 12–14–66 | 85.45 | 12– 9–67 | 31.6 | 208.5 | C, E, G, L, T, PT, Q, W |
| (C–11–24)23bcb | 18 3/8 S-4 7/8 W | ---do | LCRP 10 | 1963 | 160.8 | 1,038 | 1,033 | C | 16–12 | 165–1,002 | 2,550 | 18.5 | 12–13–66 | 79.82 | 3–27–68 | 27.7 | 248.0 | D, G, L, R, T, HA, FC, PTp, Q, W |
| (C–11–25)11ab[2] | 16 1/16 S-10 3/8 W | Yuma Valley Oil and Gas Co. | Musgrove 1 | 1940 | 90 | 4,868 | 1,650 | R | 10 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D, E, L |
| (C–12–21)14dab | 23 1/2 S-13 13/16 E | U.S. Bureau of Reclamation. | CH-25YM | 1966 | 422.2 | 369 | 369 | R | 2 | 367–369 | ---- | ---- | 11–22–66 | 345.55 | 12– 7–67 | 31.5 | 367.7 | L, T, W |
| 17cbc | 23 11/16 S-10 E | ---do | CH 23YM | 1966 | 356 | 320 | 320 | R | 2 | 318–320 | ---- | ---- | 12–14–66 | 285.21 | 12– 7–67 | 35.4 | 290 | G, L, T, W |
| 25add | 25 1/2 S-15 E | ---do | CH-24YM | 1966 | 455.4 | 410 | 410 | R | 2 | 408–410 | ---- | ---- | 10–25–66 | 383.60 | 12– 7–67 | 32.5 | 407.9 | G, L, T, W |
| (C–12–22)9bab | 22 S-5 5/16 E | U.S. Geological Survey. | LCRP 24 | 1965 | 233.5 | 415 | 415 | C | 12 | 318–346 | 600 | 65.0 | 12–14–66 | 158.82 | 12– 9–67 | 35.6 | 328.5 | D, G, L, T, PT, Q, W |
| (C–13–20)2abd1 | 27 1/8 S-19 5/8 E | U.S. Bureau of Reclamation | CH-28YM | 1966 | 577.5 | 1,427 | 1,200 | R | 1¼ | 1,198–1,200 | ---- | ---- | 11–22–66 | 501.25 | 12– 7–67 | 37.6 | 899.8 | A, Cc, G, L, T, E |
| 2abd2 | 27 1/8 S-19 5/8 E | ---do | CH-28YM | 1966 | 577.5 | 1,427 | 600 | R | 2 | 598–600 | ---- | ---- | 11–22–66 | 501.63 | ---- | ---- | ---- | A, Cc, G, L, T |
| 16S/22E–21Dbb | 2 N-3 W | ---do | CH-14RD | 1965 | 128 | 507 | 120 | R | 1¼ | 118–120 | ---- | ---- | 12–16–66 | 7.40 | 11–10–67 | 25.1 | 119.5 | C, E, G, L, T |
| 23Caa | 2 N-0 5/8 W | ---do | CH-8 | 1964 | 128.5 | 360 | 344 | C | 12 | 96–104 | ---- | ---- | 12–16–66 | 6.96 | 10–29–67 | 22.5 | 178.0 | G, L, R, T, HA, Q |
| 29Gca2 | 0 5/8 N-3 3/8 W | U.S. Geological Survey. | LCRP 26 | 1965 | 125.4 | 1,777 | 1,769 | R, G | 12–8 | 125–1,127 1,368–1,769 | 1,100 | 8.7 | 4–13–65 | 14.21 | 3–26–65 | 23.3 | 130.0 | A, Cc, Dip, E, G, L, R, T, PTc, Q, W |

See footnotes at end of table.

TABLE 16.—*Water-test wells and oil-test wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16S/23E–8Ecc | 3 1/2 N–2 E | U.S. Bureau of Reclamation. | CH–5 | 1962 | 130 | 500 | 500 | C | 8 | 110–141 | 570 | 6.0 | 12–16–66 | 7.74 | 2–26–68 | 21.9 | 118.0 | D, G, L, R, T, MA, PT, Q |
| 10Rcc | 3 N–4 13/16 E | U.S. Geological Survey. | LCRP 23 | 1964 | 143.8 | 715 | 702 | C | 12 | 120–548<br>634–694 | 650 | 4.0 | 11– 3–66 | 14.29 | 10–10–67 | 22.3 | 118.0 | D, G, L, PC, PT, PTp, C[14], Q, W |

[1] Well backfilled to 435 ft after completion of first pumping test.
[2] Well destroyed.
[3] U.S. Geol. Survey deepened U.S. Bur. of Reclamation test well CH–704 to 1,997 ft from 600 ft; pilot hole not completed.
[4] U.S. Geol. Survey deepened original well of Stardust Hotel from 830 to 1,090 ft.
[5] Well also known as Elliott 1.
[6] Old oil test reported in Allen and Press (1962, p. 2864); reported to have penetrated granite at 730 ft.

TABLE 17.—*U.S. Geological Survey auger test holes and test wells, Yuma County Water Users' Association deep observation wells, and selected U.S. Bureau of Reclamation observation wells*

Well numbers: Location of well according to the Federal Land classification. See page H17 for description of well-numbering system.
Coordinates: Location of well according to grid system used by U. S. Bureau of Reclamation in Yuma area. See text for explanation of grid system.
Owner or user. Government agency that drilled the well or had it drilled.
Other number: Number assigned to well by owner or user.
Year completed: Known or reported year of completion of well.
Altitude of land surface: Average altitude of land surface at well above mean sea-level datum. Altitudes given to nearest foot are approximate and were obtained from topographic maps; altitudes given to decimal fractions of a foot were obtained by a spirit leveling to a reference point at the well and are much more accurate. Log information, water-level data, and temperature 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—A, drilled with power auger; J, drilled by water jetting; R, drilled with rotary-mud equipment.
Casing diameter: Nominal inside diameter in inches of pipe used in well.
Water level: Date measured by Geological Survey or reported by other agency. Depth to water in feet below land-surface datum.
Water temperature: Date measured by the Geological Survey. Temperature, in degrees Celsius, measured with a thermistor or a maximum thermometer near the bottom of the well or in a few places just below the water table. A few of the water temperatures reported may have been affected by pumping with air.
Other data available: Additional information about the well available in files of the Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the letter symbols—D, driller's log; G. gamma-ray log; L, lithologic log made by a geologist from drill cuttings and other information; R, fluid-resistivity log; T, temperature log; P, paleontological studies of drill cuttings; Q, chemical quality-of-water data; W, periodic or continuous water-level records.

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C– 7–21)33caa | 3 3/8 N–11 7/16 E | U.S. Geological Survey. | --- | 1964 | 240 | 77 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |
| 33cdd1 | 3 1/16 N–11 7/16 E | ---do | --- | 1964 | 195 | 27 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |
| 33cdd2 | 3 1/16 N–11 7/16 E | ---do | --- | 1964 | 195 | 57 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |
| (C– 7–22)28acc | 4 1/2 N–5 9/16 E | ---do | --- | 1965 | 140 | 147 | 144 | A | 1½ | 11– 1–66 | 12.38 | 11– 2–67 | 22.1 | 143.0 | D, T, Q |
| (C– 8–21)3dad | 2 1/4 N–12 15/16 E | ---do | --- | 1964 | 160 | 92 | 91½ | A | 1¼ | ------- | ---- | ------- | ---- | --------- | D, Q |
| 4had1 | 2 13/16 N–11 7/16 E | ---do | --- | 1964 | 185 | 67 | 44½ | A | 1¼ | ------- | ---- | ------- | ---- | --------- | D, Q |
| 4bad2 | 2 7/8 N–11 7/16 E | ---do | --- | 1964 | 180 | 47 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |
| 10aaa1 | 1 7/8 N–12 7/8 E | ---do | --- | 1964 | 180 | 40 | 32½ | A | 1¼ | 5– –64 | 29.49 | ------- | ---- | --------- | D, Q |
| 10aaa2 | 2 N–12 15/16 E | ---do | --- | 1964 | 180 | 70 | 62½ | A | 1¼ | 5– –64 | 43.90 | ------- | ---- | --------- | D, Q |
| 10aad | 1 13/16 N–12 7/8 E | ---do | --- | 1964 | 185 | 30 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |
| 10adc | 1 5/8 N–12 3/4 E | ---do | --- | 1964 | 195 | 17 | ---- | A | ------ | ------- | ---- | ------- | ---- | --------- | D |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-8-22)3ccb | 2 1/8 N-6 E | do | | 1965 | 143 | 147 | 114 | A | 1½ | 10-31-66 | 5.51 | 11-9-67 | 24.6 | 106.0 | D, T, Q |
| 31bda1 | 2 3/8 S-3 1/2 E | do | | 1961 | 136.8 | 20 | 20 | A | 1¼ | 3-27-61 | 1.25 | | | | |
| 31bda2 | 2 3/8 S-3 1/2 E | do | | 1961 | 136.8 | 72 | 72 | A | 1¼ | 3-24-61 | 2.67 | | | | |
| 31bda3 | 2 3/8 S-3 1/2 E | do | | 1961 | 136.8 | 136 | 136 | A | 1¼ | 3-24-61 | 2.82 | | | | |
| 31dbb2 | 2 1/2 S-3 1/2 E | do | | 1961 | 141.1 | 21 | 21 | A | 1¼ | 3-24-61 | 1.04 | | | | |
| 31dbb3 | 2 1/2 S-3 1/2 E | do | | 1961 | 141.1 | 73 | 73 | A | 1¼ | 3-22-61 | 1.86 | | | | |
| 31dbb4 | 2 1/2 S-3 1/2 E | do | | 1961 | 141.1 | 135 | 135 | A | 1¼ | 3-21-61 | 2.35 | | | | |
| 35ccc | 3 S-7 E | U.S. Bureau of Reclamation. | | 1947 | 214.2 | 110 | 110 | R | 2½ | 9-22-66 | 79.16 | 9-26-66 | 23.9 | 85.0 | D, W |
| (C-8-23)20bdb | 0 1/4 S-1 5/8 W | U.S. Geological Survey. | | 1965 | 129.3 | 192 | 146 | A | 1¼ | 4-8-67 | 16.04 | 11-10-67 | 22.1 | 145.0 | T, Q |
| 20dad | 0 9/16 S-1 W | do | | 1965 | 132 | 117 | [1]116 | A | 1¼ | | | 5-11-65 | 24.4 | 114-116 | D. Q |
| 29cbb | 1 1/2 S-2 W | do | | 1965 | 124 | 147 | | A | | | | | | | |
| 31ccc | 3 S-3 W | Yuma County Water Users' Association. | 6 | 1956 | 117.8 | 112 | 112 | J | 1½ | 4-25-67 | 6.43 | 10-24-67 | 22.9 | 110.9 | G, L, T. W |
| 32bbb | 2 S-2 W | U.S. Geological Survey. | | 1965 | 122 | 172 | | A | | | | | | | D |
| 32bcc [2] | 2 1/2 S-2 W | Yuma County Water Users' Association. | 23 | 1956 | 122.0 | 136 | 136 | J | 1½ | | | | | | L |
| 32ccc | 3 S-2 W | do | 5 | 1956 | 119.6 | 136 | 136 | J | 1½ | 12-8-66 | 7.08 | 4-12-67 | 23.3 | 31.0 | L, W |
| 32dbc3 | 2 11/16 S-1 1/2 W | do | 3 | 1956 | 120.8 | 135 | 135 | J | 1½ | 3-3-67 | 19.06 | 11-2-67 | 23.3 | 133.5 | G, L, T, W |
| 33cbc1 | 2 3/4 S-0 15/16 W | do | 22 | 1956 | 203.8 | 120 | 120 | J | 1½ | | | | | | L, W |
| 33cbc2 | 2 3/4 S-0 15/16 W | do | 24 | 1956 | 203.8 | 218 | 218 | J | 4 | 4-22-67 | 86.34 | 11-2-67 | 29.9 | 219.3 | G, L, T, W |
| (C-8-24)25cba | 1 1/2 S-3 3/4 W | U.S. Geological Survey | | 1965 | 120 | 147 | 126 | A | 1¼ | 5-10-67 | 8.09 | 2-19-68 | 22.3 | 126 | D, G, T, Q |
| 27dcc | 2 S-5 1/2 W | do | | 1965 | 115 | 172 | 126 | A | 1¼ | | | | | | Q |
| 33ccc | 3 S-7 W | Yuma County Water Users' Association. | 59 | 1956 | 117.1 | 118 | | J | 1½ | 12-6-67 | 18.60 | 2-20-68 | 21.6 | 115 | G, L, T, W |
| 33ddd | 3 S-6 W | do | | | 118 | | | | 1 | 11-10-67 | 12.01 | 11-10-67 | 22.2 | 117.0 | T |
| 34cda | 2 3/4 S-5 1/2 W | do | 84 | 1956 | 118 | 146 | 140 | J | | | | | | | |
| 36ccc | 3 S-4 W | do | 63 | 1956 | 115.8 | 128 | 128 | J | 1½ | 12-6-67 | 8.40 | 10-26-67 | 23.7 | 127 | G, L, T, W |
| (C-9-21)4bbb | 3 S-11 E | U.S. Bureau of Reclamation. | | 1958 | 277.7 | 183 | 183 | R | 1½ | 9-26-66 | 143.2 | 9-26-66 | 26.1 | 146.1 | D, G, Q, W |
| 6bbb | 3 S-9 E | do | | 1951 | 222.9 | 160 | 160 | R | 2 | 9-26-66 | 88.46 | 9-26-66 | 25.0 | 92.8 | D, G, W |
| 7ccc | 5 S-9 E | do | | 1958 | 261.4 | 152 | 151 | R | 1½ | 9-27-66 | 125.18 | 9-27-66 | 25.3 | 138.8 | D, G, W |
| 8aaa | 4 S-11 E | do | | 1958 | 299.3 | 200 | 193 | R | 1½ | 9-26-66 | 165.16 | 4-27-65 | 27.8 | 190-193 | D, T, Q, W |
| 9cdd | 5 S-11 1/2 E | do | | 1958 | 330.9 | 223 | 223 | R | 1 | 9-27-66 | 197.34 | 9-27-66 | 28.6 | 201.0 | D, W |
| 19ccb | 6 3/4 S-9 E | do | | 1958 | 321.0 | 223 | 223 | R | 1½ | 12-6-66 | 184.48 | 12-6-66 | 27.2 | 220.0 | D, G, T, W |
| 21dcc | 7 S-11 1/2 E | do | | 1958 | 400.6 | 303 | 303 | R | 1 | 12-6-66 | 269.37 | 12-6-66 | 30.3 | 299.0 | D, W |
| (C-9-22)1bbc | 3 3/16 S-8 E | do | | 1951 | 211.2 | 150 | 150 | R | 2 | 9-26-66 | 76.83 | 9-26-66 | 24.4 | 82.2 | D, W |
| 5bbb1 | 3 S-4 E | U.S. Geological Survey. | | 1961 | 142.4 | 162 | 162 | A | 1¼ | | | | | | |
| 5bbb2 | 3 S-4 E | do | | 1961 | 143.2 | 84 | 84 | A | 1¼ | | | | | | |
| 5bbb3 | 3 S-4 E | do | | 1961 | 141.4 | 32 | 32 | A | 1¼ | | | | | | |
| 5bbc | 3 3/16 S-4 E | do | | 1966 | 145 | 187 | 181¼ | A | 1½ | | | 3-24-66 | 23.9 | 179¼-181¼ | D, G, Q |
| 6ada | 3 5/16 S-4 E | do | | 1966 | 172 | 187 | 169 | A | 1½ | | | 3-24-66 | 23.9 | 166-169 | D, G, Q |
| 6bbb | 3 S-3 E | U.S. Bureau of Reclamation. | | 1947 | 216.0 | 113 | 113 | R | 2½ | 9-30-66 | 75.34 | 9-30-66 | 25.0 | 99.5 | D, G, T, W |
| 10aaa | 4 S-7 E | do | | 1947 | 215.3 | 110 | 109 | R | 2½ | 9-23-66 | 78.89 | 9-23-66 | 24.4 | 83.5 | D, G, W |
| 12aaa2 | 4 S-9 E | do | | 1951 | 249.5 | 150 | 150 | R | 2 | 9-26-66 | 114.84 | 9-26-66 | 24.4 | 117.0 | D, G, W |
| 12bbb | 4 S-8 E | do | | 1958 | 211.0 | 103 | 103 | R | 1½ | 9-23-66 | 75.10 | 9-23-66 | 24.4 | 90.3 | D, G, W |
| 13bbb | 5 S-8 E | do | | | 223.6 | 129 | 129 | R | 2 | 9-23-66 | 86.21 | 9-23-66 | 24.7 | 91.4 | D, G, W |
| 16aaa | 5 S-6 E | do | | 1947 | 213.5 | 110 | 110 | R | 2½ | 3-16-67 | 71.31 | 3-16-67 | 23.6 | 107.1 | D, G, T, W |
| 16ccc | 6 S-5 E | do | | 1947 | 205.4 | 110 | 110 | R | 2½ | 12-5-66 | 54.64 | 12-5-66 | 24.7 | 106.8 | D, G, T, W |
| 17aaa | 5 S-5 E | do | | 1947 | 207.6 | 110 | 110 | R | 2½ | 12-5-66 | 60.82 | 12-5-66 | 24.4 | 101.3 | D, G, T, W |
| 22aaa | 6 S-7 E | do | | 1951 | 220.0 | 129 | 129 | R | 2 | 9-23-66 | 78.24 | 4-27-65 | 25.6 | 126-129 | D, G, T, Q, W |
| 22ccc | 7 S-6 E | do | | | 207.2 | 120 | 120 | R | 2½ | 9-23-66 | 60.13 | 9-23-66 | 25.3 | 105.1 | D, G, T, W |
| (C-9-23)2cdd | 4 S-1 1/2 E | do | | 1947 | 209.5 | 150 | 100 | R | 2½ | 9-28-66 | 57.40 | 9-28-66 | 27.8 | 62.0 | D, W |
| 3aaa | 3 S-1 E | do | | 1947 | 205.6 | 111 | 108 | R | 1½-1 | | | | | | D, W |
| 4cdd | 4 S-0 1/2 W | do | | 1947 | 193.5 | 101 | 100 | R | 2½ | 4-10-67 | 72.46 | 11-2-67 | 28.0 | 90.3 | D, T, W |
| 5aba | 3 S-1 3/8 W | Yuma County Water Users' Association. | 4 | 1956 | 124.8 | 137 | 137 | J | 1½ | 12-4-67 | 4.4 | | | | L |
| 5dbb | 3 1/2 S-1 1/2 W | do | 39 | 1956 | 119.4 | 135 | 135 | J | 1½ | 12-4-67 | 3.24 | 4-21-67 | 28.9 | 136.0 | G, L, T, W |
| 5dbc | 3 3/4 S-1 3/8 W | do | 38 | 1956 | 119.0 | 135 | 135 | J | 1½ | 3-3-67 | 4.64 | 3-3-67 | 28.6 | 135.0 | G, L, T, W |
| 5dcc | 4 S-1 1/2 W | do | 34 | 1956 | 120.6 | 130 | 130 | J | 1½ | 12-4-67 | 5.9 | 12-1-66 | 28.9 | 129.6 | G, L, T, W |
| 5ddc1 | 4 S-1 1/4 W | U.S. Bureau of Reclamation. | | 1947 | | 64 | 62 | R | 2 | | | | | | D, W |
| 5ddd | 4 S-1 W | do | | 1947 | 171.6 | 84 | 84 | R | 2 | 9-30-66 | 58.30 | 9-30-66 | 27.8 | 59.0 | D, G, W |
| 6bbb | 3 S-3 W | U.S. Geological Survey. | | 1965 | 118.0 | 172 | 128 | A | 1¼ | 10-18-66 | 7.58 | 10-24-67 | 22.4 | 126.4 | D, G, T, Q |
| 6ccc | 4 S-3 W | Yuma County Water Users' Association. | 35 | 1956 | 116.6 | 135 | 135 | J | 1½ | 12-6-67 | 7.0 | | | | L, W |
| 7ccc | 5 S-3 W | do | 88 | 1957 | 116.2 | 140 | 140 | J | 1½ | 10-10-66 | 9.47 | 12-22-66 | 26.4 | 11.7 | L |
| 8acc | 4 1/2 S-1 3/8 W | U.S. Bureau of Reclamation | | 1947 | 173.8 | 74 | 73 | R | 2 | 3-3-67 | 60.03 | 3-3-67 | 28.1 | 69.5 | D, G, W |
| 8add | 4 1/2 S-1 W | do | | 1947 | 193.3 | 104 | 104 | R | 2 | 9-30-66 | 72.88 | 9-30-66 | 24.4 | 78.7 | D, G, W |

See footnotes at end of table.

TABLE 17.—*U.S. Geological Survey auger test holes and test wells, Yuma County Water Users' Association deep observation wells, and selected U.S. Bureau of Reclamation observation wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C–9–23) 8bbb | 4 S–2 W | Yuma County Water Users' Association. | 33 | 1956 | 120.9 | 135 | 135 | J | 1½ | 12– 1–66 | 9.38 | 11–11–67 | 25.3 | 134.0 | G, L, T, W |
| 8caa | 4 1/2 S–1 5/8 W | do | 85 | 1957 | 122.9 | 146 | 146 | J | 1½ | 10–18–66 | 9.22 | 11– 5–67 | 29.0 | 142.0 | L, T, W |
| 8ccc | 5 S–2 W | do | 25 | 1956 | 116.0 | 131 | 131 | J | 1½ | 10–18–66 | 7.25 | 11–11–67 | 24.2 | 130.0 | G, L, T, W |
| 8dcc | 5 S–1 1/2 W | do | 26 | 1956 | 115.7 | 124½ | 124½ | J | 1½ | 10–18–66 | 9.20 | 11–11–67 | 26.1 | 126.5 | G, L, T, W |
| 8ddc | 5 S–1 1/8 W | U.S. Bureau of Reclamation. | --- | 1947 | 157.7 | 64 | 59 | R | 2½ | ---- | ---- | ---- | ---- | ---- | D, G, W |
| 8ddd1 | 5 S–1 W | do | --- | 1947 | 193.4 | 106 | 106 | R | 2½ | 9–29–66 | 72.31 | 9–29–66 | 24.7 | 76.0 | D, G, W |
| 8ddd2 | 5 S–1 W | Yuma County Water Users' Association. | 40 | 1956 | 193.5 | 211½ | 211½ | J | 2 | 5–14–67 | 73.93 | 11– 5–67 | 26.8 | 212.4 | G, L, T, W |
| 11bbb2 | 4 S–1 E | U.S. Bureau of Reclamation. | --- | 1947 | 204.5 | 83½ | 83½ | R | 2½ | 9–30–66 | 61.48 | 9–30–66 | 27.5 | 68.3 | D |
| 12baa1 | 4 S–2 1/2 E | do | --- | 1956 | 211.5 | 83 | 83 | R | 2 | 9–28–66 | 63.12 | 9–28–66 | 23.3 | 64.1 | D, G, W |
| 12baa2 | 4 S–2 1/2 E | do | --- | 1956 | 211.5 | 60 | ---- | R | 2 | ---- | ---- | ---- | ---- | ---- | D |
| 13aaa | 5 S–3 E | do | --- | 1947 | 209.1 | 100 | 99 | R | 2½ | 12– 8–66 | 54.60 | 12– 8–66 | 23.6 | 73.0 | D, T, W |
| 13bdd1 | 5 1/2 S–2 1/2 E | do | --- | 1956 | 210.5 | 40 | ---- | R | ---- | 9– 8–66 | 25.61 | ---- | ---- | ---- | D, W |
| 13bdd2 | 5 1/2 S–2 1/2 E | do | --- | 1956 | 210.5 | 93 | 93 | R | 2 | ---- | ---- | ---- | ---- | ---- | D, W |
| 13bdd3 | 5 1/2 S–2 1/2 E | do | --- | ---- | ---- | ---- | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | |
| 13bdd4 | 5 1/2 S–2 1/2 E | do | --- | ---- | ---- | ---- | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | |
| 13bdd5 | 5 1/2 S–2 1/2 E | do | --- | ---- | ---- | ---- | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | |
| 13cbb1 | 5 1/2 S–2 E | do | --- | 1955 | 208.4 | 42 | 42 | R | 1½ | 9–28–66 | 35.56 | 9–28–66 | 22.8 | 36.5 | D, G, W |
| 13cbb2 | 5 1/2 S–2 E | do | --- | 1956 | 208.4 | 103 | 103 | R | 1½ | 12– 8–66 | 48.86 | 12– 8–66 | 23.3 | 97.5 | D, G, T, W |
| 13ddd | 6 S–3 E | do | --- | 1947 | 204.4 | 103 | 103 | R | 2½ | 12– 8–66 | 44.55 | 12– 8–66 | 24.2 | 79.4 | D, G, T. W |
| 14bdd | 5 1/2 S–1 1/2 E | do | --- | 1947 | 205 | 105 | 100 | R | 2½ | ---- | ---- | ---- | ---- | ---- | D, W |
| 14ccc1 | 6 S–1 E | U.S. Geological Survey. | --- | 1961 | 203.0 | 56 | 56 | A | 1¼ | 9–28–66 | 45.56 | 9–28–66 | 23.9 | 49.5 | D |
| 14ccc2 | 6 S–1 E | do | --- | 1961 | 203.0 | 106 | 106 | A | 1¼ | 9–28–66 | 46.00 | 9–28–66 | 23.9 | 58.5 | D |
| 14ccc3 | 6 S–1 E | do | --- | 1961 | 203.0 | 170 | 170 | A | 1¼ | 9–28–66 | 45.85 | 12– 5–66 | 23.6 | 61.4 | D, T |
| 14cdd | 6 S–1 1/2 E | U.S. Bureau of Reclamation. | --- | 1947 | ---- | 150 | 100 | R | 2½ | ---- | ---- | ---- | ---- | ---- | D, W |
| 15bbb | 5 S–0 | do | --- | 1947 | 184.7 | 103 | 103 | R | 2 | 12– 8–66 | 47.33 | 12– 8–66 | 27.8 | 97.4 | D, T, W |
| 16bcc | 5 1/2 S–1 W | do | --- | ---- | 183.9 | 106 | 105 | R | 2½ | 12–15–66 | 62.64 | 12–15–66 | 25.3 | 92.5 | D, G, T, W |
| 16ccc | 6 S–1 W | do | --- | 1946 | 177.0 | 106 | 105 | R | 2½ | 12–15–66 | 54.85 | 12–15–66 | 25.0 | 86.0 | D, G, T, W |
| 17abc2 [2] | 5 1/4 S–1 1/2 W | Yuma County Water Users' Association. | 37 | 1956 | 115.0 | 125 | 125 | J | 1½ | ---- | ---- | ---- | ---- | ---- | L |
| 17abd | 5 1/4 S–1 1/4 W | do | 31 | 1956 | 120.5 | 132½ | 132½ | J | 1½ | 12– 1–66 | 8.38 | 12–14–67 | 27.0 | 132.2 | G, L, T, W |
| 17acc2 | 5 1/2 S–1 1/2 W | do | 36 | 1956 | 115.8 | 135 | 135 | J | 1½ | 10– 5–66 | 5.80 | 12–14–67 | 28.1 | 131.5 | G, L, T, W |
| 17bdb | 5 1/4 S–1 3/4 W | do | 32 | 1956 | 117.1 | 125 | 125 | J | 1½ | 12– 1–66 | 10.94 | 12–14–67 | 24.8 | 124.8 | G, L, T, W |
| 17ccc | 6 S–2 W | do | 2 | 1956 | 113.4 | 120 | 120 | J | 1½ | 12– 1–66 | 10.12 | 12–14–67 | 24.0 | 120.0 | L, T, W |
| 17cdd | 6 S–1 1/2 W | do | 1 | 1956 | 115.0 | 117 | 117 | J | 1½ | 12– 1–66 | 9.29 | 12– 1–66 | 26.7 | 11.0 | L, W |
| 17daa | 5 1/2 S–1 1/8 W | U.S. Bureau of Reclamation. | --- | 1947 | 149 | 64 | 62 | R | 2½ | ---- | ---- | ---- | ---- | ---- | D, G, W |
| 17ddc | 6 S–1 1/4 W | do | --- | ---- | 152.9 | 64 | ---- | R | 2½ | 2–25–67 | 38.72 | 2–25–67 | 25.8 | 44 | D, G, W |
| 19aaa1 | 6 S–2 W | U.S. Geological Survey | --- | 1961 | 112.7 | 34 | 34 | A | 1¼ | 2–28–61 | 9.53 | ---- | ---- | ---- | D, Q |
| 19aaa2 | 6 S–2 W | do | --- | 1961 | 112.7 | 63 | 63 | A | 1¼ | 2–28–61 | 11.44 | ---- | ---- | ---- | D, Q |
| 19aaa3 | 6 S–2 W | do | --- | 1961 | 112.7 | 81 | 81 | A | 1¼ | 2–28–61 | 10.25 | ---- | ---- | ---- | D, Q |
| 19aaa4 | 6 S–2 W | do | --- | 1961 | 112.7 | 136 | 136 | A | 1¼ | 2–28–61 | 9.78 | ---- | ---- | ---- | D, Q |
| 19ccc | 7 S–3 W | do | --- | 1965 | 109 | 172 | 149 | A | 1¼ | 11–29–66 | 8.73 | 11– 2–67 | 26.8 | 149.0 | D, T, Q, W |
| 20dbb | 6 1/2 S–1 7/16 W | Yuma County Water Users' Association. | 30 | 1956 | 116.4 | 140 | 140 | J | 1½ | 10–11–66 | 6.49 | 4–13–67 | 25.0 | 139.9 | L, T, W |
| 21bdd1 | 6 1/2 S–0 1/2 W | U.S. Bureau of Reclamation. | --- | ---- | 193.2 | ---- | 217.9 | R | ---- | 9– 8–66 | 54.95 | 12– 3–66 | 24.2 | 209.4 | T, W |
| 21bdd2 | 6 1/2 S–0 1/2 W | do | --- | ---- | 193.2 | ---- | 165.8 | R | ---- | 9– 8–66 | 42.25 | 9–28–66 | 22.8 | 43.4 | W |
| 21bdd3 | 6 1/2 S–0 1/2 W | do | --- | ---- | 193.2 | ---- | 147.5 | R | ---- | 9– 8–66 | 41.97 | 9–28–66 | 22.2 | 46.7 | W |
| 21bdd4 | 6 1/2 S–0 1/2 W | do | --- | ---- | 193.2 | ---- | ---- | R | ---- | 9– 8–66 | 40.09 | 9–28–66 | 22.2 | 42.4 | W |
| 21bdd5 | 6 1/2 S–0 1/2 W | do | --- | ---- | 193.1 | 101 | 101 | R | 2½ | 9– 8–66 | 39.98 | 9–28–66 | 21.7 | 40.4 | D, W |
| 22ccc1 | 7 S–0 | do | --- | 1953 | 193.2 | 70 | ---- | R | 2½ | 9–28–66 | 30.66 | 9–28–66 | 22.2 | 33.4 | D, W |
| 22ccc2 | 7 S–0 | do | --- | 1947 | 193.2 | 119 | 117 | R | 1½ | 4–13–67 | 35.24 | 4–13–67 | 23.1 | 100.4 | D, G, T, W |
| 23ccc | 7 S–1 E | do | --- | 1951 | 199.4 | 72 | ---- | R | ---- | ---- | ---- | ---- | ---- | ---- | D, W |
| 25aaa | 7 S–3 E | do | --- | 1947 | 205.4 | 103 | 103 | R | 2 | 3–16–67 | 45.47 | 3–16–67 | 24.4 | 93.7 | D, G, T, W |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25bbb | 7 S-2 E | ---do | --- | 1947 | 198.5 | 100 | 100 | R | 2 | 12- 7-66 | 33.31 | 11-29-67 | 24.3 | 95.9 | D, G, T, W |
| 27bba | 7 1/8 S-0 | ---do | --- | 1963 | 195 | 102 | 102 | R | 1¼ | 8-23-63 | 21.6 | ------- | ---- | --------- | L |
| 27bbc | 7 1/4 S-0 | ---do | --- | 1963 | 195 | 80 | 72 | R | 1¼ | 8-23-63 | 5.0 | ------- | ---- | --------- | L |
| 27bbd | 7 1/4 S-0 1/8 E | ---do | --- | 1963 | 195 | 90 | ---- | R | ------ | 8-23-63 | 26.6 | ------- | ---- | --------- | L |
| 27bcc | 7 1/2 S-0 1/8 E | ---do | --- | 1963 | 192 | 52 | 28 | R | 1¼ | 8-23-63 | 4.0 | ------- | ---- | --------- | L |
| 27cba | 7 5/8 S-0 1/8 E | ---do | --- | 1963 | 195 | 102 | 102 | R | 1¼ | 8-22-63 | 26.4 | ------- | ---- | --------- | L |
| 27cbb | 7 5/8 S-0 | ---do | --- | 1963 | 195 | 102 | 102 | R | 1¼ | 12- 6-65 | 17.2 | ------- | ---- | --------- | L |
| 27ddd | 8 S-1 E | ---do | --- | 1947 | 201.5 | 100 | 100 | R | 2½ | 12- 7-66 | 35.46 | 12- 7-66 | 24.2 | 92.4 | D, G, T, W |
| 28acc1 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 209.7 | R | 1 | 9- 8-66 | 47.17 | 11-11-67 | 25.6 | 202.2 | D, T, W |
| 28acc2 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 172.6 | R | 1 | 9- 8-66 | 36.53 | ------- | ---- | --------- | D, W |
| 28acc3 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 185.4 | R | 1 | 9- 8-66 | 25.52 | ------- | ---- | --------- | D, W |
| 28acc4 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 109.0 | R | 1 | 9- 8-66 | 26.12 | ------- | ---- | --------- | D, W |
| 28acc5 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 54.6 | R | 1 | 9- 8-66 | 10.75 | ------- | ---- | --------- | D, W |
| 28acc6 | 7 1/2 S-0 1/2 W | ---do | --- | 1957 | 192.7 | 212 | 21.0 | R | 1 | 9- 8-66 | 10.35 | ------- | ---- | --------- | D, W |
| 28cad1 | 7 3/4 S-0 1/2 W | ---do | --- | ---- | 190.1 | 40 | ---- | R | ------ | ------- | ---- | ------- | ---- | --------- | D, G, W |
| 28cad2 | 7 3/4 S-0 1/2 W | ---do | --- | 1954 | 190.1 | 93 | ---- | R | ------ | ------- | ---- | ------- | ---- | --------- | D, G, W |
| 28dcc1 | 8 S-0 1/2 W | ---do | --- | 1953 | 191.4 | 50 | ---- | R | 2½ | ------- | ---- | ------- | ---- | --------- | D, G, W |
| 28dcc2 | 8 S-0 1/2 W | ---do | --- | 1947 | 191.4 | 101 | 101 | R | 2 | ------- | ---- | ------- | ---- | --------- | D, W |
| 28ddd1 | 8 S-0 | ---do | --- | 1953 | 197.5 | 60 | ---- | R | ------ | ------- | ---- | ------- | ---- | --------- | D, W |
| 28ddd2 | 8 S-0 | ---do | --- | 1947 | 197.5 | 101 | 101 | R | 2½ | 12- 7-66 | 33.43 | 12- 7-66 | 24.2 | 87.0 | D, G, T, W |
| 29aaa1 | 7 S- 1 W | ---do | --- | 1946 | 188.5 | 125 | 115½ | R | 2½ | 9-22-66 | 52.57 | 9-22-66 | 26.1 | 56.8 | D, W |
| 29aaa2 | 7 S- 1 W | Yuma County Water Users' Association. | 27 | 1956 | 188.5 | 221 | 221 | J | 2 | 9-22-66 | 64.22 | 11-12-67 | 25.4 | 220.7 | G, L, T, W |
| 29aba1 | 7 S- 1 1/4 W | ---do | 28 | 1956 | 116.6 | 146½ | 146½ | J | 1½ | 4-24-67 | 5.01 | 11-11-67 | 25.4 | 146.0 | G, L, T, W |
| 29aba2 | 7 S-1 3/8 W | ---do | 96 | ---- | 112.4 | 135 | 135 | J | 1½ | 4-24-67 | 5.30 | 11-11-67 | 25.4 | 132.2 | G, L, T, W |
| 29abb | 7 S-1 1/2 W | ---do | 21 | 1956 | 111.1 | 136 | 136 | J | 1½ | 4-24-67 | 17.61 | 11-11-67 | 25.1 | 138.0 | G, L, T, W |
| 29abc | 7 1/8 S-1 1/2 W | ---do | 103 | 1958 | 115.2 | 139 | 139 | J | 1½ | 12- 2-66 | 7.20 | 11-28-67 | 25.9 | 139.0 | G, L, T, W |
| 29abd | 7 1/4 S-1 1/4 W | ---do | 29 | 1956 | 116.7 | 147 | 147 | J | 1½ | 10-10-66 | +2.83 | 11-29-66 | 24.2 | 2.2 | L, W |
| 29bbb | 7 S-2 W | ---do | 20 | 1956 | 111.0 | 123 | 123 | J | 1½ | 12- 3-66 | 8.30 | 12-13-67 | 25.6 | 122.2 | G, L, T, W |
| 29bcc | 7 1/2 S-2 W | ---do | 69 | 1957 | 114.5 | 148 | 148 | J | 1½ | 12- 3-66 | 6.1 | ------- | ---- | --------- | G, L, W |
| 29bda | 7 3/8 S-1 1/2 W | ---do | 104 | 1958 | 112.2 | 142 | 142 | J | 1½ | 12- 2-66 | 5.70 | 10-11-66 | 28.3 | 10.0 | G, L, W |
| 29bdd [2] | 7 7/16 S-1 1/2 W | ---do | 68 | 1957 | 114.2 | 140 | 140 | J | 1½ | 12- 2-66 | 6.0 | ------- | ---- | --------- | L |
| 30cab | 7 1/2 S-2 3/4 W | ---do | 43 | 1956 | 108.9 | 143 | 143 | J | 1½ | 12- 1-66 | 12.0 | 4-24-67 | 26.1 | 141.8 | L, T, W |
| 30cba4 | 7 5/8 S-2 3/4 W | ---do | 44 | 1956 | 108.9 | 143 | 143 | J | 1½ | 11-29-66 | 27.16 | 11-29-66 | 22.8 | 28.5 | G, L, W |
| 30cbd | 7 3/4 S-2 3/4 W | ---do | 42 | 1956 | 108.9 | 143 | 143 | J | 1½ | 4-25-67 | 13.52 | 11- 4-67 | 28.8 | 142.0 | G, L, T, W |
| 30cdd1 | 8 S-2 1/2 W | U.S. Bureau of Reclamation. | --- | 1947 | 172.1 | 101 | 101 | R | 2½ | 9-22-66 | 68.06 | 9-22-66 | 27.2 | 74.6 | D, W |
| 30cdd2 | 8 S-2 1/2 W | Yuma County Water Users' Association. | 41 | 1956 | 172.1 | 212 | 212 | J | 2 | 9-22-66 | 68.15 | 12- 9-66 | 27.8 | 211.5 | G, L, T, W |
| 31aaa | 8 S-2 W | U.S. Bureau of Reclamation. | --- | 1947 | 185.3 | 101 | 101 | R | 2½ | 9-22-66 | 74.69 | 9-22-66 | 27.2 | 84.0 | D, G, W |
| 31ccc | 9 S-3 W | ---do | --- | 1947 | 171.6 | 103 | 103 | R | 2½ | 9-22-66 | 58.22 | 9-22-66 | 26.1 | 84.2 | D, G, W |
| 31dcd1 | 9 S-2 1/4 W | U.S. Geological Survey. | --- | 1961 | 185 | 63 | 63 | A | 1¼ | 9-29-66 | 35.49 | 9-29-66 | 22.2 | 36.9 | D, Q |
| 31dcd2 | 9 S-2 1/4 W | ---do | --- | 1961 | 185 | 91 | 91 | A | 1¼ | 9-29-66 | 45.12 | 9-29-66 | 21.7 | 46.6 | D, Q |
| 31dcd3 | 9 S-2 1/4 W | ---do | --- | 1961 | 185 | 117 | 117 | A | 1¼ | 9-29-66 | 45.33 | 9-29-66 | 21.7 | 51.4 | D, Q |
| 31dcd4 | 9 S-2 1/4 W | ---do | --- | 1961 | 185 | 137 | 137 | A | 1¼ | 9-29-66 | 45.38 | 12- 7-66 | 23.1 | 126.5 | D, T, Q |
| 32aaa1 | 8 S-1 W | U.S. Bureau of Reclamation. | --- | 1953 | 189.2 | 50 | ---- | R | ------ | ------- | ---- | ------- | ---- | --------- | D, W |
| 32aaa2 | 8 S-1 W | ---do | --- | 1947 | 189.2 | 101 | 101 | R | 2½ | 12- 7-66 | 32.78 | 12- 7-66 | 25.0 | 78.7 | D, G, T, W |
| 32ccc1 | 9 S-2 W | ---do | --- | 1956 | 186 | 43 | 43 | R | 2 | ------- | ---- | ------- | ---- | --------- | D, G, W |
| 32ccc2 | 9 S-2 W | ---do | --- | 1947 | 186 | 101 | ---- | R | 2½ | ------- | ---- | ------- | ---- | --------- | D |
| 33cbd | 8 5/8 S-0 3/4 W | U.S. Geological Survey. | --- | 1966 | 195 | 90 | 88.8 | A | 1½ | 12- 7-66 | 22.87 | 12- 7-66 | 24.4 | 88.5 | D, T |
| 33ccc1 | 9 S-1 W | U.S. Bureau of Reclamation. | --- | ---- | 190.1 | ---- | ---- | R | ------ | ------- | ---- | ------- | ---- | --------- | W |
| 33ccc2 | 9 S-1 W | ---do | --- | 1947 | 190.1 | 110 | 110 | R | 2½ | 4-13-67 | 42.70 | 4-13-67 | 23.3 | 100.8 | D, T, W |
| 33dab | 8 5/8 S-0 1/4 W | U.S. Geological Survey. | --- | 1966 | 196 | 79 | 63 | A | 1½ | 9- 1-66 | 27.49 | 9-28-66 | 22.8 | 27.0 | D |
| 36bbb | 8 S-2 E | U.S. Bureau of Reclamation. | --- | 1947 | 200.0 | 100 | 100 | R | 3 | 3-17-67 | 37.34 | 11-29-67 | 25.3 | 90.1 | D, G, T, W |
| 36ccc1 | 9 S-2 E | ---do | --- | ---- | 198.9 | ---- | ---- | R | ------ | 9- 8-66 | 31.55 | 11- 9-67 | 25.4 | 199.7 | T |
| 36ccc2 | 9 S-2 E | ---do | --- | ---- | 198.9 | ---- | ---- | R | ------ | 9- 8-66 | 30.86 | 9-29-66 | 25.0 | 35.1 | |
| 36ccc3 | 9 S-2 E | ---do | --- | ---- | 198.9 | ---- | ---- | R | ------ | 9- 8-66 | 29.86 | 9-29-66 | 22.5 | 32.7 | |
| (C- 9-24) 2bbb | 3 S-5 W | Yuma County Water Users' Associations. | 62 | 1956 | 117.5 | 130 | 130 | J | 1½ | 10-11-66 | 11.28 | 2-20-68 | 22.1 | 130 | G, L, T, W |
| 2ccc | 4 S-5 W | U.S. Geological Survey. | --- | 1965 | 114.5 | 172 | 126 | A | 1¼ | 10-11-66 | 9.43 | 11-11-67 | 23.0 | 128.0 | D, T, Q |
| 3bab | 3 S-5 5/8 W | Yuma County Water Users' Association. | 61 | 1956 | 113.8 | 126½ | 126½ | J | 1½ | 10-11-66 | 8.48 | 2-20-68 | 22.9 | 125.3 | G, L, T, W |
| 3bbb | 3 S-6 W | ---do | 60 | 1956 | 118.0 | 134 | 134 | J | 1½ | 9- 5-68 | 12.98 | 9- 5-68 | 22.3 | 133.6 | L, T |
| 4aaa | 3 1/8 S-6 W | U S. Geological Survey. | --- | 1965 | 119 | 142 | 136½ | A | 1¼ | 5-13-67 | 14.06 | 11-10-67 | 21.8 | 139.4 | D, G, T, Q, W |
| 5aaa | 3 1/8 S-7 W | ---do | --- | 1965 | 117 | 187 | [1]144 | A | 1½ | ------- | ---- | ------- | ---- | --------- | D, G |
| 7ddd | 5 S- 8 1/16 W | Yuma County Water Users' Association. | 94 | 1957 | 114.8 | 135 | 135 | J | 1½ | 12- 1-66 | 16.80 | 10-26-67 | 21.7 | 135.0 | G, L, T, W |
| 8bdc | 4 1/2 S-7 5/8 W | U.S. Geological Survey. | --- | 1965 | 120 | 172 | 149 | A | 1¼ | 10-11-66 | 16.95 | 2-26-68 | 22.1 | 147.5 | D, G, T, Q |

See footnotes at end of table.

TABLE 17.—*U.S. Geological Survey auger test holes and test wells, Yuma County Water Users' Association deep observation wells, and selected U.S. Bureau of Reclamation observation wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C- 9-24)10ccd | 5 S-5 1/2 W | Yuma County Water Users' Association. | 87 | 1957 | 109.5 | 125 | 125 | J | 1½ | 10-11-66 | 5.30 | 10-27-67 | 22.6 | 114.0 | G, L, T, W |
| 11ccc | 5 S-5 W | ---do | 95 | 1958 | 110.9 | 126 | 126 | J | 1½ | 10-11-66 | 6.69 | 2- 3-68 | 22.6 | 125.8 | [3] G, L, T, W |
| 14baa | 5 S-4 1/2 W | ---do | 86 | 1957 | 110.9 | 130 | 130 | J | 1½ | 10-11-66 | 7.02 | 10-27-67 | 23.2 | 128.2 | G, L, T, W |
| 15bbb | 5 S-6 W | ---do | 92 | 1958 | 107.4 | 130 | 130 | J | 1½ | 12- 1-66 | 3.8 | 10-11-66 | 28.6 | 9.8 | L |
| 16bbb | 5 S-7 W | ---do | 93 | 1958 | 110.7 | 137 | 137 | J | 1½ | 10-11-66 | 7.12 | 10-26-67 | 22.1 | 133.5 | G, L, T, W |
| 19ccc | 7 S-9 W | U.S. Geological Survey. | --- | 1965 | 110.4 | 192 | 189 | A | 1¼ | 10-20-66 | 5.60 | 11-12-67 | 21.3 | 148.0 | D, G, T, Q |
| 20ddd2 | 7 S-7 W | Yuma County Water Users' Association. | 47 | 1956 | 106.6 | 138 | 138 | J | 1½ | 10-19-66 | 7.76 | 10-27-66 | 22.7 | 139.5 | G, L, T, W |
| 22bbb | 6 S- 6W | U.S. Geological Survey. | --- | 1965 | 107 | 167 | 107 | A | 1¼ | 10-19-66 | 5.79 | 10-27-67 | 22.6 | 106.0 | D, G, T, Q |
| 24aaa | 6 S-3 W | Yuma County Water Users' Association. | 14 | 1957 | 110.5 | 126½ | 126½ | J | 1½ | 10-10-66 | 6.76 | 4-12-67 | 25.0 | 128.2 | G, L, T, W |
| 25aaa | 7 S-3 W | ---do | 19 | 1956 | 111.3 | 133 | 133 | J | 1½ | 12- 3-67 | 7.7 | ------- | ---- | ---------- | L, W |
| 26aaa | 7 S-4 W | ---do | 18 | 1956 | 110.9 | 139½ | 139½ | J | 1½ | 10-19-66 | 11.76 | 10-27-67 | 25.4 | 141.3 | G, L, T, W |
| 26cbb | 7 1/S-5 W | U.S. Geological Survey. | --- | 1965 | 105 | 172 | 147 | A | 1¼ | 10-19-66 | 6.70 | 11-11-67 | 22.7 | 147.0 | D, T, Q |
| 26ccc | 8 S-5 W | Yuma County Water Users' Association. | 17 | 1956 | 103.9 | 147 | 147 | J | 1½ | 10-19-66 | 5.18 | 11-11-67 | 22.6 | 147.0 | G, L, T, W |
| 26ddd | 8 S-4 W | ---do | 16 | 1956 | 110.0 | 142 | 142 | J | 1½ | 10-19-66 | 11.11 | 10-28-67 | 23.9 | 142.0 | G, L, T, W |
| 27aaa | 7 S-5 W | ---do | 45 | 1956 | 106.1 | 142 | 142 | J | 1½ | ------- | ---- | ------- | ---- | ---------- | L |
| 27bbb | 7 S-5 7/8 W | ---do | 46 | 1956 | 100.0 | 129 | 129 | J | 1½ | 10-19-66 | 2.30 | 10-27-67 | 22.6 | 128.5 | G, L, T, W |
| 28ccc | 8 S-7 W | U.S Geological Survey. | --- | 1965 | 107 | 202 | (1) | A | ------ | ------- | ---- | ------- | ---- | ---------- | D |
| 29ccc | 8 S-8 W | ---do | --- | 1965 | 111 | 172 | 131 | A | 1¼ | 10-19-66 | 14.61 | 11-28-67 | 21.4 | 121.0 | D, T, Q |
| 30aaa | 7 S-8 W | Yuma County Water Users' Association. | 48 | 1956 | 115.5 | 142 | 142 | J | 1½ | 10-19-66 | 15.86 | 10-27-67 | 22.2 | 143.2 | G, L, T, W |
| 36aab | 8 S-3 1/8 W | ---do | 15 | 1956 | 110.1 | 136 | 136 | J | 1½ | 10-19-66 | 9.24 | 4-24-67 | 27.2 | 138.0 | G, L, T, W |
| 36acc | 8 1/2 S-3 3/8 W | ---do | 67 | 1957 | 105.4 | 140 | 140 | J | 1½ | 10-19-66 | 8.70 | 4-25-67 | 28.1 | 139.3 | G, L, T, W |
| 36add | 8 1/2 S-3 W | U.S. Bureau of Reclamation. | --- | 1947 | 175.7 | 100 | 100 | R | 2½ | 10- 4-66 | 72.21 | 10- 4-66 | 27.2 | 79.5 | D, W |
| (C- 9-25)25aaa | 7 S-9 W | Yuma County Water Users' Association. | 49 | 1956 | 110.4 | 150 | 150 | J | 1½ | 2- 8-67 | 15.54 | 2- 8-67 | 24.4 | 29.1 | L, W |
| (C-10-22)18cdc | 12 S-3 5/16 E | U.S. Geological Survey. | --- | 1966 | 219.3 | 122 | 104 | A | 1½ | 9-21-66 | 78.60 | 9-21-66 | 30.6 | 104.8 | D, T, W |
| (C-10-23)3aaa1 | 9 S-1 E | U.S. Bureau of Reclamation. | --- | 1947 | 202.6 | 103 | 103 | R | 2½ | ------- | ---- | 4-28-65 | 25.0 | 100-103 | D, G, W |
| 3bbb1 | 9 S-0 | ---do | --- | 1947 | 194.8 | 101 | 101 | R | 2½ | 9-29-66 | 28.84 | 9-29-66 | 23.3 | 32.5 | D, W |
| 7bbb1 | 10 S-3 W | ---do | --- | 1955 | 160.4 | 48 | 48 | R | 1½ | 9-22-66 | 35.85 | 9-22-66 | 23.3 | 37.4 | D, W |
| 7bbb2 | 10 S-3 W | ---do | --- | 1947 | 160.4 | 100 | ---- | R | 2½ | 9-22-66 | 41.68 | 9-22-66 | 22.2 | 43.8 | D, W |
| 7bbb3 | 10 S-3 W | Yuma County Water Users' Association. | 53 | 1956 | 160.6 | 203 | 203 | J | 2 | 12- 9-66 | 56.87 | 3-23-68 | 26.6 | 203 | G, L, T, W |
| 8bbb1 | 10 S-2 W | U.S. Bureau of Reclamation. | --- | ---- | 183.6 | ---- | ---- | R | ------ | 9- 9-66 | 33.30 | ------- | ---- | ---------- | W |
| 8bbb2 | 10 S-2 W | ---do | --- | 1947 | 183.6 | 101 | 101 | R | 2½ | 9-28-66 | 40.93 | 3-17-67 | 22.8 | 93.6 | D, G, W |
| 9aaa1 | 10 S-0 | U.S. Geological Survey | --- | 1961 | 196 | 86 | 86 | A | 1¼ | 9-15-64 | 48.14 | 12- 3-66 | 23.3 | 87.0 | D |
| 9aaa2 | 10 S-0 | ---do | --- | 1961 | 196 | 126 | 126 | A | 1¼ | 9-15-64 | 46.21 | ------- | ---- | ---------- | D |
| 9aaa3 | 10 S-0 | ---do | --- | 1961 | 196 | 169 | 169 | A | 1¼ | 9-15-64 | 48.13 | 11- 6-67 | 25.1 | 170.5 | D, T |
| 9bbb | 10 S-1 W | U.S. Bureau of Reclamation. | --- | 1947 | 188.8 | 101 | 101 | R | 2½ | 9-29-66 | 54.77 | 12-12-66 | 21.9 | 89.5 | D, G, T, W |
| 11ccb2 | 10 3/4 S-1 E | U.S. Geological Survey. | --- | 1962 | 195 | 182 | 147 | A | 1¼ | 9-15-64 | 57.80 | ------- | ---- | ---------- | D |
| 13bcb [2] | 11 1/4 S-2 E | ---do | --- | 1966 | 204 | 91 | ---- | A | ------ | 9- 1-66 | >90 | ------- | ---- | ---------- | D |
| 13cbb | 11 1/2 S-2 E | ---do | --- | 1966 | 204.2 | 111 | 110¼ | A | 1½ | 9-14-66 | 89.98 | 12-17-67 | 28.8 | 112.2 | D, T, W |
| 13dcc2 | 12 S-2 1/2 E | ---do | --- | 1966 | 221.0 | 122 | 120¾ | A | 1½ | 9-11-66 | 110.00 | 12-17-67 | 29.8 | 121.3 | D, T, W |
| 14bbb | 11 S- 1 E | U.S. Bureau of Reclamat'on. | --- | 1947 | 194.9 | 103 | 102 | R | 2½ | 9-22-66 | 66.64 | 9-22-66 | 25.0 | 83.6 | D, W |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16aaa | 11 S-0 | do | | 1947 | 191.2 | 115 | 113 | R | 2½ | 9-28-66 | 63.47 | 12-12-66 | 23.3 | 100.0 | D, G, T, W |
| 17aaa | 11 S-1 W | do | | 1947 | 188.9 | 105 | | R | 2½ | 9-28-66 | 64.48 | 3-17-67 | 22.2 | 92.6 | D, G, W |
| 17bbb1 | 11 S-2 W | do | | 1956 | 182.2 | 83 | 83 | R | 1½ | | | | | | D |
| 17bbb2 | 11 S-2 W | do | | 1947 | 182.2 | 101 | 101 | R | 2½ | 9-28-66 | 67.17 | 3-17-67 | 22.5 | 81.7 | D, G,W |
| 17ccc1 | 12 S-2 W | do | | 1947 | 188.0 | 120 | 120 | R | 2½ | 9-29-66 | 85.20 | 9-29-66 | 28.3 | 89.0 | D, W |
| 17ccc2 | 12 S-2 W | do | | | 188.0 | | | R | | | | | | | G |
| 17ccc3 | 12 S-2 W | U.S. Geological Survey. | | 1961 | 188.0 | | (1) | A | 1¼ | | | | | | |
| 17ddd | 12 S-1 W | U.S. Bureau of Reclamation. | | 1947 | 185.7 | 104 | | R | 2½ | 9-20-66 | 76.97 | 9-20-66 | 27.2 | 89.5 | D, G, W |
| 18ccc1 | 12 S-3 W | Yuma County Water Users' Association. | 83 | 1957 | 178.3 | 83½ | 83½ | J | 1½ | | | | | | L, W |
| 18ccc2 | 12 S-3 W | U.S. Bureau of Reclamation. | | 1947 | 178.3 | 120 | 120 | R | 2½ | 9-29-66 | 80.82 | 9-29-66 | 27.2 | 82 | D, G, W |
| 18ccc3 | 12 S-3 W | Yuma County Water Users' Association | 82 | 1957 | 178.3 | 227½ | 227½ | J | 4 | 9-29-66 | 81.47 | 11-6-67 | 28.2 | 219.5 | G, L, R, T, W |
| 20bbb2 | 12 1/16 S-2 W | U.S. Geological Survey. | | 1961 | 189 | 163 | 157 | A | 1¼ | 7-11-61 | 86.45 | | | | |
| 31bbb2 | 14 S-3 W | do | | 1961 | 172.8 | 157 | 157 | A | 1¼ | 9-16-64 | 80.44 | | | | Q |
| 31bbb3 | 14 S-3 W | U.S. Bureau of Reclamation. | | 1961 | 172.8 | 225 | 225 | R | 2 | 6-21-62 | 80.79 | | | | W |
| 31bbb4 | 14 S-3 W | do | | 1947 | 172.8 | 120 | 120 | R | 2½ | 9-20-66 | 79.77 | 9-20-66 | 27.8 | 83.6 | D, G, W |
| 31bbb5 | 14 S-3 W | U.S. Geological Survey. | | 1962 | 172.8 | 202 | 189 | A | 1¼ | 6-21-62 | 81.03 | | | | D |
| 31bbb6 | 14 S-3 W | do | | 1962 | 172.8 | 212 | 136 | A | 1¼ | 6-21-62 | 80.71 | | | | D |
| 31bbb7 | 14 S-3 W | do | | 1962 | 172.8 | 222 | 200 | A | 1¼ | 9-15-64 | 79.00 | | | | D |
| 31bbb8 | 14 S-3 W | do | | 1962 | 172.8 | 232 | 183 | A | 1¼ | 6-21-62 | 81.43 | | | | D |
| 31bbb9 | 14 S-3 W | do | | 1962 | 172.8 | | | A | 1¼ | 6-21-62 | 81.03 | | | | |
| 31bbb10 | 14 S-3 W | do | | 1962 | 172.8 | | | A | 1¼ | 6-21-62 | 81.13 | | | | |
| 33bbb | 14 S-1 W | U.S. Bureau of Reclamation. | | 1947 | 184.5 | 80 | 80 | R | 2½ | 9-20-66 | >80 | | | | D, G, W |
| (C-10-24)1bab [2] | 9 S-3 5/8 W | Yuma County Water Users' Association. | 65 | 1957 | 107.4 | 143½ | 143½ | J | 1½ | 12-2-66 | 4.0 | | | | L |
| 1bdd2 | 9 1/2 S-3 9/16 W | do | 80 | 1957 | 107.4 | 149 | 149 | J | 1½ | 10-21-66 | 8.46 | 11-29-66 | 26.1 | 12.0 | G, L, W |
| 1cdd3 | 10 S-3 9/16 W | do | 58 | 1956 | 107.6 | 146 | 146 | J | 1½ | | | | | | G, L, W |
| 2aaa | 9 S-4 W | do | 66 | 1957 | 107.4 | 138 | 138 | J | 1½ | 10-19-66 | 10.76 | 10-28-67 | 24.0 | 139.2 | G, L, T, W |
| 2add | 9 1/2 S-4 W | do | 97 | | 106.1 | 144 | 144 | J | 1½ | 12-2-66 | 6.8 | | | | L |
| 2bbb | 9 S-5 W | do | 81 | | 105.7 | 149 | 149 | J | 1½ | 10-19-66 | 9.23 | 10-28-67 | 24.2 | 139.0 | L, T, W |
| 3caa | 9 1/2 S-5 1/2 W | do | 13 | 1956 | 99.6 | 149½ | 149½ | J | 1½ | 10-21-66 | 4.72 | 11-12-67 | 24.2 | 150.0 | L, T, W |
| 3ddd | 10 S-5 W | U.S. Geological Survey. | | 1965 | 107 | 192 | 93 | A | 1¼ | 10-21-66 | 8.91 | 10-28-67 | 23.8 | 96.0 | D, G, T, Q |
| 6bcc | 9 1/2 S-9 W | do | | 1966 | 101 | 187 | 164 | A | 1½ | 10-20-66 | 12.65 | 10-28-67 | 21.5 | 166.2 | D, G, T |
| 7ccc | 11 S-9 W | do | | 1965 | 98 | 192 | 180½ | A | 1¼ | | | 6-24-65 | 23.3 | 178.5–180.5 | D, Q |
| 7ddd | 11 S-8 W | Yuma County Water Users' Association. | 11 | 1956 | 97 | 147 | 147 | J | 1½ | 10-21-66 | 7.07 | 11-12-67 | 24.6 | 145.3 | G, L, T, W |
| 11aaa | 10 S-4 W | do | 57 | 1956 | 104.2 | 144 | 144 | J | 1½ | 10-21-66 | 8.31 | 4-26-67 | 23.9 | 89.8 | G, L, T, W |
| 11daa | 10 1/2 S-4 W | do | 54 | 1956 | 101.8 | 140 | 140 | J | 1½ | 10-21-66 | 20.78 | 4-26-67 | 25.3 | 143.2 | G, L, T, W |
| 11dab | 10 1/2 S-4 1/4 W | do | 55 | 1956 | 103.1 | 142 | 142 | J | 1½ | 10-21-66 | 10.11 | 4-26-67 | 24.4 | 143.1 | L, T, W |
| 12bcc1 | 10 1/2 S-3 3/4 W | do | 56 | 1956 | 101.0 | 140 | 140 | J | 1½ | 10-21-66 | 5.45 | 10-21-66 | 26.7 | 19.8 | G, L, W |
| 12ddd1 | 11 S-3 W | U.S. Bureau of Reclamation. | | 1947 | 162.9 | 103 | 103 | R | 2½ | 9-22-66 | 62.58 | 9-22-66 | 25.6 | 68.6 | D, G, W |
| 12ddd2 | 11 S-3 W | Yuma County Water Users' Association. | 52 | 1956 | 163.8 | 207 | 205½ | J | 2 | 12-12-66 | 62.23 | 11-4-67 | 25.0 | 205.5 | G, L, T, W |
| 13abb | 11 S-3 3/8 W | do | 12 | 1956 | 101.3 | 144 | 144 | J | 1½ | 10-21-66 | 3.01 | 3-23-68 | 26.4 | 144.5 | G, L, T, W |
| 13bad | 11 1/4 S-3 1/2 W | do | 74 | 1957 | 100.4 | 149 | 149 | J | 1½ | 10-22-66 | 3.46 | 10-22-66 | 26.7 | 8.3 | G, L, W |
| 13bbc2 | 11 1/4 S-4 W | do | 75 | 1957 | 99.5 | 149 | 149 | J | 1½ | 10-22-66 | 4.29 | 10-22-66 | 25.8 | 5.0 | G, L, W |
| 13bbd2 | 11 1/4 S-3 3/4 W | do | 89 | | 99.1 | 10.0 | | J | | 6-2-66 | 3.3 | | | | L |
| 13dbb | 11 1/2 S-3 7/16 W | do | 71 | 1957 | 106.7 | 150 | 150 | J | 1½ | 10-22-66 | 9.63 | 12-12-66 | 26.9 | 148.0 | G, L, T, W |
| 14aaa1 | 11 S-4 W | do | 7 | 1956 | 101.5 | 147½ | 147½ | J | 1½ | 10-21-66 | 7.41 | 4-26-67 | 23.9 | 148.1 | G, L, T, W |
| 14bbb | 11 S-5 W | do | 8 | 1956 | 99.5 | 145 | 145 | J | 1½ | 10-21-66 | 6.33 | 10-28-67 | 23.7 | 139.1 | G, L, T, W |
| 14daa1 | 11 9/16 S-4 W | do | 70 | 1957 | 106.2 | 100 | 92 | J | 1½ | 10-22-66 | 11.34 | 10-22-66 | 26.4 | 14.6 | L, W |
| 14daa2 | 11 9/16 S-4 W | do | 76 | 1957 | 106.2 | 149 | 149 | J | 1½ | 10-22-66 | 11.56 | 11-6-67 | 24.4 | 148.6 | G, L, T, W |
| 15bbb | 11 S-6 W | do | 9 | 1956 | 98.3 | 143 | 143 | J | 1½ | 10-21-66 | 6.02 | 11-4-67 | 23.1 | 141.2 | G, L, T, W |
| 15daa | 11 1/2 S-5 W | do | 77 | 1957 | 96.7 | 149 | 149 | J | 1½ | 10-22-66 | 3.94 | 10-28-67 | 23.4 | 149.5 | G, L, T, W |
| 16baa1 | 11 S-6 1/2 W | do | 64 | 1956 | 101.0 | 142 | 142 | J | 1½ | 10-21-66 | 8.28 | 11-4-67 | 23.2 | 139.4 | G, L, T, W |
| 17aaa [2] | 11 S-7 W | do | 10 | 1956 | 98.8 | 147 | 147 | J | 1½ | | | | | | L |
| 17dcc | 12 S-7 1/2 W | U.S. Geological Survey. | | 1965 | 94 | 192 | 158 | A | 1¼ | 10-22-66 | 6.68 | 10-28-67 | 23.9 | 155.0 | D, T |
| 20aaa | 12 S-7 W | Yuma County Water Users' Association. | 91 | 1957 | 93.6 | 140 | 140 | J | 1½ | 10-22-66 | 3.89 | 10-28-67 | 23.7 | 136.7 | G, L, T, W |
| 21ddd1 | 13 S-6 W | do | 78 | 1957 | 97.5 | 149 | 149 | J | 1½ | 10-22-66 | 8.42 | 3-31-67 | 24.4 | 93.4 | L, T, W |
| 21ddd2 | 13 S-6 W | do | 79 | 1957 | 97.5 | 95.5 | 93 | J | 1½ | 10-22-66 | 8.27 | 10-22-66 | 28.1 | 10.4 | G, L, W |
| 22acc | 12 1/2 S-5 1/2 W | U.S. Geological Survey. | | 1966 | 104 | 187 | 144 | A | 1½ | 10-22-66 | 25.15 | 10-22-66 | 23.3 | 27.0 | D, G |
| 22dbc | 12 5/8 S-5 3/8 W | do | | 1966 | 121 | 187 | 166.5 | A | 1½ | 10-22-66 | 32.73 | 10-28-67 | 23.8 | 148.5 | D, G, T |

See footnotes at end of table.

TABLE 17.—*U.S. Geological Survey auger test holes and test wells, Yuma County Water Users' Association deep observation wells, and selected U.S. Bureau of Reclamation observation wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-10-24)23bbb1 | 12 S-5 W | Yuma County Water Users' Association. | 72 | 1957 | 97.0 | 107½ | 107½ | J | 1½ | 12- 2-66 | 5.20 | ---- | ---- | ---- | L, W |
| 23bbb2 | 12 S-5 W | do | 73 | 1957 | 97.0 | 149 | 149 | J | 2 | 10-22-66 | 4.84 | 10-28-67 | 23.7 | 147.9 | G, L, T, W |
| 24bbb | 12 S-4 W | U.S. Bureau of Reclamation. | --- | 1947 | 168.7 | 120 | ---- | R | 2½ | 9-29-66 | 73.48 | 9-29-66 | 25.0 | 78.7 | D, G, W |
| 26ccc | 14 S-5 W | do | --- | 1947 | 160.5 | 120 | 120 | R | 2½ | 9-29-66 | 71.16 | 12-13-66 | 25.6 | 114.5 | D, G, T, Q, W |
| 30baa | 13 S-8 1/2 W | U.S. Geological Survey. | --- | 1966 | 93 | 187 | 185 | A | 1½ | 10-22-66 | 7.84 | 3-14-68 | 21.8 | 185 | D, G, T |
| 32aaa | 14 S-7 W | do | --- | 1965 | 94 | 192 | 139 | A | 1¼ | ---- | ---- | ---- | ---- | ---- | D |
| 32aba | 14 1/16 S-7 3/8 W | Yuma County Water Users' Association. | 90 | 1958 | 97.4 | 145 | 145 | J | 1½ | 10-22-66 | 11.80 | 11-12-67 | 23.4 | 140.0 | L, T, W |
| (C-10-25)2bab1 | 9 1/8 S-10 11/16 W | U.S. Geological Survey. | --- | 1961 | 105.0 | 32 | 32 | A | 1¼ | 2-24-61 | 15.40 | ---- | ---- | ---- | D, Q |
| 2bab2 | 9 1/8 S-10 11/16 W | do | --- | 1961 | 105.0 | 62 | 62 | A | 1¼ | 2-24-61 | 23.27 | ---- | ---- | ---- | D, Q |
| 2bab3 | 9 1/8 S-10 11/16 W | do | --- | 1961 | 105.0 | 84 | 84 | A | 1¼ | 2-24-61 | 38.89 | ---- | ---- | ---- | D, Q |
| 2bab4 | 9 1/8 S-10 11/16 W | do | --- | 1961 | 105.0 | 136 | 136 | A | 1¼ | 3-14-61 | 16.05 | ---- | ---- | ---- | D, Q |
| 11ddd | 11 S-10 W | Yuma County Water Users' Association. | 51 | 1956 | 101.1 | 162 | 162 | J | 1½ | 10-21-66 | 15.81 | 10-28-67 | 23.2 | 159.1 | G, L, T, W |
| 13aaa | 11 S-9 W | do | 50 | 1956 | 98.5 | 159 | 159 | J | 1½ | 10-21-66 | 10.15 | 10-28-67 | 22.7 | 158.7 | G, L, T, W |
| 23add | 12 1/2 S-10 W | U.S. Geological Survey. | --- | 1965 | 97 | 192 | 187.7 | A | 1¼ | 10-22-66 | 14.34 | 10-28-67 | 23.6 | 187.0 | D, T, Q |
| 35bab1 | 14 1/16 S-10 3/4 W | do | --- | 1961 | 94.5 | 42 | 42 | A | 1¼ | 2-20-61 | 14.12 | ---- | ---- | ---- | D |
| 35bab2 | 14 1/16 S-10 3/4 W | do | --- | 1961 | 94.5 | 61 | 61 | A | 1¼ | 2-17-61 | 14.16 | ---- | ---- | ---- | D |
| 35bab3 | 14 1/16 S-10 3/4 W | do | --- | 1961 | 94.5 | 85 | 85 | A | 1¼ | 2-17-61 | 20.09 | ---- | ---- | ---- | D |
| 35bab4 | 14 1/16 S-10 3/4 W | do | --- | 1961 | 94.5 | 112 | 112 | A | 1¼ | 2-17-61 | 13.65 | ---- | ---- | ---- | D |
| 36ccc | 15 S-10 W | Yuma County Water Users' Association. | 99 | 1958 | 92.7 | 168 | 168 | J | 1½ | 10-22-66 | 12.08 | 10-29-67 | 22.6 | 167.2 | G, L, T, W |
| (C-11-23)7bbb | 16 S-3 W | U.S. Bureau of Reclamation. | --- | 1947 | 171.3 | 120 | 120 | R | 2½ | 9-29-66 | 85.08 | 9-29-66 | 27.2 | 90.1 | D, G, W |
| 9bbb | 16 S-1 W | do | --- | 1947 | 175.4 | 120 | 120 | R | 2½ | 9-29-66 | 87.77 | 9-29-66 | 33.6 | 90.8 | D, G, W |
| 12ddd | 17 S-3 E | U.S. Geological Survey. | --- | 1966 | 238.5 | 177 | 173.3 | A | 1½ | 12-14-66 | 155.68 | 12- 9-67 | 29.7 | 172.3 | D, G, T |
| 13ddd [2] | 18 S-3 E | do | --- | 1966 | 199 | 41 | ---- | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 15ddd | 18 S-1 E | do | --- | 1966 | 175.8 | 121 | 106 | A | 1½ | 12-14-66 | 94.33 | 12-14-66 | 28.9 | 107.0 | D, G, T |
| 16ccc | 18 S-1 W | U.S. Bureau of Reclamation. | --- | 1947 | 166.2 | 120 | 120 | R | 2½ | 9-29-66 | 83.1 | 9-29-66 | 30.6 | 88 | D, G, W |
| 18ccc | 18 S-3 W | do | --- | 1947 | 166.4 | 120 | 120 | R | 2½ | 9-29-66 | 83.9 | 9-29-66 | 27.8 | 88 | D, G, Q, W |
| 24ddd | 19 S-3 E | U.S. Geological Survey. | --- | 1966 | 198.3 | 142 | 139 | A | 1½ | 12-14-66 | 117.81 | 12- 9-67 | 31.2 | 134.6 | D, G, T |
| 29cab | 19 9/16 S-1 3/4 W | do | --- | 1961 | 160 | 192 | [1] 52 | A | 1¼ | ---- | ---- | ---- | 28.7 | ---- | D, G, T |
| 30bac | 19 3/16 S-2 3/4 W | do | --- | 1961 | 162 | 167 | 136½ | A | 1¼ | 12-14-66 | 82.49 | 12- 9-67 | 29.2 | 135.0 | D, G, T |
| 36ddd | 21 S-3 E | do | --- | 1966 | 184.0 | 152 | 148.7 | A | 1½ | 12-14-66 | 107.58 | 12- 9-67 | 27.8 | 148.2 | D, G, T, Q, W |
| (C-11-24)2ccc | 16 S-5 W | U.S. Bureau of Reclamation. | --- | 1947 | 163.6 | 120 | 120 | R | 2½ | 9-29-66 | 78.61 | 12-13-66 | ---- | 103.2 | |
| 6aba | 15 S-8 5/16 W | Yuma County Water Users' Association. | 101 | 1958 | 91.5 | 150 | 150 | J | 1½ | 10-22-66 | 9.04 | 10-29-67 | 23.9 | 147.1 | G, L, T, W |
| 6bbb | 15 S-9 W | U.S. Geological Survey. | --- | 1965 | 87.7 | 192 | 105 | A | 1¼ | 10-22-66 | 9.73 | 3-14-68 | 23.4 | 80.5 | D, T |
| 6cbc | 15 11/16 S-9 W | Yuma County Water Users' Association. | 102 | 1958 | 92.6 | 155 | 155 | J | 1½ | 10-22-66 | 14.92 | 10-29-67 | 23.5 | 154.0 | G, L, T, W |
| 9bbb | 16 S-7 W | U.S. Bureau of Reclamation. | --- | 1947 | 151.6 | 120 | 110 | R | 2½ | 9-29-66 | 68.25 | 9-29-66 | 26.1 | 74.2 | D, G, Q, W |
| 15ccc | 18 S-6 W | U.S. Geological Survey. | --- | 1961 | 156.2 | 180½ | 178½ | A | 1¼ | 12-13-66 | 75.36 | 12-13-66 | <26.4 | 178.0 | D, Q |
| 23bbb | 18 S-5 W | U S. Bureau of Reclamation. | --- | ---- | 156.5 | 120 | 120 | R | 2½ | 9-29-66 | 75.44 | 9-29-66 | 27.2 | 84.0 | D, G, Q, W |
| (C-11-25)1aaa | 15 S-9 W | Yuma County Water Users' Association. | 98 | 1958 | 93.1 | 150 | 150 | J | 1½ | 10-22-66 | 11.19 | 4-16-67 | 23.9 | 44.0 | G, L, W |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2baa | 15 S–10 5/8 W | do | 100 | 1958 | 92.0 | 172 | 172 | J | 1½ | 10–22–66 | 13.94 | 10–29–67 | 22.3 | 127.0 | L, T, W |
| (C–12–22)6daa | 21 9/16 S–4 E | U.S. Geological Survey. | ---- | 1961 | 202.3 | 202 | 168 | A | 1¼ | 12–14–66 | 127.01 | 12–9–67 | 29.8 | 168.2 | D, T, Q |
| 15S/22E–11Hda [2] | 9 1/2 N–0 1/8 W | do | ---- | 1963 | 430 | 4 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 11Jda [2] | 9 1/4 N–0 1/8 W | do | ---- | 1963 | 417 | 24 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 12Mbd [2] | 9 5/16 N–0 | do | ---- | 1963 | 423 | 5 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 13Cda [2] | 8 13/16 N–0 3/8 E | do | ---- | 1963 | 376 | 117 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 24Kdd [2] | 7 1/4 N–0 11/16 E | do | ---- | 1963 | 288 | 59 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 15S/23E–30Mbc [2] | 6 3/8 N–1 E | do | ---- | 1963 | 230 | 69 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 31Cbb | 6 N–1 5/16 E | do | ---- | 1963 | 201 | 202 | 108 | A | 1¼ | 3– –64 | 64.48 | ---- | ---- | ---- | D |
| 31Fcd [2] | 5 9/16 N–1 3/8 E | do | ---- | 1963 | 176.8 | 227 | 94 | A | 1¼ | 5–17–66 | 41.58 | 5–17–66 | 26.7 | 44 | D, Q |
| 32Rdd | 5 N– 3E | do | ---- | 1964 | 141 | 177 | 116 | A | 1¼ | 4–27–64 | 9.57 | 5–7–66 | 21.7 | 12.0 | D, Q |
| 34Dbb | 6 N–4 E | do | ---- | 1964 | 137 | 177 | 108 | A | 1¼ | 4–6–67 | 6.35 | 11–10–67 | 24.2 | 108.0 | D, T, Q |
| 16S/21E–25Gca | 0 5/8 N–5 5/16 W | do | ---- | 1965 | 120 | 172 | 123 | A | 1¼ | 10–20–66 | 9.80 | 11–10–67 | 21.9 | 115.5 | D, G, T, Q |
| 26G | ---- | do | ---- | ---- | 181 | 187 | 94 | A | 1¼ | ---- | ---- | ---- | ---- | ---- | |
| 16S/22E–1Lab | 4 1/2 N–0 3/8 E | do | ---- | 1962 | 150.1 | 102 | 61 | A | 1¼ | 10–27–66 | 18.19 | 4–6–67 | <23.6 | 59.0 | Q |
| 2Acd | 4 3/4 N–0 3/16 W | do | ---- | 1964 | 192.2 | 177 | 93 | A | 1¼ | 11–2–66 | 59.22 | 11–2–66 | 27.8 | 62.0 | D, Q |
| 2Hac | 4 11/16 N–0 1/16W | do | ---- | 1962 | 176.7 | 117 | 103 | A | 1¼ | 11–2–66 | 43.18 | 11–2–66 | 27.8 | 47.0 | D, W |
| 10Rdc [2] | 3 N– 1 1/8 W | do | ---- | 1964 | 131 | 177 | (1) | A | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 12Hdd | 3 1/2 N–1 E | do | ---- | 1964 | 129.8 | 137 | 128 | A | 1¼ | 4–6–67 | 4.78 | 6–3–67 | 27.8 | 124.5 | D, T, Q |
| 13Dbb | 3 N–0 | do | ---- | 1964 | 132 | 147 | 137 | A | 1¼ | ---- | ---- | ---- | ---- | ---- | D |
| 14Mba | 3 1/2 N–0 15/16 W | do | ---- | 1964 | 139 | 177 | 65 | A | 1¼ | 10–27–66 | ---- | 4–6–67 | 22.5 | 63.0 | D, T, Q |
| 16Lda | 2 3/8 N–2 1/2 W | do | ---- | 1964 | 133.0 | 152 | 128½ | A | 1¼ | 10–27–66 | 9.06 | 10–29–67 | 27.6 | 128.0 | D, T, Q |
| 17Aac | 2 7/8 N–3 1/ W | do | ---- | 1965 | 174.5 | ---- | 65 | A | 1¼ | 11–2–66 | 47.17 | 11–2–66 | 25.6 | 50.0 | D |
| 17Pdd | 2 N–3 1/2 W | do | ---- | 1964 | 125.9 | 147 | 123 | A | 1¼ | 11–11–66 | 5.78 | 3–10–68 | 25.1 | 121 | D, T, Q |
| 20Hdd | 1 1/2 N–3 W | do | ---- | 1964 | 126.6 | 177 | 119 | A | 1¼ | 4–6–67 | 8.16 | 11–10–67 | 23.4 | 113.5 | D, T, Q |
| 21Rdd | 1 N–2 W | do | ---- | 1964 | 128.1 | 157 | 126 | A | 1¼ | 4–6–67 | 10.58 | 11–10–67 | 22.1 | 125.0 | D, T, Q |
| 22Dbb | 2 N–2 W | do | ---- | 1964 | 131.6 | 147 | 128 | A | 1¼ | 4–6–67 | 6.64 | 4–6–67 | 22.8 | 126.0 | D, T, Q |
| 22Gdc [2] | 1 1/2 N–1 3/8 W | do | ---- | 1964 | 126.5 | 177 | 118 | A | 1¼ | 11–11–66 | 7.43 | 11–11–66 | 25.0 | 12.9 | D, Q |
| 23Ccc | ---- | do | ---- | 1964 | ---- | ---- | ---- | A | ---- | ---- | ---- | ---- | ---- | ---- | |
| 23Fcd | 1 1/2 N–0 11/16 W | do | ---- | 1964 | 131.5 | 177 | 140.5 | A | 1¼ | 4–6–67 | 11.44 | 11–10–67 | 22.1 | 136.0 | D, T, Q |
| 25Mbb2 | 0 1/2 N–0 | do | ---- | 1964 | 130 | 177 | 119 | A | 1¼ | 11–11–66 | 11.19 | 10–29–67 | 23.4 | 117.0 | T, P, Q |
| 26Bbb | 1 N–0 1/2 W | do | ---- | 1964 | 124.5 | 122 | 118 | A | 1¼ | 11–3–66 | 3.51 | 11–10–67 | 22.8 | 116.0 | T, P, Q |
| 27Jda [2] | 0 1/4 N–1 W | do | ---- | 1964 | 130 | 137 | 126 | A | 1¼ | ---- | ---- | 5–14–65 | 23.9 | 124–126 | D, Q |
| 27Mdd | 0 1/4 N–1 3/4 W | do | ---- | 1965 | 120 | 117 | [1]106 | A | 1¼ | ---- | ---- | 5–5–65 | 22.8 | 104–106 | D, Q |
| 29Gcal | 0 5/8 N–3 3/8 W | do | ---- | 1964 | 125.0 | 157 | 142 | A | 1¼ | 10–22–66 | 12.07 | 11–10–67 | 22.0 | 140.2 | D, T, Q |
| 29Jcc | 0 5/16 N–3 1/4 W | do | ---- | 1965 | 126 | 146 | [1]108 | A | 1¼ | ---- | ---- | 5–6–65 | 21.7 | 106–108 | D, Q |
| 31Bcc | 0 1/4 S–4 1/2 W | do | ---- | 1965 | 120 | 172 | 124½ | A | 1½ | ---- | ---- | 6–29–65 | 23.3 | 122.5–124.5 | D, G, Q |
| 31Dbc | 0 1/16 S–5 W | Yuma County Water users' Association. | 105 | 1958 | 127.1 | 140 | 140 | J | 1½ | 5–28–67 | 16.89 | 11–10–67 | 22.2 | 138.6 | L, W |
| 32Dbb | 0 1/16 S–4 W | do | 106 | 1958 | 127.6 | 142 | 142 | J | 1½ | 10–20–66 | 16.39 | 11–10–67 | 21.2 | 143.5 | L, T, W |
| 34Dba | 0–1 7/8 W | do | 107 | 1958 | 124.9 | 142 | 142 | J | 1½ | 10–20–66 | 11.36 | 10–29–67 | 20.5 | 137.0 | G, L, T, W |
| 35Cbb | 0–0 5/8 W | do | 108 | 1958 | 137.7 | 158 | 158 | J | 1½ | 10–20–66 | 24.00 | 10–20–66 | 21.7 | 24.3 | L, W |
| 16S/23E–3Ncc | 4 N–4 E | U.S. Geological Survey. | ---- | 1964 | 135 | 177 | 128 | A | 1¼ | 11–4–66 | 4.36 | 11–10–67 | 21.7 | 127.0 | D, T, |
| 6Cba | 5 N–1 3/8 E | do | ---- | 1963 | 147.3 | 160 | 64 | A | 1¼ | 11–2–66 | 16.73 | 11–2–66 | 24.7 | 18.0 | D, Q |
| 6Gcb | 4 5/8 N–1 1/2 E | do | ---- | 1964 | 135 | 177 | 128 | A | 1¼ | 11–2–66 | 3.96 | 11–10–67 | 24.9 | 128.0 | D, T, Q |

[1] No pipe.
[2] Destroyed.
[3] Periodic temperature measurements.

## TABLE 18.—*Drainage and supply wells*

Well number: Location of well according to the Federal land classification. See page H17 for description of well-numbering system.
Coordinates: Location of well according to grid system used by U.S. Bureau of Reclamation in Yuma area. See page H17 for explanation of grid system.
Owner or user: Government agency or irrigation district that drilled the well or had it drilled.
Other number: Number assigned to well by government agency or irrigation district.
Year completed: Known or reported year of completion of well.
Altitude of land surface. Average altitude of land surface at well above mean sea-level datum.Altitudes given to nearest foot ar approximate and were obtained from topographic maps. Altitudes given to decimal fractions of a foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Log information, water-level data, and temperature 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—C, drilled with cable-tool or percussion equipment, D, drilled, method unknown: RG, drilled with rotary-mud equipment and gravel packed; RRG, drilled with reverse-circulation rotary equipment and gravel packed.
Casing diameter. Nominal inside diameter, in inches, of casing 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-yeilding zone is perforated or screenei, figures refer to top and bottom of perforated or screenen intevals in each aquifer in downward sequence.
Type of pump and horsepower: Source of power and pump type are designated by letter symbols—E, electric; T, turbine. Number indicates horsepower.
Discharge: Measured or reported discharge of well in gallons per minute.
Drawdown: Measured or reported drawndown, in feet, accompanying discharge in previous column.
Water level: Date measured by Geological Survey or reported by owner or other agency. Depth to water in feet below land-surface datum.
Water temperature: Date measured by the Geological Survey. Temperature, in degrees Celsius, of most recent sample of water pumped from well believed to represent water from the depth of the perforated interval in the coarse-gravel zone. In some wells, not equipped with pumps, temperature was measured with a thermistor or a maximum thermometer at a depth believed to represent the middle of the coarse-gravel zone or an equivalent depth below land surface.
Other data available: Additional information about the well available in files of Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the letter symbols—D, driller's log; E, electric log (spontaneous potential and resistivity); L, lithologic log made by a geologist from drill cuttings and other information; T, temperature log; PT, pumping test or tests; $C^{14}$, radiocarbon date of formation sample; Q, chemical quality-of-water data; W, periodic or continuous water-level records.

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C- 8-22)25ddd | 2 S-9 E | U. S. Bureau of Reclamation. | CH-721 | 1964 | 152.8 | 163 | 161 | RRG | 20-14 | 100-160 | T, E, 60 | ---- | ---- | 12- 2-65 | 20 | 10-29-66 | 23.4 | 100-160 | D, L, Q |
| 26bbb | 1 S-7 E | do | CH-714 | 1964 | 151.0 | 146 | 135 | RRG | 20-14 | 84-134 | T, E, 60 | ---- | ---- | 3-16-64 | 15.0 | 11- 9-66 | 20.6 | 88-135 | D, L, T, Q |
| 26ddd | 2 S-8 E | do | CH-720 | 1964 | 150.8 | 170 | 161 | RRG | 20-14 | 90-160 | T, E, 60 | ---- | ---- | 12- 2-65 | 19 | 10-29-66 | 22.5 | 90-160 | D, L, T, Q |
| 27bbb | 1 S-6 E | do | CH-713 | 1964 | 150.4 | 150 | 147 | RRG | 20-14 | 86-147 | T, E, 60 | ---- | ---- | 12- 3-65 | 22.7 | 10-28-66 | 21.1 | 86-147 | D, L, T, Q |
| 27ccc | 2 S-6 E | do | CH-718 | 1964 | 147.5 | 182 | 177 | RRG | 20-14 | 106-176 | T, E, 60 | ---- | ---- | 12- 3-65 | 19.0 | 10-28-66 | 21.1 | 106-176 | D, L, T, Q |
| 27ddd | 2 S-7 E | do | CH-719 | 1964 | 148.6 | 169½ | 166 | RRG | 20-14 | 95-165 | T, E, 60 | ---- | ---- | 12- 3-65 | 18.3 | 10-29-66 | 22.2 | 95-165 | D, L, T, Q |
| 28ccc | 2 S-5 E | do | CH-717 | 1964 | 145.0 | 171 | 168 | RRG | 20-14 | 117-167 | T, E, 60 | ---- | ---- | 3-11-64 | 18.0 | 10-28-66 | 21.7 | 117-167 | D, L, T, Q |
| 30dbc | 1 11/16 S-3 1/2 E | do | CH-716 | 1964 | 138.5 | 171 | 165 | RRG | 20-16 | 106-164 | T, E, 60 | ---- | ---- | 12- 3-65 | 15.7 | 10-29-66 | 21.7 | 106-164 | D, L, T, Q |
| 31bcc | 2 1/2 S-3 E | do | SGDW 1 | 1961 | 138.9 | 216 | 200 | RG | 20-16 | 130-200 | T, E, 40 | 3,702 | 22.85 | 6-21-61 | 3.6 | 6- 6-67 | 24.3 | 130-200 | D, Q |
| 31dbb1 | 2 1/2 S-3 1/2 E | do | SGDW 2 | 1961 | 140.3 | 216 | 205 | RG | 20-16 | 130-205 | T, E, 60 | 3,772 | 12.97 | 8-17-61 | 3.3 | 3-31-67 | 23.5 | 130-205 | D, E, Q |
| 32cbb | 2 1/2 S-4 E | do | SGDW 9 | 1961 | 141.0 | 200 | 189 | RG | 20-16 | 124-189 | T, E, 60 | 3,800+ | 13.89 | 5-26-61 | [1]3.7 | 10-29-66 | 22.8 | 124-189 | D, E, Q |
| 32ccc | 3 S-4 E | do | SGDW 3 | 1961 | 140.3 | 216 | 204 | RG | 20-16 | 129-204 | T, E, 60 | 3,800 | 19.21 | ------- | ---- | 3- 9-67 | 23.2 | 129-204 | D, E, Q |
| 32cdd | 3 S-4 1/2 E | do | SGDW 4 | 1961 | 140.3 | 216 | 200 | RG | 20-16 | 90-200 | T, E, 60 | 3,800 | 8.39 | 8-17-61 | 8.9 | 11-30-66 | 23.4 | 90-200 | D, E, Q |
| 33add | 2 1/2 S-6 E | do | SGDW 8 | 1962 | 147.5 | 241 | 225 | C | 20 | 136-186 | T, E, 60 | ---- | ---- | 5-18-62 | 16.3 | 12- 2-66 | 22.6 | 136-186 | D, T, PT, Q |
| 33caa1 | 2 1/2 S-5 1/2 E | do | SGDW 7 | 1961 | 146.2 | 207 | -- | RG | 20-14 | ------ | ------ | 3,800 | 8.49 | 7-18-61 | 7.7 | 7-10-61 | 23.3 | ------ | D, T, Q |
| 33caa2 | 2 1/2 S-5 1/2 E | do | SGDW 7R | 1965 | 146.6 | 185 | 180 | RRG | 20-14 | 119-180 | ------ | ---- | ---- | 12- 3-65 | 21.5 | 11- 9-66 | 22.9 | 119-180 | D |
| 33cbb | 2 1/2 S-5 E | do | SGDW 6 | 1961 | 144.5 | 204 | 190 | RG | 20-16 | 115-190 | T, E, 60 | ---- | ---- | 8-17-61 | 9.2 | 6- 6-67 | 22.6 | 115-190 | D, Q |
| 33ccc | 3 S-5 E | do | SGDW 5 | 1961 | 142.2 | 204 | 190 | RG | 20-16 | 90-190 | T, E, 60 | 3,800 | 7.99 | 8-17-61 | 3.1 | 11-30-66 | 23.3 | 90-190 | D, E, Q |
| 34add | 2 3/8 S-7 E | do | CH-750 | 1964 | 150.0 | 610 | 610 | RG | 20-14 | 500-600 | T, E, 75 | ---- | ---- | 12- 6-65 | 20.6 | 3-31-67 | 22.5 | 500-600 | D, L, PT, Q |
| 35caa2 | 2 1/2 S-7 1/2 E | do | CH-751 | 1964 | 151.3 | 611 | 586 | RG | 20-14 | 484-585 | T, E, 75 | ---- | ---- | 12- 6-65 | 16.6 | 3-31-67 | 23.3 | 484-585 | D, L, PT, Q |
| 36cad | 2 11/16 S-8 3/8 E | do | CH-752 | 1964 | 149.6 | 647 | 622 | RG | 20-14 | 520-621 | T, E, 75 | ---- | ---- | 12- 6-65 | 17.9 | 10-24-66 | 24.4 | 22 | D, L, PT, Q |
| (C- 8-23)26cab | 1 1/2 S-1 1/4 E | do | CH-709 | 1965 | 135.7 | 176 | 174 | RRG | 24-14 | 124-174 | T, E, 40 | ---- | ---- | 4-23-65 | 17.1 | 3-31-67 | 23.1 | 124-174 | D, L, T, Q |
| 26ddb | 1 3/4 S-1 3/4 E | do | CH-710 | 1965 | 136.2 | 203 | 196 | RRG | 24-14 | 126-196 | ------ | ---- | ---- | 4-23-65 | 15.8 | 3-31-67 | 23.4 | 126-196 | D, L |
| 27acb | 1 1/4 S-O 1/2 E | do | CH-708 | 1965 | 128 | 225 | 160 | RRG | 24-14 | 130-160 | T, E | ---- | ---- | 4-23-65 | 11.3 | 3-31-67 | 24.7 | 132-162 | D, L, T, Q |
| 32dbc1 [2] | 2 11/16 S-1 1/2 W | Yuma County Water Users' Association. | USBR 8 | 1947 | 120.3 | 129½ | -- | D | ---- | ------ | ------ | ---- | ---- | ------- | ---- | 3- 3-67 | 23.9 | 93 | D, T |
| 32dbc2 | 2 11/16 S-1 1/2 W | do | 1 | 1956 | 120.3 | 198 | 198 | C | 24 | 130-170 | T, E, 60 | ---- | ---- | 3- 3-67 | [4]41.8 | 5-13-67 | 27.4 | 130-170 | D, Q |
| 35aac | 2 1/4 S-1 3/4 E | U.S. Bureau of Reclamation. | CH-711 | 1965 | 136.0 | 201 | 195 | RRG | 24-14 | 125-155<br>165-195 | T, E, 60 | ---- | ---- | 4-23-65 | 10.0 | 3-31-67 | 25.0 | 125-195 | D, L, T, Q |
| (C- 9-23)5cda1 [3] | 3 3/4 S-1 9/16 W | do | ---------- | --- | 119.0 | -- | -- | --- | ---- | ------ | ------ | ---- | ---- | ------- | ---- | ------ | --- | ------ | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5cda2 | 3 3/4 S-1 9/16 W | Yuma County Water Users' Association. | --- | 1964 | 119.0 | 220 | 220 | C | 24 | 121-143 | T, E, 40 | ---- | ---- | 1964 | 12 | 2- -65 | 26.7 | 121-143 | D, Q |
| 5cdb | 3 3/4 S-1 5/8 W | do | --- | 1955 | 118.0 | 194 | 184 | C | 24 | 120-184 | T, E, 150 | ---- | ---- | ---- | ---- | 11- 5-67 | 27.7 | 120-184 | D, Q |
| 5cdc [2] | 4 S-1 11/16 W | do | --- | 1947 | 120 | 118 | 118 | C | 18 | ---- | ---- | ---- | ---- | 3-24-61 | 5.4 | ---- | --- | ---- | W |
| 8bdc2 | 4 7/16 S-1 5/8 W | U.S. Bureau of Reclamation. | YVI-7 | 1966 | 118.3 | 157 | 177 | RRG | 24-14 | 118-149 | T, E, | ---- | ---- | 5-11-66 | 4.8 | 2- 3-68 | 28.4 | 118-149 | L, PT |
| 17abc1 | 5 1/4 S-1 1/2 W | Yuma County Water Users' Association. | 3 | 1955 | 115.4 | 200 | 200 | C | 24 | 130-170 | T, E, 150 | ---- | ---- | ---- | ---- | 2- 3-68 | 27.3 | 130-170 | D, PT, Q |
| 20bab | 6 S-1 3/4 W | do | 4 | 1956 | 112.5 | 204 | 194 | C | 24 | 132-192 | T, E, 150 | ---- | ---- | ---- | ---- | 4-13-67 | 27.2 | 132-192 | D, Q |
| 20bdc | 6 1/2 S-1 3/4 W | U.S. Bureau of Reclamation. | YVI-13 | 1966 | 112 | 237 | 229 | RRG | 24-14 | 95-167 | ---- | ---- | ---- | 4-30-66 | 7.1 | 10-27-67 | 27.9 | 95-167 | L, Q |
| 20ccc [2] | 7 S-2 W | do | 2 | 1947 | 110.2 | 121 | 121 | C | 18 | ---- | ---- | ---- | ---- | 10- 5-62 | 3.6 | ---- | --- | ---- | D, Q |
| 20cdd | 7 S-1 1/2 W | Yuma County Water Users' Association. | 5 | 1957 | 110.3 | 262 | 242 | C | 24 | 130-203<br>213-240 | T, E, 150 | ---- | ---- | ---- | ---- | 4-24-67 | 26.7 | 130-240 | D, PT, Q |
| 29bbc | 7 1/4 S-2 W | U.S. Bureau of Reclamation. | YVI-17 | 1964 | 110.0 | 230 | 230 | C | 24 | 148-212 | T, E, 150 | ---- | ---- | 2-25-64 | 4.7 | 5- 7-67 | 27.5 | 148-212 | D, L, Q |
| 30cba1 [2] | 7 5/8 S-2 3/4 W | --- | --- | --- | 108.9 | 109 | 109 | C | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | --- | ---- | D |
| 30cba2 [3] | 7 5/8 S-2 3/4 W | Yuma County Water Users' Association. | 6 | 1954 | 108.9 | 215 | 205 | C | 20 | 140-160<br>173-203 | T, E, 150 | ---- | ---- | ---- | ---- | 5-25-62 | 27.2 | 140-203 | D, PT, Q |
| 30cba [3] | 7 5/8 S-2 3/4 W | do | 6R | 1965 | 108.9 | 203 | 200 | C | 24 | 138-158<br>175-193 | T, E, 150 | ---- | ---- | ---- | ---- | 11-29-66 | 26.9 | 138-193 | D, L |
| (C-9-24)36caa | 8 5/8 S-3 9/16 W | do | 7 | 1957 | 105.7 | 240 | 225 | C | 24 | 145-175<br>188-220 | T, E, 150 | ---- | ---- | 4-13-61 | [4]35.1 | 11-29-66 | 26.5 | 145-220 | D, Q |
| (C-10-24)1cdd2 | 10 S-3 5/8 W | U.S. Bureau of Reclamation. | YVI-23 | 1966 | 102.5 | 186 | 173.6 | RRG | 24-14 | 130-172 | T, E | ---- | ---- | 10-21-66 | 6.1 | 3- 3-67 | 26.7 | 130-172 | L |
| 12bcc2 | 10 1/2 S-4 W | Yuma County Water Users' Association. | 8 | 1956 | 99.8 | 190 | 190 | C | 24 | 150-178 | T, E, 150 | ---- | ---- | 4-13-61 | [4]35.7 | 4-21-67 | 25.8 | 150-178 | D, PT, Q |
| 12cab | 10 1/2 S-3 11/16 W | U.S. Bureau of Reclamation. | 4 | --- | --- | 144 | 144 | C | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | --- | ---- | D |
| 12ccc2 | 11 S-4 W | do | YVI-28 | 1966 | 99.8 | 182.8 | 175 | RRG | 24-14 | 139-175 | T, E | ---- | ---- | 10-21-66 | 7.2 | 10-21-66 | 25.8 | 10 | L, PT, $C^{14}$ |
| 12cdd2 | 11 S-3 5/8 W | do | --- | 1966 | 100.5 | 180 | 167 | RRG | 24-14 | 129-166 | ---- | ---- | ---- | ---- | ---- | 12-13-66 | 25.8 | 129-166 | L, PT |
| 13bbd1 | 11 1/4 S-3 3/4 W | Yuma County Water Users' Association. | 9 | 1957 | --- | 208 | 190 | C | 24 | 142-185 | T, E, 125 | ---- | ---- | 4-13-61 | [4]103.6 | 4-23-67 | 25.7 | 142-185 | D, PT, Q |
| 13bcc2 | 11 7/16 S-4 W | U.S. Bureau of Reclamation. | YVI-27 | 1966 | 100.1 | 185 | 172 | RRG | 24-14 | 145-171 | ---- | ---- | ---- | ---- | ---- | 4-23-67 | 24.7 | 145-171 | L, PT |

[1] Thirty minutes after pump test.
[2] Unused.
[3] Replaced.
[4] Pumping level.
[5] Includes discharge from well (C-9-23)5cda2.

## TABLE 19.—*Irrigation wells*

Well number: Location of well according to the Federal land classification. See page H17 for description of well-numbering system.
Coordinates: Location of well according to grid system used by U.S. Bureau of Reclamation in Yuma area. See page H17 for explanation of grid system.
Owner or user: Owner or user at the time well canvass was made.
Other number: Number assigned to well by owner or user.
Year completed: Known or reported year of completion of well.
Altitude of land surface: Average of land surface at well above mean sea-level datum. Altitudes given to nearest foot are approximate and were obtained from topographic maps; altitudes given to decimal fractions of a foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Log information, water-level data, and temperature 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—C, drilled with cable-tool or percussion equipment; R, drilled with rotary-mud equipment; RG, drilled with rotary-mud equipment and gravel packed; RRG, drilled with reverse-circulation rotary equipment and gravel packed.
Casing diameter. Nominal inside diameter, in inches, of casing 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.
Type of pump and horsepower: Pump type and source of power are designated by letter symbols—C, centrifugal; D, diesel; E, electric; G, gasoline; Ga, gas; S, submersible; T, turbine. Number indicates horsepower.
Discharge: Measured or reported discharge of well in gallons per minute.
Drawdown: Measured or reported drawdown, in feet, accompanying discharge in previous column.
Water level: Date measured by Geological Survey or reported by owner or other agency. Depth to water in feet below land-surface datum.
Water temperature: Date measured by Geological Survey. Temperature, in degrees Celsius, of most recent sample of water pumped from well believed to represent water from the depth of the perforated interval in the coarse-gravel zone. In some wells not equipped with pumps, temperature was measured with a thermistor at a depth believed to represent the middle of the coarse-gravel zone or an equivalent depth below land surface.
Other data available: Additional information about the well available in files of the Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the letter symbols—D, driller's log; E, electric log (spontaneous potential and resistivity); G, gamma-ray log; L, lithologic log made by a geologist from drill cuttings and other information; T, temperature log; P, paleontological studies of drill cuttings; PD, pump discharge; PT, pumping test or tests; SpC, specific capacity; Q, chemical quality-of-water data; W, periodic or continuous water-level records.

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C–7–22)14acb | 6 11/16 N–7 1/2 E | L. C. Pratt | -- | 1955 | 157.2 | 191 | 191 | C | 16 | 110–176 | T, Ga, 75 | -- | -- | 10–4–62 | 8.4 | 11–1–66 | 26.7 | 12 | D, PD |
| (C–8–21)17dbb | 0 7/16 N–10 9/16 E | E. P. Roy | -- | -- | 163 | -- | -- | -- | -- | -- | T, E, 50 | -- | -- | -- | -- | -- | -- | -- | Q |
| 17dbc | 0 3/8 N–10 9/16 E | do | -- | 1965 | 163 | 122 | 120 | C | 20 | 72–112 | T, E, 50 | -- | -- | 4–23–65 | 16.5 | 10–31–66 | 21.7 | 72–112 | D, Q |
| 18add | 0 1/2 N–10 E | S. Sturges | 5 | 1966 | 159 | 143 | 143 | C | 20 | 100–136 | T, E, 100 | -- | -- | 4–26–66 | 17 | 7–1–66 | 23.9 | 100–136 | D, Q |
| 18bdc | 0 1/2 N–9 3/8 E | do | 3 | 1964 | 158 | 149 | 149 | C | 24 | 70–146 | T, E, 75 | -- | -- | 11–5–64 | 6.3 | 11–15–65 | 23.3 | 70–146 | D, Q |
| 19dad | 0 3/4 S–10 E | F. J. Hartman | -- | 1961 | 158 | 192 | 192 | C | 20 | 115–165 | T, E, 50 | -- | -- | 10–31–66 | 18.8 | 6–6–67 | 21.7 | 115–165 | D, PT, Q |
| 30abb | 1 1/8 S–9 5/8 E | Hulse | 3 | 1942 | 157 | 158 | 158 | C | 20 | 105–155 | T, E, 50 | 3,250 | 10–15 | -- | -- | 11–9–66 | 22.1 | 105–155 | D, Q |
| 30acd | 1 3/8 S–9 3/4 E | do | 2 | 1946 | 160 | 169 | 169 | C | 20 | 104–165 | T, E, 60 | -- | -- | -- | -- | 10–29–66 | 22.2 | 104–165 | D, Q |
| 30cbd | 1 3/4 S–9 1/8 E | C. M. Harvey | -- | 1956 | 155.2 | 196 | 196 | C | 16 | 150–180 | T, E, 50 | -- | -- | 1–19–61 | 17.4 | -- | -- | -- | D |
| 30ccc1 | 1 7/8 S–9 E | do | -- | 1925 | 155 | 165 | 165 | C | 16 | 95–155 | T, E, 50 | -- | -- | 1–19–61 | 16.8 | -- | -- | -- | D, Q |
| 30cdc | 1 7/8 S–9 3/8 E | F. J. Hartman | -- | 1937 | 157 | 195 | 195 | C | 20 | 120–140 | T, E, 40 | 2,050 | 11 | -- | -- | 3–27–46 | 23.9 | 120–140 | PT, Q |
| 30dca | 1 13/16 S–9 3/4 E | Hulse | 1 | -- | 165 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 6–6–67 | 22.9 | -- | Q |
| 31aba | 2 S–9 11/16 E | F. Dunn | -- | 1953 | 160 | 149 | 149 | C | 20 | 95–145 | T, E, 40 | 2,475 | -- | -- | -- | -- | -- | -- | D, Q |
| 31bba | 2 S–9 1/4 E | do | -- | -- | 155 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | Q |
| 32ccc | 3 S–10 1/16 E | Balmes | 1 | 1960 | 260 | 500 | 500 | RG | 12 | 250–500 | -- | -- | -- | 2–2–61 | 124.8 | 3–12–63 | 25.6 | 125–460 | D, T |
| (C–8–22)6bbd | 2 3/4 N–3 1/4 E | W. F. Dial | -- | -- | 134 | -- | -- | -- | -- | -- | T, D, 78 | -- | -- | -- | -- | 4–6–67 | 22.1 | -- | |
| 6ccb | 2 1/4 N–3 1/8 E | A. Barrett | -- | 1953 | 135 | 169 | 169 | C | 18 | 123–160 | T | -- | -- | -- | -- | -- | -- | -- | D |
| 6cda | 2 3/16 N–3 3/8 E | P. Perez | -- | 1955 | 139 | 184 | 184 | C | 20 | 128–166 | T, D, 78 | -- | -- | -- | -- | 6–15–67 | 22.6 | 128–166 | D |
| 7ccd | 1 N–3 1/4 E | Johnson and Drysdale. | -- | 1952 | 139 | 252 | -- | -- | 24 | 110–160 | T, E, 75 | -- | -- | -- | -- | 12–15–66 | 23.2 | 110–160 | D, Q |
| 13aaa[1] | 1 N–8 15/16 E | S. Sturges | -- | -- | 160 | 183 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | D |
| 13bdd2 | 0 1/2 N–8 1/2 E | do | 1 | 1964 | 156 | 146 | 146 | C | 24 | 109–128 | -- | 1,325 | 53 | 2–25–64 | 6 | 10–3–66 | 22.6 | 109–128 | D, Q |
| 13dad | 0 3/8 N–9 E | do | 2 | 1964 | 155 | 123 | 123 | C | 24 | 85–118 | T, E, 75 | -- | -- | 10–12–64 | 7 | 10–31–66 | 22.5 | 85–118 | D, Q |
| 14cdd | 0–7 1/2 E | do | 4 | 1966 | 150 | 133 | 133 | C | 20 | 80–129 | T, E, 100 | 3,500 | -- | 10–31–66 | 18.8 | 7–1–66 | 22.2 | 80–129 | D, Q |
| 18cbd | 0 3/8 N–3 3/16 E | Powers | -- | 1954 | 128 | 173 | 173 | C | 20 | 110–160 | T, E, 75 | -- | -- | -- | -- | 6–7–67 | 23.8 | 110–160 | D, PT. Q |
| 18ddd | 0 1/8 N–4 E | do | -- | 1954 | 131 | 163 | 163 | C | 20 | 100–155 | T, D, 78 | -- | -- | 10–10–62 | 6.0 | 6–3–67 | 21.8 | 100–155 | D, PT. Q |
| 19ccd | 1 S–3 1/4 E | K. Surber | -- | 1946 | 134 | 173 | 173 | C | 20 | 103–135 | T, E, 40 | 2,880 | -- | -- | -- | 3–19–63 | 22.2 | 105–135 | D. Q |
| 21ddd | 0 7/8 S–5 7/8 E | B. Church | -- | 1948 | 148 | 165 | 165 | C | 20 | 105–150 | T, E, 50 | -- | -- | 10–3–62 | 19.5 | 11–15–65 | 20.8 | 105–150 | D, PT, Q |
| 22caa | 0 5/8 S–6 1/2 E | do | -- | 1951 | 151 | 195 | 195 | C | 20 | 100–165 | T, E, 50 | 3,200 | 15 | 10–3–62 | 21 | 6–6–67 | 22.2 | 100–165 | D, PT, Q |
| 22cda1 | 0 13/16 S–6 1/2 E | do | -- | 1921 | 155 | 136 | 136 | C | 16 | -- | T, E, 60 | -- | -- | 1–31–61 | 20.1 | 6–6–67 | 21.1 | -- | PT, Q |
| 22cda2 | 0 7/8 S–6 1/2 E | do | -- | 1951 | 149 | 171 | 171 | C | 20 | 100–152 | T, E, 50 | -- | -- | 1–31–61 | 25.7 | 11–9–66 | 20.8 | 100–152 | D, PT, Q |
| 22cda3 | 0 7/8 S–6 1/2 E | do | -- | 1921 | 149 | 136 | 136 | C | 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | D |
| 22dcb | 0 7/8 S–6 5/8 E | do | -- | 1950 | 150 | 171 | 171 | C | 20 | 100–150 | T, E, 50 | -- | -- | 10–3–62 | 24.0 | -- | -- | -- | D, Q |
| 24cca | 0 7/8 S–8 1/4 E | S & W | -- | 1946 | 155 | 173 | 173 | C | 20 | 97–140 | T, E, 50 | -- | -- | -- | -- | -- | -- | -- | D, Q |
| 25aad | 1 1/4 S–8 7/8 E | Struve and Hartman. | -- | 1947 | 155 | 173 | 173 | C | 20 | 98–165 | T, E, 40 | -- | -- | 1–19–61 | 16.2 | -- | -- | -- | D |
| 25bad | 1 1/4 S–8 3/8 E | F. J. Hartman | -- | 1942 | 152 | 212 | 212 | C | 20 | 100–114 | T, E, 40 | 2,600 | 14 | 9–20–62 | 20 | 9–20–62 | 20.8 | 100–114 | PT, Q |
| 25cbd[1] | 1 3/4 S–8 1/8 E | F. M. Brown | -- | 1925 | 153.2 | 124 | 124 | C | 20 | 78–118 | T, E, 40 | -- | -- | 1–20–61 | 14.7 | -- | -- | -- | D, Q, W |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C- 8-22)25dac1[2] | 1 3/4 S-8 7/8 E | Morrish and Harvey. | -- | 1945 | 155 | 200 | 200 | C | 20 | 184-197 | T, E, 60 | 3,600 | 15 | ---- | ---- | 3-26-46 | 23.3 | 184-197 | D, SpC |
| 26adb | 1 1/4 S-7 3/4 E | S & W | -- | 1929 | 152 | 184 | 184 | C | 20 | ---- | T, E, 50 | 2,059 | 7 | ---- | ---- | 1-20-61 | 20.6 | ---- | PT, Q |
| 26bad | 1 1/4 S-7 1/2 E | Shattuck | -- | 1939 | 151 | 176 | 176 | C | 20 | 90-170 | T, E, 30 | 2,070 | 9.5 | ---- | ---- | ---- | ---- | ---- | D |
| 26cbd | 1 3/4 S-7 1/4 E | L. S. Bradley | -- | 1937 | 150 | 153 | 153 | C | 20 | 94-150 | T, E, 30 | 2,200 | 7 | 1-20-61 | 12.8 | ---- | ---- | ---- | D, Q |
| 26dab | 1 1/2 S-7 7/8 E | F. M. Brown | -- | 1927 | 151 | 122 | 122 | C | 16 | 90-122 | T, E, 40 | ---- | ---- | ---- | ---- | 11-12-65 | 21.4 | 90-122 | D |
| 26dba | 1 1/2 S-7 5/8 E | ---do | -- | --- | 152 | ---- | ---- | -- | -- | ---- | T, E, 40 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 26dca1 | 1 3/4 S-7 5/8 E | ---do | -- | 1923 | 151 | 151 | 151 | C | 16 | 95-125 | T, E, 20 | ---- | ---- | 1-23-61 | 14.6 | ---- | ---- | ---- | D, Q |
| 27aca | 1 1/4 S-6 3/4 E | State Farms | -- | 1942 | 150 | 135 | 135 | C | 20 | 102-134 | T, E, 75 | ---- | ---- | ---- | ---- | 4-24-63 | 21.1 | 102-134 | D, Q |
| 27bda | 1 1/4 S-6 1/2 E | Lindsey and Lindsey. | -- | --- | 148 | ---- | ---- | -- | -- | ---- | T, E, 50 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 27bdd | 1 3/8 S-6 1/2 E | ---do | -- | 1948 | 148 | 161 | 161 | C | 20 | ---- | T, E, 40 | ---- | ---- | ---- | ---- | 6-13-63 | 21.7 | ---- | D |
| 27cad | 1 3/4 S-6 1/2 E | Tamara Ranches. | -- | 1949 | 148 | 154 | 154 | C | 20 | 95-141 | T, E, 50 | 3,000 | ---- | 1-23-61 | 11.7 | ---- | ---- | ---- | D, Q |
| 27dad | 1 5/8 S-7 E | S & W | -- | 1929 | 150 | 120 | 120 | C | 20 | 100-118 | T, E, 50 | 3,000 | 8 | 1-23-61 | 12.0 | ---- | ---- | ---- | D, Q |
| 28aaa | 1 S-5 7/8 E | B. Church | -- | 1949 | 148 | 165 | 165 | C | 20 | 105-150 | T, E, 50 | 3,200 | ---- | 10- 3-62 | 19.8 | 11-15-65 | 20.6 | 105-150 | D, PT, Q |
| 28cdb | 1 3/4 S-5 1/4 E | J. Bretz, Jr. | -- | 1945 | 144 | 248 | ---- | -- | 20 | ---- | T, E, 30 | 2,200 | 10 | ---- | ---- | ---- | ---- | ---- | Q |
| 28dca[2] | 1 3/4 S-5 3/4 E | J. Dunn | -- | 1963 | 148 | 168 | 168 | R | 20 | 128-168 | T, E, 30 | ---- | ---- | 1- 7-62 | 15.4 | 6- 6-67 | 20.8 | 128-168 | Q |
| 29cdd | 1 15/16 S-4 7/16 E | Warner and Stewart. | -- | 1937 | 143 | 188 | 188 | C | 20 | 138-185 | T, E, 40 | ---- | ---- | ---- | ---- | 1-25-61 | 22.0 | 138-185 | D, Q |
| 29dda | 1 13/16 S-5 E | ---do | -- | 1946 | 145 | 187 | 187 | C | 20 | 110-175 | T, E, 75 | ---- | ---- | ---- | ---- | 11-12-65 | 21.4 | 110-175 | D, Q |
| 29ddb | 1 13/16 S-4 3/4 E | ---do | -- | --- | -- | ---- | ---- | -- | 20 | ---- | T, E, 40 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 30adc | 1 3/8 S-3 3/4 E | L. E. Mauldin | -- | --- | -- | ---- | ---- | -- | 20 | ---- | T, E, 50 | 4,050 | ---- | ---- | ---- | 6- 6-67 | 21.8 | ---- | PT, Q |
| 30cab | 1 5/8 S-3 1/4 E | C. Lord | -- | 1952 | 139 | 183 | 183 | C | 20 | 115-170 | T, E, 50 | ---- | ---- | 10- 3-62 | 15.2 | 10- 4-62 | 21.1 | 115-170 | D, PT, Q |
| 30ddd | 1 15/16 S-3 15/16 E | ---do | -- | 1930 | 143 | 162 | 162 | C | 16 | 130-160 | T, E, 30 | ---- | ---- | 1-26-61 | 4.4 | 3- 4-63 | 21.1 | 130-160 | D, PT, Q |
| 31aaa | 2 1/8 S-4 E | V. H. Gray | -- | 1942 | 143 | 228 | 228 | C | 20 | 130-190 | T, E, 40 | ---- | ---- | 1-26-61 | 4.9 | 3- 4-63 | 21.7 | 130-190 | D, Q |
| 31baa | 2 1/8 S-3 1/2 E | First Natl. Bank of Arizona. | -- | --- | 142 | ---- | ---- | -- | 18 | ---- | T, E, 50 | ---- | ---- | 10- 8-62 | 18.9 | 3- 4-63 | 22.2 | ---- | Q |
| 32aaa | 2 S-4 7/8 E | Grothas and Dunbar. | -- | 1949 | 144 | 175 | 175 | C | 20 | 133-167 | T, E, 40 | ---- | ---- | 1-25-61 | 9.2 | 10-28-66 | 25.0 | 17 | D, Q |
| 32aba | 2 1/8 S-4 11/16 E | G. Ogram | -- | 1937 | 143.0 | 172 | 172 | C | 18 | 124-169 | T, E, 30 | 2,150 | ---- | 1-24-61 | 5.9 | ---- | ---- | ---- | D |
| 32bca | 2 1/4 S-4 1/4 E | E. C. Flint | -- | 1942 | 142 | 158 | 158 | C | 16 | 125-156 | T, E, 30 | 2,000 | ---- | 1-26-61 | 3.9 | ---- | ---- | ---- | D, Q |
| 32bdb | 2 1/4 S-4 5/16 E | C. M. Harvey | -- | 1947 | 142 | 245 | 245 | C | 20-16 | 200-230 | T, E, 50 | ---- | ---- | 10- 8-62 | 16.5 | ---- | ---- | ---- | D, Q |
| 32daa1 | 2 1/2 S-4 15/16 E | E. C. Engler | -- | 1925 | 145 | >181 | >181 | C | -- | 126-181 | T, E, 40 | 2,800 | 12 | ---- | ---- | ---- | ---- | ---- | D, Q |
| 32ddc | 2 7/8 S-4 3/4 E | ---do | -- | 1951 | 144 | 151 | 151 | C | 20 | 110-125 | T, E, 40 | ---- | ---- | ---- | ---- | 6- 6-67 | 23.5 | 110-125 | D, Q |
| 33aaa | 2 S-5 7/8 E | J. Bretz | 4 | 1947 | 149 | 195 | 195 | C | 20 | 111-180 | T, E, 40 | 2,600 | 9 | ---- | ---- | ---- | ---- | ---- | D, Q |
| 33bdb | 2 1/4 S-5 1/4 E | ---do | -- | 1932 | 146 | 201 | 201 | C | 20 | 108-195 | T, E, 40 | 2,200 | ---- | ---- | ---- | 6- 6-67 | 21.9 | 108-195 | D, Q |
| 33dbc | 2 11/16 S-5 9/16 E | L. S. Bradley | -- | --- | 190 | 152 | ---- | -- | -- | ---- | S, E | ---- | ---- | 1958 | 70 | ---- | ---- | ---- | Q |
| 34aaa | 2 S-7 E | W. R. Whitman | -- | 1939 | 151 | 180 | 180 | C | 20 | 93-177 | T, E, 50 | 2,091 | 8 | ---- | ---- | ---- | ---- | ---- | D, PT, Q |
| 34bac | 2 1/4 S-6 5/16 E | ---do | -- | --- | 149 | 214 | 214 | C | 20 | 115-184 | T, E, 40 | 2,200 | ---- | 1-24-61 | 9.2 | 5-23-62 | 21.1 | 115-184 | D, PD, Q |
| 35aaa1[1] | 2 S-7 7/8 E | A. Wertz | -- | 1926 | 153.0 | 179 | 179 | C | 16 | 85-170 | T, E, 40 | ---- | ---- | ---- | ---- | 5- 1-46 | 22.2 | 85-170 | Q |
| 35aaa2 | 2 S-7 7/8 E | ---do | -- | 1953 | 153 | 139 | 139 | C | 18 | 90-137 | T, E, 40 | ---- | ---- | ---- | ---- | 6- 3-67 | 22.5 | 90-137 | D, Q |
| 35bab1 | 2 S-7 3/8 E | First Natl. Bank of Arizona. | -- | 1923 | 150 | 150 | 150 | C | 12 | 84-126 | T, E, 40 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 35bab2 | 2 S-7 3/8 E | ---do | -- | --- | 150 | ---- | ---- | -- | 16 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 35cca | 2 3/4 S-7 1/8 E | Arizona Western College. | -- | 1964 | 216 | 249 | 249 | C | 16 | 180-248 | T, E, 20 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D, PT, Q |
| 35dad | 2 5/8 S-8 E | E. C. Engler | -- | 1945 | 153 | 179 | 179 | C | 20 | 95-175 | T, E, 50 | ---- | ---- | ---- | ---- | 5- 8-46 | 23.3 | 95-175 | D, Q |
| 36abb | 2 S-8 5/8 E | A. C. Westerbeek. | -- | 1921 | 153 | 155 | 155 | C | 16 | ---- | T, E, 40 | 2,500 | ---- | ---- | ---- | ---- | ---- | ---- | PD |
| 36acb | 2 1/4 S-8 5/8 E | R. Loosier | -- | 1923 | 153 | 182 | 182 | C | 16 | 85-140 | T, E, 30 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 36bba | 2 1/16 S-8 1/4 E | A. C. Westerbeek. | -- | 1950 | 152 | 170 | 170 | C | 20-18 | 110-135 | T, E, 30 | 1,800 | 8 | ---- | ---- | ---- | ---- | ---- | D,Q |
| (C- 8-23)1dad | 2 5/16 N-2 7/8 E | J. F. Dees | -- | 1952 | 135 | 149 | 149 | C | 16 | 125-145 | T, D, 78 | ---- | ---- | 2- -52 | 13 | 6- 7-67 | 22.2 | 125-145 | D |
| 1dcc | 2 1/8 N-2 9/16 E | K. Easterday | -- | 1951 | 135 | 161 | 161 | C | 16 | 120-145 | T, D, 50 | ---- | ---- | 12- 8-61 | 12.7 | 6- 7-67 | 22.5 | 120-145 | D, PT |
| 2dda | 2 1/8 N-1 7/8 E | M. Martin | -- | 1951 | 133 | 150 | 150 | C | 12 | 115-140 | C, E, 50 | 3,500 | 8 | 10-15-62 | 6.0 | 4- 6-67 | 24.4 | 115-140 | D |
| 11dca | 1 1/4 N-1 5/8 E | W. F. Smith | -- | 1953 | 130 | 169 | 169 | C | 20 | 110-160 | T, D, 130 | ---- | ---- | ---- | ---- | 6-15-67 | 23.2 | 110-160 | D, Q |
| 12aad | 1 7/8 N-2 7/8 E | E. Evans | -- | --- | 134 | ---- | ---- | -- | -- | ---- | C, D | ---- | ---- | ---- | ---- | 6-15-67 | 22.5 | ---- | Q |
| 12bba | 2 N-2 1/4 E | Wilson and Wilke. | -- | 1930 | 134 | 143 | 143 | C | 12 | 118-140 | C, D | 1,500 | ---- | ---- | ---- | 3- 9-67 | 23.5 | 118-140 | D |
| 12cdb | 1 1/4 N-2 5/16 E | K. Easterday | -- | 1950 | 133 | 173 | 173 | C | 20 | 115-171 | T, E, 100 | ---- | ---- | 12- 8-61 | 15.1 | 6-15-67 | 23.2 | 115-171 | D, PT, Q |
| 12dac | 1 1/4 N-2 7/8 E | E. Harp | -- | 1951 | 134 | 147 | 147 | C | 18 | 105-140 | T, D, 110 | ---- | ---- | ---- | ---- | 4- 6-67 | 22.6 | 105-140 | D |
| 13aaa | 0 7/8 N-3 E | ---do | -- | 1952 | 137 | 150 | 150 | C | 16 | 125-143 | T, D, 78 | ---- | ---- | 12- 8-61 | 16.8 | 6- 7-67 | 23.3 | 125-143 | D |
| 21caa | 0 11/16 S-0 9/16 W | Yuma School District 1. | -- | 1923 | 175 | 404 | 404 | C | 16 | 180-205 | T, E, 25 | ---- | ---- | ---- | ---- | 5-18-68 | 26.7 | 180-205 | D, Q |
| 22ddc | 0 15/16 S-0 3/4 E | ---- | -- | --- | 130 | ---- | ---- | -- | 16 | ---- | ---- | ---- | ---- | ---- | ---- | 3- 4-63 | 22.2 | ---- | Q |
| 23cdb | 0 3/4 S-1 3/8 E | L. Skinner | -- | 1947 | 132 | 125 | 125 | C | 12 | 68-90 | T, E, 40 | ---- | ---- | ---- | ---- | 6- 3-67 | 21.9 | 68-90 | D, Q |
| 24cdb | 0 3/4 S-2 3/8 E | Gunther and Shirley. | -- | --- | 133 | 137 | 137 | C | 20 | 115-135 | T, E, 60 | 3,040 | ---- | ---- | ---- | 1963 | 21.7 | 115-135 | Q |
| 24dcc | 0 7/8 S-2 5/8 E | K. Marshall | -- | --- | 133 | ---- | ---- | -- | 16 | ---- | T, E, 50 | 3,040 | ---- | ---- | ---- | 3- 4-63 | 21.7 | ---- | Q |
| 25acb | 1 1/4 S-2 5/8 E | Gunther and Shirley. | 5 | 1947 | 136 | 180 | 180 | C | 20 | 115-175 | T, E, 30 | ---- | ---- | ---- | ---- | 6- 6-67 | 22.2 | 115-175 | D, PT, Q |
| 25bcc | 1 1/2 S- 2E | ---do | 3 | 1945 | 139 | 189 | 189 | C | 20 | 130-180 | T, E, 50 | 3,000 | ---- | 1-27-61 | 13.0 | 10-28-66 | 22.5 | 130-180 | D, Q |
| 25cab | 1 1/2 S-2 3/8 E | ---do | 2 | 1944 | 139 | 181 | 181 | C | 20 | 115-170 | T, E, 50 | 3,000 | 20 | ---- | ---- | 10-28-66 | 22.5 | 115-170 | D, Q |
| 25dab | 1 1/2 S-2 7/8 E | ---do | 1 | 1944 | 135 | 193 | 193 | C | 20 | 115-175 | T, E, 50 | 3,200 | 8 | 1-26-61 | 8.4 | 10- 5-62 | 21.1 | 115-175 | D, PT, Q |
| 26acd | 1 3/8 S-1 5/8 E | ---do | 4 | 1945 | 137 | 183 | 183 | C | 20 | 116-175 | T, E, 50 | 2,000 | 12 | ---- | ---- | 3- 4-63 | 22.2 | 116-175 | D, Q |
| 26bac | 1 1/8 S-1 1/4 E | G. Ogram | -- | 1948 | 134 | 183 | 183 | C | 20 | 142-180 | T, E, 50 | ---- | ---- | 5-29-62 | 16.5 | 10-10-62 | 22.2 | 142-180 | D, PT, Q |
| 26cda | 1 3/4 S-1 1/2 E | D. R. Engler | -- | 1935 | 136 | 175 | 175 | C | 20 | 145-173 | T, E, 20 | 1,900 | 25 | 1-27-61 | 11.9 | 6- 6-67 | 23.5 | 145-173 | D, Q |
| 26dbd | 1 3/4 S-1 3/4 E | ---do | -- | --- | 136 | 209 | 209 | C | 20 | 160-200 | T, E, 30 | 2,300 | 40 | 7- -42 | 20 | 6- 6-67 | 23.2 | 160-200 | Q |
| 27abb | 1 S-0 1/2 E | C. B. Molina | -- | --- | 128.5 | 189 | 189 | C | 20 | 85-180 | T, E, 50 | ---- | ---- | 1-30-61 | 20.8 | ---- | ---- | ---- | D, Q |
| 27ddd | 1 7/8 S-1 E | Carter | -- | 1947 | 134 | 163 | 163 | C | 20 | 135-158 | T, E, 50 | 1,720 | 35.65 | 10- 8-62 | 18.8 | 1-30-61 | 22.5 | 135-158 | D, PT, Q |
| 29daa | 1 9/16 S-1 1/8 W | O. C. Johnson School. | -- | 1954 | 182 | 303 | 303 | C | 16 | 160-295 | T, E | ---- | ---- | ---- | ---- | 4-22-67 | 28.6 | 160-295 | D, Q |

See footnotes at end of table.

TABLE 19.—*Irrigation wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C- 8-23) 32dda | 2 11/16 S-1 1/16 W | Greenwood Village. | -- | 1966 | 202 | 161 | 161 | C | 8 | 121-145 | S, E | | | | | | | | D, Q |
| 33bba | 2 1/16 S-0 13/16 W | Alice Byrne School. | -- | 1948 | 203 | 241 | 241 | C | 10 | 105-130 | | | | | | | | | D |
| 33bdb | 2 5/16 S-0 11/16 W | St. Francis Church. | -- | 1961 | 203 | 318 | 318 | C | 12 | | | | | | | 1961 | 29.4 | | D, L, Q |
| 33ccb | 2 3/4 S-0 15/16 W | Woodard Jr. High School. | -- | 1967 | 204 | 295 | 295 | C | 12 | 195-295 | | | | 5-23-67 | 85 | | | | Q |
| 35aca | 2 1/4 S-1 3/4 E | Barbara Ann Cattle Co. | -- | --- | 137 | 155 | 155 | C | 16 | 130-155 | T, E, 30 | | | | | | | | D, Q |
| 35adb | 2 1/4 S-1 7/8 E | Gunther and Shirley | 7 | 1949 | 137 | 180 | 180 | C | 16 | 140-171 | T, E, 40 | | | | | 6-13-63 | 25.0 | 140-171 | D, Q |
| 35caa | 2 1/2 S-1 1/2 E | S & W | -- | 1947 | 141 | 191 | 191 | C | 20 | 150-186 | T, E, 50 | 3,290 | | 2- 1-61 | 8.6 | 12-21-60 | 26.1 | 150-186 | D |
| 36aaa | 2 1/8 S-3 E | W. R. Whitman | -- | --- | 140 | | | -- | 18 | | T, E, 40 | | | | | | | | Q |
| (C- 8-24) 28aaa [3] | 1 S-6 1/16 W | Wohlford Ranch. | -- | 1934 | 115 | 155 | 155 | C | 16 | 125-150 | | | | 10-18-66 | 17.2 | 11- 2-67 | 22.2 | 138 | D, T, W |
| 33bab | 2 1/8 S-6 5/8 W | Crowe and Jessum. | -- | 1966 | 113 | 208 | 208 | C | 16 | 127-152 | T, D, 50 | | | 10-10-66 | 19.5 | 3-31-67 | 21.8 | 127-142 | D |
| (C- 9-21) 3cdd1 [3] | 3 15/16 S-12 3/16 E | V. H. Ueckert | -- | 1964 | 327 | 800 | 800 | RG | 12 | 300-800 | | | | 3-10-64 | 100 | 4-20-64 | 28.9 | 260 | D, T, Q |
| 3cdd2 [3] | 3 15/16 S-12 3/16 E | do | -- | 1963 | 327 | 400 | 296 | RG | 12 | 257-296 | | | | | | | | | Q |
| 4bcc [3] | 3 7/16 S-11 E | H. Scheckert | -- | 1962 | 286 | 500 | 500 | RG | 20 | 300-500 | | | | 12- 2-66 | 150.0 | 12- 2-66 | 26.7 | 278 | T |
| 5bcc [3] | 3 1/2 S-10 E | J. Labadie | -- | --- | 267.3 | | | C | 16 | | | | | 12- 2-66 | 132.8 | 12- 2-66 | 25.6 | 259.1 | T, W |
| 6bbc [3] | 3 3/16 S-9 1/16 E | B. Palon | -- | 1962 | 247 | 404 | 404 | RG | 8 | 284-404 | | | | 12- 2-66 | 113.9 | 11- 9-67 | 24.3 | 259.0 | D, T, Q |
| 7aad [3] | 4 1/8 S-10 E | T. S Vanderford. | -- | 1924 | 279.0 | 401 | 401 | C | 16 | 165-315 | | | | 12- 2-66 | 143.6 | 3-12-63 | 25.3 | 300 | D, T, W |
| 8ddd [3] | 4 15/16 S-10 15/16 E | V. H. Ueckert | -- | 1962 | 312 | 730 | 730 | RG | 16-12 | | | | | | | | | | E |
| 9baa [3] | 4 1/8 S-11 3/8 E | J. F. Power | 2 | 1959 | 319 | 496 | 496 | C | 12 | 240-470 | | | | | | | | | D, PT, Q |
| 13ccb [3] | 5 7/8 S-14 E | B. Palon | -- | 1965 | 423 | 603 | 603 | C | 12 | 560-596 | | | | 9-27-66 | 287.5 | 9-27-66 | 34.5 | 333.5 | D, Q |
| 14bac [3] | 5 1/4 S-13 5/16 E | do | -- | 1965 | 395 | 1,085 | 1,053 | C | 12-8 | 914-1,040 | | | | 9-27-66 | 262.6 | 9-27-66 | 33.9 | 271.0 | D, P, Q |
| 16add [3] | 5 1/2 S-12 E | H. Scheckert | -- | 1963 | 354 | 405 | 370 | RG | 10 | 294-370 | | | | 12- 2-66 | 221.7 | 12- 2-66 | 30.0 | 299 | D, T, Q |
| 17cdc [3] | 6 S-10 5/16 E | V. H. Ueckert | -- | 1962 | 340 | 350 | 350 | RG | 10 | 290-350 | | | | 9-27-66 | 199.6 | 4-20-64 | 28.3 | 360 | T |
| 18ddd [3] | 5 15/16 S-9 7/8 E | do | -- | 1962 | 330 | 350 | 350 | RG | 10 | 290-350 | | | | 9-27-66 | 194.4 | 4-20-64 | 27.2 | 310 | T, Q |
| 20aad [3] | 6 1/4 S-10 15/16 E | do | -- | 1962 | 367 | 385 | 385 | RG | 10 | 325-385 | | | | 12- 6-66 | 234.4 | 12- 6-66 | 28.9 | 297 | T |
| 21bab [3] | 6 1/8 S-11 1/4 E | do | -- | 1962 | 373 | 350 | 350 | RG | 10 | 290-350 | | | | 7-11-63 | 298 | 12- 6-66 | 29.2 | 239 | |
| 22aaa [3] | 6 1/8 S-12 15/16 E | F. H. Tammany | -- | 1955 | 385 | 340 | 340 | -- | 8 | 325-340 | | | | | | | | | D, Q |
| 23abd [3] | 6 3/16 S-13 11/16 E | B. Palon | -- | 1965 | 402 | 602 | 602 | C | 12 | 538-582 | | | | 9-27-66 | 268.1 | 9-27-66 | 32.5 | 273.8 | D, Q |
| (C- 9-22) 2ada [3] | 3 5/16 S-8 E | C. Anderson | -- | 1966 | 213 | 602 | 600 | RRG | 22-16 | 250-600 | | | | 1- 9-67 | 81.0 | | | | D |
| 2baa [3] | 3 S-7 1/2 E | do | -- | 1966 | 214 | 600 | 569 | RRG | 22-16 | 233-569 | | | | | | | | | D |
| 3cdb [1] | 3 7/8 S-6 1/4 E | Jones | -- | 1923 | 213 | 250 | 250 | C | 16 | 160-250 | | | | 11-17-23 | 91.8 | | | | D, Q |
| 4dbc1 [3] | 3 11/16 S-5 1/2 E | Sen. Murdy | -- | --- | 210.1 | 160 | 160 | -- | 12 | | | | | 12- 2-66 | 71.0 | 12- 2-66 | 24.4 | 193.5 | T, W |
| 4dbc2 [3] | 3 11/16 S-5 1/2 E | do | -- | --- | 210.1 | 240 | 240 | -- | 12 | | | | | | | | | | G, W |
| 5baa | 3 1/8 S-4 1/2 E | J. Bretz, Jr. | -- | 1948 | 144 | 135 | 135 | C | 20 | 108-123 | T, E, 40 | | | | | 2-13-63 | 23.3 | 108-123 | D, Q |
| 9bba [3] | 4 S-5 1/4 E | Ketcherside | -- | 1921 | 208.0 | 250 | 250 | C | 16 | 150-250 | | | | 12- 3-66 | 67.7 | 11- 7-67 | 23.6 | 237.2 | T, Q, W |
| 11bbb [3] | 4 1/8 S-7 E | H. R. Houck | -- | 1962 | 213 | 600 | 300 | RG | 16 | 161-300 | | | | 12- 2-66 | 75.8 | 11- 9-67 | 23.6 | 218.0 | D, T |
| 12aaa1 [3] | 4 S-8 15/16 E | J F. Power | 1 | 1959 | 249 | 408 | 408 | C | 12 | 333-400 | T, D | | | 2- 3-61 | 116.1 | | | | D |
| 17dca [3] | 5 3/4 S-4 3/4 E | P. Hairgrove | -- | 1925 | 208.9 | 263 | 263 | C | 16 | 165-218 | T, E | | | 3- 9-61 | 56.8 | 1-11-67 | 25.0 | 165-218 | D, G, Q, W |
| 23aaa [3] | 6 S-8 E | V. H. Ueckert | -- | 1964 | 262 | 300 | 300 | RG | 10 | 240-300 | | | | 12- 6-66 | 123.5 | 12- 6-66 | 25.6 | 265 | T |
| 23cbb [3] | 6 1/2 S-7 E | do | -- | 1965 | 242 | | | -- | -- | | | | | 12- 5-66 | 96.1 | 12- 5-66 | 25.3 | | |
| 24abd [3] | 6 1/4 S-8 5/8 E | do | -- | 1964 | 300 | 302 | | -- | -- | | | | | 9-27-66 | 167.1 | 9-27-66 | 25.6 | 173 | |
| 24bba [3] | 6 S-8 3/16 E | do | -- | 1964 | 280 | 274 | 274 | RG | 10 | 195-274 | | | | 9-27-66 | 143.8 | 4-16-64 | 26.3 | 210-260 | D, T |
| 29bbc [3] | 7 1/4 S-4 1/16 E | L. T. Rouse | -- | 1925 | 204 | 250 | 250 | C | 16 | 174-249 | | | | 3-16-67 | 48.9 | 11- 9-67 | 24.9 | 218.5 | D, T, W |
| (C- 9-23) 4abd | 3 1/4 S-0 5/16 W | American Legion. | -- | 1966 | 195 | 207 | 207 | C | 8 | 180-200 | | | | 6- 8-66 | 68.0 | | | | D, Q |
| 4cbd | 3 11/16 S-0 7/8 W | Palmcroft School. | -- | 1965 | 184 | 252 | 252 | C | 16 | 180-230 | T, E, 30 | | | | | 5-12-67 | 28.1 | 180-230 | D, Q |
| 5abd [3] | 3 3/16 S-1 5/16 W | Blalack and Salas. | -- | 1934 | 120 | 186 | 186 | C | 12 | 160-184 | | | | 12- 8-66 | 3.7 | 12- 8-66 | 25.6 | 79.4 | D, T |
| 8aac | 4 3/16 S-1 1/8 W | V. E. Blalack | -- | 1963 | 190 | 230 | 230 | C | 12 | 204-214 | T, E | | | | | | | | D, Q |
| 9caa [3] | 4 5/8 S-0 9/16 W | M. Miller | -- | --- | 195 | 236 | 236 | C | 16 | 190-236 | T, E, 3 | | | 3- 3-61 | 69.5 | | | | D |
| 36aab | 8 S-2 13/16 E | H. L. Morris | -- | 1965 | 200 | 198 | 198 | RG | 8 | 160-196 | | | | | | | | | Q |
| 36bdd [3] | 8 1/2 S-3 1/2 E | M. Winsor | -- | 1926 | 201 | 255 | 255 | C | 16 | 170-252 | | | | 11- 4-67 | 37.8 | 11- 4-67 | 25.1 | 170 | D, G, T, Q |
| (C- 9-24) 19bad1 [1] | 6 3/16 S-8 5/8 W | P. E. Sterling | -- | 1934 | 107 | 180 | 180 | C | 16 | 140-178 | | | | | | | | | D |
| 19bad2 | 6 3/16 S-8 5/8 W | do | -- | 1959 | 107 | 195 | 195 | C | 16 | 145-180 | T, E, 60 | | | | | 2- 2-67 | 21.7 | 145-180 | D, Q |
| 19bda1 [1] | 6 3/8 S-8 5/8 W | do | -- | 1934 | 107 | 185 | 185 | C | -- | 150-178 | | | | | | | | | D |
| 19bda2 | 6 3/8 S-8 5/8 W | do | -- | 1959 | 107 | 200 | 200 | C | 16 | 150-175 | T, E, 60 | | | | | 2- 2-67 | 22.1 | 150-175 | D, Q |
| 19bdb | 6 5/16 S-8 5/8 W | do | -- | 1966 | 107 | 194 | 190 | C | 20-16 | 94-190 | T, E, 60 | | | | | 2- 2-67 | 21.8 | 94-190 | D |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-9-24)36aad[3] | 8 1/4 S-3 W | C. Anderson | | 1966 | 179.1 | 600 | 600 | RG | 22-16 | 250-600 | | | | 3- 3-67 | 79.8 | 3- 3-67 | 28.3 | 247.5 | T |
| 36ada[3] | 8 1/4 S-3 W | do | | 1966 | 179 | 615 | 608 | RRG | 22-16 | 256-608 | | 5,200 | 58.5 | 12-14-66 | 78.0 | 12-15-66 | 28.3 | 256-608 | D, G, Q |
| (C-9-25)25aab | 7 1/8 S-9 3/16 W | J. D. Cannon | | 1967 | 114 | 180 | 170 | C | 20-16 | 110-170 | | | | | | 6-14-67 | 20.6 | 110-170 | Q |
| 35aba | 8 S-10 5/8 W | W. W. Brand | | 1959 | 109 | 310 | 319 | C | 24-14 | 100-310 | T, D, 150 | | | | | | | | D, Q |
| 36aaa | 8 S-9 W | McDaniel & Sons, Inc. | | 1952 | 110 | 193 | 193 | C | 24 | 130-180 | T, E, 125 | 3,620 | 44 | | | 3- 3-67 | 21.7 | 130-180 | D, PT, Q |
| (C-10-22)7add[3] | 10 7/16 S-4 E | M. T. Smith | | 1926 | 228.2 | 250 | 250 | C | 16 | Open bottom | | | | 1-11-66 | 80.5 | 11- 7-67 | 27.7 | 247.5 | D, G, T, W |
| (C-10-23)11ccb1 | 10 3/4 S-1 E | F. E. Booth | | 1961 | 196 | 603 | 603 | C, RRG | 20 | 130-388 | T, Ga, 150 | | | 1-18-62 | 67.0 | 9-22-66 | 25.6 | 130-388 | D, Q |
| 11dca | 10 3/4 S-1 3/4 E | do | | 1965 | 200 | | | RRG | 20 | | T, Ga, 150 | | | | | 9-22-66 | 28.9 | | |
| 11dcd | 11 S-1 11/16 E | do | | 1965 | 200 | 509 | 509 | RRG | 20 | 98-495 | T, Ga, 150 | 3,000 | 106 | 4-23-65 | 54 | 9-22-66 | 29.7 | 98-495 | D, Q |
| 12aba1[3] | 10 S-2 5/8 E | J. F. Nutt | 6 | 1963 | 199 | 704 | 704 | C | 20 | 176-686 | | | | | | 2-21-63 | 32.8 | 178-686 | D, PT, Q |
| 12aba2 | 10 S-2 5/8 E | do | | 1966 | 199 | 550 | 550 | RRG | 20 | | T, Ga | | | | | 3- 1-67 | 29.6 | | |
| 12abb | 10 S-2 1/2 E | do | | 1953 | 200 | 220 | 220 | C | 16 | 202-210 | T, Ga | | | 4-27-62 | 49.8 | | | | D, Q |
| 12bda | 10 1/4 S-2 1/2 E | do | 4 | 1962 | 200 | 694 | 694 | C | 20 | 150-680 | T, Ga | 3,940 | 26 | 1- 7-63 | 53. | 9-28-66 | 29.2 | 150-680 | D, Q |
| 12bdd | 10 1/2 S-2 1/2 E | do | 5 | 1962 | 198 | 704 | 704 | C | 20 | 132-690 | T, Ga | 4,500 | 45 | 2-21-63 | 42.7 | 9-28-66 | 29.2 | 132-690 | D, T, Q |
| 12dbc | 10 5/8 S-2 5/8 E | do | | 1959 | 201 | 282 | 282 | C | 16-14 | 165-280 | T, Ga | | | 11- 6-63 | 44.8 | | | | D, Q |
| 13abd | 11 1/4 S-3 3/4 E | do | | 1966 | 205 | 500 | 500 | RRG | 20-16 | 200-500 | T, Ga | | | 12- -65 | 56.0 | | | | D |
| 13dcc1[3] | 12 S-2 5/8 E | V. H. Ueckert | | 1963 | 220.6 | 254 | 254 | RG | 12 | 185-254 | | | | 12- 3-66 | 108.8 | 12- 3-66 | 30.6 | 203.8 | D, T |
| 14aaa[3] | 11 S-2 E | J. F. Nutt | 10 | 1965 | 200 | 550 | 550 | RRG | 20-16 | 77-546 | | | | 12- 3-66 | 52.6 | 3-27-68 | 32.3 | 77-546 | D |
| 14bbd | 11 1/4 S-1 1/4 E | F. E. Booth | | 1965 | 198 | 556 | 556 | RRG | 20-16 | 140-548 | T, Ga | | | 1-21-66 | 74 | | | | D |
| 15aaa[3] | 11 S-1 E | J. F. Nutt | 1 | 1961 | 194 | 300 | 300 | C | 20 | 112-285 | | 1,500 | 50 | 9- 1-66 | 66.4 | | | | D, Q, W |
| 15aab[3] | 11 S-0 7/8 E | do | 2 | 1961 | 194 | 890 | 890 | C | 20 | | T | | | 11-15-61 | 72.1 | | | | D, PT, Q |
| 20aad[3] | 12 1/8 S-1 1/8 W | Harrison and Espy. | 1 | 1966 | 185 | 512 | 501 | RG | 16 | 330-490 | | | | 6- 2-66 | 88 | | | | D, Q |
| 20abd[3] | 12 1/8 S-1 3/8 W | do | 3 | 1966 | 184 | 455 | 455 | RG | 16 | 305-455 | | | | 6-28-66 | 88 | | | | D, Q |
| 20aca[3] | 12 3/8 S-1 3/8 W | do | 4 | 1966 | 188 | 505 | 504 | RG | 16 | 334-494 | | | | 7- -66 | 88 | | | | |
| 20add[3] | 12 3/8 S-1 1/8 W | do | 2 | 1966 | 190 | 512 | 501 | RG | 16 | 331-491 | | | | | | | | | |
| 20baa[3] | 12 1/16 S-1 1/2 W | V. H. Ueckert | | 1964 | 185 | 334 | 334 | RG | 14 | 234-319 | | | | 8-19-64 | 80.4 | | | | D |
| 20bcb[3] | 12 5/16 S-1 15/16 W | do | | 1964 | 185 | 254 | 254 | RG | 14 | 189-254 | | | | 8-20-64 | 84.2 | | | | D |
| 20ccd[3] | 13 S-1 3/4 W | do | | 1963 | 179 | 350 | 350 | RG | 10 | 260-350 | | | | 8- -63 | 80 | 12- 9-66 | 29.4 | 220 | D, T |
| 20cdd[3] | 12 15/16 S-1 5/8 W | do | | 1964 | 181 | 174 | 174 | RG | 14 | 118-174 | | | | 8-20-64 | 81.6 | | | | D, Q |
| 21abb | 12 S-0 1/2 W | J. F. Barkley | | 1963 | 191 | 354 | 264 | RG | 12 | 200-264 | T, D | | | 8- 5-63 | 80.1 | 12- 6-66 | 28.8 | 200-264 | D, T, Q |
| 21cba[3] | 12 5/8 S-0 13/16 W | V. H. Ueckert | | 1964 | 192 | 294 | 294 | RG | 14 | 214-294 | | | | 8-19-64 | 86.9 | | | | D |
| 21cca[3] | 12 13/16 S-0 7/8 W | do | | 1964 | 191 | 294 | 294 | RG | 14 | 234-294 | | | | 12- 9-66 | 86.1 | 12- 9-66 | 27.8 | 131 | D, T |
| 21daa[3] | 12 1/2 S-0 | Graham and Murphree. | | 1966 | 191 | 500 | | RG | 16 | | | | | | | | | | |
| 22aaa[3] | 12 1/8 S-0 7/8 E | V. H. Ueckert | 4 | 1964 | 194 | 294 | 294 | RG | 14 | 214-294 | | | | 8-20-64 | 81.7 | | | | D |
| 22abb[3] | 12 S-0 1/2 E | M. Thorne | | 1963 | 194 | 294 | 230 | RG | 12 | | | | | 9-19-66 | 80.0 | 12- 3-66 | 28.3 | 199 | D, T |
| 22acc[3] | 12 3/8 S-0 9/16 E | V. H. Ueckert | 2 | 1964 | 193 | 294 | 294 | RG | 14 | 214-294 | | | | 8-20-64 | 83.3 | | | | D |
| 22adc[3] | 12 3/8 S-0 3/4 E | do | 3 | 1964 | 194 | 334 | 322 | RG | 14 | 242-322 | | | | 8-20-64 | 83.7 | | | | D |
| 22bab[3] | 12 S-0 1/4 E | | | | 194 | | | | 20 | | | | | 9-20-66 | 81.4 | 9-20-66 | 27.2 | 89.5 | |
| 22bad[3] | 12 1/4 S-0 3/8 E | | | | 193 | | | | 20 | | | | | 9-20-66 | 80.8 | 12- 9-66 | 27.5 | 98.0 | T |
| 22bbb[3] | 12 S-0 | Harrison and and Espy. | 1 | 1966 | 192 | 478 | 478 | RG | 16 | 308-468 | | | | | | | | | D |
| 22bbc[3] | 12 1/4 S-0 | do | 2 | 1966 | 192 | 477 | 477 | RG | 16 | 307-467 | | | | | | | | | D |
| 22cbd[3] | 12 3/4 S-0 1/4 E | Graham and Murphree. | | 1966 | 191 | 500 | 500 | RG | 16 | | | | | | | | | | |
| 23abb[3] | 12 S-1 9/16 E | Hub City Development Co. | | 1966 | 196.4 | 464 | 464 | C | 20-12 | 304-454 | | | | 9-19-66 | 84.3 | 12-17-67 | 27.8 | 227.0 | D, T, Q |
| 23cbd[3] | 12 3/4 S-1 1/4 E | Graham and Murphree. | | 1966 | 194 | 500 | 500 | RG | 16 | 320-500 | | 2,500 | 75 | 12- 6-66 | 84.9 | 12- 6-66 | 28.6 | 248.0 | T, Q |
| 28cad[3] | 13 11/16 S-0 9/16 W | | | | 191 | | | | | | | | | 9-20-66 | 91.5 | 12- 9-66 | 30.6 | 158.0 | T |
| 28ccd[3] | 13 15/16 S-0 7/8 W | V. H. Ueckert | | 1964 | 185 | 334 | 330 | RG | 12-10 | 230-293 | | | | 12- 9-66 | 86.8 | 3-27-68 | 34.2 | 230 | D, T |
| 28cdd[3] | 14 S-0 1/2 W | do | 2 | 1964 | 200 | 306 | 240 | RG | 14 | 160-240 | | | | | | 3-27-68 | 31.0 | 190 | D, T |
| 29acc[3] | 13 7/16 S-1 7/16 W | do | | | 184 | | | RG | 14 | | | | | | | | | | |
| 29add[3] | 13 1/2 S-1 1/16 W | do | | | 190 | | | RG | 14 | | | | | | | | | | |
| 29cab[3] | 13 9/16 S-1 3/4 W | C. L. Espy | | 1966 | 180 | 411 | 410 | RG | 20 | 134-410 | | | | 3-31-67 | 84.0 | 3-31-67 | 29.7 | 207 | T |
| 29ddc[3] | 13 15/16 S-1 13/16 W | V. H. Ueckert | | 1964 | 187 | 294 | 294 | RG | 12 | 244-294 | | | | 12- 9-66 | 88.7 | 12- 9-66 | 30.3 | 248 | D, T, Q |
| (C-10-24)5dbb[3] | 9 1/2 S-7 1/2 W | M. A. Gallagher | | 1934 | 104 | 216 | 216 | C | 16 | 175-198 | | | | 4-16-67 | 10.4 | 10-29-67 | 22.0 | 187.0 | D, T, Q |
| 15cbc[3] | 11 5/8 S-6 W | Bill Smith | | 1934 | 102.6 | 202 | 202 | C | 16 | 140-180 | | | | 2- 2-67 | 8.2 | 11- 4-67 | 22.9 | 157.0 | D, G, T, W |
| 32aca[3] | 14 3/8 S-7 1/4 W | Graham and Murphree. | | 1965 | 144 | 430 | 430 | RG | 16 | 150-420 | | | | | | | | | D, Q |
| 32ddb[3] | 14 7/8 S-7 1/4 W | do | | 1965 | 152 | 1,007 | | RG | 20 | | | | | 12-13-66 | 69.1 | 12-13-66 | 25.8 | 219.0 | T |
| (C-10-25)1bba | 9 1/8 S-9 3/4 W | P. R. Sibley | | 1951 | 106 | 295 | 295 | C | 20 | 160-285 | T, D, 125 | 5,200 | | 10-18-62 | 16.1 | 10-20-66 | 21.7 | 160-285 | D, PT, Q |
| 2cda | 9 3/4 S-10 1/2 W | F. Jeffries | | 1953 | 103 | 299 | 299 | C | 20 | 158-295 | T, D, 150 | 3,820 | 25 | | | 2- 8-67 | 21.8 | 158-295 | D, PT, Q |
| 14aac | 11 1/4 S-10 3/16 W | P. R. Sibley | | 1965 | 98 | 297 | 295 | C | 20 | 230-284 | T, E, 100 | 5,000 | 45 | 7-22-65 | 15.0 | 3-14-68 | 23.7 | 230-284 | D, Q |
| 26bab | 13 1/16 S-10 5/8 W | J. W. Lee | | 1955 | 95 | 285 | 285 | C | 20 | 203-280 | T, D, 150 | | | 11- -55 | 17 | 3- 3-67 | 23.5 | 203-280 | D, Q |
| 35cab | 14 1/2 S-10 3/4 W | J. F. Barkley | | 1955 | 94 | 303 | 303 | C | 20 | 178-293 | T, D, 150 | | | 1955 | 10 | 2- 2-67 | 23.1 | 178-293 | D, PT, Q |
| (C-11-23)36cbd[3] | 20 11/16 S-2 1/4 E | V. H. Ueckert | | 1965 | 170 | 700 | | RG | 20-16 | | | | | | | | | | |
| (C-11-24)2abd[3] | 15 1/4 S-4 1/4 W | J. F. Nutt | 8 | 1964 | 170 | 300 | 300 | RRG | 20-16 | 130-300 | | | | | | 12-30-64 | 25.0 | 130-300 | D, PT, Q |
| 2baa[3] | 15 S-4 1/2 W | do | 7 | 1964 | 166 | 159 | 102 | RRG | 20-16 | 78-102 | T, D, 200 | | | 12-13-66 | 79.1 | 3-27-68 | 25.9 | 145 | D, T, Q |
| 2bbd[3] | 15 1/4 S-4 3/4 W | do | 9 | 1965 | 164 | 400 | 376 | RRG | 20-16 | 140-376 | | 3,700 | 19 | 1-22-65 | 76.6 | 5- 3-65 | 25.6 | 140-376 | D, PT, Q |
| 9ddd | 16 15/16 S-6 1/8 W | Parker and others. | 17 | 1966 | 154 | 516 | 516 | RG | 20 | 200-506 | | 5,160 | 33 | 2-22-67 | 69.7 | 12-13-66 | 26.4 | 228.5 | D, T, SpC |
| 10cdd | 16 15/16 S-5 1/2 W | do | 11 | 1966 | 156 | 510 | 510 | RG | 20 | 214-503 | | 5,070 | 33.5 | 12-13-66 | 73.3 | 3-27-68 | 26.8 | 230 | D, T |
| 10ddd | 16 15/16 S-5 W | do | 10 | 1966 | 158 | 503 | 503 | RG | 20 | 196-493 | | 5,300 | 31.0 | 12-13-66 | 75.9 | 3-27-68 | 29.5 | 230 | D, T |
| 11bdd | 16 1/2 S-4 1/2 W | do | 5 | 1966 | 164 | 505 | 505 | RG | 20 | 215-495 | | 5,275 | 34.3 | 12-13-66 | 80.3 | 12-13-66 | 26.7 | 229.0 | D, T |
| 11cdd | 16 15/16 S-4 1/2 W | do | 3 | 1966 | 162 | 505 | 505 | RG | 20 | 209-495 | | 4,715 | 31.5 | 9-14-66 | 79.2 | 9-14-66 | 26.7 | 204-495 | D |
| 11ddd | 17 S- 4 W | do | 1 | 1966 | 166 | 266 | 266 | C | 20 | 148-212 | | 1,250 | 26 | 3- -66 | 90 | | | | D, Q |
| 23bdb[3] | 18 5/16 S-4 3/4 W | R. E. Grounds | | 1965 | 162 | 434 | 434 | C | 16 | 191-422 | T, D, 75 | | | 6-29-65 | 84 | | | | D, Q |
| (C-11-25)2bba | 15 1/16 S-10 7/8 W | W. A. Brown | | 1952 | 92 | 223 | 223 | C | 20 | 174-210 | T, D, 90 | | | 5- 2-62 | 4 | 12-13-66 | 23.2 | 174-210 | D, Q |
| 3dac | 15 11/16 S-11 1/4 W | E. Hughes | | 1956 | 92 | 282 | 282 | C | 20 | 188-282 | T, D, 150 | | | 10-18-62 | 16.9 | 2- 2-67 | 21.1 | 188-202 | D, PT, Q |

See footnotes at end of table.

TABLE 19.—*Irrigation wells*—Continued

| Well | Coordinates | Owner or user | Other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15S/23E–35Jbb | 5 7/16 N–5 13/16 E | D. C. Cole | -- | 1953 | 144 | 183 | 183 | C | 20 | 28–175 | T, D, 150 | 6,500 | 30 | 12– 7–61 | 14 | 4– 6–67 | 22.6 | 28–175 | D |
| 16S/22E–27Jdd [3] | 0 1/4 N–1 W | H. Bunton | -- | --- | 127 | 162½ | 162½ | C | 20 | ------- | ------- | ---- | ---- | 12– 7–61 | 15.2 | -------- | ---- | ------- | D |
| 28Paal | 0 3/16 N–2 1/2 W | M. Cordeiro | -- | 1945 | 125 | 155 | 155 | C | 16 | 120–143 | T, E, 25 | ---- | ---- | 7–31–62 | 9.7 | 8– 2–62 | 21.1 | 120–143 | D, Q |
| 29Dba | 0 15/16 N–4 7/8 W | J. C. Lewis | -- | 1962 | 125 | 149 | 149 | C | 20 | 118–143 | T, E, 60 | 5,500 | ---- | 2–24–64 | 14.2 | 4–14–67 | 23.1 | 118–143 | D, Q |
| 16S/23E–2Dbd | 4 7/8 N–5 1/16 E | D. W. Haygood | -- | 1954 | 140 | 159 | 159 | C | 20 | 115–153 | T, E, 100 | ---- | ---- | 3–23–61 | 9 | 12–16–66 | 21.5 | 115–153 | D |
| 9Naa | 3 1/4 N–3 1/4 E | M. E. Spencer | -- | 1951 | 137 | 235 | 235 | C | 20 | 124–225 | T, E, 60 | 3,900 | 19 | 10– –62 | 10.5 | 6– 3–67 | 22.2 | 124–225 | D, PT, Q |
| 18Pdd | 2 N–1 7/16 E | M. Coley | -- | --- | 132 | ---- | ---- | -- | -- | ------- | C, E, 50 | ---- | ---- | 10–15–62 | 9.4 | 4– 6–67 | 24.0 | ------- | |
| 19Pac | 1 3/16 N–1 7/16 E | J. Burgess | -- | --- | 126 | ---- | ---- | -- | -- | ------- | C, E, 40 | ---- | ---- | -------- | ---- | 6– 7–67 | 22.4 | ------- | Q |
| 22Fdc | 1 1/2 N–4 1/2 E | H. Mitchell | -- | 1947 | 140 | ---- | ---- | -- | -- | ------- | T, E, 75 | 4,120 | 17 | 11– 3–66 | 13.8 | 10–17–62 | 22.8 | ------- | PT, Q |
| 22Rbd | 1 3/16 N–4 13/16 E | T. Tudor | -- | 1961 | 140 | 145 | 145 | C | 20 | 105–130 | T, D, 75 | ---- | ---- | 10– 8–62 | 16.3 | 6–15–67 | 23.3 | 105–130 | D, Q |
| 31Dbc | 0 1/16 S–1 E | Dover and Webb. | -- | 1952 | 128 | 150 | 150 | -- | 24 | 100–144 | C, E, 50 | 4,000 | 25 | 12– 8–61 | 6.3 | 5–31–67 | 22.4 | 100–144 | Q |
| 32Dbb | 0 1/16 S–2 E | P. Powers | -- | --- | 130 | ---- | ---- | -- | -- | ------- | C, D | ---- | ---- | 10–11–62 | 12.4 | -------- | ---- | ------- | |

[1] Destroyed.
[2] Replaces well destroyed.
[3] Unused.

TABLE 20.—*Miscellaneous wells*

Well number: Location of well according to the Federal land classification. See page H17 for description of well-numbering system.
Coordinates: Location of well according to grid system used by U.S. Bureau of Reclamation in Yuma area. See page H17 for explanation of grid system.
Owner or user and other number. Name shown in this column is that of the owner or user reported to the Geological Survey at the time of the canvas; number shown is that assigned to well by owner or user.
Year completed: Known or reported year of completion of well.
Altitude of land surface: Average altitude of land surface at well above mean sea-level datum. Altitude given to nearest foot are approximate and were obtained from topographic maps; altitudes given to demical fractions of a foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Log information, water-level data, and temperature 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—C, cable-tool or percussion equipment; CG, cable-tool equipment and gravel packed; D, drilled, method unknown; Dr, driven; R, drilled with rotary-mud equipment; RG, drilled with rotary-mud equipment and 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.
Use: Letter symbols designate—AC, air conditioning; Dom, domestic; Dr, drainage; FWL, fish and wildlife; Ind, industrial; Irr, irrigation; PS, public supply; RR, railroad; St, stock; T, test.
Type of pump and horsepower: Pump type and source of power are designated by letter symbols—C, centrifugal; D, diesel; E, electric; G, gasoline; Ga, gas; J, jet; L, lift; P, pitcher; S, submersible; T, turbine. Number indicates horsepower.
Discharge: Measured or reported discharge of well in gallons per minute.
Drawdown: Measured or reported drawdown, in feet, accompanying discharge in previous column.
Water level: Date measured by the Geological Survey or reported by owner or other agency. Depth to water in feet below land-surface datum.
Water temperature: Date measured by Geological Survey. Temperature, in degrees Celsius, of most recent sample of water pumped from well believed to represent water from the depth of the perforated interval in the coarse-gravel zone. In some wells not equipped with pumps, temperature was measured with a thermistor or a maximum thermometer at a depth believed to represent the middle of the coarse-gravel zone or an equivalent depth below land surface.
Other data available: Additional information about the well available in files of the Geological Survey. Some of this information is given in other tables of the present report. The type of information is indicated by the letter symbols—D, driller's log; G, gamma-ray log; L, lithologic log made by a geologist from drill cuttings and other information; T, temperature log; PT, pumping test or tests; Q, chemical quality-of-water data; W, periodic or continuous water-level records.

| Well | Coordinates | Owner or user and other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Use | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C– 5–21)19dbc | 17 1/4 N–9 9/16 E | Shepard Water Company 2. | 1961 | 200 | 240 | 240 | C | 8 | ------ | PS | ------ | ---- | ---- | 9– 7–62 | 14.0 | ------ | ---- | ------ | D, Q |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-5-22)13bbb | 18 7/8 N-8 E | USD1 | 1963 | 188 | 135 | 135 | C | 16 | 90-135 | FWL | T, D, 90 | 750 | 45 | 10-21-63 | 1 | 10-21-63 | 22.2 | 90-135 | PT, Q |
| 13bdd | 18 1/2 N-8 1/4 E | do | 1963 | 187 | 170 | 170 | C | 16 | 50-164 | FWL | ---- | ---- | ---- | 10-30-63 | .4 | 10-30-63 | 26.7 | 154-164 | D, Q |
| (C-6-20)32ada | 9 3/4 N-16 13/16 E | U.S. Army C. | 1958 | 410 | 311 | ---- | D | 10 | ---- | Ind, PS | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 32adb | 9 3/4 N-16 11/16 E | U.S. Army W. | 1952 | 410 | 501 | 500 | RG | 10 | ---- | Ind, PS | T, E | 500 | 21 | 4-5-61 | 245 | ---- | 31.1 | ---- | D, PT, Q |
| (C-6-21)10acb1[1] | 13 3/4 N-13 5/8 E | U.S. Army V. | 1943 | 375 | 244 | ---- | D | 6 | ---- | Dom | L, Ga | 40 | ---- | 4-6-61 | 210 | ---- | ---- | ---- | Q |
| 10acb2 | 13 3/4 N-13 5/8 E | U.S. Army S. | 1960 | 375 | 300 | 300 | C | 20-10 | 228-254 | Dom, PS | T, E, 10 | 65 | ---- | ---- | ---- | ---- | ---- | ---- | D, Q |
| 31dab | 9 3/8 N-10 13/16 E | U.S. Army X. | 1952 | 308 | 308 | 308 | C | 16 | 210-250 | PS | T, E, 75 | 800 | 13 | 4-5-61 | 31.7 | 1961 | 28.9 | ---- | D, Q |
| 31dad | 9 5/16 N-10 15/16 E | U.S. Army Y. | 1959 | ---- | 150 | 150 | C | 16 | 110-130 | Ind, PS | T, E, 100 | 800 | 33 | 1960 | 33 | 1960 | 31.1 | ---- | D, Q |
| 34dba | 9 3/8 N-13 11/16 E | U.S. Army B. | 1958 | 380 | 271 | ---- | D | 8 | 225-271 | Ind, PS | T, E, 10 | 68 | 7 | 5-10-60 | 199.4 | 5-10-60 | 33.3 | 225-271 | |
| (C-7-21)1aab[1] | 8 7/8 N-14 7/8 E | Yuma County. | ---- | 364 | ---- | ---- | -- | 12 | ---- | PS | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 10aad | 7 13/16 N-12 15/16 E | U.S. Army T. | 1952 | 335 | 306 | 305 | D | 10 | ---- | Ind, PS | T, E, 25 | 500 | 5 | 4-5-61 | 168 | 4-5-61 | 28.3 | ---- | Q |
| 11bdc | 7 5/8 N-13 5/16 E | U.S. Army U. | 1952 | 330 | 397 | 396 | D | 10 | ---- | PS | T, E | 500 | ---- | 4-5-61 | 171 | 4-5-61 | 28.3 | ---- | Q |
| 36add | 3 9/16 N-15 E | J. Ramsey | 1964 | 190 | 500 | 491 | C | 20 | 447-486 | Irr | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D, Q |
| (C-7-22)14cad | 6 1/4 N-7 7/16 E | C. R. Kirkman. | 1960 | ---- | 31 | 31 | D | 1¼ | 29-31 | Dom | J, E, 1/3 | ---- | ---- | ---- | ---- | 10-4-62 | 22.8 | ---- | Q |
| 14ddc | 6 1/8 N-7 1/4 E | U.S. Bureau of Reclamation. | 1945 | ---- | 30 | 30 | D | 4 | ---- | Dom | P | ---- | ---- | ---- | ---- | 10-4-62 | 28.9 | ---- | Q |
| 27bba | 4 15/16 N-6 1/4 E | B. M. Mills | ---- | 143 | 30 | 30 | D | ---- | ---- | Dom | E | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 27cad | 4 N 6 3/16 E | F. Yates | ---- | 140 | 35 | 35 | D | ---- | 33-35 | Dom | E | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 27ccd | 4 N-6 1/4 E | D. Armer | ---- | 140 | 130 | 130 | D | 4 | ---- | Dom | J, E, 1 | -- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 28ddc | 4 N-5 9/16 E | W. Harrison | 1962 | 144 | 100 | 100 | D | 4-2 | ---- | Dom | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 33aba[1] | 3 15/16 N-6 3/16 E | do | ---- | 142 | 14 | 14 | D | 2 | 12-14 | Dom | J, E, 3/4 | ---- | ---- | 4-12-61 | 8 | ---- | ---- | ---- | |
| 34bca | 3 11/16 N-6 3/16 E | Laguna School. | ---- | 140 | ---- | ---- | D | 2 | ---- | Dom | J, E, 1/3 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 34bdc | 3 9/16 N-6 5/16 E | J. Chavez | ---- | 141 | 130 | 130 | D | 4 | ---- | Dom | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| (C-8-21)1bba | 2 15/16 N-14 3/16 E | Wellton Mohawk. | 1960 | 165 | 96 | 96 | C | 20 | 56-96 | Dr | T, E, 40 | 2,500 | ---- | 1- -60 | 6 | ---- | ---- | ---- | Q |
| 1bbc | 3 13/16 N-14 E | U.S. Bureau of Reclamation 1. | 1962 | 171 | 171 | 169 | C | ---- | ---- | T | ---- | ---- | ---- | 11- -62 | 17.0 | ---- | ---- | ---- | D |
| 2bab | 3 N-13 3/8 E | D. Knettle | ---- | 165 | 22 | 22 | Dr | 2 | 20-22 | Dom | J, E, 1/2 | ---- | ---- | 4-11-61 | 12 | ---- | ---- | ---- | |
| 5dcd[1] | 2 1/8 N-10 3/4 E | ---- | ---- | 165 | ---- | ---- | C | 12 | ---- | Ind | ---- | ---- | ---- | 3-31-67 | 11.5 | 3-31-67 | 24.7 | 14 | |
| 11bdb[1] | 1 3/4 N-13 5/16 E | R. G. Chenoweth. | ---- | 190 | 32.6 | 32.6 | C | 12 | ---- | ---- | ---- | ---- | ---- | 4-24-63 | 16.1 | 4-24-63 | 27.2 | ---- | Q |
| 16bca | 0 3/4 N-11 3/16 E | Tanner Paving Co. | 1963 | 195 | 396 | 396 | C | 16 | 30-396 | Ind | T, E, 100 | 1,000 | 115 | 6-12-63 | 51.0 | ---- | ---- | ---- | D, Q |
| 21bca[2] | 0 1/4 S-11 1/8 E | F. Conners | 1927 | 165 | 137 | 137 | C | 16 | 105-130 | Dom | ---- | ---- | ---- | 2- -27 | 38.0 | ---- | ---- | ---- | D |
| 28bbc[2] | 1 3/16 S-11 E | Southern Pacific Co. | ---- | ---- | ---- | ---- | -- | ---- | ---- | RR | ---- | ---- | ---- | 1-18-61 | 45.9 | ---- | ---- | ---- | |
| 28dbb[1] | 1 1/2 S-11 1/2 E | Igo | 1938 | 220 | 200 | 200 | C | 8 | 100-195 | Ind | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | D |
| 29acc | 1 1/2 S-10 9/16 E | Yuco Gin | ---- | 185 | 250 | ---- | D | 8 | ---- | Ind | T, E, 5 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 29ada | 1 1/4 S-10 7/8 E | Mid'and Co. | 1946 | 187.2 | 100 | 100 | C | 8 | 78-89 | Ind | ---- | ---- | ---- | 1-18-61 | 49.4 | ---- | ---- | ---- | D |
| 30cc2 | 1 7/8 S-9 E | C. M. Harvey. | 1955 | 154 | 240 | ---- | -- | 4 | ---- | Dom | J, E, 1/4 | ---- | ---- | 1- -61 | 18.8 | ---- | ---- | ---- | |
| (C-8-22)4aad | 2 3/4 N-5 15/16 E | F. M Ferguson. | 1956 | 140 | 70 | 70 | C | 6 | ---- | Dom | J, E, 1/2 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 4abc | 2 3/4 N-5 1/2 E | J. W. Ferguson. | 1954 | 140 | 121 | 121 | C | 4 | ---- | Dom, St | J, E, 1 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 13bdd1 | 0 1/2 N-8 7/16 E | S. Sturges | 1958 | 150 | 100 | 100 | C | 3 | ---- | Dom | P | ---- | ---- | 1-31-61 | 5.9 | ---- | ---- | ---- | D |
| 16caa | 0 1/2 N-5 1/2 E | B. Church | 1950 | 149 | 150 | 150 | C | 12 | 110-148 | St | T, E, 15 | ---- | ---- | 1-30-61 | 27 | ---- | ---- | ---- | D, Q |
| 21aaa | 0-6 E | North Gila Store. | ---- | ---- | 30 | ---- | -- | ¾ | ---- | Dom | E | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 25dac2 | 1 3/4 S-8 7/8 E | C. M. Harvey. | 1957 | 155 | 208 | 208 | C | 4 | 202-208 | Dom | J, E, 1½ | ---- | ---- | 12- -60 | 17 | ---- | ---- | ---- | |
| 26dca2 | 1 3/4 S-7 5/8 E | F. M. Brown. | 1965 | 151 | 200 | 200 | C | 6 | 184-190 | Dom | J, E | ---- | ---- | 3-25-65 | 17.0 | ---- | ---- | ---- | D, Q |
| 30cdc | 2 S-3 1/4 E | Cushing Lord. | 1964 | 141 | 390 | ---- | D | 4 | ---- | Dom, AC | T, E, 5 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 32daa2 | 2 1/2 S-4 15/16 E | E. C. Engler. | 1964 | 145 | 130 | 130 | C | 8 | 122-127 | Dom | J, E, 3/4 | ---- | ---- | 11-4-64 | 9.6 | ---- | ---- | ---- | D, Q |
| 33cda | 2 7/8 S-5 3/8 E | F. Crabtree | 1957 | 215 | 226 | 226 | C | 10 | 214-220 | Dom | T, E, 25 | 114 | 120 | ---- | ---- | ---- | ---- | ---- | D |
| 33daa | 2 1/2 S-6 E | South Gila Irrigation District. | 1963 | 150 | 408 | 288 | D | 10 | ---- | Dom, PS | T, E, 3 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |
| 33dbc | 2 11/16 S-5 9/16 E | ---- | ---- | 190 | 154 | ---- | -- | ---- | ---- | Dom | ---- | ---- | ---- | 1958 | 70 | ---- | ---- | ---- | Q |
| 35bab2 | 2 S-7 3/8 E | ---- | ---- | 150 | ---- | ---- | -- | 16 | ---- | Dom | J, E, 1 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | |
| 35ccb | 2 3/4 S-7 1/8 E | Arizona Western College 1. | 1962 | 216 | 600 | 600 | CG | 12 | 460-580 | PS | T, E, 20 | ---- | ---- | 10-1-62 | 81.6 | 9-7-62 | 22.8 | 460-580 | D, L, Q |
| (C-8-23)21aac | 0 1/4 S-0 3/16 W | First Natl. Bank of Arizona. | ---- | ---- | ---- | ---- | -- | ---- | ---- | AC | T, E, 5 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | Q |

See footnotes at end of table.

TABLE 20.—*Miscellaneous wells*—Continued

| Well | Coordinates | Owner or user and other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Use | Type of pump and horsepower | Discharge | Drawdown | Water level: Date | Water level: Depth to water | Water temperature: Date | Water temperature: °C | Water temperature: Depth, in feet below land surface | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C- 8-23)21acb | 0 3/8 S-0 1/2 W | Coronado Motel. | 1955 | 160 | 110 | 110 | C | 5 | ------ | AC | T, E, 5 | ---- | ---- | 9- 7-62 | 44.0 | 9- 7-62 | 26.7 | 110 | Q |
| 21acc1[1] | 0 1/2 S-0 1/2 W | Library | 1949 | 160 | 193 | 193 | C | 8 | 166–180 | Dom | T, E, 15 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 21acc2 | 0 3/8 S-0 1/2 W | Coronado Motel. | 1962 | 160 | 220 | 160 | C | 8–5 | 105–160 | AC | T, E, 5 | ---- | ---- | 9- 7-62 | 45.0 | 9- 7-62 | 26.7 | 105–160 | D, Q |
| 21ada | 0 3/8 S-0 1/16 W | Hotel Del Sol. | 1937 | 141 | 145 | 145 | C | 12 | 100–143 | AC | T, E, 15 | ---- | ---- | 4- -37 | 12 | ------ | ---- | ------ | D |
| 21bcd | 0 7/16 S-0 11/16 W | Southwest Ice Co. | 1926 | 141 | 132 | 132 | C | 12 | 119–123 | Ind | T, E, 15 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 21cac[1] | 0 3/4 S-0 5/8 W | Abe Marcus Pool. | 1926 | 175 | 478 | 478 | C | 16 | 180–230 | PS | ------- | ---- | ---- | 4-18-61 | 59.0 | 3-15-63 | 27.2 | 202–240 | D, G, T |
| 21ccc | 1 S-1 W | Alpha Ace Laundry. | 1965 | 165 | 208 | 208 | C | 8 | 160–208 | Ind | S, E | ---- | ---- | 7-22-65 | 50 | ------ | ---- | ------ | D, Q |
| 22bcc | 0 1/2 S-0 | Southwest Ice Co. | 1926 | 135 | 132 | 132 | C | 12 | 118–120 | Ind | T, E, 15 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 27dbc | 1 5/8 S-0 9/16 E | W. R. Whitman. | 1957 | 135 | 247 | 247 | C | 4 | ------ | Dom, St | T, E, 2 | ---- | ---- | 1-30-61 | 12 | ------ | ---- | ------ | D |
| 28ac[1] | 1 1/2 S-0 3/8 W | J. Wisener | 1934 | 195 | 185 | 185 | C | 8 | 179–183 | Dom | ------- | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 29ada | 1 1/4 S-1 W | Pepsi Cola Bottling Co. | 1956 | 165 | 126 | 126 | C | 8 | 100–118 | Ind | T, E, 5 | ---- | ---- | 4-14-61 | 57 | 4- 4-61 | 24.4 | 100–118 | D, Q |
| 31ddc | 2 15/16 S-2 1/4 W | Southwest Meat Co. | 1959 | 125 | 170 | 170 | C | ---- | 120–170 | Ind | T, E, 2 | ---- | ---- | 10- 5-62 | 12.5 | 7-27-62 | 21.7 | 120–170 | Q |
| 32baa1 | 2 1/16 S-1 5/8 W | G. R. Vaughan. | 1962 | 120 | 45 | 45 | Dr | 1½ | 43–45 | Dom | J, E, 1/3 | ---- | ---- | 4- -62 | 7.0 | 10- 1-62 | 22.2 | 43–45 | Q |
| 32baa2 | 2 1/16 S-1 5/8 W | J. R. Hazlitt. | 1960 | 120 | 18 | 18 | Dr | 1½ | 16–18 | Dom | J, E, 1/3 | ---- | ---- | 10- 1-62 | 7.0 | 10- 1-62 | 22.2 | 16–18 | Q |
| 32caa2 | 2 9/16 S-1 5/8 W | H. L. Kryger. | ---- | 120 | 147 | 147 | -- | 2 | ------ | Dom | C, E, 1 | ---- | ---- | ------ | ---- | 8- 2-62 | 25.0 | ------ | Q |
| 32caa | 2 7/8 S-1 7/8 W | ---do | ---- | 125 | 23 | 23 | Dr | 1½ | 20–23 | Dom | P | ---- | ---- | ------ | ---- | 8- 2-62 | 26.1 | 20–23 | Q |
| 32cdc | 3 S-1 3/4 W | E. Stiles | ---- | 125 | 23 | 23 | Dr | 1½ | 20–23 | Dom | C, E | ---- | ---- | ------ | ---- | 8- 2-62 | 34.4 | 20–23 | Q |
| 36ccd | 3 S-2 1/4 E | Federal Compress Co. | 1952 | 216 | 302 | 302 | -- | 12 | 185–244 | Ind | T, E, 30 | 325 | 10.0 | 3- 9-61 | 75.0 | ------ | ---- | ------ | D, Q |
| (C- 8-24)22ccd | 1 S-5 3/4 W | McLaren Produce Co. | 1930 | 116 | 204 | 204 | C | 24 | 117–142 | Dr, St | J, E, 1/4 | ---- | ---- | 2-24-61 | 5.3 | ------ | ---- | ------ | D, PT, Q |
| 22cdd | 1 S-5 9/16 W | ---do | ---- | 116 | 178 | 178 | C | 5 | ------ | Dom | C, E, 1 | ---- | ---- | 9- 7-62 | 8 | 9- 7-62 | 26.7 | ------ | Q |
| 22dca | 0 13/16 S-5 1/4 W | J. W. Olberg. | 1955 | 116 | 114 | 114 | C | 10–8 | 99–105 | Dom | J, E, 2 | ---- | ---- | 4-24-61 | 8.1 | ------ | ---- | ------ | D |
| 25add | 1 7/16 S- 3 1/8 W | R. B. Witman. | ---- | 124 | 40 | 40 | Dr | 2 | 38–40 | Dom | C, E, 1/2 | ---- | ---- | 8- 1-62 | 8 | ------ | ---- | ------ | Q |
| 27aba | 1 S-5 5/16 W | University of Arizona Experimental Farm. | 1955 | 116 | 122 | 122 | C | 8 | 114–119 | Dom, St | J, E, 3 | ---- | ---- | 1-30-61 | 3.5 | ------ | ---- | ------ | D, Q |
| (C- 9-21)2bca[1] | 3 1/4 S-13 1/8 E | Gila Fortuna Co. | 1966 | 375 | 351 | 351 | C | 10 | 280–310 | Dom | ------- | ---- | ---- | 3-31-67 | 236.5 | 3-31-67 | 36.4 | 298.0 | D, T, Q |
| 6ccc | 3 15/16 S-9 E | D. W. Cooper. | ---- | 250 | 200 | 200 | RG | 8 | ------ | Dom | T, E | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 6cdc1[1] | 4 S-9 5/16 E | E. Lincoln | 1954 | 255 | 210 | 210 | C | 8 | ------ | Dom | ------- | ---- | ---- | 2- 2-61 | 106.8 | ------ | ---- | ------ | |
| 6cdc2 | 3 15/16 S-9 5/16 E | M. T. Taboni. | 1960 | 255 | 200 | 200 | RG | 8 | ------ | Dom | S, E, 3/4 | ---- | ---- | 2- 2-61 | 107.0 | ------ | ---- | ------ | |
| 10bcc | 4 1/2 S-12 E | C. L. Tiffany. | ---- | 337 | 268 | 268 | RG | 8 | ------ | Dom | J, E, | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 10bcd | 4 3/8 S-12 3/16 E | W. T. Scrimgeour. | 1966 | 343 | 301 | 280 | D | 8 | 10–300± | Dom | J, E, 2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 12dbc[1] | 4 11/16 S-14 9/16 E | H. Savoy | 1954 | 472 | 371 | 371 | C | 6 | ------ | Dom | ------- | ---- | ---- | 9-27-66 | 334.6 | 9-27-66 | 31.9 | 339.5 | D |
| 14acc[1] | 5 1/2 S-13 1/2 E | B. Palon | 1962 | 430 | 495 | 495 | RG | 6 | 375–495 | Dom, T | ------- | ---- | ---- | 9-27-66 | 295.8 | 9-27-66 | 31.4 | 304.8 | D |
| (C- 9-22)4acb[1] | 3 5/16 S-5 9/16 E | Western Cotton Co. | 1954 | 213 | 175 | 175 | C | 8 | 165–170 | Ind | T, E, 5 | ---- | ---- | 4- -54 | 80 | 4-29-64 | 24.2 | 117–167 | D, T |
| 4bda[1] | 3 3/8 S-5 3/8 E | ---------- | ---- | 212 | ---- | ---- | D | 6 | ------ | St | ------- | ---- | ---- | 11-23-23 | 92.5 | ------ | ---- | ------ | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4caa | 3 9/16 S-5 7/16 E | Yuma Valley Livestock. | 1957 | 212 | 240 | 240 | D | 8 | 130-138 | Ind | T, E, 7½ | | | | | | | | D, Q |
| 17ccb | 5 3/4 S-4 1/8 E | H. J. Harkey. | 1952 | 208 | 179 | 179 | C | 8 | 166-177 | Dom | S, E, 2 | | | 4-21-61 | 48.9 | 7-25-62 | 29.4 | | D, Q |
| 18add [1] | 5 1/2 S-4 E | M. Garcia | | 208 | | | | 3 | | Dom | | | | | | 5-7-65 | 25.6 | | Q |
| 18ccc | 6 S-3 E | C. E. Waits | | 204 | 176 | 176 | | | | Dom | J, E, 3 | | | | | 4-21-67 | 24.4 | | Q |
| 18ddd | 6 S-4 E | J. Gardner | 1952 | 208 | 179 | 179 | C | 8 | 169-177 | Dom | J, E, 1 | | | | | 4-27-65 | 27.8 | 169-177 | D, Q |
| 22baa [1] | 6 S-6 1/2 E | Anderson Development Co. | 1960 | 205 | 530 | | D | 5 | | T | | | | | | | | | D |
| 30bbb | 7 S-3 1/16 E | N. J. Riebe | 1965 | 206 | 190 | 190 | D | | | Dom | J, E, 1 | | | | | 4-28-65 | 26.7 | | Q |
| (C-9-23)1add [1] | 3 1/2 S-2 15/16 E | Yuma Citrus Co. | 1957 | 215 | 190 | 190 | C | 8 | 180-188 | Ind | T, E, 3 | | | | | | | | D, Q |
| 1cac [1] | 3 11/16 S-2 1/4 E | Tamco Engineering. | 1952 | 213 | 201 | 201 | C | 12 | 190-200 | Ind | | | | 11- -52 | 80 | 12-8-66 | 25.3 | 210 | D, T, Q |
| 2cda | 3 3/4 S-1 7/16 E | Yuma County Fairground. | 1959 | 212 | 306 | 306 | C | 8 | Open bottom | Ind | S, E | | | | | | | | D |
| 2dda | 3 7/8 S-2 E | J. C. Neil. | 1931 | 214 | 193 | 193 | C | 8 | Open bottom | Dom | T, E, 1½ | | | | | | | | D |
| 3dcc | 4 S-0 9/16 E | Silver Spur Motel. | 1952 | 195 | 205 | 205 | C | 8 | 185-203 | Dom | T, E, 15 | | | | | 4-19-61 | 27.8 | 185-203 | D, Q |
| 4abb | 3 S-0 7/16 W | Flamingo Motel. | 1952 | 196 | 201 | 201 | C | 12 | 100-196 | Ind | | | | | | | | | D |
| 5bcc1 [1] | 3 1/2 S-2 W | Yuma County Hospital. | 1928 | 120 | 150 | 150 | C | 12 | 114-147 | PS | T, E, 1 | | | | | | | | D |
| 5bcc2 | 3 1/2 S-2 W | do | 1939 | 119 | 146 | 146 | C | 8 | 123-143 | AC, PS | T, E, 5 | | | | | | | | D, Q |
| 8bcb | 4 1/4 S-1 15/16 W | H. D. Duff | 1965 | 118 | 149 | 149 | C | 6 | 135-141 | Dom | E | | | 4-27-65 | 3.4 | | | | D, Q |
| 8bdd [1] | 4 1/2 S-1 9/16 W | Morris | 1945 | 129 | 142 | 127 | D | 4 | 116-127 | Dom | | | | | | | | | D, W |
| 9baa [2] | 4 1/16 S-0 1/2 W | Sprague | 1931 | 198 | 210 | 210 | C | | | Dom | | | | | | | | | D |
| 9bbb | 4 S-1 W | Arizona Public Service Co. | 1954 | 193 | 750 | 750 | C | 20 | 186-670 | Ind | | 4,000 | 140 | 6-15-54 | 116.3 | | | | D, Q |
| 9caa | 4 5/8 S-0 9/16 W | M. Miller | | 195 | 236 | 236 | C | 16 | 190-236 | Ind | T, E, 3 | | | 3 3-61 | 69.5 | | | | D |
| 10abb | 4 1/16 S-0 9/16 E | Yuma County Airport. | 1929 | 192 | 200 | 200 | C | 16 | 145-197 | Ind | T, E, 10 | | | 1929 | 84 | | | | D, Q |
| 11bbb [2] | 4 1/16 S-1 1/16 E | Department of Commerce. | 1931 | 206 | 193 | 193 | C | 8 | Open bottom | Dom | | | | | | | | | D |
| 12aac | 4 1/4 S-2 3/4 E | L. B. Henderson. | | 216 | 108 | 108 | C | 8 | 92-100 | Dom | J, E, 5 | | | | | 4-21-67 | 23.3 | 92-100 | Q |
| 12aca | 4 1/4 S-2 3/4 E | W. Roach | | 216 | | | | | | Dom | J, E, 3/4 | | | | | 4-21-67 | 23.5 | | Q |
| 23adc | 6 1/2 S-1 7/8 E | R. Beckett | 1953 | 203 | 173 | 173 | C | 8 | 164-170 | Dom | | | | | | 7-25-62 | 26.1 | 164-170 | Q |
| 23dcb | 6 7/8 S-1 5/8 E | J. L. Canada. | 1953 | 200 | 173 | 173 | C | 8 | 164-170 | Dom | J, E, 1/2 | | | | | 4-27-65 | 27.2 | 164-170 | D, Q |
| 24baa | 6 S-2 1/2 E | R. H. Fram | 1951 | 204 | 175 | 175 | C | 8 | Open bottom | Dom, St | T, E, 5 | | | | | 7-25-62 | 26.1 | 175 | D, Q |
| 28aab | 7 S-0 1/4 W | Curtis, Woodman, & Roach. | 1962 | 192 | 251 | 251 | C | 8 | 230-250 | Ind | T, E | | | | | | | | D, Q |
| 28ccc [1] | 8 S-1 W | University of Arizona Experimental Farm. | 1940 | 191 | 220 | 220 | C | 8 | | Dom | | | | | | | | | D, Q |
| 29adb [1] | 7 1/4 S-1 3/16 W | Yuma Mesa Fruit Growers Unit B. | 1934 | 132.9 | 209 | 209 | C | 20 | 156-207 | Ind | J, E, 1 | | | 12-9-66 | 11.5 | 12-9-66 | 25.3 | 163.9 | D, PT, T |
| 29cbd | 7 5/8 S-1 3/4 W | Yuma County Labor Camp. | | 182 | 217 | 217 | D | 8 | 205-215 | PS | T, E, 7½ | | | | | | | | D |
| 31cdc | 9 S-2 11/16 W | J. Farris | 1963 | 175 | 220 | 220 | R | 6 | | Dom | E | | | 3-25-63 | 5.4 | | | | Q |
| 31ddd | 9 S-2 W | A. Lopez | | 175 | | | | | | | | | | | | | | | |
| 32ccc3 [1] | 8 7/8 S-2 W | S. Hill | 1923 | 186 | 208 | | | | | Dom | | | | 3- -23 | 103 | | | | D |
| 33ccc3 | 9 S-1 W | Unit B Irrigation District. | | | | | | | | Dom | | | | | | | | | |
| 35dcd | 9 S-1 3/4 E | J. Rose | 1957 | 200 | 176 | 176 | | | | | | | | | | 4-21-67 | 25.4 | | Q |
| 36aab | 8 S-2 13/16 E | H. L. Morris. | 1965 | 200 | 198 | | D | 8 | 160-196 | | | | | | | | | | Q |
| (C-9-24)2aaa1 | 3 1/16 S-4 1/16 W | F. Kornegay | | 115 | 165 | | | 2 | 163-165 | Dom | C, E, 1/2 | | | | | 9-5-62 | [3]25.6 | 163-165 | Q |
| 2aaa2 | 3 1/16 S-4 1/16 W | do | | 115 | 25 | | | 2 | 23-25 | Dom | C, E, 1/2 | | | | | 9-5-62 | [3]25.6 | 23-25 | Q |
| 2ccd | 4 S-4 7/8 W | R. Gibbs | | 114 | 130 | 130 | | 2 | 128-130 | Dom | C, E, 1/2 | | | | | | | | Q |

See footnotes at end of table.

TABLE 20.—*Miscellaneous wells*—Continued

| Well | Coordinates | Owner or user and other number | Year completed | Altitude of land surface | Total depth | Completed depth | Method of construction | Casing diameter | Depth of perforated interval | Use | Type of pump and horsepower | Discharge | Drawdown | Water level | | Water temperature | | | Other data available |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Date | Depth to water | Date | °C | Depth, in feet below land surface | |
| (C-9-24)3aab | 3 1/16 S-5 7/16 W | J. B. Williams | ---- | 118 | 20 | 30 | -- | 2 | 18-20 | Dom | C, E, 1/2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 10bbb | 4 S-6 W | Watkins Cattle Co. | ---- | 111 | 60 | 60 | -- | ---- | ------ | St | C, E, 3 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 12daa | 4 9/16-3 1/8 W | S. Dick | 1962 | 116 | 21 | 21 | Dr | 2 | 19-21 | Dom | C, E, 1/2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 12dac | 4 11/16 S-3 1/8 W | ---do | ---- | 116 | 145 | 145 | C | 4 | ------ | Dom | J, E, 5 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 14dab | 5 9/16 S-4 1/4 W | Yuma Valley Cattle Co. | 1949 | 115 | 133 | 133 | C | 8 | 125-133 | Dom, St | T, E, 5 | ---- | ---- | 4-14-61 | 16.5 | ------ | ---- | ------ | D, Q |
| 14dba | 5 1/2 S-4 5/16 W | ---do | ---- | 115 | 120 | 120 | -- | 4 | ------ | Dom, St | J, E, 5 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 15dbd | 5 5/8 S-5 1/4 W | K. Drysdale | ---- | 105 | ---- | ---- | Dr | 2 | ------ | Dom | C, E, 1 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 17add | 5 7/16 S-7 W | E. Shawn | 1951 | 107 | 124 | 124 | D | 2 | Open end | Dom | J, E, 3/4 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 20cdd | 7 S-7 1/2 W | G. M. Sugden. | ---- | 113 | 160 | 160 | D | 3 | ------ | Dom, St | T, E, 3 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 20ddd1 | 6 7/8 S-7 1/16 W | ---do | ---- | 107 | 170 | 170 | D | 8 | ---- | Dom | C, E, 1/2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 22aba | 6 S-5 5/16 W | McLaren Produce Co. | 1945 | 111 | 125 | 125 | C | 8 | Open bottom | Dom | J, E, 3 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 28cbb | 7 1/2 S-7 W | Woods Co | ---- | 108 | ---- | ---- | -- | ---- | ------ | Dom | ------- | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 32ddb | 8 7/8 S-7 1/4 W | Yuma County Labor Camp. | 1952 | 105 | 203 | 203 | C | 12 | 170-195 | PS | T, E, 20 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 34dcb1 [1] | 8 13/16 S-5 1/2 W | City of Somerton. | 1920 | 106.2 | 215 | 215 | C | 12 | ------ | PS | C, E, 20 | 2,000 | ---- | 1-12-61 | 12.1 | ------ | ---- | ------ | D, Q, W |
| 34dcb2 | 8 13/16 S-5 1/2 W | ---do | ---- | 106.2 | ---- | ---- | C | 16 | ------ | PS | ------- | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 34dcb3 | 8 13/16 S-5 1/2 W | ---do | 1965 | 106.2 | 1,163 | 1,163 | C | 12 | ------ | PS | ------- | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, G, Q |
| (C-10-22)22bab | 12 1/16 S-6 5/16 E | U.S. Marine Corps. | 1958 | 266.7 | 319 | 319 | C | 12 | ------ | PS | S, G | ---- | ---- | 1-11-66 | 132.5 | 1-11-66 | 28.9 | 139 | Q |
| (C-10-23)3aaa2 | 9 1/16 S-0 15/16 E | Allec Bros. | 1960 | 203 | 186 | 186 | C | 8 | 170-184 | Dom | T, E, 7½ | ---- | ---- | 5-24-61 | 44.1 | 5-24-61 | 26.1 | 170-184 | Q |
| 3aba | 9 S-0 11/16 E | R. A. Patrick. | 1960 | 199 | 190 | 190 | R | 4 | Open bottom | Dom | J, E, 1 | 11 | ---- | 8-5-68 | 34.0 | ------ | ---- | ------ | Q |
| 4ada [1] | 9 1/4 S-0 1/16 W | S. K. Lamb | 1953 | 197.8 | 211 | 211 | C | 8 | 185-195 | Dom | ------- | ---- | ---- | 3-3-67 | 40.2 | 11-6-67 | 27.3 | 188 | D, G, T |
| 5cad [1] | 9 11/16 S-1 9/16 W | W. Si'va | ---- | 186 | 186 | ---- | D | 6 | ------ | Dom | ------- | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 5dcc | 10 S-1 1/2 W | Unit B School. | 1928 | 186 | 225 | 225 | C | 16 | 190-200 | Dom | J, E, 1½ | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 20bbb1 [1] | 12 1/16 S-2 W | U.S. Navy | 1961 | 189 | 315 | 315 | C | 12 | 212-232 | Ind | E | 500 | 12 | 7-12-61 | 86.0 | ------ | ---- | ------ | D, G, Q |
| (C-10-24)2aab | 9 S-4 1/4 W | W. Jacoby & Sons, Inc. | ---- | 105 | 147 | ---- | D | 6 | ------ | Ind | C, E, 5 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 4add | 9 3/8 S-6 1/16 W | Western Cotton Co. | 1962 | 102 | 189½ | 189½ | C | 16 | 155-187 | Dom, Ind | T, E, 5 | ---- | ---- | 8-24-62 | 8.0 | ------ | ---- | ------ | D, Q |
| 4bbb | 9 S-7 W | Williams Store. | ---- | 105 | 25 | 25 | Dr | 2 | 23-25 | Dom | C, E, 1/2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 9bba | 10 1/16 S-6 7/8 W | H. Holling | ---- | 103 | 140 | ---- | -- | | ------ | Dom, St | C, E, 1 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 10cdd | 11 S-5 9/16 W | F. Jones | ---- | 100 | 140 | 140 | C | 8 | ------ | Dom, St | C, E, 1 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 16baa2 | 11 S-5 9/16 W | Western Cotton Co. | 1965 | 100 | 423 | 423 | C | 12 | 152-180 | Dom, Ind | T, E, 5 | ---- | ---- | 8-4-65 | 7.0 | ------ | ---- | ------ | D, Q |
| 28ddb | 13 3/4 S-6 1/8 W | L. P. Barkley. | 1962 | 97 | 217 | 217 | C | 8 | ------ | Dom, St | J, E, 5 | ---- | ---- | ------ | ---- | 4-22-64 | 26.7 | ------ | Q |
| (C-10-25)13cca | 11 3/4 S-9 7/8 W | E. Malone | ---- | 98 | 157 | 157 | -- | 2 | ------ | Dom | C, E, 1/2 | ---- | ---- | 9-4-62 | 7 | ------ | ---- | ------ | Q |
| 26dba | 13 1/2 S-10 1/4 W | A. H. Clark | 1945 | 95 | 167 | 167 | -- | 2 | ------ | Dom | J, E, 1/2 | ---- | ---- | 9-4-62 | 6 | ------ | ---- | ------ | Q |
| (C-11-25)12bca | 16 3/8 S-9 3/4 W | Flying A Service. | 1961 | 130 | 198 | 198 | C | 6 | 183-195 | Dom | J, E, 1½ | ---- | ---- | ------ | ---- | 1-25-62 | 22.8 | 183-195 | D, Q |
| 12bdb | 16 3/8 S-9 5/8 W | San Luis Water Co. | 1964 | 130 | 213 | 213 | C | 8 | 177-200 | PS | T, E | 150 | 16 | 1-10-64 | 47.0 | ------ | ---- | ------ | D, Q |
| 12cab | 16 5/8 S-9 11/16 W | U.S. Government. | 1931 | 130 | 105 | 105 | C | 5 | ------ | Dom | J, E, 1 | ---- | ---- | ------ | ---- | 1-25-62 | 26.7 | ------ | Q |
| 15S/23E-33Fac | 5 5/8 N-3 7/16 E | R. S. Dillman. | 1933 | 138 | 130 | 130 | D | 6 | Open bottom | Dom | J, E, 1 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 35Eac | 5 11/16 N-5 3/16 E | T. Cardoza | 1961 | 140 | 130 | 130 | D | 4 | ------ | Dom | J, E, 1 | ---- | ---- | 12-11-61 | 14.2 | ------ | ---- | ------ | Q |
| 16S21/E-35Qbc1 [1] | 0 3/4 S-6 1/2 W | Southern Pacific Co. | 1953 | 123 | 107 | 107 | C | 8 | 80-90 | PS, RR | S, E | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 35Qbc2 | 0 3/4 S-6 1/2 W | U.S. Customs. | 1960 | 123 | 155 | 155 | C | 4 | 115-135 | Dom, PS | S, E, 2 | ---- | ---- | ------ | ---- | 10-10-62 | 23.3 | 115-135 | D, Q |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36Fca | 0 7/16 S–5 5/8 W | Arizona Public Service Co. | 1957 | 117 | 978 | 978 | C | 20 | 518–912 | Ind | T, E | 3,000 | 61 | 6– 1–57 | 11 | ------ | ---- | ------ | D, Q |
| 36Mad | 0 5/8 S–5 3/4 W | ---do | 1957 | 117 | 797 | 797 | C | 20 | 471–740 | Ind | T, E | 2,470 | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 16S/22E–19G[2] | 1 5/8 N–4 7/16 W | Southern Pacific Co. | 1925 | 145 | 147 | 147 | C | 8 | 135–137 | RR | ------ | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 25Mbb1 | 0 1/2 N–0 | Indian School. | 1930 | 125 | 121 | 121 | C | 8 | 90–117 | PS | T, E, 20 | ---- | ---- | 12–12–61 | 9.0 | ------ | ---- | ------ | D |
| 26Ecc | 0 1/2 N–1 W | K. Sowers | 1960 | 130 | 141 | 141 | C | 12 | 121–133 | PS | C, E, 10 | ---- | ---- | 10–29–61 | 14.0 | 4–28–65 | 23.3 | 121–133 | D, Q |
| 26Gcd | 0 9/16 N–0 7/16 W | U.S. Public Health Service. | 1964 | 130 | 169½ | 160 | C | 10 | 140–150 | PS | T, E, 10 | ---- | ---- | 11– –64 | 20 | ------ | ---- | ------ | D, Q |
| 27Fda | 0 9/16 N–1 1/2 W | C. A. Nelson | 1959 | 127 | 105 | ---- | -- | 2 | ------ | Dom | J, E | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 27Hda[1] | 0 1/2 N–1 W | K. Sowers | 1934 | 130 | 150 | 150 | C | 12 | 135–146 | PS | T, E, 7½ | ---- | ---- | 7–19–61 | 13.1 | 7–19–61 | 21.7 | 135–146 | D, Q |
| 27Pcb | 0 1/8 N–1 11/16 W | City of Yuma. | 1962 | 125 | 35 | 35 | Dr | 1½ | 33–35 | Dom, St | C, E, 1/3 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 28Kcc | 0 5/16 N–2 1/2 W | M. Cordeiro | ---- | 118 | 130 | 130 | C | 4 | Open bottom | Dom | S, E | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 28Nbc | 0 1/8 N–3 W | City of Yuma. | 1956 | 128 | 119 | 119 | C | 6 | 110–115 | Dom, Ind | ------ | ---- | ---- | ------ | ---- | ------ | ---- | ------ | |
| 28Paa2 | 0 3/16 N–2 1/2 W | M. Cordeiro | 1962 | 125 | 252 | 248 | C | 6 | ------ | Dom | ------ | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 28Rab1 | 0 3/16 N–2 1/8 W | E. Lukas | ---- | 126 | 35 | 35 | Dr | 1½ | 33–35 | Dom | L, E | ---- | ---- | ------ | ---- | 8–23–63 | 21.9 | 33–35 | T, Q |
| 28Rab2 | 0 3/16 N–2 1/8 W | ---do | 1963 | 126 | 112 | 112 | -- | 3 | 109–112 | Dom | ------ | ---- | ---- | ------ | ---- | 8–23–63 | 21.1 | 109–112 | Q |
| 28Rab3 | 0 3/16 N–2 1/8 W | ---do | 1964 | 126 | 134 | 134 | C | 10 | 117–132 | Dom, Irr | T, G | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 32Fdc | 0 1/2 S–3 9/16 W | J. W. Olberg | 1955 | 123 | 120 | 120 | C | 8 | Open bottom | St | J, E, 2 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 35Gba | 0 1/4 S–0 7/16 W | Yuma County Water Users' Association. | ---- | 123 | 94 | 94 | D | 8 | 74–94 | AC, Dom | J, E | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 35Hac | 0 3/8 S–0 1/8 W | San Carlos Hotel. | 1930 | 145 | 173 | 173 | C | 12 | 43–48 | AC | T, E, 50 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D |
| 36Bba | 0–0 9/16 E | P. A. Birdick. | ---- | 123 | 133 | 133 | C | 4 | 132–133 | Dom | ------ | ---- | ---- | ------ | ---- | ------ | ---- | ------ | D, Q |
| 16S/23E–3Dbb | 5 N–4 E | T. A. Sorrels. | 1951 | 140 | 118 | 118 | -- | 2½ | 115–118 | Dom, St. | J, E, 3/4 | ---- | ---- | ------ | ---- | 12–11–61 | 23.3 | 115–118 | Q |
| 4Ecc | 4 9/16 N–3 1/16 E | J. V. Colby | 1931 | 135 | 124 | 124 | C | 12 | 95–124 | Dom | J, E, 1 | ---- | ---- | 12–11–61 | 9.3 | ------ | ---- | ------ | |
| 4Qac | 4 3/16 N–3 1/2 E | L. B. Hovren. | 1937 | 135 | 130 | 130 | Dr | 2 | Open bottom | Dom | J, E, 3/4 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | |
| 7Caa | 4 N–1 1/2 E | R. B. Rogers. | 1960 | 134 | 113 | ---- | -- | 2 | ------ | Dom | J, E, 1/3 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | Q |
| 18Mcc | 2 1/4 N–1 1/16 E | W. M. Dorries. | 1936 | 132 | 108 | 108 | -- | 2 | Open bottom | Dom | J, E, 1/4 | ---- | ---- | ------ | ---- | ------ | ---- | ------ | |
| 19Mbc | 1 3/8 N–1 1/16 E | San Pacqual School. | 1954 | 130 | 204 | 200 | D | 8 | 120–200 | PS | T, E, 7½ | 200 | ---- | 7–19–61 | 11.4 | 5–18–61 | 21.1 | 120–200 | D, Q |

[1] Unused.
[2] Destroyed.
[3] Wells 1 and 2 pumped into the same pressure tanks; temperature and samples represent either or both.

# APPENDIX B.

## SELECTED LOGS OF WATER WELLS

Appendix B presents logs of 61 water wells and water test wells in the Yuma area. These logs, which are selected from more than 700 logs in the files of the Geological Survey, are probably representative and give good areal coverage. Logs of most of the private wells are by the drillers; those of the test wells are by Geological Survey or Bureau of Reclamation geologists, based on sample studies and borehole geophysical logs. The materials logged are assigned by F. H. Olmsted to the various water-bearing units described in the text.

The well number given for each well is that given in Appendix A, tables 16–20. The name following the well numbers is the Government agency that drilled the well or had it drilled, or the owner or user at the time the well canvass was made. The type or use of the well and its approximate location are also listed, as are the name of the driller and the type of drilling equipment used. The depths of perforated intervals are given where available; these are indicative of the productive horizons within the respective areas. Altitudes listed are of the land surface at the well from which depths were logged (mean-sea-level datum). Altitudes given to the nearest foot are approximate and were estimated from topographic maps; those given to decimal fractions of a foot were obtained by spirit leveling to a reference point at the well and are much more accurate. Other information about the wells is listed in Appendix A, tables 16–20.

*Selected logs of water wells*

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-7-22)14bcd** | | |
| [U.S. Geological Survey test well LCRP 14 at Laguna Dam. Drilled with cable-tool equipment by Hamilton and Hood. Log by F. H. Olmsted, F. L. Doyle, and F. J. Frank. Casing perforated from 118 to 128, 152–162, and 410–490 ft. Altitude 155.1 ft] | | |
| Upper, fine-grained zone: | | |
| Sand and silt containing plant fragments; thin strata of clay and pebbly clay. Upper 14 ft represents fill accumulated since construction of Laguna Dam | 16 | 16 |
| Sand, fine to medium | 4 | 20 |
| Sand and silt containing plant fragments; some clay | 8 | 28 |
| Sand, scattered pebbles, and some clay and silt | 9 | 37 |
| Sand, medium, and subangular gravel | 3 | 40 |
| Sand and silt containing plant fragments; some gravel and clay | 13 | 53 |
| Sand, fine to medium; interbedded pebbly silt and clay | 16 | 69 |
| Sand, fine to medium, some gravel; thin beds of silt and clay | 31 | 100 |
| Sand and gravel, scattered cobbles. Gravel includes well-rounded siliceous rocks | 3 | 103 |
| Sand, fine to medium, some gravel; thin beds of silt and clay | 11 | 114 |
| Coarse-gravel zone: | | |
| Gravel, well-rounded to subrounded; contains cobbles as much as 5 in.; some coarse sand and cemented streaks | 14 | 128 |
| Sand, medium to coarse; gravel contains rounded pebbles and cobbles as much as 3 in.; some silt | 7 | 135 |
| Sand, fine to coarse; scattered pebbles | 4 | 139 |
| Gravel, coarse, rounded | 2 | 141 |
| Sand, medium; scattered pebbles | 7 | 148 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-7-22)14bcd—Continued** | | |
| Coarse-gravel zone—Continued: | | |
| Gravel, chiefly well rounded to subrounded; contains cobbles as much as 5 in. including abundant siliceous rocks; some coarse sand and cemented streaks | 15 | 163 |
| Wedge zone: | | |
| Sand and gravel; thin streaks of conglomerate. Gravel finer and contains more rocks of local derivation than that above | 17 | 180 |
| Sand, fine to medium, silty, brown; scattered granules and small pebbles including pebbles of clay and sandstone concretions | 29 | 209 |
| Bouse Formation: | | |
| Clay, silty and sandy, tough, gray; contains concretions of clayey siltstone and sandstone | 5 | 214 |
| Sand, silty, soft, micaceous; contains some carbonized wood | 3 | 217 |
| Clay, silty and sandy, tough, gray; contains concretions of clayey siltstone and sandstone | 11 | 228 |
| Clay, silty, gray; fossiliferous | 15 | 243 |
| Clay, silt, and fine sand; thin bedded greenish- to bluish-gray fossiliferous | 228 | 471 |
| Nonmarine sedimentary rocks (Tertiary): | | |
| Conglomerate composed of angular to subrounded granules, pebbles, cobbles, and scattered boulders of plutonic, metamorphic, and few silicic volcanic rocks in a sandy and silty matrix. Fairly hard drilling | 34 | 505 |
| **Well (C-8-21)1bbc** | | |
| [U.S. Bureau of Reclamation test well 1 in Dome Valley. Drilled with cable-tool equipment by Hamilton and Hood. Log by Bureau of Reclamation. Altitude 171 ft] | | |
| Upper, fine-grained zone: | | |
| No record | 10 | 10 |
| Sand (80 percent), fine to medium, slightly micaceous, light-grayish-tan; silt (20 percent), slightly clayey; with small clay balls | 21 | 31 |
| Sand (85 percent), fine to medium; silt (10 percent), light-grayish-tan; clay (5 percent), plastic, dark-brown | 6 | 37 |
| Clay (60 percent), dense, plastic, dark-brown; sand (30 percent), fine to medium, light-grayish-tan; gravel (10 percent), fine to coarse, angular to subangular; composed mostly of gneiss and granite | 13 | 50 |
| Sand (70 percent), slightly silty, fine to medium, light-grayish-tan; gravel (15 percent), fine to coarse (2 in.), rounded; with a few angular pieces (mostly quartz); clay (15 percent), dense, plastic, dark-brown | 18 | 68 |
| Coarse-gravel zone: | | |
| Sand (60 percent), fine to medium, slightly silty, light-gray; fine to coarse gravel (30 percent), with cobbles as much as 4 inches, smooth, rounded quartzite predominant; dense dark-brown clay (5 percent); silt (5 percent) | 11 | 79 |
| Gravel (75 percent), fine to coarse, predominantly rounded; a few cobbles as much as 3 in.; sand (25 percent), fine to coarse, clean, light-grayish-tan; some clay in upper part | 13 | 92 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-21)1bbc—Continued** | | |
| Coarse-gravel zone—Continued: | | |
| Gravel 70–90 percent), fine to coarse, predominantly smooth and rounded; sand (10–30 percent), clean, fine to coarse, light-grayish-tan | 48 | 140 |
| Wedge zone: | | |
| Gravel (85–90 percent), fine to coarse (2 in.); predominantly angular and subangular; composed of granite and gneiss; sand (10–15 percent), fine to coarse, light-grayish-tan | 20 | 160 |
| Sand (60–75 percent), medium to coarse, angular to subangular, predominantly granitic and quartzitic; gravel (15–25 percent), subangular; composed predominantly of gneiss and granite; some quartzite; clay (10 to 15 percent), fine, light-dun-colored | 9 | 169 |
| Wedge zone(?): | | |
| Granite gneiss (large boulder; possibly bedrock) | 2 | 171 |

**Well (C-8-21)19dad**

[F. J. Hartman. Irrigation well in South Gila Valley. Drilled with cable-tool equipment by Frank H Leideneker (Arizona Machine & Welding Works). Casing perforated from 115 to 165 ft Altitude 158 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Silt | 2 | 2 |
| Sand | 12 | 14 |
| Silt and sand | 3 | 17 |
| Sand, some pebbles | 1 | 18 |
| Sand, silt, and clay strata | 38 | 56 |
| Clay with sand streaks | 18 | 74 |
| Clay, sand, and some pebbles | 9 | 83 |
| Coarse-gravel zone: | | |
| Gravel with sand | 14 | 97 |
| Gravel, large, with sand | 11 | 108 |
| Gravel, good | 8 | 116 |
| Gravel with sand | 6 | 122 |
| Sand with some gravel streaks | 3 | 125 |
| Gravel with sand | 1 | 126 |
| Gravel, good, with large rock | 10 | 136 |
| Sand | 1 | 137 |
| Gravel, good | 19 | 156 |
| Boulder, very large | 0 | 156 |
| Wedge zone: | | |
| Sand, packed; with clay layers | 35 | 191 |
| Gravel with sand (increased salt in water) | 1 | 192 |

**Well (C-8-22)7ccd**

[Johnson and Drysdale. Irrigation well in The Island area. Drilled by Henderson & Sons. Casing perforated from 110 to 160 ft; open bottom. Altitude 139 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Silt and sand, dry | 10 | 10 |
| Clay, heavy | 8 | 18 |
| Water sand, water at 18 ft; rose to 15 ft | 86 | 104 |
| Sand, gravel | 6 | 110 |
| Coarse-gravel zone: | | |
| Gravel, coarse; cobble stones and pea gravel | 50 | 160 |
| Wedge zone: | | |
| Coarse water sand and small gravel | 84 | 244 |
| Sand and gravel | 8 | 252 |

**Well (C-8-22)14cdd**

[S. Sturges. Irrigation well in North Gila Valley. Drilled with cable-tool equipment by Hamilton and Hood. Casing perforated from 80 to 129 ft. Altitude 150 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Silty sand | 75 | 75 |
| Coarse-gravel zone: | | |
| Gravel to 8 in. diameter | 57 | 132 |
| Gravel, cemented | 1 | 133 |

*Selected logs of water wells*—Continued

**Well (C-8-22)15bdd**

[U.S. Bureau of Reclamation test well CH-6 in North Gila Valley. Drilled with cable-tool equipment by Hamilton and Hood. Log by E. L. Smith, Bureau of Reclamation: modified slightly by F. H. Olmsted. Casing perforated from 90 to 150 and 160 to 185 ft. Altitude 140.5 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand (about 75 percent), fine to medium, brown; subrounded grains of quartz; silt (about 25 percent); contains a few small clay balls | 32 | 32 |
| Sand (about 75 percent), fine to medium; subrounded grains of gray quartz; occasional fine gravel; silt (about 25 percent); chocolate-brown plastic clay about 6 in. thick at 44 ft | 26 | 58 |
| Sand (about 70 percent), fine; subrounded grains of gray quartz; occasional fine gravel; silt (about 30 percent); contains thin layers of chocolate-brown plastic clay | 18 | 76 |
| Sand (about 65 percent), fine, gray; silt (about 20 percent); contains a little chocolate-brown plastic clay; gravel (about 10–15 percent), subrounded to well-rounded pebbles of quartzite | 9 | 85 |
| Coarse-gravel zone: | | |
| Gravel (about 85 percent), fine to coarse, well-rounded; predominantly quartzite with some volcanic rocks, a few clasts, cobbles as much as 4 in.; sand (about 10 percent), fine, gray; silt and clay (about 5 percent) | 9 | 94 |
| Gravel (about 75 percent), fine to coarse; well-rounded, clasts predominantly quartzite; many cobbles as large as 6 in.; sand (about 25 percent), fine, gray; contains little silt and clay | 36 | 130 |
| Gravel (about 70 percent), predominantly fine and well-rounded; a few cobbles as much as 4 by 8 in.; sand (about 30 percent), fine to coarse, gray; contains little silt and clay | 5 | 135 |
| Gravel (about 60 percent), poorly graded, well-rounded; some cobbles as much as 4 in.; sand (about 40 percent), fine to coarse, poorly graded; contains little silt and clay | 15 | 150 |
| Wedge zone: | | |
| Sand (about 60 percent), granitic, coarse, gray; gravel (about 40 percent), fine, angular to subangular, granitic; contains a few pebbles of quartzite | 8 | 158 |
| Gravel (about 70 percent), predominantly fine, angular to rounded; composed of volcanic rocks; sand (about 30 percent), granitic, fine to coarse, angular to rounded,, gray | 11 | 169 |
| Sand (about 70 percent), granitic, fine to coarse, gray; gravel (about 30 percent), granitic, fine, angular to subangular; a few well-rounded pebbles of quartzite | 16 | 185 |
| Sand (about 60 percent), fine to coarse, brown; gravel (about 30 percent), volcanic, fine, subrounded to rounded; clay (about 10 percent), moderately plastic light-brownish-green | 25 | 210 |
| Sand, fine to coarse, brown and gray, angular to rounded; scattered fine gravel; some yellowish-brown nonplastic clay from 233 to 244 ft | 60 | 270 |
| Sand (about 60 percent), fine to coarse, subangular to subrounded, grayish-brown; gravel (about 40 percent), volcanic, poorly graded, fine to coarse, subrounded to rounded | 10 | 280 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)15bdd—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to medium, grayish-brown; scattered fine gravel | 45 | 325 |
| Sand (60–70 percent), fine to coarse, subangular to rounded, gray; gravel (30–40 percent), volcanic, fine to 1-in. angular to subrounded | 14 | 339 |
| Clay, silty, moderately plastic, light-grayish-brown | 2 | 341 |
| Clay, gray, dense, plastic; a small amount of chocolate-brown clay; few lime concretions and gravel near 350 ft | 34 | 375 |
| Sand (about 80 percent), fine to medium, gray; gravel (about 10 percent), fine; composed of clasts of volcanic rocks and quartzite; silt (about 10 percent); a small amount of clay | 18 | 393 |
| Clay, dense, plastic, chocolate-brown; with a few green streaks | 12 | 405 |
| Clay, sandy, silty, limy, grayish-brown, moderately plastic | 7 | 412 |
| Sand (about 75 percent), fine to coarse, gray; silt (about 15 percent), a small amount of clay; gravel (about 10 percent), fine; occasional cobbles as much as 4 in. | 6 | 418 |
| Sand (about 65 percent), fine to coarse, gray; gravel (about 25 percent), volcanic, fine to coarse; silt and clay (about 10 percent) | 4 | 422 |
| Bouse Formation: | | |
| Clay, silty, plastic, chocolate-brown and brown; gravelly and sandy moderately plastic clay; lime concretions from 439 to 441 ft. Fossiliferous | 19 | 441 |
| Clay. Thin interbeds of medium-brown plastic clay, dark-grayish-brown silty and sandy micaceous clay, and grayish-brown moderately plastic clay; all slightly expansive on drying. Fossiliferous | 49 | 490 |
| Sand (80–90 percent), fine to coarse, greenish-gray; gravel (10–20 percent), fine to 2-in., subangular; some pieces of limestone and sandstone | 4 | 494 |
| Silt and clay, greenish-gray; little very fine sand | 3 | 497 |
| Nonmarine sedimentary rocks (Tertiary): | | |
| Gravel, very coarse; consists of cobbles and possibly boulders; only broken pieces recovered | 4 | 501 |
| **Well (C-8-22)19ccc** | | |
| [U.S. Bureau of Reclamation test well CH-702 in South Gi'a Valley. Drilled with cable-tool equipment by Hamilton and Hood. Log by E. L. Smith of Bureau of Reclamation; modified partly on basis of gamma log, by F. H. Olmsted. Casing perforated from 115 to 150, 370 to 390, 395 to 435, and 455 to 463 ft. Altitude 129.6 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, uniform, fine, gray; brown above 10 ft | 25 | 25 |
| Sand, gray; some gray clay and scattered fine angular volcanic gravel | 18 | 43 |
| Clay, sandy, grayish-brown to chocolate-brown; interbedded in thin layers with fine gray sand | 13 | 56 |
| Sand, fine, gray (about 75 percent); silt, a small amount of clay, few pieces of sandstone (about 25 percent) | 14 | 70 |
| Sand, uniform, fine, gray; little fine angular volcanic gravel and rounded quartzite gravel | 13 | 83 |
| Sand and gravel | 5 | 88 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)19ccc—Continued** | | |
| Coarse-gravel zone: | | |
| Gravel, fine to coarse; consists of subangular to rounded clasts of volcanic rocks and quartzite as much as 5 in.; some fine grayish-brown sand and a little gray clay at 93 ft | 14 | 102 |
| Sand, fine to medium, gray | 4 | 106 |
| Gravel, fine to coarse; predominantly well rounded clasts of quartzite (70 percent); sand, fine, gray (30 percent) | 16 | 122 |
| Sand, fine to medium, gray (90 percent); interbedded fine gravel (10 percent) | 4 | 126 |
| Gravel, fine to coarse, predominantly well rounded; some cobbles as much as 7 in.; interbedded sandy zones | 27 | 153 |
| Wedge zone: | | |
| Sand, fine to coarse, gray; consists chiefly of subangular to subrounded grains of quartz; scattered granules and pebbles of volcanic rocks and quartzite; some limestone fragments (concretions) | 134 | 287 |
| Gravel, volcanic, fine, subangular (about 80 percent); fine to coarse gray sand; some concretions and a little tan to grayish-green non-plastic clay (20 percent) | 5 | 292 |
| Sand, fine to medium, gray; scattered fine gravel and a little grayish-green non-plastic clay | 45 | 337 |
| Limestone concretions | 2 | 339 |
| Sand, fine, gray (75–90 percent); fine volcanic gravel; with a few rounded clasts of quartzite | 11 | 350 |
| Sand, gravel, and tan to grayish-green sandy clay | 7 | 357 |
| Sand, fine, gray; with a little brown sand and scattered fine gravel | 13 | 370 |
| Gravel, predominantly volcanic, fine to coarse, subangular (25–50 percent); fine to coarse sand (50–75 percent); a little clay at about 390 ft | 20 | 390 |
| Sand, fiue to medium, gray; scattered fine gravel | 5 | 395 |
| Sand, fine to coarse, gray (about 60 percent); fine volcanic and quartzitic gravel (40 percent); a few limestone concretions and some wood between 405 and 410 ft | 15 | 410 |
| Sand, fine to coarse, gray (75 percent); gravel (25 percent) | 20 | 430 |
| Sand (60 percent); fine to 1-in. subangular to rounded volcanic and quartzite gravel (40 percent) | 5 | 435 |
| Sand, predominantly coarse (80 percent); grayish-brown to grayish-green clay (10 percent); fine to 2 in. volcanic and quartzite gravel (10 percent) | 12 | 447 |
| Sand, fine to coarse, light-gray (95 percent); fine volcanic and quartzite gravel (5 percent) | 6 | 453 |
| Gravel, fine to 3 in., volcanic; quartzite (50 percent); fine to coarse gray (50 percent) sand | 2 | 455 |
| Gravel, fine to 2 in., subangular, volcanic (80 percent); fine to coarse gray sand, and a few limestone concretions (20 percent) | 5 | 460 |
| Sand, fine to coarse, gray (55 percent); fine to coarse volcanic and quartzite gravel (30 percent); lime-cemented conglomerate (15 percent) | 3 | 463 |
| Clay, sandy, hard, nonplastic; light-gray lime inclusions (80 percent); coarse sand | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)19ccc—Continued** | | |
| Wedge zone—Continued: | | |
| and fine gravel imbedded in the clay (20 percent) | 3 | 466 |
| Sand, fine to coarse, gray (80 percent); fine to 1½ in. volcanic and quartzite gravel (20 percent) | 3 | 469 |
| Gravel, fine, volcanic, and quartzite (60 percent); sand and a little green sandy clay (40 percent) | 5 | 474 |
| Sand, fine to coarse, gray, and a few limestone concretions (90 percent); fine volcanic gravel (10 percent) | 6 | 480 |
| Gravel, subangular to subrounded, volcanic (50 percent); fine to coarse gray sand (50 percent) | 4 | 484 |
| Sand, fine to medium; a few pieces of lime-cemented sandstone | 6 | 490 |
| Gravel, subangular to subrounded, volcanic (50 percent); fine to coarse gray sand (50 percent) | 5 | 495 |
| Sand, fine to medium; a few pieces of lime-cemented sandstone | 5 | 500 |

**Well (C-8-22)22cda2**

[B. Church. Irrigation well in South Gila Valley. Drilled with cable-tool equipment by Frank H. Leidendeker. Casing perforated from 100 to 152 ft. Altitude 149 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Clay | 15 | 15 |
| Sand, silted | 10 | 25 |
| Sand, clay strata | 15 | 40 |
| Clay, sticky | 5 | 45 |
| Sand | 17 | 62 |
| Clay, sandy | 4 | 66 |
| Clay, sticky | 2 | 68 |
| Sand, silted | 7 | 75 |
| Sand | 16 | 91 |
| Coarse-gravel zone: | | |
| Gravel, water-bearing (good) | 61 | 152 |
| Wedge zone: | | |
| Sand, some gravel | 5 | 157 |
| Sand, packed | 14 | 171 |

**Well (C-8-22)23dad**

[U.S. Bureau of Reclamation test well CH-4 in South Gila Valley. Drilled with cable-tool equipment by San Diego Well Drillers. Log by Bureau of Reclamation; modified by F. H Olmsted, using gamma log. Casing perforated from 100 to 130 and 334 to 354 ft. Altitude 152.4 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, fine; and alternate layers of brown and gray clayey silt and silty clay. Some sand contains mica and a considerable proportion of highly colored grains | 60 | 60 |
| Sand, clayey, fine; and silt; contains thin layers of gray silty clay and brown clayey silt | 20 | 80 |
| Coarse-gravel zone: | | |
| Gravel containing cobbles as much as 7 in. (65–70 percent); fine to coarse sand consisting of abundant colored grains (30–35 percent). | 30 | 110 |
| Sand (60–70 percent); gravel contains cobbles as much as 8 in. (30–40 percent) | 10 | 120 |
| Gravel containing cobbles as much as 7 in. (65–70 percent); fine to coarse sand consisting of abundant colored grains (30–35 percent) | 22 | 142 |
| Sand, fine; and silt; contains 6-in. layers of light-green to gray clay | 9 | 151 |
| Gravel and sand | 6 | 157 |
| Wedge zone: | | |
| Sand, fine to coarse; and scattered pebbles | 35 | 192 |
| Clay, hard, dry | 2 | 194 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)23dad—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to coarse; contains scattered pebbles as much as 2 in.; thin bed of clay at 250 ft | 76 | 270 |
| Gravel consisting mainly of pebbles as much as 2 in., partly cemented with $CaCO_3$ (50 percent); well-graded sand (50 percent) | 5 | 275 |
| Sand, fine; and scattered pebbles | 10 | 285 |
| Gravel consisting mainly of pebbles as much as 2 in., partly cemented with $CaCO_3$ (50 percent); well-graded sand (50 percent) | 11 | 296 |
| Sand (70 percent) and gravel (30 percent). Much of gravel subangular and cemented | 14 | 310 |
| Sand, fine | 12 | 322 |
| Gravel, largely cemented (50 percent); and sand | 39 | 361 |
| Clay, red, soft | 2 | 363 |
| Sand, fine; and scattered angular and subangular pebbles | 125 | 488 |
| Gravel, sandy; cemented with $CaCO_3$ (conglomerate) | 12 | 500 |

**Well (C-8-22)32cdd**

[U.S. Bureau of Reclamation drainage well SGDW 4 in South Gila Valley. Drilled with mud-rotary equipment by Layne Texas Co. Cased and gravel packed to a depth of 200 ft; screened from 90 to 200 ft. Altitude 140.3 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Soil | 5 | 5 |
| Clay | 21 | 26 |
| Streaks of sand and clay | 34 | 60 |
| Clay and gravel | 10 | 70 |
| Clay and sand | 15 | 85 |
| Coarse-gravel zone: | | |
| Gravel, coarse | 20 | 105 |
| Gravel, fine | 12 | 117 |
| Gravel, coarse; and streaks of clay | 11 | 128 |
| Gravel, fine; and streaks of sand | 17 | 145 |
| Gravel, coarse; and streaks of clay | 22 | 167 |
| Gravel and hard streaks | 18 | 185 |
| Gravel, coarse | 13 | 198 |
| Wedge zone: | | |
| Sand and gravel | 6 | 204 |
| Clay, sandy | 12 | 216 |

**Well (C-8-22)35caa1**

[U.S. Bureau of Reclamation test well CH-704; deepened by U.S. Geological Survey from 600 to 1,997 ft as test well LCRP 29; in South Gila Valley. Drilled to 600 ft with cable-tool equipment by Hamilton and Hood; deepened (pilot hole only) from 600 to 1,997 ft with mud-rotary equipment by Desert Water Drilling Co. Log to 600 ft by Bureau of Reclamation; modified by F. H. Olmsted using gamma log; from 600 to 1,997 ft, log by F. H. Olmsted Casing perforated from 99 to 170, 435 to 445, 480 to 490, 507 to 540, and 550 to 570 ft. Altitude 150.8 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, silty, light-brown; some clay and organic matter | 3 | 3 |
| Clay, reddish-brown; sand and silt | 45 | 48 |
| Sand, fine, light-brown (50 percent); brown plastic clay (50 percent); occasional subangular volcanic pebbles | 41 | 89 |
| Coarse-gravel zone: | | |
| Gravel, fine to coarse; consists of rounded clasts of quartzite and a few subangular clasts of volcanic rocks and scattered cobbles as much as 6 in. (65–80 percent); fine to coarse sand; a little clay (20–35 percent) | 85 | 174 |
| Wedge zone: | | |
| Sand, fine to coarse, light-grayish-brown (80 percent); fine to coarse volcanic and quartzite gravel (15 percent); yellow moderately plastic clay (5 percent) | 13 | 187 |
| Sand, fine to medium, light-brown; scattered fine pebbles | 108 | 295 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)35caa1—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to coarse, poorly graded, light-brown (75 percent); predominantly fine volcanic and quartzite gravel ((25 percent) | 10 | 305 |
| Sand, fine to medium, light-brown; and occasional pebbles | 10 | 315 |
| Sand, fine to coarse, poorly graded, light-brown (70–75 percent); predominantly fine volcanic and quartzite gravel (20–25 percent); hard medium-brown clay balls (0–10 percent) | 20 | 335 |
| Sand, fine to medium, light-brown; and scattered pebbles | 45 | 380 |
| Gravel, predominantly fine, volcanic; and some quartzite (60 percent); fine sand (40 percent) | 3 | 383 |
| Sand, fine to coarse, light-brown; and scattered small pebbles | 43 | 426 |
| Sand, fine to coarse; some gravel and green to brown plastic clay | 4 | 430 |
| Sand, fine to coarse (70 percent); fine volcanic and quartzite gravel (30 percent); chocolate-brown plastic clay at 445 ft | 15 | 445 |
| Sand, fine to medium, light-brown; and scattered pebbles and pieces of sandstone | 18 | 463 |
| Sand, fine to coarse, light-brown (70–95 percent); fine to 1½ in., volcanic and quartzite gravel (5–30 percent); a few green bentonitic clay balls | 27 | 490 |
| Sand and scattered fine pebbles | 17 | 507 |
| Gravel (70 percent) and sand (30 percent | 8 | 515 |
| Sand, fine to coarse, light-grayish-brown (60–70 percent); fine to 2½ in. gravel; quartzite gravel (30–40 percent) | 25 | 540 |
| Sand and about 10–15 percent fine quartzite and volcanic gravel | 5 | 545 |
| Clay, slightly silty, medium-brown | 3 | 548 |
| Gravel, chiefly subrounded volcanic and quartzite; contains a few cobbles as much as 4 in. (70–85 percent); fine to coarse sand (15–30 percent) | 22 | 570 |
| Sand, fine to coarse, light-grayish-brown; and occasional fine pebbles | 11 | 581 |
| Sand and about 30–35 percent fine volcanic gravel | 9 | 590 |
| Sand, predominantly fine, grayish-brown; and scattered fine pebbles | 10 | 600 |
| Sand and gravel, interbedded | 105 | 705 |
| Clay, soft, brown | 9 | 714 |
| Gravel and sand | 14 | 728 |
| Silt, clayey, brown | 3 | 731 |
| Sand and gravel, interbedded | 22 | 753 |
| Silt, clayey, brown | 6 | 759 |
| Sand, some gravel | 35 | 794 |
| Transition zone(?): | | |
| Clay, soft, grayish-brown; some gray clay | 15 | 809 |
| Sand | 7 | 816 |
| Clay, soft, grayish-brown; some gray clay | 15 | 831 |
| Sand, some gravel | 54 | 885 |
| Transition zone: | | |
| Clay, brown and gray, fossiliferous; interbedded sand | 59 | 944 |
| Gravel, somewhat cemented, and sand | 25 | 969 |
| Sand and gravel; thin beds of fossiliferous gray silty clay | 76 | 1,045 |
| Bouse Formation: | | |
| Clay, bluish-gray and pinkish-brown, fossiliferous | 20 | 1,065 |
| Silt and fine sand, well-sorted, gray | 6 | 1,071 |
| Clay, bluish-gray and pinkish-brown, fossiliferous | 17 | 1,088 |
| Silt and fine sand, well-sorted, gray | 5 | 1,093 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-22)35caa1—Continued** | | |
| Bouse Formation—Continued: | | |
| Clay, bluish-gray and pinkish-brown, fossiliferous | 17 | 1,110 |
| Silt and fine sand, well-sorted, gray | 8 | 1,118 |
| Clay and silty clay, bluish-gray and pinkish-brown, fossiliferous | 131 | 1,249 |
| Silt and clayey silt, gray | 8 | 1,257 |
| Clay and silty clay, bluish-gray and pinkish-brown, fossiliferous | 40 | 1,297 |
| Silt and clayey silt, gray, fossiliferous | 33 | 1,330 |
| Clay and silty clay, bluish-gray and pinkish-brown, fossiliferous | 15 | 1,345 |
| Silt and clayey silt, gray fossiliferous | 27 | 1,372 |
| Clay and silty clay, bluish-gray and pinkish-brown, fossiliferous | 24 | 1,396 |
| Older marine sedimentary rocks: | | |
| Sand, fine, gray, somewhat indurated; some medium sand and silt; fossiliferous | 39 | 1,435 |
| Clay, gray; and fine gray sand, interbedded ; somewhat indurated and fossiliferous | 38 | 1,473 |
| Silt, gray; somewhat indurated and fossiliferous | 33 | 1,506 |
| Clay, gray; and some pinkish-brown clay; somewhat indurated and fossiliferous | 23 | 1,529 |
| Sand, fine, gray, somewhat indurated; some medium sand and silt; fossiliferous | 46 | 1,575 |
| Clay, gray; and some pinkish-brown clay; somewhat indurated and fossiliferous | 16 | 1,591 |
| Sand, fine to medium, somewhat indurated; interbedded gray clay and silt | 24 | 1,615 |
| Clay, gray, fossiliferous, somewhat indurated | 17 | 1,632 |
| Sand, fine to medium, somewhat indurated; interbedded gray clay and silt | 19 | 1,651 |
| Clay, gray; and some pinkish-brown clay; fossiliferous and somewhat indurated | 17 | 1,668 |
| Sand, fine to medium, gray, somewhat indurated | 12 | 1,680 |
| Clay, gray, indurated, somewhat fossiliferous | 6 | 1,686 |
| Sand, fine to medium, gray, somewhat indurated | 15 | 1,701 |
| Clay, gray, indurated, somewhat fossiliferous | 5 | 1,706 |
| Sand, fine to medium, gray, somewhat indurated | 16 | 1,722 |
| Clay, gray, indurated, somewhat fossiliferous | 9 | 1,731 |
| Sand, fine to medium; some silt; somewhat indurated | 26 | 1,757 |
| Clay, gray, indurated, somewhat fossiliferous | 11 | 1,768 |
| Silt, fine sand, and clay, interbedded, somewhat fossiliferous | 61 | 1,829 |
| Sand, fine to medium; some silt; somewhat indurated | 32 | 1,851 |
| Silt, fine sand, and clay, interbedded, somewhat fossiliferous | 86 | 1,937 |
| Clay, gray, bentonitic (altered volcanic ash) | 5 | 1,942 |
| Sand, fine to medium, gray, somewhat indurated | 34 | 1,976 |
| Clay, sandy and silty, pale-greenish-gray | 21 | 1,997 |

**Well (C-8-23)27ada**

[U.S. Bureau of Reclamation test well CH–701 in South Gila Valley. Drilled with cable-tool equipment by Hamilton and Hood. Log by Bureau of Reclamation; modified by F. H. Olmsted using gamma log. Casing perforated from 84 to 88 ft and 125 to 160 ft. Altitude 133.4 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, predominantly fine, some medium and coarse; small amount of silt and brown clay balls | 40 | 40 |

*Selected logs of water wells*—Continued

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-23)27ada—Continued** | | |
| Upper, fine-grained zone—Continued: | | |
| Clay, tough, brown, moderately plastic; some interbedded sand | 27 | 67 |
| Sand, clean, quartz | 5 | 72 |
| Clay, tough, brown; some silt | 10 | 82 |
| Coarse-gravel zone(?): | | |
| Gravel, predominantly to subangular to subrounded pebbles of volcanic rocks and quartzite; about 20 percent fine to coarse sand | 7 | 89 |
| Sand, silt, clay, and about 10 percent fine gravel | 15 | 104 |
| Sand, fine, brown, and silt; scattered small pebbles | 18 | 122 |
| Coarse-gravel zone: | | |
| Gravel, coarse; well-rounded pebbles and cobbles as much as 10 in.; 14–15 percent coarse gray sand | 38 | 160 |
| Wedge zone: | | |
| Sand, gray; and scattered small pebbles | 10 | 170 |
| Clay, sandy, tough, grayish-green | 2 | 172 |
| Sand, fine, gray; and about 25 percent silt | 17 | 189 |
| Clay, sandy and limy, grayish-green; contains scattered small pebbles | 16 | 205 |
| Clay balls as much as 5 in., with sand and fine gravel coating | 10 | 215 |
| Sand, silt, and gravel; occasional cobbles and a green clay ball at 220 ft | 12 | 227 |
| Sand, fine, gray; and 40 percent silt, some clay | 21 | 248 |
| Sand, fine; and loosely cemented fine sandstone, and 30 percent green sandy clay | 2 | 250 |
| **Well (C-8-23)29daa** | | |
| [O. C. Johnson School. Irrigation well on Yuma Mesa, in Yuma. Drilled with cable-tool equipment by Frank H. Leidendeker Casing perforated from 160 to 262, 265 to 270, 283 to 286, and 291 to 295 ft. Altitude 182 ft] | | |
| Older alluvium, undivided: | | |
| Sand and silt strata | 98 | 98 |
| Sand, some pebbles | 50 | 148 |
| Sand, packed | 7 | 155 |
| Clay, soft, sticky | 7 | 162 |
| Sand, packed; and thin sandstone layers | 32 | 194 |
| Sandstone; some clay and sand layers | 27 | 221 |
| Quicksand | 10 | 231 |
| Sand with sandstone and clay layers | 9 | 240 |
| Sand and gravel | 20 | 260 |
| Sand | 5 | 265 |
| Gravel and sandstone | 3 | 268 |
| Sand | 14 | 282 |
| Sandstone and clay | 3 | 285 |
| Sand, fine | 5 | 290 |
| Sandstone and sand | 6 | 296 |
| Sand, fine | 7 | 303 |
| **Well (C-8-23)33cdd** | | |
| [Stardust Hotel test well; deepened from 830 to 1,090 ft as U.S. Geological Survey test well LCRP 13. On Yuma Mesa, in Yuma. Drilled and deepened with cable-tool equipment by Hamilton and Hood. Log below 830 ft by G. R. Vaughan. Casing perforated from 182 to 200 ft. Altitude 197 ft] | | |
| Upper, fine-grained zone: | | |
| Sand | 70 | 70 |
| Clay | 5 | 75 |
| Sand | 30 | 105 |
| Clay and sand | 30 | 135 |
| Clay | 35 | 170 |
| Coarse-gravel zone: | | |
| Gravel and about 40–50 percent sand | 30 | 200 |
| Clay | 6 | 206 |
| Gravel | 10 | 216 |
| Wedge zone: | | |
| Clay | 4 | 220 |

*Selected logs of water wells*—Continued

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-8-23)33cdd—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, very little gravel | 53 | 273 |
| Clay, gray, hard | 5 | 278 |
| Sand, small gravel | 38 | 316 |
| Sand, ½ inch gravel and "rock" | 14 | 330 |
| Sand, little gravel | 30 | 360 |
| Sand, with clay balls and streaks from 372 to 392 ft | 35 | 395 |
| Clay | 15 | 410 |
| Sand, with clay streaks | 15 | 425 |
| Clay | 5 | 430 |
| Sand | 35 | 465 |
| Clay | 9 | 474 |
| Sand | 26 | 500 |
| Clay and sand | 15 | 515 |
| Sand | 5 | 520 |
| Clay | 5 | 525 |
| Sand, packed | 42 | 567 |
| Clay, hard | 8 | 575 |
| Sand | 10 | 585 |
| Sand and gravel | 15 | 600 |
| Sandstone | 5 | 605 |
| Clay and gravel | 20 | 625 |
| Sand | 10 | 635 |
| Clay | 58 | 693 |
| Sandstone | 57 | 750 |
| Clay, hard | 7 | 757 |
| Sand and sandstone | 11 | 768 |
| Sand and gravel | 12 | 780 |
| Clay | 45 | 825 |
| Casing reduced to 8 in. at 825 ft | | |
| Clay, gray sandy streaks of brown fine sand | 30 | 855 |
| Sand, fine on sandstone | 2 | 857 |
| Sand, gray and clay | 39 | 896 |
| Clay or shale | 3 | 899 |
| Sand and silt | 6 | 905 |
| Clay and streaks of sand | 5 | 910 |
| Sand, clay, and silt (thin layer), cemented sand and gravel at 917 ft | 10 | 920 |
| Sand, with cemented streaks, and streaks of clay | 30 | 950 |
| Clay, brown | 3 | 953 |
| Clay, gray, and sand | 12 | 965 |
| Clay and sandstone | 5 | 970 |
| Sand, loose | 3 | 973 |
| Clay and sandstone | 12 | 985 |
| Sandstone | 3 | 988 |
| Clay, silt, sand, and sandstone | 37 | 1,025 |
| Sandy clay | 43 | 1,068 |
| Sand, loose | 3 | 1,071 |
| Clay, sandy, and sandstone | 14 | 1,085 |
| Granite | 5 | 1,090 |
| **Well (C-8-23)36ccd** | | |
| [Federal Compress Co. Industrial well on Yuma Mesa, just east of Yuma. Drilled with cable-tool equipment by Freeleve Drilling Co. Casing perforated from 185 to 196 and 238 to 244 ft, open bottom. Altitude 216 ft] | | |
| Upper, fine-grained zone: | | |
| Sand | 38 | 38 |
| Clay | 4 | 42 |
| Sand | 37 | 79 |
| Clay | 11 | 90 |
| Sand | 50 | 140 |
| Clay, sandy; water test | 6 | 146 |
| Sand, loose | 36 | 182 |
| Coarse-gravel zone: | | |
| Gravel, coarse; little sand | 16 | 198 |
| Sand | 17 | 215 |
| Clay | 2 | 217 |
| Sand | 5 | 222 |
| Sand and gravel, mostly sand | 15 | 237 |
| Gravel, coarse; looks like washed gravel | 8 | 245 |
| Gravel and sand, loose (50–50) | 13 | 258 |

*Selected logs of water wells*—Continued

**Well (C-8-23)36ccd—Continued**

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Wedge zone: | | |
| Sandy with some gravel, little firmer | 37 | 295 |
| Conglomerate | 3 | 298 |
| Sand, loose, some gravel | 4 | 302 |

**Well (C-9-21)14bac**

[B. Palon Unused irrigation well on "Fortuna Mesa" piedmont area west of northern Gila Mountains. Drilled with cable-tool equipment by Hamilton and Hood. Casing perforated from 914 o 1,040 ft. Altitude 395 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Older alluvium, undivided: | | |
| Clay and rock | 22 | 22 |
| Sandy clay and gravel | 11 | 33 |
| Sand | 55 | 88 |
| Red clay | 2 | 90 |
| Sand | 131 | 221 |
| Sand and gravel, ¼ in. maximum | 19 | 240 |
| Sand | 146 | 386 |
| Sand and gravel | 4 | 390 |
| Sandstone and gravel, 3 in. maximum | 8 | 398 |
| Sand | 16 | 414 |
| Clay | 7 | 421 |
| Sand | 27 | 448 |
| Clay | 2 | 450 |
| Sand | 1 | 451 |
| Clay | 8 | 459 |
| Sand and boulders, 4½ in. maximum | 4 | 463 |
| Granite gravel and boulders, 5 in. maximum | 12 | 475 |
| Clay | 4 | 479 |
| Sand and sandstone | 75 | 554 |
| Clay | 4 | 558 |
| Sand and sandstone | 98 | 656 |
| Granite gravel and boulders, 4 in. maximum | 6 | 662 |
| Sand and sandstone | 18 | 680 |
| Sand and gravel, 1½ in. maximum | 3 | 683 |
| Sandstone | 9 | 692 |
| Decomposed granite and sandstone | 8 | 700 |
| Bouse Formation: | | |
| Clay | 40 | 740 |
| Sand and sandstone | 10 | 750 |
| Clay | 5 | 755 |
| Sand and sandstone | 15 | 770 |
| Clay and shale | 15 | 785 |
| Sand | 2 | 787 |
| Clay and shale | 127 | 914 |
| Sand | 90 | 1,004 |
| Sand and decomposed granite | 65 | 1,069 |
| Clay | 13 | 1,082 |
| Crystalline rocks: | | |
| Decomposed granite | 1 | 1,083 |
| Granite | 2 | 1,085 |

**Well (C-9-22)9bba**

[Ketcherside. Unused irrigation well on Yuma Mesa. Drilled with cable-tool equipment by F. E. Leidendeker. Driller's log modified by F. H. Olmsted on basis of gamma log. Casing perferated from 150 to 182 and 230 to 250 ft. Altitude 208.0 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand | 8 | 8 |
| Sand and cemented gravel | 8 | 16 |
| Sand | 19 | 35 |
| Clay and sand | 9 | 44 |
| Clay | 26 | 70 |
| Sand and gravel | 14 | 84 |
| Clay and sand | 6 | 90 |
| Sand | 46 | 136 |
| Clay and sand | 10 | 146 |
| Sand | 7 | 153 |
| Coarse-gravel zone(?): | | |
| Sand and gravel | 11 | 164 |
| Sand | 6 | 170 |
| Sand and gravel | 16 | 186 |
| Coarse-gravel zone: | | |
| Gravel, some interbedded sand | 23 | 209 |
| Sand | 11 | 220 |
| Gravel, sandy | 30 | 250 |

*Selected logs of water wells*—Continued

**Well (C-9-22)17dca**

[P. Hairgrove. Unused irrigation well on Yuma Mesa Drilled with cable-tool equipment by A. G. Tschour. Driller's log from 0 to 190 ft modified by F. H. Olmsted on basis of gamma log. Casing perforated from 165 to 190, 194 to 198, and 215 to 218 feet. Altitude 208.9 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Silt, sandy | 11 | 11 |
| Sand | 8 | 19 |
| Silt and sand | 16 | 35 |
| Sand | 13 | 48 |
| Clay | 10 | 58 |
| Sand | 20 | 78 |
| Sand and gravel | 5 | 83 |
| Sand | 9 | 92 |
| Clay, silt, and fine sand | 34 | 126 |
| Sand | 28 | 154 |
| Sand and silt | 12 | 166 |
| Coarse-gravel zone: | | |
| Sand and gravel | 7 | 173 |
| Gravel | 17 | 190 |
| Sand | 3 | 193 |
| Clay | 1 | 194 |
| Sand and gravel | 4 | 198 |
| Sand | 17 | 215 |
| Gravel | 3 | 218 |
| Wedge zone(?): | | |
| Clay | 3 | 221 |
| Sand | 4 | 225 |
| Clay, green | 1 | 226 |
| Sand, water | 37 | 263 |

**Well (C-9-22)28cbb**

[U.S. Geological Survey test well LCRP 25 on Yuma Mesa. Drilled with mud-rotary equipment by Evans Brothers. Log by F. H. Olmsted. Completed to 2,002 ft and gravel-packed; casing perforated from 862 to 2,002 ft. Altitude 204.6 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, fine to medium, light-brown; some silt | 25 | 25 |
| Gravel and brown medium to coarse sand | 20 | 45 |
| Sand, medium to coarse, light-brown; gravel and some brown clay and silt | 24 | 69 |
| Clay, silty, brown; gravel and some sand | 13 | 82 |
| Sand, silty, brown; some gravel and brown clay | 27 | 109 |
| Sand, brown; brown clay and some gravel and silt | 33 | 142 |
| Sand, fine to coarse, brown | 18 | 160 |
| Coarse-gravel zone: | | |
| Gravel, cemented | 5 | 165 |
| Clay, silty, brown | 10 | 175 |
| Sand, fine to coarse; some silt in upper part | 13 | 188 |
| Gravel, cemented | 9 | 197 |
| Sand, fine to coarse, brown; some gravel | 10 | 207 |
| Clay, silty, brown | 3 | 210 |
| Sand, gravel, and some brown silty clay | 35 | 245 |
| Coarse-gravel zone(?) | | |
| Clay, silty, brownish-gray | 4 | 249 |
| Sand, coarse, gray | 5 | 254 |
| Clay, silty, brownish-gray | 7 | 261 |
| Gravel and coarse sand, gray; much rounded quartzite and chert | 43 | 304 |
| Wedge zone: | | |
| Sand, silt, and clay, gray to brownish-gray | 13 | 317 |
| Sand, fine to coarse; gravel and thin beds of brownish-gray silty clay and silt | 110 | 427 |
| Silt, brownish-gray | 4 | 431 |
| Sand, fine to coarse; gravel and thin beds of brownish-gray silty clay and silt | 95 | 526 |
| Silt, brownish-gray | 4 | 530 |
| Sand, fine to coarse; gravel and thin beds of brownish-gray silty clay and silt | 43 | 573 |
| Silt, brownish-gray | 5 | 578 |
| Sand, fine to coarse; some gravel and thin beds of brownish-gray silt and silty clay | 83 | 661 |
| Clay, silty, brownish-gray | 4 | 665 |
| Sand, fine to coarse; some gravel and thin | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-22)28cbb—Continued** | | |
| Wedge zone—Continued: | | |
| beds of brownish-gray silt and silty clay | 68 | 733 |
| Silt, brownish-gray | 3 | 736 |
| Sand, fine to coarse; some gravel and thin beds of brownish-gray silt and silty clay | 20 | 756 |
| Silt, brownish-gray | 4 | 760 |
| Sand, some gravel, and brownish-gray silt | 11 | 771 |
| Silt, brownish-gray | 3 | 774 |
| Sand, some gravel, and brownish-gray silt | 8 | 782 |
| Silt, brownish-gray | 3 | 785 |
| Sand and gravel; a small amount of brownish-gray silt | 32 | 817 |
| Silt, brownish-gray | 3 | 820 |
| Sand and fine gravel; some fine white sandstone | 17 | 837 |
| Clay, silty, brownish-gray | 4 | 841 |
| Sand, coarse; and gravel (chiefly metamorphic and volcanic); some fine to medium sand and silt | 50 | 891 |
| Silt, brownish-gray | 3 | 894 |
| Gravel and sand; some fine white sandstone | 26 | 920 |
| Silt, sandy, brownish-gray | 3 | 923 |
| Sand, fine to coarse, gray | 7 | 930 |
| Sand, fine to coarse; and gravel (metamorphic, volcanic, chert, quartzitic, and some granitic) | 11 | 941 |
| Sand, fine to coarse, gray | 3 | 944 |
| Sand and gravel | 11 | 955 |
| Sand, fine to coarse, gray | 10 | 965 |
| Gravel and sand | 10 | 975 |
| Clay, silty, grayish-brown | 3 | 978 |
| Gravel and sand | 8 | 986 |
| Sand, fine to coarse; and gravel | 34 | 1,020 |
| Silt, brownish-gray | 3 | 1,023 |
| Sand, fine to coarse; and gravel | 13 | 1,036 |
| Silt, brownish-gray | 4 | 1,040 |
| Sand, fine to coarse; and gravel | 3 | 1,043 |
| Sand, fine to medium, gray | 11 | 1,054 |
| Gravel and sand | 4 | 1,058 |
| Sand, fine to medium, gray | 8 | 1,066 |
| Clay, gray or brownish-gray | 5 | 1,071 |
| Sand, fine to medium; some gravel | 19 | 1,090 |
| Gravel and sand | 37 | 1,127 |
| Sand, fine to medium; some gravel | 32 | 1,159 |
| Silt, sandy | 5 | 1,164 |
| Sand, fine to medium; some gravel | 24 | 1,188 |
| Clay, gray | 4 | 1,192 |
| Sand, fine to medium; some cemented sand and gravel | 62 | 1,254 |
| Silt, gray | 4 | 1,258 |
| Sand, fine to coarse; and gravel | 19 | 1,277 |
| Silt, clayey | 4 | 1,281 |
| Sand, fine to coarse; some gravel | 7 | 1,288 |
| Clay, hard, light-brownish-gray | 11 | 1,299 |
| Sand, fine to coarse; some gravel | 23 | 1,322 |
| Silt, sandy | 3 | 1,325 |
| Sand, fine to coarse; some gravel | 25 | 1,350 |
| Gravel and sand | 7 | 1,357 |
| Sand, fine to medium; some cemented sand and gravel | 21 | 1,378 |
| Clay, silty | 6 | 1,384 |
| Sand, fine to medium; a small amount of cemented sand and gravel | 36 | 1,420 |
| Silt, sandy | 4 | 1,424 |
| Sand, fine to medium; a small amount of cemented sand and gravel | 17 | 1,441 |
| Silt, sandy | 3 | 1,444 |
| Sand, fine to medium; a small amount of cemented sand and gravel | 10 | 1,454 |
| Clay, light-brownish-gray | 7 | 1,461 |
| Sand, fine to medium, gray | 6 | 1,467 |
| Gravel and coarse sand | 13 | 1,480 |
| Sand, fine to coarse; some gravel | 17 | 1,497 |
| Silt, sandy | 5 | 1,502 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-22)28cbb—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to coarse; and gravel | 33 | 1,535 |
| Clay, silty | 4 | 1,539 |
| Sand, fine to medium; some gravel | 37 | 1,576 |
| Clay, silty | 4 | 1,580 |
| Sand, fine to medium; a small amount of gravel | 10 | 1,590 |
| Clay, soft, sticky, light-brownish-gray | 26 | 1,616 |
| Gravel (mostly plutonic, volcanic, and metamorphic rock detritus, some chert and quartzite); some sand | 15 | 1,631 |
| Sand; some gravel and grayish-brown silt | 17 | 1,648 |
| Silt, sandy, soft, grayish-brown | 3 | 1,651 |
| Sand, fine to medium; a small amount of gravel | 24 | 1,675 |
| Silt, sandy, soft, grayish-brown | 3 | 1,678 |
| Sand; beds of cemented sand and gravel | 54 | 1,732 |
| Clay, hard, light-grayish-brown | 9 | 1,741 |
| Sand, fine to medium | 13 | 1,754 |
| Sand, somewhat cemented, and gravel | 13 | 1,767 |
| Clay, soft, light-brownish-gray | 5 | 1,772 |
| Sand, fine to coarse; a small amount of gravel | 28 | 1,800 |
| Clay, silty and sandy, soft, pale-yellowish-brown (10YR 6/2); much moderate-brown (5YR 4/4) clay | 23 | 1,823 |
| Sand and gravel, somewhat indurated | 35 | 1,858 |
| Silt, sandy, grayish-brown | 5 | 1,863 |
| Sand, fine to coarse; some gravel | 70 | 1,933 |
| Clay, brown | 10 | 1,943 |
| Sand, fine to coarse; some gravel | 21 | 1,964 |
| Clay, brown | 10 | 1,974 |
| Sand, fine to coarse; some gravel | 10 | 1,984 |
| Clay, brown | 13 | 1,997 |
| Sand, medium to coarse; some beds of gravel | 104 | 2,101 |
| Transition zone: | | |
| Clay, hard; or pale-bluish-gray and pale brown claystone; pelecypods | 9 | 2,110 |
| Sand, fine to medium, gray | 7 | 2,117 |
| Clay, hard; or pale-bluish-gray and pale brown claystone; pelecypods | 5 | 2,122 |
| Sand, fine to medium; and interbedded clay | 9 | 2,131 |
| Clay and claystone, medium-bluish-gray and brown; pelecypods | 13 | 2,144 |
| Sand and silt; some gravel | 10 | 2,154 |
| Clay and claystone, medium bluish-gray and brown; pelecypods | 31 | 2,185 |
| Sand, fine to coarse; somewhat indurated, gray | 31 | 2,216 |
| Clay | 3 | 2,219 |
| Sand, fine to coarse, somewhat indurated, gray | 34 | 2,253 |
| Clay and claystone, bluish-gray, olive-gray, and brown; pelecypods; some interbedded sand and silt | 18 | 2,271 |
| Sand, fine to medium; some silt and clay in thin beds | 15 | 2,286 |
| Clay and claystone, olive-gray, bluish-gray, and brown; pelecypods; some interbedded gray sand and silt | 8 | 2,294 |
| Sand, fine to medium; some silt | 13 | 2,307 |
| Clay, hard; or tough sticky olive-gray claystone; some pelecypods | 11 | 2,318 |
| **Well (C-9-23)7baa** | | |
| [U.S. Bureau of Reclamation test well YVI-5(P) in Yuma Valley. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett and E. L. Smith, modified in part by F H. Olmsted. Well point installed at a depth of 143–145 ft. Altitude 116.1 ft] | | |
| Upper, fine-grained zone: | | |
| Silt, clayey, medium- to dark-brown | 4 | 4 |
| Sand, fine, light-brown, poorly graded | 2 | 6 |
| Clay, fat, reddish-brown | 2 | 8 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–9–23)7baa—Continued** | | |
| Upper, fine-grained zone—Continued: | | |
| Sand, fine, poorly graded | 10 | 18 |
| Clay, silty, reddish-brown | 6 | 24 |
| Sand, fine to medium, gray | 7 | 31 |
| Clay, silty | 4 | 35 |
| Sand, fine to medium, gray; thin cemented layers | 15 | 50 |
| Sand; thin beds of clay and silt | 12 | 62 |
| Sand, fine to medium, gray; thin cemented layers | 10 | 72 |
| Clay, silty and sandy, bluish-gray | 3 | 75 |
| Sand, fine to coarse, poorly graded; a few small pebbles | 13 | 88 |
| Clay, fat, reddish-brown to brown; a few silt layers | 20 | 108 |
| Sand | 4 | 112 |
| Clay and sand, interbedded | 14 | 126 |
| Coarse-gravel zone: | | |
| Gravel, poorly graded, containing abundant rounded pebbles of quartzite, chert, and volcanic rocks. Thin interbeds of fine sand | 4 | 130 |
| Gravel, well-graded, otherwise similar to that above. "Pea" gravel more abundant below 157 ft. Layer of fine sand from 160 to 161 ft | 35 | 165 |
| Wedge zone(?): | | |
| Sand, fine, poorly graded; occasional pebbles or cobbles above 176 ft, thin layer of green clay at 176 ft | 37 | 202 |
| **Well (C–9–23)9bbb** | | |
| [Arizona Public Service Co. Industrial well on Yuma Mesa. Drilled with cable-tool equipment by A. G. Tschour. Casing perforated from 641 to 670 ft. Altitude 193 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, mesa | 14 | 14 |
| Sand and clay streaks, some water at 74 ft | 143 | 157 |
| Clay, soft | 29 | 186 |
| Coarse-gravel zone: | | |
| Gravel, good; water | 19 | 205 |
| Wedge zone: | | |
| Sand, quick; and fine broken sandstone strata | 19 | 224 |
| Sand, clay, sandstone streaks | 16 | 240 |
| Sand | 76 | 316 |
| Sandstone, gravel strata | 8 | 324 |
| Caliche | 6 | 330 |
| Sand, sandstone in layers; water bearing | 55 | 385 |
| Sand and some water | 41 | 426 |
| Caliche and clay | 6 | 432 |
| Sand | 18 | 450 |
| Clay | 3 | 453 |
| Sand | 79 | 532 |
| Clay and sandstone | 3 | 535 |
| Sand | 19 | 554 |
| Clay and sandstone | 18 | 572 |
| Clay, tough | 8 | 580 |
| Clay, soft, sandy | 10 | 590 |
| Sand and sandstone streaks | 4 | 594 |
| Sand | 47 | 641 |
| Sandstone, gravel, sand strata; water | 29 | 670 |
| Sand | 7 | 677 |
| Clay, tough | 5 | 682 |
| Clay, sandy | 68 | 750 |
| **Well (C–9–23)20bdc** | | |
| [U.S. Bureau of Reclamation drainage well YVI–13 in Yuma Valley. Drilled with reverse-circulation-rotary equipment by G. Maddox. Log by Bureau of Reclamation. Completed and gravel packed to 229 ft; screened from 95 to 167 ft. Altitude 112 ft] | | |
| Upper, fine-grained zone: | | |
| Clay, silty to highly plastic, light- to medium-brown | 7 | 7 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–9–23)20bdc—Continued** | | |
| Upper, fine-grained zone—Continued: | | |
| Sand, poorly graded, light- to medium-brown; a few thin interbeds of fat clay and weakly cemented sand; scattered small pebbles | 38 | 45 |
| Sand and clay, interbedded. Fine gray sand with scattered pebbles; silty light-brown clay | 4 | 49 |
| Clay, silty, light-brown | 4 | 53 |
| Sand, predominantly fine, light-grayish-brown | 24 | 77 |
| Clay, silty, light-brown | 1 | 78 |
| Sand, predominantly fine, light-grayish-brown | 27 | 105 |
| Clay, silty, grayish-brown | 1 | 106 |
| Sand, predominantly fine, a little medium and coarse; contains a few thin cemented layers | 8 | 114 |
| Coarse-gravel zone: | | |
| Gravel, fine to 3 in., predominantly rounded (65 percent); sand, fine to coarse, gray (35 percent) | 7 | 121 |
| Gravel, fine to 6 in., rounded (80 percent); coarse to fine sand (20 percent) | 30 | 151 |
| Gravel, fine to 5 in. (65 percent); fine to coarse, gray sand (35 percent); thin layers of reddish- to grayish-brown clay between 170 and 172 ft | 38 | 189 |
| Coarse-gravel zone(?): | | |
| Sand, fine to medium, some coarse, gray; few thin interbeds of gravel (less than 10 percent) | 6 | 195 |
| Gravel, predominantly subrounded, fine to 16 in.; about 20 percent fine to coarse sand | 28 | 223 |
| Gravel, subrounded to rounded, fine to 5 in.; about 30 percent fine to coarse sand; trace of greenish limy clay | 6 | 229 |
| Sand, gray, poorly graded; scattered pebbles | 8 | 237 |
| **Well (C–9–23)25dba1** | | |
| [U.S. Bureau of Reclamation test well SH–7A on Yuma Mesa. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by Bureau of Reclamation, modified by F. H. Olmsted on basis of electric log and gamma log. Altitude 204 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine, light-grayish-tan | 20 | 20 |
| Sand, fine to coarse, grayish-tan | 65 | 85 |
| Sand, fine to medium, grayish-tan; grains more rounded than in overlying sand | 35 | 120 |
| Sand, fine to coarse, grayish-tan; scattered pebbles, chiefly silicic volcanic rocks | 20 | 140 |
| Sand, medium to coarse, light-grayish-tan; a few lumps of dark-reddish-brown silty clay | 25 | 165 |
| Coarse-gravel zone: | | |
| Sand, fine to coarse; and fine gravel composed mostly of quartz and silicic volcanic rocks | 24 | 189 |
| Sand and clay; scattered pebbles | 11 | 200 |
| Gravel, fine, angular to subrounded; composed primarily of granitic rocks, silicic volcanic rocks, and some metamorphic rocks | 17 | 217 |
| Sand, grayish-brown; and some gravel | 13 | 230 |
| Gravel, fine to coarse, angular to rounded; some quartzite, as well as other rock types | 16 | 246 |
| Wedge zone: | | |
| Sand, fine to medium, some coarse; few streaks of brown sandy and silty clay, occasional greenish-black silt. Gamma | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well-(C-9-23)25dba1—Continued** | | |
| Wedge zone—Continued: | | |
| radiation significantly higher than from sands above the coarse-gravel zone | 94 | 340 |
| Sand, fine, silty and clayey, grading into fine gravel; high gamma radiation | 30 | 370 |
| Sand, clayey, dark-gray; scattered pebbles and cobbles | 40 | 410 |
| Sand, fine to coarse, dark-gray; about 25 percent bluish-gray sandy and silty clay | 40 | 450 |
| Sand, compacted, fine to medium; about 5 percent fine gravel and 5 percent gray to reddish-brown clay | 120 | 570 |
| Sand, fine to medium, some coarse, dark-gray; about 50 percent gray to reddish-brown clay and 10 percent fine gravel | 10 | 580 |
| Sand, compacted, fine to medium, small amount of coarse sand; about 5 percent gravel and 5 percent grayish-blue clay (pebbles?) | 120 | 700 |
| Sand, fine to medium; and gray clay and silt, thin-bedded | 10 | 710 |
| **Well (C-9-23)32bad** | | |
| [U.S. Bureau of Reclamation test well CH-21YM on Yuma Mesa about 7 miles south of Yuma. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett of Bureau of Reclamation. modified by F. H. Olmsted on basis of gamma log. Well point installed at 267½ to 269½ ft. Altitude 188.0 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine, with little medium and coarse; scattered small pebbles; few thin seams of hard reddish-brown clay | 46 | 46 |
| Clay and silt, calcareous, medium-brown | 4 | 50 |
| Sand, fine; few thin beds of medium-brown clay | 16 | 66 |
| Clay and silt, medium-brown | 2 | 68 |
| Sand, fine | 3 | 71 |
| Clay, calcareous, medium-brown to reddish-brown | 8 | 79 |
| Silt and clay | 3 | 82 |
| Sand, fine | 6 | 88 |
| Sand and brown clay | 4 | 92 |
| Clay, calcareous, brown | 4 | 96 |
| Sand and layers of brown clay | 10 | 106 |
| Sand, fine | 8 | 114 |
| Sand, fine, and brown clay | 6 | 120 |
| Clay, medium-brown to reddish-brown | 5 | 125 |
| Sand, fine, and layers of brown clay | 8 | 133 |
| Sand, fine; some weakly cemented sand, scattered small pebbles | 34 | 167 |
| Clay, calcareous, brownish-gray to dark-gray; some fine sand and silt | 15 | 182 |
| Sand, fine | 23 | 205 |
| Coarse-gravel zone: | | |
| Gravel, fine to 3 in., subrounded to rounded; thin beds of sand. Pebbles and cobbles include granitic and volcanic rocks, quartzite, and chert | 17 | 222 |
| Sand and scattered pebbles | 3 | 225 |
| Gravel, fine to 3 in., subrounded to rounded | 18 | 243 |
| Sand, fine brownish-gray | 11 | 254 |
| Gravel, fine to 3 in., subrounded to rounded | 5 | 259 |
| Sand, fine brownish-gray | 5 | 264 |
| Gravel, fine to 3 in., subrounded to rounded | 3 | 267 |
| Crystalline rocks: | | |
| Granite. Nx diamond core from 280 to 285 ft contained friable to coherent grayish-white granite, coarse-grained, containing about 60 percent feldspar, 20 percent quartz, and 20 percent dark minerals (chiefly biotite). Dry-weight density 2.7 g per cm³ | 17 | 285 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-23)35ccc** | | |
| [U.S. Bureau of Reclamation test well CH-13YM on Yuma Mesa. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by W. Moffitt of Bureau of Reclamation, modified above a depth of 250 ft by F. H. Olmsted on basis of gamma log. Well point installed at 248-250 ft. Altitude 202.2 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine to coarse, pebbly | 20 | 20 |
| Sand, fine to medium, a few scattered pebbles | 22 | 42 |
| Sand and rounded-quartzite gravel | 6 | 48 |
| Sand, scattered pebbles, a few thin beds of pebbly clay | 9 | 57 |
| Sand, clean | 3 | 60 |
| Sand, scattered pebbles, a few thin beds of compact silty sand and pebbly clay | 14 | 74 |
| Sand, fine | 5 | 79 |
| Gravel, sand, and red clay | 1 | 80 |
| Sand, fine, brown | 6 | 86 |
| Clay, red, and thin beds of fine sand | 24 | 110 |
| Sand, fine, brown | 16 | 126 |
| Clay, hard, red, and silty sand | 2 | 128 |
| Sand, fine, brown | 7 | 135 |
| Clay, reddish-tan; some coarse sand | 2 | 137 |
| Sand, fine, brown; some thin beds of red clay | 11 | 148 |
| Clay, soft, reddish-tan | 1 | 149 |
| Sand and scattered pebbles | 9 | 158 |
| Clay, soft, reddish-tan | 1 | 159 |
| Sand and scattered pebbles | 13 | 172 |
| Coarse-gravel zone: | | |
| Sand and fine gravel; few thin beds of red clay | 10 | 182 |
| Sand and scattered pebbles | 6 | 188 |
| Gravel, fine to 4 in., well-rounded clasts of quartzite and subrounded to subangular clasts of granitic and volcanic rocks; some coarse sand | 12 | 200 |
| Sand and scattered pebbles | 2 | 202 |
| Clay, hard, dark-gray to brown; silt interbeds below about 206 ft | 16 | 218 |
| Sand, fine, brown | 18 | 236 |
| Gravel, fine to 6 in., and coarse sand; small amount of dark-gray clay. Well-rounded clasts of quartzite and subrounded to subangular clasts of granitic and volcanic rocks | 28 | 264 |
| Wedge zone: | | |
| Sand, fine to medium, grayish-brown | 32 | 296 |
| Sand, silty, and clay in thin interbeds | 1 | 297 |
| Sand, grayish-brown, and scattered small pebbles | 8 | 305 |
| Clay, dark-gray, and about 20 percent fine sand | 3 | 308 |
| Sand, fine, grayish-brown | 3 | 311 |
| Clay, dark-gray, and about 20 percent fine sand | 1 | 312 |
| Sand, fine, grayish-brown; a few pieces of cemented sand and a few thin lenses of gray clay | 17 | 329 |
| Clay, sandy, white to light-gray | 2 | 331 |
| Sand, fine | 3 | 334 |
| Clay, sandy, white to light-gray | 1 | 335 |
| Sand, fine, gray | 5 | 340 |
| Silt, sandy, gray to black | 1 | 341 |
| Sand, fine, gray; scattered small pebbles | 48 | 389 |
| Sand, fine to coarse, and 20-30 percent fine well-rounded quartzite to subangular granitic and volcanic gravel | 6 | 395 |
| Sand, fine; scattered small pebbles | 13 | 408 |
| Silt, sandy, light-gray | 2 | 410 |
| Sand, fine, grayish-brown; occasional small pebbles | 10 | 420 |
| Sand, silty, light-gray | 2 | 422 |
| Sand, fine, grayish-brown | 35 | 457 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–9–23)35ccc—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to coarse, silty, and small pebbles | 5 | 462 |
| Sand, fine | 5 | 467 |
| Sand, dense, silty, dark-gray; little bluish-gray clay | 4 | 471 |
| Sand, some interbedded fine gravel, grayish-brown | 33 | 504 |
| **Well (C–9–24)8baa** | | |
| [U.S. Geological Survey test well LCRP 28 in Yuma Valley on east bank of Colorado River. Drilled with mud-rotary equipment by Desert Water Drilling Co. Log by F. H. Olmsted, F. J. Frank, G. R. Vaughan, and J. H. Robison. Cased to 292 ft. Altitude 118.7 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine, and silt; thin pebbly streaks | 28 | 28 |
| Sand, fine to medium | 57 | 85 |
| Clay, silty, brown | 8 | 93 |
| Sand, fine to medium | 16 | 109 |
| Sand, some pebbles | 6 | 115 |
| Sand, fine to medium | 9 | 124 |
| Coarse-gravel zone: | | |
| Gravel, coarse, predominantly subrounded to rounded; some coarse sand | 62 | 186 |
| Wedge zone: | | |
| Sand, silt, and clay; thin streaks of gravel | 28 | 214 |
| Sand, fine to coarse; thin beds of clay and silt | 76 | 290 |
| Sand, fine, and silt | 36 | 326 |
| Silt, pale-brown | 4 | 330 |
| Sand, fine to medium | 26 | 356 |
| Silt, light-brown | 6 | 362 |
| Sand, fine to coarse, somewhat pebbly | 33 | 395 |
| Silt, light-brown | 6 | 401 |
| Sand, sparse small pebbles | 7 | 408 |
| Silt, light-brown | 2 | 410 |
| Sand, fine to coarse | 11 | 421 |
| Clay, silty, brown | 4 | 425 |
| Sand, fine to coarse | 23 | 448 |
| Silt, light-brown | 3 | 451 |
| Sand, fine to medium, some coarse and pebbly; a few thin streaks or pebbles of gray and brown clay | 79 | 530 |
| Silt, light-brown | 4 | 534 |
| Sand, fine to medium, brownish-gray; a little silt and scattered small pebbles | 15 | 549 |
| Silt, light-brown | 3 | 552 |
| Sand, fine to medium; some coarse pebbly sand. Pebbles mostly plutonic, volcanic, and metamorphic rocks; a few are well-rounded chert and quartzite. Many fragments of plants and carbonized wood | 80 | 632 |
| Silt, light-brown | 5 | 637 |
| Sand, some fine to medium gravel; some coarse pebbly sand. Pebbles most plutonic, volcanic, and metamorphic rocks; a few are well-rounded chert and quartzite. Many fragments of plants and carbonized wood | 14 | 651 |
| Silt, light-brown | 6 | 657 |
| Sand, some fine to medium gravel; some coarse pebbly sand. Pebbles mostly plutonic, volcanic, and metamorphic rocks; a few well-rounded chert and quartzite. Many fragments of plants and carbonized wood | 23 | 680 |
| Sand; a few streaks or clasts of light-gray clay; scattered pebbles | 30 | 710 |
| Sand, fine to medium, some coarse, gray; thin beds of fine gravel | 40 | 750 |
| Sand, medium to coarse; scattered sandstone concretions and pebbles of light-gray claystone; some carbonized wood. Gravel rare | 40 | 790 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–9–24)8baa—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to medium; some silt | 20 | 810 |
| Sand, scattered pebbles | 50 | 860 |
| Sand, fine to medium, gray; some silt | 48 | 908 |
| Sand, medium to coarse, gray | 10 | 918 |
| Silt, light-brown | 5 | 923 |
| Sand, fine to coarse, poorly sorted; granules and small pebbles mostly of black chert and silicic volcanic rocks | 52 | 975 |
| Silt, light-brown | 4 | 979 |
| Sand, some gravel, fine to coarse, poorly sorted; granules and small pebbles mostly of black chert and silicic volcanic rocks | 21 | 1,000 |
| Sand, fine to medium, and silt; a few thin cemented streaks or flat sandstone concretions | 72 | 1,072 |
| Sand, fine to coarse, pebbly | 6 | 1,078 |
| Sand and silt, fine to medium; a few thin cemented streaks or flat sandstone concretions | 90 | 1,168 |
| Clay, brown to brownish-gray | 7 | 1,175 |
| Sand and silt, fine to medium; a few thin cemented streaks or flat sandstone concretions | 202 | 1,377 |
| Clay, light-brownish gray | 5 | 1,382 |
| Sand, fine to coarse, and fine gravel; scattered pebbles and small cobbles | 80 | 1,462 |
| Silt, light-brown, and light-brownish-gray clay | 9 | 1,471 |
| Sand and fine gravel | 9 | 1,480 |
| Gravel, cemented | 5 | 1,485 |
| Sand, medium to coarse; scattered pebbles and thin beds of gravel | 187 | 1,672 |
| Clay, gray and brown | 5 | 1,677 |
| Sand, coarse, and gravel; thin cemented zones or flat concretions | 22 | 1,699 |
| Silt and grayish-white clay; possibly a few pebbles | 4 | 1,703 |
| Sand, some gravel and clay balls | 37 | 1,740 |
| Silt and clay, brown and gray | 2 | 1,742 |
| Sand, some gravel; thin cemented zones or concretions | 14 | 1,756 |
| Clay, silty, gray | 4 | 1,760 |
| Sand, some gravel; thin cemented zones or concretions | 34 | 1,794 |
| Sand, coarse, and fine gravel, somewhat cemented | 5 | 1,799 |
| Sand, some gravel; thin cemented zones or concretions | 16 | 1,815 |
| Clay, grayish-brown | 5 | 1,820 |
| Sand, some gravel; thin cemented zones or concretions | 40 | 1,860 |
| Sand, fine to coarse; trace of gravel, silt, and clay | 67 | 1,927 |
| Transition zone: | | |
| Clay, gray, fossiliferous | 11 | 1,938 |
| Sand and silt, gray | 17 | 1,955 |
| Clay, gray, fossiliferous | 21 | 1,976 |
| Sand, fine to coarse, gray; some fine gravel | 52 | 2,028 |
| Clay, gray, and fine sand, fossiliferous | 17 | 2,045 |
| Sand, fine to coarse, gray and subangular to rounded gravel composed of chert and quartzite in addition to plutonic, volcanic, and metamorphic rocks | 45 | 2,090 |
| Clay, gray, silt and fine sand, fossiliferous | 40 | 2,130 |
| Sand, some fine gravel | 13 | 2,143 |
| Clay, silty, gray, fossiliferous | 13 | 2,156 |
| Sand, fine to medium, gray | 20 | 2,176 |
| Clay and silt, gray, fossiliferous | 4 | 2,180 |
| Sand and gravel, fine to coarse, gray, subangular to rounded; composed of chert and quartzite in addition to plutonic, volcanic, and metamorphic rocks | 38 | 2,218 |

*Selected logs of water wells*—Continued

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-24)8baa—Coutinued** | | |
| Transition zone—Continued: | | |
| Clay, gray, fossiliferous | 5 | 2,223 |
| Sand and gravel, fine to coarse, gray, subangular to rounded: composed of chert and quartzite in addition to plutonic, volcanic, and metamorphic rocks | 69 | 2,292 |
| Clay, gray, and fine sand, fossiliferous | 10 | 2,302 |
| Sand and gravel, somewhat cemented | 48 | 2,350 |
| Clay, gray, and fine sand, interbedded | 45 | 2,395 |
| Sand and gravel, somewhat cemented | 51 | 2,446 |
| Clay, gray; fossiliferous | 20 | 2,466 |

**Well (C-9-24)13cdd**

[U.S. Bureau of Reclamation test well CH-3 in Yuma Valley. Drilled with cable-tool equipment by San Diego Well Drillers. Log by Bureau of Reclamation; modified by F. H. Olmsted, on basis of gamma log. Casing perforated from 139 to 170 ft. Altitude 105.0 ft]

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Clay and fine sand and silt, brown, containing much organic matter | 12 | 12 |
| Silt and fine sand, clayey, brown | 6 | 18 |
| Sand, fine to medium; roots and bark at 25 ft | 18 | 36 |
| Clay, silt, and fine sand | 6 | 42 |
| Sand, fine to medium | 12 | 54 |
| Clay, brown, plastic, and sand | 2 | 56 |
| Sand, fine to medium; scattered pebbles | 8 | 64 |
| Clay and sand | 5 | 69 |
| Sand, fine to medium; few thin layers of clay and silt | 57 | 126 |
| Coarse-gravel zone: | | |
| Sand, fine to medium, and about 35 percent gravel | 3 | 129 |
| Sand, fine to medium, silty; a few pebbles | 11 | 140 |
| Gravel, fine to 8 in., much of it well-rounded (about 60–70 percent); sand, fine to coarse (30–40 percent) | 26 | 166 |
| Sand, fine to medium (50–85 percent); gravel, fine to 5 in. (15–50 percent) | 29 | 195 |
| Wedge zone: | | |
| Sand, fine to medium, containing some silt | 25 | 220 |
| Sand, fine to medium | 20 | 240 |
| Sand, fine, containing some silt and clay | 10 | 250 |
| Sand, fine; scattered angular to subangular pebbles | 15 | 265 |
| Sand, fine, containing some silt and clay | 15 | 280 |
| Sand, fine to coarse; scattered pebbles | 20 | 300 |
| Sand and gravel | 6 | 306 |
| Sand, fine | 18 | 324 |
| Sand, silt, and some gravel | 71 | 395 |
| Sand and 20 percent gravel up to 2 in. | 10 | 405 |
| Sand, fine to medium, containing some silt and clay | 35 | 440 |
| Sand, fine, well-sorted; some coarse sand | 35 | 475 |
| Sand, fine to coarse; layers of well-cemented sand | 25 | 500 |

**Well (C-9-24)19bad2**

[P. E. Sterling. Irrigation well in western Yuma Valley. Drilled with cable-tool equipment by San Diego Well Drillers. Casing perforated from 145 to 180 ft. Atitude 107 ft]

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Top soil | 5 | 5 |
| Silt and decomposed wood | 44 | 49 |
| Sand and silt | 4 | 53 |
| Sand and clay streaks | 32 | 85 |
| Brown clay | 8 | 93 |
| Coarse sand with small amount of gravel | 23 | 116 |
| Coarse sand with gravel | 7 | 123 |
| Coarse-gravel zone: | | |
| Gravel, ¼–4 in. | 57 | 180 |
| Wedge zone(?): | | |
| Coarse sand with gravel | 15 | 195 |

*Selected logs of water wells*—Continued

**Well (C-9-24)34dcb3**

[City of Somerton. Public-supply well in Yuma Valley. Drilled with cable-tool equipment by Hamilton and Hood. Driller's log modified by F. H. Olmsted on basis of gamma log. Altitude 106.2 ft]

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Silt and clay | 14 | 14 |
| Sand, fine | 42 | 56 |
| Clay | 2 | 58 |
| Sand, fine | 22 | 80 |
| Clay | 5 | 85 |
| Sand, fine | 51 | 136 |
| Sand and gravel | 12 | 148 |
| Coarse-gravel zone: | | |
| Gravel | 14 | 162 |
| Sand | 10 | 172 |
| Gravel | 28 | 200 |
| Sand | 12 | 212 |
| Gravel | 44 | 256 |
| Wedge zone: | | |
| Sand | 304 | 560 |
| Sand and clay | 44 | 604 |
| Sand, small amount of gravel | 10 | 614 |
| Sand | 169 | 783 |
| Clay | 4 | 787 |
| Sand, some clay | 154 | 941 |
| Sand, clay, and gravel | 5 | 946 |
| Sand | 19 | 965 |
| Clay | 4 | 969 |
| Sand, some clay | 33 | 1,002 |
| Sand | 5 | 1,007 |
| Sand, clay, and gravel | 4 | 1,011 |
| Sand | 67 | 1,078 |
| Sand, with small amount of gravel | 5 | 1,083 |
| Clay, sandy | 18 | 1,101 |
| Sand | 62 | 1,163 |

**Well (C-9-25)35cbd**

[U.S. Geological Survey test well LCRP 9 in western Yuma Valley, on east bank of Colorado River. Drilled with mud-rotary equipment by R. E. Anderson. Log by F. H. Olmsted, F. J. Frank, and G. R. Vaughan. Screened in 5- and 10-ft intervals from 310 to 1,108 ft. Altitude 104 ft]

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand; some thin beds of silt and clay | 26 | 26 |
| Sand; silt; some wood | 11 | 37 |
| Sand, fine gravel; some wood | 10 | 47 |
| Sand; some silt and wood | 44 | 91 |
| Silt, clayey; some sand, gravel, and carbonized wood | 10 | 101 |
| Coarse-gravel zone: | | |
| Sand and gravel; thin clay at 103 ft | 17 | 118 |
| Gravel and sand | 13 | 131 |
| Gravel, coarse | 2 | 133 |
| Sand; some coarse gravel beds | 19 | 152 |
| Gravel and sand; some clay and carbonized wood | 6 | 158 |
| Gravel, coarse; thin beds of coarse sand | 21 | 179 |
| Coarse-gravel zone(?): | | |
| Sand; some gravel | 7 | 186 |
| Sand; some silt | 14 | 200 |
| Gravel, boulders | 1 | 201 |
| Gravel, fine; and sand | 4 | 205 |
| Sand; thin beds of clayey silt | 17 | 222 |
| Sand and gravel; some silt | 28 | 250 |
| Gravel, coarse; thin beds of sand | 29 | 279 |
| Clay, silt, and sand | 2 | 281 |
| Sand and fine gravel | 4 | 285 |
| Gravel, boulders, and cobbles | 17 | 302 |
| Wedge zone: | | |
| Silt or silty clay | 4 | 306 |
| Sand and gravel | 32 | 338 |
| Sand, silty or silt | 4 | 342 |
| Sand; some beds of gravel | 12 | 354 |
| Sand, silty | 3 | 357 |
| Sand and fine gravel | 30 | 387 |
| Silt | 4 | 391 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-25)35cbd—Continued** | | |
| Wedge zone—Continued: | | |
| Sand; some beds of gravel | 12 | 403 |
| Sand, silty | 4 | 407 |
| Sand; some gravel | 13 | 420 |
| Silt, clayey | 5 | 425 |
| Sand | 4 | 429 |
| Silt, clayey | 3 | 432 |
| Sand; some gravel | 16 | 448 |
| Silt, sandy | 3 | 451 |
| Sand, gray, fine to coarse | 23 | 474 |
| Silt, clayey, gray | 4 | 478 |
| Sand, medium to coarse; some gravel | 11 | 489 |
| Sand | 8 | 497 |
| Sand, silty | 3 | 500 |
| Sand, medium to coarse | 10 | 510 |
| Sand; some beds of gravel | 31 | 541 |
| Sand, silty | 3 | 544 |
| Sand | 4 | 548 |
| Silt, sandy | 3 | 551 |
| Sand | 8 | 559 |
| Gravel | 2 | 561 |
| Sand | 6 | 567 |
| Gravel; some sand | 5 | 572 |
| Sand, silty | 5 | 577 |
| Sand; some gravel | 18 | 595 |
| Silt | 5 | 600 |
| Gravel and coarse sand | 8 | 608 |
| Sand; some gravel and silt | 31 | 639 |
| Sand; coarse; some gravel | 13 | 652 |
| Silt | 4 | 656 |
| Sand | 8 | 664 |
| Silt | 6 | 670 |
| Sand; some soft sandstone and fine gravel | 10 | 680 |
| Silt | 10 | 690 |
| Sand; some soft sandstone and very little fine gravel | 33 | 723 |
| Silt, sandy | 10 | 733 |
| Sand; some gravel | 50 | 783 |
| Silt, sandy | 4 | 787 |
| Sand and soft sandstone | 18 | 805 |
| Silt | 4 | 809 |
| Sand; soft sandstone; some beds of gravel | 59 | 868 |
| Sand, silty | 4 | 872 |
| Gravel | 2 | 874 |
| Sand | 8 | 882 |
| Gravel; soft sandstone | 3 | 885 |
| Sand | 4 | 889 |
| Gravel; soft sandstone | 3 | 892 |
| Sand and silt | 10 | 902 |
| Sand | 6 | 908 |
| Sand, silty; brown clay | 4 | 912 |
| Gravel and sand | 5 | 917 |
| Sand, fine to medium | 10 | 927 |
| Sand, silty | 4 | 931 |
| Sand | 6 | 937 |
| Silt, sandy | 4 | 941 |
| Sand; some beds of gravel | 39 | 980 |
| Silt, sandy | 4 | 984 |
| Sand; some gravel | 8 | 992 |
| Silt | 5 | 997 |
| Sand; some gravel, silt, and fine white sandstone | 27 | 1,024 |
| Clay | 8 | 1,032 |
| Sand; some carbonized wood and gravel | 36 | 1,068 |
| Silt, sandy | 4 | 1,072 |
| Sand; some carbonized wood and fine white sandstone | 11 | 1,083 |
| Silt and white clay | 9 | 1,092 |
| Sand; some gravel | 22 | 1,114 |
| Sand, silty | 7 | 1,121 |
| Sand; some gravel and soft sandstone | 13 | 1,134 |
| Sand, silty | 3 | 1,137 |
| Sand; some carbonized wood | 12 | 1,149 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-9-25)35cbd—Continued** | | |
| Wedge zone—Continued: | | |
| Sand; some gravel | 4 | 1,153 |
| Clay, white | 5 | 1,158 |
| Sand | 20 | 1,178 |
| Sand, silty | 3 | 1,181 |
| Sand | 14 | 1,195 |
| Sand, silty | 4 | 1,199 |
| Sand | 2 | 1,201 |
| **Well (C-10-23)11dcd** | | |
| [F. Booth. Irrigation well on Yuma Mesa. Drilled with cable-tool equipment by Hamilton and Hood. Casing perforated from 98 to 113, 192 to 222, 260 to 280, 320 to 334, and 445 to 495 ft. Altitude 200 ft] | | |
| Upper, fine-grained zone: | | |
| Sand and caliche | 10 | 10 |
| Sand | 19 | 29 |
| Gravel, 3 in. maximum | 2 | 31 |
| Sand and gravel, 1 inch maximum | 32 | 63 |
| Sand and gravel, 5 in. maximum; with clay lenses | 17 | 80 |
| Shale | 1 | 81 |
| Sand | 11 | 92 |
| Gravel, 4 in. maximum | 3 | 95 |
| Sand and gravel | 18 | 113 |
| Sand | 72 | 185 |
| Coarse-gravel zone: | | |
| Sand and gravel, 5 in. maximum | 13 | 198 |
| Sand and gravel | 6 | 204 |
| Sand and gravel, 4 in. maximum | 18 | 222 |
| Sand | 34 | 256 |
| Gravel, 3 in. maximum | 24 | 280 |
| Coarse-gravel zone(?): | | |
| Sand | 36 | 316 |
| Sand and gravel, 3 in. maximum | 18 | 334 |
| Wedge zone: | | |
| Sand | 6 | 340 |
| Sand, cemented | 20 | 360 |
| Shale, blue | 2 | 362 |
| Sand, cemented | 3 | 365 |
| Sand, cemented lenses | 90 | 455 |
| Sand | 54 | 509 |
| **Well (C-10-23)20bbb** | | |
| [U.S. Navy. Industrial well on Yuma Mesa. Drilled with cable-tool equipment by Weber Well Drilling Co. Log by G. E. Hendrickson. Casing perforated from 212 to 232 ft. Altitude 189 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine | 5 | 5 |
| Clay and caliche | 2 | 7 |
| Sand, fine to coarse | 15 | 22 |
| Sand | 5 | 27 |
| Sand, fine | 3 | 30 |
| Sand, coarse, with some gravel | 6 | 36 |
| Sand, medium | 4 | 40 |
| Do | 20 | 60 |
| Sand, coarse | 10 | 70 |
| Sand, medium | 10 | 80 |
| Sand, medium, with small pebbles | 10 | 90 |
| Clay, with some very fine sand | 10 | 100 |
| Sand, very fine | 10 | 110 |
| Sand, fine | 10 | 120 |
| Sand, very fine | 10 | 130 |
| Sand, very fine, with traces of silt or clay | 10 | 140 |
| Sand, fine, some cemented | 5 | 145 |
| Sand, fine, trace of silt or clay | 5 | 150 |
| Sand, fine, with about 10 percent gravel | 2 | 152 |
| Coarse-gravel zone: | | |
| Gravel ¼ in. and smaller, 5–15 percent fine sand and clay | 2 | 154 |
| Gravel, with coarse sand | 1 | 155 |
| Sand, fine to coarse, with about 25 percent gravel | 5 | 160 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-10-23)20bbb—Continued** | | |
| Coarse-gravel zone—Continued: | | |
| Gravel, small with coarse sand | 10 | 170 |
| Description missing | 5 | 175 |
| Sand, medium to very coarse, with clay balls | 7 | 182 |
| Pebbles, sand, and clay | 3 | 185 |
| Sand, fine to coarse, about 35–40 percent gravel | 5 | 190 |
| Sand, fine to medium; some silt or clay | 5 | 195 |
| Sand, very fine to fine; some silt or clay | 5 | 200 |
| Sand, fine, with some silt and clay | 10 | 210 |
| Sand, medium to coarse, with about 40 percent gravel | 2 | 212 |
| Gravel, with about 40 percent sand, medium to coarse | 8 | 220 |
| Gravel, with about 20 percent sand | 20 | 240 |
| Wedge zone: | | |
| Sand, fine to medium | 10 | 250 |
| Sand, fine to medium, with 5–10 percent pebbles | 10 | 260 |
| Sand, fine to medium, with 0–10 percent pebbles | 10 | 270 |
| Sand, fine to medium, with 5–10 percent pebbles | 10 | 280 |
| Sand, fine to medium, with 15–20 percent pebbles | 10 | 290 |
| Gravel, with some sand, had some water, no rise | 4 | 294 |
| Sand, medium | 21 | 315 |
| **Well (C-10-23)28ccd** | | |
| [V. H. Ueckert. Unused irrigation well on Yuma Mesa. Drilled with mud-rotary equipment by Gragg. Gravel-packed. casing perforated from 230 to 293 ft. Altitude 185 ft] | | |
| Upper, fine-grained zone: | | |
| Sand | 45 | 45 |
| Coarse-gravel zone: | | |
| Gravel, cemented | 25 | 70 |
| Gravel | 64 | 134 |
| Sand, fine | 40 | 174 |
| Gravel | 6 | 180 |
| Gravel, sandy | 45 | 225 |
| Sandstone | 25 | 250 |
| Gravel, small | 20 | 270 |
| Gravel, sandy | 64 | 334 |
| **Well (C-10-23)31bbb1** | | |
| [U.S. Geological Survey test well LCRP 1 on Yuma Mesa. Drilled with cable-tool equipment by Arizona Machine and Welding Works. Log by F. J. Frank. Casing perforated from 220 to 280 ft. Altitude 172.8 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, light-brown, and about 10 percent gravel; thin strata of clay at 15, 25, 60, and 65 ft | 82 | 82 |
| Gravel, ¼–2 in.; streak of clay and sand | 2 | 84 |
| Sand, light-brown, somewhat pebbly; streaks of clay, cemented gravel, and cemented sand from 115 to 123 ft | 53 | 137 |
| Coarse-gravel zone: | | |
| Gravel, pebbles, and cobbles, and about 10 percent sand; a few strata of weakly cemented sand | 16 | 153 |
| Gravel, pebbles, and cobbles, and more sand than above; strata of conglomerate and clay from 162 to 164 ft | 17 | 170 |
| Sand, pebbly; streaks of reddish-brown clay | 8 | 178 |
| Gravel, pebbles, and cobbles, and about 40 percent sand; streaks of reddish-brown clay from 178 to 180 ft | 12 | 190 |
| Sand, pebbly, grayish-brown; pebbles ¼–2 in. | 6 | 196 |
| Gravel, ¼–4 in., and 10–30 percent sand; some clay streaks and cemented zones | 77 | 263 |
| Gravel, ¼–1 in., scattered large cobbles, | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-10-23)31bbb1—Continued** | | |
| Coarse-gravel zone—Continued: | | |
| and about 50 percent very fine to medium-grained grayish-brown sand | 24 | 297 |
| Wedge zone: | | |
| Sand, very fine to medium-grained, grayish-brown | 28 | 325 |
| Sand, medium- to coarse-grained, brownish-gray; scattered pebbles and thin strata of blue clay | 70 | 395 |
| Gravel, ¼–3 in., and a small amount of medium sand | 12 | 407 |
| Clay, bluish-gray | 1 | 408 |
| Sand, medium, brownish-gray | 8 | 416 |
| Gravel, ¼–3 in., and about 40–50 percent medium gray sand; thin streaks of clay at 417 and 418 ft | 4 | 420 |
| Sand, fine to medium, brownish-gray, and scattered small pebbles | 13 | 433 |
| Sand, brownish-gray, and about 30–50 percent gravel; thin streaks of clay at 435 ft | 7 | 440 |
| Sand, brownish-gray, and a few small pebbles; streaks of clay at 457 and 459 ft | 32 | 472 |
| Gravel, ¼–¾ in., and about 40 percent sand; some wood embedded in bluish-gray clay from 472–475 ft | 8 | 480 |
| Sand, coarse to very coarse, grayish-brown; trace of silt and ¼-in. gravel | 17 | 497 |
| Sand, coarse to very coarse, grayish-brown, and about 35 percent angular gravel; some cemented sand and gravel | 3 | 500 |
| Sand, medium to coarse, brownish-gray; scattered gravel ¼–3 in.; streaks of clay at 527, 530, 532, and 540 ft | 42 | 542 |
| Sand, medium to coarse, brownish-gray; and 10–40 percent gravel | 13 | 555 |
| Sand, medium to coarse, brownish-gray and less than 10 percent gravel, ¼–3 in. | 20 | 575 |
| Sand, medium to coarse, pebbly, medium-brown | 15 | 590 |
| Sand, medium to coarse, grayish-brown; some sandstone and gray clay balls | 14 | 604 |
| Gravel, subangular to well-rounded, ¼–2 in., and 30 percent medium to coarse grayish brown sand | 6 | 610 |
| Sand, well-rounded, medium to coarse, medium-brown | 10 | 620 |
| Sand, well-rounded, coarse, grayish-brown, and streaks of gray shaly clay from 630 to 635 ft | 21 | 641 |
| Sand, poorly sorted, fine to very coarse, and 15–20 percent gravel, ¼–1 in. | 1 | 643 |
| Sand, fine to coarse; scattered pebbles and streaks of bluish-gray shaly clay and silt | 43 | 686 |
| Sand, medium to very coarse, and 15 percent well-rounded ¼–¾ in. gravel, streaks of greenish-blue clay | 3 | 689 |
| Sand, poorly sorted, fine to very coarse, gray | 12 | 701 |
| Sand, medium to coarse, gray, and 20 percent gravel, ¼–½ in.; some clay at 708 ft | 9 | 710 |
| Sand, medium to very coarse, grayish-brown | 25 | 735 |
| Sand, medium, grayish-brown; and gray platy clay | 5 | 740 |
| Sand, medium to coarse, grayish-brown; a few pieces of broken lava rock | 5 | 745 |
| Sand, very fine to medium, poorly sorted, grayish-brown | 35 | 780 |
| Sand, coarse to very coarse, grayish-brown; some angular pieces of volcanic origin at 780 and 787 ft | 15 | 795 |
| Sand, medium to coarse, poorly sorted, grayish-brown | 12 | 807 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–10–23)31bbb1—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, medium, gray; 20–25 percent ¼–1 in. gravel and a few gray clay balls | 2 | 809 |
| Sand, medium to coarse, well-rounded, gray; silt and clay at 816 ft; and a few subangular volcanics at 820 ft | 9 | 818 |
| Sand, very coarse, gray; 15 percent, ¼–4 in., angular gravel | 2 | 820 |
| Sand, very coarse, gray; some fine sand and gray silt | 15 | 835 |
| Sand, well-rounded, medium; some gray silt and a few gray clay balls at 805–850 ft | 25 | 860 |
| Sand, fine to medium, gray; contains more silt than preceding beds; poorly sorted, fairly well rounded | 20 | 880 |
| Sand, medium to coarse, gray; silt and gray clay balls with a few large angular pieces of rock | 2 | 882 |
| Sand, medium to coarse, gray; more fine particles than in bed above; few gray clay balls from 885 to 890 ft | 8 | 890 |
| Sand, fine to medium, gray, subangular to fairly well rounded; very few coarse grains | 25 | 915 |
| Sand, fine, moderate-yellowish-brown, angular to rounded; contains a few rounded pebbles ¼–1 in. and some angular pebbles of volcanic rocks. Carbonized wood at 939 ft | 25 | 940 |
| Sand, fine to medium, dark-yellowish-brown, subangular to rounded; about 5 percent granule gravel, rounded | 5 | 945 |
| Sand, fine to medium, moderate-yellowish-brown, and greenish-gray clay balls | 5 | 950 |
| Sand, fine to medium, light-brown, subangular, fairly well sorted | 10 | 960 |
| Sand, fine, fairly well sorted, subangular, pale-yellowish-brown; a few yellowish-brown clay balls | 5 | 965 |
| Sand, fine, fairly well sorted, subangular, pale-yellowish-brown; a few yellowish-brown clay balls; contains a few rounded pebbles ½–1 in. | 10 | 975 |
| Sand, fine to medium, subangular, pale-yellowish-brown, fairly well sorted; some $CaCO_3$ cementation and a few angular pebbles of volcanic rocks | 10 | 895 |
| Sand, fine to medium, subangular, pale-yellowish-brown, fairly well sorted; about 20 percent light-gray platy clay | 5 | 990 |
| Sand, fine to medium, subangular, pale-yellowish-brown, fairly well sorted; about 20 percent light-gray platy clay; a few subangular pebbles of volcanic rocks | 10 | 1,000 |
| **Well (C–10–23)36ddd** [U.S. Bureau of Reclamation test well CH–22YM on "Upper Mesa." Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett of Bureau of Reclamation. Well point installed at end of 2-in. pipe at a depth of 209–211 ft. Altitude 285 ft] | | |
| Older alluvium, undivided: | | |
| Sand, fine, light-brown, poorly graded; scattered gravel | 7 | 7 |
| Gravel, fine to coarse, well-graded, ½–1½ in., a few 3 in. Well-rounded to subrounded clasts of volcanic rocks granite and quartzite (amber and purple) | 47 | 54 |
| Gravel and sand, interbedded | 3 | 57 |
| Sand, fine, poorly graded; scattered gravel | 11 | 68 |
| Sand, fine, and thin layers of fat light-grayish-brown calcareous clay | 6 | 74 |
| Sand, fine, poorly graded | 29 | 103 |
| Sand, fine, poorly graded; a few thin layers of coarse sand and fine gravel. Well-rounded to subrounded clasts of volcanic rocks, granite, and quartzite | 107 | 210 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–10–24)1bdd1** [U.S. Bureau of Reclamation test well CH–1 on east edge of Yuma Valley, at foot of Yuma Mesa escarpment. Drilled with cable-tool equipment by San Diego Well Drillers. Log by Bureau of Reclamation, modified by F. H. Olmsted on basis of gamma log. Casing perforated from 144 to 170 ft. Altitude 110 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, very fine to medium; a few thin streaks of silty clay | 25 | 25 |
| Sand and brown silty clay with black streaks | 3 | 28 |
| Sand, fine to medium | 6 | 34 |
| Sand and brown silty clay | 2 | 36 |
| Sand, fine to medium; a few thin (¼–2 in.) beds of silt, clay, and clayey sand | 51 | 87 |
| Clay, sandy and silty | 2 | 89 |
| Sand, fine to coarse; few thin beds of silty clay and about 2–3 percent pebbles | 23 | 112 |
| Sand, clayey | 4 | 116 |
| Sand, fine to coarse, and about 10 percent gravel up to 3 in. | 25 | 141 |
| Coarse-gravel zone: | | |
| Gravel containing well-rounded cobbles up to 8 in.; about 25–30 percent sand | 40 | 181 |
| Coarse-gravel zone(?): | | |
| Sand, fine to coarse; beds of gravel (25 percent) | 24 | 205 |
| Gravel containing 30–40 percent sand and a higher percentage of mafic rocks than gravel from 141 to 181 ft | 5 | 210 |
| Sand, fine to coarse, and gravel up to 2 in. | 17 | 227 |
| Wedge zone: | | |
| Sand, fine to coarse, and about 5 percent scattered granules up to ¼ in. | 23 | 250 |
| Sand, fine to coarse, containing pieces of silty clay | 15 | 265 |
| Sand, fine to coarse, containing angular granules and pebbles up to 2 in. composed of volcanic rocks | 15 | 280 |
| Sand, very fine to medium, containing layers of cemented gravel 3–6 in. thick | 20 | 300 |
| Sand, fine to medium; some silt and clay, scattered granules and pebbles | 13 | 313 |
| Sand, fine to medium | 19 | 332 |
| Sand, fine to coarse; some silt and clay and 3–4 percent gravel | 43 | 375 |
| Clay, very hard | 1 | 376 |
| Sand, fine to coarse, containing layers of clay 3–4 in. thick and 2–3 percent gravel | 19 | 395 |
| Sand, fine to coarse; some silt and 5–8 percent gravel | 10 | 405 |
| Sand, fine to coarse; some silt, clay, and cemented sand | 10 | 415 |
| Sand, fine to coarse; silt and clay; contains more clay than bed above | 10 | 425 |
| Sand, fine to coarse; 2–3 percent gravel; some cemented sand and a few pieces of light-gray sandy clay | 25 | 450 |
| Sand, fine to coarse; some silt and clay | 35 | 485 |
| Sand, fine to coarse; 2–3 percent gravel and some poorly cemented sand | 15 | 500 |
| **Well (C–10–24)5ddd** [U.S. Bureau of Reclamation test well CH–2 in Yuma Valley. Drilled with cable-tool equipment by San Diego Well Drillers. Log by Bureau of Reclamation; modified by F. H. Olmsted on basis of gamma log. Casing perforated from 170 to 215 ft. Altitude 100 ft] | | |
| Upper, fine-grained zone: | | |
| Silt, sandy, and clay, brown | 13 | 13 |
| Sand, fine to medium; scattered pebbles in lower part | 73 | 86 |
| Silt, brown, containing a few granules and small pebbles | 4 | 90 |
| Clay, silty, brown; some gray clay | 6 | 96 |
| Silt, brown | 12 | 108 |
| Sand, fine to coarse; a few thin layers of silty clay; scattered pebbles below 120 ft | 59 | 167 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-10-24)5ddd—Continued** | | |
| Coarse-gravel zone: | | |
| Gravel; some fine to coarse sand | 13 | 180 |
| Sand, fine to medium; pieces of wood at 180 ft | 18 | 198 |
| Gravel, rounded cobbles up to 6 in.; some sand | 22 | 220 |
| Clay, silty | 1 | 221 |
| Gravel containing cobbles up to 8 in.; some sand | 31 | 252 |
| Wedge zone: | | |
| Sand, fine to coarse; some pebbles up to 1½ in. | 23 | 275 |
| Sand, fine to coarse; few thin beds of cemented gravel | 29 | 305 |
| Sand, fine to coarse, and 10–15 percent cemented gravel with angular pebbles up to 2 in. | 13 | 318 |
| Sand, fine to coarse; little gravel in thin cemented layers | 40 | 358 |
| Sand, fine to coarse, and 20 percent gravel up to 3 in. | 5 | 363 |
| Sand, fine to coarse; some gravel in thin cemented layers | 137 | 500 |

**Well (C-10-24)13bcc1**

[U.S. Bureau of Reclamation test well YVI-27(P) in Yuma Valley. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by F. Mamaril and E. L. Smith of Bureau of Reclamation. Well point installed at a depth of 168–170 ft on end of 1½ in. pipe. Altitude 101.0 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Clay | 15 | 15 |
| Sandy clay, sand lenses | 15 | 30 |
| Clay | 4 | 34 |
| Sand, with clay lenses | 36 | 70 |
| Sand, pebbly, ⅓ in. maximum | 27 | 97 |
| Clay, with sand lenses 2 or 3 in. thick | 23 | 120 |
| Sand, few gravel and clay lenses | 29 | 149 |
| Gravel, sand lens 156 to 157 feet | 9 | 158 |
| Gravel, cobbles, and sand | 22 | 180 |
| Sand, occasional gravel | 23 | 203 |

**Well (C-10-24)16baa2**

[Western Cotton Co. Industrial well in Yuma Valley. Drilled with cable-tool equipment by Arizona Machine and Welding Works. Casing perforated from 112 to 180 ft. Altitude 100 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand | 46 | 46 |
| Clay and wood, sandy | 12 | 58 |
| Sand | 17 | 75 |
| Clay | 35 | 110 |
| Sand | 8 | 118 |
| Clay | 20 | 138 |
| Coarse-gravel zone: | | |
| Rock and sand | 60 | 198 |
| Clay | 8 | 206 |
| Rock and sand | 19 | 225 |
| Gravel and sand | 25 | 250 |
| Wedge zone: | | |
| Sand | 25 | 275 |
| Clay | 12 | 287 |
| Sand | 13 | 300 |
| Rock and gravel | 5 | 305 |
| Sand | 118 | 423 |

**Well (C-10-24)23ddd**

[U.S. Bureau of Reclamation test well CH-17 YM on Yuma Mesa. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett of Bureau of Reclamation; modified from a depth of 0 to 192 ft by F. H. Olmsted on basis of gamma log. Below 192 ft, interpretation of gamma log does not correspond to geologist's log, as indicated below. Well point installed on end of 1½-in. pipe at depth of 428 to 430 ft; later removed and reset at 198 to 200 ft. Altitude 166.9 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, fine, light-brown; scattered pebbles of volcanic rocks and quartzite | 19 | 19 |
| Clay, calcareous, reddish-brown | 2 | 21 |
| Sand, fine; scattered medium and coarse sand | 23 | 44 |
| Clay, calcareous, reddish-brown | 14 | 58 |
| Sand, fine to coarse | 4 | 62 |
| Sand and fine gravel | 7 | 69 |
| Sand, fine to coarse | 4 | 73 |
| Sand and fine gravel | 4 | 77 |
| Sand, fine to coarse | 3 | 80 |
| Clay, calcareous, reddish-brown | 9 | 89 |
| Sand, fine to medium; some silt, and scattered fine to 2-in. pebbles of volcanic rocks | 19 | 108 |
| Sand and fine volcanic gravel | 7 | 115 |
| Sand, fine to coarse | 7 | 122 |
| Gravel | 1 | 123 |
| Sand, fine to coarse | 5 | 128 |
| Gravel | 3 | 131 |
| Sand, fine, medium-brown; scattered pebbles | 35 | 166 |
| Coarse-gravel zone: | | |
| Gravel, subangular to well-rounded, up to 3 in., predominantly quartzite, quartz, and granitic rocks, some volcanic rocks and sandstone | 17 | 183 |
| Sand and gravel | 5 | 188 |
| Gravel, subangular to well-rounded, up to 3 in., predominantly quartzite, quartz, and granitic rocks, some volcanic rocks and sandstone | 4 | 192 |
| (Gamma log indicates lower gamma intensity from 192 to 278 ft, then generally high intensity below 278 ft.) | | |
| Gravel (geologist's log) | 51 | 243 |
| Wedge zone: | | |
| Sand and gravel, interbedded | 8 | 251 |
| Sand, fine, some medium and coarse; small amount of gravel, and traces of gray, limy clay and hard-brown clay | 95 | 347 |
| Gravel, fine to 1 in.; thin layers of sand from 359 to 362 ft | 18 | 365 |
| Sand, fine, gray; traces of white limy material and gray clay. Scattered fine gravel from 412 to 419 ft | 54 | 419 |
| Gravel, fine to 1½ in.; pebbles predominantly granitic rocks and quartz, with few volcanic rocks | 19 | 438 |
| Sand, fine, poorly graded; thin beds of fine gravel at 441 and 450 ft | 17 | 455 |
| Sand and gravel, interbedded | 7 | 462 |

**Well (C-10-24)30baa**

[U.S. Geological Survey auger test well in southern Yuma Valley. Drilled with truck-mounted power auger by Geological Survey. Log by G. R. Vaughan; modified by F. H. Olmsted on basis of gamma log. Well point installed on end of 1½-in. pipe at a depth of 183 to 185 ft. Altitude 93 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Clay and silt, brown | 10 | 10 |
| Sand, fine, brownish-gray | 38 | 48 |
| Sand and silt, gray | 12 | 60 |
| Sand, gray | 5 | 65 |
| Sand and silt, gray | 19 | 84 |
| Sand, gray | 16 | 100 |
| Clay and sand | 6 | 106 |
| Sand | 14 | 120 |
| Gravel | 4 | 124 |
| Sand, some pebbly zones | 26 | 150 |
| Sand and gravel | 8 | 158 |
| Coarse-gravel zone: | | |
| Gravel, coarse | 20 | 178 |
| Sand | 5 | 183 |
| Gravel, coarse | 4 | 187 |

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*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–10–25)1bba** | | |
| [P. R. Sibley. Irrigation well in Yuma Valley. Drilled with cable-tool equipment by Frank H. Leidendeker. Casing perforated from 160 to 180, 195 to 205, and 250 to 285 ft. Altitude 106 ft] | | |
| Upper, fine-grained zone: | | |
| Soil | 2 | 2 |
| Clay | 2 | 4 |
| Sand | 3 | 7 |
| Clay, soft, sticky | 10 | 17 |
| Clay and sand strata | 22 | 39 |
| Clay, tough, sticky | 24 | 63 |
| Sand, clay, some sharp gravel | 23 | 86 |
| Quicksand | 10 | 96 |
| Quicksand and clay strata | 9 | 105 |
| Sand with approximately 10 percent gravel | 10 | 115 |
| Clay, hard | 11 | 126 |
| Clay, soft, sandy | 22 | 148 |
| Coarse-gravel zone: | | |
| Gravel in silted sand | 5 | 153 |
| Gravel, sandy | 3 | 156 |
| Gravel, good water | 19 | 175 |
| Quicksand | 12 | 187 |
| Gravel and sand strata | 18 | 205 |
| Sand with scattered pebbles | 8 | 213 |
| Sand | 4 | 217 |
| Sand with pebbles | 17 | 234 |
| Sand, packed, gravel, and clay | 3 | 237 |
| Sand and pebbles | 3 | 240 |
| Gravel, sandy | 4 | 244 |
| Gravel, good water | 35 | 279 |
| Wedge zone: | | |
| Sand, packed | 16 | 295 |
| **Well (C–10–25)23add** | | |
| [U.S. Geological Survey auger test well in Yuma Valley. Drilled with truck-mounted power auger by Geological Survey. Log by G. R. Vaughan. Well point installed on end of 1¼-in. pipe at a depth of 185.7 to 187.7 ft. Altitude 97 ft] | | |
| Upper, fine-grained zone: | | |
| Clay and silt | 27 | 27 |
| Sand and silt, clay streak at 81 ft | 99 | 126 |
| Clay | 3 | 129 |
| Sand and silt | 26 | 155 |
| Gravel, small; with sand and silt | 9 | 164 |
| Coarse-gravel zone: | | |
| Gravel, heavy, with sand | 28 | 192 |
| **Well (C–10–25)35bbd** | | |
| [U.S. Geological Survey test well LCRP 17 on east bank of Colorado River in southwestern Yuma Valley. Drilled with mud-rotary equipment by Roscoe Moss Co. Log by F. H. Olmsted, F. J. Frank, J. H. Robison, and G. R. Vaughan Gravel packed and cased to 1,988 ft; casing perforated from 520 to 1.998 ft, with a blank section from 1,398 to 1,438 ft. Altitude 94 ft] | | |
| Upper, fine-grained zone: | | |
| Sand and silt, some clay, gastropods, and carbonized wood | 71 | 71 |
| Sand and gravel, some silt and clay | 103 | 174 |
| Coarse-gravel zone: | | |
| Gravel, coarse, probably somewhat cemented | 32 | 206 |
| Sand, some gravel | 25 | 231 |
| Gravel, coarse, probably cemented, at least in part | 45 | 276 |
| Wedge zone: | | |
| Sand and gravel | 30 | 306 |
| Gravel, coarse, probably cemented in part | 44 | 350 |
| Sand, some coarse gravel beds | 58 | 408 |
| Gravel, coarse, probably cemented in part | 64 | 472 |
| Sand, some gravel | 122 | 594 |
| Gravel, fine to medium, cemented in part | 50 | 644 |
| Sand, some gravel; a few thin beds of silt and cemented gravel | 203 | 847 |
| Silt, clayey, in two thin beds, with sand between them | 12 | 859 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–10–25)35bbd—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, some gravel; a few thin beds of silt and cemented gravel | 171 | 1,030 |
| Silt | 8 | 1,038 |
| Sand, some silt and fine gravel | 394 | 1,432 |
| Clay | 2 | 1,434 |
| Sand, compact, silty and pebbly; thin clay beds at depths of 1,520, 1,688, 1,692, 1,750, 1,778, 1,920, and 1,934 ft | 556 | 1,990 |
| Clay | 10 | 2,000 |
| Sand, compact; and cemented gravel | 30 | 2,030 |
| Sand, silty; a few thin beds of cemented gravel | 27 | 2,057 |
| Clay, silty | 3 | 2,060 |
| Sand and thin beds of grayish-white compact silt | 30 | 2,090 |
| Sand, silty, and thin beds of cemented gravels | 57 | 2,147 |
| Silt, clayey | 3 | 2,150 |
| Sand, silt, and thin beds of clay and cemented gravel | 50 | 2,200 |
| Sand, compact; and cemented gravel | 12 | 2,212 |
| Clay | 8 | 2,220 |
| Silt and sand | 13 | 2,233 |
| Clay | 5 | 2,238 |
| Sand, compact, silty; thin beds of clay | 62 | 2,300 |
| Sand, silty | 42 | 2,342 |
| Clay, silty | 6 | 2,348 |
| Sand, compact; thin beds of cemented sand and gravel | 67 | 2,415 |
| Clay, silty | 2 | 2,417 |
| Sand, thin beds of silt and silty clay | 97 | 2,514 |
| Transition zone(?): | | |
| Clay | 6 | 2,520 |
| Sand, some cementation; some silt | 154 | 2,674 |
| Clay | 2 | 2,676 |
| Sand, silty; and thin cemented beds | 52 | 2,728 |
| Clay | 2 | 2,730 |
| Sand, silty; and thin cemented streaks | 74 | 2,804 |
| Clay | 2 | 2,806 |
| Sand, silty; and a few thin lenses of cemented gravel | 12 | 2,818 |
| Clay | 4 | 2,822 |
| Sand, silt, and thin beds of clayey silt | 30 | 2,852 |
| Sand and some silt and cementation | 40 | 2,892 |
| Clay | 8 | 2,900 |
| Sand, silt, and thin lenses of silty clay | 46 | 2,946 |
| **Well (C–11–21)4ddc** | | |
| [U.S. Bureau of Reclamation test well CH–9 YM on "Fortuna Plain" (Yuma Desert). Drilled with mud-rotary equipment by Bureau of Reclamation. Log by J. Granchi of Bureau of Reclamation. Cased to 350 ft; perforated from 293.5 to 328.5 ft. Altitude 403.3 ft] | | |
| Older alluvium, undivided: | | |
| Sand, fine, grayish-tan; lower 2 ft lime cemented | 3 | 3 |
| Sand, fine to medium, silty and clayey, tan; scattered angular to rounded pebbles composed predominantly of volcanic and granitic rocks, a few metamorphic rocks | 7 | 10 |
| Sand, medium to coarse, some fine, tan to grayish-brown. Thin beds of tan and reddish-brown clay | 27 | 37 |
| Sand, cemented, fine to coarse, grayish-tan; of granitic and volcanic composition | 12 | 49 |
| Clay, hard, chocolate-brown; a few angular to subrounded clasts of granitic and volcanic rocks | 5 | 54 |
| Sand, cemented, fine to coarse, grayish-brown; fine gravel | 4 | 58 |
| Gravel, fine to medium; abundant metamorphic and basaltic rocks; some medium to coarse gray and brown sand | 11 | 69 |
| Clay, reddish-brown | 4 | 73 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-11-21)4ddc—Continued** | | |
| Older alluvium, undivided—Continued: | | |
| Sand, fine to coarse, grayish-tan; a few cemented layers. Scattered pebbles; a few thin layers of light-grayish-brown clay | 27 | 100 |
| Sand, fine to coarse, grayish-tan, loose | 10 | 110 |
| Sand, predominantly fine to medium, grayish-tan; scattered granules and pebbles of volcanic rocks; few thin beds of grayish-brown limy clay | 51 | 161 |
| Clay, hard, reddish-brown | 2 | 163 |
| Sand, predominantly fine to medium, grayish-tan; scattered granules and pebbles of volcanic rocks; few thin beds of grayish-brown limy clay | 12 | 175 |
| Gravel, cemented | 3 | 178 |
| Sand, medium to coarse, grayish-tan to grayish-brown; occasional streaks of fine gravel | 28 | 206 |
| Sand, fine to medium, limy, and light-grayish-brown clay, possibly in thin layers or lenses | 30 | 236 |
| Sand and fine gravel, cemented | 2 | 238 |
| Sand, fine to medium, limy, and light-grayish-brown clay, possibly in thin layers or lenses | 4 | 242 |
| Clay, limy, light-grayish-brown and gray | 14 | 256 |
| Sand, medium to coarse, grayish-brown; scattered volcanic granules and pebbles | 20 | 262 |
| Sand, lime-cemented | 2 | 264 |
| Sand and scattered gravel, medium to coarse, grayish-brown; scattered volcanic granules and pebbles | 21 | 285 |
| Clay, sandy, limy, tuffaceous; a few subrounded to rounded granules and small pebbles | 13 | 298 |
| Sand, fine to medium, limy, grayish-brown to gray; scattered granules and pebbles, a few streaks of grayish- and reddish-brown clay | 4 | 302 |
| Sand, consolidated, limy and ashy | 4 | 306 |
| Gravel, fine, and coarse cemented sand | 1 | 307 |
| Sand, fine to medium, limy, grayish-brown to gray; scattered granules and pebbles, a few streaks of grayish- and reddish-brown clay | 13 | 320 |
| Sand, fine to medium, clayey, limy, tuffaceous, gray to light-grayish-tan; some coarse sand, and a few layers of light-grayish- and reddish-brown clay | 53 | 373 |
| **Well (C-11-22)24bab** | | |
| [U.S. Bureau of Reclamation test well CH-27 YM on "Upper Mesa." Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett of Bureau of Reclamation. Well point installed on end of 2-in. pipe at a depth of 268-270 ft. Altitude 322.3 ft. | | |
| Older alluvium, undivided: | | |
| Sand, fine, light-brown, poorly graded; scattered pebbles | 6 | 6 |
| Clay, calcareous, light-reddish-brown; interbeds of coarse sand and fine gravel consisting of subrounded to well-rounded clasts of chert, quartzite, and granitic and volcanic rocks | 8 | 14 |
| Sand, fine, well-graded; numerous thin layers of fine to coarse sand and fine gravel | 36 | 50 |
| Gravel, predominantly fine, some coarse; pebbles consist of subrounded to well-rounded amber and black chert, amber to white quartzite, granitic and volcanic rocks. Small amount of cemented sand | 14 | 64 |
| Sand, fine, poorly graded; scattered pebbles | 30 | 94 |
| Sand, fine; thin layers of light-brown clay; small amount of fine gravel and cemented sand | 4 | 98 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-11-22)24bab—Continued** | | |
| Older alluvium, undivided—Continued: | | |
| Clay, light-brown; small amount of fine gravel | 1 | 99 |
| Sand, fine, poorly graded; scattered pebbles and occasional trace of clay | 8 | 107 |
| Gravel, predominantly fine; similar in composition to gravels above; few thin layers of fine sand, some cemented | 11 | 118 |
| Sand, fine, poorly graded; scattered granules and small pebbles; occasional trace of clay | 14 | 132 |
| Gravel, predominantly fine; thin layers of cemented sand (calcareous) | 4 | 136 |
| Sand, fine, poorly graded; thin cemented layers at intervals of about 10 feet; occasional silt | 134 | 270 |
| **Well (C-11-23)34bbc** | | |
| [U.S. Geological Survey test well LCRP 30 on Yuma Mesa at southerly international boundary. Drilled with mud-rotary equipment by Desert Water Drilling Co. Log by J. H. Robison. Well cased and gravel packed to 600 ft; perforated from 160 to 600 ft. Altitude 163.0 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, very fine to coarse, silty; some very fine angular gravel. Few pieces brown clay | 53 | 53 |
| Sand, very fine to coarse | 19 | 72 |
| Coarse-gravel zone: | | |
| Gravel, very fine to coarse (pebbles and chips to 25 mm), with fine to very coarse sand. Gravel is subangular to subrounded, has relatively high percentage of tuffs and other light volcanic types. Partly cemented. (Coarse and very loose, 109-115 ft; cemented, 119-124 ft) | 58 | 130 |
| Gravel, very fine to coarse, and fine to very coarse sand. Somewhat finer and less cemented than previous interval | 12 | 142 |
| Sand, fine to very coarse. Small amount of brown silt, silty clay, and very fine gravel | 48 | 190 |
| Gravel, very fine to medium, and fine to very coarse sand. Gravel is subangular to subrounded, to 15 mm or larger; includes chert, quartzite, tuff, andesite, and granite | 12 | 202 |
| Sand, fine to very coarse. Small amount of very fine to fine gravel | 7 | 209 |
| Gravel, very fine to medium, and small amount of medium to coarse cemented sand. Gravel is subangular to rounded, pebbles and chips to 15 mm or larger. Includes granite, chert, quartzite, but less andesite than above, a very little tuff. Some of the quartzitic pebbles look typical of Colorado River deposits. | 23 | 232 |
| Sand, fine to very coarse, and very fine to medium gravel. Gravel similar to previous interval. Small amount of brown silt | 57 | 289 |
| Gravel, very fine to medium, and small amount of medium to very coarse sand. May be partly cemented, but very permeable | 12 | 301 |
| Gravel, very fine to medium, and fine to very coarse sand. Cemented | 9 | 310 |
| Wedge zone: | | |
| Sand, fine to very coarse; some very fine to medium gravel. Few thin layers of brown silt | 15 | 325 |
| Gravel, very fine to medium, and sand, medium to very coarse. Cemented | 35 | 360 |
| Sand, fine to very coarse; some very fine to medium gravel | 21 | 381 |
| Gravel, very fine to medium (10 mm or larger) and medium to very coarse | 28 | 409 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–11–23)34bbc—Continued** | | |
| Wedge zone—Continued: | | |
| Sand, fine to very coarse and some very fine to medium gravel. Small amount of brown silty clay. Fragments of carbonized wood below 442 ft | 57 | 466 |
| Sand, fine to very coarse. Some very fine to medium gravel | 30 | 496 |
| Sand, fine to very coarse. Small amount of very fine to medium gravel | 48 | 544 |
| Sand, fine to very coarse. Small amount of very fine to medium gravel and some brown clayey silt. Loose, uncemented | 79 | 623 |
| **Well (C–11–24)11ddd** | | |
| [Parker and others. Irrigation well on southern Yuma Mesa Drilled with cable-tool equipment by Hamilton and Hood. Casing perforated from 148 to 160 and 187 to 212 ft. Altitude 166 ft] | | |
| Upper, fine-grained zone: | | |
| Sand | 53 | 53 |
| Clay and gravel as much as 3 in. | 8 | 61 |
| Sand | 19 | 80 |
| Gravel as much as 3 in. | 1 | 81 |
| Clay, tough | 6 | 87 |
| Sand, cemented, and gravel | 5 | 92 |
| Sand | 9 | 101 |
| Clay, jointed, and gravel as much as 3 in. | 3 | 104 |
| Clay, tough | 24 | 128 |
| Silt and fine sand | 14 | 142 |
| Coarse-gravel zone: | | |
| Sand, medium, and gravel as much as 2½ in. | 20 | 162 |
| Sand, medium | 18 | 180 |
| Sand, medium, and gravel as much as 4½ in. | 32 | 212 |
| Sand, cemented, and sandstone strata | 47 | 259 |
| Large rocks imbedded in sandstone | 7 | 266 |
| **Well (C–11–24)23bcb** | | |
| [U.S. Geological Survey test well LCRP 10 on Yuma Mesa at southerly international boundary. Drilled with cable-tool equipment by Roscoe Moss Co. Log by F. H. Olmsted and F. J. Frank. Casing perforated at following depth intervals: 167–170, 190–202, 213–220, 240–250, 280–305, 320–325, 375–395, 405–425, 475–500, 520–545, 630–635, 643–648, 685–705, 855–875, and 985–1,002 ft. Altitude 160.8 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine to medium, some coarse moderate-yellowish-brown; grains subrounded to rounded, fairly well sorted | 27 | 27 |
| Sand, fine to coarse, moderate-yellowish-brown; some fine gravel, and streaks or pieces of silty clay | 26 | 53 |
| Clay, silty and sandy, moderate-brown | 3 | 56 |
| Sand, ill-sorted, clayey and silty; streaks of gravel and coarse sand | 6 | 62 |
| Sand, fine to medium; smaller amounts of silt, clay, and gravel | 17 | 79 |
| Sand, medium to coarse, some fine, grayish-orange | 14 | 93 |
| Sand, fine to coarse, moderate-yellowish-brown to grayish-orange; about 15–20 percent granule and pebble gravel, scattered small cobbles | 7 | 100 |
| Sand, fine to medium | 5 | 105 |
| Sand, medium to coarse, some fine, moderate--yellowish-brown; 10–30 percent fine to medium gravel, some of it well rounded; a little yellowish-brown clay | 19 | 124 |
| Sand, fine to medium | 7 | 131 |
| Sand, medium to coarse, moderate-yellowish-brown, pebbly | 7 | 138 |
| Sand, fine to medium | 4 | 142 |
| Sand, coarse, some fine to medium; about 30 percent subangular to rounded pebble gravel | 7 | 149 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C–11–24)23bcb—Continued** | | |
| Upper, fine-grained zone—Continued: | | |
| Sand, fine, and moderate-brown clay; scattered pebbles | 12 | 161 |
| Sand, coarse, pebbly, and streaks of ill-sorted sandy silt; some flat sandstone concretions | 9 | 170 |
| Sand, fine to medium, clean, well-sorted | 19 | 189 |
| Coarse-gravel zone: | | |
| Gravel, fine to coarse, subangular to rounded; medium to coarse sand, some sandstone concretions | 12 | 201 |
| Sand, fine to coarse; some gravel | 6 | 207 |
| Gravel, fine to coarse, sandy; some sandstone concretions | 18 | 225 |
| Sand and scattered pebbles | 10 | 235 |
| Gravel, sandy; similar in composition and size to gravels above | 14 | 249 |
| Sand, fine to coarse; scattered pebbles and sandstone concretions | 31 | 280 |
| Gravel, fine to coarse, subrounded to rounded; interbedded coarse gray sand | 51 | 331 |
| Wedge zone: | | |
| Sand, fine to medium, gray; some coarse sand and thin beds of pebbly sand; chunks of brown to gray clay and white sandstone concretions | 38 | 369 |
| Gravel, coarse, and varying amounts of gray sand | 16 | 385 |
| Sand and some gravel | 8 | 393 |
| Gravel, coarse, and varying amounts of gray sand | 16 | 409 |
| Sand, scattered pebbles and granules | 8 | 417 |
| Gravel, fine to medium; some coarse sand | 10 | 427 |
| Sand, fine to medium, gray | 4 | 431 |
| Sand and gravel | 6 | 437 |
| Sand, medium to coarse, gray; thin beds of gravel, in part cemented | 20 | 457 |
| Sand, fine, silty | 9 | 466 |
| Sand, fine to medium, clean | 5 | 471 |
| Gravel and sand, cemented(?) | 5 | 476 |
| Sand, medium to coarse; some pebbly zones | 11 | 487 |
| Gravel, fine to medium, subangular to rounded; abundant pebbles of chert and quartzite, as well as volcanic, plutonic, and metamorphic rocks; some sand | 37 | 524 |
| Sand, fine to coarse, gray; sparse granules and pebbles | 13 | 537 |
| Gravel, fine to medium; interbedded sand. Gravel contains abundant subangular to subrounded pebbles of granitic and silicic volcanic rocks | 43 | 580 |
| Sand, fine, somewhat silty, grayish-orange-pink | 7 | 587 |
| Sand, coarse, and granule gravel | 8 | 595 |
| Sand, fine to coarse, gray; thin beds of fine to medium gravel | 30 | 625 |
| Gravel, fine to coarse; thin beds of sand | 30 | 655 |
| Sand, fine to medium, a small amount coarse; sparse granules and pebbles | 29 | 684 |
| Sand and fine to coarse gravel, interbedded | 23 | 707 |
| Sand, fine to medium; scattered granules and pebbles and thin lenses or chunks of clay | 12 | 719 |
| Sand and thin beds of gravel; a few clay balls | 10 | 729 |
| Sand and fine to medium gravel | 8 | 737 |
| Sand, fine to medium; a few clay balls and sandstone concretions | 9 | 746 |
| Sand, fine, silty; some clay balls and sandstone concretions | 33 | 779 |
| Sand, fine to medium, clean | 10 | 789 |
| Sand, silt, and clay | 5 | 794 |
| Sand, fine to medium, clean | 9 | 803 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-11-24)23bcb—Continued** | | |
| Wedge zone—Continued: | | |
| Gravel, cemented (conglomerate) | 4 | 807 |
| Sand and some fine to medium gravel | 13 | 820 |
| Sand, fine to medium, gray, clean | 4 | 824 |
| Sand and gravel | 9 | 833 |
| Sandy, silty, fine; a few clay balls in lower part | 22 | 855 |
| Gravel, coarse; interbedded medium to coarse sand | 18 | 873 |
| Sand, silty, fine; scattered pebbles and pieces of clayey sandstone | 21 | 894 |
| Sand, fine to medium, gray | 9 | 903 |
| Sand, clayey sandstone, and fine gravel; small amount of wood | 20 | 923 |
| Sand, fine, silt, and sandy clay; scattered granules and pieces of carbonized wood | 57 | 980 |
| Sand, fine to coarse, and gravel, interbedded. Some zones cemented | 26 | 1,006 |
| Sand, fine, and thin beds of brown and gray clay | 7 | 1,013 |
| Clay, brown, pebbly, and sand | 14 | 1,027 |
| Sand, some fine gravel, and thin streaks of clay | 11 | 1,038 |
| **Well (C-12-21)14dab** | | |
| [U.S. Bureau of Reclamation test well CH-25YM near west edge of "Fortuna Plain," about 2 miles north of southerly international boundary. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett and E. Smith of Bureau of Reclamation. Well point installed at a depth of 367-369 ft. Altitude 422.2 ft] | | |
| Younger alluvium (alluvial-fan deposits): | | |
| Sand, fine, light-brown; intermixed white angular coarse granitic sand | 6 | 6 |
| Clay, sandy, calcareous, reddish-brown | 10 | 16 |
| Sand, fine, light-brown; intermixed white angular, coarse granitic sand | 2 | 18 |
| Clay, sandy, calcareous, reddish-brown | 9 | 27 |
| Sand, fine, light-brown; intermixed white angular coarse granitic sand | 11 | 38 |
| Clay, sandy, reddish-brown; streaks of coarse granitic sand | 3 | 41 |
| Sand, fine, light-brown; intermixed white angular coarse granitic sand; few thin seams of clay or silt | 18 | 59 |
| Clay, sandy, reddish-brown; streaks of coarse granitic sand | 3 | 62 |
| Sand, fine, silty, medium-brown | 10 | 72 |
| Clay, silty, medium-brown; little fine sand | 4 | 76 |
| Sand, fine, poorly graded | 3 | 79 |
| Clay, soft, calcareous, reddish-brown | 10 | 89 |
| Sand, silty, fine; little medium to coarse sand | 4 | 93 |
| Older alluvium: | | |
| Sand, fine; scattered granules of angular to well-rounded granite, chert, quartzite, and quartz; few thin layers or lenses of medium-brown to light-grayish-brown highly plastic fines | 8 | 101 |
| Sand, fine, poorly graded | 6 | 107 |
| Sand, fine to coarse, and some fine gravel similar in composition to that from 93 to 101 ft | 3 | 110 |
| Gravel, fine to coarse, predominantly subrounded to well-rounded, similar in composition to gravels above | 11 | 121 |
| Sand, fine, poorly graded; scattered granules and pebbles | 248 | 369 |
| **Well (C-12-21)17cbc** | | |
| [U.S. Bureau of Reclamation test well CH-23YM on "Upper Mesa" at southerly international boundary. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett of Bureau of Reclamation. Well point installed at a depth of 318-320 ft. Altitude 356 ft] | | |
| Older alluvium, undivided: | | |
| Sand, fine, light-brown; scattered granules and small pebbles of well-rounded quartzite and volcanic and granitic rocks | 4 | 4 |
| Gravel, similar in size and composition to that above; thin layers or lenses of reddish-brown clay | 7 | 11 |
| Sand, fine to coarse, and rounded pebbles and granules of quartzite and volcanic and granitic rocks | 10 | 21 |
| Gravel, fine, rounded | 12 | 33 |
| Sand, fine to coarse; layers or lenses of gravel | 11 | 44 |
| Sand, fine; layers or lenses of fine gravel at intervals of 3-10 ft; traces of reddish- to grayish-brown clay | 28 | 72 |
| Sand, fine; scattered gravel | 39 | 111 |
| Gravel, fine; similar in composition to that above, with black chert pebbles also | 5 | 116 |
| Sand, fine; scattered gravel | 17 | 133 |
| Sand and fine gravel, interbedded | 25 | 158 |
| Sand, fine; scattered gravel. More indurated or compacted below 235 ft | 162 | 320 |
| **Well (C-12-22)9bab** | | |
| [U.S. Geological Survey test well LCRP 24 on "Upper Mesa" at southerly international boundary. Drilled with cable-tool equipment by R. E. Anderson. Log by F. J. Frank, Rex Anderson, and F. H. Olmsted. Casing perforated from 318 to 324, 330 to 336, and 340 to 346 ft. Altitude 233.5 ft] | | |
| Older alluvium, undivided: | | |
| Soil, brown, sandy; some pebbles | 2 | 2 |
| Sand, pinkish-brown, tough, silty; gravelly lenses; white caliche throughout, gravels mostly rounded to subrounded and include quartzite, chert, and granitic, metamorphic, and volcanic rocks | 20 | 22 |
| Sand, light-brown, poorly sorted; with less than 5 percent well-rounded gravel | 4 | 26 |
| Sand, light-brown, medium to coarse, poorly sorted | 5 | 31 |
| Sand, brown; with 40 percent rounded to subrounded gravel composed of mostly chert and quartzite | 4 | 35 |
| Sand, brown, medium to coarse; poorly sorted with a few scattered quartzite and chert pebbles | 15 | 50 |
| Sand, brown, medium to coarse, poorly sorted; some cementation and thin lenses of sandstone | 30 | 80 |
| Sand, brown, medium to coarse | 13 | 93 |
| Sand, brown, medium to coarse; some small pebbles and granules | 1 | 94 |
| Gravel, with small amount of medium-brown sand; gravel mostly well-rounded quartzite and chert ¼-¾ in. | 6 | 100 |
| Gravel, with small amount of medium to coarse brown sand. Gravel includes well-rounded quartzite and chert as much as 3 in. with some subrounded gravel of local origin | 25 | 125 |
| Sand, brown, medium to coarse; with a few ¼-½ in. subrounded, subangular gravel | 46 | 171 |
| Sand, brown, fine; silty with a few scattered subangular ¼-in. gravel; some cementation | 62 | 233 |
| Clay, silty, reddish-brown to buff; coarse sand and a few subangular to angular metamorphic and volcanic pebbles | 2 | 235 |
| Silt and fine buff sand; some clay; cemented in part | 27 | 262 |
| Sand, medium, brown; with cementation and thin sandstone lenses; some pinkish-brown clay balls | 13 | 275 |
| Sand, medium, brown; some cementation | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well (C-12-22)9bab—Continued** | | |
| Older alluvium, undivided—Continued: | | |
| and thin lenses of sandstone; some clay balls and a few subangular pebbles of local origin | 20 | 295 |
| Sand, fine to medium, brown, somewhat cemented | 7 | 302 |
| Sand, medium to coarse, brown; some subrounded to subangular ¼–⅜-in. gravel; some cementation | 8 | 312 |
| Gravel and sand. Gravel subrounded to subangular, ¼–⅜ in., mostly granite and volcanic rocks with a few well-rounded pebbles of chert and quartzite; some cementation and about 50 percent brown medium to coarse sand | 12 | 324 |
| Sand, medium to coarse, brown, somewhat cemented | 6 | 330 |
| Sand and gravel; sand more than 50 percent; medium to coarse subangular ¼–1 in. gravel | 6 | 336 |
| Sand, medium to coarse, brown | 4 | 340 |
| Sand and gravel; gravel mostly granitic and volcanic, subangular to subrounded | 6 | 346 |
| Sand, medium, brown, with a few angular gravels | 20 | 366 |
| Clay and silt, buff | 4 | 370 |
| Sand, fine to medium, buff, somewhat cemented | 4 | 374 |
| Sand, very fine, silty, buff, somewhat cemented | 18 | 392 |
| Sand, fine to medium; well cemented in part, thin gray clay and 5–10 percent subangular to subrounded ¼–⅜-in. gravel. Gravel mostly granitic and volcanic, with a few well-rounded pebbles of chert and quartzite | 5 | 397 |
| Sand, fine to medium; a few thin lenses of gray silty clay | 18 | 415 |

**Well (C-13-20)2abd1**

[U.S. Bureau of Reclamation test well CH–28YM on "Fortuna Plain" at southerly international boundary. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by E. Burnett, J. W. Julian, and E. Smith. Well point set on end of 1¼-in. pipe at a depth of 1,198–1,200 ft. Another well point installed in same hole as well (C–13–20) 2abd2 at a depth of 598–600 ft. Altitude 577.5 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Older and younger alluvium, undifferentiated: | | |
| Sand, fine; few thin layers of clay from 0 to 21 ft; occasional thin layers or lenses of cemented sand below 62 ft | 95 | 95 |
| Clay, calcareous, medium-brown | 5 | 100 |
| Sand, fine; few thin layers of clay; occasional thin layers or lenses of cemented sand | 5 | 105 |
| Clay, calcareous, medium-brown; interbedded medium to coarse granitic sand | 10 | 115 |
| Sand, fine, predominantly quartz; abundant medium to coarse angular to subangular granitic sand; thin layers of cemented sand | 165 | 280 |
| Clay, silty, medium-brown; interbeds of fine to coarse granitic sand | 30 | 310 |
| Gravel, fine; consists of angular to well-rounded clasts of chert, quartzite, quartz and granitic and volcanic rocks; fine to coarse sand | 15 | 325 |
| Clay, brown, silty | 10 | 335 |
| Sand, fine to coarse; considerable amount of fine gravel | 45 | 380 |
| Clay, brown, silty | 5 | 385 |
| Sand and gravel, fine to coarse | 10 | 395 |
| Sand, fine; thin beds of light-brown sandy to silty clay | 50 | 445 |
| Clay, silty, light-brown | 5 | 450 |
| Sand, coarse | 10 | 460 |
| **Well (C-13-20)2abd1—Continued** | | |
| Older and younger alluvium, undifferentiated—Continued: | | |
| Sand, fine; little silt and clay | 175 | 635 |
| Clay, light-brown, silty | 5 | 640 |
| Sand, fine; little silt or clay | 35 | 675 |
| Clay, light-brown | 5 | 680 |
| Sand, fine | 20 | 700 |
| Clay | 5 | 705 |
| Sand, fine | 10 | 715 |
| Clay | 5 | 720 |
| Sand, fine | 5 | 725 |
| Clay | 5 | 730 |
| Sand, fine; cemented layer at 755 ft | 30 | 650 |
| Sand, fine; clay layers, thin cemented zones, and scattered fine gravel | 50 | 810 |
| Sand, fine; thin beds of clay; cemented layer at 810 ft | 60 | 870 |
| Sand, fine; thin beds of cemented fine sand from 870 to 880 ft, 890 to 895 ft, and at 940 ft; little silt or clay | 100 | 970 |
| Clay | 5 | 975 |
| Sand, fine; thin cemented layers at 1,015, 1,025, and 1,075 ft; little silt or clay | 110 | 1,085 |
| Claystone (probably calcareous) | 5 | 1,090 |
| Sand, fine; thin cemented layers at 1,145–1,150 ft; little silt or clay | 70 | 1,160 |
| Clay | 5 | 1,165 |
| Sand, fine | 5 | 1,170 |
| Clay | 5 | 1,175 |
| Sand, fine; little silt or clay | 40 | 1,215 |
| Clay | 5 | 1,220 |
| Sand, fine; more indurated (higher acoustic velocity) than materials above | 55 | 1,275 |
| Sand, coarse | 10 | 1,285 |
| Transition zone: | | |
| Sand, fine, clayey, bluish to greenish-gray | 20 | 1,305 |
| Clay, gray | 5 | 1,310 |
| Sand, fine, gray | 5 | 1,315 |
| Clay, gray | 5 | 1,320 |
| Sand, fine, clayey, gray; thin cemented layers at 1,320 ft, 1,360–1,365 ft, and 1,370 ft | 55 | 1,375 |
| Clay, gray | 10 | 1,385 |
| Sand, fine, clayey, gray; thin cemented layers at 1,385, 1,405, and 1,410 ft | 42 | 1,427 |

**Well 16S/21E-36Fca**

[Arizona Public Service Co., Industrial well in northwestern Yuma Valley. Drilled with cable-tool equipment by Roscoe Moss Co. Casing perforated from 518 to 560, 592 to 650, 706 to 740, 752 to 766, 864 to 880, and 904 to 912 ft. Altitude 117 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Topsoil | 4 | 4 |
| Clay, silty, water at 11 ft | 7 | 11 |
| Sand, fine, brown (quicksand action) | 28 | 39 |
| Clay, bluish, silty | 1 | 40 |
| Sand, bluish, fine, clay streaks, slow-draining | 65 | 105 |
| Silt, mixed, and clay with pebbles | 7 | 112 |
| Coarse-gravel zone: | | |
| Gravel, clean, possible clay layer 6 in. thick | 8 | 120 |
| Gravel, clean; fair gradation with rocks as much as 6 in. | 22 | 142 |
| Gravel and coarse sand; rocks as much as 2 in. | 10 | 152 |
| Wedge zone: | | |
| Sand, lightly cemented fine sand lumps, and some small gravel | 10 | 162 |
| Clay | 5 | 167 |
| Gravel, round and fractured, as much as 2 in.; brown dirty water | 3 | 170 |
| Gravel, small, round and fractured; lightly cemented sand laminae, 3 in. thick; piece hard to break | 14 | 184 |
| Sand, mixed; gravel with clay an ash; | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/21E-36Fca—Continued** | | |
| Wedge zone—Continued: | | |
| soft, slimy, possibly colloidal clay | 16 | 200 |
| Sand and pea gravel; some lightly consolidated sand streaks | 7 | 207 |
| Sand and gravel as much as 1½ in. | 8 | 215 |
| Sand, lightly cemented laminae, fine gravel, few shale particles | 10 | 225 |
| Sand; gravel as much as 1½ in.; brown silt | 10 | 235 |
| Sand, soft, some gravel, bluish | 15 | 250 |
| Sand; some gravel as much as 1½ in.; lightly consolidated sand laminae | 16 | 266 |
| Sand; some gravel, few large rocks at 280 ft | 14 | 280 |
| Sand, fine; thin consolidated clay streaks at 280 ft | 5 | 285 |
| Sand, fine | 9 | 294 |
| Firm clay strata with shale and gravel | 6 | 300 |
| Sand; some lightly cemented laminae | 10 | 310 |
| Sand, fine | 20 | 330 |
| Sand, mixed, and clay; some gravel | 4 | 334 |
| Sand, fine | 4 | 338 |
| Sand, lightly cemented laminae with few shale particles | 12 | 350 |
| Sand, medium; some clay balls at 335 ft | 10 | 360 |
| Sand, medium | 12 | 372 |
| Sand, medium, and loose gravel. Apparently good aquifer | 10 | 382 |
| Sand, medium, and gravel as much as 1½ in. | 6 | 388 |
| Sand; gravel and clay layer about 8 in. thick at 390 ft | 4 | 392 |
| Sand, coarse, and fine gravel | 6 | 398 |
| Sand, gray; some angular and rounded gravel with thin clay layers | 12 | 410 |
| Sand, medium; with very little gravel, some wood as lignite | 10 | 420 |
| Sand, gravelly; some clay, cemented silt and ash layer 6 in. thick at 420 ft | 4 | 424 |
| Sand, gravelly; some clay balls and silt | 6 | 430 |
| Sand; some gravel pieces of lignite at 475 ft | 44 | 474 |
| Clay layer preceded and followed by dirty clay and gravelly sand with cemented shales and gravel | 14 | 488 |
| Sand, fine; very little gravel | 10 | 498 |
| Sand, lightly cemented; some small gravel | 8 | 506 |
| Sand, coarse; well-graded angular gravel as much as 2 in. | 4 | 510 |
| Sand, coarse, and fine gravel | 8 | 518 |
| Sand, coarse, and small gravel, some 2 in. | 10 | 528 |
| Sand and small gravel with clay streaks | 10 | 538 |
| Sand; some small gravel | 22 | 560 |
| Sand, medium; very little gravel; few thin cemented sandy laminae | 24 | 584 |
| Sand, coarse; some small gravel | 16 | 600 |
| Sand, small amount of gravel, some clay | 10 | 610 |
| Sandy gravel as much as 2 in., mixed round and angular, clean | 12 | 622 |
| Gravel, sandy, clean; as much as 3 in.; few cemented conglomerate zones | 6 | 628 |
| Sand, coarse, and small gravel; good gradation | 4 | 632 |
| Gravel, sandy, sharp and clean; as much as 2 in.; firmly cemented sand layer 6 in. thick near 638 ft | 8 | 640 |
| Gravel, sandy; as much as 2 in.; streaks of hard clay and cemented sand laminae | 4 | 644 |
| Firm clay grading to sand and silt | 36 | 680 |
| Sand, mixed, and clay | 24 | 704 |
| Sand and small gravel | 4 | 708 |
| Sand and small gravel as much as 2 in. | 32 | 740 |
| Sand, gravel, and clay and cemented volcanic ash | 10 | 750 |
| Granite pieces, larger fractured, as much as 6 in. with sand | 2 | 752 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/21E-36Fca—Continued** | | |
| Wedge zone—Continued: | | |
| Gravel, mixed, loose; angular as much as 3 in., with sand and silt filler | 14 | 766 |
| Clay, firm; grades to softer mixed clay; fine silty sand | 30 | 796 |
| Sand and clay, mixed; very muddy | 16 | 812 |
| Sand, small gravel, and some clay | 8 | 820 |
| Clay with some sand and gravel | 8 | 828 |
| Clay with fine sand, very little gravel, quite muddy water | 12 | 840 |
| Clay and sand; increased amount of sand with small gravel, muddy water | 10 | 850 |
| Sand and small gravel | 4 | 854 |
| Sand and gravel as much as 2 in.; sand not sharp and only moderately clean | 16 | 870 |
| Sand with some fine gravel, increased amount of sand | 14 | 884 |
| Sand, medium | 16 | 900 |
| Sand and gravel as much as 2 in. | 12 | 912 |
| Sand with silt and clay | 12 | 924 |
| Silt, tight; with mixed clay and sand | 12 | 936 |
| Clay, silty red, some very firm | 8 | 944 |
| Clay, silty; with granite pieces as much as 2 in. | 4 | 948 |
| Granite detritus with clay and silt fill | 4 | 952 |
| Clay, firm, and brown silt | 12 | 964 |
| Silt and sand with cemented layers | 8 | 972 |
| Sand and gravel as much as 3 in.; granitic | 6 | 978 |

**Well 16S/22E-21Dbb**

[U.S. Bureau of Reclamation test well CH-14RD in western Bard Valley. Drilled with mud-rotary equipment by Bureau of Reclamation. Log by Granchi and Moffitt of Bureau of Reclamation; modified by F. H. Olmsted on basis of gamma, electric, and caliper logs. Well point installed on end of 1¼-in. pipe at a depth of 118-120 ft. Altitude 128.0 ft]

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| Upper, fine-grained zone: | | |
| Sand, fine, tan | 7 | 7 |
| Sand and brown clay | 15 | 22 |
| Sand, fine, brown | 14 | 36 |
| Clay, soft, reddish-brown | 3 | 39 |
| Sand, fine to coarse, dark-gray to brown; fine gravel composed of subangular to subrounded granite and quartzite clasts | 11 | 50 |
| Clay, soft, brown | 1 | 51 |
| Sand, fine; scattered granules and pebbles, chiefly quartzite | 51 | 102 |
| Sand, fine to coarse; fine gravel | 11 | 113 |
| Coarse-gravel zone: | | |
| Gravel, fine to coarse; composed of subangular to rounded granules, pebbles, and cobbles of granite, volcanic rocks, and quartzite; fine to coarse brown sand | 20 | 133 |
| Sand, fine to coarse, brown | 7 | 140 |
| Sand, pebbly | 2 | 142 |
| Sand, fine to coarse, brown | 14 | 156 |
| Sand, fine to coarse; some fine gravel | 5 | 161 |
| Sand, fine to medium, brown | 4 | 165 |
| Sand and gravel | 19 | 184 |
| Clay, dense, brown | 3 | 187 |
| Sand and gravel | 5 | 192 |
| Wedge zone(?): | | |
| Sand, fine to medium, brown | 31 | 223 |
| Clay, dense, brown | 7 | 230 |
| Sand, silty, grayish-brown | 7 | 237 |
| Sand, fine, grayish-brown | 12 | 249 |
| Silt, dense, gray | 2 | 251 |
| Sand, fine, grayish-brown | 19 | 270 |
| Sand, some gravel composed chiefly of granite and quartzite | 13 | 283 |
| Gravel | 3 | 286 |
| Sand, fine to coarse, gray | 8 | 294 |
| Sand and clay, interbedded; soft bluish to grayish-green clay | 16 | 310 |
| Sand, fine, brown | 14 | 324 |

*Selected logs of water wells*—Continued

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/22E–21Dbb—Continued** | | |
| Wedge zone(?)—Continued: | | |
| Sand, fine to coarse, pebbly | 28 | 352 |
| Sand, fine, brown | 8 | 360 |
| Sand, fine to coarse, pebbly | 16 | 376 |
| Sand, fine, brown | 12 | 388 |
| Sand, fine to coarse, pebbly | 8 | 396 |
| Sand, fine, brown | 6 | 402 |
| Sand, fine to coarse, pebbly; gravel more abundant below 415 feet | 17 | 419 |
| Sand, fine to medium, grayish-brown; scattered granules and pebbles | 21 | 440 |
| Clay, hard, and cobbles | 4 | 444 |
| Sand, fine to medium, some coarse, grayish-brown | 15 | 459 |
| Sand, medium to coarse, brown, and fine, well-rounded gravel | 14 | 473 |
| Sand, fine to medium, brown | 6 | 479 |
| Gravel, fine, well-rounded, and fine to coarse brown sand | 5 | 484 |
| Sand, silty, fine, and thin beds of bluish-gray clay | 6 | 490 |
| Sand, fine to coarse, brown, and fine gravel, interbedded | 17 | 507 |
| **Well 16S/22E–23Caa** | | |
| [U.S Bureau of Reclamation test well CH–8 in Bard Valley. Drilled with cable-tool equipment by E. McBride. Log by E. L. Smith of Bureau of Reclamation; modified by F. H. Olmsted on basis of gamma log. Casing perforated from 96 to 104 ft. Altitude 128.5 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine to coarse, light-brown (above 20 ft), and grayish-brown (below 20 ft); interbedded reddish-brown to dark-brown clay and silty sandy clay | 38 | 38 |
| Sand, fine to coarse; little reddish-brown clay; little gravel from 72 to 75 ft | 41 | 79 |
| Sand, gray, and 10–40 percent gravel containing abundant concretions of limy sandstone | 19 | 98 |
| Coarse-gravel zone: | | |
| Gravel, fine to 3 in., angular to well-rounded; about 35–40 percent coarse gray sand | 6 | 104 |
| Wedge zone: | | |
| Sand, fine to coarse, gray; scattered pebbles, and some beds of yellowish-green and brown clay and silt | 57 | 161 |
| Sand, gray, and gravel | 26 | 187 |
| Sand; little gravel | 7 | 194 |
| Sand and gravel | 26 | 220 |
| Sand; little gravel | 22 | 242 |
| Gravel, fine to 2 in., and gray sand | 14 | 256 |
| Sand, fine to coarse, gray; scattered granules and pebbles | 12 | 268 |
| Gravel and sand | 9 | 277 |
| Sand, fine, and scattered "pea" gravel | 17 | 294 |
| Gravel and sand; some cobbles and concretions of limy sandstone up to 8 in. | 26 | 320 |
| Sand, fine to medium, and about 40 percent fine to 1-in. subangular gravel | 8 | 328 |
| Bouse Formation(?): | | |
| Clay, silty, dark-gray | 3 | 331 |
| Sand, fine to medium, gray; moderately to firmly cemented | 1 | 332 |
| Clay, silty, dark-gray, partly calcareous; thin layers of cemented sand | 10 | 342 |
| Volcanic rocks (Tertiary?): | | |
| Basalt, fine-grained, dark-gray, slightly glassy; weathered and vesicular | 18 | 360 |

*Selected logs of water wells*—Continued

| Material | Thick-ness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/22E–29Gca2** | | |
| [U.S. Geological Survey test well LCRP 26 in western Bard Valley. Drilled with mud-rotary equipment by Kalco Development Co. Log by F. H Olmsted, F. J. Frank, and A. G. Hely. Well cased and gravel packed to 1,769 ft; perforated from 125 to 1,127 and 1,368 to 1,769 ft. Altitude 125.4 ft] | | |
| Upper, fine-grained zone: | | |
| Silt, brown | 7 | 7 |
| Sand, fine to medium, brown | 18 | 25 |
| Clay, silty, medium-brown | 10 | 35 |
| Sand, fine to medium, and grayish-brown silt | 11 | 46 |
| Clay, silty | 5 | 51 |
| Sand, grayish-brown | 18 | 69 |
| Silt, sand, and clay | 7 | 76 |
| Sand, grayish-brown | 8 | 84 |
| Silt, sand, and clay | 7 | 91 |
| Sand, grayish-brown | 19 | 110 |
| Sand; scattered granules and pebbles | 10 | 120 |
| Coarse-gravel zone: | | |
| Gravel, coarse, loose; contains abundant well-rounded pebbles and cobbles of siliceous rocks | 11 | 131 |
| Gravel, coarse to fine, and sand | 22 | 153 |
| Coarse-gravel zone(?): | | |
| Sand, silty, brown, soft | 3 | 156 |
| Gravel and sand, loose; subangular to well-rounded pebbles, cobbles, and granules of a wide variety of rocks including abundant quartzite and chert | 24 | 180 |
| Wedge zone (gravel similar in composition to that above): | | |
| Sand and gravel | 30 | 210 |
| Gravel and sand | 30 | 240 |
| Sand and gravel | 52 | 292 |
| Gravel and sand | 33 | 325 |
| Sand and gravel | 10 | 335 |
| Gravel and sand | 39 | 374 |
| Clay, silty | 2 | 376 |
| Sand and gravel | 20 | 396 |
| Gravel and sand | 14 | 410 |
| Sand and gravel | 23 | 433 |
| Sand, little gravel | 11 | 444 |
| Gravel and sand | 8 | 452 |
| Sand | 8 | 460 |
| Gravel and sand | 4 | 464 |
| Sand | 5 | 469 |
| Sand and gravel | 19 | 488 |
| Sand | 11 | 499 |
| Gravel and sand | 23 | 522 |
| Conglomerate (cemented gravel and sand) | 14 | 536 |
| Sand | 10 | 546 |
| Sand and gravel | 18 | 564 |
| Sand; scattered gravel | 24 | 588 |
| Gravel and sand | 11 | 599 |
| Sand, some gravel | 12 | 611 |
| Gravel and sand | 8 | 619 |
| Sand, some gravel | 27 | 646 |
| Gravel and sand | 25 | 671 |
| Silt, sand, and clay | 6 | 677 |
| Gravel and sand | 46 | 723 |
| Sand and silt | 20 | 743 |
| Sand, some gravel and silt | 40 | 783 |
| Sand and silt | 49 | 832 |
| Sand, some gravel | 42 | 874 |
| Sand and silt | 56 | 930 |
| Sand, some gravel; thin beds of clay | 16 | 946 |
| Gravel and sand | 20 | 966 |
| Sand, some gravel | 34 | 1,000 |
| Gravel and sand | 17 | 1,017 |
| Sand, some gravel | 16 | 1,033 |
| Transition zone: | | |
| Clay, silty, gray | 7 | 1,040 |
| Clay and sand, interbedded | 43 | 1,083 |
| Gravel and sand; some chert and quartzite granules and pebbles | 19 | 1,102 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/22E-29Gca2—Continued** | | |
| Transition zone—Continued: | | |
| Sand, fine to medium, gray | 13 | 1,115 |
| Bouse Formation: | | |
| Clay, silty, gray | 39 | 1,154 |
| Clay and fine to medium gray sand | 6 | 1,160 |
| Clay, silty, gray | 33 | 1,193 |
| Sand, fine to medium, and gray clay | 4 | 1,197 |
| Clay, silty, gray | 124 | 1,321 |
| Sand, fine to medium, gray, and silty clay | 7 | 1,328 |
| Clay, silty, gray | 15 | 1,343 |
| Tuff or ash(?) | 9 | 1,352 |
| Limestone, sandy | 28 | 1,380 |
| Nonmarine sedimentary rocks: | | |
| Conglomerate composed of pebbles, cobbles, and boulders of gneiss, granite, pegmatite, vein quartz, and other crystalline rocks; some beds of coarse, gritty sandstone | 285 | 1,665 |
| Boulder conglomerate or megabreccia: Blocks and boulders of crystalline rocks in an earthy sandstone matrix | 112 | 1,777 |
| **Well 16S/23E-2Dbd** | | |
| [D. W. Haygood. Irrigation well in Bard Valley, near west bank of Colorado River. Drilled with cable-tool equipment by Frank H. Leidendeker. Casing perforated from 115 to 153 ft. Altitude 140 ft] | | |
| Upper, fine-grained zone: | | |
| Clay with wood roots | 8 | 8 |
| Sand, silted | 10 | 18 |
| Clay, soft | 2 | 20 |
| Water sand and some sharp gravel | 25 | 45 |
| Quicksand with some gravel and clay streaks | 62 | 107 |
| Coarse-gravel zone: | | |
| Gravel, good | 33 | 140 |
| Gravel, small, coarse sand | 13 | 153 |
| Wedge zone: | | |
| Gravel, very sandy | 6 | 159 |
| **Well 16S/23E-8Ecc** | | |
| [U.S. Bureau of Reclamation test well CH-5 in Bard Valley. Drilled with cable-tool equipment by San Diego Well Drilers. Log by Bureau of Reclamation; modified by F. H. Olmsted on basis of gamma log. Casing perforated from 110 to 141 ft. Altitude 130 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, silt, and clay; 1-ft layer of black organic silt and clay at 10 ft | 11 | 11 |
| Sand, fine, light-brown, grading downward into fine gray sand | 26 | 37 |
| Clay, brown, silty, and fine sand | 3 | 40 |
| Clay, pebbly | 1 | 41 |
| Clay, brown, silty, and fine sand; also layers of gray silty clay; scattered pebbles in lower part | 19 | 60 |
| Sand, fine, gray | 5 | 65 |
| Clay, brown, silty, and fine sand; scattered pebbles | 12 | 77 |
| Sand, fine, varicolored; scattered pebbles and small cobbles up to 4 in., and a few lenses of clay | 32 | 109 |
| Coarse-gravel zone: | | |
| Gravel containing rounded pebbles and cobbles up to 4 in.; 30–40 percent fine to coarse sand; more sand in lowest several feet | 39 | 148 |
| Wedge zone: | | |
| Sand, fine to coarse; silt, clay, and scattered fine gravel | 18 | 166 |
| Sand, fine to coarse, and fine gravel. Below 166 ft the materials are characterized by higher gamma radiation than those above; this is probably due to a high percentage of both clay and gravel to coarse sand containing abundant silicic volcanic and granitic rocks | 13 | 179 |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/23E-8Ecc—Continued** | | |
| Wedge zone—Continued: | | |
| Sand | 5 | 184 |
| Sand, locally cemented; streaks of gravel | 18 | 202 |
| Gravel and sand | 7 | 209 |
| Sand; some gravel and silty clay | 4 | 213 |
| Sand, fine to coarse, and angular to subangular gravel up to 1½ in. | 19 | 232 |
| Gravel, granules and pebbles, up to 2 in.; sand | 17 | 249 |
| Sand and scattered granules and pebbles | 7 | 256 |
| Sand and gravel up to 2 in. | 35 | 291 |
| Sand, fine | 9 | 300 |
| Gravel containing pebbles up to 3 in.; 40 percent sand | 13 | 313 |
| Sand, fine; about 5 percent pebbles | 21 | 334 |
| Sand and angular granules and pebbles; about 10 percent cobbles; some zones contain little gravel | 78 | 412 |
| Gravel, up to 3 in., and sand | 40 | 452 |
| Sand, fine to coarse; 5–8 percent gravel | 28 | 480 |
| Sand, gravel, and carbonized wood | 10 | 490 |
| Sand, coarse; contains a few angular pebbles | 10 | 500 |
| **Well 16S/23E-9Naa** | | |
| [M. E. Spencer. Irrigation well in Bard Valley. Drilled with cable-tool equipment by Frank H. Leidendeker. Casing perforated from 124 to 150, 154 to 164, 198 to 204, 205 to 217, and 218 to 225 ft. Altitude 137 ft] | | |
| Upper, fine-grained zone: | | |
| Soil | 4 | 4 |
| Clay | 1 | 5 |
| Sand, silt, and clay mixed | 2 | 7 |
| Sand, silted | 30 | 37 |
| Clay, sand with pebble strata | 28 | 65 |
| Sand and clay strata | 13 | 78 |
| Quicksand | 9 | 87 |
| Clay and gravel in sand | 10 | 97 |
| Gravel, sandy | 6 | 103 |
| Sand | 11 | 114 |
| Coarse-gravel zone: | | |
| Gravel | 36 | 150 |
| Wedge zone: | | |
| Sand | 2 | 152 |
| Sand, coarse, and fine pea size gravel | 12 | 164 |
| Sand, some pebbles | 14 | 178 |
| Gravel, sandy | 3 | 181 |
| Clay | 1 | 182 |
| Sand and some gravel | 6 | 188 |
| Sand, coarse, and pea size gravel | 16 | 204 |
| Sand, some pebbles | 6 | 210 |
| Gravel, sandy | 8 | 218 |
| Gravel, not too large | 7 | 225 |
| Sand, some pebbles | 1 | 226 |
| Sand | 9 | 235 |
| **Well 16S/23E-10Rcc** | | |
| [U.S. Geological Survey test well LCRP 23 in eastern Bard Valley, on west bank of Colorado River. Drilled with cable-tool equipment by Hamilton and Hood. Log by F. H. Olmsted and G. R. Vaughan. Casing perforated from 120 to 548 and 634 to 694 ft. Altitude 143.8 ft] | | |
| Upper, fine-grained zone: | | |
| Sand, fine, silty, brown | 14 | 14 |
| Sand, fine to medium, grayish-brown; scattered granules and pebbles | 35 | 49 |
| Clay, silty and sandy; some sand and scattered granules and pebbles | 13 | 62 |
| Sand, fine to medium, grayish-brown | 11 | 73 |
| Sand, fine to coarse; some clay and silt, and about 10–15 percent gravel | 28 | 101 |
| Sand, fine to medium, grayish-brown | 11 | 112 |
| Coarse-gravel zone: | | |
| Gravel containing abundant well-rounded and subrounded pebbles and cobbles of quartzite, chert, silicic volcanic rocks and | | |

*Selected logs of water wells*—Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well 16S/23E-10Rcc—Continued** | | |
| Coarse-gravel zone—Continued: various types of crystalline rocks; some medium to coarse sand, probably as lenses | 43 | 155 |
| Wedge zone: | | |
| Sand, fine to coarse, and thin beds of cemented gravel | 11 | 166 |
| Gravel, fine to coarse, subangular to well-rounded; chert and quartzite somewhat less abundant than in interval from 112 to 155 ft; medium to coarse sand, probably as lenses | 49 | 215 |
| Gravel containing abundant bluish-gray, pink, and green volcanic detritus; some vein quartz, quartzite, and chert and variable amounts of crystalline rocks (pre-Tertiary). Fine to coarse sand present in variable amounts throughout. Gamma radiation noticably higher than in overlying materials. Sample of charcoal from a depth of 224–234 ft gave an age of >36,000 years by the $C^{14}$ method | 333 | 548 |
| Bouse Formation: | | |
| Clay, greenish-gray, and interbedded gray silt and fine sand; fossiliferous | 86 | 634 |
| Conglomerate composed chiefly of angular to subrounded clasts of gneiss and granite; some coarse sandstone | 22 | 656 |
| Clay or mudstone, bluish-gray | 3 | 659 |
| Conglomerate composed chiefly of angular to subrounded clasts of gneiss and granite; some coarse sandstone | 22 | 681 |
| Limestone, pale-yellowish-gray | 6 | 687 |
| Nonmarine sedimentary rocks: | | |
| Fanglomerate composed chiefly of angular and subangular blocks and slabs of granite, gneiss, schist, and various other crystalline rocks similar to those now exposed in Laguna and Chocolate Mountains | 16 | 703 |
| Quartz monzonite, porphyritic, coarse; either in large boulders and blocks or as bedrock (crystalline rocks of pre-Tertiary age) | 12 | 715 |

## APPENDIX C. CHEMICAL ANALYSES OF GROUND WATER

Appendix C presents 776 chemical analyses of ground-water samples from 396 wells in the Yuma area. Most of the analyses were made in laboratories of the U.S. Geological Survey in Yuma, Ariz., or in Albuquerque, N. Mex., during the period 1961–67; a few earlier analyses were obtained from the files or publications of the Geological Survey, the Bureau of Reclamation, other Federal or State agencies, or from individuals. Some of these earlier analyses were recomputed from originally reported values in order to agree with the format of the Survey analyses.

The 776 analyses were selected from a substantially larger number so as to provide a representative sample of the various chemical types of ground water in the Yuma area. The analyses are grouped according to the four subareas and 19 sectors described in the chemical-quality section of the report (p. H129) and are listed sequentially by well number (Federal land classification) within each sector.

Most of the analyses are reported in terms of concentration, in milligrams per liter, of six principal ionic constituents (calcium, magnesium, sodium plus potassium, bicarbonate, sulfate, and chloride) and also silica, hardness as calcium carbonate (both calcium plus magnesium and noncarbonate), and sum of dissolved solids. Some analyses also include the concentrations of sodium and potassium separately, and of fluoride, nitrate, and boron. Additional information includes specific conductance, pH, and percent sodium. All the above characteristics adequately describe the chemical quality of the ground water as it relates to its suitability for common uses in the Yuma area.

Almost all the analyses are identified according to depth (usually the depth of the perforated interval in a well) and the aquifer from which the sample was obtained. Most of the analyses represent water in the coarse-gravel zone—the zone of greatest hydrologic significance in the areas of present and probably future water development. Changes in water quality with time are documented by records of drainage wells for which analyses are listed for a period of years (commonly 1961–67).

## *Chemical analyses of ground water*

Analysis number: Number used for identification in text and on illustrations.
Well number: Location of well according to the Federal land classification. See text for description of well-numbering system.
Use: Letter symbols designate—AC, air-conditioning; Dom, domestic; Dr. drainage; Ind, industrial; Irr, irrigation; Iru, irrigation, unused; Ob, observation; PS, public supply; St, stock; T, test; Ta, auger test.
Depth of sample: Source according to well-perforation record or other infomation.
Aquifer: Letter symbols designate—B, Bouse Formation; C, coarse-gravel zone; N, nonmarine sedimentary rocks; O, older alluvium undivided, U, upper, fine-grained zone; W, wedge zone.
[Analyzed in laboratories of the U.S. Geological Survey at Yuma, Ariz., or Albuquerque, N. Mex., unless otherwise noted. Analyses given in milligrams per liter, except as indicated. Dissolved solids calculated]

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Na + 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 | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **GILA VALLEY SUBAREA** | | | | | | | | | | | | | | | | |
| | | | | | | | **Gila Siphon sector** | | | | | | | | | | | | | | | | |
| 1a | (C– 8–21)16bca | Ind | 30–396 | O, N | 5– 1–63 | 27 | 97 | 51 | | | 437 | 288 | 350 | 568 | ---- | ---- | 1,670 | 450 | 214 | 2,860 | 7.4 | 68 | ---- |
| 1b | | | 30–396 | O, N | 6–28–63 | 28 | 68 | 39 | | | 426 | 264 | 412 | 430 | 1.6 | ---- | 1,540 | 330 | 114 | 2,550 | 7.4 | 74 | ---- |
| 1c | | | 30–396 | O, N | 1–20–67 | 26 | 90 | 44 | | | 481 | 236 | 375 | 615 | ---- | ---- | 1,750 | 405 | 212 | 3,140 | 7.7 | 72 | ---- |
| 2 | 17bad1 | T | 90–105 | C | 11–18–57 | 25 | 73 | 32 | 386 | 3.9 | | 281 | 365 | 398 | 1.3 | ---- | 1,420 | 316 | 86 | 2,320 | 8.0 | 72 | 0.57 |
| 3 | 17dbb | Irr | <100 | C (?) | 7– 1–65 | 28 | 110 | 86 | | | 620 | 340 | 750 | 650 | 1.2 | ---- | 2,410 | 630 | 351 | 3,880 | 7.7 | 68 | ---- |
| 4 | 17dbc | Irr | 72–112 | C | 7– 1–65 | 24 | 78 | 52 | | | 581 | 416 | 700 | 425 | 1.6 | ---- | 2,070 | 408 | 67 | 3,170 | 7.8 | 76 | ---- |
| 5 | 18add | Irr | 100–136 | C | 11–22–67 | 27 | 214 | 106 | | | 650 | 428 | 675 | 942 | 1.0 | ---- | 2,830 | 970 | 619 | 4,610 | 7.6 | 59 | ---- |
| 6a | 18bdc | Irr | 70–146 | C | 11– 5–64 | 21 | 119 | 62 | | | 374 | 436 | 438 | 388 | 1.0 | ---- | 1,620 | 550 | 192 | 2,570 | 7.6 | 60 | ---- |
| 6b | | | 70–146 | C | 7– 1–66 | 24 | 153 | 62 | | | 316 | 360 | 475 | 378 | ---- | ---- | 1,770 | 635 | 340 | 2,740 | 7.5 | 52 | ---- |
| 6c | | | 70–146 | C | 11–22–67 | 26 | 206 | 89 | | | 396 | 396 | 525 | 615 | .9 | ---- | 2,060 | 880 | 556 | 3,550 | 7.8 | 49 | ---- |
| 7a | (C– 8–22)13bdd2 | Irr | 109–128 | C | 4– 9–64 | 26 | 234 | 91 | | | 459 | 292 | 575 | 795 | ---- | ---- | 2,330 | 960 | 720 | 3,840 | 7.5 | 51 | ---- |
| 7b | | | 109–128 | C | 7– 1–66 | 26 | 230 | 99 | | | 456 | 468 | 625 | 665 | ---- | ---- | 2,340 | 980 | 596 | 3,800 | 7.4 | 50 | ---- |
| 7c | | | 109–128 | C | 11–20–67 | 26 | 246 | 106 | | | 482 | 488 | 675 | 705 | .9 | ---- | 2,480 | 1,050 | 650 | 4,070 | 7.6 | 50 | ---- |
| 8a | 13dad | Irr | 85–118 | C | 11–15–65 | 25 | 141 | 61 | | | 282 | 376 | 450 | 308 | .9 | ---- | 1,460 | 600 | 292 | 2,390 | 7.6 | 51 | ---- |
| 8b | | | 85–118 | C | 7– 1–66 | 24 | 170 | 68 | | | 300 | 408 | 500 | 355 | 1.0 | ---- | 1,620 | 705 | 370 | 2,640 | 7.5 | 48 | ---- |
| 8c | | | 85–118 | C | 11–22–67 | 26 | 206 | 91 | | | 377 | 452 | 600 | 505 | .9 | ---- | 2,030 | 890 | 520 | 3,340 | 7.8 | 48 | ---- |
| 9 | 14cdd1 | Irr | 80–129 | C | 7– 1–66 | 24 | 132 | 51 | | | 290 | 356 | 425 | 308 | .9 | ---- | 1,410 | 540 | 248 | 2,320 | 7.6 | 54 | ---- |
| | | | | | | | **East sector** | | | | | | | | | | | | | | | | |
| 10a | (C– 8–21)19dad | Irr | 115–165 | C | 9–11–62 | 28 | 105 | 40 | | | 270 | 280 | 375 | 278 | 0.9 | ---- | 1,240 | 428 | 198 | 1,990 | 7.4 | 58 | ---- |
| 10b | | | 115–165 | C | 6– 6–67 | 23 | 274 | 94 | | | 419 | 332 | 525 | 825 | ---- | ---- | 2,330 | 1,070 | 798 | 3,840 | 7.3 | 46 | ---- |
| 12a | 29acc | Ind | <250 | C (?) | 2–18–63 | 21 | 416 | 161 | | | 1,580 | 516 | 1,150 | 2,500 | ---- | ---- | 6,090 | 1,700 | 1,280 | 9,690 | 7.4 | 67 | ---- |
| 12b | | | <250 | C (?) | 10–25–67 | 22 | 332 | 163 | | | 1,490 | 552 | 1,100 | 2,220 | 1.1 | ---- | 5,600 | 1,500 | 1,050 | 9,010 | 7.5 | 68 | ---- |
| 13 | 30abb | Irr | 105–155 | C | 10– 4–62 | 16 | 144 | 85 | | | 644 | 246 | 675 | 855 | ---- | ---- | 2,540 | 710 | 508 | 4,360 | 7.8 | 66 | ---- |
| 14a | 30acd | Irr | 104–165 | C | 10– | 31 | 182 | 121 | | | 942 | 330 | 1,050 | 1,160 | ---- | ---- | 3,650 | 950 | 680 | 5,790 | 7.6 | 68 | ---- |
| 14b | | | 104–165 | C | 6–13–63 | 26 | 182 | 89 | | | 609 | 436 | 600 | 825 | ---- | ---- | 2,550 | 820 | 462 | 4,200 | 7.3 | 62 | ---- |
| 15a | 30ccc1 | Irr | 95–155 | C | 10– 5–62 | 22 | 270 | 92 | | | 461 | 256 | 675 | 808 | ---- | ---- | 2,460 | 1,050 | 840 | 4,080 | 7.4 | 49 | ---- |
| 15b | | | 95–155 | C | 6–13–63 | 24 | 250 | 111 | | | 623 | 360 | 512 | 1,140 | ---- | ---- | 2,840 | 1,080 | 785 | 4,790 | 7.7 | 56 | ---- |
| 16 | 30cdc | Irr | 120–140 | C | 10– 9–62 | 23 | 344 | 151 | | | 1,000 | 432 | 750 | 1,790 | ---- | ---- | 4,270 | 1,480 | 1,130 | 7,130 | 7.2 | 60 | ---- |
| 17a | 30dca | Irr | (?) | C(?) | 10– 4–62 | 26 | 200 | 117 | | | 903 | 368 | 1,020 | 1,120 | ---- | ---- | 3,570 | 980 | 678 | 5,790 | 7.5 | 67 | ---- |
| 17b | | | (?) | C(?) | 6–13–63 | 27 | 210 | 101 | | | 786 | 478 | 825 | 992 | ---- | ---- | 3,180 | 940 | 548 | 5,220 | 7.4 | 64 | ---- |
| 18a | 31aba | Irr | 95–145 | C | 6–13–62 | 24 | 464 | 210 | | | 1,020 | 336 | 850 | 2,180 | ---- | ---- | 4,920 | 2,020 | 1,740 | 7,910 | 7.6 | 52 | ---- |
| 18b | | | 95–145 | C | 3–26–63 | 27 | 468 | 168 | | | 1,120 | 376 | 1,030 | 2,020 | ---- | ---- | 5,100 | 1,860 | 1,550 | 7,910 | 7.4 | 57 | 0.47 |
| 19 | 31bba | Irr | (?) | (?) | 5– 8–63 | 24 | 276 | 139 | | | 967 | 292 | 725 | 1,680 | ---- | ---- | 3,960 | 1,260 | 1,020 | 6,630 | 7.6 | 62 | ---- |
| | | | | | | | **East-central sector** | | | | | | | | | | | | | | | | |
| 20a | (C– 8–22)22caa | Irr | 100–165 | C | 5–29–62 | 18 | 124 | 49 | | | 264 | 357 | 300 | 338 | 1.2 | ---- | 1,270 | 510 | 218 | 2,250 | 7.4 | 53 | ---- |
| 20b | | | 100–165 | C | 10– 5–62 | 24 | 150 | 63 | | | 314 | 360 | 400 | 429 | .8 | ---- | 1,560 | 635 | 340 | 2,580 | 7.4 | 52 | ---- |
| 20c | | | 100–165 | C | 4–10–63 | 24 | 238 | 93 | | | 440 | 344 | 488 | 810 | ---- | ---- | 2,260 | 975 | 693 | 3,830 | 7.3 | 50 | ---- |
| 21a | 22cda1 | Irr | <136 | C | 5–29–62 | 16 | 127 | 57 | | | 284 | 362 | 183 | 480 | 1.1 | ---- | 1,330 | 550 | 253 | 2,540 | 7.6 | 53 | ---- |
| 21b | | | <136 | C | 10– 5–62 | 26 | 128 | 55 | | | 323 | 394 | 317 | 421 | .7 | ---- | 1,470 | 545 | 222 | 2,480 | 7.5 | 56 | ---- |
| 21c | | | <136 | C | 4–10–63 | 24 | 118 | 55 | | | 321 | 368 | 233 | 478 | ---- | ---- | 1,410 | 520 | 218 | 2,470 | 7.4 | 57 | ---- |
| 21d | | | <136 | C | 11–11–65 | 25 | 170 | 70 | | | 348 | 376 | 350 | 562 | .9 | ---- | 1,710 | 710 | 402 | 2,950 | 7.5 | 52 | ---- |
| 22a | 22cda2 | Irr | 100–152 | C | 5–29–62 | 19 | 125 | 50 | | | 299 | 383 | 288 | 392 | .9 | ---- | 1,370 | 518 | 204 | 2,380 | 7.5 | 56 | ---- |
| 22b | | | 100–152 | C | 4–10–63 | 24 | 126 | 51 | | | 308 | 392 | 308 | 392 | ---- | ---- | 1,400 | 526 | 204 | 2,370 | 7.5 | 56 | ---- |
| 23 | 22dcb | Irr | 100–150 | C | 4–10–63 | 24 | 116 | 50 | | | 305 | 364 | 233 | 438 | ---- | ---- | 1,350 | 496 | 198 | 2,360 | 7.5 | 57 | ---- |
| 24 | 23dad | T | [1]500 | W | 2–26–62 | 8 | 73 | 29 | | | 228 | 202 | 138 | 346 | ---- | ---- | 923 | 302 | 136 | 1,740 | 7.6 | 62 | ---- |
| 25 | 24cca | Irr | 97–140 | C | 4–24–63 | 22 | 146 | 62 | | | 264 | 320 | 342 | 408 | ---- | ---- | 1,400 | 620 | 358 | 2,420 | 7.1 | 48 | ---- |
| 26 | 25bad | Irr | 100–114 | C | 9–20–62 | 28 | 194 | 79 | | | 554 | 476 | 500 | 780 | ---- | ---- | 2,370 | 808 | 419 | 3,900 | 7.3 | 60 | ---- |
| 27 | 25cbd | Irr | 7[illegible]–118 | C | 10– 5–62 | 23 | 185 | 76 | | | 454 | 278 | 375 | 812 | ---- | ---- | 2,060 | 775 | 547 | 3,710 | 7.3 | 56 | ---- |
| 28a | 25ddd | Dr | 100–160 | C | 4–20–64 | 24 | 416 | 180 | | | 1,120 | 388 | 950 | 2,060 | ---- | ---- | 4,940 | 1,780 | 1,460 | 8,000 | 7.3 | 58 | ---- |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28b[2] | | | 100–160 | C | 7– 7–65 | ---- | 425 | 186 | 1,190 | 393 | 946 | 2,220 | ---- | ---- | 5,160 | 1,830 | 1,500 | 8,360 | ---- | 59 | ---- |
| 29a | 26adb | Irr | <184 | C | 1–20–61 | 32 | 108 | 43 | 270 | 298 | 197 | 414 | ---- | 2.9 | 1,210 | 445 | 201 | 2,060 | 7.6 | 57 | 0.32 |
| 29b | | | <184 | C | 10– 8–62 | 22 | 148 | 58 | 345 | 344 | 288 | 552 | ---- | ---- | 1,580 | 610 | 328 | 2,840 | 7.2 | 55 | ---- |
| 29c | | | <184 | C | 1–17–63 | 23 | 99 | 43 | 271 | 288 | 208 | 398 | ---- | ---- | 1,190 | 425 | 189 | 2,120 | 7.7 | 58 | ---- |
| 30 | 26bad | Irr | 90–170 | C | 4–24–63 | 21 | 222 | 91 | 426 | 284 | 258 | 960 | ---- | ---- | 2,120 | 930 | 697 | 3,840 | 7.3 | 50 | ---- |
| 31a | 26bbb | Dr | 84–134 | C | 3–24–64 | 23 | 114 | 43 | 294 | 298 | 275 | 402 | .9 | .1 | 1,300 | 460 | 216 | 2,240 | 7.4 | 58 | .31 |
| 31b | | | 84–134 | C | 4–20–65 | 25 | 97 | 37 | 267 | 288 | 267 | 328 | ---- | ---- | 1,160 | 395 | 159 | 1,940 | 7.8 | 60 | ---- |
| 31c[2] | | | 84–134 | C | 7– 7–65 | ---- | 110 | 42 | 278 | 304 | 256 | 391 | ---- | ---- | 1,230 | 446 | 197 | 2,120 | ---- | 58 | ---- |
| 32[3] | 26cbd | Irr | 94–150 | C | 5– –60 | ---- | 224 | 97 | 553 | 281 | 350 | 1,110 | ---- | ---- | 2,470 | 957 | 726 | 3,500 | ---- | 56 | ---- |
| 33 | 26dca1 | Irr | 95–125 | C | 10– 5–62 | 23 | 151 | 69 | 474 | 288 | 250 | 848 | ---- | ---- | 1,960 | 660 | 424 | 3,660 | 7.4 | 61 | ---- |
| 34 | 26dca2 | Dom | 184–190 | W | 3–25–65 | 21 | 137 | 48 | 299 | 222 | 125 | 622 | .8 | ---- | 1,360 | 540 | 358 | 2,470 | 7.4 | 55 | ---- |
| 35a | 26ddd | Dr | 90–160 | C | 3–30–64 | 20 | 272 | 120 | 745 | 376 | 512 | 1,380 | 1.2 | ---- | 3,240 | 1,170 | 862 | 5,510 | 7.6 | 58 | ---- |
| 35b[2] | | | 90–160 | C | 4– 6–65 | ---- | 395 | 170 | 1,080 | 387 | 740 | 2,130 | ---- | ---- | 4,710 | 1,690 | 1,370 | 7,660 | ---- | 58 | ---- |
| 35c[2] | | | 90–160 | C | 12– 2–65 | ---- | 365 | 160 | 1,150 | 384 | 746 | 2,120 | ---- | ---- | 4,730 | 1,570 | 1,250 | 7,760 | ---- | 61 | ---- |
| 36 | 27aca | Irr | 102–134 | C | 4–24–63 | 22 | 204 | 80 | 426 | 400 | 300 | 795 | ---- | ---- | 2,030 | 836 | 508 | 3,600 | 7.1 | 52 | ---- |
| 37a | 27bbb | Dr | 86–147 | C | 4–12–64 | 25 | 226 | 98 | 442 | 488 | 338 | 833 | ---- | ---- | 2,210 | 965 | 565 | 3,870 | 7.3 | 50 | ---- |
| 37b | | | 86–147 | C | 1–22–65 | 26 | 242 | 104 | 504 | 528 | 350 | 942 | ---- | ---- | 2,430 | 1,030 | 597 | 4,080 | 7.3 | 52 | ---- |
| 37c[2] | | | 86–147 | C | 7– 7–65 | ---- | 195 | 82 | 411 | 457 | 310 | 748 | ---- | ---- | 2,020 | 825 | 450 | 3,360 | ---- | 52 | ---- |
| 38 | 27bda | Irr | <161(?) | C(?) | 6–13–63 | 25 | 106 | 45 | 278 | 268 | 140 | 487 | .8 | ---- | 1,220 | 448 | 228 | 2,240 | 7.4 | 57 | ---- |
| 39 | 27bdd | Irr | 80–161 | C | 10– 5–62 | 23 | 219 | 92 | 472 | 248 | 350 | 982 | ---- | ---- | 2,260 | 925 | 722 | 4,190 | 7.3 | 53 | ---- |
| 40a | 27cad | Irr | 95–141 | C | 10– 4–62 | 25 | 198 | 105 | 495 | 288 | 288 | 1,040 | ---- | ---- | 2,300 | 925 | 689 | 4,210 | 7.2 | 54 | ---- |
| 40b | | | 95–141 | C | 4–24–63 | 21 | 214 | 87 | 536 | 300 | 275 | 1,080 | ---- | ---- | 2,360 | 890 | 644 | 4,280 | 7.3 | 57 | ---- |
| 41a | 27ccc | Dr | 106–176 | C | 4– 6–64 | 23 | 206 | 93 | 564 | 336 | 283 | 1,100 | ---- | ---- | 2,440 | 895 | 620 | 4,300 | 7.3 | 58 | ---- |
| 41b[2] | | | 106–176 | C | 7– 7–65 | ---- | 149 | 64 | 499 | 259 | 230 | 896 | ---- | ---- | 1,970 | 638 | 426 | 3,530 | ---- | 63 | ---- |
| 41c[2] | | | 106–176 | C | 12– 2–65 | ---- | 149 | 65 | 491 | 268 | 251 | 874 | ---- | ---- | 1,960 | 636 | 416 | 3,450 | ---- | 63 | ---- |
| 42 | 27dad | Irr | 100–118 | C | 5–23–62 | 13 | 194 | 89 | 432 | 269 | 200 | 965 | ---- | ---- | 2,030 | 850 | 630 | 3,880 | 7.4 | 52 | ---- |
| 43a | 27ddd | Dr | 95–165 | C | 3–14–64 | 11 | 198 | 77 | 545 | 252 | 425 | 955 | ---- | ---- | 2,340 | 810 | 604 | 3,790 | 7.5 | 59 | ---- |
| 43b[2] | | | 95–165 | C | 4– 5–65 | ---- | 208 | 81 | 494 | 253 | 266 | 976 | ---- | ---- | 2,150 | 852 | 644 | 3,950 | ---- | 57 | ---- |
| 43c[2] | | | 95–165 | C | 7– 7–65 | ---- | 233 | 94 | 532 | 253 | 299 | 1,160 | ---- | ---- | 2,490 | 966 | 759 | 4,320 | ---- | 54 | ---- |
| 44a | 34aaa | Irr | 93–177 | C | 3–30–63 | 13 | 338 | 150 | 1,090 | 297 | 550 | 2,140 | ---- | ---- | 4,430 | 1,460 | 1,220 | 7,670 | 7.4 | 62 | ---- |
| 44b | | | 93–177 | C | 10– 9–62 | 22 | 160 | 66 | 375 | 244 | 208 | 758 | ---- | ---- | 1,710 | 670 | 470 | 3,210 | 7.3 | 55 | ---- |
| 44c | | | 93–177 | C | 5– 8–63 | 20 | 151 | 69 | 422 | 220 | 225 | 825 | ---- | ---- | 1,820 | 660 | 480 | 3,320 | 7.8 | 58 | ---- |
| 45a | 34add | Dr | 500–600 | W | 10– 7–64 | 21 | 66 | 14 | 222 | 216 | 72 | 321 | 1.0 | ---- | 825 | 224 | 47 | 1,490 | 7.7 | 68 | ---- |
| 45b | | | 500–600 | W | 11–12–65 | 19 | 63 | 18 | 205 | 216 | 62 | 308 | 1.0 | ---- | 784 | 232 | 55 | 1,480 | 7.6 | 66 | ---- |
| 46 | 34bac1 | Irr | 115–184 | C | 5–23–62 | 27 | 182 | 84 | 454 | 244 | 217 | 965 | ---- | ---- | 2,050 | 870 | 600 | 3,910 | 7.5 | 55 | ---- |
| 47a | 35aaa2 | Irr | 90–137 | C | 10– 5–62 | 24 | 177 | 85 | 410 | 260 | 325 | 802 | ---- | ---- | 1,950 | 790 | 577 | 3,560 | 7.4 | 53 | ---- |
| 47b | | | 90–137 | C | 6–13–63 | 22 | 412 | 195 | 1,230 | 336 | 750 | 2,450 | ---- | ---- | 5,230 | 1,830 | 1,550 | 8,790 | 7.3 | 59 | ---- |
| 48 | 35bab1 | Irr | 84–126 | C | 5– 8–63 | 21 | 256 | 122 | 755 | 200 | 375 | 1,580 | ---- | ---- | 3,210 | 1,140 | 976 | 5,710 | 7.5 | 59 | ---- |
| 49a | 35caa1 | T | 435–570 | W | 12–22–63 | 20 | 66 | 15 | 220 | 216 | 70 | 322 | .8 | ---- | 822 | 228 | 51 | 1,500 | 7.6 | 68 | ---- |
| 49b | | | 99–170 | C | 1– 7–64 | 21 | 182 | 88 | 467 | 236 | 225 | 995 | ---- | ---- | 2,100 | 815 | 622 | 3,890 | 7.4 | 56 | ---- |
| 50a | 35caa2 | Dr | 484–585 | W | 5– 7–64 | 18 | 64 | 17 | 218 | 211 | 75 | 319 | 1.0 | ---- | 818 | 230 | 57 | 1,530 | 7.2 | 67 | ---- |
| 50b | | | 484–585 | W | 10–13–64 | 20 | 66 | 16 | 223 | 214 | 70 | 331 | .8 | ---- | 834 | 232 | 56 | 1,530 | 7.7 | 68 | ---- |
| 50c | | | 484–585 | W | 7– 1–66 | 17 | 62 | 18 | 224 | 218 | 70 | 328 | .9 | ---- | 829 | 230 | 51 | 1,540 | 7.4 | 68 | ---- |
| 51a | 35dad | Irr | 95–175 | C | 5– 8–63 | 21 | 118 | 50 | 354 | 236 | 192 | 622 | ---- | ---- | 1,480 | 500 | 307 | 2,730 | 7.9 | 61 | ---- |
| 51b | | | 95–175 | C | 7–23–64 | 24 | 138 | 57 | 394 | 228 | 250 | 700 | ---- | ---- | 1,680 | 580 | 393 | 3,050 | 7.5 | 60 | ---- |
| 52 | 36abb | Irr | 100–155 | U, C | 6–13–63 | 25 | 558 | 267 | 1,480 | 432 | 1,020 | 3,050 | ---- | ---- | 6,620 | 2,490 | 2,140 | 10,700 | 7.3 | 56 | ---- |
| 53a | 36acb | Irr | 85–140 | C | 10– 5–62 | 22 | 189 | 77 | 503 | 292 | 575 | 742 | ---- | ---- | 2,250 | 790 | 550 | 3,790 | 7.4 | 58 | ---- |
| 53b | | | 85–140 | C | 6–13–63 | 23 | 372 | 163 | 1,680 | 396 | 1,050 | 2,720 | ---- | ---- | 6,210 | 1,600 | 1,280 | 10,100 | 7.4 | 70 | ---- |
| 54a | 36bba | Irr | 110–135 | C | 10– 4–62 | 24 | 160 | 66 | 327 | 246 | 192 | 765 | ---- | ---- | 1,700 | 670 | 468 | 3,220 | 7.2 | 55 | ---- |
| 54b | | | 110–135 | C | 6–13–63 | 21 | 354 | 157 | 1,220 | 384 | 800 | 2,160 | ---- | ---- | 4,900 | 1,530 | 1,220 | 8,200 | 7.5 | 64 | ---- |
| 55a | 36cad | Dr | 520–621 | W | 5–26–64 | 19 | 97 | 27 | 245 | 220 | 85 | 435 | .6 | .1 | 1,010 | 352 | 172 | 1,950 | 7.8 | 60 | .23 |
| 55b | | | 520–621 | W | 10– 1–64 | 19 | 98 | 25 | 254 | 222 | 85 | 445 | .5 | ---- | 1,040 | 348 | 166 | 1,920 | 7.5 | 61 | ---- |
| 55c[2] | | | 520–621 | W | 10–26–65 | 15 | 98 | 23 | 261 | 226 | 83 | 442 | .6 | ---- | 1,040 | 338 | 154 | 1,870 | 7.8 | 61 | .21 |
| | | | | | | | | | West-central sector | | | | | | | | | | | | |
| 56a | (C–8–22)19ccc | T | 370–463 | W | 11–13–63 | 14 | 202 | 59 | 316 | 244 | 120 | 785 | 0.4 | 0.3 | 1,620 | 745 | 545 | 3,080 | 7.4 | 48 | 0.23 |
| 56b | | | 115–150 | C | 2–17–64 | 15 | 199 | 81 | 499 | 482 | 512 | 700 | ---- | .7 | 2,250 | 830 | 435 | 3,740 | 7.4 | 57 | .45 |
| 57 | 19ccd | Irr | 103–135 | C | 3–19–63 | 26 | 127 | 43 | 293 | 329 | 272 | 408 | ---- | 1.2 | 1,330 | 492 | 222 | 2,220 | 7.7 | 56 | .22 |
| 57a | 21ddd | Irr | 105–150 | C | 5–29–62 | 20 | 138 | 60 | 307 | 393 | 325 | 422 | 1.0 | ---- | 1,470 | 590 | 268 | 2,490 | 7.6 | 53 | ---- |
| 57b | | | 105–150 | C | 10–10–62 | 25 | 140 | 56 | 311 | 384 | 338 | 418 | ---- | ---- | 1,480 | 580 | 265 | 2,530 | 7.2 | 54 | ---- |
| 58a | 28aaa | Irr | 105–150 | C | 5–29–62 | 20 | 159 | 68 | 356 | 393 | 262 | 605 | ---- | ---- | 1,670 | 675 | 352 | 2,960 | 7.6 | 53 | ---- |
| 58b | | | 105–150 | C | 10–10–62 | 24 | 156 | 66 | 360 | 400 | 283 | 582 | ---- | ---- | 1,670 | 660 | 332 | 2,980 | 7.3 | 54 | ---- |
| 58c | | | 105–150 | C | 1–22–65 | 24 | 145 | 64 | 365 | 376 | 258 | 595 | .9 | ---- | 1,640 | 625 | 316 | 2,770 | 7.5 | 56 | ---- |
| 59a | 28ccc | Dr | 117–167 | C | 3– 2–64 | 21 | 204 | 88 | 504 | 264 | 438 | 918 | ---- | ---- | 2,300 | 870 | 654 | 3,990 | 7.6 | 56 | ---- |
| 59b | | | 117–167 | C | 4–20–65 | 25 | 202 | 84 | 650 | 320 | 350 | 1,160 | ---- | ---- | 2,630 | 850 | 588 | 4,580 | 7.7 | 62 | ---- |
| 59c[2] | | | 117–167 | C | 12– 2–65 | ---- | 203 | 89 | 691 | 317 | 403 | 1,210 | ---- | ---- | 2,750 | 872 | 612 | 4,730 | ---- | 63 | ---- |
| 60 | 28cdb | Irr | <248 | C(?) | 5– 8–63 | 23 | 127 | 66 | 401 | 244 | 208 | 742 | ---- | ---- | 1,690 | 590 | 390 | 3,100 | 7.8 | 60 | ---- |
| 61 | 28dca | Irr | 128–168 | C | 6– 1–62 | 18 | 185 | 75 | 414 | 306 | 233 | 835 | ---- | ---- | 1,910 | 770 | 519 | 3,430 | 7.6 | 54 | ---- |
| 62a | 29cdd | Irr | 138–185 | C | 1–25–61 | 32 | 260 | 110 | 625 | 277 | 443 | 1,270 | ---- | 3.8 | 2,880 | 1,100 | 873 | 4,900 | 7.4 | 55 | .47 |
| 62b | | | 138–185 | C | 3–26–63 | 27 | 258 | 101 | 631 | 285 | 405 | 1,260 | ---- | .3 | 2,820 | 1,060 | 826 | 4,870 | 7.5 | 56 | .42 |
| 63a | 29dda | Irr | 110–175 | C | 1–25–61 | 30 | 211 | 86 | 583 | 310 | 334 | 1,110 | ---- | 2.4 | 2,510 | 880 | 626 | 4,380 | 7.4 | 59 | .68 |
| 63b | | | 110–175 | C | 5– 8–63 | 22 | 135 | 71 | 467 | 284 | 267 | 805 | ---- | ---- | 1,910 | 630 | 397 | 3,420 | 7.8 | 62 | ---- |
| 64a | 30adc | Irr | (?) | (?) | 10–25–61 | 29 | 198 | 84 | 384 | 319 | 308 | 775 | ---- | ---- | 1,940 | 840 | 578 | 3,420 | 8.0 | 50 | ---- |
| 64b | | | (?) | (?) | 2–13–63 | 27 | 180 | 79 | 363 | 314 | 250 | 742 | ---- | ---- | 1,800 | 775 | 518 | 3,290 | 7.7 | 50 | ---- |
| 65a | 30cab | Irr | 115–170 | C | 10– 4–62 | 27 | 194 | 77 | 411 | 334 | 250 | 822 | ---- | ---- | 1,950 | 800 | 526 | 3,530 | 7.2 | 53 | ---- |
| 65b | | | 115–170 | C | 3– 4–63 | 27 | 186 | 73 | 426 | 258 | 262 | 855 | ---- | 1.9 | 1,960 | 765 | 554 | 3,430 | 7.9 | 55 | .28 |
| 66 | 30cdc | Dom | <390 | W(?) | 8– 8–67 | 14 | 166 | 37 | 285 | 244 | 120 | 608 | .9 | ---- | 1,150 | 565 | 365 | 2,540 | 7.1 | 52 | ---- |
| 67a | 30dbc | Dr | 106–164 | C | 4–15–64 | 24 | 278 | 106 | 498 | 400 | 388 | 1,050 | ---- | ---- | 2,540 | 1,130 | 802 | 4,500 | 7.3 | 49 | ---- |
| 67b | | | 106–164 | C | 4–20–65 | 27 | 260 | 85 | 485 | 340 | 325 | 1,020 | ---- | ---- | 2,370 | 1,000 | 721 | 4,110 | 7.6 | 51 | ---- |
| 67c[2] | | | 106–164 | C | 12– 2–65 | ---- | 243 | 93 | 536 | 336 | 351 | 1,080 | ---- | ---- | 2,470 | 918 | 714 | 4,260 | ---- | 54 | ---- |
| 68a | 30ddd | Irr | 130–160 | C | 5–23–62 | 24 | 250 | 116 | 650 | 282 | 512 | 1,240 | ---- | ---- | 2,930 | 1,100 | 869 | 4,960 | 7.4 | 56 | ---- |

See footnotes at end of table.

*Chemical analyses of ground water*—Continued

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) + Potassium (K) (Na + 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 | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **GILA VALLEY SUBAREA—Continued** | | | | | | | | | | | | | | | | |
| | | | | | **West-central sector—Continued** | | | | | | | | | | | | | | | | |
| 68b | (C–8–22) 30ddd | Irr | 130–160 | C | 10–9–62 | 23 | 268 | 132 | 735 | 296 | 500 | 1,450 | ---- | ---- | 3,260 | 1,210 | 968 | 5,840 | 7.2 | 57 | ---- |
| 69a | 31aaa | Irr | 130–190 | C | 2–13–63 | 21 | 146 | 57 | 339 | 248 | 238 | 628 | ---- | ---- | 1,550 | 600 | 396 | 2,850 | 7.7 | 55 | ---- |
| 69b | | | 130–190 | C | 3–4–63 | 24 | 186 | 65 | 433 | 272 | 341 | 775 | ---- | 1.4 | 1,960 | 730 | 507 | 3,330 | 7.9 | 56 | 0.29 |
| 69c | | | 130–190 | C | 5–8–63 | 20 | 155 | 76 | 444 | 252 | 338 | 785 | ---- | ---- | 1,940 | 700 | 494 | 3,450 | 7.7 | 58 | ---- |
| 70 | 31baa | | (?) | (?) | 3–4–63 | 21 | 162 | 57 | 355 | 262 | 242 | 670 | ---- | ---- | 1,640 | 640 | 425 | 2,970 | 7.6 | 55 | ---- |
| 71a | 31bcc | Dr | 130–200 | C | 2–14–61 | 30 | 375 | 120 | 475 | 237 | 703 | 1,100 | ---- | 3.1 | 2,920 | 1,430 | 1,240 | 4,660 | 7.6 | 42 | .35 |
| 71b | | | 130–200 | C | 10–4–61 | 16 | 328 | 107 | 508 | 256 | 825 | 920 | ---- | ---- | 2,830 | 1,260 | 1,050 | 4,320 | 7.8 | 47 | ---- |
| 71c | | | 130–200 | C | 2–21–62 | 20 | 300 | 98 | 475 | 254 | 725 | 865 | ---- | ---- | 2,610 | 1,150 | 942 | 4,200 | 7.4 | 47 | ---- |
| 71d | | | 130–200 | C | 11–8–62 | 23 | 256 | 100 | 464 | 254 | 675 | 815 | ---- | 1.3 | 2,460 | 1,050 | 842 | 3,990 | 7.6 | 49 | .40 |
| 71e | | | 130–200 | C | 2–19–64 | 20 | 233 | 82 | 481 | 262 | 700 | 725 | ---- | ---- | 2,370 | 920 | 705 | 3,790 | 7.4 | 53 | ---- |
| 71f | | | 130–200 | C | 1–28–65 | 23 | 212 | 83 | 495 | 258 | 725 | 695 | ---- | ---- | 2,360 | 870 | 689 | 3,660 | 7.6 | 55 | ---- |
| 71g | | | 130–200 | C | 7–12–65 | 21 | 218 | 74 | 508 | 252 | 725 | 705 | ---- | ---- | 2,380 | 850 | 644 | 3,630 | 7.4 | 56 | ---- |
| 71h [4] | | | 130–200 | C | 7–15–65 | 21 | 214 | 74 | 502 | 256 | 700 | 705 | ---- | ---- | 2,340 | 840 | 630 | 3,570 | 7.4 | 56 | ---- |
| 71i | | | 130–200 | C | 1–24–66 | 22 | 202 | 74 | 461 | 256 | 625 | 675 | ---- | ---- | 2,190 | 810 | 600 | 3,580 | 7.6 | 55 | ---- |
| 72a | 31dbb1 | Dr | 130–205 | C | 8–23–61 | 25 | 232 | 79 | 423 | 266 | 464 | 795 | ---- | 2.2 | 2,150 | 905 | 687 | 3,510 | 7.6 | 50 | .42 |
| 72b | | | 130–205 | C | 10–4–61 | 16 | 232 | 85 | 464 | 276 | 575 | 790 | ---- | ---- | 2,300 | 930 | 704 | 3,700 | 7.8 | 52 | ---- |
| 72c | | | 130–205 | C | 2–21–62 | 20 | 223 | 79 | 441 | 270 | 550 | 742 | ---- | ---- | 2,190 | 880 | 658 | 3,580 | 7.6 | 52 | ---- |
| 72d | | | 130–205 | C | 11–8–62 | 22 | 230 | 78 | 449 | 272 | 575 | 745 | ---- | ---- | 2,240 | 895 | 672 | 3,650 | 7.6 | 52 | ---- |
| 72e | | | 130–205 | C | 1–28–65 | 22 | 194 | 70 | 418 | 280 | 525 | 640 | ---- | ---- | 2,010 | 770 | 540 | 3,390 | 7.6 | 54 | ---- |
| 72f | | | 130–205 | C | 1–24–66 | 22 | 198 | 67 | 460 | 284 | 550 | 685 | ---- | ---- | 2,120 | 770 | 537 | 3,520 | 7.6 | 56 | ---- |
| 73 | 32aaa | Irr | 133–167 | C | 9–25–62 | 27 | 180 | 102 | 713 | 314 | 438 | 1,210 | ---- | ---- | 2,830 | 870 | 612 | 4,800 | 7.4 | 64 | ---- |
| 74 | 32bdb | Irr | 200–230 | C | 3–26–63 | 25 | 180 | 76 | 448 | 268 | 350 | 815 | ---- | ---- | 2,030 | 760 | 540 | 3,600 | 7.7 | 56 | ---- |
| 75a | 32cbb | Dr | 124–189 | C | 1–30–62 | 26 | 205 | 86 | 454 | 291 | 575 | 720 | ---- | ---- | 2,210 | 865 | 626 | 3,650 | 7.6 | 53 | ---- |
| 75b | | | 124–189 | C | 6–11–62 | 19 | 178 | 74 | 419 | 286 | 425 | 698 | ---- | ---- | 1,960 | 750 | 516 | 3,400 | 7.6 | 55 | ---- |
| 75c | | | 124–189 | C | 11–8–62 | 26 | 168 | 71 | 439 | 282 | 450 | 685 | ---- | ---- | 1,980 | 710 | 479 | 3,400 | 7.4 | 57 | .41 |
| 75d | | | 124–189 | C | 2–19–64 | 17 | 166 | 70 | 449 | 286 | 450 | 690 | ---- | ---- | 1,980 | 700 | 466 | 3,380 | 7.4 | 58 | ---- |
| 75e | | | 124–189 | C | 1–28–65 | 26 | 158 | 60 | 436 | 284 | 462 | 620 | ---- | ---- | 1,900 | 640 | 407 | 3,180 | 7.6 | 60 | ---- |
| 75f | | | 124–189 | C | 1–24–66 | 25 | 158 | 62 | 451 | 288 | 412 | 685 | ---- | ---- | 1,940 | 650 | 414 | 3,420 | 7.4 | 60 | ---- |
| 76a | 32ccc | Dr | 129–204 | C | 8–26–61 | 30 | 198 | 77 | 502 | 316 | 716 | 635 | ---- | 2.7 | 2,320 | 810 | 551 | 3,540 | 7.7 | 57 | .64 |
| 76b | | | 129–204 | C | 9–28–61 | 19 | 188 | 80 | 572 | 316 | 875 | 620 | ---- | ---- | 2,510 | 800 | 541 | 3,700 | 8.0 | 60 | ---- |
| 76c | | | 129–204 | C | 1–2–62 | 29 | 181 | 77 | 517 | 316 | 725 | 625 | ---- | ---- | 2,310 | 770 | 511 | 3,520 | 7.8 | 59 | ---- |
| 76d | | | 129–204 | C | 11–8–62 | 24 | 164 | 66 | 438 | 306 | 575 | 555 | ---- | ---- | 1,980 | 680 | 429 | 3,310 | 7.7 | 58 | ---- |
| 76e | | | 129–204 | C | 3–4–63 | 24 | 162 | 67 | 454 | 300 | 626 | 545 | ---- | .2 | 2,030 | 680 | 434 | 3,120 | 7.7 | 59 | .53 |
| 76f | | | 129–204 | C | 2–19–64 | 19 | 146 | 60 | 453 | 306 | 588 | 520 | ---- | ---- | 1,940 | 610 | 359 | 3,110 | 7.5 | 62 | ---- |
| 76g | | | 129–204 | C | 1–28–65 | 24 | 146 | 50 | 430 | 304 | 562 | 475 | ---- | ---- | 1,840 | 570 | 320 | 3,000 | 7.6 | 62 | ---- |
| 76h | | | 129–204 | C | 1–24–66 | 22 | 134 | 55 | 407 | 308 | 475 | 495 | ---- | ---- | 1,740 | 560 | 308 | 3,050 | 7.7 | 61 | ---- |
| 77a | 32cdd | Dr | 90–200 | C | 9–5–61 | 28 | 252 | 100 | 497 | 272 | 475 | 995 | ---- | 2.8 | 2,470 | 1,040 | 817 | 4,320 | 7.6 | 51 | .47 |
| 77b | | | 90–200 | C | 1–2–62 | 31 | 264 | 107 | 596 | 270 | 600 | 1,100 | ---- | ---- | 2,830 | 1,100 | 878 | 4,600 | 7.8 | 54 | ---- |
| 77c | | | 90–200 | C | 3–30–62 | 19 | 294 | 130 | 856 | 273 | 625 | 1,600 | ---- | ---- | 3,660 | 1,270 | 1,050 | 6,230 | 7.4 | 59 | ---- |
| 77d | | | 90–200 | C | 4–24–62 | 21 | 264 | 112 | 636 | 272 | 525 | 1,230 | ---- | ---- | 2,920 | 1,120 | 897 | 5,220 | 7.5 | 55 | ---- |
| 77e | | | 90–200 | C | 11–8–62 | 23 | 254 | 99 | 639 | 278 | 625 | 1,100 | ---- | ---- | 2,880 | 1,040 | 812 | 4,670 | 7.7 | 59 | ---- |
| 77f | | | 90–200 | C | 4–24–63 | 21 | 254 | 109 | 707 | 280 | 575 | 1,270 | ---- | ---- | 3,080 | 1,080 | 850 | 5,320 | 7.3 | 59 | ---- |
| 77g | | | 90–200 | C | 11–19–63 | 23 | 236 | 90 | 584 | 282 | 538 | 1,020 | ---- | ---- | 2,630 | 960 | 720 | 4,380 | 7.6 | 57 | ---- |
| 77h | | | 90–200 | C | 2–19–64 | 18 | 218 | 96 | 593 | 284 | 575 | 975 | ---- | ---- | 2,610 | 940 | 707 | 4,330 | 7.4 | 57 | ---- |
| 77i | | | 90–200 | C | 1–28–65 | 24 | 202 | 87 | 607 | 282 | 575 | 958 | ---- | ---- | 2,590 | 860 | 629 | 4,240 | 7.5 | 61 | ---- |
| 77j | | | 90–200 | C | 1–24–66 | 22 | 186 | 77 | 605 | 292 | 575 | 892 | ---- | ---- | 2,500 | 780 | 540 | 4,140 | 7.7 | 63 | ---- |
| 78 | 32daa1 | Irr | 126–181 | C | 3–26–63 | 25 | 258 | 94 | 696 | 301 | 483 | 1,270 | ---- | ---- | 2,980 | 1,030 | 784 | 4,970 | 7.6 | 59 | .63 |
| 79 | 32daa2 | Dom | 122–127 | C | 11–4–64 | 20 | 428 | 202 | 1,500 | 364 | 900 | 2,790 | ---- | ---- | 6,020 | 1,900 | 1,600 | 9,880 | 7.3 | 63 | ---- |
| 80a | 32ddc | Irr | 100–125 | C | 5–17–62 | 20 | 300 | 122 | 523 | 252 | 538 | 1,150 | ---- | ---- | 2,780 | 1,250 | 1,040 | 4,940 | 7.4 | 48 | ---- |
| 80b | | | 100–125 | C | 3–26–63 | 26 | 292 | 98 | 538 | 264 | 619 | 1,020 | ---- | ---- | 2,720 | 1,130 | 914 | 4,390 | 7.3 | 51 | ---- |
| 80c | | | 100–125 | C | 4–24–64 | 22 | 264 | 124 | 489 | 268 | 600 | 985 | ---- | ---- | 2,620 | 1,170 | 950 | 4,540 | 7.2 | 48 | ---- |
| 81 | 33aaa | Irr | 111–180 | C | 3–26–63 | 26 | 206 | 73 | 619 | 296 | 325 | 1,120 | ---- | ---- | 2,520 | 815 | 572 | 4,310 | 7.7 | 62 | .61 |
| 82a | 33add | Dr | 136–186 | C | 5–28–62 | 25 | 200 | 79 | 372 | 224 | 205 | 875 | 0.7 | .3 | 1,870 | 825 | 642 | 3,350 | 7.4 | 49 | .15 |
| 82b | | | 136–186 | C | 11–8–62 | 25 | 170 | 70 | 392 | 216 | 212 | 825 | ---- | ---- | 1,800 | 710 | 533 | 3,310 | 7.3 | 55 | .28 |
| 82c | | | 136–186 | C | 2–19–64 | 19 | 175 | 71 | 399 | 234 | 240 | 820 | ---- | ---- | 1,840 | 730 | 538 | 3,370 | 7.4 | 54 | ---- |
| 82d | | | 136–186 | C | 1–28–65 | 25 | 198 | 66 | 415 | 228 | 292 | 835 | ---- | ---- | 1,940 | 765 | 578 | 3,420 | 7.5 | 54 | ---- |
| 82e | | | 136–186 | C | 1–24–66 | 23 | 182 | 70 | 400 | 232 | 300 | 785 | ---- | ---- | 1,880 | 740 | 550 | 3,410 | 7.5 | 54 | ---- |
| 83 | 33bdb | Irr | 108–195 | C | 6–13–63 | 24 | 182 | 95 | 816 | 384 | 425 | 1,320 | ---- | ---- | 3,050 | 845 | 530 | 5,330 | 7.6 | 68 | ---- |
| 84a | 33caa1 | Dr | (?) | C | 1–12–62 | 25 | 268 | 117 | 476 | 248 | 333 | 1,160 | ---- | ---- | 2,500 | 1,150 | 946 | 4,440 | 7.6 | 47 | ---- |
| 84b | | | (?) | C | 2–21–62 | 26 | 235 | 81 | 440 | 240 | 263 | 995 | .7 | .7 | 2,160 | 920 | 724 | 3,760 | 8.0 | 57 | .32 |
| 84c | | | (?) | C | 11–8–62 | 25 | 210 | 87 | 446 | 244 | 292 | 955 | ---- | ---- | 2,140 | 880 | 680 | 3,830 | 7.4 | 52 | ---- |
| 85a | 33cbb | Dr | 115–190 | C | 1–22–62 | 18 | 278 | 113 | 618 | 295 | 438 | 1,280 | ---- | ---- | 2,890 | 1,160 | 918 | 5,110 | 7.6 | 54 | ---- |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85b | | | 115–190 | C | 2–21–62 | 26 | 255 | 93 | 638 | 289 | 376 | 1,260 | .8 | .3 | 2,790 | 1,020 | 783 | 4,780 | 7.4 | 58 | .56 |
| 85c | | | 115–190 | C | 11– 8–62 | 25 | 222 | 94 | 619 | 286 | 400 | 1,160 | ---- | ---- | 2,660 | 940 | 706 | 4,680 | 7.5 | 59 | ---- |
| 85d | | | 115–190 | C | 12–13–63 | 24 | 230 | 94 | 608 | 282 | 412 | 1,150 | ---- | ---- | 2,660 | 960 | 729 | 4,540 | 7.4 | 58 | ---- |
| 85e | | | 115–190 | C | 2–19–64 | 20 | 206 | 101 | 588 | 280 | 412 | 1,100 | ---- | ---- | 2,570 | 930 | 700 | 4,530 | 7.4 | 58 | ---- |
| 85f | | | 115–190 | C | 1–28–65 | 27 | 228 | 102 | 655 | 278 | 462 | 1,210 | ---- | ---- | 2,820 | 990 | 762 | 4,900 | 7.4 | 59 | ---- |
| 85g | | | 115–190 | C | 1–24–66 | 23 | 230 | 99 | 644 | 284 | 450 | 1,190 | ---- | ---- | 2,780 | 980 | 747 | 4,760 | 7.5 | 59 | ---- |
| 86a | 33ccc | Dr | 90–190 | C | 1–22–62 | 24 | 308 | 117 | 472 | 249 | 475 | 1,120 | ---- | ---- | 2,640 | 1,250 | 1,050 | 4,630 | 7.8 | 45 | ---- |
| 86b | | | 90–190 | C | 2–21–62 | 26 | 315 | 101 | 524 | 239 | 512 | 1,140 | ---- | ---- | 2,740 | 1,200 | 1,000 | 4,500 | 7.5 | 49 | ---- |
| 86c | | | 90–190 | C | 11– 8–62 | 25 | 274 | 101 | 517 | 246 | 575 | 1,010 | ---- | ---- | 2,620 | 1,100 | 898 | 4,350 | 7.4 | 50 | ---- |
| 86d | | | 90–190 | C | 2–19–64 | 19 | 242 | 99 | 499 | 256 | 612 | 885 | ---- | ---- | 2,480 | 1,010 | 800 | 4,120 | 7.3 | 52 | ---- |
| 86e | | | 90–190 | C | 1–28–65 | 25 | 222 | 79 | 522 | 266 | 650 | 795 | ---- | ---- | 2,430 | 880 | 612 | 3,870 | 7.5 | 56 | ---- |
| 86f | | | 90–190 | C | 1–24–66 | 24 | 198 | 72 | 493 | 280 | 600 | 715 | ---- | ---- | 2,240 | 790 | 560 | 3,610 | 7.5 | 58 | ---- |
| 87a | 33daa | PS | 260–280 | W | 5–23–63 | 21 | 74 | 24 | 236 | 208 | 85 | 379 | .9 | ---- | 924 | 284 | 114 | 1,720 | 7.4 | 64 | ---- |
| 87b | | | 260–280 | W | 11–29–63 | 17 | 62 | 22 | 230 | 180 | 80 | 362 | .8 | ---- | 864 | 244 | 96 | 1,620 | 7.6 | 67 | ---- |
| 87c | | | 260–280 | W | 10–13–67 | 17 | 74 | 33 | 253 | 196 | 100 | 428 | .8 | ---- | 1,000 | 320 | 160 | 1,880 | 7.6 | 63 | ---- |
| 88a | (C– 9–22) 5baa | Irr | 108–123 | C | 2–13–63 | 24 | 278 | 99 | 568 | 292 | 775 | 915 | ---- | ---- | 2,800 | 1,100 | 860 | 4,530 | 7.7 | 53 | ---- |
| 88b | | | 108–123 | C | 4–24–63 | 22 | 274 | 109 | 581 | 288 | 725 | 995 | ---- | ---- | 2,850 | 1,130 | 894 | 4,750 | 7.2 | 53 | ---- |
| 88c | | | 108–123 | C | 12–13–63 | 23 | 254 | 94 | 570 | 298 | 750 | 875 | ---- | ---- | 2,720 | 1,020 | 776 | 4,360 | 7.4 | 55 | ---- |
| 89 | 5bbc | Ta | 179–181 | C | 3–24–66 | 21 | 119 | 47 | 475 | 336 | 725 | 348 | 1.2 | ---- | 1,900 | 490 | 214 | 2,850 | 7.9 | 68 | ---- |

**West sector**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | (C– 8–23) 22ddc | Irr | (?) | (?) | 3– 4–63 | 22 | 174 | 67 | 312 | 344 | 250 | 600 | ---- | ---- | 1,600 | 710 | 428 | 2,860 | 7.5 | 49 | ---- |
| 91a | 23cdb | Irr | 68–90 | C | 1–17–63 | 28 | 193 | 90 | 377 | 384 | 550 | 555 | ---- | ---- | 1,980 | 850 | 535 | 3,180 | 7.6 | 49 | ---- |
| 91b | | | 68–90 | C | 5– 8–63 | 24 | 196 | 93 | 392 | 392 | 550 | 588 | ---- | ---- | 2,040 | 870 | 548 | 3,270 | 7.6 | 50 | ---- |
| 92a | 24cdb | Irr | 115–135 | C | 3– 4–63 | 26 | 193 | 75 | 295 | 432 | 388 | 478 | ---- | ---- | 1,670 | 790 | 436 | 2,850 | 7.5 | 45 | ---- |
| 92b | | | 115–135 | C | 5– 8–63 | 25 | 179 | 76 | 318 | 384 | 425 | 492 | ---- | ---- | 1,710 | 760 | 445 | 2,800 | 7.7 | 48 | ---- |
| 93a | 24dcc | Irr | (?) | (?) | 3– 4–63 | 29 | 204 | 78 | 406 | 370 | 350 | 740 | ---- | 2.4 | 1,990 | 830 | 527 | 3,330 | 7.8 | 52 | 0.28 |
| 93b | | | (?) | (?) | 5– 8–63 | 25 | 242 | 73 | 414 | 444 | 375 | 745 | ---- | ---- | 2,100 | 905 | 541 | 3,570 | 7.5 | 50 | ---- |
| 94a | 25acb | Irr | 115–175 | C | 10– 5–62 | 26 | 180 | 71 | 360 | 365 | 233 | 695 | ---- | ---- | 1,750 | 740 | 440 | 3,200 | 7.2 | 51 | ---- |
| 94b | | | 115–175 | C | 5– 8–63 | 23 | 169 | 75 | 375 | 336 | 242 | 722 | ---- | ---- | 1,770 | 730 | 454 | 3,140 | 7.6 | 53 | ---- |
| 95a | 25bcc | Irr | 130–180 | C | 2– 3–63 | 24 | 190 | 82 | 476 | 350 | 312 | 875 | ---- | ---- | 2,130 | 810 | 523 | 3,850 | 7.5 | 56 | ---- |
| 95b | | | 130–180 | C | 3– 4–63 | 25 | 212 | 61 | 435 | 346 | 287 | 810 | ---- | .2 | 2,000 | 780 | 496 | 3,390 | 7.9 | 55 | .32 |
| 95c | | | 130–180 | C | 6–13–63 | 23 | 194 | 84 | 459 | 398 | 325 | 825 | ---- | ---- | 2,110 | 830 | 504 | 3,660 | 7.3 | 55 | ---- |
| 96a | 25cab | Irr | 115–170 | C | 1–27–61 | 32 | 240 | 76 | 499 | 403 | 337 | 950 | ---- | 4.5 | 2,340 | 910 | 580 | 3,960 | 7.4 | 54 | .54 |
| 96b | | | 115–170 | C | 3– 4–63 | 24 | 183 | 74 | 441 | 360 | 242 | 832 | ---- | ---- | 1,980 | 760 | 465 | 3,590 | 7.4 | 56 | ---- |
| 96c | | | 115–170 | C | 4–10–63 | 24 | 185 | 74 | 442 | 364 | 267 | 815 | ---- | ---- | 1,990 | 765 | 466 | 3,560 | 7.4 | 56 | ---- |
| 97a | 25dab | Irr | 115–175 | C | 10– 5–62 | 24 | 194 | 73 | 393 | 348 | 242 | 782 | ---- | ---- | 1,880 | 785 | 500 | 3,400 | 7.3 | 52 | ---- |
| 97b | | | 115–175 | C | 4–10–63 | 24 | 191 | 79 | 399 | 354 | 233 | 805 | ---- | ---- | 1,910 | 800 | 510 | 3,460 | 7.3 | 52 | ---- |
| 98 | 26acd | Irr | 116–175 | C | 3– 3–63 | 22 | 258 | 101 | 610 | 438 | 350 | 1,180 | ---- | ---- | 2,740 | 1,060 | 701 | 4,850 | 7.4 | 56 | ---- |
| 99a | 26bac | Irr | 142–180 | C | 10–10–62 | 23 | 300 | 117 | 557 | 432 | 475 | 1,130 | ---- | ---- | 2,820 | 1,230 | 876 | 4,860 | 7.1 | 50 | ---- |
| 99b | | | 142–180 | C | 5– 8–63 | 22 | 278 | 123 | 577 | 360 | 450 | 1,200 | ---- | ---- | 2,830 | 1,200 | 905 | 4,850 | 7.4 | 51 | ---- |
| 101 | 26cab | Dr | 124–174 | C | 3– 6–65 | 23 | 588 | 234 | 1,680 | 416 | 725 | 3,540 | ---- | ---- | 7,000 | 2,430 | 2,090 | 11,600 | 7.3 | 60 | ---- |
| 102a | 26cda | Irr | 145–173 | C | 5–29–62 | 18 | 366 | 148 | 940 | 338 | 475 | 1,980 | ---- | ---- | 4,100 | 1,520 | 1,240 | 7,120 | 7.4 | 57 | ---- |
| 102b | | | 145–173 | C | 6–13–63 | 21 | 358 | 155 | 964 | 368 | 512 | 1,980 | ---- | ---- | 4,170 | 1,530 | 1,230 | 7,190 | 7.4 | 58 | ---- |
| 103a | 26ddb | Dr | 126–196 | C | 3–29–65 | 28 | 402 | 189 | 1,180 | 384 | 575 | 2,440 | ---- | ---- | 5,010 | 1,780 | 1,460 | 7,780 | 7.4 | 59 | ---- |
| 103b [2] | | | 126–196 | C | 12– 2–65 | ---- | 333 | 137 | 899 | 357 | 432 | 1,850 | ---- | ---- | 3,830 | 1,400 | 1,100 | 6,590 | ---- | 58 | ---- |
| 104a | 26dbd | Irr | 160–200 | C | 5–29–62 | 17 | 316 | 137 | 785 | 344 | 362 | 1,700 | ---- | ---- | 3,490 | 1,350 | 1,070 | 6,320 | 7.5 | 56 | ---- |
| 104b | | | 160–200 | C | 3–19–63 | 24 | 355 | 135 | 872 | 361 | 413 | 1,850 | ---- | ---- | 3,830 | 1,140 | 1,140 | 6,530 | 7.7 | 57 | .55 |
| 104c | | | 160–200 | C | 7–13–67 | 27 | 238 | 94 | 632 | 448 | 500 | 1,040 | ---- | ---- | 2,760 | 980 | 612 | 4,570 | 7.5 | 58 | ---- |
| 105a | 27abb | Irr | 85–180 | C | 5–22–61 | 28 | 275 | 98 | 448 | 344 | 273 | 1,040 | ---- | ---- | 2,340 | 1,090 | 808 | 4,050 | 7.6 | 47 | .26 |
| 105b | | | 85–180 | C | 3–19–63 | 24 | 258 | 123 | 484 | 296 | 312 | 1,160 | ---- | ---- | 2,510 | 1,150 | 908 | 4,670 | 7.3 | 48 | ---- |
| 106 | 27acb | Dr | 130–160 | C | 4– 1–65 | 25 | 278 | 109 | 493 | 320 | 233 | 1,210 | ---- | ---- | 2,510 | 1,140 | 878 | 4,360 | 7.3 | 48 | ---- |
| 107 | 27ada | T | 84–160 | C | 12– 2–63 | 21 | 860 | 256 | 1,160 | 336 | 600 | 3,420 | ---- | ---- | 6,480 | 3,200 | 2,920 | 10,700 | 7.2 | 44 | ---- |
| 108a | 27ddd | Irr | 135–158 | C | 1–30–61 | 28 | 292 | 110 | 739 | 339 | 394 | 1,520 | ---- | 2.2 | 3,250 | 1,180 | 902 | 5,550 | 7.2 | 58 | .61 |
| 108b | | | 135–158 | C | 10– 8–62 | 23 | 312 | 132 | 715 | 340 | 438 | 1,610 | ---- | ---- | 3,460 | 1,320 | 1,040 | 6,190 | 7.0 | 56 | ---- |
| 108c | | | 135–158 | C | 6–13–63 | 22 | 342 | 128 | 832 | 348 | 500 | 1,690 | ---- | ---- | 3,690 | 1,380 | 1,090 | 6,360 | 7.4 | 57 | ---- |
| 108d | | | 135–158 | C | 2–19–64 | 17 | 350 | 128 | 796 | 348 | 512 | 1,640 | ---- | ---- | 3,620 | 1,400 | 1,110 | 6,210 | 7.2 | 55 | ---- |
| 109a | 35aac | Dr | 125–195 | C | 4–19–65 | 24 | 242 | 87 | 671 | 312 | 562 | 1,120 | ---- | ---- | 2,860 | 960 | 704 | 4,640 | 7.5 | 60 | ---- |
| 109b [2] | | | 125–195 | C | 12– 2–65 | ---- | 254 | 93 | 742 | 320 | 576 | 1,250 | ---- | ---- | 3,080 | 1,010 | 750 | 5,180 | ---- | 61 | ---- |
| 110a | 35aca | Irr | 130–155 | C | 3–26–63 | 22 | 258 | 109 | 742 | 332 | 575 | 1,300 | ---- | ---- | 3,170 | 1,090 | 818 | 5,500 | 7.7 | 60 | ---- |
| 110b | | | 130–155 | C | 11–19–63 | 23 | 262 | 73 | 741 | 340 | 625 | 1,250 | ---- | ---- | 3,140 | 1,080 | 801 | 5,190 | 7.5 | 60 | ---- |
| 111 | 35adb | Irr | 140–171 | C | 6–13–63 | 23 | 187 | 73 | 465 | 272 | 338 | 852 | ---- | ---- | 2,070 | 765 | 542 | 3,590 | 7.6 | 57 | ---- |
| 112a | 35caa | Irr | 150–186 | C | 3–26–63 | 25 | 182 | 54 | 406 | 246 | 454 | 627 | ---- | 0.3 | 1,870 | 675 | 474 | 3,060 | 7.5 | 57 | .26 |
| 112b | | | 150–186 | C | 11–19–63 | 25 | 214 | 62 | 469 | 248 | 562 | 725 | ---- | ---- | 2,180 | 790 | 586 | 3,560 | 7.6 | 56 | ---- |
| 113a | 36aaa | Irr | (?) | (?) | 1–31–63 | 24 | 274 | 94 | 446 | 248 | 512 | 925 | ---- | ---- | 2,400 | 1,070 | 866 | 4,050 | 7.5 | 48 | ---- |
| 113b | | | (?) | (?) | 3–19–63 | 20 | 267 | 91 | 412 | 232 | 425 | 925 | ---- | ---- | 2,260 | 1,040 | 850 | 3,950 | 7.6 | 46 | ---- |
| 113c | | | (?) | (?) | 4–10–63 | 21 | 270 | 92 | 415 | 252 | 425 | 925 | ---- | ---- | 2,270 | 1,050 | 844 | 4,030 | 7.4 | 46 | ---- |

**UPPER VALLEY SUBAREA**

**"Laguna Valley" sector**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 201a | 15S/24E–17L | PS | (?) | (?) | 1–24–61 | 20 | 93 | 28 | 115 | 174 | 297 | 108 | ---- | 0 | 748 | 348 | 206 | 1,160 | 7.4 | 42 | 0.16 |
| 201b | | | (?) | (?) | 1– 4–62 | 20 | 97 | 29 | 131 | 178 | 325 | 115 | ---- | ---- | 806 | 362 | 216 | 1,220 | 7.8 | 44 | ---- |
| 202 | 17K5 | T | 17 | U | 5–14–62 | 9 | 39 | 7.2 | 255 | 192 | 300 | 150 | ---- | ---- | 856 | 127 | 0 | 1,370 | 8.3 | 81 | ---- |
| 203 | 20H1 | T | 16 | U | 5–14–62 | 19 | 216 | 59 | 123 | 218 | 308 | 388 | ---- | ---- | 1,220 | 780 | 601 | 2,230 | 7.6 | 26 | 0 |
| 204 | 30R1 | T | 16 | U | 5–14–62 | 16 | 212 | 76 | 227 | 372 | 400 | 435 | ---- | ---- | 1,550 | 840 | 535 | 2,690 | 7.0 | 37 | ---- |
| 205 | (C– 7–21) 6ccd | T | 13 | U | 5–14–62 | 14 | 71 | 21 | 190 | 166 | 242 | 205 | ---- | ---- | 826 | 264 | 128 | 1,540 | 7.8 | 61 | ---- |
| 206a | (C– 7–22) 14bdc | T | 118–162 | C | 5–29–63 | 15 | 103 | 30 | 132 | 180 | 330 | 126 | ---- | .1 | 825 | 382 | 234 | 1,280 | 7.7 | 43 | .14 |
| 206b | | | 470–490 | N | 5–23–63 | 32 | 297 | 57 | 860 | 136 | 660 | 1,450 | ---- | .4 | 3,420 | 975 | 864 | 5,610 | 7.9 | 66 | .76 |
| 207 | 14cad | Dom | 29–31 | U | 10– 4–62 | 23 | 131 | 62 | 186 | 194 | 362 | 317 | 1.1 | ---- | 1,180 | 582 | 423 | 2,010 | 7.1 | 41 | ---- |

See footnotes at end of table.

*Chemical analyses of ground water*—Continued

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica (SiO₂) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Na + K | Bicarbonate (HCO₃) | Sulfate (SO₄) | Chloride (Cl) | Fluoride (F) | Nitrate (NO₃) | Dissolved solids (sum) | Hardness as CaCO₃: Calcium magnesium | Hardness as CaCO₃: Noncarbonate | Specific conductance (micromhos at 25°C) | pH | Percent sodium | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPPER VALLEY SUBAREA—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| **North Gila sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 208 | (C–7–22)14ddc | Dom | 30 | U | 10–4–62 | 13 | 98 | 31 | | | 155 | 166 | 362 | 137 | 0.7 | ---- | 880 | 370 | 234 | 1,400 | 7.3 | 48 | ---- |
| 209 | 27bba | Dom | 28–30 | U | 8–28–62 | 19 | 167 | 57 | | | 234 | 362 | 550 | 204 | 1.1 | ---- | 1,410 | 650 | 353 | 2,320 | 7.2 | 44 | ---- |
| 210 | 27cad | Dom | 33–35 | U | 8–28–62 | 26 | 196 | 61 | | | 453 | 368 | 875 | 362 | .9 | ---- | 2,160 | 740 | 438 | 3,270 | 7.4 | 57 | ---- |
| 211 | 27ccd | Dom | 130 | C | 8–28–62 | 26 | 218 | 57 | | | 264 | 258 | 325 | 570 | .5 | ---- | 1,590 | 780 | 568 | 2,860 | 7.3 | 42 | ---- |
| 212a | 28acc | Ta | 142–144 | C | 5–7–65 | 21 | 158 | 15 | | | 210 | 324 | 412 | 155 | .4 | ---- | 1,130 | 456 | 190 | 1,670 | 7.7 | 50 | ---- |
| 212b | | | 142–144 | C | 7–6–65 | 14 | 150 | 31 | | | 181 | 320 | 401 | 152 | .6 | ---- | 1,090 | 500 | 238 | 1,650 | 7.9 | 44 | ---- |
| 213 | 28ddc | Dom | <100 | C | 8–28–62 | 23 | 148 | 35 | | | 170 | 245 | 450 | 151 | .6 | ---- | 1,100 | 515 | 314 | 1,710 | 7.4 | 42 | ---- |
| 214 | 34bdc | Dom | <130 | C | 8–28–62 | 23 | 42 | 12 | | | 249 | 221 | 325 | 123 | .9 | ---- | 885 | 154 | 0 | 1,480 | 7.6 | 78 | ---- |
| 215a | (C–8–22)3cb | Ta | 112–114 | C | 5–10–65 | 30 | 106 | 48 | | | 543 | 368 | 600 | 505 | 1.2 | ---- | 2,020 | 460 | 158 | 3,190 | 8.0 | 72 | ---- |
| 215b | | | 112–114 | C | 7–6–65 | 25 | 86 | 50 | | | 525 | 384 | 550 | 475 | 1.4 | ---- | 1,900 | 420 | 105 | 3,170 | 8.2 | 77 | ---- |
| 216 | 4abc | Dom | <121 | C | 8–28–62 | 25 | 150 | 45 | | | 172 | 259 | 412 | 207 | .6 | ---- | 1,140 | 560 | 348 | 1,830 | 7.4 | 40 | ---- |
| 217a | 15bdd | T | 90–185 | C, W | 1–30–64 | 30 | 114 | 44 | | | 216 | 304 | 400 | 189 | .6 | 0.2 | 1,140 | 464 | 214 | 1,800 | 7.5 | 50 | ---- |
| 217b | | | 491 | W | 12–20–63 | 6 | 111 | 25 | | | 254 | 152 | 125 | 478 | .8 | ---- | 1,080 | 378 | 254 | 2,050 | 7.8 | 59 | ---- |
| 218 | 16caa | St | 110–148 | C | 8–28–62 | 27 | 97 | 40 | | | 242 | 347 | 400 | 162 | 1.0 | ---- | 1,140 | 406 | 122 | 1,850 | 7.5 | 56 | ---- |
| 219 | 21aaa | Dom | 30 | U | 8–28–62 | 28 | 182 | 67 | | | 205 | 487 | 500 | 180 | .8 | ---- | 1,410 | 730 | 330 | 2,200 | 7.2 | 40 | ---- |
| **Bard sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 220 | 15S/23E–31Cbb | Ta | 106–108 | O | 4–16–63 | 22 | 227 | 79 | | | 172 | 130 | 350 | 562 | 0.6 | ---- | 1,480 | 890 | 784 | 2,580 | 7.3 | 30 | ---- |
| 221a | 31Fcd | Ta | 92–94 | O | 4–16–63 | 28 | 170 | 62 | | | 335 | 278 | 575 | 412 | .3 | ---- | 1,720 | 680 | 452 | 2,760 | 7.9 | 52 | ---- |
| 221b | | | 92–94 | O | 5–4–64 | 19 | 143 | 52 | | | 327 | 316 | 575 | 300 | ---- | ---- | 1,570 | 570 | 311 | 2,490 | 7.6 | 56 | ---- |
| 222 | 32Rdd | Ta | 114–116 | C | 4–29–64 | 24 | 74 | 13 | | | 78 | 195 | 95 | 102 | ---- | ---- | 482 | 234 | 74 | 838 | 7.4 | 42 | ---- |
| 223 | 33 Fac | Dom | 130 | C | 5–9–64 | 16 | 164 | 40 | | | 201 | 304 | 512 | 162 | .9 | ---- | 1,250 | 575 | 326 | 1,860 | 7.5 | 43 | ---- |
| 224 | 34Dbb | Ta | 106–108 | C | 4–29–64 | 12 | 73 | 22 | | | 202 | 208 | 350 | 126 | ---- | ---- | 889 | 272 | 102 | 1,410 | 7.2 | 62 | ---- |
| 225 [5] | 35Eac | Dom | <130 | C(?) | 3–17–64 | ---- | 50 | 35 | | | 158 | 204 | 195 | 174 | .4 | ---- | 714 | 270 | 102 | ---- | 7.9 | 56 | ---- |
| 227a | 16S/22E–1Lab | Ta | 59–61 | U | 2–9–62 | 12 | 94 | 31 | | | 133 | 175 | 342 | 109 | ---- | ---- | 809 | 364 | 221 | 1,220 | 7.9 | 44 | ---- |
| 227b | | | 59–61 | U | 5–1–64 | 10 | 105 | 28 | | | 120 | 168 | 308 | 127 | ---- | ---- | 782 | 376 | 238 | 1,270 | 7.5 | 41 | ---- |
| 228 | 2acd | Ta | 91–93 | O | 5–1–64 | 14 | 66 | 20 | | | 181 | 152 | 183 | 231 | ---- | ---- | 771 | 248 | 124 | 1,360 | 6.9 | 61 | ---- |
| 229 | 12Hdd | Ta | 126–128 | C | 4–28–64 | 16 | 73 | 12 | | | 110 | 161 | 120 | 151 | ---- | ---- | 562 | 230 | 98 | 1,000 | 7.3 | 51 | ---- |
| 230 | 14Mba | Ta | 63–65 | U | 4–28–64 | 7 | 96 | 30 | | | 136 | 188 | 317 | 125 | ---- | ---- | 805 | 364 | 210 | 1,290 | 7.7 | 45 | ---- |
| 231a | 23Caa | T | [6] 320 | W | 3–22–64 | 16 | 100 | 9.4 | | | 271 | 234 | 362 | 217 | ---- | ---- | 1,090 | 288 | 96 | 1,790 | 7.6 | 67 | ---- |
| 231b | | | [6] 355 | W | 3–25–64 | 15 | 99 | 27 | | | 348 | 70 | 412 | 447 | ---- | ---- | 1,380 | 302 | 99 | 2,370 | 7.8 | 68 | ---- |
| 232 | 23Fcd | Ta | 138.5–140.5 | C | 4–28–64 | 14 | 84 | 22 | | | 128 | 156 | 292 | 102 | ---- | ---- | 720 | 298 | 170 | 1,130 | 7.6 | 48 | ---- |
| 233 | 26Bbb | Ta | 116–118 | C | 4–28–64 | 13 | 191 | 47 | | | 173 | 256 | 333 | 348 | ---- | ---- | 1,230 | 670 | 460 | 2,070 | 7.7 | 36 | ---- |
| 234 | 26Gcd | PS | 140–150 | C | 5–31–66 | 16 | 114 | 38 | | | 118 | 200 | 275 | 173 | .6 | ---- | 835 | 440 | 276 | 1,430 | 7.3 | 37 | ---- |
| 235 | 16S/23E–3Dbb | Dom, St | 108–118 | C | 12–11–61 | 25 | 150 | 38 | | | 161 | 280 | 450 | 131 | ---- | ---- | 1,100 | 532 | 302 | 1,600 | 7.8 | 40 | ---- |
| 236 | 3Ncc | Ta | 126–128 | C | 4–29–64 | 19 | 239 | 57 | | | 310 | 200 | 775 | 262 | ---- | ---- | 1,860 | 830 | 502 | 2,710 | 7.4 | 45 | ---- |
| 237a | 6Cba | Ta | 62–64 | U | 4–16–63 | 20 | 80 | 35 | | | 173 | 194 | 342 | 145 | .6 | ---- | 893 | 344 | 185 | 1,420 | 7.8 | 52 | ---- |
| 237b | | | 62–64 | U | 4–30–64 | 16 | 62 | 39 | | | 189 | 170 | 362 | 147 | .7 | ---- | 901 | 314 | 174 | 1,420 | 7.3 | 57 | ---- |
| 238 | 6Gcb | Ta | 126–128 | C | 4–29–64 | 21 | 89 | 24 | | | 114 | 178 | 267 | 102 | ---- | ---- | 706 | 320 | 174 | 1,120 | 7.6 | 44 | ---- |
| 239 | 7Caa | Dom | 113 | C | 12–12–61 | 24 | 209 | 54 | | | 173 | 356 | 559 | 174 | .3 | 1.2 | 1,370 | 898 | 606 | 1,970 | 7.8 | 34 | ---- |
| 240 | 8Ecc | T | 110–141 | C | 12–18–63 | 18 | 194 | 49 | | | 256 | 392 | 600 | 208 | .7 | 1.5 | 1,520 | 685 | 364 | 2,320 | 7.6 | 45 | 0.29 |
| 241 | 19Mbc | PS | 120–200 | C, W | 5–18–61 | 11 | 230 | 56 | 278 | 6.4 | | 376 | 606 | 332 | .3 | .3 | 1,710 | 805 | 497 | 2,530 | 8.0 | 43 | ---- |
| **The Island sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 242a | 16S/23E–9Naa | Irr | 124–225 | C, W | 5–24–62 | 28 | 130 | 36 | | | 138 | 292 | 250 | 195 | 0.5 | ---- | 973 | 474 | 234 | 1,630 | 7.2 | 39 | ---- |
| 242b | | | 124–225 | C, W | 4–20–63 | 23 | 159 | 50 | | | 231 | 277 | 490 | 262 | ---- | 0.3 | 1,350 | 604 | 377 | 2,050 | 7.7 | 45 | ---- |
| 242c | | | 124–225 | C, W | 6–15–67 | 21 | 161 | 60 | | | 212 | 332 | 462 | 252 | .7 | ---- | 1,330 | 650 | 378 | 2,150 | 7.5 | 41 | ---- |
| 243a | 10Rcc | T | [6] 133 | C | 10–16–64 | 12 | 188 | 15 | | | 231 | 302 | 525 | 169 | .7 | ---- | 1,290 | 532 | 284 | 1,930 | 7.7 | 48 | ---- |
| 243b | | | [1] 634–694 | B | 1–21–65 | 26 | 108 | 27 | | | 281 | 144 | 200 | 468 | 1.9 | ---- | 1,180 | 380 | 262 | 2,120 | 7.6 | 62 | ---- |
| 243c | | | [1] 120–548 | C, W | 4–7–65 | 19 | 75 | 18 | 104 | 4.2 | | 207 | 126 | 129 | .4 | .1 | 581 | 260 | 85 | 964 | ---- | ---- | 0.12 |
| 244 | 19Pac | Irr | (?) | (?) | 10–23–65 | 23 | 223 | 74 | | | 222 | 404 | 500 | 348 | .6 | ---- | 1,590 | 860 | 528 | 2,630 | 7.7 | 36 | ---- |
| 245 | 22Fdc | Irr | (?) | (?) | 10–29–62 | 24 | 147 | 57 | | | 298 | 332 | 350 | 432 | .7 | ---- | 1,470 | 600 | 328 | 2,570 | 7.4 | 52 | ---- |
| 246 | 22Rbd | Irr | 105–130 | C | 6–15–67 | 24 | 170 | 62 | | | 347 | 312 | 238 | 660 | ---- | ---- | 1,660 | 680 | 424 | 3,010 | 7.3 | 53 | ---- |
| 247a | 31Dbc | Ir | 100–144 | C | 7–11–62 | 20 | 165 | 63 | | | 311 | 394 | 412 | 422 | ---- | ---- | 1,590 | 670 | 347 | 2,570 | 7.6 | 50 | ---- |
| 247b | | | 100–144 | C | 4–30–63 | 25 | 169 | 60 | | | 322 | 392 | 400 | 448 | ---- | ---- | 1,620 | 670 | 348 | 2,650 | 7.3 | 51 | ---- |
| 248 | (C–8–22)6cda | Irr | 128–166 | C | 6–15–67 | 21 | 111 | 37 | | | 164 | 300 | 205 | 232 | .6 | ---- | 920 | 430 | 184 | 1,430 | 7.3 | 45 | ---- |
| 249a | 7ccd | Irr | 110–160 | C | 4–27–64 | 21 | 151 | 49 | | | 379 | 304 | 283 | 608 | .7 | ---- | 1,640 | 580 | 330 | 2,880 | 7.6 | 59 | ---- |
| 249b | | | 110–160 | C | 12–15–66 | 21 | 153 | 53 | | | 388 | 334 | 228 | 615 | 1.0 | ---- | 1,690 | 600 | 326 | 2,950 | 7.6 | 58 | ---- |
| 250a | 18cbd | Irr | 110–160 | C | 5–29–62 | 18 | 178 | 67 | | | 417 | 334 | 210 | 805 | .8 | ---- | 1,860 | 720 | 446 | 3,560 | 7.8 | 56 | ---- |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 250b | | | 110–160 | C | 10–16–62 | 25 | 162 | 63 | | 434 | | 326 | 275 | 748 | ---- | ---- | 1,870 | 665 | 398 | 3,420 | 7.4 | 59 | ---- |
| 251 | 18ddd | Irr | 100–155 | C | 10–15–62 | 23 | 91 | 38 | | 256 | | 264 | 292 | 299 | ---- | ---- | 1,130 | 384 | 168 | 1,930 | 7.4 | 59 | ---- |
| 252 | (C– 8–23)11dca | Irr | 110–160 | C | 6–15–67 | 23 | 183 | 54 | | 224 | | 348 | 325 | 385 | .6 | ---- | 1,370 | 680 | 394 | 2,370 | 7.4 | 42 | ---- |
| 253 | 12aad | Irr | (?) | (?) | 6–15–67 | 22 | 156 | 51 | | 252 | | 352 | 350 | 350 | .7 | ---- | 1,360 | 600 | 312 | 2,310 | 7.4 | 48 | ---- |
| 254a | 12cdb | Irr | 115–171 | C | 11– 8–62 | 23 | 175 | 52 | | 293 | | 330 | 183 | 585 | ---- | ---- | 1,480 | 650 | 380 | 2,720 | 7.4 | 50 | ---- |
| 254b | | | 115–171 | C | 6–15–67 | 23 | 194 | 60 | | 338 | | 376 | 238 | 645 | ---- | ---- | 1,690 | 730 | 422 | 3,010 | 7.3 | 50 | ---- |
| 255 | 16S/22E–25Mbb2 | Ta | 117–119 | C | 4–28–64 | 22 | 117 | 41 | | 196 | | 314 | 375 | 170 | ---- | ---- | 1,080 | 460 | 202 | 1,660 | 7.7 | 48 | ---- |
| **Winterhaven sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 256 | 16S/22E–16Lda | Ta | 126½–128½ | C | 4–30–64 | 23 | 65 | 20 | | 139 | | 168 | 283 | 81 | ---- | ---- | 695 | 244 | 106 | 1,070 | ---- | 55 | ---- |
| 257 | 17Aac | Ta | 63–65 | U | 7– 6–65 | ---- | 24 | 14 | | 316 | | 268 | 325 | 151 | 12 | ---- | 976 | 116 | 0 | 1,680 | ---- | 86 | ---- |
| 258 | 17Pdd | Ta | 121–123 | C | 4–30–64 | 22 | 51 | 17 | | 203 | | 216 | 308 | 100 | ---- | ---- | 809 | 188 | 21 | 1,270 | ---- | 69 | ---- |
| 259 | 20Hdd | Ta | 117–119 | C | 4–30–64 | 21 | 156 | 44 | | 279 | | 360 | 525 | 238 | ---- | ---- | 1,440 | 570 | 275 | 2,220 | ---- | 52 | ---- |
| 260 | 21Rdd | Ta | 124–126 | C | 4–30–64 | 11 | 201 | 65 | | 396 | | 364 | 750 | 392 | ---- | ---- | 2,000 | 770 | 472 | 2,990 | ---- | 53 | ---- |
| 261 | 22Dbb | Ta | 126–128 | C | 4–29–64 | 22 | 144 | 40 | | 209 | | 304 | 488 | 158 | ---- | ---- | 1,210 | 525 | 276 | 1,850 | ---- | 46 | ---- |
| 262 | 22Gdc | Ta | 116–118 | C | 4–29–64 | 22 | 130 | 32 | | 218 | | 328 | 350 | 210 | ---- | ---- | 1,130 | 455 | 186 | 1,770 | ---- | 51 | ---- |
| 263a | 26Ecc | PS | 121–133 | C | 9–20–61 | 29 | 120 | 34 | 138 | | 4.2 | 218 | 374 | 120 | .4 | 0.1 | 927 | 440 | 262 | 1,390 | ---- | 40 | 0.40 |
| 263b | | | 121–133 | C | 4–28–65 | 22 | 156 | 51 | | 207 | | 296 | 500 | 202 | .7 | ---- | 1,290 | 600 | 358 | 1,980 | ---- | 43 | ---- |
| 263c | | | 121–133 | C | 5–26–66 | 23 | 150 | 50 | | 220 | | 298 | 525 | 188 | .7 | ---- | 1,310 | 580 | 336 | 1,990 | ---- | 45 | ---- |
| 264 | 27Hda | PS | 135–146 | C | 7–19–61 | 29 | 128 | 36 | 185 | | 5.0 | 262 | 437 | 142 | .2 | 1.4 | 1,600 | 467 | 252 | 1,600 | ---- | 46 | ---- |
| 265 | 27Jda | Ta | 124–126 | C | 5– 4–65 | 23 | 172 | 56 | | 231 | | 356 | 538 | 218 | .9 | ---- | 1,420 | 660 | 368 | 2,190 | ---- | 43 | ---- |
| 266 | 27Mdd | Ta | 104–106 | C | 5– 5–65 | 23 | 414 | 118 | | 642 | | 484 | 850 | 1,160 | ---- | ---- | 3,450 | 1,520 | 1,120 | 5,200 | ---- | 48 | ---- |
| 267a | 29Dba | Irr | 118–143 | C | 2–10–64 | 17 | 168 | 49 | | 178 | | 282 | 200 | 403 | .4 | ---- | 1,160 | 620 | 389 | 2,060 | ---- | 38 | ---- |
| 267b | | | 118–143 | C | 2–19–65 | 23 | 164 | 44 | | 185 | | 272 | 200 | 398 | ---- | ---- | 1,150 | 590 | 367 | 1,980 | ---- | 40 | ---- |
| 268a | 29Gca1 | Ta | 140–142 | C | 4–30–64 | 19 | 76 | 20 | | 120 | | 207 | 130 | 161 | ---- | ---- | 630 | 270 | 100 | 1,080 | ---- | 49 | ---- |
| 268b | | | 140–142 | C | 4–30–65 | 17 | 78 | 16 | | 120 | | 192 | 120 | 168 | .5 | ---- | 616 | 260 | 102 | 1,040 | ---- | 50 | ---- |
| 268c | | | 140–142 | C | 7– 9–65 | 4 | 52 | 16 | | 114 | | 148 | 100 | 155 | .2 | ---- | 515 | 196 | 74 | 944 | ---- | 56 | ---- |
| 269a | 29Gca2 | T | [7]38–40 | U | 2–17–65 | 19 | 310 | 87 | | 428 | | 368 | 700 | 730 | ---- | ---- | 2,460 | 1,130 | 828 | 3,870 | ---- | 45 | ---- |
| 269b | | | 125–1,769 | C, W, N | 4–13–65 | 19 | 100 | 24 | 118 | | 4.8 | 200 | 102 | 244 | ---- | ---- | 712 | 349 | 185 | 1,270 | ---- | 42 | .14 |
| **YUMA VALLEY SUBAREA** | | | | | | | | | | | | | | | | | | | | | | | |
| **California sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 301 | 16S/21E–25Gca | Ta | 121–123 | C | 7– 7–65 | 1 | 23 | 16 | | 109 | | 84 | 82 | 143 | 1.7 | ---- | 418 | 123 | 55 | 797 | 7.2 | 66 | ---- |
| 302 | 25R | Dom | 110–120 | C | 2–28–64 | 22 | 102 | 26 | | 113 | | 252 | 210 | 128 | .1 | ---- | 727 | 360 | 154 | 1,170 | 7.8 | 41 | ---- |
| 303a | 36Fca | Ind | 518–912 | W | 6–14–61 | 18 | 58 | 13 | | 80 | | 182 | 82 | 98 | .3 | 0.6 | 439 | 196 | 47 | 750 | 7.5 | 47 | 0.26 |
| 303b | | | 518–912 | W | 2– 1–66 | 15 | 61 | 15 | | 80 | | 186 | 80 | 107 | ---- | ---- | 451 | 212 | 60 | 810 | 7.5 | 45 | ---- |
| 304 | 36Mad | Ind | 471–740 | W | 11– 1–65 | 15 | 58 | 13 | | 80 | | 178 | 75 | 103 | .4 | ---- | 433 | 196 | 50 | 761 | 7.6 | 47 | ---- |
| 306 | 16S/22E–27Pcb | Dom | 33–35 | U | 9– 7–62 | 23 | 159 | 45 | | 175 | | 464 | 208 | 205 | ---- | ---- | 1,050 | 580 | 200 | 1,740 | 7.4 | 35 | ---- |
| 307 | 28Kcc | Dom | 130 | C | 8– 2–62 | 17 | 60 | 15 | | 69 | | 172 | 82 | 96 | .4 | ---- | 425 | 212 | 71 | 719 | 7.6 | 42 | ---- |
| 308a | 28Paa1 | Irr | 120–143 | C | 8– 2–62 | 15 | 103 | 28 | | 130 | | 282 | 308 | 149 | .8 | ---- | 925 | 372 | 141 | 1,410 | 7.4 | 51 | ---- |
| 308b | | | 120–143 | C | 5–19–64 | 16 | 106 | 24 | | 176 | | 276 | 300 | 145 | .7 | ---- | 906 | 362 | 136 | 1,420 | 7.4 | 51 | ---- |
| 309 | 16S/22E–28Paa2 | Dom | <248 | C, W(?) | 7– 6–64 | 27 | 50 | 15 | | 68 | | 192 | 57 | 80 | .4 | ---- | 392 | 184 | 26 | 675 | 7.7 | 44 | ---- |
| 310 | 28Rab1 | Dom | 33–35 | U | 8–23–63 | 22 | 166 | 55 | | 374 | | 532 | 550 | 315 | ---- | ---- | 1,750 | 166 | 55 | 2,800 | 7.6 | 56 | ---- |
| 311 | 28Rab2 | Dom | <112 | C(?) | 8–23–63 | 18 | 84 | 22 | | 80 | | 242 | 115 | 109 | .4 | ---- | 549 | 298 | 100 | 1,030 | 7.7 | 37 | ---- |
| 312 | 28Rab3 | Dom<br>Irr | 117–132 | C | 1–25–65 | 18 | 71 | 25 | | 94 | | 214 | 150 | 106 | .3 | ---- | 571 | 278 | 102 | 955 | 7.7 | 42 | ---- |
| 313 | 29Jcc | Ta | 106–108 | U | 5– 6–65 | 21 | 190 | 40 | | 294 | | 378 | 562 | 272 | .7 | ---- | 1,570 | 640 | 330 | 2,470 | 7.7 | 50 | ---- |
| 315 | 31Bcc | Ta | 122½–124½ | C | 6–29–65 | 22 | 132 | 39 | | 173 | | 276 | 412 | 148 | .6 | ---- | 1,060 | 488 | 262 | 1,630 | 7.9 | 44 | ---- |
| **East sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 316a[2] | (C– 8–23)32dbc2 | Dr | 130–176 | C | 5–22–57 | 24 | 162 | 46 | 236 | | 7.0 | 278 | 217 | 470 | 0.2 | 0.1 | 1,300 | 594 | 366 | 2,250 | 7.7 | 46 | 0.23 |
| 316b | | | 130–170 | C | 1– 2–62 | 23 | 203 | 60 | | 280 | | 257 | 258 | 628 | ---- | ---- | 1,580 | 755 | 544 | 2,800 | 7.6 | 45 | ---- |
| 316c | | | 130–170 | C | 5–25–62 | 22 | 219 | 53 | | 288 | | 258 | 244 | 655 | .3 | .4 | 1,610 | 765 | 554 | 2,760 | 7.4 | 45 | .08 |
| 316d | | | 130–170 | C | 11–27–62 | 22 | 210 | 63 | | 274 | | 252 | 242 | 655 | ---- | ---- | 1,590 | 785 | 578 | 2,890 | 7.2 | 43 | ---- |
| 316e | | | 130–170 | C | 2– 4–63 | 19 | 210 | 62 | | 271 | | 252 | 233 | 652 | ---- | ---- | 1,570 | 780 | 574 | 2,880 | 7.2 | 43 | ---- |
| 316f | | | 130–170 | C | 1–13–64 | 17 | 223 | 62 | | 281 | | 246 | 267 | 668 | ---- | ---- | 1,640 | 810 | 608 | 2,930 | 7.3 | 43 | ---- |
| 316g | | | 130–170 | C | 2– 5–65 | 21 | 228 | 67 | | 302 | | 244 | 283 | 715 | ---- | ---- | 1,740 | 845 | 645 | 3,070 | 7.4 | 44 | ---- |
| 316h | | | 130–170 | C | 11– 3–67 | 20 | 242 | 72 | | 331 | | 248 | 325 | 765 | ---- | ---- | 1,880 | 900 | 696 | 3,230 | 7.4 | 44 | ---- |
| 317 | (C– 9–23)5cda2 | Dr | 121–143 | C | 2– 5–65 | 25 | 242 | 72 | | 466 | | 248 | 525 | 825 | ---- | ---- | 2,280 | 900 | 696 | 3,700 | 7.6 | 53 | ---- |
| 318a | 5cdb | Dr | 120–184 | C | 1– 2–62 | 26 | 196 | 80 | | 460 | | 141 | 512 | 832 | ---- | ---- | 2,180 | 820 | 705 | 3,660 | 7.8 | 55 | ---- |
| 318b | | | 120–184 | C | 5–25–62 | 26 | 241 | 73 | | 462 | | 248 | 488 | 845 | ---- | ---- | 2,260 | 900 | 697 | 3,680 | 7.4 | 53 | .14 |
| 318c | | | 120–184 | C | 11–27–62 | 26 | 226 | 82 | | 459 | | 244 | 500 | 835 | ---- | ---- | 2,250 | 900 | 700 | 3,810 | 7.3 | 53 | ---- |
| 318d | | | 120–184 | C | 2– 4–63 | 24 | 230 | 77 | | 463 | | 246 | 512 | 825 | ---- | ---- | 2,250 | 890 | 688 | 3,800 | 7.4 | 53 | ---- |
| 318e | | | 120–184 | C | 1–13–64 | 23 | 234 | 79 | | 440 | | 240 | 488 | 825 | ---- | ---- | 2,210 | 910 | 713 | 3,810 | 7.3 | 51 | ---- |
| 318f | | | 120–184 | C | 3– 3–64 | 19 | 222 | 76 | | 441 | | 256 | 500 | 775 | ---- | ---- | 2,160 | 865 | 655 | 3,730 | 7.4 | 53 | ---- |
| 318g | | | 120–184 | C | 2– 5–65 | 26 | 226 | 74 | | 476 | | 240 | 538 | 815 | ---- | ---- | 2,280 | 870 | 673 | 3,760 | 7.4 | 54 | ---- |
| 319a | 17abc1 | Dr | 130–170 | C | 1– 2–62 | 26 | 185 | 67 | | 494 | | 230 | 725 | 615 | ---- | ---- | 2,230 | 735 | 546 | 3,500 | 7.8 | 59 | ---- |
| 319b | | | 130–170 | C | 5–25–62 | 27 | 205 | 62 | | 463 | | 244 | 674 | 615 | ---- | ---- | 2,170 | 765 | 565 | 3,380 | 7.5 | 57 | .25 |
| 319c | | | 130–170 | C | 11–27–62 | 26 | 182 | 65 | | 447 | | 248 | 625 | 595 | ---- | ---- | 2,060 | 720 | 516 | 3,460 | 7.6 | 58 | ---- |
| 319d | | | 130–170 | C | 2– 4–63 | 24 | 172 | 62 | | 455 | | 242 | 625 | 585 | ---- | ---- | 2,040 | 685 | 486 | 3,430 | 7.4 | 59 | ---- |
| 319e | | | 130–170 | C | 1–13–64 | 22 | 175 | 59 | | 471 | | 244 | 700 | 550 | ---- | ---- | 2,100 | 680 | 480 | 3,280 | 7.4 | 60 | ---- |
| 319f | | | 130–170 | C | 2– 5–65 | 26 | 169 | 56 | | 478 | | 244 | 700 | 540 | ---- | ---- | 2,090 | 650 | 450 | 3,200 | 6.5 | 62 | ---- |
| 320a[2] | 20bab | Dr | 132–192 | C | 5–22–57 | 26 | 155 | 50 | 402 | | 5.9 | 247 | 432 | 584 | .6 | .6 | 1,780 | 592 | 390 | 2,910 | 8.0 | 59 | ---- |
| 320b | | | 132–192 | C | 1– 2–62 | 25 | 136 | 50 | | 423 | | 214 | 550 | 508 | ---- | ---- | 1,800 | 545 | 370 | 2,830 | 7.8 | 63 | ---- |
| 320c | | | 132–192 | C | 5–25–62 | 26 | 162 | 59 | | 379 | | 258 | 494 | 525 | .5 | .4 | 1,770 | 645 | 434 | 2,820 | 7.7 | 56 | .21 |
| 320d | | | 132–192 | C | 11–27–62 | 26 | 150 | 51 | | 401 | | 260 | 525 | 495 | ---- | ---- | 1,780 | 585 | 372 | 2,890 | 7.5 | 60 | ---- |
| 320e | | | 132–192 | C | 2– 4–63 | 24 | 146 | 51 | | 382 | | 256 | 475 | 498 | ---- | ---- | 1,700 | 575 | 365 | 2,850 | 7.4 | 59 | ---- |
| 320f | | | 132–192 | C | 1–13–64 | 20 | 145 | 48 | | 335 | | 258 | 500 | 472 | ---- | ---- | 1,700 | 560 | 348 | 2,820 | 7.4 | 60 | ---- |

See footnotes at end of table.

*Chemical analyses of ground water*—Continued

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Na + 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 | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **YUMA VALLEY SUBAREA—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| **East sector—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| 320g | (C–9–23)17abc1 | | 132–192 | C | 2–5–65 | 24 | 143 | 47 | | | 382 | 256 | 475 | 480 | | | 1,680 | 550 | 340 | 2,790 | 7.6 | 60 | |
| 321a | 20bdc | Dr | 95–167 | C | 6–15–67 | 23 | 121 | 41 | | | 305 | 248 | 400 | 365 | | | 1,380 | 470 | 266 | 2,310 | 7.3 | 59 | |
| 321b | | | 95–167 | C | 11–3–67 | 22 | 122 | 40 | | | 327 | 252 | 425 | 378 | | | 1,440 | 470 | 264 | 2,330 | 7.6 | 60 | |
| 322a | 20cdd | Dr | 130–240 | C, W | 1–2–62 | 26 | 125 | 46 | | | 396 | 183 | 525 | 472 | | | 1,680 | 500 | 350 | 2,630 | 7.8 | 63 | |
| 322b | | | 130–240 | C, W | 5–25–62 | 25 | 155 | 40 | | | 366 | 249 | 464 | 465 | 0.6 | 0.4 | 1,640 | 550 | 346 | 2,610 | 7.5 | 59 | 0.23 |
| 322c | | | 130–240 | C, W | 11–27–62 | 25 | 140 | 43 | | | 362 | 252 | 450 | 452 | | | 1,600 | 525 | 318 | 2,650 | 7.5 | 60 | |
| 322d | | | 130–240 | C, W | 2–4–63 | 23 | 143 | 41 | | | 353 | 246 | 450 | 442 | | | 1,580 | 525 | 324 | 2,650 | 7.4 | 59 | |
| 322e | | | 130–240 | C, W | 1–13–64 | 19 | 136 | 41 | | | 353 | 250 | 462 | 420 | | | 1,560 | 510 | 305 | 2,590 | 7.4 | 60 | |
| 322f | | | 130–240 | C, W | 2–5–65 | 24 | 132 | 41 | | | 353 | 256 | 450 | 418 | | | 1,550 | 500 | 290 | 2,560 | 7.6 | 61 | |
| 323a | 20bbc | Dr | 148–212 | C | 2–17–64 | 21 | 108 | 35 | | | 273 | 220 | 145 | 478 | .9 | | 1,170 | 415 | 234 | 2,140 | 7.6 | 59 | |
| 323b | | | 148–212 | C | 3–6–64 | 22 | 109 | 33 | | | 269 | 216 | 125 | 472 | .6 | | 1,130 | 390 | 213 | 2,150 | 7.4 | 60 | |
| 323c | | | 148–212 | C | 4–30–64 | 24 | 114 | 37 | | | 299 | 222 | 200 | 492 | .6 | | 1,280 | 436 | 254 | 2,270 | 7.4 | 60 | |
| 323d | | | 148–212 | C | 2–5–65 | 26 | 130 | 43 | | | 319 | 232 | 275 | 508 | | | 1,420 | 500 | 310 | 2,440 | 7.5 | 58 | |
| 324a [2] | 30cba2 | Dr | 140–203 | C | 11–5–54 | 30 | 140 | 41 | 320 | 6.6 | | 247 | 296 | 504 | .6 | | 1,460 | 520 | 318 | 2,440 | 8.0 | 57 | .20 |
| 324b | | | 140–203 | C | 1–2–62 | 24 | 139 | 49 | | | 387 | 208 | 388 | 578 | | | 1,670 | 548 | 378 | 2,810 | 7.9 | 60 | |
| 324c | | | 140–203 | C | 5–23–62 | 24 | 163 | 42 | | | 371 | 250 | 340 | 585 | .4 | .6 | 1,650 | 580 | 375 | 2,770 | 7.7 | 58 | .56 |
| 324d | | | 140–203 | C | 11–27–62 | 23 | 150 | 48 | | | 355 | 252 | 312 | 575 | | | 1,590 | 570 | 364 | 2,840 | 7.4 | 58 | |
| 324e | | | 140–203 | C | 2–4–63 | 21 | 151 | 48 | | | 345 | 244 | 312 | 568 | | | 1,570 | 575 | 375 | 2,820 | 7.4 | 57 | |
| 324f | | | 140–203 | C | 1–13–64 | 19 | 150 | 48 | | | 352 | 240 | 338 | 558 | | | 1,580 | 570 | 373 | 2,790 | 7.2 | 57 | |
| 324g | | | 140–203 | C | 2–5–65 | 22 | 151 | 47 | | | 375 | 240 | 350 | 585 | | | 1,650 | 570 | 373 | 2,770 | 7.4 | 59 | |
| 325a | (C–9–24)36caa | Dr | 145–220 | C | 1–3–62 | 25 | 160 | 59 | | | 416 | 178 | 325 | 752 | | | 1,830 | 640 | 494 | 3,220 | 7.8 | 59 | |
| 325b | | | 145–220 | C | 5–25–62 | 25 | 193 | 56 | | | 414 | 258 | 311 | 760 | .3 | .6 | 1,890 | 710 | 498 | 3,210 | 7.6 | 56 | .54 |
| 325c | | | 145–220 | C | 2–4–63 | 22 | 185 | 53 | | | 407 | 256 | 300 | 740 | | | 1,840 | 680 | 470 | 3,240 | 7.2 | 57 | |
| 325d | | | 145–220 | C | 1–13–64 | 22 | 178 | 55 | | | 389 | 256 | 300 | 705 | | | 1,780 | 670 | 460 | 3,170 | 7.5 | 56 | |
| 325e | | | 145–220 | C | 2–5–65 | 24 | 177 | 56 | | | 408 | 252 | 317 | 725 | | | 1,830 | 670 | 464 | 3,140 | 7.6 | 57 | |
| 326a [2] | (C–10–24)12bcc2 | Dr | 150–178 | C | 3–21–57 | 26 | 143 | 47 | 290 | 5.9 | | 223 | 174 | 605 | .4 | | 1,400 | 550 | 368 | 2,460 | 7.9 | 53 | .24 |
| 326b | | | 150–178 | C | 4–13–61 | 26 | 127 | 33 | | | 253 | 235 | 179 | 440 | .3 | .7 | 1,180 | 452 | 260 | 2,060 | 7.9 | 55 | .35 |
| 326c | | | 150–178 | C | 1–2–62 | 27 | 118 | 38 | | | 273 | 233 | 206 | 452 | | | 1,230 | 450 | 259 | 2,150 | 7.8 | 57 | |
| 326d | | | 150–178 | C | 11–27–62 | 25 | 115 | 40 | | | 240 | 236 | 150 | 442 | | | 1,130 | 420 | 256 | 2,110 | 7.5 | 54 | |
| 326e | | | 150–178 | C | 2–4–63 | 24 | 116 | 39 | | | 238 | 234 | 150 | 438 | | | 1,120 | 448 | 256 | 2,110 | 7.5 | 54 | |
| 326f | | | 150–178 | C | 1–13–64 | 22 | 122 | 36 | | | 246 | 232 | 190 | 425 | | | 1,160 | 452 | 262 | 2,120 | 7.4 | 54 | |
| 326g | | | 150–178 | C | 2–5–65 | 26 | 116 | 39 | | | 266 | 230 | 208 | 442 | | | 1,210 | 450 | 262 | 2,110 | 7.6 | 56 | |
| 327a | 13bdd1 | Dr | 142–185 | C | 1–2–62 | 27 | 118 | 36 | | | 307 | 231 | 238 | 478 | | | 1,320 | 444 | 254 | 2,380 | 7.8 | 60 | |
| 327b | | | 142–185 | C | 5–25–62 | 27 | 122 | 33 | | | 293 | 228 | 219 | 470 | .4 | .3 | 1,280 | 442 | 255 | 2,210 | 7.8 | 59 | .41 |
| 327c | | | 142–185 | C | 11–27–62 | 27 | 110 | 38 | | | 279 | 228 | 192 | 462 | | | 1,220 | 432 | 245 | 2,240 | 7.6 | 58 | |
| 327d | | | 142–185 | C | 2–4–63 | 25 | 108 | 36 | | | 290 | 226 | 208 | 458 | | | 1,240 | 418 | 232 | 2,230 | 7.5 | 60 | |
| 327e | | | 142–185 | C | 1–13–64 | 25 | 112 | 36 | | | 284 | 226 | 233 | 438 | | | 1,240 | 428 | 242 | 2,200 | 7.5 | 59 | |
| 327f | | | 142–185 | C | 2–5–65 | 27 | 111 | 37 | | | 282 | 214 | 233 | 442 | | | 1,240 | 430 | 253 | 2,170 | 7.6 | 59 | |
| **Central sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 328 | (C–8–23)20bdb | Ta | 144–146 | C | 4–30–65 | 23 | 132 | 46 | | | 325 | 512 | 500 | 202 | 0.7 | | 1,480 | 520 | 100 | 2,340 | 7.8 | 58 | |
| 329 | 20dad | Ta | 114–116 | U | 5–11–65 | 30 | 60 | 22 | | | 332 | 480 | 362 | 132 | 2.5 | | 1,180 | 240 | 0 | 1,830 | 7.9 | 75 | |
| 330 | 31ddc | Ind | 120–170 | C | 7–27–62 | 19 | 206 | 72 | | | 478 | 397 | 800 | 490 | | | 2,260 | 810 | 484 | 3,580 | 7.4 | 56 | |
| 331 | 32baa1 | Irr | 43–45 | U | 4–9–62 | 16 | 86 | 40 | | | 155 | 211 | 350 | 127 | | | 880 | 378 | 205 | 1,440 | 7.4 | 47 | |
| 332 | 32baa2 | Dom | 16–18 | U | 5–27–62 | 17 | 142 | 57 | | | 325 | 266 | 700 | 248 | | | 1,620 | 590 | 372 | 2,270 | 7.4 | 54 | |
| 333 | 32caa2 | Dom | <147 | C | 8–2–62 | 18 | 112 | 31 | | | 243 | 280 | 438 | 177 | .9 | | 1,160 | 408 | 178 | 1,750 | 7.1 | 57 | |
| 334 | 32cca | Dom | 20–23 | U | 8–2–62 | 17 | 218 | 72 | | | 374 | 334 | 950 | 278 | | | 2,080 | 840 | 566 | 2,860 | 7.2 | 49 | |
| 335 | 32cdc | Dom | 20–23 | U | 8–2–62 | 23 | 238 | 79 | | | 493 | 362 | 1,100 | 390 | | | 2,500 | 920 | 623 | 3,460 | 7.2 | 54 | |
| 336a [2] | (C–8–24)22ccd | Dr, St | 117–142 | C | 3–31–30 | | 99 | 28 | | | 92 | 226 | 128 | 165 | | | 625 | 352 | 166 | 1,090 | 7.2 | 36 | |
| 336b [2] | ---------- | ------ | 117–142 | C | 7–17–30 | | 129 | 33 | | | 117 | 201 | 201 | 241 | | | 821 | 459 | 294 | 1,480 | 7.7 | 36 | |
| 337 | 22cdd | Dom | <178 | C(?) | 9–7–62 | 23 | 226 | 57 | | | 265 | 312 | 550 | 388 | .7 | | 1,670 | 800 | 544 | 2,670 | 7.4 | 42 | |
| 338 | 25add | Dom | 38–40 | U | 8–1–62 | 15 | 137 | 56 | | | 159 | 334 | 400 | 161 | 1.1 | | 1,100 | 574 | 300 | 1,710 | 7.2 | 38 | |
| 339 | 25cba | Ta | 124–126 | C | 6–22–65 | 30 | 196 | 49 | | | 316 | 336 | 625 | 318 | .9 | | 1,700 | 690 | 414 | 2,590 | 7.6 | 50 | |
| 340 [3] | 27aba | Dom, St | 114–119 | C | 1961 | | 234 | 61 | | | 321 | 308 | 665 | 420 | .5 | 1.0 | 1,860 | 834 | 582 | 2,900 | | 46 | |
| 341 | 27dcc | Ta | 124–126 | C | 7–7–65 | 3 | 56 | 25 | | | 126 | 98 | 250 | 125 | .5 | | 635 | 244 | 164 | 1,080 | 7.1 | 53 | |
| 342 | (C–9–23)5bcc2 | Dom | 123–143 | C | 9–4–62 | 26 | 236 | 79 | | | 437 | 260 | 475 | 822 | | | 2,200 | 915 | 702 | 3,800 | 7.0 | 51 | |
| 343 | 6bbb | Ta | 126–128 | C | 6–23–65 | 24 | 346 | 96 | | | 587 | 424 | 825 | 942 | .9 | | 3,030 | 1,260 | 912 | 4,640 | 7.5 | 50 | |
| 344 | 8bcb | Dom | 135–141 | C | 3–23–65 | 26 | 180 | 62 | | | 457 | 236 | 258 | 875 | .6 | | 1,980 | 705 | 512 | 3,460 | 7.7 | 59 | |
| 345 | 19aaa1 | Ta | 32–34 | U | 1–12–62 | 17 | 122 | 38 | | | 139 | 226 | 338 | 161 | | | 928 | 462 | 276 | 1,470 | 8.1 | 40 | |
| 346 | 19aaa2 | Ta | 61–63 | U | 1–12–62 | 22 | 106 | 45 | | | 158 | 251 | 325 | 175 | | | 957 | 448 | 242 | 1,490 | 8.2 | 43 | |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 347 ---- | 19aaa3 -- | Ta | 79–81 | C | 1–11–62 | 23 | 105 | 43 | 202 | 276 | 388 | 175 | ---- | ---- | 1,070 | 438 | 212 | 1,640 | 8.2 | 50 | ---- |
| 348 ---- | 19aaa4 -- | Ta | 134–136 | C | 1–11–62 | 25 | 165 | 56 | 479 | 234 | 675 | 558 | ---- | ---- | 2,080 | 640 | 448 | 3,470 | 8.1 | 62 | ---- |
| 349 ---- | 19ccc --- | Ta | 147–149 | C | 6–23–65 | 24 | 366 | 123 | 827 | 260 | 625 | 1,670 | ---- | ---- | 3,760 | 1,420 | 1,210 | 6,260 | 7.5 | 56 | ---- |
| 350 ---- | (C– 9–24) 2aa1, 2 -- | Dom | 25, 165 | U, C | 9– 5–62 | 23 | 214 | 57 | 386 | 340 | 525 | 555 | .6 | ---- | 1,930 | 770 | 491 | 3,160 | 7.5 | 52 | ---- |
| 351 ---- | 2ccc ---- | Ta | 124–126 | C | 6–23–65 | 4 | 150 | 55 | 199 | 106 | 300 | 448 | 1.0 | ---- | 1,210 | 600 | 513 | 2,190 | 6.9 | 42 | ---- |
| 352 ---- | 2ccd ---- | Dom | 128–130 | C | 9– 5–62 | 23 | 220 | 61 | 352 | 368 | 525 | 508 | .6 | ---- | 1,870 | 800 | 498 | 3,020 | 7.5 | 49 | ---- |
| 353 ---- | 3abb ---- | Dom | 18–20 | U | 9– 7–62 | 21 | 166 | 49 | 196 | 294 | 525 | 179 | .9 | ---- | 1,280 | 615 | 374 | 1,890 | 7.4 | 41 | ---- |
| 355 ---- | 4aaa ---- | Ta | 134½–136½ | C | 6–22–65 | 13 | 222 | 77 | 484 | 348 | 1,020 | 405 | 1.5 | ---- | 2,400 | 870 | 584 | 3,780 | 7.9 | 55 | ---- |
| 356 ---- | 8bdc ---- | Ta | 147–149 | C | 6–23–65 | 13 | 148 | 41 | 147 | 244 | 350 | 208 | .6 | ---- | 1,030 | 540 | 340 | 1,710 | 7.6 | 37 | ---- |
| 357 ---- | 10bbb -- | St | <60 | U | 9– 5–62 | 25 | 140 | 33 | 154 | 268 | 400 | 129 | .5 | ---- | 1,020 | 485 | 265 | 1,650 | 7.5 | 41 | ---- |
| 358 ---- | 12daa --- | Dom | 19–21 | U | 8–23–62 | 15 | 110 | 35 | 137 | 184 | 312 | 170 | .8 | ---- | 872 | 420 | 269 | 1,460 | 7.6 | 41 | ---- |
| 359 ---- | 12dac --- | Dom | <145 | C | 8–23–62 | 22 | 212 | 67 | 283 | 322 | 375 | 542 | .5 | ---- | 1,660 | 805 | 541 | 2,850 | 7.3 | 43 | ---- |
| 360a ---- | 13cdd -- | T | [6] 165 | C | 2– –62 | 9 | 201 | 59 | 331 | 194 | 412 | 622 | ---- | ---- | 1,730 | 745 | 586 | 3,110 | 7.8 | 49 | ---- |
| 360b ---- | | | [6] 225 | W | 2– –62 | 16 | 149 | 32 | 193 | 155 | 125 | 472 | ---- | ---- | 1,060 | 504 | 377 | 1,980 | 7.9 | 45 | ---- |
| 360c ---- | | | [6] 260 | W | 2– –62 | 10 | 182 | 59 | 325 | 186 | 412 | 582 | ---- | ---- | 1,660 | 695 | 542 | 2,850 | 7.9 | 50 | ---- |
| 360d ---- | | | [6] 340 | W | 2– –62 | 15 | 186 | 53 | 218 | 128 | 169 | 620 | ---- | ---- | 1,320 | 680 | 575 | 2,500 | 7.8 | 41 | ---- |
| 360e ---- | | | [6] 440 | W | 2–15–62 | 20 | 196 | 53 | 220 | 136 | 190 | 620 | ---- | ---- | 1,370 | 705 | 594 | 2,520 | 7.8 | 40 | ---- |
| 360f ---- | | | [6] 490 | W | 2–15–62 | 10 | 223 | 62 | 209 | 112 | 183 | 698 | ---- | ---- | 1,440 | 812 | 720 | 2,810 | 7.6 | 36 | ---- |
| 360g ---- | | | [1] 139–170 | C | 12–30–63 | 19 | 182 | 50 | 266 | 218 | 275 | 548 | .2 | ---- | 1,450 | 660 | 481 | 2,510 | 7.4 | 47 | ---- |
| 360h ---- | | | [1] 139–170 | C | 12–31–63 | 18 | 181 | 58 | 290 | 236 | 325 | 558 | .4 | .1 | 1,550 | 690 | 496 | 2,720 | 7.9 | 48 | .21 |
| 361 ---- | 14dab -- | Dom, St | 125–133 | C | 10– 6–64 | 24 | 138 | 39 | 172 | 260 | 388 | 185 | .7 | ---- | 1,080 | 505 | 292 | 1,690 | 7.6 | 43 | ---- |
| 362 ---- | 14dba --- | Dom St | <120 | C(?) | 9– 4–62 | 25 | 106 | 26 | 184 | 260 | 338 | 144 | .8 | ---- | 954 | 370 | 157 | 1,540 | 7.4 | 52 | ---- |
| 363 ---- | 15dbd --- | Dom | (?) | (?) | 9– 7–62 | 26 | 92 | 25 | 135 | 256 | 190 | 154 | .4 | ---- | 750 | 332 | 122 | 1,220 | 7.4 | 47 | ---- |
| 364 ---- | 17add --- | Dom | 122–124 | C | 8–23–62 | 25 | 99 | 26 | 165 | 268 | 312 | 118 | .5 | ---- | 880 | 354 | 134 | 1,420 | 7.5 | 50 | ---- |
| 365 ---- | 20cdd --- | Dom St | 157–160 | C | 9– 5–62 | 25 | 376 | 103 | 399 | 528 | 1,120 | 445 | .9 | ---- | 2,740 | 1,360 | 927 | 3,870 | 7.2 | 39 | ---- |
| 366 ---- | 20ddd1 -- | Dom | <170 | C | 9– 5–62 | 24 | 308 | 83 | 348 | 500 | 975 | 312 | .7 | ---- | 2,300 | 1,110 | 700 | 3,360 | 7.5 | 40 | ---- |
| 367 ---- | 22aba --- | Dom | 125 | C | 10– 6–64 | 19 | 82 | 19 | 102 | 248 | 88 | 149 | .4 | ---- | 583 | 284 | 80 | 1,030 | 7.7 | 44 | ---- |
| 368 ---- | 22bbb --- | Ta | 105–167 | C | 6–23–65 | 3 | 58 | 28 | 144 | 124 | 217 | 173 | .8 | ---- | 686 | 260 | 158 | 1,210 | 7.3 | 55 | ---- |
| 369 ---- | 26cbb --- | Ta | 145–147 | C | 6–23–65 | 22 | 270 | 94 | 667 | 348 | 538 | 1,180 | .8 | ---- | 2,950 | 1,060 | 774 | 4,970 | 7.6 | 58 | ---- |
| 370 ---- | 28cbb --- | Dom | (?) | (?) | 9– 4–62 | 24 | 322 | 99 | 242 | 434 | 700 | 462 | ---- | ---- | 2,070 | 1,210 | 854 | 3,220 | 7.1 | 30 | ---- |
| 371 ---- | 29ccc --- | Ta | 129–131 | C | 6–24–65 | 17 | 161 | 65 | 230 | 432 | 488 | 218 | .7 | ---- | 1,400 | 670 | 316 | 2,160 | 7.7 | 43 | ---- |
| 372 ---- | 32dbb --- | PS | 170–195 | C | 8–24–62 | 26 | 166 | 52 | 373 | 227 | 425 | 575 | ---- | ---- | 1,730 | 628 | 442 | 3,080 | 7.2 | 56 | ---- |
| 373 ---- | 34dcb1 -- | PS | <215 | C | 7– 6–65 | 23 | 186 | 55 | 278 | 316 | 512 | 355 | .7 | ---- | 1,570 | 690 | 431 | 2,460 | 7.7 | ---- | ---- |
| 374a ---- | 34dcb2 -- | PS | (?) | (?) | 7–27–62 | 20 | 175 | 17 | 285 | 304 | 408 | 320 | .6 | ---- | 1,380 | 506 | 256 | 2,180 | 7.4 | 47 | ---- |
| 374b ---- | | | (?) | (?) | 9– 5–62 | 26 | 183 | 52 | 217 | 304 | 425 | 318 | .6 | ---- | 1,370 | 670 | 420 | 2,200 | 7.3 | 41 | ---- |
| 374c ---- | | | (?) | (?) | 7– 6–65 | 23 | 188 | 46 | 233 | 296 | 450 | 322 | .6 | ---- | 1,410 | 660 | 418 | 2,190 | 7.8 | 48 | ---- |
| 375a ---- | 34dcb3 -- | PS | [6] 470 | W | 8– 4–65 | 15 | 151 | 42 | 161 | 176 | 167 | 412 | .4 | ---- | 1,040 | 550 | 406 | 1,940 | 7.6 | 39 | ---- |
| 375b ---- | | | [6] 609 | W | 8–10–65 | 16 | 150 | 38 | 169 | 164 | 200 | 392 | .5 | ---- | 1,050 | 530 | 396 | 1,890 | 7.6 | 41 | ---- |
| 375c ---- | | | [6] 762 | W | 8–17–65 | 17 | 148 | 37 | 168 | 164 | 192 | 390 | .4 | ---- | 1,030 | 520 | 386 | 1,850 | 7.4 | 41 | ---- |
| 375d ---- | | | [6] 848 | W | 8–23–65 | 10 | 153 | 39 | 184 | 126 | 258 | 402 | .5 | ---- | 1,110 | 540 | 436 | 1,960 | 7.4 | 43 | ---- |
| 375e ---- | | | [6] 924 | W | 8–25–65 | 16 | 187 | 49 | 179 | 162 | 225 | 490 | .4 | ---- | 1,230 | 670 | 537 | 2,230 | 7.5 | 37 | ---- |
| 375f ---- | | | [6] 1,055 | W | 9– 3–65 | 17 | 215 | 52 | 206 | 168 | 275 | 548 | .5 | ---- | 1,400 | 750 | 612 | 2,490 | 7.5 | 37 | ---- |
| 375g ---- | | | [6] 1,143 | W | 9– 8–65 | 19 | 250 | 62 | 206 | 140 | 233 | 688 | .4 | ---- | 1,530 | 880 | 765 | 2,800 | 7.6 | 34 | ---- |
| 376a ---- | (C–10–24) 1bdd1 --- | T | [6] 152 | C | 1–23–62 | 24 | 107 | 42 | 295 | 226 | 225 | 468 | ---- | ---- | 1,270 | 438 | 252 | 2,310 | 7.5 | 59 | ---- |
| 376b ---- | | | [6] 265 | W | 1– –62 | 17 | 158 | 46 | 422 | 210 | 250 | 758 | ---- | ---- | 1,760 | 584 | 412 | 3,040 | 7.8 | 61 | ---- |
| 376c ---- | | | [6] 370 | W | 1– –62 | 16 | 123 | 41 | 308 | 169 | 350 | 455 | ---- | ---- | 1,380 | 474 | 336 | 2,360 | 7.8 | 59 | ---- |
| 376d ---- | | | [6] 435 | W | 1– –62 | 12 | 142 | 52 | 378 | 182 | 294 | 665 | ---- | ---- | 1,630 | 570 | 421 | 2,880 | 7.8 | 59 | ---- |
| 376e ---- | | | [6] 485 | W | 1– –62 | 10 | 131 | 52 | 353 | 178 | 342 | 572 | ---- | ---- | 1,550 | 540 | 394 | 2,690 | 7.7 | 59 | ---- |
| 376f ---- | | | [1] 144–170 | C | 1–14–64 | 24 | 106 | 41 | 295 | 220 | 267 | 438 | ---- | .1 | 1,280 | 434 | 254 | 2,260 | 7.4 | 60 | .27 |
| 377 ---- | 2aab ---- | Ind | <147 | C | 9– 4–62 | 26 | 225 | 73 | 348 | 318 | 362 | 695 | ---- | ---- | 1,390 | 860 | 599 | 3,280 | 7.1 | 47 | ---- |
| 378 ---- | 3ddd --- | Ta | 91–83 | U | 6–24–65 | 4 | 62 | 43 | 251 | 140 | 258 | 348 | .7 | ---- | 1,040 | 330 | 215 | 1,830 | 7.4 | 62 | ---- |
| 380a ---- | 4add --- | Dom Ind | 155–187 | C | 8–24–62 | 24 | 148 | 41 | 227 | 302 | 250 | 371 | .7 | ---- | 1,210 | 540 | 292 | 2,170 | 7.2 | 48 | ---- |
| 330b ---- | | | 155–187 | C | 7– 6–65 | 23 | 126 | 48 | 218 | 284 | 258 | 342 | .6 | ---- | 1,160 | 510 | 277 | 1,970 | 7.6 | 48 | ---- |
| 380c ---- | | | 155–187 | C | 10–19–65 | 18 | 122 | 43 | 216 | 292 | 217 | 342 | .5 | ---- | 1,110 | 480 | 240 | 1,920 | 7.7 | 49 | ---- |
| 381 ---- | 4bbb --- | Dom | 23–25 | U | 9– 5–62 | 26 | 194 | 61 | 196 | 320 | 550 | 230 | .9 | ---- | 1,420 | 735 | 472 | 2,220 | 7.0 | 37 | ---- |
| 382a ---- | 5dbb --- | Iru | 175–198 | C | 12–30–65 | 25 | 201 | 70 | 157 | 416 | 462 | 218 | .7 | ---- | 1,340 | 790 | 449 | 2,130 | 7.2 | 30 | ---- |
| 382b ---- | | | [1] 175–198 | C | 1– 7–66 | 16 | 196 | 66 | 164 | 408 | 475 | 202 | .7 | ---- | 1,320 | 760 | 426 | 2,130 | 7.6 | 32 | ---- |
| 383a ---- | 5ddd ---- | T | [6] 190 | C | 1– –62 | 16 | 114 | 36 | 191 | 194 | 350 | 231 | ---- | ---- | 1,040 | 434 | 275 | 1,650 | 3.0 | 49 | ---- |
| 383b ---- | | | [6] 280 | W | 1– –62 | 12 | 87 | 32 | 144 | 199 | 225 | 188 | ---- | ---- | 788 | 348 | 185 | 1,340 | 8.1 | 47 | ---- |
| 383c ---- | | | [6] 330 | W | 2– –62 | 12 | 79 | 26 | 144 | 217 | 190 | 172 | ---- | ---- | 731 | 306 | 128 | 1,220 | 8.0 | 51 | ---- |
| 383d ---- | | | [6] 400 | W | 2– –62 | 13 | 69 | 19 | 159 | 152 | 215 | 177 | ---- | ---- | 728 | 252 | 148 | 1,120 | 8.2 | 58 | ---- |
| 383e ---- | | | [6] 460 | W | 2– –62 | 7 | 82 | 31 | 182 | 133 | 308 | 213 | ---- | ---- | 889 | 334 | 225 | 1,400 | 7.5 | 54 | ---- |
| 383f ---- | | | [1] 170–215 | C | 5–27–65 | 22 | 78 | 20 | 115 | 266 | 105 | 141 | .4 | ---- | 614 | 276 | 58 | 1,050 | 7.7 | 48 | ---- |
| 384 ---- | 7ccc ---- | Ta | 176½–178 | C | 6–24–65 | 22 | 156 | 50 | 231 | 356 | 450 | 238 | .7 | ---- | 1,330 | 595 | 303 | 2,100 | 7.7 | 46 | ---- |
| 385a ---- | 9bba --- | Dom | 138–140 | C | 9– 4–62 | 25 | 110 | 29 | 159 | 334 | 200 | 182 | .7 | ---- | 873 | 394 | 120 | 1,490 | 7.3 | 47 | ---- |
| 385b ---- | | | 138–140 | C | 1–20–66 | 20 | 98 | 19 | 176 | 320 | 170 | 189 | .6 | ---- | 833 | 324 | 62 | 1,400 | 7.5 | 54 | ---- |
| 386 ---- | 10cdd --- | Dom St | <140 | C | 9– 5–62 | 27 | 113 | 35 | 164 | 234 | 135 | 318 | .5 | ---- | 910 | 425 | 233 | 1,650 | 7.3 | 46 | ---- |
| 387 ---- | 14aaa2 -- | T | 58–60 | U | 1–15–65 | 30 | 70 | 56 | 431 | 264 | 450 | 465 | ---- | ---- | 1,630 | 404 | 188 | 2,800 | 7.7 | 70 | ---- |
| 388a ---- | 15dcc --- | T | 78–80 | U | 1– 4–65 | 27 | 444 | 521 | 1,760 | 440 | 1,900 | 3,360 | 1.4 | ---- | 8,230 | 3,250 | 2,890 | 12,500 | 7.7 | 54 | ---- |
| 388b ---- | | | 78–80 | U | 1–15–65 | 14 | 516 | 504 | 1,930 | 400 | 2,050 | 3,620 | ---- | ---- | 8,830 | 3,360 | 3,030 | 13,090 | 7.6 | 56 | ---- |
| 388c ---- | | | 164–166 | C | 1– 4–65 | 14 | 105 | 32 | 301 | 196 | 250 | 442 | .7 | ---- | 1,240 | 392 | 232 | 2,140 | 8.0 | 62 | ---- |
| 389 ---- | 16baa2 -- | Dom Ind | 152–180 | C | 10–19–65 | 20 | 80 | 22 | 129 | 256 | 105 | 179 | .5 | ---- | 664 | 292 | 82 | 1,150 | 7.7 | 49 | ---- |
| 390a ---- | 28ddb --- | Dom St | <217 | C | 9– 4–62 | 23 | 134 | 44 | 207 | 278 | 312 | 291 | .6 | ---- | 1,150 | 515 | 287 | 1,960 | 7.2 | 47 | ---- |
| 390b ---- | | | <217 | C | 4–22–64 | 20 | 135 | 42 | 209 | 264 | 300 | 308 | .3 | ---- | 1,150 | 510 | 294 | 1,910 | 7.4 | 47 | ---- |

See footnotes at end of table.

*Chemical analyses of ground water*—Continued

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Na + 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 | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | |
| **YUMA VALLEY SUBAREA—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| **Central sector—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| 391 | (C–10–25) 13cca | Dom | 155–157 | C | 9–4–62 | 25 | 129 | 35 | | | 112 | 296 | 217 | 170 | 0.7 | ---- | 837 | 465 | 222 | 1,400 | 7.2 | 34 | ---- |
| 392 | 23add | Ta | 185.7–187.7 | C | 6–29–65 | 15 | 191 | 67 | | | 222 | 264 | 450 | 388 | .3 | ---- | 1,460 | 750 | 534 | 2,400 | 7.5 | 39 | ---- |
| 393 | 26dba | Dom | 165–167 | C | 9–4–62 | 26 | 201 | 51 | | | 365 | 512 | 675 | 269 | .9 | ---- | 1,840 | 710 | 290 | 2,800 | 7.2 | 53 | ---- |
| **Floodway sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 394a | (C–9–24) 19bad2 | Irr | 145–180 | C | 2–17–62 | 21 | 178 | 46 | | | 158 | 270 | 450 | 202 | 0.7 | ---- | 1,180 | 632 | 410 | 1,870 | 7.8 | 35 | ---- |
| 394b | | | 145–180 | C | 3–27–62 | 24 | 174 | 49 | | | 149 | 267 | 438 | 203 | ---- | ---- | 1,170 | 636 | 417 | 1,830 | 7.6 | 34 | ---- |
| 394c | | | 145–180 | C | 6–4–62 | 20 | 180 | 46 | | | 167 | 272 | 462 | 212 | .5 | ---- | 1,220 | 640 | 417 | 1,880 | 7.9 | 36 | ---- |
| 394d | | | 145–180 | C | 4–17–64 | 21 | 201 | 51 | | | 195 | 304 | 525 | 238 | .7 | ---- | 1,380 | 710 | 460 | 2,100 | 7.4 | 37 | ---- |
| 394e | | | 145–180 | C | 7–22–64 | 20 | 198 | 55 | | | 193 | 312 | 512 | 248 | .9 | ---- | 1,380 | 720 | 464 | 2,130 | 7.5 | 37 | ---- |
| 395a | 19bda2 | Irr | 150–175 | C | 4–17–64 | 21 | 206 | 48 | | | 200 | 320 | 488 | 265 | .7 | ---- | 1,390 | 710 | 448 | 2,200 | 7.4 | 38 | ---- |
| 395b | | | 150–175 | C | 7–22–64 | 21 | 196 | 49 | | | 215 | 324 | 500 | 262 | .7 | ---- | 1,410 | 690 | 424 | 2,140 | 7.5 | 40 | ---- |
| 396 | 19ccc | Ta | 187–189 | C | 6–24–65 | 21 | 94 | 28 | | | 106 | 224 | 250 | 95 | .4 | ---- | 706 | 348 | 164 | 1,110 | 7.9 | 40 | ---- |
| 397a | (C–9–25) 25aab | Irr | 110–170 | C | 6–14–67 | 20 | 100 | 39 | | | 159 | 244 | 250 | 208 | .5 | ---- | 899 | 410 | 210 | 1,690 | 7.6 | 46 | ---- |
| 397b | | | 110–170 | C | 8–10–67 | 21 | 159 | 45 | | | 169 | 316 | 362 | 220 | .5 | ---- | 1,130 | 580 | 321 | 1,800 | 7.7 | 39 | ---- |
| 398 | 35aba | Irr | 100–310 | C, W | 4–30–62 | 21 | 106 | 29 | | | 121 | 300 | 240 | 105 | .7 | ---- | 773 | 382 | 136 | 1,190 | 7.8 | 41 | ---- |
| 399a | 35cbd | T | [1] 310–1,108 | W | 9–15–62 | 16 | 69 | 18 | | | 111 | 258 | 112 | 114 | .4 | ---- | 569 | 248 | 36 | 915 | 7.5 | 49 | ---- |
| 399b | | | [1] 310–1,108 | W | 9–19–62 | 13 | 78 | 22 | | | 132 | 231 | 217 | 111 | .5 | ---- | 690 | 287 | 98 | 1,080 | 7.6 | 50 | ---- |
| 399c | | | [1] 605–660 | W | 11–8–62 | 19 | 82 | 21 | | | 93 | 232 | 140 | 112 | .4 | 0.2 | 583 | 292 | 102 | 983 | 7.8 | 41 | 0.12 |
| 399d | | | [1] 436–560 | W | 11–28–62 | 20 | 84 | 25 | | | 103 | 216 | 208 | 103 | .3 | ---- | 651 | 314 | 137 | 1,100 | 7.8 | 42 | ---- |
| 399e | | | [1] 965–1,015 | W | 12–5–62 | 16 | 76 | 17 | | | 110 | 173 | 195 | 108 | ---- | ---- | 608 | 258 | 116 | 992 | 8.0 | 48 | ---- |
| 399f | | | [1] 436–560 | W | 12–1–62 | 20 | 97 | 29 | | | 107 | 246 | 240 | 102 | ---- | ---- | 718 | 362 | 160 | 1,140 | 7.9 | 39 | ---- |
| 400 | 36aaa | Irr | 130–180 | C | 10–19–62 | 22 | 138 | 43 | | | 132 | 374 | 275 | 153 | ---- | ---- | 950 | 520 | 214 | 1,580 | 7.2 | 36 | ---- |
| 401a | C–10–25) 1bba | Irr | 160–285 | C | 7–27–62 | 20 | 113 | 34 | | | 112 | 318 | 155 | 171 | .4 | ---- | 764 | 420 | 159 | 1,360 | 7.8 | 37 | ---- |
| 401b | | | 160–285 | C | 11–9–62 | ---- | 118 | 31 | | | --- | 310 | ---- | 171 | ---- | ---- | ---- | 424 | 170 | 1,360 | 7.4 | ---- | ---- |
| 402 | 2bab1 | Ta | 30–32 | U | 1–29–62 | 25 | 142 | 63 | | | 151 | 402 | 400 | 138 | ---- | ---- | 1,120 | 612 | 282 | 1,630 | 8.2 | 35 | ---- |
| 403 | 2bab2 | Ta | 60–62 | U | 1–29–62 | 16 | 169 | 58 | | | 185 | 356 | 500 | 177 | ---- | ---- | 1,280 | 660 | 368 | 1,880 | 8.0 | 38 | ---- |
| 404 | 2bab3 | Ta | 82–84 | U | 1–29–62 | 2 | 42 | 27 | | | 147 | 32 | 317 | 126 | ---- | ---- | 1,080 | 214 | 188 | 1,080 | 7.8 | 60 | ---- |
| 405 | 2bab4 | Ta | 134–136 | C(?) | 1–29–62 | 5 | 23 | 19 | | | 135 | 39 | 210 | 127 | ---- | ---- | 539 | 135 | 103 | 866 | 8.4 | 69 | ---- |
| 406a | 2cda | Irr | 158–295 | C | 5–28–62 | 12 | 107 | 30 | | | 103 | 300 | 160 | 143 | .7 | ---- | 705 | 390 | 144 | 1,250 | 7.6 | 36 | ---- |
| 406b | | | 158–295 | C | 8–10–62 | 24 | 105 | 29 | | | 106 | 295 | 175 | 132 | .4 | ---- | 719 | 380 | 138 | 1,210 | 7.2 | 38 | ---- |
| 406c | | | 158–295 | C | 10–30–62 | 21 | 96 | 28 | | | 106 | 288 | 150 | 137 | .5 | ---- | 683 | 356 | 120 | 1,210 | 7.2 | 39 | ---- |
| 406d | | | 158–295 | C | 4–24–64 | 21 | 118 | 26 | | | 117 | 304 | 185 | 150 | .5 | ---- | 770 | 400 | 150 | 1,260 | 7.4 | 39 | ---- |
| 406e | | | 158–295 | C | 5–25–66 | 20 | 118 | 31 | | | 120 | 318 | 175 | 168 | .4 | ---- | 791 | 420 | 159 | 1,330 | 7.7 | 38 | ---- |
| 406f | | | 158–295 | C | 2–9–67 | 20 | 116 | 34 | | | 119 | 320 | 175 | 172 | .5 | ---- | 796 | 430 | 168 | 1,350 | 7.7 | 38 | ---- |
| 406g | | | 158–295 | C | 3–1–67 | 20 | 118 | 33 | | | 115 | 308 | 183 | 168 | ---- | ---- | 791 | 430 | 178 | 1,370 | 7.7 | 37 | ---- |
| 407a | 14aac | Irr | 230–284 | C | 9–24–65 | 23 | 129 | 34 | | | 119 | 288 | 208 | 188 | .5 | ---- | 846 | 460 | 224 | 1,430 | 7.5 | 36 | ---- |
| 407b | | | 230–284 | C | 11–1–65 | 20 | 132 | 34 | | | 119 | 292 | 208 | 191 | .4 | ---- | 850 | 468 | 228 | 1,500 | 7.6 | 36 | ---- |
| 407c | | | 230–284 | C | 7–5–66 | 21 | 122 | 43 | | | 121 | 298 | 217 | 192 | .5 | ---- | 866 | 480 | 236 | 1,490 | 7.5 | 35 | ---- |
| 407d | | | 230–284 | C | 1–16–67 | 21 | 126 | 43 | | | 133 | 304 | 233 | 202 | .5 | ---- | 911 | 490 | 240 | 1,520 | 7.4 | 37 | ---- |
| 408a | 26bab | Irr | 203–280 | C | 7–9–63 | 21 | 132 | 44 | | | 148 | 302 | 300 | 192 | .6 | ---- | 989 | 510 | 262 | 1,600 | 7.4 | 39 | ---- |
| 408b | | | 203–280 | C | 9–6–63 | 21 | 135 | 36 | | | 150 | 300 | 275 | 196 | .7 | ---- | 964 | 484 | 238 | 1,560 | 7.8 | 40 | ---- |
| 408c | | | 203–280 | C | 4–24–64 | 20 | 137 | 39 | | | 153 | 300 | 292 | 202 | .5 | ---- | 994 | 504 | 258 | 1,600 | 7.4 | 40 | ---- |
| 408d | | | 203–280 | C | 5–13–64 | 19 | 140 | 39 | | | 145 | 294 | 283 | 205 | .5 | ---- | 979 | 510 | 269 | 1,590 | 7.4 | 38 | ---- |
| 408e | | | 203–280 | C | 11–5–65 | 19 | 156 | 49 | | | 150 | 320 | 292 | 248 | .6 | ---- | 1,080 | 590 | 328 | 1,790 | 7.5 | 36 | ---- |
| 408f | | | 203–280 | C | 5–25–66 | 20 | 159 | 47 | | | 154 | 316 | 312 | 242 | .4 | ---- | 1,090 | 590 | 331 | 1,780 | 7.6 | 36 | ---- |
| 408g | | | 203–280 | C | 11–9–66 | 20 | 177 | 48 | | | 161 | 332 | 325 | 268 | .6 | ---- | 1,170 | 640 | 368 | 1,930 | 7.6 | 35 | ---- |
| 408h | | | 203–280 | C | 2–11–67 | 19 | 164 | 51 | | | 152 | 320 | 312 | 258 | ---- | ---- | 1,120 | 620 | 358 | 1,900 | 7.4 | 35 | ---- |
| 408i | | | 203–280 | C | 4–11–67 | ---- | 170 | 51 | | | --- | 320 | ---- | 255 | ---- | ---- | ---- | 635 | 372 | 1,910 | 7.5 | ---- | ---- |
| 408j | | | 203–280 | C | 2–19–68 | 20 | 171 | 54 | | | 175 | 324 | 365 | 272 | .5 | ---- | 1,220 | 650 | 384 | 1,980 | 7.6 | 37 | ---- |
| 409a | 35bbd | T | [1] 1,800 | W | 3–19–64 | 9 | 41 | 79 | | | 219 | 60 | 338 | 147 | 1.0 | ---- | 793 | 135 | 86 | 1,210 | 8.1 | 78 | ---- |
| 409b | | | [1] 1,438–1,998 | W | 3–24–64 | 16 | 63 | 14 | | | 149 | 225 | 155 | 135 | .5 | ---- | 645 | 214 | 30 | 1,080 | 7.9 | 60 | ---- |
| 409c | | | [1] 1,530 | W | 3–26–64 | 10 | 46 | 10 | | | 198 | 160 | 250 | 137 | 1.0 | ---- | 732 | 156 | 25 | 1,220 | 8.1 | 73 | ---- |
| 409d | | | [1] 520–1,998 | W | 3–28–64 | 15 | 65 | 15 | 138 | 3.7 | | 218 | 145 | 139 | .6 | .2 | 629 | 224 | 45 | 1,060 | 7.6 | 58 | .10 |
| 409e | | | [1] 520–1,998 | W | 4–21–64 | 15 | 63 | 17 | 140 | 3.7 | | 193 | 142 | 162 | .4 | .6 | 624 | 226 | 68 | 1,100 | 7.6 | 58 | .11 |
| 409f | | | [1] 520–1,998 | W | 4–21–64 | 15 | 62 | 17 | | | 133 | 210 | 125 | 149 | .5 | ---- | 607 | 224 | 52 | 1,050 | 7.8 | 56 | ---- |
| 410a | 35cab | Irr | 178–293 | C | 6–1–62 | 18 | 100 | 29 | | | 89 | 266 | 110 | 163 | .4 | ---- | 642 | 370 | 152 | 1,230 | 7.7 | 34 | ---- |
| 410b | | | 178–293 | C | 6–18–62 | 16 | 137 | 42 | | | 127 | 312 | 233 | 208 | .3 | ---- | 919 | 516 | 260 | 1,540 | 7.7 | 35 | ---- |
| 410c | | | 178–293 | C | 7–20–62 | 18 | 127 | 40 | | | 136 | 304 | 233 | 202 | .5 | ---- | 909 | 482 | 232 | 1,470 | 7.6 | 38 | ---- |
| 410d | | | 178–293 | C | 11–21–62 | 21 | 110 | 24 | | | 143 | 280 | 185 | 186 | ---- | ---- | 809 | 374 | 144 | 1,350 | 7.7 | 45 | ---- |
| 410e | | | 178–293 | C | 7–5–63 | 20 | 141 | 38 | | | 162 | 308 | 283 | 222 | .5 | ---- | 1,020 | 510 | 258 | 1,620 | 7.4 | 41 | ---- |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410f | | | 178–293 | C | 11–29–65 | 20 | 124 | 34 | | 136 | | 280 | 183 | 228 | .5 | ---- | 866 | 448 | 218 | 1,510 | 7.5 | 40 | ---- |
| 410g | | | 178–293 | C | 1–17–67 | 19 | 138 | 40 | | 141 | | 284 | 225 | 248 | .4 | ---- | 953 | 510 | 277 | 1,630 | 7.4 | 38 | ---- |
| 410h | | | 178–293 | C | 4–28–67 | 19 | 153 | 53 | | 142 | | 304 | 283 | 258 | .6 | ---- | 1,060 | 600 | 350 | 1,820 | 7.5 | 34 | ---- |
| 411a | (C–11–25)2bba | Irr | 174–210 | C | 4–30–62 | 17 | 134 | 39 | | 152 | | 331 | 267 | 196 | .7 | ---- | 972 | 496 | 224 | 1,590 | 7.7 | 40 | ---- |
| 411b | | | 174-210 | C | 6–28–63 | 20 | 126 | 41 | | 152 | | 320 | 258 | 199 | .5 | ---- | 957 | 482 | 220 | 1,570 | 7.8 | 41 | ---- |
| 411c | | | 174-210 | C | 5– 1–64 | 20 | 134 | 39 | | 152 | | 328 | 267 | 198 | .4 | ---- | 974 | 495 | 226 | 1,580 | 7.2 | 40 | ---- |
| 411d | | | 174–210 | C | 11–15–65 | 20 | 134 | 40 | | 147 | | 332 | 242 | 208 | .5 | ---- | 958 | 500 | 228 | 1,600 | 7.4 | 39 | ---- |
| 411e | | | 174–210 | C | 4–28–67 | 21 | 134 | 43 | | 150 | | 336 | 250 | 212 | .5 | ---- | 979 | 510 | 234 | 1,660 | 7.4 | 39 | ---- |
| 412a | (C–11–25)3dac | Irr | 188–282 | C | 5– 1–62 | 13 | 143 | 40 | | 161 | | 302 | 375 | 163 | .9 | ---- | 1,050 | 520 | 272 | 1,600 | 7.8 | 40 | ---- |
| 412b | | | 188–282 | C | 8– 3–62 | ---- | ---- | ---- | | --- | | 282 | ---- | 150 | ---- | ---- | ---- | 506 | 275 | 1,510 | 7.3 | ---- | ---- |
| 412c | | | 188–282 | C | 6–21–63 | 19 | 138 | 39 | | 146 | | 294 | 350 | 154 | .6 | ---- | 994 | 506 | 265 | 1,530 | 7.4 | 39 | ---- |
| 412d | | | 188–282 | C | 9– 6–63 | 21 | 140 | 32 | | 158 | | 304 | 342 | 155 | .4 | ---- | 1,000 | 482 | 232 | 1,570 | 7.8 | 42 | ---- |
| 412e | | | 188–282 | C | 5–13–64 | 18 | 143 | 45 | | 138 | | 300 | 350 | 162 | .3 | ---- | 1,010 | 540 | 294 | 1,580 | 7.2 | 36 | ---- |
| 412f | | | 188–282 | C | 11– 1–64 | 20 | 153 | 39 | | 145 | | 296 | 358 | 170 | ---- | ---- | 1,030 | 540 | 298 | 1,590 | 7.3 | 37 | ---- |
| 412g | | | 188–282 | C | 2– 8–66 | 18 | 146 | 43 | | 122 | | 300 | 308 | 168 | .5 | ---- | 956 | 540 | 294 | 1,610 | 7.3 | 33 | ---- |
| 412h | | | 188–282 | C | 6– 7–66 | 19 | 135 | 47 | | 158 | | 316 | 342 | 183 | .5 | ---- | 1,040 | 530 | 271 | 1,630 | 7.5 | 39 | ---- |
| 412i | | | 188–282 | C | 1–31–67 | 18 | 148 | 43 | | 141 | | 304 | 312 | 188 | ---- | ---- | 1,000 | 545 | 296 | 1,650 | 7.4 | 35 | ---- |

## YUMA MESA SUBAREA

### Fortuna sector

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 501 | (C– 9–21)2bca | Dom | 280–310 | O | 3–14–66 | 12 | 302 | 84 | | 1,190 | | 68 | 900 | 1,910 | 3.5 | ---- | 4,440 | 1,100 | 1,040 | 7,300 | 7.0 | 70 | ---- |
| 502 | 3ccd1 | Iru | 300–800 | O | 4–13–64 | 19 | 143 | 53 | | 638 | | 116 | 412 | 1,020 | ---- | ---- | 2,340 | 575 | 480 | 4,180 | 7.3 | 71 | ---- |
| 503 | 3ccd2 | Iru | 257–296 | O | 6–10–64 | 28 | 37 | 11 | | 44 | | 198 | 17 | 36 | .3 | ---- | 272 | 136 | 0 | 468 | 7.6 | 41 | ---- |
| 504 | 4bbb | Ob | 180–183 | O | 4–22–65 | 1 | 10 | 0 | | 189 | | 196 | 30 | 171 | 1.8 | ---- | 510 | 27 | 0 | 974 | 8.2 | 93 | ---- |
| 505a | 10bcd | Dom | <301 | O | 5– 9–67 | 17 | 191 | 57 | | 480 | | 140 | 360 | 895 | .9 | ---- | 2,070 | 710 | 595 | 3,680 | 7.3 | 60 | ---- |
| 505b | | | <301 | O | 10– 9–67 | 18 | 206 | 61 | | 500 | | 132 | 375 | 958 | .9 | ---- | 2,180 | 765 | 657 | 3,930 | 7.2 | 59 | ---- |
| 506 | 13ccb | Iru | 560–596 | O | 11– 4–65 | 7 | 124 | 32 | | 743 | | 76 | 525 | 1,020 | 3.0 | ---- | 2,490 | 440 | 378 | 4,360 | 6.8 | 79 | ---- |
| 507 | 14bac | Iru | [6] 680 | O | 8–11–65 | 4 | 146 | 43 | | 779 | | 100 | 550 | 1,120 | ---- | ---- | 2,690 | 540 | 458 | 4,540 | 7.2 | 76 | ---- |
| 508a | 16add | Iru | 294–370 | O | 9– 9–67 | 16 | 166 | 55 | | 667 | | 112 | 400 | 1,120 | 1.1 | ---- | 2,480 | 640 | 548 | 4,480 | 6.8 | 69 | ---- |
| 508b | | Dom | [8] 220–272 | O | 9–28–67 | 18 | 47 | 6.4 | | 80 | | 150 | 12 | 129 | .2 | ---- | 368 | 144 | 0 | 704 | 7.2 | 55 | ---- |
| 508c | | | [8] 220–272 | O | 10– 9–67 | 18 | 74 | 12 | | 114 | | 140 | 29 | 237 | .2 | ---- | 554 | 232 | 117 | 1,090 | 7.1 | 52 | ---- |
| 509 [5] | 22aaa | Iru | 325–340 | O | 2–15–56 | ---- | 79 | 9 | | 296 | | 166 | 236 | 348 | 2.0 | ---- | 1,050 | 234 | 98 | 1,800 | 7.8 | 73 | ---- |
| 510 | 23abd | Iru | [6] 580(?) | O | 11– 3–65 | 8 | 113 | 34 | | 738 | | 92 | 525 | 992 | 1.8 | ---- | 2,460 | 420 | 344 | 4,160 | 7.2 | 79 | ---- |
| 511a | 10bcd | Dom | 194(?) | O | 3– 7–66 | 20 | 27 | 6.4 | | 51 | | 176 | 12 | 34 | .1 | ---- | 238 | 94 | 0 | 413 | 7.1 | 54 | ---- |
| 511b | | | 194(?) | O | 9– 7–67 | 19 | 27 | 8.4 | | 58 | | 200 | 11 | 36 | .2 | ---- | 260 | 102 | 0 | 431 | 7.5 | 55 | ---- |

### Arizona Western sector

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 512 | (C– 9–21)6bbc | Iru | 284–404 | O | 8–27–62 | 25 | 129 | 46 | | 316 | | 248 | 135 | 605 | 0.9 | ---- | 1,380 | 512 | 308 | 2,600 | 7.4 | 57 | ---- |
| 513 | 6ccc | Dom | <200 | O | 4–27–62 | 22 | 84 | 42 | | 281 | | 208 | 107 | 503 | 1.0 | ---- | 1,140 | 382 | 212 | 2,210 | 7.9 | 62 | ---- |
| 514 | 8aaa | Ob | 190–193 | O | 4–27–65 | 1 | 76 | 8.4 | | 127 | | 132 | 17 | 265 | .1 | ---- | 560 | 224 | 116 | 1,140 | 6.8 | 55 | ---- |
| 515 | 9baa | Iru | 240–470 | O | 2– 5–66 | 17 | 103 | 42 | | 306 | | 220 | 120 | 558 | .3 | ---- | 1,260 | 428 | 103 | 2,300 | 6.9 | 61 | ---- |
| 516 | 18ddd | Iru | 290–350 | O | 6–11–62 | 15 | 66 | 26 | | 284 | | 241 | 100 | 417 | .3 | ---- | 1,030 | 272 | 74 | 1,960 | 7.6 | 70 | ---- |
| 517a | (C– 8–22)35cca | Irr | 180–248 | C | 11– 4–64 | 23 | 132 | 51 | | 291 | | 228 | 175 | 568 | .7 | ---- | 1,350 | 540 | 353 | 2,470 | 7.6 | 54 | ---- |
| 517b | | | 180–248 | C | 8– 5–65 | 23 | 127 | 49 | | 300 | | 224 | 183 | 565 | .7 | ---- | 1,360 | 520 | 336 | 2,450 | 7.4 | 56 | ---- |
| 518a | 35ccb | PS | 460–580 | W | 7–30–62 | 20 | 66 | 18 | | 225 | | 250 | 78 | 311 | .7 | ---- | 844 | 237 | 32 | 1,570 | 7.5 | 67 | ---- |
| 518b | | | 460–580 | W | 8–30–63 | 19 | 73 | 13 | | 225 | | 248 | 75 | 313 | .9 | ---- | 843 | 236 | 32 | 1,530 | 7.5 | 68 | ---- |
| 518c | | | 460–580 | W | 2–10–66 | 11 | 68 | 16 | | 219 | | 244 | 70 | 311 | ---- | ---- | 817 | 236 | 36 | 1,530 | 7 5 | 67 | ---- |
| 519 | (C– 9–22)12aaa1 | Iru | 330–400 | W | 12– –59 | ---- | 64 | 14 | | 362 | | 254 | 120 | 476 | ---- | ---- | 1,160 | 217 | 8 | 2,200 | ---- | 78 | ---- |
| 520 | 22aaa | Ob | 126-129 | U | 4–27–65 | ---- | ---- | ---- | | --- | | ---- | ---- | 515 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 521 | 28cbb | T | 862–2,002 | W | 1–19–65 | 24 | 94 | 26 | 225 | | 5.5 | 218 | 92 | 398 | .4 | 0.4 | 972 | 340 | 160 | 1,770 | 7.7 | 58 | 0.30 |
| 522 | (C–10–22)22bab | PS | <319 | O | 6–28–62 | 12 | 79 | 40 | | 224 | | 113 | 108 | 455 | .5 | ---- | 975 | 362 | 270 | 1,760 | ---- | ---- | ---- |

### Citrus sector

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 523 [3] | (C– 8–22)33dbc | Dom | <154 | C | 8– –58 | ---- | 113 | 11 | | 456 | | 278 | 214 | 610 | ---- | ---- | 1,540 | 327 | 99 | 2,400 | ---- | 75 | ---- |
| 524a [3] | (C– 8–23)36ccd | Ind | 185-244 | C | 8– 4–52 | 21 | 88 | 28 | | 276 | | 281 | 77 | 444 | ---- | ---- | 1,070 | 337 | 105 | ---- | 7.6 | 64 | ---- |
| 524b [5] | | | 185-244 | C | 2– 1–55 | 21 | 128 | 41 | | 290 | | 262 | 77 | 582 | ---- | ---- | 1,270 | 487 | 272 | ---- | 7.8 | 56 | ---- |
| 524c [5] | | | 185-244 | C | 10–26–55 | ---- | 204 | 64 | | 402 | | 256 | 187 | 888 | ---- | ---- | 1,890 | 776 | 568 | ---- | ---- | 53 | ---- |
| 524d [5] | | | 185-244 | C | 5– 9–58 | 34 | 214 | 85 | | 453 | | 226 | 408 | 895 | ---- | ---- | 2,200 | 886 | 700 | ---- | 7.7 | 53 | ---- |
| 524e | | | 185-244 | C | 5–29–52 | 22 | 190 | 57 | | 509 | | 272 | 830 | 515 | ---- | ---- | 2,260 | 710 | 487 | 3,350 | 7.8 | 61 | 0.28 |
| 525 [3] | (C– 9–22)3cdb | Irr | 160–250 | C | ca. 1930 | ---- | 67 | 26 | | 228 | | 210 | 40 | 360 | ---- | ---- | 853 | 274 | 102 | ---- | ---- | 64 | ---- |
| 526a [2] | 4caa | | 130–138 | U | 5–22–57 | 23 | 312 | 102 | 472 | | 8.6 | 218 | 241 | 1,280 | 0.6 | ---- | 2,550 | 1,200 | 1,020 | 4,530 | 7.7 | 46 | .33 |
| 526b | | Ind | 130–138 | U | 11– 9–67 | 22 | 222 | 87 | | 492 | | 264 | 750 | 695 | 1.0 | ---- | 2,400 | 910 | 694 | 3,920 | 7.5 | 54 | ---- |
| 527 | 6ada | Ob | 166-169 | C | 3–24–66 | 22 | 95 | 39 | | 475 | | 336 | 725 | 282 | 1.4 | ---- | 1,810 | 398 | 122 | 2,630 | 7.9 | 72 | ---- |
| 529 [2] | 9bba | Iru | 150-250 | C | 7–26–29 | ---- | 23 | 23 | | 229 | | 152 | 40 | 344 | ---- | ---- | 735 | 154 | 60 | 1,400 | ---- | 76 | ---- |
| 530a [2] | 17ccb1 | Dom | 166–177 | C | 4– 1–54 | 30 | 104 | 36 | 373 | | 8.6 | 293 | 523 | 309 | 1.0 | 3.7 | 1,530 | 407 | 167 | 2,340 | 7.8 | 60 | 1.60 |
| 530b [2] | | | 166–177 | C | 5–22–57 | 25 | 66 | 22 | 334 | | 4.3 | 359 | 451 | 152 | 1.7 | 6.2 | 1,240 | 258 | 0 | 1,890 | 7.9 | 73 | .96 |
| 530c | | | 166–177 | C | 7–25–62 | 23 | 48 | 20 | | 392 | | 391 | 475 | 167 | 2.4 | ---- | 1,320 | 204 | 0 | 2,170 | 7.6 | 81 | ---- |
| 531a | 17dca | Iru | 165–218 | C | 5–25–66 | 25 | 66 | 21 | | 305 | | 294 | 425 | 162 | 1.5 | ---- | 1,150 | 252 | 11 | 1,860 | 7.6 | 72 | ---- |
| 531b | | | 165–218 | C | 1–11–67 | 25 | 66 | 23 | | 303 | | 288 | 425 | 168 | 1.6 | ---- | 1,160 | 260 | 24 | 1,870 | 7.6 | 72 | ---- |
| 532 | 18add | Dom | (?) | (?) | 5– 7–65 | 22 | 33 | 12 | | 327 | | 260 | 388 | 155 | 1.9 | ---- | 1,070 | 130 | 0 | 1,710 | 7.8 | 84 | ---- |
| 533 | 18ccc | Dom | (?) | C(?) | 4–26–65 | 22 | 28 | 7.8 | | 318 | | 224 | 375 | 152 | 1.7 | ---- | 1,020 | 120 | 0 | 1,600 | 7.9 | 87 | ---- |
| 534a | 18ddd | Dom | 169–177 | C | 7–25–62 | 21 | 25 | 14 | | 346 | | 306 | 388 | 153 | 1.6 | ---- | 1,100 | 121 | 0 | 1,840 | 7.8 | 86 | ---- |
| 534b | | | 169–177 | C | 4–27–65 | 23 | 31 | 5.5 | | 363 | | 294 | 388 | 168 | 3.2 | ---- | 1,130 | 100 | 0 | 1,840 | 7.8 | 89 | ---- |
| 535a | 30bbb | Dom | <179 | C | 5–19–62 | 13 | 40 | 17 | | 439 | | 229 | 650 | 182 | 1.8 | ---- | 1,460 | 170 | 0 | 2,160 | 7.7 | 85 | ---- |
| 535b [9] | [9] 30bbb | | [9] 179 | C | 4–28–65 | 24 | 28 | 9.7 | | 345 | | 268 | 412 | 145 | 2.5 | ---- | 1,100 | 110 | 0 | 1,680 | 8.0 | 87 | ---- |
| 536a [3] | (C– 9–23)1add | Ind | 180-188 | C | 3–21–57 | ---- | 296 | 97 | | 892 | | 256 | 1,600 | 850 | .6 | ---- | 3,860 | 1,140 | 930 | ---- | ---- | 63 | ---- |
| 536b [2] | | | 180-188 | C | 5–22–57 | 24 | 317 | 171 | 1,410 | | 11 | 290 | 2,640 | 1,120 | 1.9 | 4.3 | 5,850 | 1,490 | 1,260 | 7,820 | 7.9 | 67 | ---- |

See footnotes at end of table.

*Chemical analyses of ground water*—Continued

| Analysis | Well | Use | Depth of sample (feet) | Aquifer | Date of sample | Silica (SiO₂) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Na + K | Bicarbonate (HCO₃) | Sulfate (SO₄) | Chloride (Cl) | Fluoride (F) | Nitrate (NO₃) | Dissolved solids (sum) | Hardness as CaCO₃: Calcium magnesium | Hardness as CaCO₃: Noncarbonate | Specific conductance (micromhos at 25°C) | pH | Percent sodium | Boron (B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **YUMA MESA SUBAREA—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| **Citrus sector—Continued** | | | | | | | | | | | | | | | | | | | | | | | |
| 537 [2] | (C- 9-23)1cc | Ind | 190–200 | C | 4- 1-54 | 29 | 95 | 34 | 276 | 8.6 | | 265 | 108 | 469 | 0.6 | ---- | 1,150 | 379 | 162 | 2,040 | 7.9 | 61 | ---- |
| 538a | 8aac | Irr | 204–214 | C | 8-27-63 | 24 | 66 | 19 | | | 284 | 220 | 438 | 158 | 1.1 | ---- | 1,100 | 244 | 64 | 1,800 | 8.0 | 72 | ---- |
| 538b | | | 204–214 | C | 12- 9-63 | 20 | 101 | 36 | | | 339 | 229 | 638 | 200 | 1.0 | ---- | 1,450 | 398 | 210 | 2,240 | 8.0 | 65 | ---- |
| 539a [3] | 10abb | Ind | 145–197 | U, C | 8- 1-29 | ---- | 85 | 44 | | | 264 | 259 | 101 | 462 | ---- | ---- | 1,090 | 393 | 180 | 1,950 | ---- | 59 | ---- |
| 539b [3] | | | 145–197 | U, C | 1942(?) | ---- | 68 | 34 | | | 264 | 106 | 120 | 476 | ---- | ---- | 1,020 | 309 | 222 | ---- | ---- | 65 | ---- |
| 540 [2] | 11bbb | Ind | 193 | U, C | 3- 5-33 | ---- | 93 | 34 | | | 268 | 290 | 90 | 419 | ---- | ---- | 1,050 | 370 | 132 | 1,890 | ---- | 60 | ---- |
| 541 | 12aac | Dom | 92–100 | U | 4-26-65 | 19 | 34 | 16 | | | 359 | 280 | 425 | 182 | 1.5 | ---- | 1,180 | 152 | 0 | 1,890 | 7.8 | 84 | ---- |
| 542 | 12aca | Dom | (?) | (?) | 4-26-65 | 21 | 90 | 42 | | | 379 | 296 | 500 | 322 | 1.1 | ---- | 1,500 | 396 | 154 | 2,400 | 7.6 | 68 | ---- |
| 543a [5] | 23adc | Dom | 164–170 | C | 2- 5-53 | ---- | 33 | 6 | | | 235 | 209 | 320 | 80 | ---- | ---- | 778 | 105 | 0 | 1,320 | 8.0 | 83 | ---- |
| 543b | | | 164–170 | C | 7-25-62 | 24 | 65 | 28 | | | 201 | 288 | 317 | 122 | .9 | ---- | 895 | 304 | 68 | 1,570 | 7.6 | 59 | ---- |
| 544 | 23dcb | Dom | 164–170 | C | 4-27-65 | 24 | 55 | 16 | | | 320 | 314 | 400 | 158 | 1.6 | ---- | 1,130 | 204 | 0 | 1,800 | 7.8 | 77 | ---- |
| 545a [2] | 24baa | Dom | 175 | C | 5-22-57 | 26 | 51 | 21 | 316 | 4.3 | | 390 | 384 | 126 | 1.5 | 7.4 | 1,130 | 214 | 0 | 1,730 | 7.8 | 76 | ---- |
| 545b | | | 175 | C | 7-25-62 | 21 | 29 | 19 | | | 283 | 281 | 325 | 134 | 3.5 | ---- | 955 | 151 | 0 | 1,740 | 7.8 | 80 | ---- |
| 545c | | | 175 | C | 4-28-65 | 23 | 33 | 7.7 | | | 342 | 268 | 400 | 152 | 3.1 | ---- | 1,090 | 114 | 0 | 1,730 | 7.9 | 81 | ---- |
| 546a | 25dba2 | T | 160–250 | C | 3- 5-64 | 25 | 69 | 23 | | | 411 | 320 | 538 | 234 | 1.8 | 11.0 | 1,470 | 268 | 6 | 2,250 | 7.5 | 77 | 1.1 |
| 546b | | | 160–250 | C | 3-18-64 | 21 | 64 | 24 | | | 398 | 316 | 525 | 222 | 2.4 | ---- | 1,410 | 260 | 1 | 2,230 | 7.8 | 77 | ---- |
| 547 | 28aab | Dom | 230–250 | C | 8-13-62 | 28 | 65 | 28 | | | 429 | 302 | 650 | 201 | .4 | ---- | 1,550 | 276 | 28 | 2,310 | 7.6 | 77 | ---- |
| 548 [2] | 28ccc | Dom | <220 | C | 5-22-57 | 22 | 211 | 75 | 417 | 7.0 | | 187 | 510 | 762 | .6 | .6 | 2,090 | 836 | 683 | 3,430 | 8.0 | 52 | ---- |
| 549 | 31cdc | Dom | <220 | C | 1-26-64 | 15 | 140 | 40 | | | 314 | 200 | 325 | 490 | .6 | ---- | 1,420 | 512 | 348 | 2,480 | 8.0 | 57 | ---- |
| 550 | 31dcd1 | Ta | 61–63 | U | 1-26-62 | 27 | 58 | 33 | | | 278 | 258 | 475 | 148 | ---- | ---- | 1,180 | 280 | 68 | 1,770 | 8.4 | 69 | ---- |
| 551 | 31dcd2 | Ta | 89–91 | U | 1-26-62 | 12 | 9 | 7 | | | 412 | 284 | 475 | 156 | ---- | ---- | 1,210 | 51 | 0 | 2,060 | 8.6 | 95 | ---- |
| 552 | 31dcd3 | Ta | 115–117 | U | 1-26-62 | 18 | 44 | 26 | | | 481 | 274 | 700 | 221 | ---- | ---- | 1,630 | 218 | 0 | 2,580 | 8.2 | 88 | ---- |
| 553 | 31dcd4 | Ta | 135–137 | U | 1-26-62 | 18 | 40 | 24 | | | 506 | 256 | 750 | 219 | ---- | ---- | 1,680 | 200 | 0 | 2,500 | 8.2 | 85 | ---- |
| 555 | 35dcd | Dom | <176 | C(?) | 4-28-65 | 26 | 49 | 15 | | | 443 | 412 | 488 | 208 | 3.2 | ---- | 1,440 | 184 | 0 | 2,310 | 7.7 | 84 | ---- |
| 556 | 36aab | Dom | 160–196 | C | 8-17-66 | 24 | 70 | 26 | | | 332 | 288 | 450 | 208 | 1.7 | ---- | 1,260 | 280 | 44 | 2,060 | 7.6 | 72 | ---- |
| 557 | 36bdd | Iru | 170–252 | C | 7-26-29 | ---- | 85 | 39 | | | 277 | 232 | 141 | 454 | ---- | ---- | 1,110 | 374 | 184 | 2,010 | ---- | 62 | ---- |
| 558 | 36ada | Iru | 256–608 | W, C | 12-15-66 | 19 | 130 | 38 | | | 309 | 224 | 262 | 492 | .7 | ---- | 1,360 | 480 | 296 | 2,400 | 7.5 | 58 | ---- |
| 559 | (C-10-23)3aaa1 | Ob | 100–103 | U | 4-28-65 | 6 | 70 | 30 | | | 414 | 176 | 438 | 422 | .8 | ---- | 1,470 | 152 | 70 | 2,470 | 7.8 | 75 | ---- |
| 560 | 3aaa2 | Dom | 170–184 | C | 5-24-61 | ---- | ---- | ---- | | | 434 | 262 | 600 | 472 | ---- | ---- | ---- | 562 | 347 | 2,860 | 8.0 | 63 | ---- |
| 561a | 3aba | Dom | <190 | C | 12-14-62 | 23 | 94 | 29 | | | 441 | 306 | 625 | 292 | ---- | ---- | 1,660 | 354 | 103 | 2,650 | 7.4 | 73 | ---- |
| 561b | | | <190 | C | 7- 6-66 | 20 | 94 | 28 | | | 391 | 304 | 650 | 192 | ---- | ---- | 1,530 | 350 | 100 | 2,350 | 7.6 | 71 | ---- |
| 561c | | | <190 | C | 1-10-68 | 19 | 82 | 28 | | | 369 | 308 | 600 | 172 | 1.1 | ---- | 1,410 | 320 | 68 | 2,190 | 7.7 | 72 | ---- |
| 562 | 9aaa2 | Ta | 124–126 | U | 2- 9-62 | 16 | 25 | 9 | | | 471 | 351 | 588 | 158 | ---- | ---- | 1,440 | 98 | 0 | 2,190 | 8.4 | 91 | ---- |
| 563 | 9aaa3 | Ta | 167–169 | C | 2- 9-62 | 13 | 118 | 33 | | | 401 | 240 | 562 | 370 | ---- | ---- | 1,620 | 432 | 235 | 2,530 | 7.9 | 69 | ---- |
| **City sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 564 | (C- 8-23)21acb | AC | <110 | O | 9- 7-62 | 23 | 71 | 31 | | | 330 | 298 | 375 | 272 | 1.2 | ---- | 1,250 | 304 | 60 | 2,110 | 7.6 | 70 | ---- |
| 565 | 21acc2 | AC | 165–166 | O | 9-10-62 | 23 | 230 | 74 | | | 339 | 268 | 538 | 592 | .8 | ---- | 1,930 | 880 | 660 | 3,200 | 7.4 | 46 | ---- |
| 566a | 21caa | Irr | 180–205 | C | 10-29-65 | 19 | 234 | 96 | | | 771 | 336 | 850 | 1,060 | .9 | ---- | 3,200 | 980 | 704 | 4,950 | 7.3 | 63 | ---- |
| 566b | | | 180–205 | C | 7- 5-66 | 19 | 238 | 94 | | | 735 | 340 | 800 | 1,040 | ---- | ---- | 3,270 | 980 | 701 | 4,990 | 7.2 | 62 | ---- |
| 567 | 21ccc | Ind | 160–208 | C | 10-26-65 | 20 | 71 | 20 | | | 194 | 240 | 200 | 195 | .7 | ---- | 821 | 260 | 63 | 1,380 | 7.6 | 62 | ---- |
| 568 | 29ada | Ind | 100–188 | C(?) | 4-14-61 | 23 | 95 | 30 | 279 | 6.4 | | 247 | 364 | 272 | .7 | 13 | 1,200 | 362 | 160 | 1,940 | 7.5 | 62 | ---- |
| 569 | 29daa | Irr | 160–295 | C | 6- 8-67 | 19 | 246 | 74 | | | 367 | 276 | 600 | 615 | ---- | ---- | 2,060 | 920 | 694 | 3,400 | 7.4 | 46 | ---- |
| 571 | 32dda | Irr | 121–145 | C(?) | 8-22-67 | 22 | 382 | 140 | | | 666 | 180 | 1,000 | 1,270 | ---- | ---- | 3,570 | 1,530 | 1,380 | 5,760 | 7.6 | 49 | ---- |
| 572 | 33bdb | Irr | <318 | W(?) | 10- 3-61 | 29 | 168 | 59 | | | 519 | 247 | 588 | 675 | .6 | 2.8 | 2,160 | 660 | 458 | 3,400 | 7.7 | 63 | ---- |
| 573a | 33cdd | T | 182–200 | C | 6-11-62 | 16 | 231 | 96 | | | 439 | 190 | 412 | 950 | ---- | ---- | 2,370 | 970 | 814 | 3,950 | 7.7 | 50 | ---- |
| 573b | | | [6] 965 | W | 4-30-62 | 2 | 153 | 17 | | | 497 | 50 | 375 | 780 | ---- | ---- | 1,850 | 450 | 409 | 3,310 | 7.1 | 71 | ---- |
| 573c | | | [6] 1,035 | W | 5- 7-63 | 2 | 144 | 17 | | | 534 | 28 | 240 | 935 | ---- | ---- | 1,890 | 430 | 407 | 3,610 | 7.2 | 73 | ---- |
| 573d | | | [6] 1,070 | W | 5-14-63 | 1 | 185 | 4.5 | | | 636 | 16 | 288 | 1,100 | ---- | ---- | 2,220 | 480 | 467 | 4,220 | 7.5 | 74 | ---- |
| 574 | 33ccb | Irr | 195–295 | C, W | 5-23-67 | 21 | 318 | 113 | | | 550 | 200 | 520 | 1,240 | .7 | ---- | 2,860 | 1,260 | 1,100 | 4,990 | 7.2 | 48 | ---- |
| 575 | (C- 9-23)3dcc | Dom | 185–203 | C | 4-19-61 | 28 | 292 | 85 | 676 | 9.2 | | 190 | 718 | 1,160 | .5 | 1.0 | 3,060 | 1,080 | 924 | 4,880 | 7.3 | 57 | ---- |
| 576 | 4abd | Irr | 180–200 | C(?) | 6-15-66 | 37 | 188 | 66 | | | 455 | 184 | 475 | 767 | .7 | ---- | 2,080 | 740 | 589 | 3,530 | 7.5 | 57 | ---- |
| 577 | 4cbd | Irr | 180–230 | C(?) | 7-14-64 | 25 | 217 | 75 | | | 522 | 228 | 675 | 775 | 1.2 | ---- | 2,400 | 850 | 663 | 3,920 | 7.5 | 57 | ---- |
| **South sector** | | | | | | | | | | | | | | | | | | | | | | | |
| 578 | (C-10-23)11ccb2 | Irr | 130–388 | C | 1-18-62 | 23 | 49 | 11 | 302 | 3.4 | | 221 | 394 | 170 | 2.3 | 7.5 | 1,070 | 166 | 0 | 1,680 | 8.2 | 79 | 0.64 |
| 579a | 11dcd | Irr | 98–495 | C, W | 4-20-65 | 20 | 86 | 26 | | | 214 | 140 | 110 | 388 | .3 | ---- | 910 | 312 | 197 | 1,580 | 7.4 | 60 | ---- |
| 579b | | | 98–495 | C, W | 4-28-66 | 20 | 100 | 32 | | | 245 | 168 | 262 | 355 | .8 | ---- | 1,100 | 380 | 242 | 1,970 | 7.4 | 58 | ---- |
| 580a | 12aba1 | Irr | 178–686 | C, W | 2-21-63 | 15 | 56 | 18 | | | 201 | 52 | 68 | 380 | .4 | ---- | 764 | 212 | 170 | 1,480 | 7.6 | 67 | ---- |
| 580b | | | 178–686 | C, W | 3-29-63 | 21 | 78 | 21 | | | 201 | 110 | 74 | 390 | .3 | .2 | 840 | 280 | 192 | 1,540 | 7.7 | 61 | .12 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 580c | | | 178–686 | C, W | 7– –63 | 17 | 87 | 24 | | 204 | | 134 | 90 | 392 | .5 | ---- | 881 | 314 | 204 | 1,660 | 7.6 | 58 | ---- |
| 580d | | | 178–686 | C, W | 10–31–63 | 18 | 90 | 26 | | 205 | | 132 | 95 | 403 | ---- | ---- | 903 | 330 | 222 | 1,690 | 7.7 | 57 | ---- |
| 580e | | | 178–686 | C, W | 6–29–64 | 18 | 123 | 35 | | 244 | | 148 | 192 | 468 | .6 | ---- | 1,150 | 452 | 330 | 2,100 | 7.2 | 54 | ---- |
| 581a | 12abb | Irr | 202–210 | C | 3–29–63 | 22 | 85 | 30 | | 194 | | 123 | 90 | 398 | .2 | ---- | 881 | 334 | 233 | 1,670 | 7.7 | 56 | ---- |
| 581b | | | 202–210 | C | 6–24–64 | 20 | 106 | 35 | | 211 | | 180 | 167 | 388 | .5 | ---- | 1,020 | 410 | 262 | 1,860 | 7.2 | 53 | ---- |
| 581c | | | 202–210 | C | 4–24–65 | 23 | 130 | 39 | | 254 | | 176 | 217 | 472 | .4 | ---- | 1,220 | 485 | 340 | 2,160 | 7.5 | 53 | ---- |
| 582a | 12bda | Irr | 150–680 | C, W | 7–11–62 | 14 | 73 | 25 | | 222 | | 142 | 135 | 362 | .7 | ---- | 903 | 286 | 170 | 1,590 | 7.6 | 63 | ---- |
| 582b | | | 150–680 | C, W | 8–20–62 | 24 | 84 | 28 | | 219 | | 166 | 155 | 358 | .4 | ---- | 951 | 326 | 190 | 1,730 | 7.4 | 59 | ---- |
| 582c | | | 150–680 | C, W | 7– –63 | 20 | 90 | 23 | | 240 | | 180 | 188 | 352 | .6 | ---- | 1,000 | 320 | 172 | 1,850 | 7.7 | 62 | ---- |
| 582d | | | 150–680 | C, W | 11– 6–63 | 22 | 88 | 26 | | 237 | | 186 | 216 | 330 | .4 | ---- | 1,010 | 328 | 176 | 1,790 | 7.5 | 61 | ---- |
| 582e | | | 150–680 | C, W | 6–24–64 | 21 | 122 | 42 | | 311 | | 180 | 325 | 472 | .8 | ---- | 1,380 | 476 | 328 | 2,440 | 7.2 | 59 | ---- |
| 582f | | | 150–680 | C, W | 4–22–65 | 24 | 135 | 45 | | 306 | | 168 | 325 | 502 | .6 | ---- | 1,420 | 520 | 382 | 2,410 | 7.5 | 56 | ---- |
| 583a | 12bdd | Irr | 132–690 | C, W | 11– –62 | 13 | 63 | 26 | | 207 | | 136 | 80 | 368 | ---- | ---- | 825 | 264 | 152 | 1,590 | 7.4 | 63 | ---- |
| 583b | | | 132–690 | C, W | 2–21–63 | 21 | 113 | 27 | | 243 | | 163 | 185 | 422 | .6 | ---- | 1,090 | 394 | 260 | 1,970 | 7.4 | 57 | ---- |
| 583c | | | 132–690 | C, W | 7– –63 | 21 | 137 | 32 | | 331 | | 188 | 425 | 422 | .8 | ---- | 1,460 | 474 | 320 | 2,440 | 7.8 | 60 | ---- |
| 583d | | | 132–690 | C, W | 4–22–65 | 21 | 97 | 30 | | 295 | | 192 | 275 | 398 | 1.0 | ---- | 1,210 | 365 | 208 | 2,090 | 7.6 | 64 | ---- |
| 584a[3] | 12dbc | Irr | 165–280 | C | 8–18–59 | ---- | 92 | 35 | 260 | | 2.8 | 178 | 190 | 422 | ---- | ---- | 1,090 | 374 | 228 | 1,700 | ---- | 60 | ---- |
| 584b | | | 165–280 | C | 4–22–65 | 26 | 126 | 48 | | 297 | | 168 | 275 | 518 | .4 | ---- | 1,370 | 510 | 372 | 2,360 | 7.5 | 56 | ---- |
| 585a | 15aaa | Irr | 112–285 | C | 8– 4–61 | 26 | 80 | 21 | 282 | | 3.8 | 242 | 403 | 198 | 1.0 | 6.7 | 1,140 | 286 | 88 | 1,770 | 7.5 | 68 | .60 |
| 585b | | | 112–285 | C | 6– 7–62 | 13 | 69 | 26 | | 259 | | 274 | 400 | 141 | 1.3 | ---- | 1,050 | 280 | 56 | 1,700 | 7.5 | 67 | ---- |
| 586a | 15aab | Irr | <890 | C, W | 11–18–61 | 23 | 83 | 24 | 202 | | 4.2 | 154 | 80 | 380 | .4 | 2.5 | 875 | 304 | 178 | 1,570 | 8.0 | 59 | .32 |
| 586b | | | <890 | C, W | 6–12–62 | 18 | 130 | 411 | | 218 | | 187 | 250 | 391 | .3 | ---- | 1,140 | 492 | 338 | 2,110 | 7.3 | 49 | ---- |
| 587 | 20aad | Iru | 330–490 | C, W | 6–10–66 | 14 | 90 | 21 | | 290 | | 176 | 225 | 398 | .5 | ---- | 1,130 | 310 | 166 | 1,980 | 7.7 | 67 | ---- |
| 588 | 20abd | Iru | 305–455 | C, W | 6–28–68 | 19 | 87 | 22 | | 267 | | 190 | 145 | 408 | 1.1 | ---- | 1,040 | 306 | 150 | 1,930 | 7.6 | 65 | ---- |
| 589 | 20bbb1 | Ind | 212–232 | C | 7–13–61 | 27 | 108 | 31 | 290 | | 5.3 | 210 | 318 | 365 | .4 | 8.1 | 1,260 | 396 | 224 | 2,050 | 7.3 | 61 | ---- |
| 590 | 20cdd | Iru | 118–174 | C | 5– 1–64 | 25 | 78 | 28 | | 271 | | 178 | 158 | 415 | .8 | ---- | 1,060 | 308 | 162 | 1,970 | 7.4 | 66 | ---- |
| 591a | 21abb | Irr | 200–264 | C | 4–20–64 | 30 | 102 | 29 | | 247 | | 188 | 145 | 428 | .7 | ---- | 1,080 | 374 | 220 | 1,930 | 7.8 | 58 | ---- |
| 591b | | | 200–264 | C | 4–27–64 | 24 | 135 | 42 | | 283 | | 188 | 325 | 448 | .8 | ---- | 1,350 | 510 | 356 | 2,340 | 7.0 | 55 | ---- |
| 591c | | | 200–264 | C | 7–18–66 | 23 | 122 | 43 | | 282 | | 200 | 312 | 428 | .6 | ---- | 1,310 | 480 | 316 | 2,330 | 7.2 | 56 | ---- |
| 592 | 23abb | Iru | 304–454 | W | 3–31–66 | 22 | 81 | 27 | | 195 | | 156 | 82 | 371 | ---- | ---- | 856 | 312 | 184 | 1,590 | 7.4 | 58 | ---- |
| 593[3] | 23cbd | Irr | 320–500 | W | 12– 6–66 | ---- | ---- | ---- | | --- | | ---- | 79 | 377 | ---- | ---- | 890 | ---- | ---- | ---- | ---- | ---- | ---- |
| 595 | 29ddc | Iru | 244–294 | C | 8–19–64 | 18 | 86 | 27 | | 237 | | 176 | 110 | 411 | .4 | ---- | 977 | 324 | 180 | 1,830 | 7.3 | 61 | ---- |
| 596a | 31bbb1 | T | [6] 129 | U | 6– 6–61 | 13 | 100 | 33 | | 268 | | 159 | 135 | 492 | .5 | ---- | 1,120 | 384 | 254 | 2,070 | 7.4 | 60 | ---- |
| 596b | | | [6] 288 | C | 6– 9–61 | 12 | 176 | 39 | | 279 | | 134 | 135 | 498 | .5 | ---- | 1,110 | 348 | 238 | 2,070 | 7.8 | 64 | ---- |
| 596c | | | [6] 460 | W | 6–23–61 | 20 | 79 | 49 | | 290 | | 171 | 160 | 512 | .4 | ---- | 1,200 | 400 | 260 | 2,100 | 7.8 | 61 | ---- |
| 596d | | | [6] 571 | W | 7–18–61 | 10 | 91 | 32 | | 296 | | 113 | 160 | 525 | .5 | ---- | 1,150 | 358 | 266 | 2,130 | 7.6 | 64 | ---- |
| 596e | | | [6] 798 | W | 9–14–61 | 11 | 120 | 33 | | 284 | | 149 | 150 | 548 | ---- | ---- | 1,220 | 434 | 312 | 2,260 | 7.4 | 59 | ---- |
| 596f | | | [6] 932 | W | 10–23–61 | 5 | 80 | 29 | | 277 | | 184 | 140 | 502 | ---- | ---- | 1,070 | 320 | 251 | 2,070 | 7.9 | 65 | ---- |
| 596g | | | [6] 1,000 | W | 10–30–61 | ---- | ---- | ---- | | --- | | 102 | ---- | 515 | ---- | ---- | ---- | 348 | 264 | 2,120 | 7.8 | ---- | ---- |
| 596h | | | [1] 220–280 | C | 11–20–61 | 28 | 98 | 28 | | 260 | | 133 | 145 | 470 | ---- | ---- | 1,100 | 358 | 249 | 2,030 | 8.0 | 61 | ---- |
| 596i | | | [1] 220–280 | C | 6–20–62 | 23 | 110 | 32 | | 263 | | 178 | 116 | 502 | .5 | .1 | 1,140 | 406 | 260 | 2,070 | 7.5 | 58 | .20 |
| 597 | 31bbb2 | Ta | 155–157 | C | 1–26–62 | 11 | 99 | 32 | | 254 | | 152 | 133 | 473 | ---- | ---- | 1,080 | 378 | 254 | 1,990 | 8.1 | 59 | ---- |
| 598 | (C-10-24) 32aca | Iru | 150–420 | C, W | 3–26–65 | 23 | 182 | 57 | | 220 | | 312 | 438 | 322 | ---- | ---- | 1,400 | 690 | 434 | 2,190 | 7.6 | 41 | ---- |
| 599 | (C-11-23) 30bac | Ta | 135–137 | C | 1–24–62 | 21 | 97 | 38 | | 256 | | 129 | 160 | 485 | ---- | ---- | 1,120 | 400 | 294 | 2,050 | 8.1 | 58 | ---- |
| 600 | 34bbc | T | 160–600 | C, W | 8–31–65 | 19 | 65 | 17 | | 230 | | 96 | 75 | 412 | .6 | ---- | 867 | 230 | 152 | 1,670 | 7.6 | 69 | ---- |
| 601 | (C-12-22) 6daa | Ta | 166–168 | O | 11–25–62 | 18 | 27 | 10 | | 229 | | 140 | 85 | 287 | ---- | ---- | 726 | 110 | 5 | 1,350 | 8.1 | 82 | ---- |
| 602a | 9bab | T | [1] 318–346 | O | 1–21–65 | 7 | 44 | 12 | | 170 | | 140 | 115 | 207 | .5 | ---- | 626 | 158 | 43 | 1,100 | 7.6 | 92 | ---- |
| 602b | | | [1] 318–346 | O | 3–16–65 | 37 | 23 | 7.2 | 227 | | 5.6 | 144 | 73 | 284 | 1.0 | .1 | 729 | 87 | 0 | 1,290 | 7.9 | 84 | ---- |
| 603a | (C-11-24) 2abd | Iru | 130–300 | C | 12–30–64 | 22 | 87 | 27 | | 244 | | 218 | 185 | 345 | .5 | ---- | 1,020 | 328 | 149 | 1,760 | 7.6 | 62 | ---- |
| 603b | | | [1] 130–300 | C | 1–14–65 | 23 | 84 | 29 | | 233 | | 216 | 158 | 349 | .5 | ---- | 985 | 328 | 151 | 1,790 | 7.6 | 61 | ---- |
| 604a | 2baa | Iru | [1] 102 | U | 12– 9–64 | 21 | 97 | 34 | | 343 | | 198 | 362 | 415 | .9 | ---- | 1,370 | 380 | 218 | 2,270 | 7.5 | 66 | ---- |
| 604b | | | 78–102 | U | 12–17–64 | 24 | 94 | 33 | | 247 | | 208 | 180 | 388 | .7 | ---- | 1,070 | 370 | 200 | 1,910 | 7.4 | 59 | ---- |
| 605 | 2bbd | Iru | 140–376 | C, W | 5– 3–65 | 22 | 89 | 31 | | 207 | | 216 | 160 | 322 | .6 | ---- | 940 | 350 | 173 | 1,630 | 7.4 | 56 | ---- |
| 606a | 11ddd | Irr | 148–212 | C | 3–14–66 | 15 | 92 | 28 | | 235 | | 168 | 165 | 385 | .6 | ---- | 1,010 | 344 | 206 | 1,870 | 7.4 | 60 | ---- |
| 606b | | | 148–212 | C | 3–23–66 | 20 | 97 | 27 | | 245 | | 160 | 183 | 398 | .5 | ---- | 1,050 | 352 | 221 | 1,890 | 7.8 | 60 | ---- |
| 606c | | | 148–212 | C | 4–20–66 | 18 | 100 | 28 | | 247 | | 164 | 162 | 423 | .3 | ---- | 1,060 | 364 | 230 | 1,910 | 7.7 | 60 | ---- |
| 607 | | | 178–180 | U | 1–25–62 | 17 | 76 | 22 | | 176 | | 230 | 170 | 211 | ---- | ---- | 787 | 280 | 0 | 1,340 | 8.2 | 58 | ---- |
| 608a | 23bcb | T | [1] 165–1,002 | C, W | 2–11–63 | 13 | 48 | 16 | | 180 | | 190 | 125 | 205 | .6 | ---- | 683 | 186 | 30 | 1,220 | 7.6 | 68 | ---- |
| 608b | | | [1] 985–1,002 | W | 2–26–63 | 15 | 59 | 18 | | 180 | | 206 | 140 | 211 | .3 | ---- | 726 | 222 | 53 | 1,280 | 7.8 | 64 | ---- |
| 608c | | | [1] 855–875 | W | 2–27–63 | 15 | 59 | 18 | | 179 | | 198 | 140 | 213 | .4 | ---- | 723 | 220 | 58 | 1,270 | 7.8 | 64 | ---- |
| 608d | | | [1] 685–705 | W | 2–27–63 | 17 | 60 | 19 | | 173 | | 192 | 140 | 214 | .2 | ---- | 719 | 228 | 70 | 1,260 | 7.8 | 62 | ---- |
| 608e | | | [1] 475–545 | W | 2–28–63 | 19 | 56 | 19 | | 181 | | 180 | 155 | 214 | .2 | ---- | 734 | 218 | 70 | 1,260 | 7.8 | 64 | ---- |
| 608f | | | [1] 240–325 | C | 2–28–63 | 20 | 52 | 16 | | 178 | | 196 | 135 | 199 | .2 | ---- | 698 | 196 | 36 | 1,220 | 7.8 | 66 | ---- |
| 608g | | | [1] 165–220 | C | 3– 1–63 | 20 | 53 | 16 | | 177 | | 196 | 130 | 202 | .3 | ---- | 696 | 196 | 36 | 1,230 | 7.8 | 66 | ---- |
| 608h | | | [1] 165–1,002 | C, W | 4–10–63 | 20 | 56 | 18 | | 177 | | 196 | 140 | 206 | .4 | ---- | 715 | 212 | 52 | 1,230 | 7.6 | 64 | ---- |
| 608i | | | [1] 165–1,002 | C, W | 4–11–63 | 21 | 60 | 16 | | 174 | | 194 | 137 | 208 | ---- | .1 | 711 | 216 | 57 | 1,220 | 8.2 | ---- | .12 |
| 609 | 23bdb | Iru | [6] 200 | C | 5–11–65 | ---- | 56 | 17 | | --- | | 182 | ---- | 227 | ---- | ---- | ---- | 208 | 59 | 1,290 | 7.8 | ---- | ---- |
| 610 | (C-11-25) 12bca | Dom | 183–195 | C | 1–25–62 | 26 | 56 | 18 | | 134 | | 228 | 118 | 139 | ---- | ---- | 605 | 214 | 27 | 1,010 | 7.9 | 58 | ---- |
| 611 | 12bdb | PS | 177–200 | C | 1–10–64 | 24 | 63 | 17 | | 129 | | 198 | 115 | 159 | .3 | ---- | 606 | 226 | 64 | 1,040 | 7.8 | 56 | ---- |
| 612a[3] | 12cab | Dom | <105 | U | 1–19–45 | ---- | 72 | 18 | | 131 | | 210 | 128 | 162 | .3 | ---- | 616 | 253 | 81 | ---- | ---- | 53 | ---- |
| 612b[3] | | | <105 | U | 5– 3–61 | ---- | 56 | 19 | | 134 | | 212 | 119 | 149 | .2 | ---- | 583 | 218 | 44 | 1,000 | ---- | 57 | ---- |
| 612c | | | <105 | U | 1–25–62 | 25 | 63 | 17 | 132 | | 4.4 | 217 | 117 | 157 | .4 | 0 | 623 | 226 | 48 | 1,050 | 8.0 | 55 | .11 |

[1] Sample from outlet pipe, thief sampler, or packer during development or test pumping.
[2] Analysis by U.S. Salinity Laboratory.
[3] Analysis by Arizona Univrsity Agricultural Experiment Station or Arizona State Health Department.
[4] Sampled 20 hours after acid treatment.
[5] Analysis by private laboratory.
[6] Sample from mud scow, bailer, or thief sampler during drilling.
[7] Shallow well for water supply for main well.
[8] Well plugged back, reperforated.
[9] Replacement well.

## APPENDIX D. SELECTED PUMPING TESTS

Selected pumping test data are shown in figures 50–54, inclusive. The data illustrates some of the problems that arise when pumping tests are made under less than ideal conditions for determining representative transmissivity values.

### WELL 16S/23E–10Rcc, LCRP 23 TEST

Figure 50 shows selected data for well 16S/23E–10Rcc, LCRP 23. Graphs *A*, *B*, *C*, and *D* show some of the data obtained on January 21, 1965, during and following a step-drawdown test. Graph *E* shows recovery data for strata at much shallower depths than those tested in January.

Pertinent data for the January tests are as follows:

Method of drilling ----------Cable tool.
Casing diameter ------------12 inches.
Perforated interval ----------634–694 feet.
Aquifer tested --------------Bouse Formation conglomerate.
Test conditions:

Pumped with turbine pump and gasoline engine.
Orifice installed at end of discharge pipe.
Steady rate of discharge maintained by manually controlling valve in discharge pipe to maintain constant head on orifice.

March 20, 1965:

Step 1 of test consisted of pumping well at steady rate of 423 gpm for 45 minutes.
Step 2 consisted of pumping well at steady rate of 847 gpm for 45 minutes.

March 21, 1965:

Step 3 consisted of pumping well at steady rate of 1,235 gpm for 2 hours after completion of step 2.

#### DISCUSSION OF TEST DATA

The specific capacity data in graph *A* shows that head losses in the well are substantial at moderate rates of pumping. The separation of observed drawdown into components of drawdown due to loss of head in the formations tapped by the well and drawdown due to well construction and friction losses was made on the basis of the extrapolation of the straight-line plot shown in the lower part of graph *A* to its intersection with the ordinate of zero discharge. The intersection at 0.004 foot of drawdown per gallon per minute of yield is equivalent to 250 gallons per minute per foot of drawdown, which is the slope of the line shown in the upper part of graph *A*, which separates the drawdown into the two components.

From Theis, Brown, and Meyer (1963, p. 333), it is estimated that for the conditions of this test the transmissivity should be about 1,500 times the specific capacity, or almost 400,000 gpd per foot. This value is 50 percent more than that obtained by using drawdown data of step 3 to compute transmissivity. Drawdown data during steps 1 and 2 were not suitable for analysis because they showed no consistent downward trend.

The transmissivity computed on the basis of recovery data shown in graph *D* is unreasonably large, perhaps 5–10 times too large. The pattern of the recovery data from about 2 minutes after pumping stopped to 40 minutes after pumping stopped is very near the theoretical pattern, and were this the only data available, one might consider the value to be fairly reliable. However, the water level began to drop after 40 minutes, which shows conditions were markedly different from those necessary if the formula that was used to compute the transmissivity is to yield valid results.

The recovery-of-water-level data following step 2 of the pumping test made the previous day could not be used to compute the transmissivity because the plotted data had a negative slope. The water level in the well attained its maximum recovery, which was the prepumping level, about 1½ minutes after pumping stopped. During the next 15 minutes the water level declined about 0.03 foot; about 10 hours after, it had declined an additional 0.15 foot.

The conditions responsible for these unusual water-level recoveries are unknown. It seeems possible that the surge from the 680-foot column of water in the pump column might be responsible for part of the unusual recovery pattern, and, possibly, the elasticity of the aquifer might also be partly responsible. Te water in the zone tapped by the well has an artesian head about 3 feet above the water table.

Graph *B* shows that practically all the yield was obtained from a 40-foot section of material between depths of 640 and 680 feet, and that the rate of yield from the various strata was quite uniform. The lithologic log indicates that the material is predominantly conglomerate containing a 3-foot interbed of clay or mudstone between depths of 656 and 659 feet. (See appendix B.) The rate of yield from the conglomerate as computed from the test data is about 30 gpm per foot of thickness, and the formation head loss as shown in graph A is about 5 feet. On this basis, the average hydraulic conductivity is almost 9,000 gallons per day per square foot, which is comparable to the known maximum hydraulic conductivity of Colorado River gravel of comparable thickness in the Yuma area. Some secondary porosity, therefore, is indicated because elsewhere the hydraulic conductivity of similar conglomerate is generally much less.

Secondary porosity may be indicated by the manner in which the well developed. Although the well pumped very little sand, it never yielded clear water during the 8 hours it was pumped. The water was always milky or whitish. Examination of the residue of a sample of water by means of a 30-power binocular microscope showed the very fine residue to be rock of probable granitic origin. When subjected to hydrochloric acid only a mild effervescence was observed. Thus, some development of the aquifer probably persisted throughout the tests.

On the basis of the hydraulic conductivity of almost 9,000 gallons per day per square foot and the thickness of 40 feet, the transmissivity of the conglomerate is about 360,000 gallons per day per foot, rather than the 5 million gallons per day per foot computed from the recovery data shown in graph *D*.

Graph *E* is recovery data for a pumping test to determine the transmissivity of the coarse-gravel and wedge zones, from a depth of 120 feet to 548 feet. This test was made April 6, 1965, after the well had been perforated with a Mills knife in the above interval and plugged to a depth of about 550 feet. Considerable difficulty was experienced in developing the well. The well tended to sand in, and eventually caving occurred at the land surface. Several tens of cubic yards of gravel were dropped into the caved area before the formations adjacent to the well were stabilized. Some sort of gravel pack thereby resulted, at least in the upper part of the well. On April 6, a 5-inch diameter

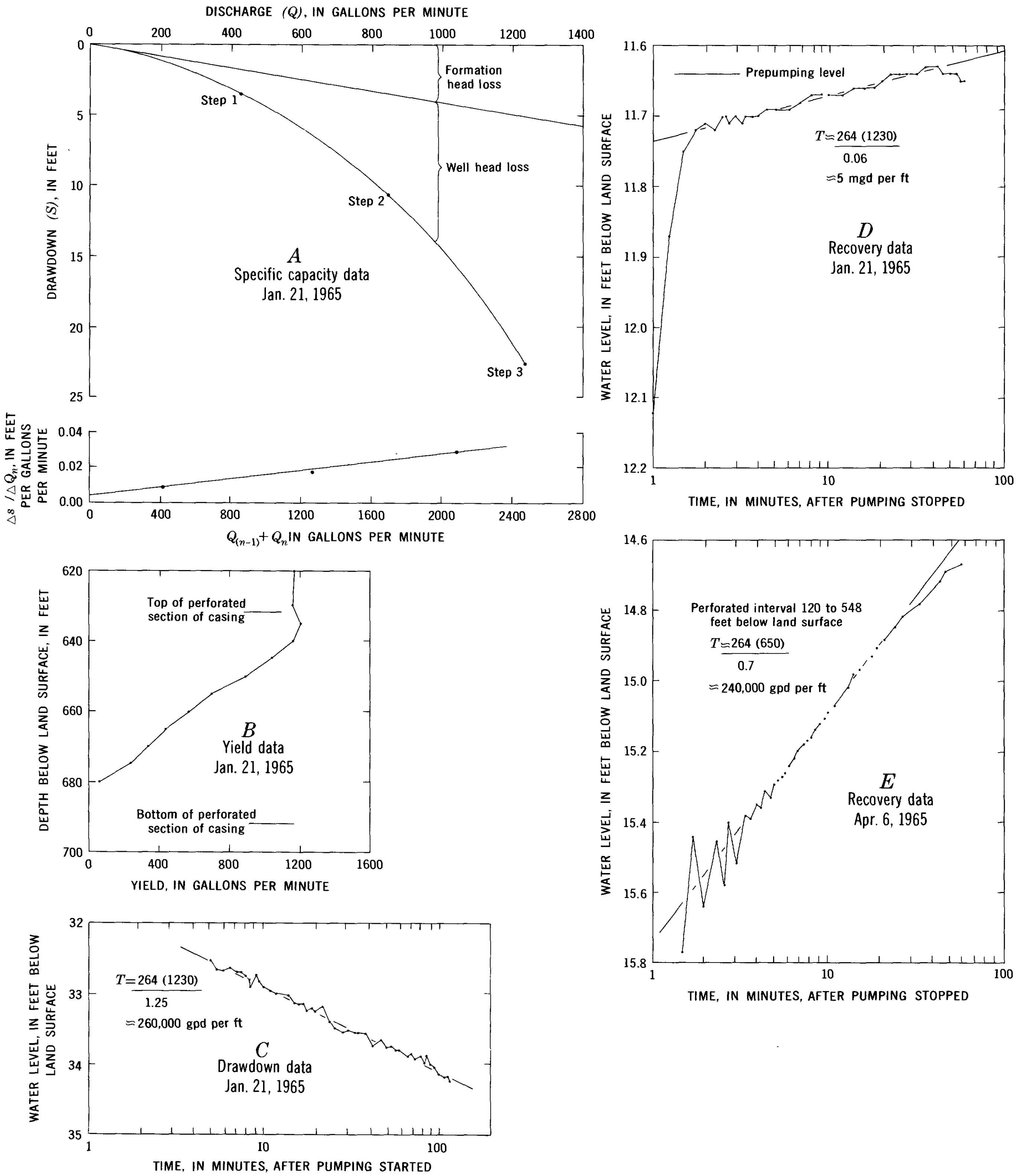



FIGURE 50.—Pumping-test data for well 16S/23E–10Rcc (LCRP 23). Graphs *A*, *B*, *C*, and *D*, show data pertaining to the Bouse Formation (conglomerate) between depths of 634 and 694 feet, whereas graph *E* shows data pertaining only to the coarse-gravel and wedge zones between depths of 120 and 548 feet.

eductor pipe was installed to a depth of 500 feet, and the well was pumped for 2 hours by the air-lift method. At the pumping rate of 650 gpm, the drawdown in the annular space between the eductor pipe and the casing was 4 feet, which indicates a specific capacity of about 160 gpm per foot of drawdown. The drawdown, as measured, is a minimum value, and is less than the drawdown on any of the water-yielding strata except the uppermost. Granting that the specific capacity for computing transmissivity would be less than the above figure, the transmissivity computed from the recovery data appears reasonable. The drawdown data obtained during the test were not consistent enough for computing transmissivity.

The oscillations of water-level that were measurable for at least 5 minutes after pumping stopped probably are due in large part to the imbalance between the head in the 500-foot long column of water inside the eductor pipe and the head in the hollow cylinder of water of comparable length between the eductor pipe and the casing that persisted after pumping stopped.

### WELL 16S/22E–29Gca2 LCRP 26 TEST

Figure 51 shows selected pumping-test data for well 16S/22E–29Gca2, LCRP 26. The graphs are of the same general nature as those for well LCRP 23 which were explained in the preceding section.

Pertinent information regarding the well and the tests is as follows:

Method of drilling ---Mud rotary.

Casing record --------12-inch diameter from land surface to depth of 121 feet; 12- to 8-inch reducer, 121 to 124 feet; 8-inch diameter, 124 to 1,765 feet.
Horizontal-louver type perforations between depths of 124 and 1,105 feet; and between 1,345 and 1,765 feet. Gravel packed from land surface to depth of 1,105 feet.

Aquifers tested -------Coarse-gravel zone; wedge zone; nonmarine sedimentary rocks.

Test conditions:

March 11, 1965: Recovery period followed 2 hours of continuous pumping at rate of 250 gpm at end of a 90-hour intermittent period of developing the well by the airlift-pressuring method. The 5-inch diameter eductor pipe was set 1,740 feet below land surface, and drawdown was measured in the annular space between the well casing and the eductor pipe.

April 13, 1965: The well was pumped by means of a turbine pump and gasoline engine. An orifice was installed on the end of the discharge pipe. A steady rate of discharge was maintained by manually controlling a valve in the discharge line to maintain a constant head on the orifice. Drawdown was measured in the annular space between the pump column and the well casing. Step 1 consisted of pumping the well at a uniform rate of 380 gpm for 2 hours; step 2 of pumping at a uniform rate of 715 gpm for 2 hours, 30 minutes; step 3 of pumping at a uniform rate of 1,100 gpm for 1 hour, 30 minutes; and step 4 of pumping at a uniform rate of 1,365 gpm for 2 hours, 40 minutes.

#### DISCUSSION OF TEST DATA

The recovery data obtained on March 11, 1965 (graph *C*), shows surging, which also was noted in well LCRP 23. This phenomenon seems to be characteristic of recovery data following the airlift method of pumping when the recovery measurements show the changes in water level in one long column of water that is freely connected with another of comparable length. The drawdown of only 0.75 of a foot while the well was being pumped at the rate of 250 gpm indicates a maximum value of 335 gpm per foot of drawdown as the specific capacity. Recognizing that this value is larger than the value that would be valid for computing transmissivity on the basis of specific capacity, it appears that the transmissivity of 400,000 gpd per foot computed on the basis of rate of recovery of water level shown in graph *C* is a reasonable value.

The specific-capacity data in graph *A* imply specific capacities much less than the 330 gpm per foot that was computed for the airlift pumping test of March 11, 1965. Somewhat lower specific capacities are to be expected as the discharge rates increase, because for any part of the system in which turbulent flow exists, (and this type of flow occurs in the vicinity of the perforations even at rather low rates of yield), the loss of head increases at a faster rate than the yield. This increase in rate of drawdown with yield is shown by the increasing slope of the line through steps 1, 2, and 3, as contrasted with the line of uniform slope which separates the drawdown into components of formation head loss and wellhead loss. However, at comparable yields one ordinarily expects comparable specific capacities.

The reasons for the large differences in specific capacity at comparable rates of discharge between the two tests are not all known. A small part of the differences may be due to errors in measurements of yields or drawdown. Also, part of the differences are due to differences in the pumping equipment. The measurement of drawdown in the annular space between the eductor pipe and the casing as made for the airlift pumping test excludes all internal well losses, whereas the measurement of drawdown in the annular space between the pump column and the well casing as made for the test using a turbine pump includes all internal well losses. Furthermore, the distribution of drawdown along the perforated sections of casing is different for the two tests. When the well was pumped by the airlift method, the maximum drawdown opposite the perforated sections of the casing occurred near the bottom of the sections at a depth of 1,740 feet, whereas when the turbine pump was used, the maximum drawdown occurred near the top of the perforated section at a depth of 124 feet. It is also possible that the well sanded in below a depth of 1,100 feet between the times of the two tests.

The transmissivity of 550,000 gpd per foot shown in graph *B*, which was computed on the basis of recovery data, appears somewhat high, although not unreasonably so, if a formation specific capacity of about 200 gpd per foot is accepted as a valid value. The transmissivity computed on the basis of recovery data, following the test in which the turbine pump was used, is only slightly higher than the transmissivity computed on the basis of recovery data following the test for which the airlift method was used.

Graph *D* shows that either the permeability of the strata below a depth of 730 feet is very low relative to the average permeability above that depth or these lower strata were not developed (cleared of drilling mud). The graph also shows that particular strata within the zone of average higher permeability differ greatly in permeability (or possibly in degree of development), some strata apparently being practically impermeable (or undeveloped) and others being very permeable (or well developed). The latter evidently occur at depths of about 390, 450, and 530 feet. A comparison of the relative permeabilities as indicated by the current-meter survey shown in graph *D* with relative permeabilities

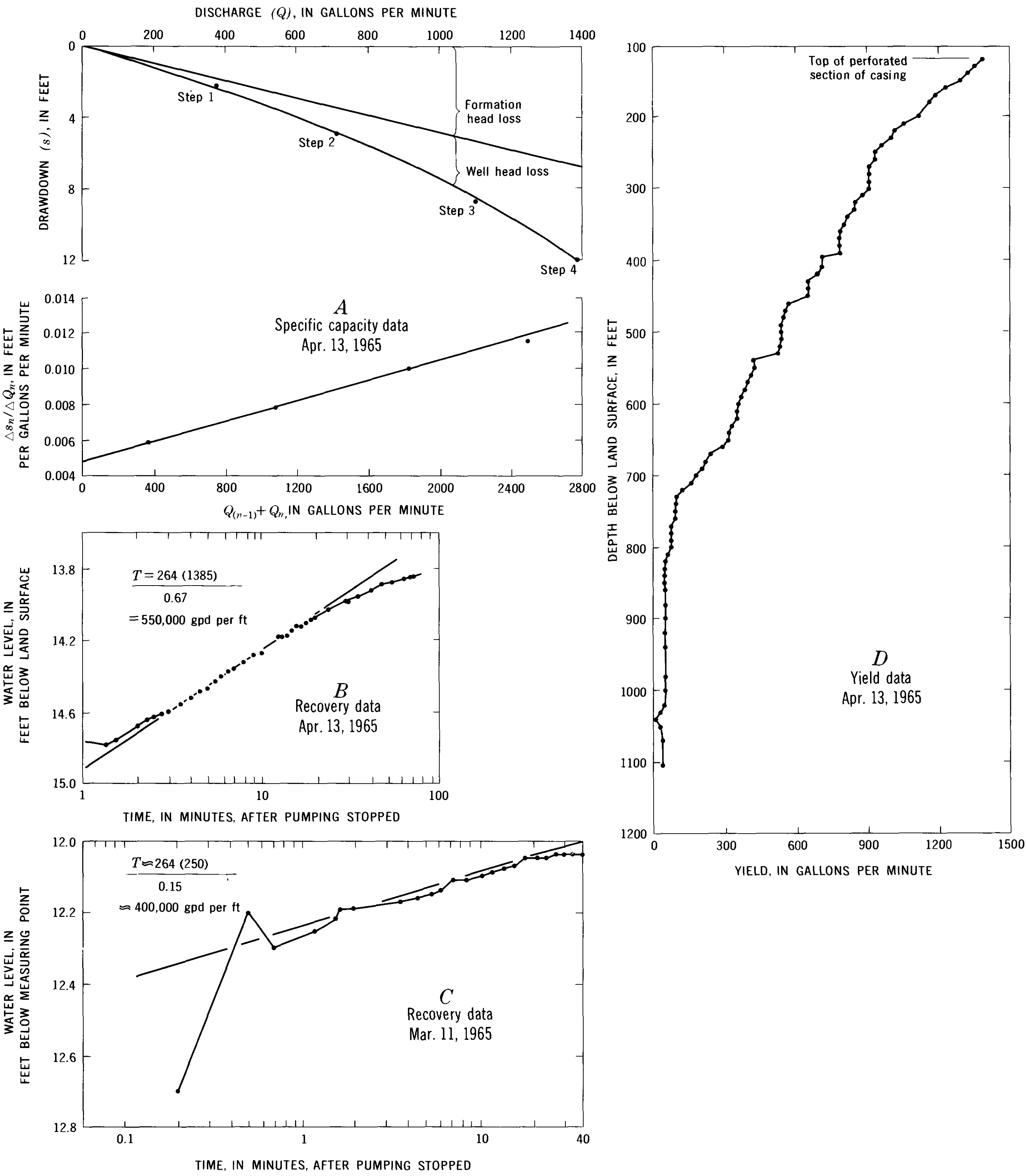
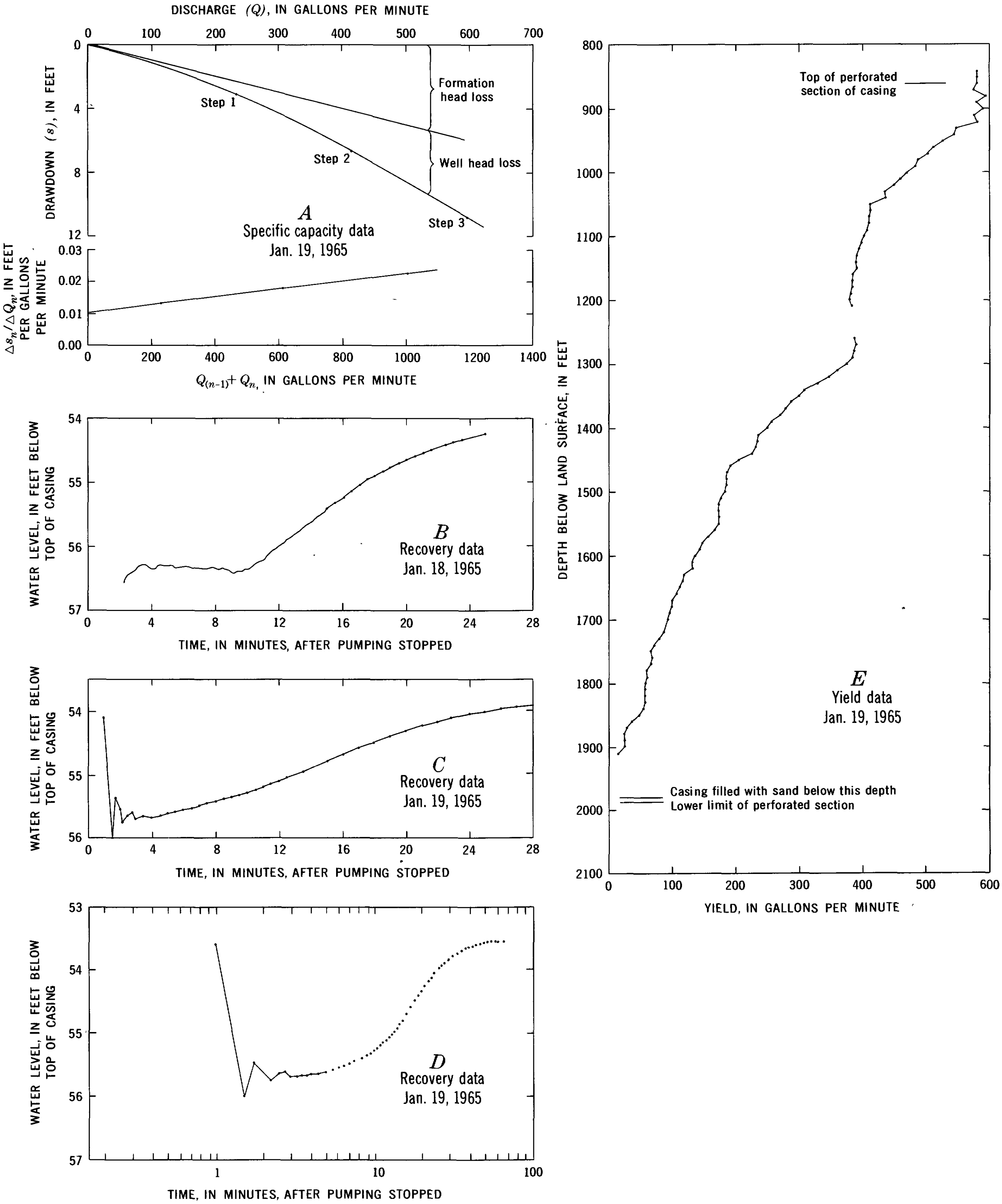



FIGURE 51.—Pumping test data for well 16S/22E-29Gca2 (LCRP 26).

suggested by the lithologic logs (appendix B) shows substantial differences for some strata, although in general the relative permeabilities indicated by the two methods agree quite well. In the few places where the permeability indicated by the current-meter survey substantially exceeds that indicated by the lithologic log, the log probably is in error.

### WELL (C–9–22)28cbb1, LCRP 25 TEST

Figure 52 shows selected test data for well (C–9–22)


DISCHARGE (Q), IN GALLONS PER MINUTE
DRAWDOWN (s), IN FEET
Formation head loss
Well head loss
Step 1
Step 2
Step 3
A
Specific capacity data
Jan. 19, 1965
$\Delta s_n/\Delta Q_n$, IN FEET PER GALLONS PER MINUTE
$Q_{(n-1)}+Q_n$, IN GALLONS PER MINUTE
WATER LEVEL, IN FEET BELOW TOP OF CASING
B
Recovery data
Jan. 18, 1965
TIME, IN MINUTES, AFTER PUMPING STOPPED
C
Recovery data
Jan. 19, 1965
D
Recovery data
Jan. 19, 1965
DEPTH BELOW LAND SURFACE, IN FEET
Top of perforated section of casing
E
Yield data
Jan. 19, 1965
Casing filled with sand below this depth
Lower limit of perforated section
YIELD, IN GALLONS PER MINUTE

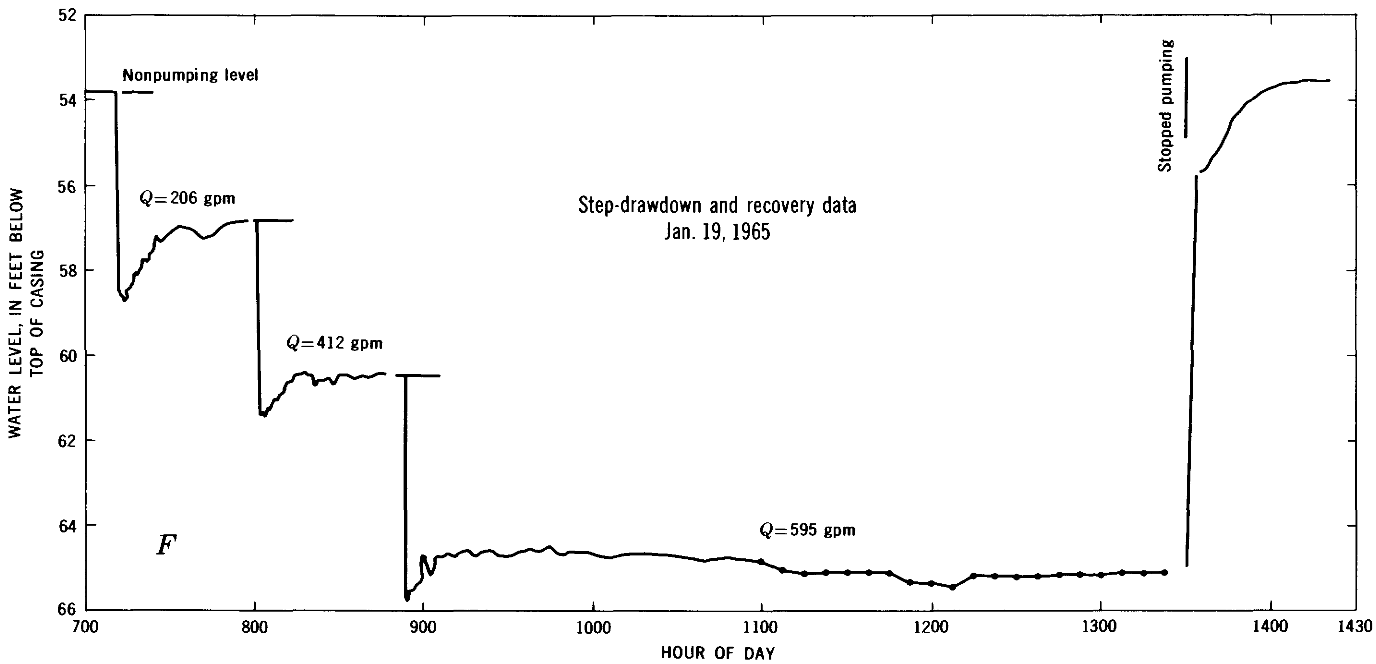



FIGURE 52.—Pumping test data for well (C-9-22)28cbb1 (LCRP 25).

28 cbb1 (LCRP 25). Pertinent information for the well and tests is as follows:

Method of drilling ---Mud rotary.

Casing record ---------12-inch diameter blank casing from land surface to depth of 320 feet; 8-inch blank casing from 320 to 862 feet; 8-inch horizontal louver-type casing from 862 to 2,002 feet. Drilled hole, 16-inch diameter, gravel packed from 2,002 feet to land surface.

Aquifer tested: Wedge zone.

Test conditions:

Pumped with turbine pump and gasoline engine; pump bowls 100 feet below land surface; orifice installed at end of discharge pipe; steady rate of discharge maintained by manually controlling valve in discharge pipe to maintain constant head on orifice; deep-well current meter installed below pump.

January 18, 1965:

Further developed well with turbine pump after well had previously been developed by airlift method; developed for 2 hours and then made recovery measurements.

January 19, 1965:

Using same equipment as on preceding day made a step-drawdown and recovery test. Also made a rate of flow survey during the test.

DISCUSSION OF TEST DATA

Graph *B* shows recovery data following a 2-hour pumping period, the last hour of which the rate was kept fairly constant at about 700 gpm. The pattern of the recovery data is unusual in that after an initial recovery period of 3 minutes, recovery ceased for the next 6 minutes, but then resumed at a rate that appeared to be fairly normal and which resulted in a rise of 2 feet in 15 minutes.

Graph *C* shows recovery data following the step-drawdown test shown in Graph *F*.

The period of virtually no recovery is 2 minutes to 6 minutes after pumping stopped. The failure of the latter recovery data to follow the theoretical pattern, is shown by graph *D*. Theoretically, the recovery data should plot very nearly as a straight line sloping upward to the right.

The reasons for the interruptions in recovery that were observed are not fully understood. A possible explanation is that there is considerable movement of water from deep strata to shallower strata when pumping is stopped. This is probable because when pumping is in progress, the drawdown in the deep strata is less than the drawdown in the shallower strata because of friction losses within the well. When pumping is stopped the friction losses within the well virtually cease and thus water from the strata that had the lesser drawdown will flow to strata where the drawdown was greater until the drawdown in both are equal, after which recovery in both will proceed at a uniform rate.

Evidence that this internal movement was occurring during the recovery period shown in graph *B* are the observations of rate of flow through the deep-well current meter that was suspended in the well at a depth of 1,000 feet. This depth is near the bottom of the better-than-average water yielding zone near the upper part of the perforated section of casing (graph *E*). The current meter indicated an upward flow of at least 60 gpm during the early part of the period of non-rising water level. This rate gradually lessened to about 30 gpm 10 minutes after pumping stopped, and ultimately became less than that needed to actuate the meter.

Graph *F* illustrates still another anomaly. The water level is lowest in the well immediately after an increase in the pumping rate and then recovers to a high stage for the pumping rate within a 10- to 20-minute period.

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The reason for this phenomenon is not fully understood but it is probably due to a change in the distribution of drawdown with time along the 1,100-foot length of perforated casing following a sudden increase in pumping rate.

Graph *E* shows the cumulative yield from strata below a given depth when the well was being pumped at the rate of 585 gpm. The rate of yield from strata between specific depths is easily computed by dividing the difference in yield between the given depths by the difference in the depths.

It is seen that strata below 1,900 feet yield a relative small percentage of the total discharge; that between 1,900 and 1,300 feet the yield per unit thickness of strata generally increases; that between 1,300 and 1,050 feet the yield is much less, with some strata apparently yielding no water; and that from 1,050 to about 920 feet, the yield per unit thickness is as high as, if not higher than anywhere in the entire section.

A comparison of the yield data graph with the borehole gephysical logs shows that the correlation is good for rather thick clay beds, but that it is only fair for beds logged as sand or gravel. This lack of good correlation for sand and gravel strata may indicate either that the borehole geophysical logs are not dependable guides as to the permeability of sand and gravel strata, or more likely, that some of the permeable sand and gravel strata were still sealed with drilling mud and therefore were not yielding water.

Further development work confined to particular strata by the use of packers and use of chemicals to break down drilling mud would determine which of the above inferences is more nearly correct.

Graph *A* indicates that when well losses are excluded, the specific capacity is about 100 gpd per foot. The specific capacity is considered to be the most useful value of all the pumping-test data for computing the transmissivity of the water-bearing material tapped by the well.

## WELL (C–10–25)35bbd LCRP 17 TEST

Figure 53 shows selected test data for well (C–10–25) 35bbd (LCRP 17).

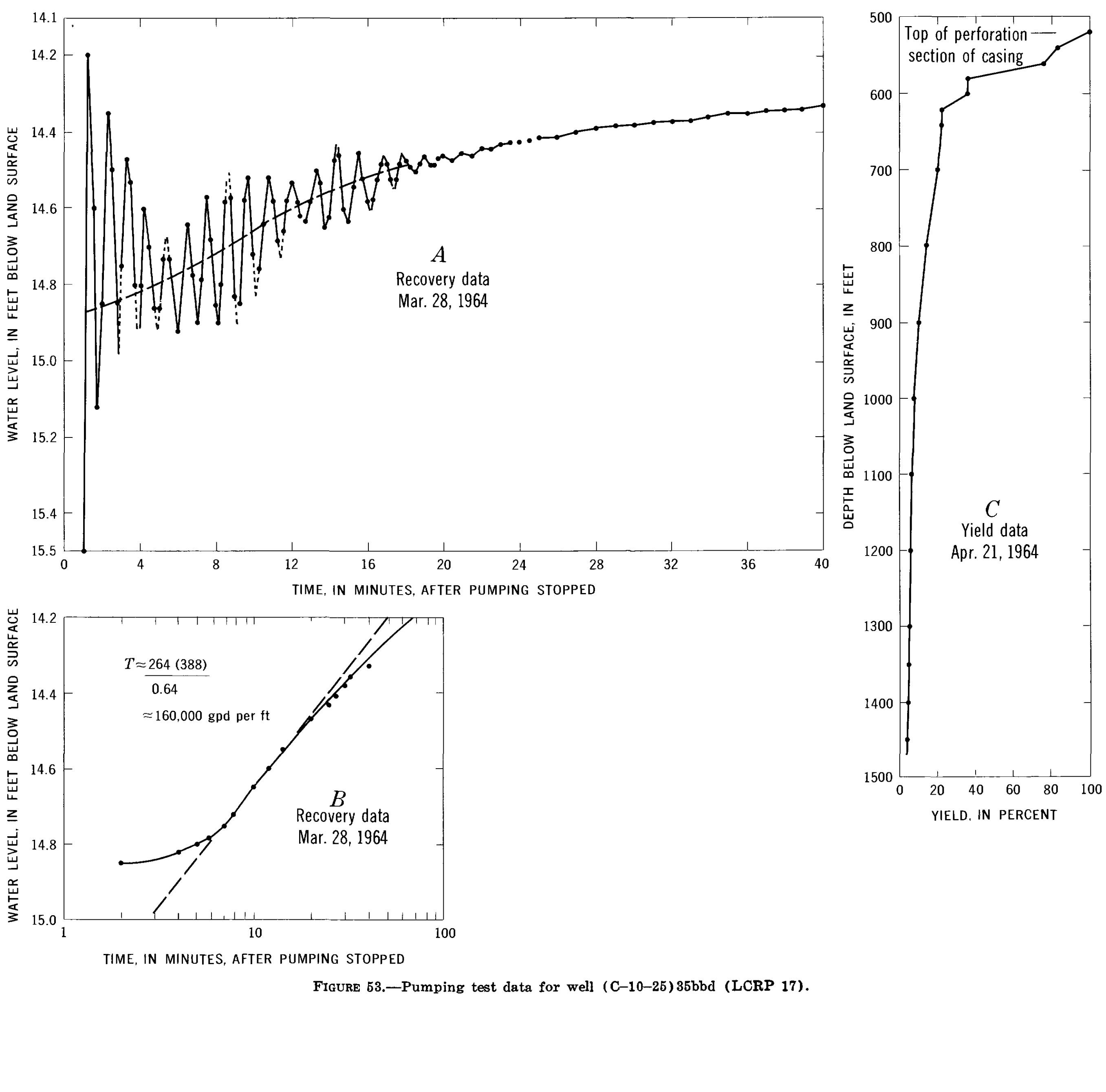



FIGURE 53.—Pumping test data for well (C–10–25)35bbd (LCRP 17).

Pertinent information regarding the well and tests is as follows:

Method of drilling ---Mud rotary.

Casing record --------18-inch diameter blank casing from land surface to depth of 300 feet; 8-inch blank casing, from 270 to 520 feet; 8-inch horizontal-louver casing from 520 to 1,398 feet; 8-inch diameter blank casing 1,398 to 1,438 feet; 8-inch diameter screen from 1,438 to 2,000 feet. Drilled hole, 15-inch diameter, gravel packed from 300 to 2,000 feet.

Test conditions:

March 28, 1964:

The well was pumped by the air-lift method. A 4-inch diameter eductor pipe extended to a depth of 1,420 feet below land surface. A packer to prevent upward movement of water from strata below a depth of 1,398 feet was set in the section of blank casing 10 feet below the eductor pipe. After an initial period of development of the well, the well was pumped at the rate of 388 gpm for a 4-hour period. Pumping was then stopped and the recovery measurements shown on graphs *A* and *B* were made.

April 21, 1964.

A centrifugal pump was used to pump the well at the rate of about 165 gpm for a 2-hour period. During the pumping period a survey of the rate of upward movement of water within the well was made by means of a heat flow velocity meter furnished and operated by the Hydrologic Equipment Laboratory of the U.S. Geological Survey, Denver, Colo.

DISCUSSION OF TEST DATA

The oscillations of water level that are shown on graph A persisted longer than observed oscillations at any other site. Most of the same explanations that were postulated for oscillations noted at wells LCRP 23 and 26 are probably valid for well LCRP 17. However, the movement of water into and out of the formations tapped by the well may be more significant at this site than at the other test sites.

Support for this probability is offered by the observations made on May 5, 1964. On that date the thermal velocity meter was lowered to a depth of 590 feet. An annular plate had been attached to the meter so as to limit most of any movement of water within well casing to a path through the meter, thereby causing the meter to respond to very slow movements of water within the 8-inch casing. The lowering of the meter to the depth of 590 feet was accomplished over a period of more than an hour.

The meter was being used in an attempt to determine if there was any movement of water in the well at the depth of 590 feet under non-pumping conditions. Movement of water in either direction through the meter was indicated on a chart by the trace of a pen, whose deflections increased from zero for no flow to a limit of 4 inches as the rate of flow through the meter increased. For a period of 53 minutes after observations began, the pen continued to move in an apparently erratic manner, throughout the 4-inch wide range. Much of the pattern, especially during the first 7 minutes suggested alternate times of zero and maximum flow through the meter; from 9 until 13 minutes, the deflections were less thrn 1 inch; after which they began to increase and reached the full-scale deflection 16 minutes after observations began. Other near-full-scale deflections were noted 21, 31, 33, 35, 36, 38, 41, 47, and 50 minutes after observations began. Less than one-half inch deflections generally were observed between the above times. From about 37 to 53 minutes the deflections tended to stay in the neighborhood of 2 inches. Observations were discontinued after 53 minutes. The tendency of the deflections to center about a value of 2 inches suggests that after equilibrium was attained some vertical movement of water at a uniform rate probably occurred at the depth of 590 feet.

The apparently erratic pattern of the deflections suggests that water was moving through the meter at varying rates which probably resulted from imparting an oscillatory movement to the 500-foot long column of water in the casing above the uppermost perforations and to a column of water of unknown length inside the casing below the uppermost perforations as the meter was lowered to the 590-foot depth. The rest of the oscillatory system presumably is water that was going into or coming from some of the strata that were tapped by the well.

Water levels corresponding to the means of the oscillations shown in graph *A* are plotted in graph *B*. Some of the higher than theoretical values of water levels that occurred during the first 6 minutes of the recovery period may have been due to leakage of water from the pump suction hose to the well. The value of about 160,000 gpd per foot for the transmissivity appears to be reasonable, although not necessarily precise.

The yield data in graph *C* shows that about 80 percent of the water was derived from strata between depths of 520 and 620 feet and that only 10 percent was yielded by strata below a depth of 900 feet. An average hydraulic conductivity of about 1,400 gpd per square foot is indicated for the strata between depths of 520 and 620 feet if the value of 160,000 gpd per foot is accepted as a reasonable indication of the transmissivity of all the strata tapped by the well.

## WELL (C–11–24)23bcb LCRP 10 TEST

Figure 54 shows selected data for well (C–11–24)23bcb (LCRP 10).

Pertinent information regarding the well and the tests from which the data in figure 54 were obtained are as follows:

Method of drilling ---Scow and cable tool.

Casing record --------16-inch diameter steel casing, land surface to depth of 240 feet; 12-inch diameter casing from 220 to 1,055 feet; horizontal-louver perforations made in place at following depth intervals in feet below land surface: 165–170; 190–202; 213–220; 240–250; 280–305; 320–325; 375–395; 405–425; 475–500; 520–545; 630–635; 643–648; 685–705; 855–875; 985–1,002.

Test conditions:

February 26, 1963, to March 1, 1963:

Pneumatic packers were used to isolate the perforated intervals shown in figure 54. The packers were placed in position by means of string of 4-inch pipe which also functioned as the eductor

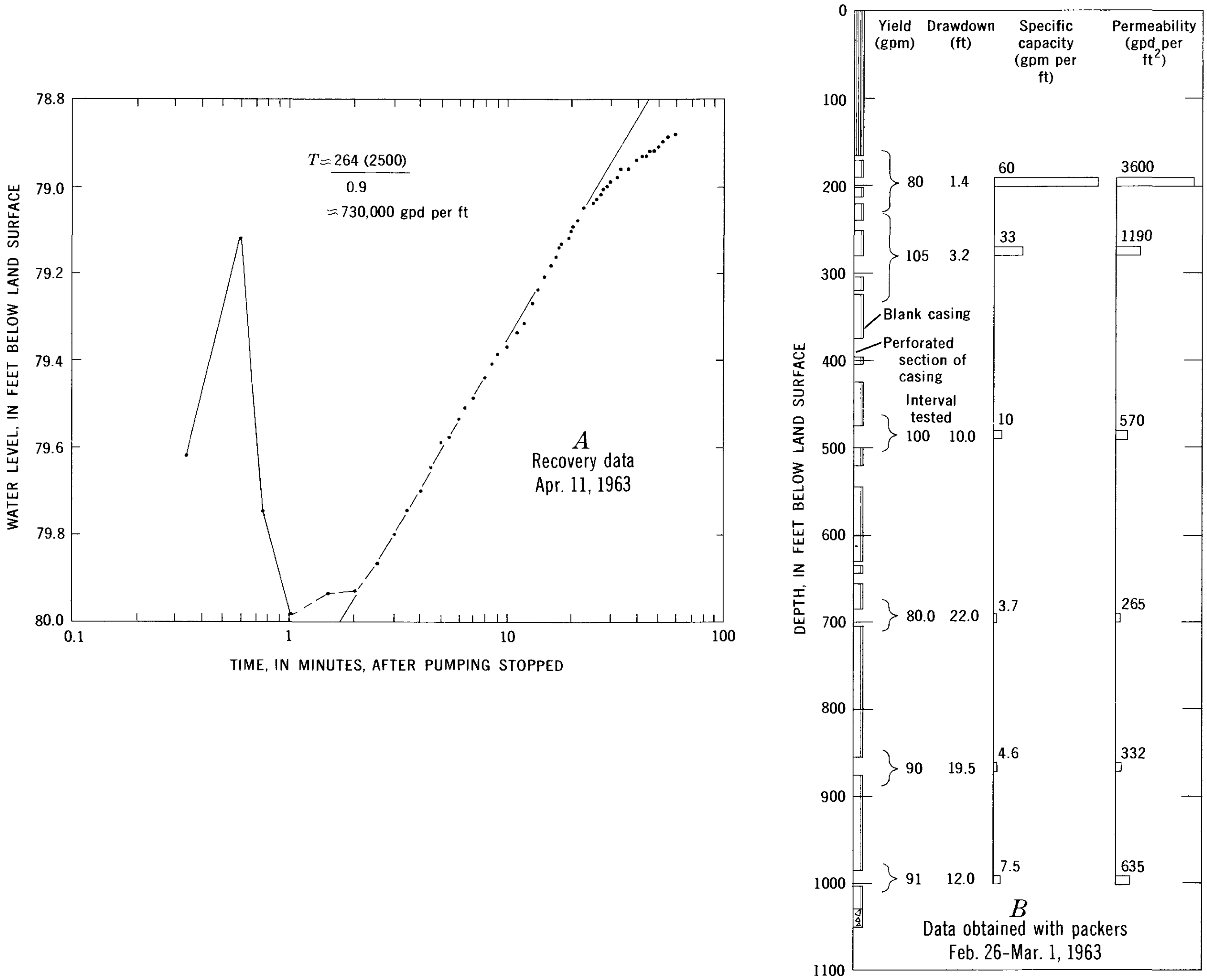



**FIGURE 54.—Pumping test data for well (C–11–24)23bcb (LCRP 10).**

pipe for the airlift method that was used for developing and pumping the well. Water levels were measured inside a string of ½-inch pipe whose lower end extended 21 feet below the 1¼-inch pipe through which the air was introduced, both pipes being inside the 4-inch eductor pipe.

April 10, 11, 1963:

A turbine pump was used for this test. The well was pumped for 9½ hours at varying rates to develop the well and then pumped steadily at 2,500 gpm for 8 hours prior to the recovery test shown in graph *A*.

Discussion of test data:

Graph *A* shows that during the first 2 minutes of the recovery period water levels were influenced considerably by the return flow of water from the pump column. After this initial period the recovery data followed the theoretical pattern quite well. The reliability of the transmissivity computed from the data is considered good.

Graph *B* shows that the permeability of the deposits decreases rapidly with depth. The deposits between depths of about 165 and 220 feet have a hydraulic conductivity of about 3,600 gpd per square foot, whereas, those that were tested between depths of 240 and 325 feet had an average hydraulic conductivity of almost 1,200 gpd per square foot. At greater depths the hydraulic conductivity is considerably less, ranging from 265 to 635 gpd per square foot. On the basis of specific capacity, it might be expected that strata above a depth of 325 feet (the coarse-gravel zone) will provide about three-fourths of the total yield from all the strata that were tested.

## APPENDIX E. MOISTURE INVESTIGATIONS

One of the major items of the water budget for the Yuma area appeared to be the water that went into storage beneath the Yuma Mesa and Yuma Desert ("Upper Mesa" and "Fortuna Plain"). It was desirable, therefore, to ascertain as closely as practical how much water was represented by a given increase in volume of saturated material. The latter could be computed on the basis of the rise of water levels in observation wells which had been recorded periodically by the U.S. Bureau of Reclamation. Pumping tests did not appear to be a practical means for obtaining estimates of storage coefficients. There were only a few wells that possibly would have been suitable for pumping tests, and then only after observation wells were drilled at each site. Further, it was thought that the storage coefficient computed from a pumping test would be too low, because the coefficient computed from the pumping test would be no larger than the drainage during the pumping test, whereas, the water table of the mound was rising through material whose moisture content was no more than the residual after long-term drainage and possibly considerably less. It was concluded that a more reliable estimate of the storage coefficient under water-table conditions could be obtained by determining the average moisture content of material below the water table and subtracting therefrom the average moisture content of material above the capillary fringe. A neutron moisture probe together with access tubes appeared to be a practical means for obtaining the moisture content both above and below the water table. The sites for access holes in which moisture content was to be determined were selected with the view of obtaining representative values for clay, silt, and sand, and various combinations of these materials. A comparable study was made for Imperial, Palo Verde, and Parker Valleys. The results of the studies for the above valleys are given in other chapters of U.S. Geological Survey Professional Paper 486. In general, the results in the other areas substantiate the results in the Yuma area.

The probe used in the soil-moisture studies consisted of a 5-millicurie fast neutron source, a slow neutron detector tube, and a transistorized amplifier circuit. The number of fast neutrons that were converted to slow neutrons and picked up by the detector depended primarily on the number of hydrogen atoms in the material surrounding the probe. The number of hydrogen atoms in inorganic material in turn, was largely a function of the free water in the material. Thus, when the probe was surrounded by inorganic material, as it was during the soil-moisture determination studies, the rate at which the detector picked up slow neutrons was a function of the water content of the material surrounding the probe. When the relation between pick-up rate by the detector, commonly referred to as the counting rate, and water content of material surrounding the probe had been determined, the water content of the surrounding material could be computed from the observed counting rate.

The counting rate was registered visually by the glow of five decade counters. Determining the relationship between counting rate and moisture content for the various types of materials and for specific types of access tubes posed many problems.

The first access holes were drilled with an air drill that could remove cuttings either by vacuum, air pressure, or with slight modification, by circulating water or mud. As the drilling progressed the holes were cased with 2-inch outside-diameter and 1.75-inch inside-diameter aluminum tubing. The objective was to obtain an access hole in which the moisture content of the material within a foot or so of the hole at any particular depth was a function of the moisture content of the material at that depth before the hole was drilled.

This objective was never fully realized because of the caving of material, the removal of material beyond that needed to obtain a skintight fit between the drilled hole and the tubing, or the migration of moisture from the position it occupied at the time drilling began. The principal advantage of this method of constructing access holes is that holes can be drilled to greater depths in unsaturated material than is practical either by augering by hand or by driving the casing.

During the latter part of the study, the access holes were constructed by driving a length of steel tubing (1.75 inches outside diameter, 1.62 inches inside diameter) to depths of as much as 16 feet. Portable steel scaffolding was used to enable two men to place a gasoline operated mechanical hammer atop the steel tubing and drive it to the required depth. After the tubing was cleared of the material that commonly became packed in the first few feet of the tubing a rubber stopper device was installed near the lower end and made water tight. All water was then bailed from the tubing. The above method was relatively rapid and probably resulted in truer indications of moisture content than could be obtained by the air drilling method. Under certain conditions somewhat more reliable results can be obtained by augering material from inside the tubing as it is advanced. However, the improvement in reliability probably will not be substantial enough on the average to warrant the construction of access holes by the more time-consuming hand-augering method.

Several field tests were made to determine to what extent and under what conditions access holes constructed by the hand-augering method gave different counts per minute from those constructed by the driven tubing method; also to what extent the counts per minute for the air-drill aluminum-tubing holes differed from those for the driven-steel tubing holes. The tests suggested that the counts per minute in driven-steel tubing holes was about 400 less adjacent to saturated silt and clay than in steel tubing holes in which the material had been removed by hand auger as the tubing was advanced. In saturated sand, the counts per minute in the driven-steel tubing holes was about 200 less than in the holes in which they had been installed by the hand augering method.

Differences in counts per minute in the zone of saturation between holes of the air-drill aluminum-tubing type and those of the driven-steel tubing type were checked at three sites. At site (C–8–23)22ddc the counts per minute in the aluminum tubing exceeded those at comparable depths in a nearby driven-steel tubing by 500 to 1,000, but at sites (C–9–24)18cdd and (C–9–25)35dcd the differences in counts per minute between the two types of access holes were negligible.

Although the foregoing results suggest that counts per minute in the zone of saturation in access holes of the air-drill aluminum-tubing type may exceed those in holes of the driven-steel tubing type, the average indicated difference of about 250 counts per minute (equivalent to somewhat less than 2 percent moisture) did not appear to be large enough in view of all the other uncertainties relative to the relation between counts per minute and moisture content to justify separate rating curves for the two types of access holes.

After trying several different methods for obtaining a rating curve for the neutron moisture probe it was decided that the most practical method consisted of obtaining counts per minute with the probe in place in the access tube in the field and then averaging the moisture content of several samples obtained from a depth near the center of a zone 2 or more feet thick in which the counts per minute were nearly constant.

The relation between counts per minute and moisture content for material having a moisture content of about 10 per cent or less was relatively easy to establish because the moisture content of the sample that was sent to the laboratory for determination of moisture content was likely to be the same as the moisture content at the depth from which the sample was collected.

Relating counts per minute to moisture content for moisture contents between relatively dry values and values for the zone of saturation was impractical. In this interval, there was no way of knowing to what extent water had migrated from the sample as it was being collected. In clay soils the migration undoubtedly was much less than in sand, but the migration still was a problem. The rating curve in this intermediate interval thus had to be estimated on the basis of the relationships for relatively dry materials and those for saturated material. The latter were determined on the assumption that the counts per minute were a function of the porosity of the material, which in turn was a function of the apparent specific gravity of the material and its absolute density.

Twenty-five samples of material ranging from sand to clay that were thought to be representative of the bulk of the material in which water-level fluctuations occur in the lower Colorado River valley were analyzed by the Geological Survey Hydrologic Laboratory, Denver, Colo.

The absolute specific gravity of these samples ranged from 2.66 for a sandy loam in Imperial Valley to 2.81 for a dark brown clay loam in the Palo Verde Valley.

Fourteen samples classified as sand had absolute specific gravities that ranged between 2.66 and 2.70 and averaged 2.68. Five samples classified as silt had values that ranged from 2.69 to 2.75 and averaged 2.72. Six samples classified as clay or clayey silt had values that ranged from 2.72 to 2.81 and averaged 2.76. Thus it appears that the absolute density increased as the particle size decreased. It also appears that the absolute density of a sample of a given particle size is predictable within about 1 percent for sand, 1½ percent for silt and 2 percent for clay. It was concluded therefore that using the volume of the sample as computed in the field, its oven-dry weight, and the average absolute density of the material was a better basis for determining its porosity, and hence moisture content when saturated, than was its volume and its loss of weight when oven dried.

The values of the rating curve for the higher percentages of moisture versus counts per minute that were adopted for use in the present study are based on computations using average absolute density values for different types of material. Figure 55 shows the rating curve that was used for the present study to determine the average moisture content of all material penetrated by access tubes.

Figures 56–58 show the counts per minute observed at various depths at the individual sites.

The profiles show that at some sites the capillary fringe is thin, less than a foot, whereas at other sites it may be 8 feet or more thick. The thin fringes indicate relatively clean sand, whereas the thick fringes are associated with fine silt and clay. There are also differences in the maximum

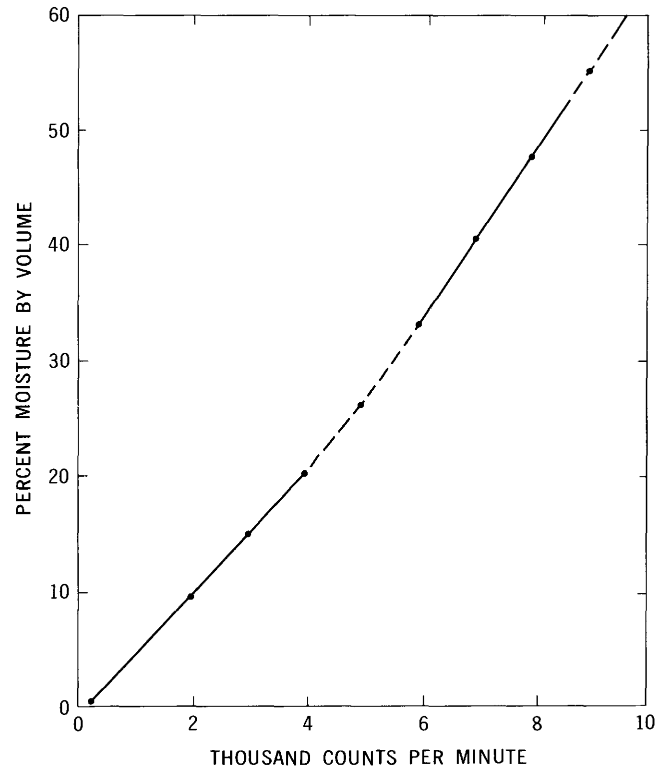



FIGURE 55.—Relation between counts per minute and moisture content.

average count per minute in the zone of saturation. As stated previously, it was found during the calibration procedure work that the average count per minute in silt or clay was several hundred to a thousand higher than in sand. It was also found that the counts per minute in the zone of saturation tended to be less in holes constructed by driving steel casing than for those constructed with the air drill or by hand auger.

A combination of these factors may have caused the counts per minute in the zone of saturation for the access holes on Yuma Mesa to average almost a thousand counts per minute less than the average maximum count per minute for access holes in the South Gila and Yuma Valleys.

Using the data shown in figures 56–58 and the rating table, average moisture contents both below and above the capillary fringe were computed where the data was considered adequate to give meaningful values. Table 21 lists the pertinent data for each of the access holes and segregates them according to location. The average capacity for storage is seen to vary quite widely between the three subareas, from a minimum of about 28 percent for the access holes on Yuma Mesa, to 37 percent for the holes in the South Gila Valley, to about 42 percent for the holes in the Yuma Valley.

Undoubtedly the higher percentages for storage capacities in the flood-plain valleys are related to the larger percentages of fine-grained material in the flood plain.

Although the moisture studies made during this investigation are neither precise nor as adequate as desirable they do provide a basis for estimating storage capacity under certain given conditions. In particular, they show that in desert areas the moisture content of alluvium above the capillary fringe is only a few percent of the volume occupied by the material. Therefore, the storage capacity during an initial rise of water levels is principally a function of the porosity of the material less a few percent for the moisture that already is present. A more economical means for determining the porosity of alluvium in place at depths beyond 10 feet than is presently available would increase the practicability of the above method for determining storage characteristics.

In computing quantities of water that have gone into storage during the build up of the ground-water mound beneath Yuma Mesa a storage coefficient of 31 percent rather than the 28 percent indicated by the access-hole data for the lower Yuma Mesa was used. Originally a value of 35 percent—about midway between values for the Mesa and the Valleys—was selected for analog model studies because the access holes were thought to have penetrated a a larger percentage of sand and a lesser percentage of silt and clay than the average percentages of these materials that occur beneath the mesa. However, the analog model studies indicated that the correlation between model response and observed changes in water level was better when the storage coefficient was modeled as 31 percent rather than 35 percent.

TABLE 21.—*Moisture content and storage capacity of alluvium as indicated by neutron moisture probe study. All quantities in percentage by volume*

| Location | Average moisture content | | Storage capacity |
|---|---|---|---|
| | Below water table | Above capillary fringe | |
| **South Gila Valley** | | | |
| (C–8–21)21bca | 33.0 | 6.0 | 27.0 |
| (C–8–22)22bbb | 45.0 | 4.0 | 41.0 |
| (C–8–22)31cbb | 48.0 | | |
| (C–8–22)33daa | 36.5 | 9.0 | 27.5 |
| (C–8–23)22ddc | 45.5 | 15.0 | 30.5 |
| (C–8–23)25ccc | | 10.0 | |
| (C–8–23)27cad | 40.0 | 4.0 | 36.0 |
| (C–8–23)36bcc | 47.5 | 5.5 | 42.0 |
| (C–9–22)6aad | 50.0 | 5.0 | 45.0 |
| 16/22E–36B | 47.5 | 4.0 | 43.5 |
| Average | 43.7 | 6.9 | 36.6 |
| **Yuma Valley** | | | |
| (C–9–24)18cdd | 44.0 | 2.5 | 41.5 |
| (C–9–25)25bad | 49.0 | 3.0 | 46.0 |
| (C–9–25)26ddd | 43.0 | 4.0 | 39.0 |
| (C–9–25)35dcd | 47.5 | 5.5 | 42.0 |
| (C–9–25)36ddd | 53.0 | | |
| (C–10–25)2dcd | 51.0 | 4.0 | 47.0 |
| Average | 47.9 | 3.8 | 42.6 |
| **Yuma Mesa** | | | |
| (C–9–23)27cbb | 34.0 | | |
| (C–9–23)28aaa | 34.0 | | |
| (C–9–23)28acd | 34.0 | 7.0 | 27.0 |
| (C–9–23)28dcc | 38.0 | | |
| (C–9–23)32caa | | 6.0 | |
| (C–9–23)32ddd | | 4.0 | |
| (C–9–23)33bbb | | 6.0 | |
| (C–9–23)33bcd | 36.0 | 8.0 | 28.0 |
| (C–10–23)2aaa | | 6.0 | |
| (C–10–23)8bbb | | 4.0 | |
| Average | 35.2 | 5.9 | 27.5 |

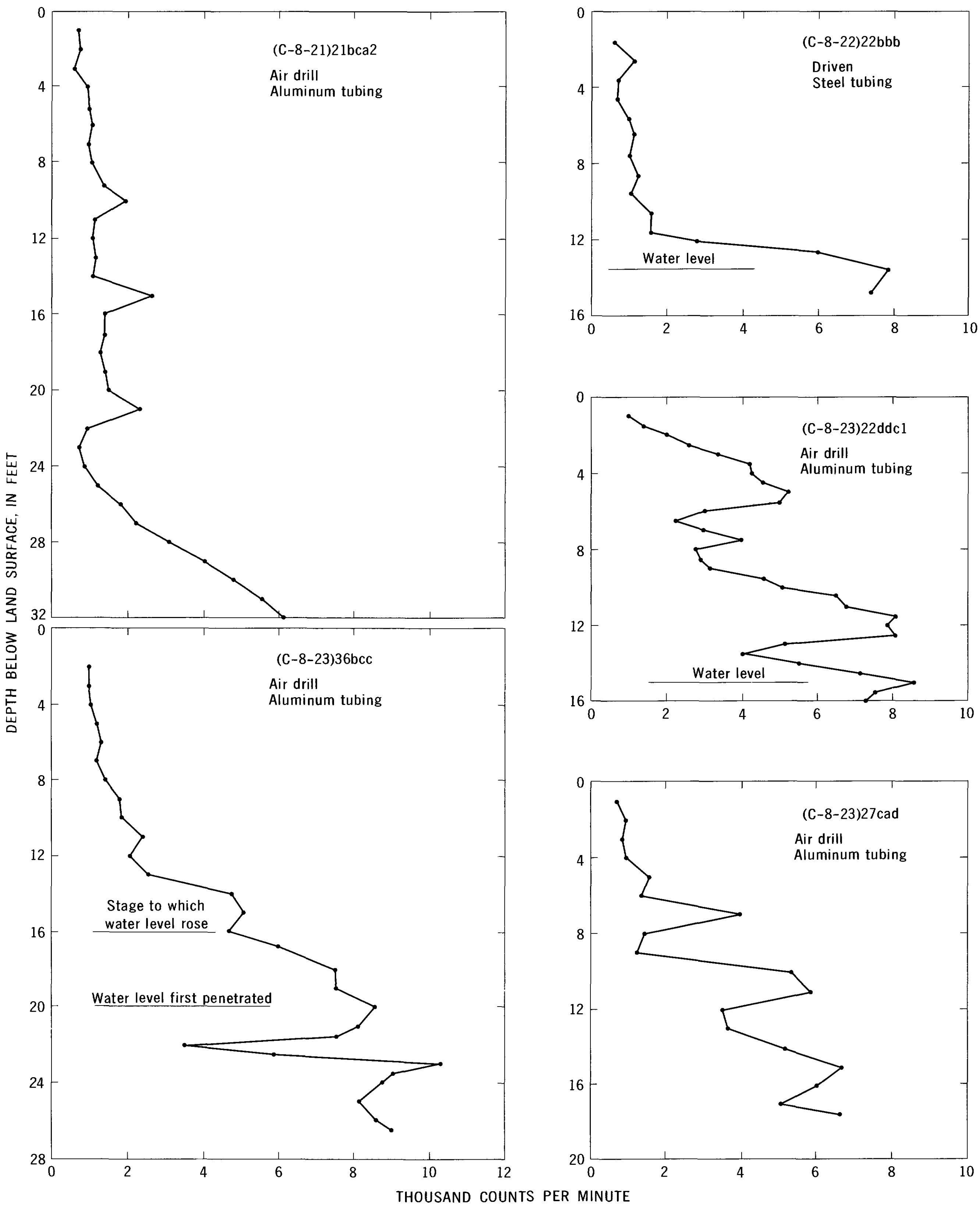
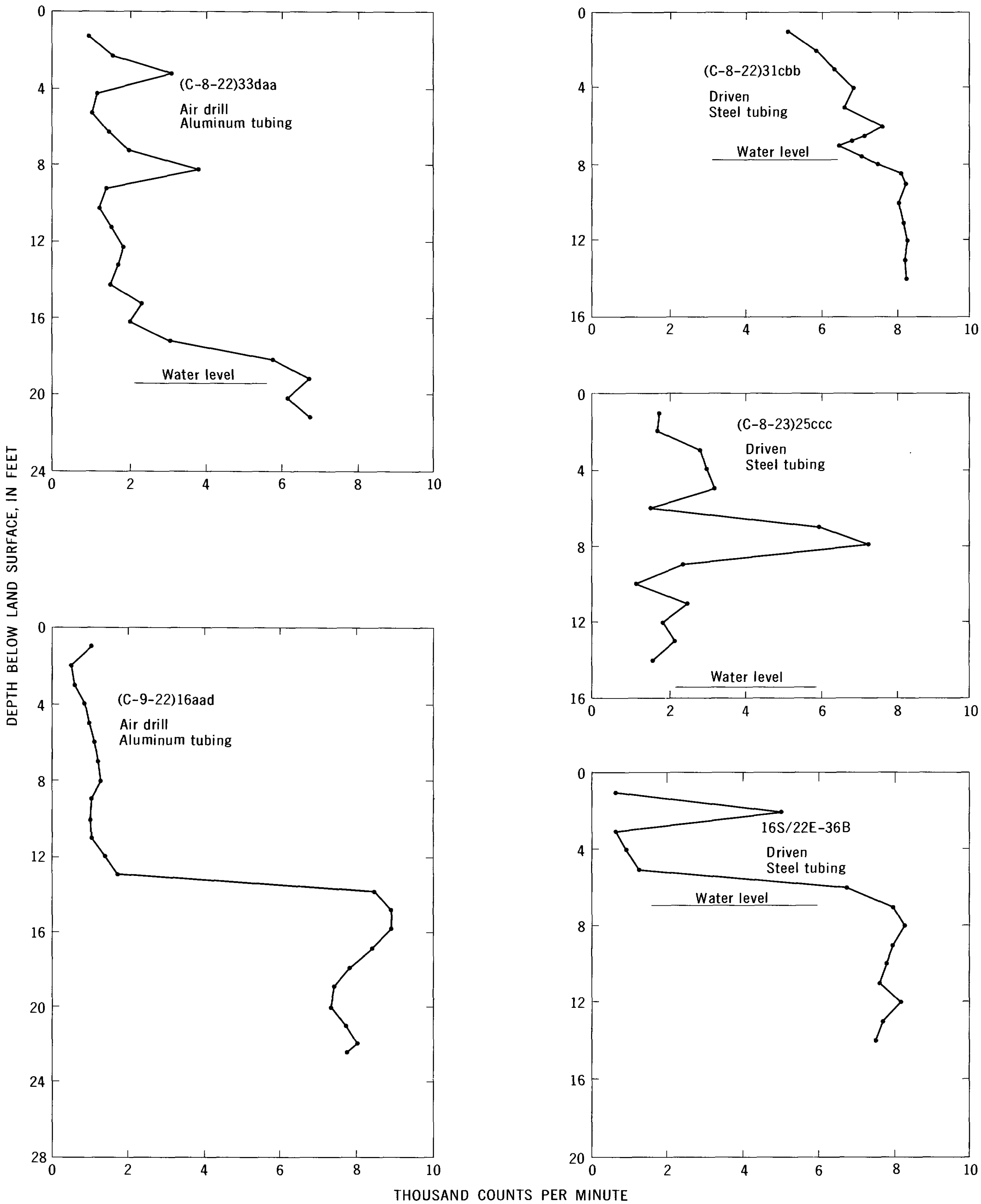



FIGURE 56.—Counts per minute at various depths below land surface




obtained by use of a neutron moisture probe at 10 sites in South Gila Valley.

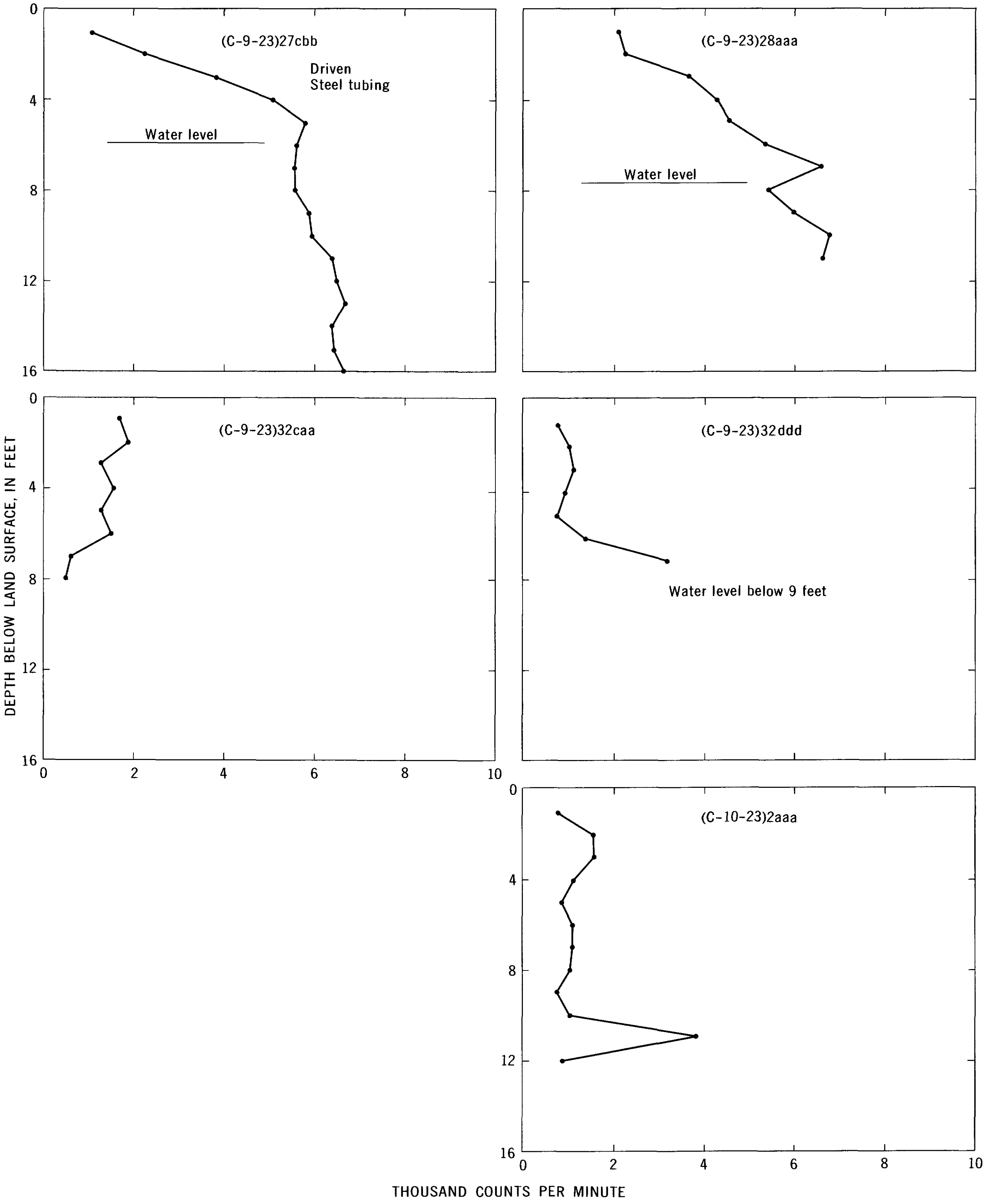
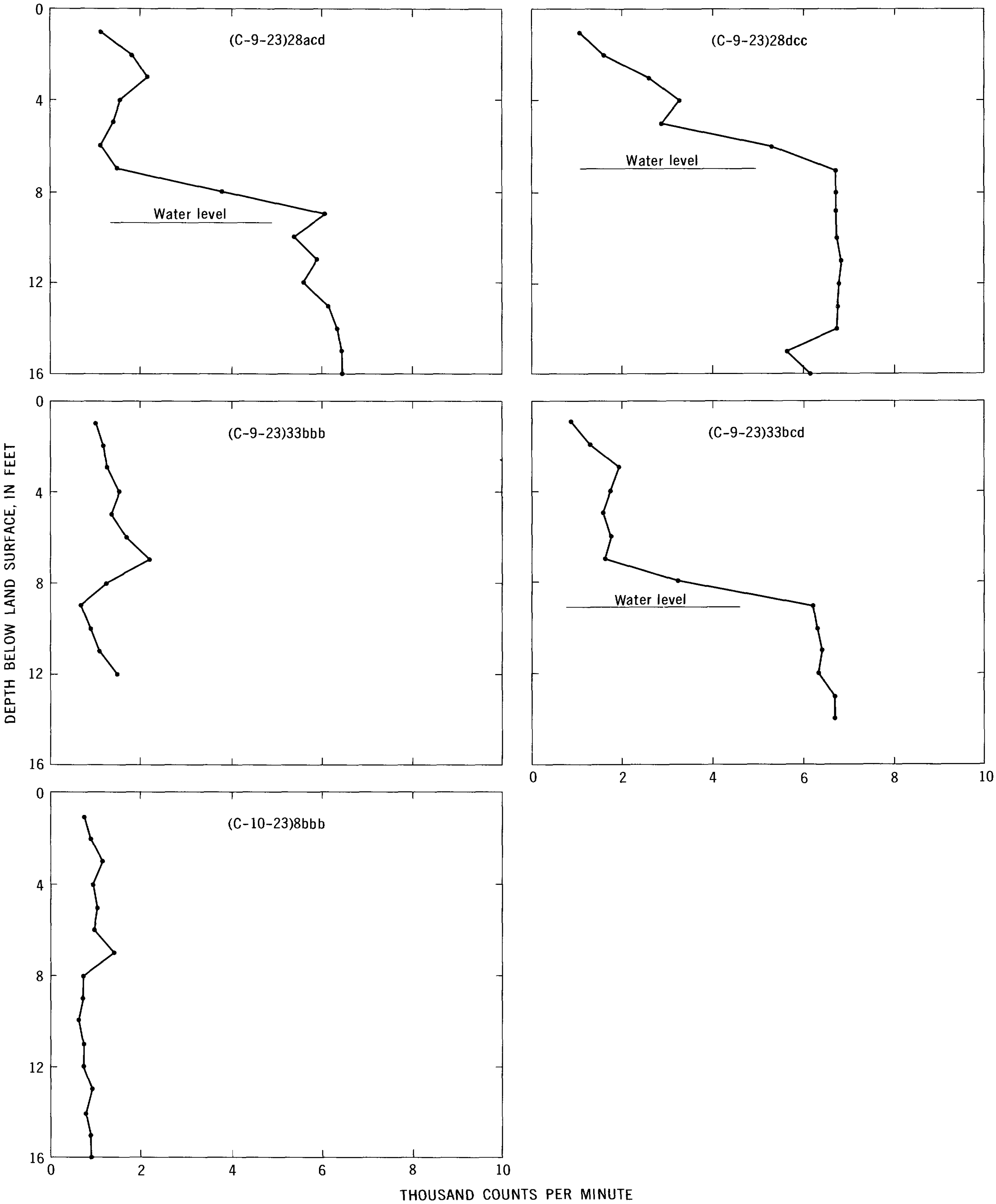



FIGURE 57.—Counts per minute at various depths below land surface




obtained by use of a neutron moisture probe at 10 sites on Yuma Mesa.

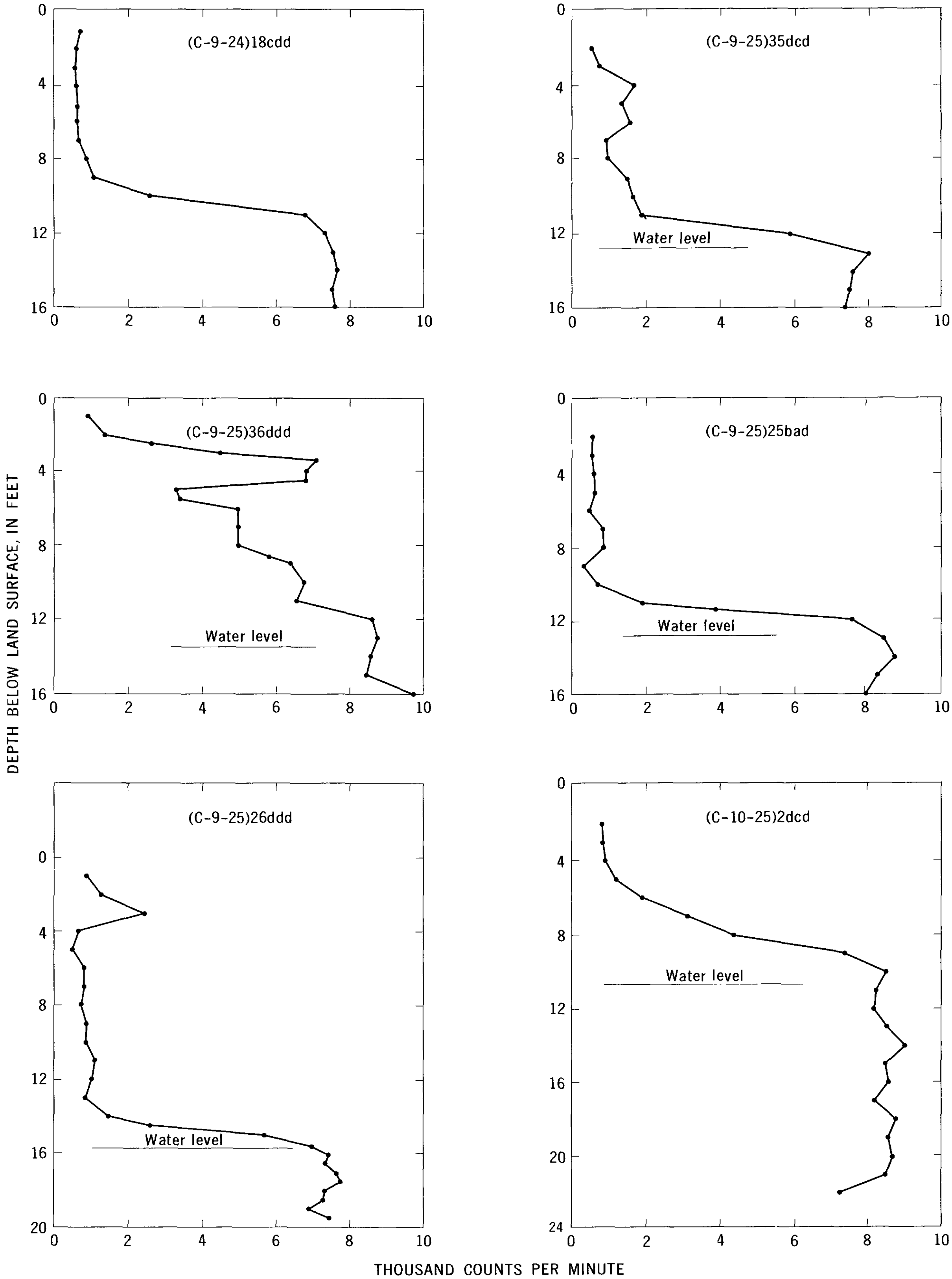



FIGURE 58.—Counts per minute at various depths below land surface obtained by use of a neutron moisture probe at six sites in Yuma Valley.

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[Italic page numbers indicate major references]

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