Geohydrologic Reconnaissance of the Imperial Valley, California

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F. H. OLMSTED

WATER RESOURCES OF LOWER COLORADO RIVER–SALTON SEA AREA

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GEOHYDROLOGIC RECONNAISSANCE OF THE IMPERIAL VALLEY, CALIFORNIA

By O. J. LOELTZ, BURDGE IRELAN, J. H. ROBISON, and F. H. OLMSTED

ABSTRACT

The Imperial Valley occupies a broad lowland in the southern, wider part of the Salton Trough section of the Basin and Range physiographic province. The trough is a landward extension of the depression filled by the Gulf of California, from which it is separated by the broad, fan-shaped subaerial delta of the Colorado River. Much of the land surface is below sea level, and the valley drains northwestward to the Salton Sea, which was 232 feet below mean sea level in 1968. The Imperial Valley is bordered by the Chocolate Mountains on the northeast, the Peninsular Range of Baja California and southern California on the southwest, and the Salton Sea on the northwest; it is contiguous with the Mexicali Valley in Mexico on the southeast.

The Salton Trough, which evolved during Cenozoic time, is a structural as well as a topographic depression in which the surface of the basement complex lies thousands to tens of thousands of feet below the basement-complex surface in the bordering mountains. The basement complex is composed of plutonic rocks of early and late Mesozoic age which intrude Mesozoic and older metamorphic rocks. The Salton Trough is traversed by the San Andreas fault system. Development of the trough involved both folding and warping as well as faulting; much of the folding is related to movement along the major faults. Structural relief caused by folding, faulting, and warping is inferred to exceed 14,000 feet.

The pre-Tertiary basement complex of the trough is overlain by a thick sequence of predominantly nonmarine sedimentary rock that ranges in age from Eocene to Holocene. The Cenozoic rocks beneath the south-central part of the Imperial Valley probably are more than 20,000 feet thick. Rocks as old as Eocene crop out in the bordering mountains, but none of the fill in the central part of the trough appears to be older than about middle Miocene, and most of it is Pliocene and younger. The sedimentary and volcanic rocks of Eocene and Miocene age that are exposed in the mountains are moderately to strongly deformed and are semiconsolidated to consolidated. Consequently, these rocks constitute an insignificant part of the ground-water reservoir.

A marine unit, the Imperial Formation of late Tertiary (Miocene or Pliocene) age, is extensively exposed in the western part of Imperial Valley, but apparently it was not penetrated in an oil test hole 13,443 feet deep in the central part of the valley. The Imperial Formation is overlain by a thick heterogeneous sequence of nonmarine deposits. Some of the deposits were derived locally, but most were brought in by the Colorado River. Generally, the river deposits consist of silt, sand, and clay, as contrasted with the locally derived deposits of coarse sand and gravel near the margins of the valley.

The last major marine invasion of the Salton Trough is probably represented by the Imperial Formation. Subsequent incursions of the Gulf of California appear to have been minor and of short duration.

The hydraulic phases of this study were concerned principally with water in the heterogeneous sequence of nonmarine deposits in the upper few thousand feet of the ground-water reservoir. At depths greater than a few thousand feet, the ground water commonly is too saline for irrigation and most other uses, and the hydraulic connection between the water in the deeper deposits and the water in the upper part of the ground-water reservoir is poor. Short-term pumping tests at several sites indicate that in both the eastern and the western parts of the Imperial Valley moderate to high yields can be obtained from wells that tap several hundred feet of the marginal alluvial deposits or deposits of the Colorado River. Transmissivities of several hundred thousand gallons per day per foot are characteristic of these deposits. Wells with specific capacities of 50 gallons per minute per foot of drawdown or more may be attainable in the more favorable areas. In contrast, the fine-grained deposits that are characteristic of the central part of the valley are likely to have transmissivities of only 1,000 to 10,000 gallons per day per foot to depths of 500 feet. At greater depths, transmissivities are likely to be even less for a similar thickness of deposits. The maximum transmissivity computed from pumping tests was 880,000 gallons per day per foot at well LCRP 6, near the head of the Coachella Canal on the East Mesa in the southeastern part of the valley. Other tests indicate that the transmissivity of the deposits decreases westward and northwestward from well LCRP 6. The extent of the high transmissivity eastward from LCRP 6 is not known but probably is several miles.

Soil-moisture studies indicate that in an area of rising water levels in fine-grained alluvial deposits outside of irrigated areas, about 40 percent of the volume of the material in which the rise occurs acts as a storage reservoir. Beneath mesas and other areas where the deposits are not all fine grained, the storage capacity under similar conditions may be more nearly 30 percent. Smaller quantities of water per unit volume than those indicated by the foregoing percentages can be expected to be released from storage as water levels decline.

Although the Colorado River was a major source of recharge under natural conditions, the areas where the recharge occurred varied widely depending on whether the river was flowing to the Gulf of California or to the Salton Trough. The last uncontrolled flooding of the Salton Trough by the Colorado River occured in 1905-7, when the present Salton Sea was formed. Importation of Colorado River water for irrigation beginning in 1901 caused the rate of recharge to the shallow part of the ground-water reservoir to increase over that prevailing under natural conditions. Much of the additional recharge in the irrigated area is due to leakage from the numerous conveyance channels and to the application of irrigation water in excess of crop requirements.

Recharge to the ground-water system from excess irrigation water is estimated to be more than 400,000 acre-feet annually. However, this

added recharge is balanced largely by discharge from the system through an extensive drainage network, and therefore it does not appreciably affect the aquifers several hundred feet or more below the land surface.

In 1942 the All-American Canal became the sole means for diverting Colorado River water to the Imperial Valley; in 1948 the Coachella Canal, which supplies water to the lower part of Coachella Valley, was completed. Leakage from these canals is a major source of recharge to the ground-water system. Leakage during 1950-67 totaled about 4.5 million acre-feet from the All-American Canal and 2.7 million acre-feet from the Coachella Canal.

Along the All-American Canal the water-level rise generally was more than 40 feet between 1939 and 1960; along the Coachella Canal it was about 40 feet near the head of the canal and gradually increased northward to more than 70 feet.

Recharge to the ground-water reservoir by underflow from tributary areas is small compared with recharge from the imported Colorado River water. Ground-water underflow from tributary areas in the San Felipe Creek drainage basin in western Imperial Valley is about 10,000 acre-feet per year. Total recharge to the ground-water system from precipitation within the valley is estimated to be somewhat less than 10,000 acre-feet per year.

Ground water generally moves toward the axis of the valley and thence northwestward toward the Salton Sea. The principal area of discharge is the central, cultivated part of the valley. Ground water also is discharged to the lower reaches of the Alamo and New Rivers and through numerous small springs and seeps. Some of the springs probably are associated with discharge of ground water along the San Andreas fault system, and many are associated with leakage from the Coachella Canal.

Wells discharge only a small part of the ground-water supply, because most of the hundreds of used wells furnish only small stock or domestic supplies. Many of the wells are in a 6- to 10-mile-wide flowing-well area between the Alamo River and the East Highline Canal that extends about 30 miles northward from near the international boundary. A few wells yield hot water used to heat homes, but most are utilized only for domestic and stock purposes. The average rate of discharge is about 10 gallons per minute, and the total average annual discharge is only a few thousand acre-feet. Most of the few wells that are used for irrigation are in the lower Borrego Valley, where alfalfa is the principal crop. A few hundred acre-feet of ground water is pumped for industrial, private, and public supplies in the western part of the valley near Ocotillo and Coyote Wells.

The chemical quality of the ground water in the Imperial Valley differs greatly. Total dissolved solids range from a few hundred to more than 10,000 mg/l (milligrams per liter). Generally, ground water that is derived locally from precipitation and that has not yet reached the more saline deposits of the central part of the valley contains only a few hundred milligrams per liter of dissolved solids. Highest concentrations of dissolved solids commonly occur in areas where ground water is discharged principally by evaporation.

Water from 10 wells on the Chocolate Mountains piedmont slope in eastern Imperial Valley contained 360 to 4,930 mg/l dissolved solids. Samples of water from wells in the Pilot Knob Mesa-Sand Hills area downslope from the piedmont area contained 370 to 2,080 mg/l dissolved solids. Water from 51 wells on the East Mesa, southwest of the Pilot Knob Mesa-Sand Hills area, contained 498 to 7,280 mg/l dissolved solids; more than three-fourths of the samples contained less than 2,000 mg/l, which indicates that water of this quality or better can be obtained in much of the area. In areas of substantial recharge because of leakage from canals, the chemical quality of the water resembles that of Colorado River water, which is characterized by sulfate as the predominant ion. Where recent leakage has not been substantial, sodium or bicarbonate is the principal ion.

The extent to which ground water that is satisfactory for domestic or irrigation use occurs in the central part of Imperial Valley is not known, but on the basis of past attempts to develop usable water in this part of the valley, such occurrence is thought to be extremely limited. Concentrations of fluoride higher than the concentration recommended for drinking water are common, as are concentrations of boron higher than those recommended for certain agricultural crops. Test wells drilled to depths of 500 to 1,000 feet in the southern and western parts of the central Imperial Valley yielded water containing about 5,000 to 10,000 mg/l dissolved solids.

In the western part of Imperial Valley, water suitable for irrigation probably can be obtained in much of the lower Borrego Valley. Ground water beneath the developed area of Coyote Valley generally contains less than 400 mg/l dissolved solids. The principal undesirable characteristic of the water is the high concentration of fluoride; half of the samples analyzed contained more than 2 mg/l fluoride. Concentrations of dissolved solids apparently increase to the east. Test well LCRP 8, perforated from 135 to 560 feet, yielded water that contained about 2,000 mg/l dissolved solids; two test wells a few miles farther east yielded water containing about 5,000 mg/l dissolved solids.

INTRODUCTION

The Imperial Valley in southern California is the largest desert irrigation development in the United States. Half a million acres of otherwise parched desert lands have been transformed into one of the most productive agricultural areas in the Nation by the importation of Colorado River water. This importation is but one of many diversions of the river water that are being made by the Colorado River basin States. Recognizing that the ever increasing demands for Colorado River water might exceed the available supply, the U.S. Geological Survey in 1950 undertook a comprehensive study of the water resources of the upper Colorado River region, and in 1960, of the lower Colorado River region. This report on Imperial Valley is one of a series of reports resulting from the latter study. It presents the results of a reconnaissance of the geology, hydrology, and chemical quality of the ground water in the valley. The surface-water resources are described in other chapters (Hely and Peck, 1964; Hely and others, 1966; Hely, 1969; Irelan, 1971) of U.S. Geological Survey Professional Paper 486, the principal medium for publishing the results of the series of investigations.

Original plans included a study of the water resources of the Coachella Valley, Calif., which is in the Salton Sea area northwest of the Imperial Valley. However, shortly after the investigation began in 1960, the California Department of Water Resources also began an investigation of the ground-water resources of the Coachella Valley. To avoid duplication of work, the Geological Survey and the California Department of Water Resources reached an informal agreement whereby investigations in the Coachella Valley by the staff of the Geological Survey were reduced in scope to assisting the California agency and to drilling two deep test holes. A report on the Coachella Valley was published in 1964 by the California Department of Water Resources.

The investigation of Imperial Valley was made under the general supervision of C. C. McDonald, project hydrologist for the Lower Colorado River Project from 1960 to 1968. J. H. Robison, geologist, was principal investigator from 1961 until 1966. F. H. Olmsted, geologist, assisted materially in completing the geologic section of the report. O. J. Loeltz, hydrologist, was responsible for the hydraulic phase of the investigation; Burdge Irelan, chemist, prepared the chemical-quality-of-water phase of the report. G. R. Vaughan and R. H. Westphal, of the Lower Colorado River Project staff, aided in the field investigations.

PURPOSE OF THE INVESTIGATION

The broad objectives of the investigation of Imperial Valley were (1) to describe the geology in relation to the occurrence of ground water, (2) to define the hydraulic characteristics (transmissivity and storage) of the aquifers, (3) to determine the sources of ground water, (4) to determine the direction of movement of ground water, (5) to determine the principal means by which ground water is discharged, (6) to determine the chemical quality of the ground water in various parts of the system, and (7) to relate differences in chemical composition of the water to differences in the sources of recharge and to man-caused and natural processes.

LOCATION AND CLIMATE

The Imperial Valley is a broad lowland in southeastern California just north of the boundary between the United States and Mexico (fig. 1). Most of the central part of the valley is below sea level and drains northwestward from the international boundary, which is near sea level, to the Salton Sea, a saline lake whose surface in 1968 was about 232 feet below mean sea level.

The climate of Imperial Valley is characterized by extreme aridity and high summer temperatures. Average annual precipitation is less than 3 inches in a large part of the valley (Hely and Peck, 1964). Summer maximum temperatures commonly exceed 40°C (104°F), and winter minimums seldom are below 0°C (32°F).

PREVIOUS INVESTIGATIONS

The earliest geologic and hydrologic studies that included Imperial Valley were the regional reconnaissance studies by Mendenhall (1909a, b). Brown (1923) made a more detailed study, which included a general description of the geography, geology, and hydrology of the Salton Sea region. Other geologic studies include those by Woodring (1932), Tarbet and Holman (1944), and Dibblee (1954). In the 1960's, during the present study, the results of many other geologic studies were published or made available to the writers.

METHODS OF INVESTIGATION

More than 300 wells were inventoried, and selected well data — such as depth of well, date drilled, depth to water, and discharge — are given in table 3. Drillers' logs of wells are given in table 4. Both of these tables are in the "Basic Data" section of this report.

Eight deep test wells in the Imperial Valley and two in the Coachella Valley were drilled for the U.S. Geological Survey by commercial well drillers. (All Geological Survey test wells are noted in this report by LCRP — Lower Colorado River Project.) The drilling of the two wells in the Coachella Valley was supervised by employees of the California Department of Water Resources; all other test drilling was supervised by employees of the Geological Survey. Electric logs were obtained for the test wells drilled with hydraulic-rotary equipment. Pumping tests were made on the Geological Survey test wells that were completed as permanent wells and on several privately owned wells. Lithologic, electric-resistivity, electric-potential, gamma-ray, and temperature logs of these test wells and information on well construction, static water level, and water movement under static conditions are shown on plate 2.

Many small-diameter test wells, some of which are almost 200 feet deep, were bored by the Geological Survey using a power auger. Many of the holes were completed by casing with pipes fitted with sand points. Water levels were measured periodically in these and numerous other wells. Continuous graphic water-stage recorders were installed on most of the Geological Survey test wells, on several of the Imperial Irrigation District test wells, and on a few strategically located privately owned wells.

Water samples were collected from the test wells, many of the augered wells, and many previously existing wells. Chemical analyses were made of these water samples, either in a field laboratory at Yuma, Ariz., or in the Geological Survey's laboratories at Albuquerque, N. Mex., or Tucson, Ariz. Also, the results of hundreds of chemical analyses made prior to the present study were assembled and evaluated. Selected results of all chemical analyses are given in table 5, in the "Basic Data" section of this report.

Large water samples from three test wells on the East Mesa, after being processed in Yuma according to standard procedures for concentrating their carbon content, were sent to Washington, D.C., for radiocarbon dating.

Gravity and seismic-refraction surveys were made by the Geological Survey. A generalized geologic map for the area was compiled from reconnaissance geologic mapping and from published geologic maps.

ACKNOWLEDGMENTS

Many agencies, groups, and individuals provided valuable assistance to the U.S. Geological Survey. The U.S. Bureau of Reclamation, Yuma Projects office, furnished much information from its files regarding water levels and well logs on the East Mesa. The Imperial Irrigation District was most cooperative in making available the

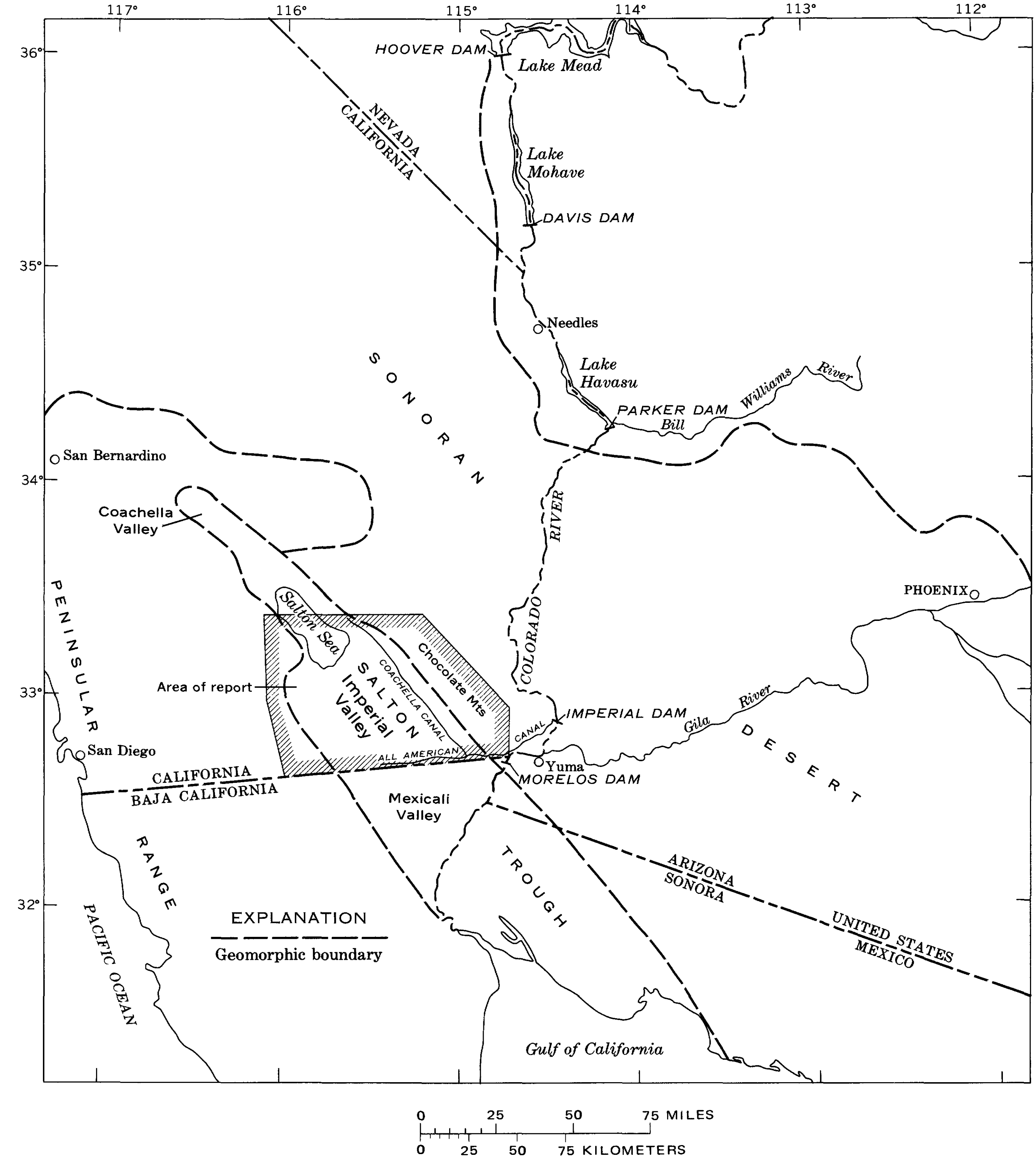

FIGURE 1. — Area of report.

large store of hydrologic data in its files.

Several local water-well drilling companies — notably Coachella Valley Pump and Supply and the Desert Drilling Co., which are near Indio, Calif. — provided well logs and other pertinent information. Farmers and other land owners were most cooperative in permitting access to their lands and wells and in furnishing information about their wells.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is in accordance with the system employed in southern California by the California Department of Water Resources and the U.S. Geological Survey. The wells are assigned numbers according to their township, range, and section locations in the Federal land survey based on the San Bernardino base line and meridian. Each land section is subdivided into 40-acre tracts, which are lettered as shown in the well-location diagram:

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

WELL-LOCATION DIAGRAM.

As an example, a well in the NE¼NE¼ sec. 32, T. 6 S., R. 9 E., has the number 6S/9E-32A. The part of the well number preceding the slash indicates the township (T. 6 S.); the part immediately after the slash indicates the range (R. 9 E.); the digits after the hyphen indicate the section (sec. 32); and the letter after the section number indicates the 40-acre tract within the section (NE¼NE¼). In a few instances, where more than one well was inventoried in a 40-acre tract or where the California Department of Water Resources had previously assigned the well number, a final digit indicates the order in which the well or wells were inventoried. For example, well 6S/8E-10A4 was the fourth well to be inventoried within the particular 40-acre tract.

GEOLOGIC SETTING

LANDFORMS

The Imperial and Coachella Valleys of southeastern California are in a topographic and structural trough — the Salton Trough section of the Basin and Range physiographic province of Fenneman (1931, 1946; fig. 1). The trough, which is about 130 miles long and as much as 70 miles wide, is a landward extension of the depression filled by the Gulf of California, from which it is separated by the broad fan-shaped subaerial delta of the Colorado River. Much of the land surface is below sea level. The lowest part of the trough is occupied by the Salton Sea, whose surface in 1968 was about 232 feet below mean sea level.

The Imperial Valley occupies the southern, wider part of the Salton Trough in the United States. On the northwest, the valley is bordered by the Salton Sea; and on the southeast, it is contiguous with the Mexicali Valley in Mexico — the part of the Colorado River delta that is above sea level. The Chocolate Mountains are on the northeast, and the Peninsular Range of Baja California and southern California is on the southwest. The land surface slopes northwestward from about sea level at the international boundary to the Salton Sea, 50 miles distant. Several shorelines of prehistoric Lake Cahuilla, at 42 to 50 feet above mean sea level, are well-preserved features in both the eastern and the western parts of the valley.

EASTERN IMPERIAL VALLEY

The northeast and east boundaries of eastern Imperial Valley are herein defined as being the northwest-trending Chocolate Mountains and a line extending southward from the Chocolate Mountains through the Cargo Muchacho Mountains and Pilot Knob near the international boundary (pl. 1). The Chocolate Mountains are a low rugged chain formed principally of pre-Tertiary plutonic and metamorphic rocks in the northwestern part and extensive Tertiary volcanic rocks in the southeastern part. The altitudes of the mountains generally are somewhat less than 2,500 feet; one especially low gap separating southwestward drainage in Imperial Valley from northeastward drainage to the Colorado River has an altitude of only about 1,100 feet. The smaller but equally rugged Cargo Muchacho Mountains and Pilot Knob are masses of pre-Tertiary rocks that reach altitudes of about 2,200 and 900 feet, respectively. The eastern Imperial Valley, lying between the mountains just cited and the eastern shoreline of prehistoric Lake Cahuilla, comprises four principal subareas: (1) Chocolate Mountains piedmont slope, (2) Pilot Knob Mesa, (3) Sand Hills, and (4) East Mesa.

The Chocolate Mountains piedmont slope extends southwestward from the Chocolate Mountains to the northeast margin of the Sand Hills. The area is underlain by poorly sorted fluvial deposits of local ephemeral streams. The piedmont surface is extensively dissected by washes and is partly covered with desert pavement. Trees and large shrubs are sparse except along some of the larger washes, where small desert hardwood trees, chiefly paloverde (*Cercidium floridum*) and desert ironwood (*Olneya tesota*), are abundant.

Pilot Knob Mesa is a southerly extension of the Chocolate Mountains piedmont slope and is similar in most respects (fig. 2). The southeastern part of Pilot Knob Mesa is underlain by deposits of the Colorado River, as well as by local deposits. Desert pavement on the river deposits is characterized by lag gravel of well-rounded siliceous rocks of distant source, as contrasted with the more angular, generally less resistant pebbles of local derivation (fig. 3).

FIGURE 2. — View across Pilot Knob Mesa. Cargo Muchacho Mountains are in right background; Chocolate Mountains are in left background. Dark bands in fore and middle distances are areas of varnish-coated desert pavement.

FIGURE 3. — Desert pavement consisting of rounded quartzitic gravels of the Colorado River. Near Cargo Muchacho Mountains.

The Sand Hills, also referred to as the Algodones Dunes, occupy a belt that is more than 40 miles long and 5 to 6 miles wide. These dunes lie on a southwestward- to westward-sloping surface that is continuous with the Pilot Knob Mesa to the northeast and the East Mesa to the southwest. The southwestern part of the Sand Hills is marked by longitudinal southeast-trending ridges, but most of the belt consists of transverse ridges and smaller barchan or quasi-barchan dunes. Some of the ridges are as much as 300 feet above the mesa surface, which is exposed locally in blowouts in the southeastern part of the belt. The southwest margin of the dunes is adjacent to a lacustrine (or marine?) shoreline that probably furnished the sand for the dunes, as discussed in the section "Paleohydrology of the Salton Trough."

The East Mesa occupies a triangular area southwest of the Sand Hills, north of the international boundary, and east of the shoreline of prehistoric Lake Cahuilla. Physiographically, the East Mesa, which is an extension of the Pilot Knob Mesa to the northeast, is a sloping surface that merges gradually with central Imperial Valley. The East Mesa was formed mainly by fluvial processes but was locally modified by lacustrine (or marine?) processes. The broad, southern part of the East Mesa slopes west-southwestward at about 6 feet per mile. The mesa surface is mantled extensively by irregular sheets of windblown sand that generally are less than 20 feet thick. The natural vegetation consists largely of scattered creosote bushes (*Larrea divaricata*).

CENTRAL IMPERIAL VALLEY

The large contiguous area of cultivated land constituting the central Imperial Valley is entirely within the shorelines of prehistoric Lake Cahuilla. The soils formed from the lakebed materials contain a large proportion of clay and silt, in contrast with the predominantly sandy soils of the adjacent East Mesa and West Mesa. Topographically, the central Imperial Valley is a broad flat trough whose axis slopes north-northwestward from about sea level at the international boundary to and beyond the shore of the Salton Sea, which had an altitude of 232 feet below sea level in 1968. The lowest point of the trough's surface is beneath the southern part of Salton Sea and is about 275 feet below sea level (Littlefield, 1966). The average land-surface gradient from the international boundary to this point is 1.7 feet per mile.

Most of central Imperial Valley is a monotonous plain dissected by two major drainages — the Alamo and New Rivers — which have cut trenches as much as 40 feet deep in the soft silty lacustrine deposits. Much of the cutting took place during 1905-7, when virtually the entire Colorado River flowed uncontrolled in these channels and established the present-day Salton Sea.

Obsidian Butte and other nearby buttes, formed of rhyolite obsidian, and the mud volcanoes, built up by rising thermal water and mud highly charged with carbon dioxide, are small domical hills 20 to 100 feet above the valley near the southeast shore of the Salton Sea. Some of these hills became surrounded by water as the sea rose in recent years.

WESTERN IMPERIAL VALLEY

Western Imperial Valley is a topographically complex area between the central irrigated plain of Imperial

Valley and the Peninsular Range to the west. The boundary between the western and central parts of the valley is less distinct than that between the eastern and central parts. The altitudes of the piedmont surfaces ranges from 100 feet or more below mean sea level near the Salton Sea in the northwestern part of the area to nearly 2,000 feet above mean sea level at the foot of the Peninsular Range in the southwestern part.

Spurs and outliers of the main Peninsular Range, which are formed chiefly of pre-Tertiary basement complex, include the Fish Creek, Coyote, and Jacumba Mountains, and Superstition Mountain — the lowest and easternmost outlier, about 20 miles northwest of El Centro. In contrast to these rugged exposures of crystalline rocks are the low flanking hills and badlands underlain by deformed Cenozoic sedimentary and minor volcanic rocks.

Western Imperial Valley is drained by San Felipe Creek, which has perennial reaches in the mountains but not in the valley, and by many ephemeral washes. The most prominent ephemeral streams are Fish Creek, Carrizo, Coyote, Yuha, and Pinto Washes.

The most extensive alluvial slope in western Imperial Valley is the West Mesa, a broad flat plain straddling the Lake Cahuilla shorelines in the east-central part of the area. On the northwest, the West Mesa merges with lower Borrego Valley, and on the northeast, it merges with the dissected lacustrine deposits of Superstition Hills and with the downstream part of the flood plain of San Felipe Creek. To the southwest, along Palm Canyon Wash and Coyote Wash, is the informally designated Coyote Valley area, underlain by gravelly alluvium from the Peninsular Range. The Yuha Desert area extends south of West Mesa to the international boundary and includes the Yuha Buttes, which are colorful badland exposures of deformed Cenozoic sedimentary rocks.

STRUCTURAL FEATURES

The trough of the Gulf of California and its landward extension, the Salton Trough, are structural as well as topographic depressions in which the surface of the basement complex lies thousands to tens of thousands of feet below the basement-complex surface in the bordering mountains. The basement complex is composed of plutonic rocks of early and late Mesozoic age which intrude Mesozoic and older metamorphic rocks (Bushee and others, 1963).

The Gulf of California and the Salton Trough evolved during late Cenozoic time. Hamilton (1961) attributed the formation of the Gulf of California to a combination of strike-slip displacement and cross-strike separation. According to Larson, Menard, and Smith (1968), the gulf resulted from ocean-floor spreading from the crest of the East Pacific Rise, which apparently extends landward (northward) near the present mouth of the gulf. These authors infer that the spreading has rafted the Baja California peninsula away from the mainland of Mexico, mostly within the last 4 million years (late Pliocene to Holocene), but that the northern part of the gulf formed earlier, probably at least by late Miocene time.

The San Andreas fault system, the major strike-slip fault system that traverses the Salton Trough, probably was in existence in early Tertiary time. Although not conclusively demonstrated, possibly as much as 200 miles of aggregate strike-slip displacement has occurred in the region since the middle Eocene (Crowell and Susuki, 1959, p. 590). The various faults have been active at different times, however, so that the loci of major displacements have shifted substantially throughout the Cenozoic Era.

The Elsinore fault is the southwesternmost fault of the San Andreas system in the United States part of the Salton Trough (Biehler and others, 1964, p. 139). The dip-slip component on the fault northwest of the Imperial Valley is as much as 3,000 feet (Jahns, 1954, p. 45). The strike-slip component is unknown, but conceivably it might be several times the dip slip. The Laguna Salada fault, which lies mostly in Baja California, Mexico, is an extension of the Elsinore fault; together, they coincide approximately with the southwestern boundary of the Imperial Valley.

The San Jacinto fault of the San Andreas fault system begins in the San Gabriel Mountains, about 120 miles northwest of the Imperial Valley, extends southeastward, forming the northeast edge of Borrego Valley, and then splits into several subparallel faults before entering the Imperial Valley northwest of El Centro. The Imperial fault may be a part of this system (Biehler and others, 1964, p. 138). As much as 13 feet of right slip took place on the Imperial fault near the international boundary during an earthquake on May 18, 1940 (Dibblee, 1954, p. 26).

The San Andreas fault and several parallel or en echelon faults lie along the northeast margin of Imperial Valley. Biehler (1964; oral commun., 1967) inferred the existence of the fault zone on the basis of an alinement of gravity lows that extend from the Salton Sea southeastward beneath the Sand Hills and the East Mesa to the Colorado River south of Pilot Knob. The gravity data are supported by seismic-refraction profiles that also indicate a fault beneath the northeast margin of the Sand Hills. The surface of the basement complex is downthrown several thousand feet to the southwest along this fault (Kovach and others, 1962, p. 2867-2869). This fault (or possibly a parallel fault), named the "Algodones fault" by Olmsted, Loeltz, and Irelan (1973), extends southeastward across the Yuma area.

The development of the Salton Trough in late Cenozoic time has involved folding and warping as well as faulting. Much of the folding is related to movement along the major faults and indicates right-lateral drag. Some folding, generally not as tight as that near faults, apparently is unrelated or only indirectly related to faulting. Folding of Quaternary alluvial and lacustrine deposits and of Tertiary nonmarine and marine sedimentary rocks has been noted (fig. 4). This folding is in contrast to the relatively mild deformation—mainly warping—of upper Tertiary and Quaternary nonmarine deposits along the Colorado River to the east in the Yuma and Parker-Blythe-Cibola areas. (See Metzger and others, 1973, and Olmsted and others, 1973.)

FIGURE 4. — Fold in Brawley Formation of Dibblee (1954) east of Niland. View is to the north. Lake Cahuilla shoreline is faintly visible in background.

A measure of late Tertiary and Quaternary deformation in the Salton Trough is provided by the configuration of the base of the marine Imperial Formation (Miocene or Pliocene) and the possibly correlative Bouse Formation. Although the base of the Bouse Formation is exposed at an altitude of about 1,050 feet in a gap in the Chocolate Mountains about 15 miles northeast of Glamis, marine deposits similar to either the Bouse or the Imperial Formation apparently were not penetrated in a 13,443-foot-deep oil test well 7 miles northwest of Holtville, in the central part of the trough. In the Coyote Mountains along the west side of Imperial Valley, the base of the Imperial Formation is as high as 1,000 feet above sea level. Much of the inferred structural relief of more than 14,000 feet has resulted from large-scale downwarp of the Salton Trough and upwarp of the bordering mountains, as well as from folding and faulting.

Warping continued at least through late Pleistocene time, as indicated by the tilting of lacustrine (or marine?) shorelines, which is discussed in the section "Upper Tertiary and Quaternary Predominantly Nonmarine Deposits." Not all the warping was in the same direction; some shorelines on the west side of the trough appear to slope southeastward, whereas a prominent shoreline on the east side slopes northwestward. Exploration with geoelectrical methods has indicated a gentle southward dip of strata in the upper water-bearing deposits beneath central Imperial Valley (Meidav, 1969).

CENOZOIC STRATIGRAPHY

Overlying the pre-Tertiary basement complex in the Salton Trough and adjacent mountains is a thick sequence of dominantly nonmarine sedimentary rocks that ranges in age from Eocene to Holocene. The aggregate thickness of this sequence is many thousands of feet, both in exposures and beneath the Imperial Valley in the central part of the Salton Trough. Geophysical evidence indicates that the Cenozoic fill beneath south-central Imperial Valley probably is more than 20,000 feet thick (Kovach and others, 1962). Rocks as old as Eocene crop out in the bordering mountains, but the fill in the central part of the trough does not appear to be older than about middle Miocene, and most of the fill is Pliocene and younger (Durham, 1954, p. 27). The inferred stratigraphic relations of the generally recognized units and formations are shown in figure 5.

For the purpose of the discussion below, the Cenozoic deposits are grouped in three broad categories: (1) a lower sequence comprising chiefly nonmarine sedimentary rocks of early to middle Tertiary age but including also volcanic rocks and minor marine sedimentary rocks; (2) a middle marine unit, the Imperial Formation, of late Tertiary (Miocene or Pliocene) age; and (3) an upper sequence composed of predominantly nonmarine deposits of late Tertiary (Pliocene) and Quaternary age. The upper sequence constitutes the main part of the ground-water reservoir beneath the Imperial Valley.

LOWER TO MIDDLE TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Sedimentary and volcanic rocks that range in age from Eocene to Miocene are exposed in the mountains on the margins of the Salton Trough but generally are believed to be thin or absent beneath the central part of the trough. These rocks are moderately to strongly deformed and are semiconsolidated to consolidated; they do not constitute a significant part of the ground-water reservoir and are described only briefly. Earlier geologists made several different interpretations of the stratigraphic relations of these rocks, but the differences are not pertinent to this report. The inferred stratigraphic relations of the lower to middle Tertiary sedimentary and volcanic rocks shown in figure 5 are based largely on the interpretations of Durham and Allison (1961) and Woodard (1961), adapted and modified by Robison.

The Maniobra Formation (lower and middle Eocene) of Crowell and Susuki (1959) comprises the earliest known Cenozoic rocks of the Salton Trough region. The

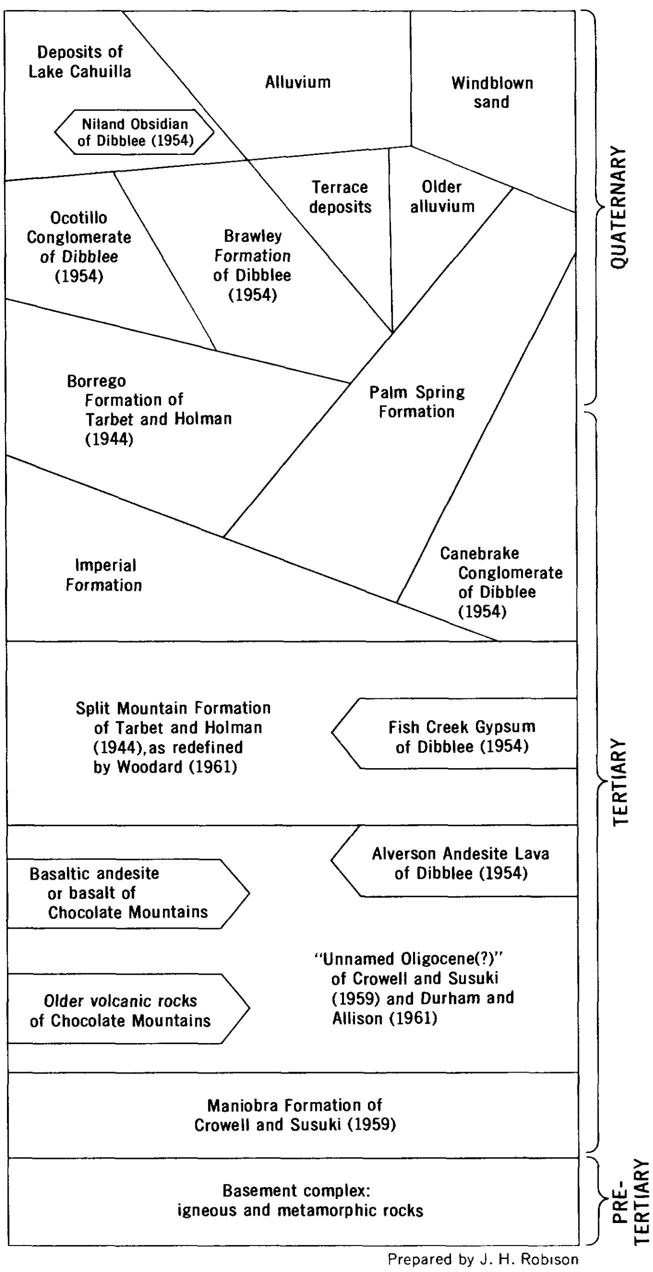

FIGURE 5. — Composite column of Salton Trough, showing inferred time relations of stratigraphic units.

Maniobra Formation is exposed in the Orocopia Mountains, about 5 to 10 miles beyond the northern limits of the geologic map (pl. 1). The formation consists of about 4,800 feet of fossiliferous marine clastic rocks of early to middle Eocene age, ranging from coarse conglomerate and breccia in the lower part to siltstone and sandstone in the upper part.

In the Orocopia Mountains, the Maniobra Formation is overlain unconformably by about 5,000 feet of nonmarine sedimentary rocks and intercalated andesitic flows and sills of Oligocene(?) age (Crowell, 1962, p. 28). Similar, probably correlative rocks are exposed in the Chocolate Mountains northeast of Imperial Valley and in the Vallecito-Fish Creek Mountains and Jacumba-Coyote Mountains areas southwest of the valley (Durham and Allison, 1961).

The volcanic rocks in the Chocolate Mountains are herein grouped in two units (pl. 1 and fig. 5): (1) older volcanic rocks, consisting of pyroclastic rocks and minor flows of andesitic to rhyolitic composition; and (2) basaltic andesite or basalt, a ridge-capping sequence of dark-gray to dark-brown flows and flow breccias. These volcanic rocks are associated with predominantly conglomeratic nonmarine sedimentary rocks. Volcanic rocks in the southeastern Chocolate Mountains and nearby Laguna Mountains east of the area shown on plate 1 have potassium-argon ages of 23 to 26 million years, indicating a middle Tertiary age for these rocks and associated nonmarine sedimentary rocks (Olmsted and others, 1973).

In the Vallecito-Fish Creek Mountains and Carrizo Wash-Coyote Mountains areas on the southwest margin of the Imperial Valley, the sedimentary and volcanic rocks of middle Tertiary age include (1) the Split Mountain Formation of Tarbet and Holman (1944), (2) the Alverson Andesite Lava of Dibblee (1954), and (3) the Fish Creek Gypsum of Dibblee (1954). The Split Mountain Formation of Tarbet and Holman (1944) was redefined by Woodard (1961), who excluded the lower 1,800 feet of arkosic arenite (sandstone) and sedimentary breccia below an unconformity at the type section. Woodard (1961, p. 74) described this restricted Split Mountain Formation as consisting of two nonmarine members of very coarse grained sedimentary breccia separated by a middle member of marine arenite, which includes the Fish Creek Gypsum of Dibblee (1954) as an evaporite facies. The Alverson Andesite Lava of Dibblee (1954) underlies the Split Mountain Formation as redefined by Woodard (1961) and overlies the lower part of Tarbet and Holman's (1944) Split Mountain Formation.

IMPERIAL FORMATION

The Imperial Formation was redefined and renamed from the Carrizo Formation by Woodring (1932, p. 7). He defined the Imperial Formation as having a basal member of "conglomerate, sandstone, coralliferous limestone, and at places basalt flows and flow breccias" and a siltstone member of "buff siltstone with occasional hard beds of very fossiliferous limy sandstone." Woodring (1932) described the Imperial Formation at the type locality to be "the entire series of marine deposits bordering Carrizo Mountain, and to exclude overlying nonmarine beds."

Christensen (1957) described the Imperial Formation in its type area bordering the Coyote Mountains as follows (top to bottom):[1]

Unit	*Thickness (ft)*	*Description*
Member	600-900	*Upper one-third:* Reddish, tan, and yellow silty sandstone and tan, green, and gray claystone and siltstone. Grades upward and laterally into sand and clay of Palm Spring Formation. Some wood fragments and marine fossils.
		Lower two-thirds: Gray calcareous siltstone and light-tan and yellow fine-grained arkosic sandstone. Flag and spheroidal weathering.
Member	900-1,500	Cream to buff arkosic sandstone and gray-green and light-gray calcareous siltstone. Sandstone contains *Ostrea*, *Anomia*, and *Pecten*. Locally recrystallized into coquina limestone that crops out as cuestas. Sandstone weathers dark brown; siltstone weathers yellow with green cast.
Member	20-250	Gray, light-tan, and olive-drab siltstone. Weathers yellow and greenish yellow. Thin lenses of fine-grained buff sandstone.
(Undesignated)	≤10-150	Buff cobble conglomerate. Lithologically heterogeneous. Lenses of buff sandstone. Oysters, corals.
(Undesignated)	≤10-150	Red to brown massive cobble conglomerate and yellow to pink volcanic conglomerate.

Although exposed extensively on the west side of Imperial Valley, the Imperial Formation has not been recognized in several oil test wells, one as deep as 13,443 feet, in the central part of the valley (see Muffler and Doe, 1968) and was not recognized in U.S. Geological Survey test well LCRP 6A (total depth 2,519 ft) on the East Mesa. In the Parker-Blythe-Cibola area along the Colorado River northeast of Imperial Valley, Metzger (1968) named and described the Bouse Formation, a Pliocene marine unit whose stratigraphic position and general lithology suggest possible correlation with the Imperial Formation, although the microfaunas of the two units generally are dissimilar (Smith, 1968). The Bouse Formation also has been recognized in the subsurface of the Yuma area, just southeast of the Imperial Valley (Olmsted and others, 1973). The apparent absence of the Imperial Formation in the intervening central Imperial Valley (although it may be present below the depths reached by oil test wells) is a problem of major paleogeographic significance.

The age of the Imperial Formation is uncertain; estimates range from early Miocene for the lower part (Woodring, 1932) to possible early Pleistocene for the upper part (Allison, 1964). Metzger (1968) presented evidence that the possibly equivalent Bouse Formation is Pliocene. The present consensus is that at least part of the Imperial Formation is Pliocene.

[1]The members, as Christensen described them, were assigned names, but since these names have no official status and do not fully correspond with the units of Woodring (1932), they are not indicated here.

UPPER TERTIARY AND QUATERNARY PREDOMINANTLY NONMARINE DEPOSITS

Overlying the marine Imperial Formation is a thick hetreogeneous sequence of predominantly nonmarine deposits. In some tributary valleys and marginal parts of the Imperial Valley these deposits are derived locally, but most of the deposits in the central part of the valley were brought in by the Colorado River. The deposits are many thousands of feet thick; Muffler and Doe (1968) reported that the Standard Oil Co. Wilson No. 1 oil test well near the center of Imperial Valley, between Brawley and Holtville was still in deposits of the Colorado River at its bottom depth of 13,443 feet.

In general, the deposits of the Colorado River are finer grained than the locally derived deposits and consist predominantly of silt, sand, and clay, as contrasted with the locally derived coarse sand and gravel. Muffler and Doe (1968) stated that the deposits of the Colorado River are characterized by dominant quartz and calcite and subordinate dolomite, plagioclase, potassium feldspar, and the clay minerals montmorillonite, illite, and kaolinite; minor constituents are magnetite, zircon, leucoxene, clinozoisite, biotite, and chlorite. According to these authors (Muffler and Doe, 1968), the deposits derived from the margins of the basin are markedly different from the deposits of the Colorado River in that they contain much more feldspar, less clay, and very little or no calcite or dolomite.

The deposits overlying the Imperial Formation have been subdivided by previous workers into several formations and informal units. In places the formations and units are separated by unconformities, but in general they are not well-defined time-stratigraphic units, and they appear to intergrade laterally (fig. 5). Each formation is therefore a crudely defined rock-stratigraphic unit and represents a particular facies. The various formations and informal units are described briefly in the following paragraphs.

The Canebrake Conglomerate of Dibblee (1954) is a coarse pebble and cobble conglomerate composed of pre-Tertiary granitic and metamorphic detritus of local derivation. It occurs along the west margin of Imperial Valley, where it is generally several thousand feet thick; basinward it grades into the Imperial Formation and the overlying Palm Spring Formation.

The Palm Spring Formation, named by Woodring (1932, p. 9-10) for exposures in lower Vallecito Creek, comprises many thousands of feet of fluvial and deltaic sand, silt, and clay deposited by the ancestral Colorado River. The Palm Spring Formation overlies the Imperial Formation gradationally, and its lower part contains probable brackish-water deposits. Both the Imperial and the Palm Spring Formations are weakly to moderately consolidated and are locally folded and tilted to a significant degree, especially near faults of the San Andreas system. The Palm Spring Formation grades toward the western mountains into the Canebrake Conglomerate of Dibblee (1954) and toward the center of the valley into the lacustrine silt and clay of the Borrego Formation of Tarbet and Holman (1944). The uppermost part of the Palm Spring Formation may include time equivalents of the Brawley Formation and Ocotillo Conglomerate, both of Dibblee (1954). The relatively coarse grained deposits mapped as older alluvium in the eastern Imperial Valley (pl. 1) and the older alluvium of the Parker-Blythe-Cibola area (Metzger and others, 1973) and the Yuma area (Olmsted and others, 1973) probably are in large part equivalent in age and source of sediment to the Palm Spring Formation.

The Palm Spring Formation was regarded as middle or upper Miocene by Woodring (1932, p. 10), but because it overlies the Imperial Formation (which is probably younger than Woodring believed), it is unlikely to be older than Pliocene. Most workers who have studied the area more recently regard the Palm Spring Formation as Pliocene and Pleistocene. Downs and Woodard (1961, p. 21) found a middle Pleistocene vertebrate fauna in the upper 2,500 feet, and Merriam and Bandy (1965, p. 913) considered the Palm Spring Formation to be mostly Pleistocene.

The Borrego Formation of Tarbet and Holman (1944) is a thick sequence of mostly fine-grained lacustrine deposits typically exposed northwest of Borrego Mountain. The Borrego Formation contains a microfauna similar to that occurring in deposits of prehistoric Lake Cahuilla and in the Salton Sea. Arnal (1961, p. 473) regarded the Borrego Formation as late Pliocene or early Pleistocene in age.

In western and northwestern Imperial Valley the Borrego Formation of Tarbet and Holman (1944) is overlain with local unconformity by the Ocotillo Conglomerate of Dibblee (1954), a coarse gray conglomerate composed chiefly of granitic detritus. The Ocotillo grades eastward into fine-grained lacustrine beds assigned by Dibblee (1954, p. 24) to his Brawley Formation. The Brawley Formation is similar to the underlying Borrego Formation of Tarbet and Holman, from which it is not readily differentiated where an angular unconformity does not exist between the two units. On the geologic map (pl. 1), the Brawley Formation of Dibblee (1954) is included in the unit designated as lake deposits.

The unit shown as older alluvium on the geologic map (pl. 1) consists largely of coarse-grained alluvial-fan deposits and includes the Ocotillo Conglomerate of Dibblee (1954) in western Imperial Valley. Near the Chocolate Mountains, along the east edge of the valley, the older alluvium may constitute only a thin blanket overlying deformed sedimentary rocks of Tertiary age. Toward the center of the valley the older alluvium grades laterally into the lacustrine silt, sand, and clay of the Brawley Formation of Dibblee (1954). The older alluvium also may include deposits correlative with the upper part of the Palm Spring Formation.

The unit designated on the geologic map (pl. 1) as terrace deposits is composed of thin blankets of gravel and sand overlying pediments cut on the Palm Spring and Imperial Formations in western Imperial Valley. In places the terrace deposits appear to thicken, and they may grade laterally into deposits classified as the older alluvium.

The deposits of Lake Cahuilla are the uppermost lacustrine silt, sand, and clay in the central part of the valley within the shorelines of the lake. On the geologic map (pl. 1) the deposits are included in the unit designated as lake deposits, which also includes the somewhat older Brawley Formation of Dibblee (1954). In the subsurface, present data do not allow the deposits of Lake Cahuilla to be differentiated from those of the Brawley Formation.

The unit designated as alluvium on the geologic map (pl. 1) consists of the youngest fluvial and deltaic deposits in the Imperial Valley. They lie along present ephemeral stream channels and also beneath broad gently sloping surfaces on both sides of the valley. In contrast to the soils formed on the older alluvium and the terrace deposits, the soils on the younger alluvium are immature and lack the profile development characteristic of the older soils.

Well-sorted fine to medium sand of windblown origin is extensive on the sides of the valley, especially in the East Mesa and in the Sand Hills (Algodones Dunes). The Sand Hills are related to the water bodies that once occupied the Salton Trough. Brown (1923, p. 28-29) believed the dunes had been formed from sand blown eastward from Lake Cahuilla across the East Mesa. Norris and Norris (1961) also ascribed the source of the sand to Lake Cahuilla, but only from an area northwest of where the Lake Cahuilla shorelines adjoin the north end of the dunes. The present writers believe that an older, higher shoreline (discussed in the next section) was the local source of the sand in the Sand Hills. The Colorado River provided the sand by depositing a large volume in the East Mesa. When the water body associated with the high shoreline was present, wind and shoreline processes formed the dunes from this source, probably in a manner similar to that of dune formation along the present California and Oregon coasts. The position of the high shoreline and the dunes appears to have been determined by the Algodones fault and, possibly, by a parallel branch of the San Andreas fault (pl. 1).

Volcanic rocks crop out in a row of small domical buttes, one of which is called Obsidian Butte, along the southeast shore of the Salton Sea (pl. 1). Together with the nearby mud volcanoes — a series of fumaroles, which emit carbon dioxide and other gases — these knobs of obsidian, scoria, and pumice are evidence of geologically recent volcanic activity. A strong thermal anomaly characterized by abnormally high geothermal gradients is present in this area (Rex and Randall, 1969) and has been explored by several steam test wells.

PALEOHYDROLOGY OF THE SALTON TROUGH

Certain aspects of the geologic history of the Salton Trough are of particular interest here because they relate to the origin of the ground water in the Imperial Valley. If the trough was occupied (perhaps intermittently) by an arm of the Gulf of California until only a few thousand or tens of thousands of years ago, incompletely flushed marine water still may be present in the relatively young deposits, which are of primary interest in this study. On the other hand, if the trough has been isolated from the gulf during all or most of the period since the marine Imperial Formation was deposited, the ground water in the post-Imperial deposits probably had a nonmarine source or sources. The first hypothesis was supported by Mendenhall (1909b, p. 16–18) and Brown (1923, p. 26), who concluded that the Salton Trough was part of the Gulf of California, having subsided prior to the seaward advance of the Colorado River delta, and that the trough was separated from the gulf only recently in geologic time, when the delta was built above sea level. The second hypothesis was proposed by Free (1914, p. 25–26) and expanded by Buwalda and Stanton (1930). According to this hypothesis, downwarping of the central part of the Salton Trough below sea level was contemporaneous with the building of the Colorado River delta. The available data tend to support the second hypothesis rather than the first, although the possibility that the Gulf of California may have invaded the Salton Trough for short periods up to very late Pleistocene time cannot be ruled out. Some of the pertinent evidence is summarized in the following paragraphs.

Stratigraphic evidence indicates that the major marine invasion of the Salton Trough is represented by the Imperial Formation, which is probably at least in part Pliocene. The late Cenozoic stratigraphic record is subject to some dispute, but most workers have agreed that nonmarine conditions predominated in post-Imperial time. Downs and Woodard (1961) noted an "impoverished brackish-marine" fauna interbedded with Irvingtonian (early Pleistocene) vertebrates in the upper part of the Palm Spring Formation. However, the brackish or marine interbeds do not constitute a major part of the Palm Spring Formation. The Borrego Formation of Tarbet and Holman (1944), which is largely equivalent to the Palm Spring Formation, is chiefly lacustrine in origin, although, according to Arnal (1961, p. 471), it includes strata of shallow-marine origin.

The deposits overlying the Borrego Formation of Tarbet and Holman (1944) and the Palm Spring Formation are mostly lacustrine in the central part of the trough and fluvial in the marginal parts. The lacustrine deposits are represented by the Brawley Formation of Dibblee (1954), which, according to Arnal (1961, p. 473), contains a freshwater fauna. The limits of the Brawley Formation are defined approximately by the highest extensive shoreline remnants in the Imperial Valley, and the Brawley Formation is inferred to be at least partly contemporaneous with these shorelines.

One of the high shorelines has an altitude of 140 to 160 feet above mean sea level in western Imperial Valley near Plaster City. G. M. Stanley (oral commun., 1965) reported that this shoreline slopes southward in Baja California and crosses the younger, Lake Cahuilla shorelines at about 45 to 50 feet above mean sea level. In eastern Imperial Valley a high shoreline, possibly equivalent to that near Plaster City but sloping toward the northwest, extends northwestward along the southwest edge of the Sand Hills. This shoreline slopes from an altitude of about 160 feet near the south end of the Sand Hills to 120 feet at the northwest end; farther northwest, about 4 miles north of Niland, it is truncated by the younger shoreline of Lake Cahuilla (fig. 6). Several shoreline segments lie farther north, near the Riverside-Imperial County line, at altitudes of 160 feet or more. The segments probably were uplifted to these altitudes by a branch of the Banning–Mission Creek fault, which extends through a nearby hot mineral spa.

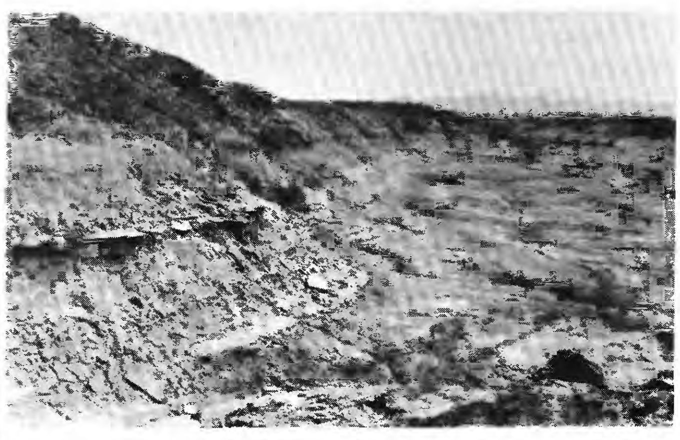

FIGURE 6. — Upper shoreline, extending from left foreground to right background and cutting into the Brawley Formation of Dibblee (1954). Located north of Niland, near intersection of upper shoreline and Lake Cahuilla shoreline.

Other, probably related shorelines are cut in bedrock on the northwest flank of Superstition Mountain, where they have been uplifted and tilted by movements along the San Jacinto fault. The oldest shoreline slopes about

10° southwestward and has an altitude of nearly 500 feet at its northeast end. Remnants of a high shoreline farther north, on the west side of the Salton Trough, occur as far north as Travertine Point; but north of San Felipe Creek the shoreline is not apparent, probably because it is concealed by younger alluvial fans.

The youngest and most prominent shorelines are those associated with Lake Cahuilla, a name given by Blake (1856) to the prehistoric lake that antedates the present, much smaller lake, the Salton Sea. The last main stages of Lake Cahuilla, which, prior to 1962, were the only ones with published reference, had altitudes of 42 to 45 and 47 to 50 feet above mean sea level (Stanley, 1962). Unlike the older, higher shorelines, the shorelines of Lake Cahuilla are virtually undeformed.

Stanley (1962), Hubbs (in Hubbs and others, 1963), and Thomas (1963) all believed that the higher shorelines represent fresh-water lakes. The morphology, tufa coating, and molluscs associated with these shorelines all seem to indicate a fresh-water ecology. However, one of the present authors (Robison, 1965) noted several problems involved in this interpretation. One involves the containment of fresh water in the basin, or exclusion of sea water from the Gulf of California. The present divide between the drainage southward into the Gulf of California and northward into the Salton Sea has a minimum altitude of 47 feet (Arnal, 1961, p. 445) — about the right altitude to contain the latest stages of Lake Cahuilla, but far too low to account for fresh-water bodies at the higher levels of the older shorelines. Another problem involves the maintenance of sufficient inflow to keep the water in the lakes fresh. As Mendenhall (1909b, p. 18–19) pointed out, the average flow of the Colorado River (the predominant source of inflow at present and probably also during moister stages of the Pleistocene and Holocene Epochs) probably was insufficient to maintain a fresh Lake Cahuilla — the lake probably was somewhat brackish. The area within the older shorelines is greater than the 2,000-square-mile area covered by Lake Cahuilla; therefore, the older water bodies necessarily would have been more brackish than Lake Cahuilla if the Colorado River was the primary source of water.

Another problem is the satisfactory explanation of events that are thought to have occurred within the time span indicated by dating of fossils and tufa deposits of the higher shorelines and early Lake Cahuilla. Fossils from one of the higher shorelines yielded a radiocarbon date of 37,100 ±2,000 years B.P. (before present) (Hubbs and others, 1963, p. 262).The oldest tufa deposits from Travertine Point, 100 feet below the Lake Cahuilla shoreline, gave a date of 13,040 ± 200 years B.P. (Hubbs and others, 1963, p. 260). If these ages are valid, the maximum time interval between the high stage and an early stage of Lake Cahuilla was about 25,000 years. If the higher shorelines represent lakes and not an arm of the Gulf of California, then during the 25,000-year interval a topographic divide separating the Salton Trough from the Gulf of California was removed, and the higher shorelines were faulted and tilted. The problem of how the divide was removed does not, of course, exist if the higher shorelines are actually marine rather than lacustrine. The reconnaissance nature of the present study did not allow further study toward determining more definitely the nature and age of the higher shorelines and the hydrologic events that followed their formation.

The dates of the last main stages of Lake Cahuilla have been well documented from radiocarbon evidence. A radiocarbon date of 1,510 ± 180 years B.P. was obtained from tufa associated with a beachline at an altitude of about 43 feet; other dates range from several hundred to about 1,900 years B.P. (Hubbs and others, 1963, p. 269–270). The Indians in Coachella Valley have legends about a large body of water (Lake Cahuilla) which disappeared slowly — probably by evaporation after the Colorado River ceased to flow into the Salton Trough and began to flow into the Gulf of California. When the first white men entered the region, the floor of the trough (Salton Sink) was a dry salt flat.

The most recent major hydrologic event was a series of uncontrolled inflows of floodwater of the Colorado River into the Salton Trough during 1905–7, thereby forming the present Salton Sea. Diversion intakes on the Colorado River below Yuma, Ariz., which has been constructed in the late summer of 1904 to increase the amount of water available for irrigation in the Imperial Valley during that low-flow period, were breached by the spring flood of 1905. The diversion intakes were greatly enlarged by repeated floods, so at times virtually the entire flow of the river was westward and northwestward into the Salton Sea by way of the Alamo and New Rivers. In early 1907 the river was finally brought under control and diverted to its former course to the Gulf of California. At its maximum extent, the Salton Sea reached a stage of about 195 feet below mean sea level, covered an area of more than 500 square miles (less than one-fourth that of Lake Cahuilla), and had a depth of more than 80 feet (Hely and others, 1966).

HYDROLOGY

THE GROUND-WATER RESERVOIR

The ground-water reservoir in Imperial Valley consists of Cenozoic valley-fill deposits; these deposits are underlain by rocks of pre-Tertiary age that are referred to as the basement complex. Although the valley fill probably is more than 20,000 feet thick, the hydraulic phases of this study are concerned principally with the heterogeneous sequence of nonmarine deposits in the upper few thousand feet of the ground-water reservoir. The studies were limited to depths of several thousand feet because at greater depths the water is too saline for irrigation and most other uses and because the hydraulic connection between the water in the deeper deposits and the water in the upper part of the ground-water reservoir is poor.

Near the margins of the valley, the deposits are derived locally and range from boulders to clay; coarse sand and gravel predominate. Colorado River deposits, which for the most part consist of sand, silt, and clay, underlie the central part of the valley and extend to the margins of the locally derived deposits.

WATER-BEARING CHARACTERISTICS OF THE ROCK

DEFINITION OF TERMS

The term "aquifer" is applied to any water-bearing formation or rock unit that is capable of yielding an adequate water supply. The adjectives "excellent," "good," "fair," or "poor" may be used to denote the degree to which the yield from an aquifer is adequate; but they are not specific enough for a quantitative appraisal of an aquifer or for comparing one aquifer with another. To be more specific, the water-bearing ability of an aquifer may be expressed in terms of the aquifer's transmissivity. In this report, transmissivity is expressed as the rate of flow in gallons per day through a 1-foot-wide vertical strip of the entire saturated thickness of the aquifer under a unit hydraulic gradient at the prevailing temperature of the water.

The water-bearing ability of an aquifer may also be expressed in terms of field hydraulic conductivity. As used in this report, the field hydraulic conductivity is the rate of flow in gallons per day that will occur through a 1-foot-square cross section of the aquifer under a unit hydraulic gradient. Generally, the horizontal hydraulic conductivity of an aquifer is greater than the vertical hydraulic conductivity. This is especially true for alluvial materials because of size sorting and the alinement of platy and ellipsoidal grains that occur during deposition of the material. The vertical hydraulic conductivity of some aquifers that consist of many different strata ranging from clay or silt to sand or gravel may be only hundredths or thousandths of the horizontal hydraulic conductivity. Horizontal hydraulic conductivities in Imperial Valley probably range from a fraction of a gallon per day per square foot for clay and silt to several thousand gallons per day per square foot for well-sorted sand and gravel.

Transmissivities commonly are computed from the results of controlled pumping tests. They also can be computed on the basis of the width of a vertical section through which ground water is moving at a known rate under a known hydraulic gradient, or on the basis of the specific capacity, which is the rate of yield per unit drawdown, of a well (Theis and others, 1963, p. 331). In many areas the specific capacities of wells are the only data available for computing transmissivity. If only lithologic or good driller's logs are available, transmissivity can be estimated if the relation between hydraulic conductivity and some physical parameter, such as median grain size, is known. Such a relation has been established for alluvial material in the Arkansas River valley, Arkansas (Bedinger and Emmett, 1963). To the extent that the relation is applicable to the materials of the area being investigated or that a new relation can be established, the transmissivity can be computed by summing the products of the different hydraulic conductivities and the thicknesses of the strata to which they apply. All the aforementioned methods were used in varying degrees during this study.

In this report, most of the transmissivities computed from pumping-test data are for a section of the aquifer that is not much thicker than the strata tapped by the wells. The extent to which the computed transmissivities are representative of the entire saturated thickness must be judged on the basis of the thickness of the different kinds of material tapped by the wells and the thickness and kinds of material that comprise the entire reservoir.

In many areas of the Imperial Valley the transmissivity of the entire thickness of saturated material is of little significance in the development of irrigation or municipal water supplies. As stated earlier, the hydraulic connection between the deposits at great depth and those in the upper part of the reservoir is so poor that the two parts are virtually completely isolated. However, the occurrence of highly transmissive material at depth may be greatly significant for other types of development, such as the generation of electrical power by utilizing the thermal energy of ground water, or the recovery of specific minerals from the deep water. The feasibility of developments of these types is beyond the scope of this study.

Another important characteristic of a water-bearing rock is its capacity to store or to release water in response to changes in head. A measure of this characteristic is called the storage coefficient (formerly termed "coefficient of storage") and is a dimensionless number that is defined as the volume of water that is released from or is taken into storage per unit surface area of an aquifer per unit change in the component of head normal to that surface (Ferris and others, 1962, p. 74).

When water is confined — that is, when it occurs under artesian conditions — the changes in storage that result from changes in head are attributed entirely to compressibility of the water and of the aquifer materials. Storage coefficients under artesian conditions are small and generally range from about 0.00001 to 0.01. However, in Imperial Valley, the upper limit may be several times higher because of the unusually great thickness of the deposits.

When water is unconfined — that is, when it occurs under water-table conditions — the changes in storage that result from changes in head are dependent mainly on the drainage characteristics of the aquifer material. In an unconfined aquifer the volume of water involved in gravity drainage ordinarily is many hundreds or even thousands of times greater than the volume attributable to compressibility of the aquifer materials and of the water in the saturated zone, so the volume of water involved in gravity drainage divided by the volume of the zone through which the water table moves is the specific yield. Under dewatering and unconfined conditions, the storage coefficient therefore is sensibly equal to the specific yield. However, when water is going into storage — that is, when the water table is rising — the storage coefficient may exceed the specific yield if the material in which the water is being stored contains less moisture than it can retain against gravity drainage. In this instance, the upper limit of the storage coefficient is the porosity of the material. Generally, however, storage coefficients under water-table conditions range from almost zero to a few hundredths for clay and silt, and from 0.2 to 0.4 for clean sand and gravel.

Storage coefficients, especially those for artesian aquifers, are commonly computed from the results of controlled pumping tests. However, the computed coefficients have little significance if the field conditions differ markedly from the conditions that were assumed in deriving the mathematical formulas used for computing the coefficients. The pumping-test data obtained during this study either were not adequate or were otherwise considered unsatisfactory for computing meaningful storage coefficients.

A neutron moisture probe, in conjunction with access tubes driven to depths of several feet below the water table, was used to determine storage characteristics of several types of material in Imperial Valley. Construction details and the scientific principles that relate neutron-probe data to moisture content at a particular depth are explained in previous water-resources reports on the lower Colorado River area (Metzger and others, 1973; Olmsted and others, 1973).

The method is especially useful for determining the capacity of materials to store water when water levels are rising. Water levels have been rising for 20 or 30 years in the parts of Imperial Valley where the ground-water reservoir is recharged by leakage from the All-American and the Coachella Canals. The average difference between the moisture content of the material above the capillary zone and that of the material below the water table is an indicator of the quantity of water that will go into storage as the water table rises. The results of the neutron-probe moisture studies are given in a later section entitled "Soil-Moisture Studies."

PUMPING TESTS

Short-term pumping tests were made at several widely scattered sites to obtain data for computing transmissivity. Although some of the short-term tests did not provide adequate data, most of the tests were satisfactory. The pumping-test sites are shown in figure 7, and pertinent data from the tests are listed in table 1.

The test data were analyzed by the Theis (1935) nonequilibrium formula. The reliability of the computed transmissivity is classified arbitrarily as follows: Good, if the difference between computed transmissivity and true transmissivity is thought to be less than 25 percent of the values listed; fair, if the difference is between 25 and 50 percent; and poor, if it is more than 50 percent (table 1). None of the computed transmissivities are considered significant to more than two figures, and most, to only one figure. The classification takes into account not only the degree to which the test data conformed to theoretical values, but also other known factors that might influence the results, such as the theoretical relation between transmissivity and specific capacity previously mentioned and consistency of results obtained from drawdown data and from recovery data.

The data indicate that in the eastern and western parts of Imperial Valley moderate to high yields can be obtained from wells that tap several hundred feet of the marginal alluvial deposits or deposits of the Colorado River. Transmissivities of several hundred thousand gallons per day per foot seem to be characteristic of these deposits, and wells with specific capacities of as much as 50 gallons per minute per foot of drawdown or more may be attainable in the more favorable areas. In the central part of Imperial Valley, the two pumping tests that were made by the Imperial Irrigation District prior to this study indicate that the transmissivity of the fine-grained deposits that are characteristic in this part of the valley is likely to be only 1,000 to 10,000 gallons per day per foot to depths of 500 feet. The geologic studies suggest that at greater depths the transmissivity may be even lower for a similar thickness of deposits.

The exceptionally high transmissivity and hydraulic conductivity computed for deposits at well LCRP 6 (fig. 7; table 1) indicate that some of the Colorado River deposits at the site are very permeable. The values are similar to those obtained from pumping tests of large-yielding wells in the Mexicali and Yuma Valleys. The lower transmissivities and hydraulic conductivities at wells LCRP 11, 12, and 18 (fig. 7; table 1) indicate that the permeability of the deposits decreases westward and northwestward from well LCRP 6. The eastward extent from well LCRP 6 of the region of high transmissivity is not known, but consideration of possible past courses of the Colorado River suggests that it probably is several miles.

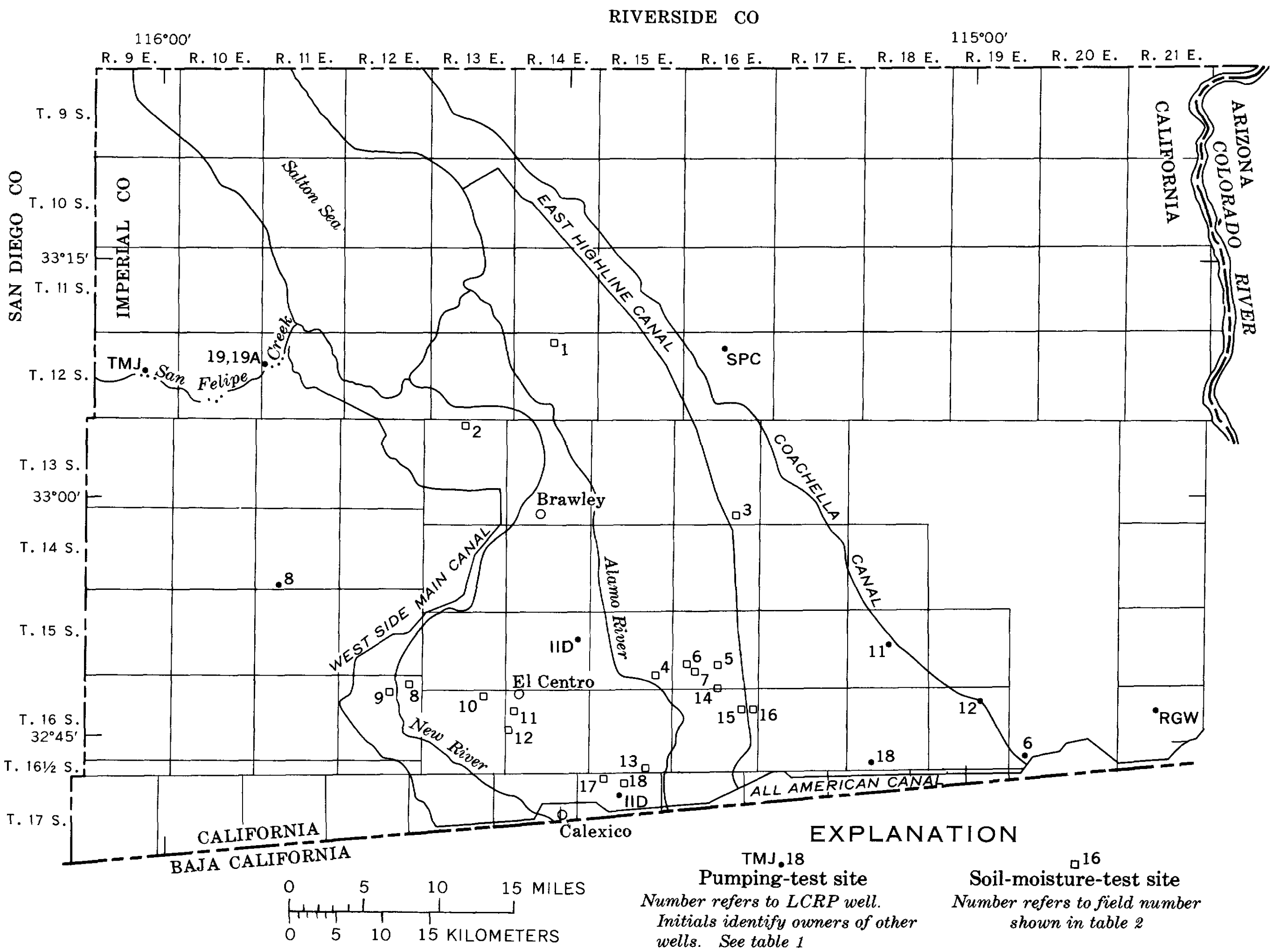

FIGURE 7. — Location of pumping-test and soil-moisture-test sites.

SOIL-MOISTURE STUDIES

The moisture content of soil profiles was determined at 18 sites in Imperial Valley (fig. 7). A neutron probe was lowered inside access holes of 1.62-inch ID steel tubing, generally driven to depths of about 16 feet below the land surface, and a counting rate was determined at 1-foot intervals. From the counting rate the moisture content of the material at a particular depth was determined on the basis of the relation shown in figure 8. This relation was inferred from specific relations between laboratory determinations of moisture content or porosity of samples and the respective counting rate obtained with the soil-moisture meter for the samples in the field; it is valid only for the conditions under which the data were obtained. Experiments during this study showed that the relation changes if different methods are used for installing the tubing or if other kinds and diameters of tubing are used. Figure 9 shows graphs of the counts per minute that were obtained with the soil-moisture meter at different depths below the land surface at several sites in the valley. In the zone of saturation — that is, below the water table — the rate generally is 7,000 to 8,000 counts per minute, which corresponds to a moisture content of 41 to 48 percent by volume of the material. The high counting rate sometimes persists for several feet above the water table, which indicates that the lower part of the capillary fringe is saturated or nearly saturated. At three of the sites the counting rate was 1,000 or less per minute for a part of the depth tested. The low counting rate is related to the slight moisture content of the material above the capillary fringe; 1,000 counts per minute corresponds to a moisture content of somewhat less than 5 percent.

The difference between the average moisture content of the saturated material and that of the material above the capillary fringe is an estimate of the quantity of water that will go into storage per unit volume of material as water levels rise in an area where the capillary fringe does not reach the land surface. Table 2 lists the moisture content below the water table and above the capillary fringe and the difference between these contents at each site where

TABLE 1. — *Results of pumping tests*

[Type of test: D, drawdown; R, recovery. All wells completed in Quaternary alluvium. LCRP, Lower Colorado River Project of U.S. Geol. Survey]

Well (fig. 7)	Owner or name	Date of test	Type of test	Interval tested (ft below land surface)	Yield (gpm)	Draw-down (ft)	Specific capacity in gpm per foot of drawdown	Transmissivity computed from tests (gpd per ft)	Conformance of test data to theoretical values	Reliability of computed transmissivity	Indicated average field hydraulic conductivity (gpd per sq ft)
Western Imperial Valley											
12S/ 9E-22A2	T. M. Jacobs	7-29-63	R	285- 667	1,450	14	100	290,000	Excellent	Good	760
12S/11E-18J1	LCRP 19	5-20-64	R	310- 650	150	4	38	100,000	Fair	Fair	300
18J2	LCRP 19A	5-20-64	R	35- 55	45	8.5	5	37,000	do	do	1,800
14S/11E-32R	LCRP 8	5-11-62	R	135- 165 218- 258 310- 354 390- 416 430- 560	250	13	19	130,000	Good	Good	480
Central Imperial Valley											
15S/14E-18C	Imperial Irrigation District.	5-9-58	R	140- 440	160	86	2	2,200	Good	Good	7
17S/15E-10N	do	5-16-58	R	110- 450	90	68	1.3	1,700	do	do	5
Eastern Imperial Valley											
12S/16E-9A	Southern Pacific Co.	7-9-63	R	150-1,000	975	43	23	62,000	Excellent	Good	73
		7-9-63	D	150-1,000	675	27	25	47,000	Good	do	55
15S/18E-15M	LCRP 11	5-10-63	R	309- 894	1,000	20	50	220,000	do	do	380
		5-10-63	D	309- 894	1,000	20	50	220,000	Excellent	do	380
16S/18E-32R	LCRP 18	6-29-64	R	140- 630	900	21	43	140,000	do	do	240
16S/19E-11D	LCRP 12	5-14-63	R	300- 610	990	24	41	240,000	Good	do	770
16S/20E-31K	LCRP 6	5-2-62	R	340- 410 510- 520	1,035	12	85	850,000	Excellent	do	10,000
		5-2-62	D	340- 410 510- 520	1,035	12	85	880,000	Good	do	10,000
16S/21E-16B	R. G. Winder	12-4-62	R	598- 806	1,550	36	43	[1]630,000	Poor	Poor	3,000
		12-4-62	D	598- 806	1,550	36	43	[1]590,000	do	do	2,800

[1]May be too high by a factor of 2.

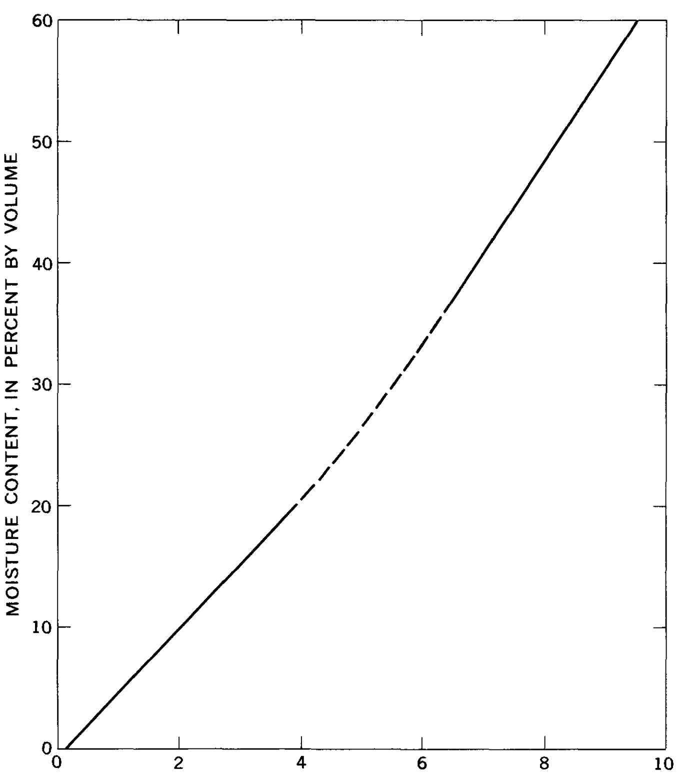

FIGURE 8. — Relation between counts per minute obtained with the soil-moisture meter and moisture content of the soil. The line is dashed where the relation was not determined for this study.

TABLE 2. — *Moisture content and storage capacity of alluvium*

[All quantities in percent by volume]

Field No. (fig. 7)	Location	Average moisture content: Below water table	Average moisture content: Above capillary fringe	Storage capacity
1	12S/14E-4K	44	----	----
2	13S/13E-3E	45	----	----
3	13S/16E-35M	----	2	----
4	15S/15E-35A	41	----	----
5	15S/16E-27D	45	4	41
6	15S/16E-29D	44	----	----
7	15S/16E-29Q	44	----	----
8	16S/12E-1M	44	----	----
9	16S/12E-11E	43	----	----
10	16S/13E-2H	45	----	----
11	16S/14E-7K	43	----	----
12	16S/14E-19D	46	----	----
13	16S/15E-35P	41	----	----
14	16S/16E-3D	41	----	----
15	16S/16E-12P	44	----	----
16	16S/16E-12Q	43	3	40
17	17S/15E-5J	43	8	35
18	17S/15E-10C	44	----	----
	Average	43	4	39

such determinations were possible; the average for each of the determinations is also given.

The average moisture contents for deposits in the Imperial Valley compare favorably with moisture contents for flood-plain deposits in the other valleys in the lower Colorado River area in which similar studies were made. For example, at 11 sites in Parker Valley, Ariz., the average moisture content was 45 percent in the zone of saturation and 6 percent in the zone above the capil-

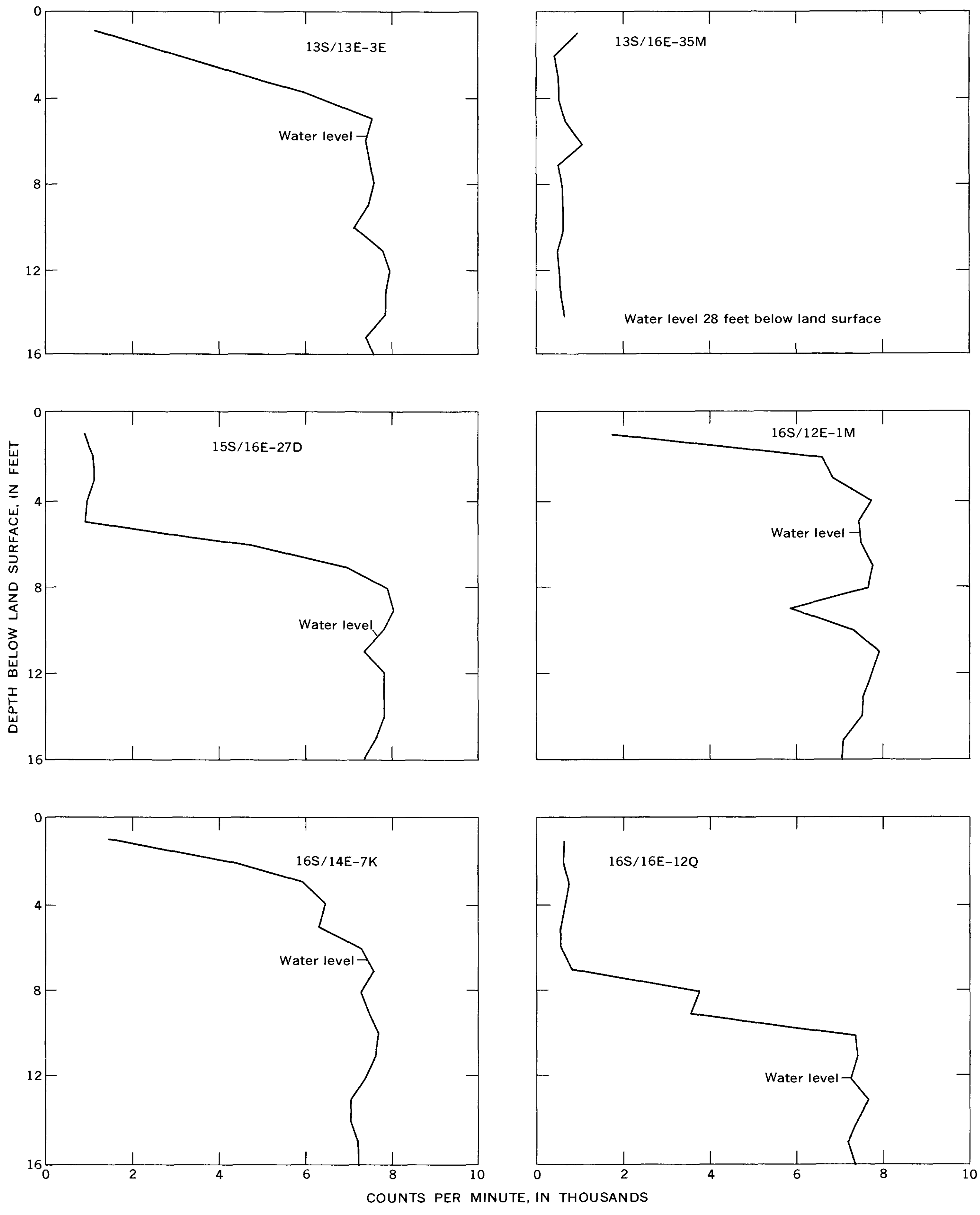

FIGURE 9. — Counts per minute obtained with the soil-moisture meter at different depths below the land surface at selected sites in Imperial Valley.

lary fringe, which indicates a storage capacity of 39 percent. In Palo Verde Valley, Calif., average values for 16 sites for corresponding zones were 44 and 12 percent, indicating a storage capacity of 32 percent (Metzger and others, 1973). In the South Gila Valley east of Yuma, Ariz., the indicated storage capacity was 37 percent, and in Yuma Valley, it was about 42 percent. In contrast, the indicated storage capacity of shallow deposits beneath the Yuma Mesa was only about 28 percent (Olmsted and others, 1973). The lesser capacity of the mesa deposits for storing water probably is due to the smaller percentage of fine-grained material they contain. The capacity of the shallow deposits of the East Mesa of Imperial Valley for storing water likewise may be less than the average of 39 percent determined for the material in the valley.

In summary, the soil-moisture studies indicate that in an area of rising water levels in fine-grained deposits outside of irrigated areas, the storage capacity is about 40 percent of the volume of the material in which the rise occurs. Beneath mesas and other areas where the deposits are not all fine-grained, the storage capacity may be more nearly 30 percent. Smaller quantities of water per unit volume than those indicated by the foregoing percentages can be expected to be released from storage as water levels decline, the quantities being dependent largely on the fineness of the material and the length of the drainage period. The storage capacities of materials beneath irrigated areas are likely to be less than beneath nonirrigated areas because of the incomplete gravity drainage of irrigation water in the profile above the capillary fringe.

SOURCES OF GROUND-WATER RECHARGE

The most important source of ground-water recharge in Imperial Valley is the Colorado River. Minor sources are underflow from tributary areas, precipitation, and local runoff.

COLORADO RIVER

The Colorado River has been recharging the ground-water reservoir of Imperial Valley since its delta was built sufficiently high to exclude the Gulf of California from the Salton Trough. However, the areas where the recharge has occurred have varied widely depending on whether the river was discharging to the Gulf of California or to the Salton Trough.

When the river was flowing to the Gulf of California, recharge in Imperial Valley was principally underflow from Mexicali Valley and underflow through the alluvial section between the Cargo Muchacho Mountains and Pilot Knob. When the river was flowing to the Salton Trough, a substantial amount of recharge also resulted from the infiltration of river water in the eastern part of the Imperial Valley.

IMPORTED WATER

Recharge to the shallow part of the ground-water reservoir, as it occurred under natural conditions, was increased by the importation of Colorado River water to the Imperial Valley for irrigation beginning in 1901. Development of an agricultural economy based on irrigation was interrupted occasionally, notably by the uncontrolled flooding of the valley by the Colorado River in 1905–7, when the present Salton Sea was formed. However, irrigation agriculture continued to expand until, in the latter part of the 1960's, more than 430,000 acres of cropland was being irrigated. Much of the additional recharge in the irrigated area is due to leakage from the numerous conveyance channels and to the application of irrigation water in excess of crop requirements, the latter practice being necessary to prevent an excessive accumulation of salts in the root zone.

The quantity of recharge resulting from the application of excess water is difficult to determine. However, it may be estimated by multiplying (1) the rate of water delivery (in acre-feet per year per acre) by (2) the irrigated acreage (in acres), by (3) a rule-of-thumb figure of 25 percent as the minimum amount of water, in excess of crop requirements, needed to prevent an excessive accumulation of salts. Because 430,000 acres is irrigated and consumptive use is about 4 acre-feet per year per irrigated acre (Hely, 1969, p. 33), the recharge is estimated to be more than 400,000 acre-feet per year. However, this recharge to the ground-water system is balanced largely by discharge from the system through an extensive drainage network, and therefore it does not greatly influence recharge to aquifers several hundred or more feet below the land surface.

LEAKAGE FROM CANALS

The completion of the All-American Canal, which permitted the diversion of Colorado River water to Imperial Valley by an all-American route rather than through Mexicali Valley by the Alamo Canal, greatly increased the opportunity for recharge to the ground-water system. In February 1942 the All-American Canal became the sole means for diverting Colorado River water to the Imperial Valley. Six years later the Coachella Canal was completed and thereafter supplied water to the lower part of Coachella Valley.

The canals are major sources of recharge because (1) they are unlined; (2) they are as much as 200 feet wide; (3) they flow across many miles of sandy terrain, especially in the eastern part of Imperial Valley; and (4) the water surface in the canals is much higher than the general ground-water levels along their alinement. In the Sand Hills area of the East Mesa the stage of the All-American Canal is about 80 feet above precanal ground-water levels; the difference between precanal levels and canal stage is similar at the head of the Coachella Canal and northward.

The rate of leakage of water from these canals cannot be determined precisely. However, the records of measured canal flows corrected for diversions and evaporation losses give a rough estimate of the rates of leakage. In 1948 the Imperial Irrigation District assumed responsibility for operation of the All-American Canal and the upper 50 miles of the Coachella Canal; since that time the canal flow, diversions, and evaporation losses have been recorded. Water losses in selected reaches of the All-American Canal and the upper end of the Coachella Canal, as compiled by the Imperial Irrigation District, are shown in figure 10.

Errors in measurement probably account for a large part of the annual variations in the leakage rates as indicated on the graphs (fig. 10). The plotted values are residual differences in canal flow in the reaches and, therefore, include the net effect of any errors in measurement. The annual flows in the upper end of the All-American Canal generally are 3 to 4 million acre-feet, and at the head of the Coachella Canal, they are about 0.5 million acre-feet. A small percentage of error in flow measurement, therefore, can account for much of the year-to-year variations in computed rates of leakage.

The total quantity of leakage from the All-American Canal between Pilot Knob and the East Highline Canal and from the Coachella Canal in the reach above the 6A check can be estimated as follows. The average annual rate of leakage from the All-American Canal from 1941, when the canal was first used for conveying large flows to Imperial Valley, to 1950 probably was about the same as the average annual rates for the first 3 years shown in figure 10. The rates were about, 90,000 acre-feet per year for the reach Pilot Knob to Drop 1 and about 130,000 acre-feet per year for the reach Drop 1 to East Highline Canal, or a total of about 220,000 acre-feet per year. From 1950 through 1967 (fig. 10), the leakage from the two reaches was about 140,000 acre-feet per year. Through 1967, therefore, the total leakage from the All-American Canal between Pilot Knob and East Highline Canal was nearly 4.5 million acre-feet. The leakage from the Coachella Canal in the reach above the 6A check averaged nearly 150,000 acre-feet per year; thus, from 1950, when the canal was first used to near capacity, through 1967, leakage amounted to about 2.7 million acre-feet. The ground-water recharge to the East Mesa as a result of leakage from these canals thus was about 7 million acre-feet through 1967.

The leakage caused ground-water ridges to form beneath the canals almost immediately, and in time, the tops of the ridges intercepted the canals. The leakage also spread horizontally, thereby causing water levels over large areas to rise many tens of feet. Eventually much of the recharge due to the leakage, especially from the All-American Canal, caused additional discharge to drains and areas of natural discharge, rather than continuing to add to the quantity of ground water stored in the system.

The rise in water levels that resulted from leakage from the canals between 1939, before the canals were completed, and 1960 is shown in figure 11. In 1960 the All-American Canal had been in operation for 18 years, and the Coachella Canal, for 12 years.

Along the All-American Canal the water-level rise generally was more than 40 feet, and along the Coachella Canal it was about 40 feet near the head of the canal and gradually increased northward to more than 70 feet (fig. 11). Throughout most of the length of the East Highline Canal the change in water levels was small.

UNDERFLOW FROM TRIBUTARY AREAS

Recharge to the ground-water reservoir by underflow from tributary areas is small compared with recharge that results from the importation of Colorado River water. The tributary areas that provide the major part of the underflow are the Mexicali Valley and the areas drained by Pinto and Coyote Washes and Carrizo and San Felipe Creeks (pl. 1). Of these, the two that contribute most of the recharge are the Mexicali Valley and the area drained by San Felipe Creek. Upper limits for the probable magnitude of the inflow can be estimated on the basis of the transmissivity of the deposits through which most of the flow occurs, the hydraulic gradient, and the width of sections. Most of the ground-water inflow from Mexicali Valley occurs through a section that extends westward from Calexico, Calif., to the mountains, a distance of about 12 miles (pl. 1). The average hydraulic gradient is about 5 feet per mile, and the transmissivity of the deposits through which most of the water moves, as estimated from well logs and pumping-test results, is about 100,000 gallons per day per foot. Multiplying these parameters of width, hydraulic gradient, and transmissivity results in a computed average annual flow of ground water across the section of about 7,000 acre-feet. A similar computation indicates that the underflow beneath San Felipe Creek is about 10,000 acre-feet per year. Underflow from the area drained by Coyote Wash is considerably smaller, and the underflow from areas drained by Pinto Wash is estimated to be hundreds rather than thousands of acre-feet per year.

PRECIPITATION AND RUNOFF

Direct infiltration of precipitation to the ground-water reservoir is a minor source of recharge. Only on the higher alluvial slopes of the mountains bordering the

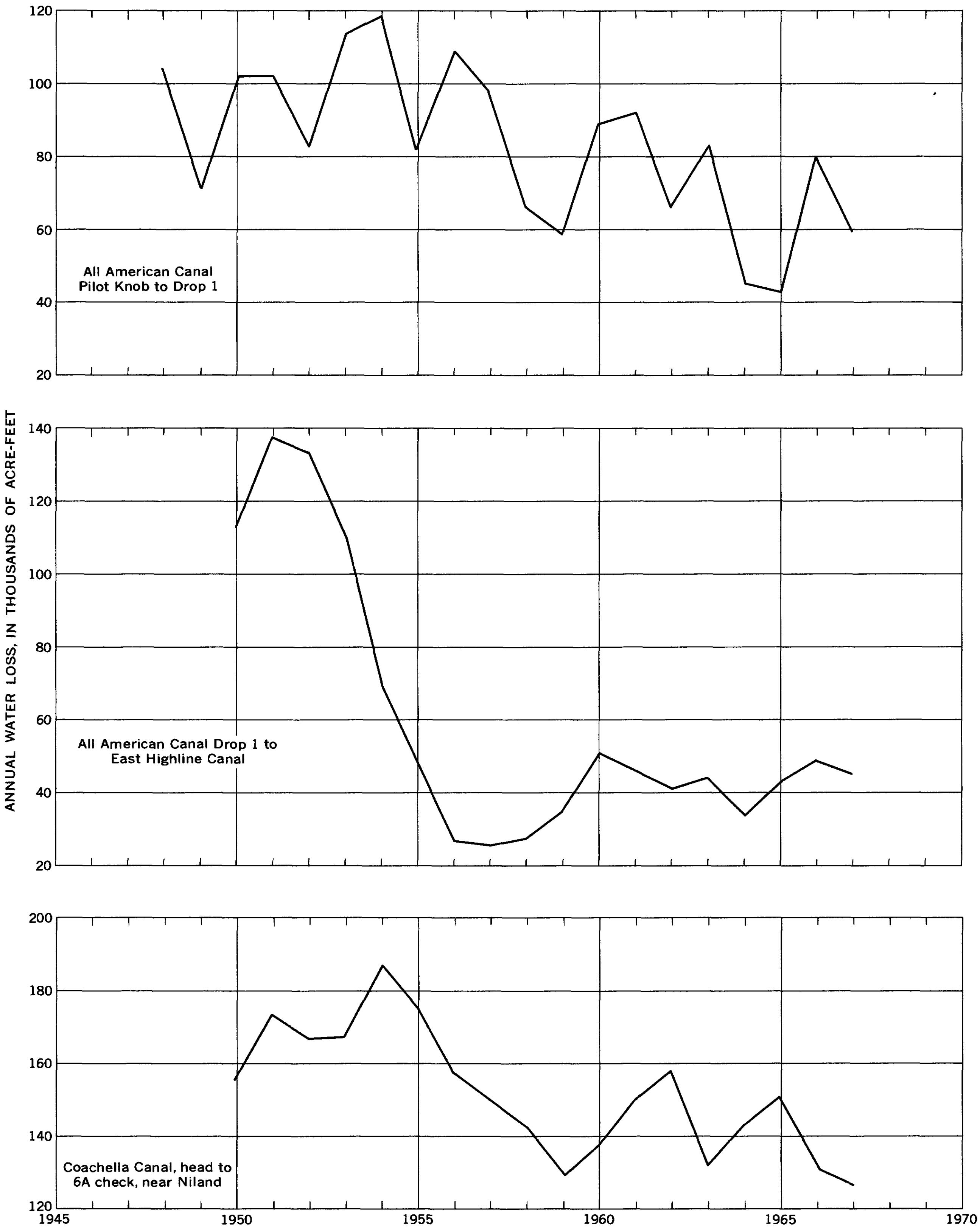

FIGURE 10. — Water losses in selected reaches of the All-American and Coachella Canals.

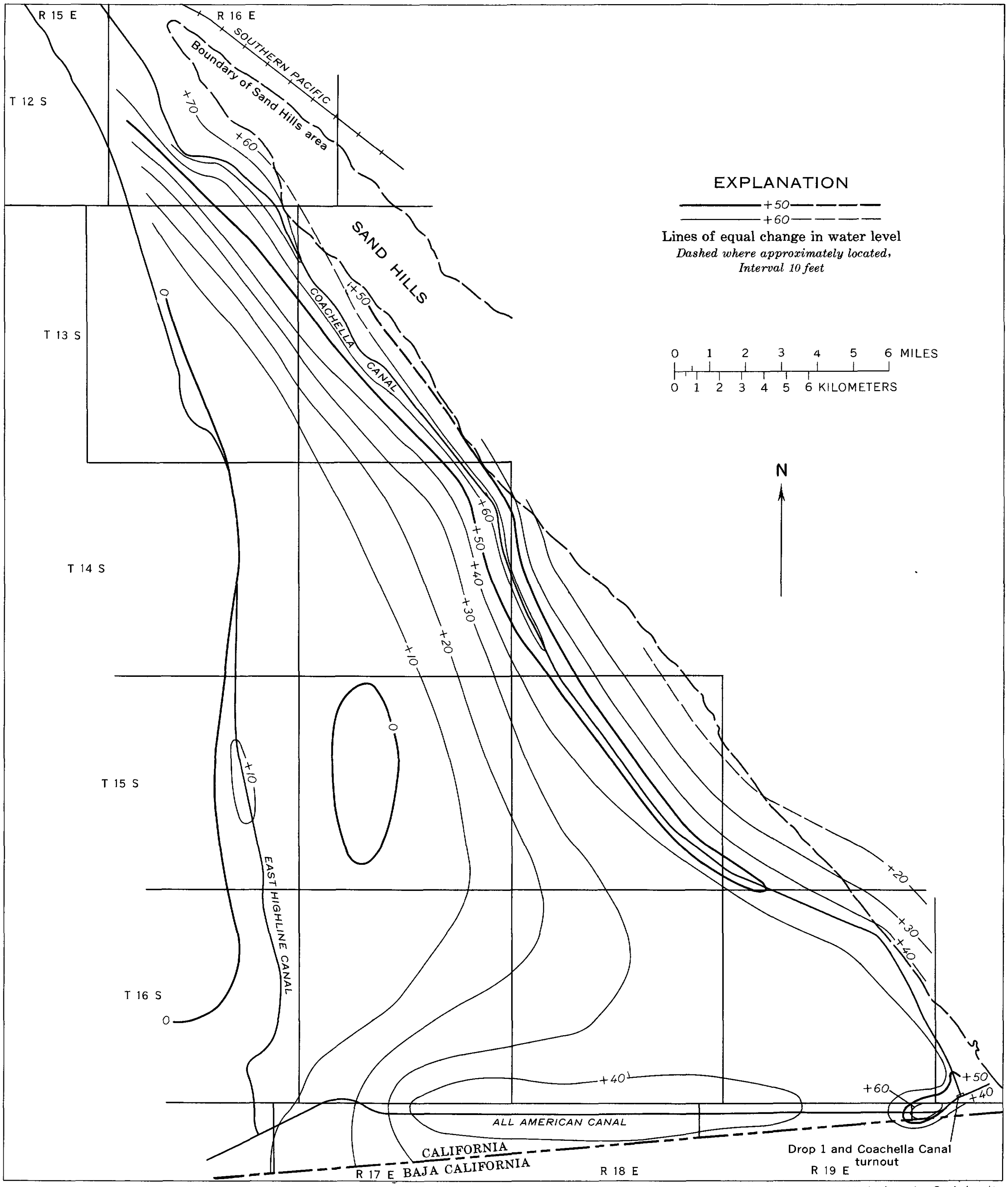

FIGURE 11. — Change in ground-water levels in East Mesa, 1939–60.

southwest side of Imperial Valley is the precipitation sufficient to provide recharge by direct infiltration.

Recharge also results from infiltration of runoff, mainly in washes and drainageways that discharge to the central part of the valley or to the Salton Sea. This recharge is estimated to average somewhat less than that from the tributary area of San Felipe Creek. Thus, the average annual recharge due to precipitation within the study area probably is somewhat less than 10,000 acre-feet.

MOVEMENT OF GROUND WATER

The general direction of movement of ground water can be inferred from the water-level contour lines on plate 1. In general, the direction of ground-water movement is at right angles, or normal, to the contour lines and toward the next lower contour line. The contours were drawn on the basis of all known water-level altitudes that, in the authors' judgment, provided useful information on the probable altitude of water levels in wells tapping the main water-bearing zones in 1965. Altitudes of water levels in wells that tap only water-bearing strata either above or below the main water-bearing zones, therefore, may differ from the altitudes indicated on plate 1. In some areas these differences may be as much as several tens of feet, but generally they are much smaller.

The broad ground-water mound that extends westward from Pilot Knob (pl. 1) is the result of leakage from the All-American and Coachella Canals. Between the canals the direction of movement is principally westward, but south of the All-American Canal the movement is southward toward Mexico.

The relatively wide spacing of the contours on the East Mesa is due to the high transmissivity in this region; immediately west of the East Mesa the transmissivity is much less.

Ground water generally moves toward the axis of the valley and thence northwestward toward the Salton Sea. The principal area of discharge is the central, cultivated part of the valley. Substantial amounts of ground water move toward the Alamo River, as shown by the convexity of the contour lines in the upstream direction of the river, especially north of Holtville. Ground water also moves toward the New River, but the configuration of the lines suggests that considerably less water moves toward the New River than toward the Alamo River. The hydraulic gradients of 2 to 5 feet per mile that are common near the New River upstream from the −80-foot contour line contrast markedly with the gradients of 10 to 15 feet per mile that are common along the Alamo River at corresponding water-level altitudes. Although the wider spacing of contour lines in the western part of the valley floor, which includes the New River area, might be interpreted as an indicated that the transmissivity beneath this area is higher than that beneath the eastern part of the valley floor, the wider spacing more likely is an indication that the rate of movement of ground water, and consequently the annual discharge, is less in this part of the valley floor than in the eastern part.

In addition to moving toward the Alamo and New Rivers, appreciable quantities of ground water move upward to the extensive system of drains in the irrigated area. Most of the movement in the irrigated area, however, is downward to the drains. The contours on plate 1 do not represent the altitude of the drain water.

A wide range of hydraulic gradients is indicated on plate 1 for the ground water that moves from the adjacent mountains and tributary areas toward the valley floor or the Salton Sea. However, adequate control for drawing the contour lines for most of the marginal areas is lacking, so explanations for the wide range of gradients that are shown are somwhat speculative. Steep gradients — 20 feet and more per mile — in areas where the rate of ground-water movement is known to be small indicate that the deposits are poorly permeable. Some of the seemingly abrupt changes in gradient are caused by the barrier effects of faults. The very steep gradients west of the Coachella Canal near Niland and northwestward undoubtedly result from substantial leakage from the canal into poorly permeable deposits.

DISCHARGE OF GROUND WATER

SPRINGS

Ground water is discharged by numerous small springs and seeps. On the northeast side of the Salton Sea they commonly are found in a zone that roughly parallels the San Andreas fault system, and many of them are downgradient from the Coachella Canal. The fact that many of the springs and seeps postdate the completion of the canal in 1948 indicates that the source of many of them and the reason for increased flows from some of the historic springs are seepage from the canal. Springs and seeps southwest of the Salton Sea are less numerous and generally have smaller flows than those northeast of the sea. The total discharge of springs and seeps, excluding the discharge due to seepage from the Coachella Canal, is estimated to be only a few thousand acre-feet per year.

WELLS

Wells discharge only a small part of the ground water in Imperial Valley. Although there are hundreds of wells (table 3) in the area, most of them are small domestic or stock wells. Much of the ground water they tap is confined and therefore has some artesian head. In some areas the head is sufficient to raise the water level above the land surface, and the wells flow. The principal area of flowing wells is in the eastern part of the valley, extending from about 2 miles north of the international boundary northward for about 30 miles in a 6- to 10-mile-wide belt between the Alamo River and the East Highline Canal (fig. 12). Most of the wells are 350 to 1,300 feet deep, casings are 2 to 3 inches in diameter, are either slot perforated or not perforated, and are open at the bottom in fine- to medium-grained sand (tables 3 and 4). Total dissolved-solids content of the water commonly ranges from 700 to 5,000 mg/l (milligrams per liter), and the percent sodium is more than 90. Only the better quality water is used for domestic and stock purposes. A few wells that yield hot water have been used to heat homes. The discharge from each of the several hundred wells in this area averages about 10 gallons per minute, so the annual discharge is only a few thousand acre-feet.

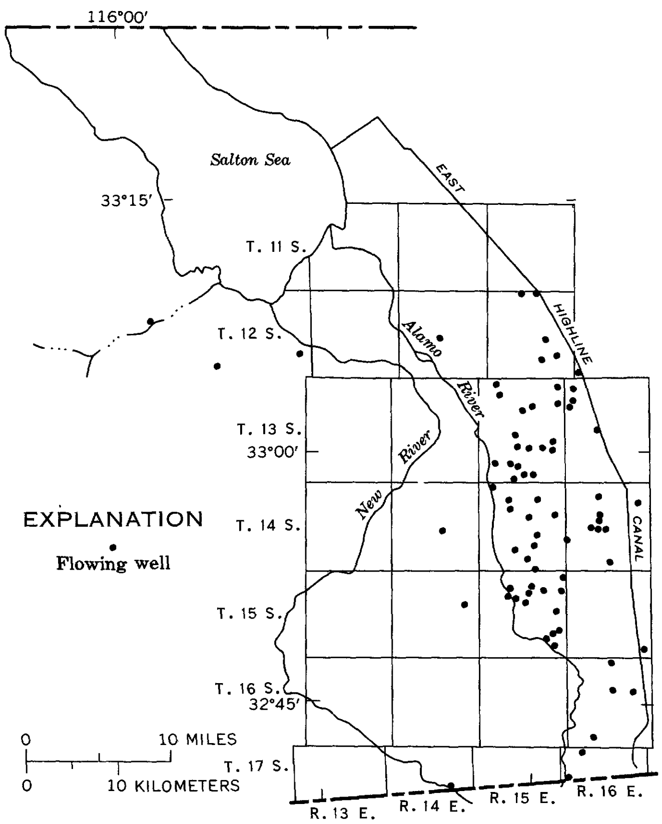

FIGURE 12. — Location of flowing wells, 1960–64.

Irrigation of crops by pumping from wells was attempted prior to 1915 (Hutchins, 1915); however, only a few wells were being used for this purpose in the 1960's — mainly to irrigate alfalfa in the lower Borrego Valley. On the northeast side of Imperial Valley, the Southern Pacific Co. drilled well 12S/16E–9A (table 3) in 1963 to provide a water supply for irrigating saltcedar windbreaks along its track. Well 16S/12E–16B, in the Pilot Knob area, was used for a few years in an attempt to irrigate citrus, but it was no longer being used at the time this study was completed.

A group of wells in the Ocotillo–Coyote Wells area in the southeastern part of T. 16 S., R. 9 E., has been developed for industrial supply at the gypsum-products plant at Plaster City; for local, private, and public supply; and for drinking water to be delivered to other communities in the area. Pumpage probably is only a few hundred acre-feet per year.

The Imperial Irrigation District uses wells 17S/18E–4A and 17S/17E–3C (table 3) to supply cooling water for the electrical turbine generators at drops 3 and 4, respectively, on the All-American Canal. A few wells have been drilled near the Hot Mineral Spa in sec. 2, T. 9 S., R. 12 E., in an effort to tap the source of the ground water that was discharging as springs and seeps under natural conditions. Some of the wells flow; the discharge of well 9S/12E–2A1 (table 3) reportedly was 900 gpm in September 1948.

In addition to the aforementioned wells, 15 deep wells have been drilled by private interests as part of the exploratory programs for assessing and developing the vast geothermal resources of the area. The drilling has been centered in the Buttes area southeast of the Salton Sea, although preliminary investigations indicate that the thermal area probably is much more widespread. The activities regarding development of this resource are beyond the scope of this study. Information on the geothermal resources of the area, their magnitude, and some of the problems that have arisen with their development are contained in California Department of Water Resources Bulletin 143-7 (1970), entitled "Geothermal Wastes and the Water Resources of the Salton Sea Area."

DRAINS, RIVERS, AND UPWARD LEAKAGE

Most of the ground-water discharge in Imperial Valley is by an extensive network of drains that serve the irrigated land. The network discharges about 1 million acre-feet per year of ground water and surface waste water, most of which previously had been diverted to cropland for irrigation. Some of the discharge, however, is water that has moved upward to the drains from the deeper aquifers, principally near the east edge of the irrigated area.

The water-level contours on plate 1 indicate upward leakage of water from the main ground-water body to the Alamo and New Rivers and in the vicinity of the Salton Sea. However, the amount of such leakage averages only a few tens of thousands of acre-feet per year.

CHEMICAL QUALITY OF THE GROUND WATER

The geographic and geologic controls that govern the occurrence, movement, and chemical quality of the ground water of the Salton Trough vary widely. The variability of the chemical quality of the water contained in the rocks is due to differences in location with respect to the water table and opportunities for recharge, to compositional differences in sources of rechage, and to the high evaporation rate in the hot arid climate.

Some of the deeper ground water may be moderately altered connate ocean water. At shallower depths, the water in the deltaic deposits probably consists of evaporation residuals of water from prehistoric Lake Cahuilla or earlier fresh-water lakes. Some of the residual water may be nearly fresh, and some, moderately saline. Locally, the ground water may have become somewhat saline because storm runoff has leached soluble evaporites from sedimentary rocks now above the water table. Some small lenses of fresh ground water may have resulted from impoundment of runoff from the ephemeral desert washes against sand dunes, as along the northeast margin of the Sand Hills.

In the following discussion, interpretations of chemical relations are based mainly on chemical analyses of water samples collected from wells. However, interpretations about physical conditions near some rotary-drilled wells are based on electric logs.

The chemical analyses specifically referred to are in table 5. The individual analyses are grouped according to specific geographic areas, and the order of analyses in the areas is by blocks according to township, range, and section. Each analysis is given an identifying number, and if it is one of two or more analyses for a particular well, it is also given an identifying letter. In the discussions, references to analyses are made by these identifying numbers and letters.

EASTERN IMPERIAL VALLEY

CHOCOLATE MOUNTAINS PIEDMONT SLOPE

Chemical analyses of water samples from 10 wells and one mine shaft on the Chocolate Mountains piedmont slope (table 5, analyses 1–11) indicate considerable differences in the quality of the ground water. Although the number of sites sampled is small relative to the area (more than 500 sq mi), the analyses suggest some generalizations associated with well location and depth. Water at higher altitudes appears to be less mineralized than water at lower altitudes. Also, water from deep wells apparently is generally more mineralized than water from shallow wells. Most of the shallow wells are dug wells, and most of them yielded usable water.

Calcium bicarbonate water containing less than 500 mg/l dissolved solids was obtained from two rather deep dug wells (table 5, analyses 1 and 11) that probably penetrate pockets of alluvium in hollows of the crystalline rocks of the mountains. Three shallow dug wells yielded water containing a mixture of calcium and sodium sulfates, lesser quantities of bicarbonate and chloride salts, and 849 to 1,080 mg/l dissolved solids (table 5, analyses 2–4). Water of this type commonly is produced from shaly sediments.

Water from the drilled wells, all of which are much deeper than the dug wells, contained a little less to substantially more dissolved solids than the most mineralized water from the dug wells. One drilled well about halfway down the piedmont slope yielded a sodium mixed-anion water containing 1,350 mg/l dissolved solids (table 5, analysis 6). Three other drilled wells farther down the slope yielded water containing 844 to 1,510 mg/l dissolved solids, predominantly sodium chloride; the extreme concentrations were different samples from the same well (table 5, analyses 8a and 8b). Two samples (table 5, analyses 5 and 9) were too highly mineralized for continued use as drinking water. One was from a mine shaft and may not be representative of ground water beneath the piedmont slope; the other sample was obtained many years ago from a well, now destroyed, that was used to supply water for a mine and probably was not used for drinking water.

PILOT KNOB MESA–SAND HILLS AREA

Water from wells in the Pilot Knob Mesa–Sand Hills area (table 5, analyses 12–28) has less areal range in quality than that from the Chocolate Mountains piedmont slope. However, samples were available from only two wells in the northwest end of the area; hence, the quality of water there is not well defined. Samples from a deep well (table 5, analyses 12a and b) drilled to supply water for a windbreak along the Southern Pacific Co. railroad were the most mineralized of any in the entire Pilot Knob Mesa–Sand Hills area. Although the chemical composition of the water was still changing after seceral hours of pumping, the analyses indicate that the water contains more than 2,000 mg/l dissolved solids and is a mixture of sodium chloride and bicarbonate and lesser quantities of other constituents. This type of water probably is suitable for growing salt-tolerant plants in permeable soils. A single water sample (table 5, analysis 13) obtained in 1917 during the drilling of a well for railroad use at Amos indicated that the water would have been satisfactory for domestic use. The well was not completed, however, because the yield was inadequate.

Water from the part of the Pilot Knob Mesa–Sand Hills area that is south and southeast of Ogilby contains less than 1,000 mg/l dissolved solids and is satisfactory for domestic use. Generally, bicarbonate or chloride is the principal anion, and sodium is the principal cation; however, water from several small-diameter wells augered by the U.S. Geological Survey near the All-

American Canal contained more sulfate than any other anion and resembled Colorado River water except for being somewhat softer. The quality presumably reflects leakage from the All-American Canal. Evidence of changes in chemical quality of ground water resulting from such leakage is the variation in the quality of water obtained from well 16S/20E-27D (table 5, analyses 17a–d). Analysis 17a shows that in 1941, before the utilization of the All-American Canal, the ground water was mixed-anion type; analysis 17b shows that by 1958 it resembled Colorado River water.

The only deep well in the southeastern part of the Pilot Knob Mesa–Sand Hills area yielded water having sodium and chloride as the principal ionic constituents (table 5, analysis 22). The water was used to irrigate alfalfa and citrus for 2 or 3 years, but apparently the soil was so permeable that pumping costs were excessive and irrigation was discontinued. According to reports, the chemical quality of the water was not a consideration in the cessation of irrigation. Several of the wells that were sampled have served as rural domestic supplies for 10 or more years.

EAST MESA

Part of the East Mesa probably has a greater potential for new ground-water development than any other part of the study area, because of the substantial recharge due to leakage from the All-American and Coachella Canals and the proximity of the Colorado River. Therefore, a determination of the quantity and chemical quality of ground water that might be developed on the East Mesa was given high priority during this study. Four deep test wells were drilled on the mesa as an aid in making this determination.

Chemical analyses of water from 51 wells on the East Mesa (table 5, analyses 29–79) show substantial differences in chemical characteristics. The dissolved-solids concentrations ranged from 498 to 7,280 mg/l. However, more than three-fourths of the samples contained less than 2,000 mg/l dissolved solids, so water containing less than this concentration can probably be obtained in a large part of the mesa.

During and after the construction of the All-American and Coachella Canals, the U.S. Bureau of Reclamation and the Imperial Irrigation District installed several hundred observation wells extending just below the original water table or to an average depth of about 50 feet to determine the effects of the canals on the water table beneath the mesa. The Geological Survey analyzed many water samples bailed from these wells during this study and also studied earlier analyses of water from some of the wells. Study of the analyses by plotting on maps and by comparing samples taken from the same well indicated that a large percentage of the analytical results were spurious. The spurious analyses may have resulted from insufficient pumping of the wells before sampling to remove water standing in and around the casings that possibly might have been differentially concentrated by evaporation, changed by microbial activity, or altered by reaction with the iron casings. Consequently, analyses of water from the shallow observation wells are not included in table 5, and the only generalization made about water in the top few feet of the aquifer is that it is variable in composition and may have chemical characteristics unlike the water a few tens of feet below the water table.

Twenty-nine of the 51 wells for which water analyses are shown in table 5 were small-diameter holes augered by the Geological Survey during the project investigation. Most of these wells were sampled by pumping them immediately after well points had been installed, generally at depths somewhat less than the total depth drilled; the several wells not sampled upon completion were later sampled by bailing. The analyses of the water from the augered wells did not exhibit the peculiarities of those from the network of shallow observation wells previously described, and they were in general agreement with analyses of water from nearby test and production wells. We concluded, therefore, that these samples are valid representations of the chemical quality of the ground water near the well-point settings. However, the conclusions based on these analyses probably would not be valid for depths substantially below the well points.

Water containing less than 1,000 mg/l dissolved solids (table 5, analyses 59–61 and 68–79) has been produced from all wells near the All-American Canal and U.S. Highway 80, both before and after the canal was constructed. However, the analytical data indicate that the water quality may have changed gradually as a result of infiltration of Colorado River water from the canal. Of the six samples (table 5, analyses 60, 61, 69, 72, 73a, and 73b) obtained from wells near the present location of the canal prior to its construction, five contained more chloride than sulfate. All but two samples obtained from wells in the same area since the canal was constructed contained more sulfate than chloride. Because the Colorado River water in the canal contains substantially more sulfate than chloride, the change in the chemical quality of the ground water is assumed to have resulted from infiltration of water from the canal.

Chemical analyses of water from the six test wells in the southeast quarter of the East Mesa indicate a rather large volume of ground water that is nearly as suitable for irrigation and other purposes as present Colorado River water, although ground water in at least part of the area has relatively more chloride and less sulfate than the river water. Some of the ground water may contain as much as two or three times the dissolved-solids content of the river water (800 mg/l).

The easternmost of the test wells, LCRP 6, was drilled for the Geological Survey near the head of the Coachella Canal. It was completed to a depth of 1,000 feet by the cable-tool method in April 1962 and was deepened to 2,519 feet by the rotary method in March 1964. Analyses of water samples obtained at numerous times during the drilling of the cable-tool section of the well indicated no great changes in chemical quality with depth. Water entered the well, as originally completed, through perforations at a depth of 340 to 520 feet below the land surface. Three samples of water (table 5, analyses 71a–c) entering the well through these perforations during different extended test periods showed that the chemical quality of the pumped water was not greatly different from that of recent Colorado River water and that it more nearly approached the composition of river water as pumping continued. The electric log indicated fresh water to the total depth (2,519 ft) of the rotary section of the well.

Information obtained from the Imperial Irrigation District's test wells 3 and 3a, which were drilled for the district in 1958 at its experimental farm 2, about 5 miles west of LCRP 6, gave the first indication of a substantial body of fresh ground water at depth in the East Mesa. Although the records concerning formations penetrated in drilling were obtained for both wells, chemical analyses of water were available for only one well. The two wells were drilled to depths of 275 and 500 feet, respectively, and were perforated from 40 to 240 feet and 69 to 273 feet, respectively. Evidently, development of the deeper materials was not considered feasible. The water from test well 3 (table 5, analyses 68a and b) was similar to Colorado River water except that the first analysis, 68a, indicated a large amount of fluoride. No plausible reason can be given for the 5 mg/l fluoride that was reported, as this was the only well water in the area having a large concentration of fluoride. The sample may have been contaminated, or the analysis may be in error. However, high fluoride concentrations also occur in ground water beneath the central Imperial Valley, so the reported concentration may represent some unusual local condition.

The area known to be underlain by ground water of good quality was extended 5 miles farther west on the basis of information obtained from well LCRP 18, drilled in May 1964 near drop 3 of the All-American Canal. The well was drilled by the rotary method to a depth of 815 feet, and an electric log was made. The well was then cased, perforated from 140 to 630 feet below the land surface, and pumped to determine aquifer characteristics. A water sample (table 5, analysis 59) obtained during the aquifer test contained 874 mg/l dissolved solids, 93 mg/l hardness, and approximately equal concentrations of bicarbonate, sulfate, and chloride. Obviously the water had not been greatly affected by infiltration from the nearby All-American Canal.

To determine whether fresh ground water, similar to that found in LCRP 6 in 1962, extends northwestward along the Coachella Canal, the Geological Survey in 1963 arranged for the drilling of two deep rotary test wells. The pilot hole for one well, LCRP 11, 13 miles northwest of LCRP 6, was drilled to a depth of 1,140 feet. Casing was installed to a depth of 900 feet, and selective perforations were made from 309 to 894 feet below the land surface. The electric log of the pilot hole indicated fresh water (specific conductance less than 3,000 micromhos) to a depth of 250 feet and brackish water throughout the rest of the saturated deposits penetrated. The chemical quality of the water produced from the well varied slightly after pumping began but became uniform at the end of three tests (table 5, analyses 45a–c). Water from this well contained considerably less bicarbonate and sulfate, more calcium and magnesium, and substantially more sodium and chloride than the water produced from LCRP 6 (table 5, analyses 71a–c). The data indicate that the pumped water contained no leakage from the Coachella Canal.

The pilot hole for another test well, LCRP 12, 5½ miles northwest of LCRP 6, was drilled to a depth of 1,000 feet. An electric log indicated fresh water throughout the depth drilled. The well was cased to 630 feet, gravel packed, and completed by perforating the casing from 300 to 610 feet. Water obtained from the well immediately upon completion of development (table 5, analysis 66a) contained slightly more dissolved solids, a little less sulfate, and about double the chloride that is characteristic of recent Colorado River water. A sample collected 8 months later (table 5, analysis 66b), however, contained water very similar to recent Colorado River water. The change in chemical composition indicates that leakage from the Coachella Canal had moved downward through the gravel pack surrounding the well and into the principal water-bearing zone.

After the Geological Survey completed its test-well drilling on the East Mesa, the U.S. Bureau of Reclamation investigated the area to determine if ground water might be recovered to augment surface-water supplies in the Imperial and Coachella Valleys. Using its own rotary drilling equipment, the Bureau drilled a 500-foot test hole north of the junction of U.S. Highway 80 and State Highway 98 about halfway between the All-American and Coachella Canals. The well was completed by inserting small-diameter pipes to four different depths and then by hydraulically isolating each pipe from the others. Water samples for chemical analysis were obtained by pumping from each of the pipes separately. The samples (table 5, analyses 57a–d) showed a small range in dissolved-solids content (708–929 mg/l) and small differences in anion ratios, possibly caused by the manner in which the samples were collected. However, all four samples indicate that the chemical quality of the water is good. We concluded, therefore, that the area of good-quality water extends across the southeast corner of the East Mesa.

Water samples from augered wells on both sides of the Coachella Canal but mainly west of the canal indicate that water of the same general composition as that from well LCRP 11 probably is present at depths of 50 to 150 feet or more in the area between the edge of the Sand Hills and a line within 2 or 3 miles of the main Lake Cahuilla shoreline that extends northward from the international boundary to a few miles north of the Brawley-Glamis highway. The dissolved-solids content of the water may increase westward and range from 1,000 to 3,000 mg/l.

An artesian well was drilled in 1961 to supply water for a proposed citrus project east of Holtville. Water from the well was sufficiently low in dissolved solids — 787 mg/l (table 5, analysis 41a) — to be satisfactory for the proposed use, but the percent sodium (96) was too high, and the project was abandoned.

About 10 miles farther north an unused 2-inch artesian well has flowed uncontrolled for many years. Two analyses of water from this well (table 5, analyses 36a and b) indicate that the water may be somewhat different in origin from that yielded by the artesian well east of Holtville. The dissolved-solids content (1,190 mg/l) is higher and consists of relatively more sodium chloride and less sodium bicarbonate.

About 6 miles farther northeast a cable-tool test well was drilled for the Imperial Irrigation District to a depth of 329 feet. The well flowed when completed in 1958 but was capped and not used. Water from the well (table 5, analysis 30) contained 1,660 mg/l dissolved solids, mainly sodium chloride, and 2.3 mg/l boron. On the basis of this analysis, the water was deemed unfit for irrigation.

Water samples from the augered wells within a mile or two of the west edge of the East Mesa (table 5, analyses 31, 38–40, and 51) indicate that the chemical quality of the shallow water is not uniform and that the water is generally more mineralized and contains more sulfate than water from artesian wells. The difference in chemical quality suggests that water from the augered wells probably is separated from the artesian water by a confining bed or beds and that it is at least partly derived from seepage from the East Main Canal.

The East Mesa narrows northwestward to the limiting boundary of the Sand Hills near Mammoth Wash, where it becomes difficult to define. However, for discussion, it is arbitrarily extended northwestward to include the areas where the land-surface altitudes are 30 to 160 feet above mean sea level. Two analyses of water samples (table 5, analyses 29a and b) from a private well in this northern extension of East Mesa indicate that the local ground water contains more dissolved solids (2,190 mg/l) than most ground water in the southeastern part of the mesa. The well, drilled to a total depth of 550 feet, was perforated only from 25 to 150 feet below the land surface. The rather high ratio of sulfate to chloride suggests that the water, in part, may have been seepage from the nearby Coachella Canal.

CENTRAL IMPERIAL VALLEY

Deep exploration holes drilled to find oil or water have shown that most of the central Imperial Valley is underlain by great thicknesses of water-saturated lacustrine and playa deposits overlying older sediments. Studies elsewhere have shown that such deposits generally have low vertical permeability and that water from them may be moderately to highly mineralized in some zones and fresh in others. Thus, the shallow ground water (water immediately below the root zone of plants) may be saline, and the deeper water, which is separated from the shallow water by a layer of poorly permeable material, may be fresh.

Many years ago widespread waterlogging developed as a result of repeated irrigation whose only drainage was slow seepage to the Alamo and New Rivers. Evaporation from the waterlogged areas increased the salinity of both the soil and the shallow ground water. Later, networks of ditch and tile drains extending throughout the cultivated area were constructed. Waterlogging is now virtually ended, and unconfined ground-water levels have been stabilized at depths between 5 and 20 feet below the land surface. However, white saline crusts still persist in uncultivated fields and along river, canal, and drain banks, indicating that the shallow ground water is still rather saline in most of the areas that formerly were waterlogged.

Although the extent to which usable ground water occurs in the central Imperial Valley is unknown, the occurrence of such water certainly must be limited. Early attempts to construct wells to supply municipal water at Brawley and El Centro were failures. The only successful large-capacity wells drilled in the area are two drain wells adjacent to major canals. Many small artesian wells have supplied domestic water in an area east of the Alamo River extending from about 6 miles south of Holtville to several miles northeast of Calipatria. Old records indicate that wells west of the Alamo River are not likely to flow and that they have water of very poor chemical quality.

Chemical analyses of water from 115 wells in the central Imperial Valley are shown in table 5. There are 86 privately owned artesian wells, 22 observation wells augered by the Geological Survey, 4 test and 2 drainage wells owned by the Imperial Irrigation District, and 1 test well drilled for the Geological Survey. Because all the artesian wells and several other wells are east of the Alamo River, the analytical data are greatly biased toward the eastern part of the area.

Although the artesian water has a rather large range of dissolved-solids content, it includes only a small number of different compositional types. The dissolved-solids content of the artesian water ranged from 663 to 5,710 mg/l, but most of the concentrations ranged from 1,000 to 2,000 mg/l. Salts dissolved in the artesian water are mainly mixtures of sodium chloride and sodium bicarbonate, but the water from a few wells contains considerable sodium sulfate.

Generally, the least concentrated artesian waters contain bicarbonate as the dominant anion or contain equal or nearly equal amounts of bicarbonate and chloride. As the dissolved-solids content increases, the bicarbonate content tends to become less than the chloride content until, in the most concentrated artesian water, the chloride content is several times larger than the bicarbonate content.

The sulfate content of water samples from a large number of the artesian wells is less than 100 mg/l; one sample contained no sulfate. Sulfate contents greater than 100 mg/l generally are associated with high chloride contents. However, the water that contained 5,710 mg/l dissolved solids (table 5, analysis 110) contained 2,200 mg/l sulfate and only 1,360 mg/l chloride.

Several characteristics make the artesian water rather undesirable for various uses. Most of the samples analyzed for fluoride content contained more than 0.8 mg/l recommended as the upper limit for drinking water in hot climates, and many contained more than the 1.7 mg/l recommended as the upper limit for cool climates (U.S. Public Health Service, 1962). All the samples contained more than 80 percent sodium, and most contained more than 90 percent. Because of these high percents sodium, the artesian water probably would be hazardous for continued irrigation. Boron concentrations were moderately high (0.67–2.50 mg/l) for most of the samples analyzed for that constituent. However, in several analyses the boron content was greater than the upper limit (3.75 mg/l) considered acceptable for any crop.

Analyses of successive water samples from the same wells taken over a long period of time showed, for the most part, only small changes in the chemical quality of the water, such as might result from analytical errors or differences in analytical procedures. However, the analyses of samples from one well (table 5, analyses 134a–e) showed a considerable reduction in both chloride and dissolved solids that may indicate a real reduction in the mineral content of the water yielded by the well.

Areal differences in the chemical quality of the artesian water were studied by plotting diagrams prepared from the chemical-analysis data at points on topographic maps corresponding to well locations. The diagrams suggested some generalizations of chemical patterns, but the generalizations were far from conclusive. Apparently, the water from artesian wells near the East Highline Canal contains less dissolved solids and more bicarbonate than water from wells farther west. Also, the highest dissolved-solids contents were found mainly in water from wells within a few miles of the Alamo River. However, exceptions to both patterns indicate that there may be zones yielding fair to poor water between other zones yielding better water.

With but two exceptions, both of which were flowing wells, the augered wells yielded water from below the root zone of plants and above the uppermost zone likely to yield artesian water. The chemical analyses of the water samples from the 20 nonflowing augered wells indicate that the prospects for obtaining water acceptable for domestic use at depths of less than 150 feet are poor. Only three water samples from nonflowing augered wells contained less than 2,000 mg/l dissolved solids, whereas 11 samples contained more than 9,000 mg/l dissolved solids. The chemical characteristics of the water from these wells were quite variable, but generally the bicarbonate content was less than the sulfate content, and the sulfate content was less than the chloride content. Although sodium was the principal cation in almost all the samples from these wells, the water contained enough calcium and magnesium to produce several hundred milligrams per liter noncarbonate hardness. Thus, the upper water can be differentiated from the deeper artesian water, because the latter generally contained much more bicarbonate than sulfate, rather low concentrations of calcium and magnesium, and moderately low to zero noncarbonate hardness.

East of the Alamo River two augered wells penetrated artesian water under sufficient head to cause the wells to flow. A water sample from one well (table 5, analysis 83) had the highest specific conductance and the highest chloride content of any water sampled in the central Imperial Valley during this study. The water from the other well (table 5, analysis 122) was very similar to water from nearby privately owned flowing wells.

Analyses of water from the five test wells in the central Imperial Valley support the generalizations based on the analyses of samples from the artesian and augered wells. A well drilled east of Calexico in 1958 for the Imperial Irrigation District was perforated between the depths of 110 and 450 feet and yielded water contained 5,610 mg/l dissolved solids (table 5, analysis 192), most of which were a mixture of sodium chloride and sodium sulfate. A 1,000-foot well at the west edge of Calexico, drilled for the Geological Survey in 1962, yielded from strata below a packer set at 260 feet water containing 4,920 mg/l dissolved solids (table 5, analysis 191), principally sodium salts, and the ratio of chloride to sulfate was higher than that for the water from the well east of Calexico.

Farther north, at Imperial, a 500-foot test well that was drilled for the Imperial Irrigation District in 1958 yielded only a small quantity of water. The dissolved-solids content, most of which was sodium chloride, exceeded 10,000 mg/l (table 5, analyses 149a and b).

Two of the Imperial Irrigation District test wells drilled in 1958 penetrated artesian strata. One well, 603 feet deep, near the East Highline Canal southeast of Holtville, was perforated in three zones: 590 to 432 feet, 400 to 320 feet, and 234 to 46 feet below the land surface. Samples of water bailed from each of the two lower zones were of similar chemical composition (table 5, analyses 187a and b); each sample contained about 1,000 mg/l dissolved solids of mixed sodium salts and was very much like water produced from several nearby privately owned artesian wells. Water bailed from the upper perforated zone (table 5, analyses 187c and d) was much more highly mineralized; the samples contained 5,750 and 6,890 mg/l dissolved solids, respectively, consisting mainly of sodium sulfate and sodium chloride but also including considerable quantities of calcium and magnesium salts Water (table 5, analyses 171a–c) from the second artesian test well, about 3 miles northeast of Holtville, also was different in chemical composition, depending on the zone from which the water was obtained.

Analyses (182 and 188, table 5) of water from two rather shallow drain wells on opposite sides of the central Imperial Valley suggest the possibility that careful exploration might disclose sites near major canals where ground water of good quality can be obtained from shallow permeable zones. Both wells were drilled in 1947 and were pumped for several years but were not in use when visited in 1962..The chemical quality of the water from the wells was very similar to that of Colorado River water.

WESTERN IMPERIAL VALLEY

Much of the area of the western Imperial Valley is referred to locally as the West Mesa. In this study, however, the term "West Mesa" is restricted to a smaller area, considered suitable for irrigation, that is immediately west of the Westside Main Canal. Major subdivisions of the western Imperial Valley are the lower Borrego Valley, the San Felipe Creek–Superstition Hills area, the Coyote Valley, and the West Mesa and Yuha Desert.

LOWER BORREGO VALLEY

The lower Borrego Valley, which has also been referred to as the Ocotillo Valley, extends north and northwest of the Fish Creek Mountains. The valley is mostly barren desert, but it contains scattered areas where ground water is pumped for irrigation; and old maps show numerous wells, many of which no longer exist. Most of the irrigation is in San Diego County. Water samples (table 5, analyses 195–198) were collected from four wells in San Diego County, although several times this number of wells may be in use. The chemical analyses indicate that the ground water is satisfactory for irrigating most crops grown in the Imperial Valley. One of the wells, used for domestic supply, yielded water of substantially better quality (table 5, analysis 196) than that obtained from the other three. Water from three irrigation wells (table 5, analyses 199–201) in the Imperial County part of the valley was more highly mineralized than the water from the irrigated area in San Diego County.

Although chemical characteristics of water from the wells sampled in the lower Borrego Valley differed from well to well, without exception, sodium was the dominant cation, and bicarbonate was less abundant than sulfate or chloride. The analyses also indicate that the dissolved-solids content of the ground water increases eastward.

SAN FELIPE CREEK–SUPERSTITION HILLS AREA

The San Felipe Creek–Superstition Hills area, north of Superstition Mountain and between the central Imperial Valley and the lower Borrego Valley, is a somewhat dissected part of the western Imperial Valley surrounding the Superstition Hills. The surface drainage is mostly to San Felipe Creek and thence to the Salton Sea, but some washes flow directly into the sea. A part of the area is flat enough to be cultivated, and sufficient wells are indicated on old maps to suggest that attempts have been made to develop ground water. The lack of other evidence of development suggests that satisfactory ground-water supplies were not found.

Three water samples (table 5, analyses 202a–c) collected from Harper's Well in 1918, 1949, and 1962, respectively, were of a nearly uniform mixed sodium chloride sulfate type that could be used for drinking water but that probably contained too much sodium for irrigating clay soils. The water from nearby Harper's Spring, sampled in 1949 (table 5, analysis 203), was somewhat more mineralized, but this may be partly the result of evapotranspiration of water seeping from Harper's Well.

Another old well yielded moderately saline water containing 3,920 and 4,520 mg/l dissolved solids when sampled in 1949 and 1962, respectively (table 5, analyses 204a and b). Sodium chloride was the principal salt, and the sulfate ion concentration was low. Water from this well ordinarily would not be considered satisfactory for drinking by humans except in an emergency, although it probably could be drunk by animals.

To determine whether substantial quantities of usable water could be obtained nearer the Salton Sea, the Geological Survey in 1964 contracted for the drilling of a deep rotary test well, LCRP 19, near the intersection of

California State Highway 78 and U.S. Highway 99, and a short distance from the channel of San Felipe Creek. The well was drilled to a depth of 958 feet; the casing was perforated from 310 to 650 feet below the land surface. When completed, the well flowed about 200 gpm. Water from the well (table 5, analyses 205a and b) contained slightly more than 1,400 mg/l dissolved solids, mostly sodium salts; chloride was the principal anion, although considerable sulfate also was present. Boron content was 2.0 and 2.6 mg/l, respectively, in the two water samples. Water from this well, therefore, might be satisfactory for domestic use, whereas it might not be satisfactory for irrigation.

A shallow test well was also drilled at the same site, and the casing was perforated from 35 to 55 feet below the land surface. The water (table 5, analysis 206) from the well contained 8,420 mg/l dissolved solids consisting of a mixture of sodium chloride and sodium sulfate and slight amounts of other salts. At this locality the shallow water and the deep artesian water evidently are separated by very poorly permeable deposits.

Springs formerly were used regularly as watering places in the Colorado Desert, but they have been used much less since the automobile replaced the horse as a means of travel. Thus, the apparent large increase in the dissolved-solids content of two water samples (table 5, analyses 207a and b) taken in 1917 and 1962, respectively, from Kane Spring may be more the result of differences in the way the area around the spring was maintained at the times of sampling than of real changes in water quality. If so, the much higher concentration (5,270 mg/l) represents a change because of greater evapotranspiration at the spring; cleaning the springs might result in a return to the 1917 quality. However, water of even this lower concentration (2,090 mg/l) would not be considered very satisfactory by most travelers today.

COYOTE VALLEY

Coyote Valley is the only area in the western Imperial Valley south of San Felipe Creek where development of ground water has been significant. The area extends from a boundary west of Ocotillo to a boundary east of the former railroad station at Coyote Wells. A few dozen wells scattered over several sections of land supply domestic and municipal water that is used both locally and at Plaster City, about 10 miles northeast. Water from wells near Ocotillo is hauled in tank trucks to Mexicali, where it is sold for drinking water.

Most of the wells in Coyote Valley yield soft bicarbonate water containing less than 400 mg/l dissolved solids (table 5, analyses 208–216 and 220b). Limited data indicate that most of the wells are screened or perforated between depths of 100 and 500 feet. Dissolved-solids content of the water is higher, and the depth of perforations in the casings of wells is shallower, toward the east end of the productive area. The principal undesirable characteristic of the water is the high concentration of fluoride. About half of the water samples whose fluoride concentrations were determined contained at least 2.0 mg/l fluoride, and several samples contained more than 3.0 mg/l.

WEST MESA AND YUHA DESERT

The large, nearly barren area east of the Coyote Valley development and between the international boundary and Superstition Mountain is designated as the West Mesa for that part north of U.S. Highway 80 and as the Yuha Desert for that part south of the highway. Irrigation from wells was attempted on the West Mesa prior to 1915 (Hutchins, 1915), but apparently the undertaking was a failure. No information is now available as to the quantity or quality of the water that was developed. To obtain information concerning the availability and chemical quality of the ground water in the West Mesa, the Geological Survey contracted for a deep rotary test well, LCRP 8, at a site about 7 miles north of Plaster City. The well was drilled to a depth of 985 feet and was completed by perforating the casing from 135 to 560 feet. Two water samples (table 5, analyses 221a and b) obtained when the well was being tested differed slightly in mineral content. If the well had been fully developed as a production well, the water would have contained about 2,000 mg/l dissolved solids, with sodium sulfate the dominant mineral salt. The water probably would be satisfactory for irrigating salt-tolerant crops.

During its 1958 test-drilling program, the Imperial Irrigation District drilled one well about a mile north of Dixieland and about half a mile west of the district's Westside Main Canal. A water sample from this well (table 5, analysis 224) contained 2,620 mg/l dissolved solids, mainly sodium chloride and sodium sulfate salts. The water was not considered satisfactory for irrigation because of the availability of canal water of better quality. However, water having a chemical composition similar to that of the well water has been used for irrigation in other areas of the Colorado River basin.

As a part of its exploratory program the Geological Survey drilled two wells with a power auger near the east edge of the West Mesa. The permeability of the materials penetrated appeared to be low, and the chemical quality of the water (table 5, analyses 222 and 223) was poor (5,210 and 4,680 mg/l dissolved solids, respectively). The prospects for obtaining much usable water in this area also appear to be poor.

Small quantities of good-quality ground water may be present in the west edge of the Yuna Desert, but information on chemical quality is sparse and undependable. A water sample (table 5, analysis 232) taken from an oil test hole about 5 miles southeast of Ocotillo contained 721 mg/l dissolved solids, which consisted mainly of a mixture of sodium salts; chloride was the principal anion. Water samples (table 5, analyses 228a and b) reported to have been obtained in 1952 and 1958 from an oil test hole that was finished as a water well contained 493 and 568 mg/l dissolved solids, respectively. When the site was visited in 1962, the well was not found, but two water samples (table 5, analyses 229 and 230) taken from nearby shallow dug wells contained 13,000 and 2,630 mg/l dissolved solids, respectively. The much higher concentrations in the water from the shallow dug wells suggest that better water might be obtained at greater depths. A water sample (table 5, analysis 233) from an auger hole drilled by the Geological Survey where Pinto Wash crosses State Highway 98 contained 2,770 mg/l dissolved solids.

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BASIC DATA

TABLE 3. — *Records of selected wells and springs*

Well location: See text section entitled "Well-Numbering System" for explanation.
Owner or name: LCRP, Lower Colorado River Project (U.S. Geol. Survey).
Altitude of land surface: Approximate altitude above (+) or below (−) mean sea level.
Depth of well: Greatest depth to which well was drilled; well may have been completed or tested at a shallower depth. M, measured depth; all others reported.
Type of well: D, dug; C, drilled by cable-tool method; R, drilled by rotary method; A, augered; G, gravel packed (if known or reported).
Water level: F, flowing artesian, static level unknown; R, reported.
Type of pump and power: T, turbine; S, submersible; J, jet; P, pitcher; N, none; E, electric; G gasoline.
Use of well: Irr., irrigation; Ind., industrial or mining; PS, public supply; Dom., domestic; S stock; T, deep test hole; O, shallow observation well; U, unused; Des., destroyed or filled in above the water table.
Discharge: E, estimated; R, reported.
Other data available: Data in files of U.S. Geol. Survey. D, driller's log; E, electric log; G, gamma-ray log; T, temperature log; P, pumping-test data; W, hydrograph or periodic water-level measurements; C, chemical analysis of water.]

Well location (pl. 1)	Owner or name	Year completed	Altitude of land surface (ft)	Depth of well (ft)	Type of well	Diameter (in.)	Perforated interval (ft)	Water level: Feet above (+) or below (−) land surface	Water level: Date measured (month, yr)	Pump and power	Use of well	Discharge (gpm)	Other data available
Western Imperial Valley													
9S/ 9E-16D	Coolidge Springs	----	−185	300	----	6	----	F	9-62	N	U	----	C
23L		----	−228	----	----	2½	----	F	9-62	N	Dom.	----	C
9S/11E-4J	Southern Pacific Co.	1902	−190	1,261	R	----	----	----	----	----	T, Des.	----	D
9S/12E-2A1	Hot Mineral Spa	1938	−90	309	----	10	252- 309	F	8-62	N	Dom.	900(R)	C
2A2	Noxon Construction Co.	1962	−90	325	R	16	----	F	8-62	N	U	----	D, C
22A	W. Newell	1961	−200	585	R	----	----	----	----	----	T, Des.	----	D
10S/ 9E-35N	Salton City	1958	+30	1,980	R	8	1,370-1,980	F	9-62	N	U	5(E)	D, E, C
36P1	do	1958	−45	635	R	10	240- 635	−6.8	9-62	N	U	110(R)	D, T, C
36P2	do	1959	−50	790	R, G	10	220- 616	−11.0	9-62	N	U	400(R)	D, E, C
10S/10E-9N	do	1958	−180	3,030	R	----	----	----	----	----	T, Des.	----	E
19K	do	1961	−80	1,002	R, G	14	100- 400	−34.6	9-62	N	T	850(R)	D
11S/10E-35N	K. D. G. Enterprises	1960	+50	809	R	----	----	−181(R)	1960	----	T, Des.	12(R)	D
12S/ 8E-6P	Magill	1952	+410	293	R, G	10	----	−179	1954	----	Dom.	----	C
8K	Kenck	----	+295	----	----	7	----	−239	1953	J	Dom.	---	C
9H	J. B. Craig	1952	+185	174	R, G	6	100- 174	−128	1952	----	Dom.	----	D
10N	J. Sundquist	1950	+125	222	C	12	----	−117	1950	T	Dom.	----	C
22E	J. M. Cornish	1929	+120	226	C	16	----	−100.8	2-54	T, E	Dom.	----	C
12S/ 9E-22A1	T. M. Jacobs	1953	−13	445	R	6	312- 412	----	----	T, E	Dom.	----	D, C
22A2	do	1961	−12	667	R	24	285- 667	−91	7-63	T, E	Irr.	1,450	D, E, P, C
23D	do	1953	−15	628	----	12	250- 580	−65.8	2-54	T, E	Irr.	1,400(R)	C
12S/10E-26M	Harper's Well	----	−115	320	----	8	----	−3.4	9-62	N	U	----	C
34G	Mesquite Drill Hole	----	−95	26(M)	----	10	----	−21.6	9-62	N	U	----	C
12S/11E-18J1	LCRP 19	1964	−175	958	R, G	10	310- 650	+5.8	7-64	----	T	200	D, E, G, T, P, C
18J2	LCRP 19A	1964	−175	55	R, G	10	35- 55	−11.3	7-64	N	T	45	D, P, C
36K	G. Mellon	1959	−130	503	R	6	352- 422	F	1959	----	U	----	D
14S/10E-25G1	Purple Flower N	----	+84	126	C	12	----	−112.4	4-49	----	----	----	
				110(M)	----	----	----	Dry	11-60	N	Des.	----	
25G2	Purple Flower S	----	+84	----	C	10	----	−115	4-49	----	----	----	
				100(M)	----	----	----	Dry	1962	N	Des.	----	
25R	Hudson	1913	+92	248	----	----	----	−124	4-49	----	----	----	
				110(M)	----	----	----	Dry	1962	N	Des.	----	
14S/11E-32R	LCRP 8	1962	+88	985(M)	R, G	8	135- 560	−120.8	1962	N	T	250	D, E, P, W, C
14S/12E-25D	U.S. Geol. Survey	1964	+10	157(M)	A	1¼	122- 124	−67.5	4-64	N	O	----	D
15S/11E-13K	do	1964	0	100(M)	A	1¼	93- 95	−41.8	4-64	N	O	----	D, C
32R	do	1964	+65	152(M)	A	1¼	138- 140	−101	3-64	----	O	----	D, C
16S/ 9E-25K	Clifford Realty Co.	1958	+360	256	----	10	90- 247	−84(R	1958	T, E	PS	----	D, C
26H	G. N. Root	1930	+430	410	----	10	----	−150(R)	1960	T, E	Dom.	----	C
35M	A. Miller	1962	+610	535	----	8	415- 495	−321(R)	1962	S, E	Dom.	15(R)	D, C
36C1	B. C. Weaver	----	+382	157	----	10	----	----	----	S, E	PS	----	C
36C2	do	1961	+390	300	R, G	8	180- 300	−115(R)	1961	T, E	PS	300(R)	C
36G	A. E. Smith	1957	+384	235	C	8	199- 214	−116(R)	1957	T, E	PS	60(R)	D, C
16S/10E-30R	Coyote Wells Service Sta.	1960	+290	100	----	6	----	−65(R	1960	T, E	Dom.	----	C
16S/11E-23B	U.S. Geol. Survey	1964	+30	127	A	1¼	121- 123	−101.2	3-64	----	O	----	C
16S/12E-6P	Imperial Irrigation District	1958	−32	385	R	6	262- 364	−12.5	10-60	N	T	----	D, E, G, C, W
16½S/10E-5D	G. Graham	----	+324	180	----	10	----	−85.3	7-62	T, E	Ind.	----	C
16½S/11E-6M1		----	+220	8(M)	----	48	----	−6.8	8-62	N	U	----	C
6M2		----	+220	13(M)	D	----	----	−6.8	8-62	----	U	----	C
17S/ 9E-11G		----	+1,050	100	----	8	----	F	7-62	N	U	3(E)	C
17S/12E-17A	U.S. Geol. Survey	1964	+108	70	A	1¼	68- 70	−57.7	3-64	N	O	----	D, C
Central Imperial Valley													
11S/13E-22H	U.S. Geol. Survey	1962	−229	152(M)	A	1¼	145- 147	+2.0	5-62	N	O	----	D, C, W
12S/12E-25F	do	1961	−219	105(M)	A	1¼	103- 105	+1.7	7-61	N	O	----	D, C, W
12S/13E-15L	do	1962	−202	127(M)	A	1¼	113- 115	−9.5	2-62	N	O	----	D, C, W
12S/14E-21J	do	1962	−176	152(M)	A	1¼	145- 147	+0.3	2-62	N	O	----	D, C, W
12S/15E-23M	D. D. Brownell	1956	−78	325	R	3	285- 325	F	4-62	N	Dom.	----	D, C
26J	R. Drysdale	1958	−60	344	R	3	304- 344	F	4-62	N	Dom., S	----	D, C
27R	G. C. Brownell	----	−85	430	R	2½	----	+25(R)	1962	N	Dom.	----	C
12S/16E-31N	P. J. Rebik	1948	−25	925	R	2	----	F	4-62	N	Dom.	5(E)	C
13S/13E-22G	U.S. Geol. Survey	1962	−138	152(M)	A	1¼	145- 147	−6.8	2-62	N	O	----	D, C, W
13S/14E-21K	do	1962	−160	152(M)	A	1¼	145- 147	+7.6	5-62	N	O	----	D, C, W
13S/15E-1B	A. C. Pickett	----	−62	1,089	R	2	----	+24(R)	1948	N	Dom.	16(R)	C
1Q	Holt Ave. Store	1945	−65	400	R	2½	----	F	4-62	N	Dom.	----	C
3N	Mulberry School	----	−113	890	R	4	----	F	3-62	N	Dom.	----	C
3Q	D. Butters	----	−102	----	R	2	----	F	2-62	N	Dom.	10	C
5D1	J. M. Williams	1942	−142	866	R	2½	851- 866	F	3-62	N	Dom.	10(E)	C
5D2	Wiest Store	----	−138	687	R	2½	----	+24(R)	1940	N	Des.	----	C
5D3	do	1963	−138	812	R	2	772- 812	F	11-63	N	Dom.	----	C
16Q	M. J. Lunceford	----	−118	760	R	4	----	F	2-62	N	Dom., S	10	C
21Q	G. R. Farr	----	−115	----	R	4	----	F	11-61	N	Dom.	----	C
22P	J. K. Feffer	----	−105	----	R	4	----	F	11-61	N	Dom.	----	C

TABLE 3. — *Records of selected wells and springs* — Continued

Well location (pl.1)	Owner or name	Year completed	Altitude of land surface (ft)	Depth of well (ft)	Type of well	Diameter (in.)	Perforated interval (ft)	Water level		Pump and power	Use of well	Discharge (gpm)	Other data available
								Feet above (+) or below (−) land surface	Date measured (month, yr)				
Central Imperial Valley — Continued													
23Q	Rutherford Bros.	----	−82	1,300	R	2	----	F	2-62	N	Dom.	40(E)	C
24E	W. Rutherford	----	−75	----	R	3	----	F	2-62	N	Dom.	10	C
24N	V. F. Butters	----	−74	700	R	2½	----	F	2-62	N	Dom.	15	C
28N	B. Warner	----	−119	1,150	R	4	----	F	2-62	N	Dom.	----	C
32D	T. B. Shenk	----	−127	1,000	R	2	----	F	9-62	N	Dom.	----	C
33A	Magnolia School	1958	−110	1,389	R	2½	1,269-1,389	F	11-61	N	Dom.	----	D, C
33K	Orita Ginning Assoc.	----	−110	----	R	2½	----	F	2-62	N	Dom.	----	C
34J	Orita Feed Lot	----	−93	900	R	2½	----	F	2-62	N	S	25	C
34M	M. Phegley	1938	−103	954	R	2½	936- 954	F	2-62	N	Dom.	10	C
13S/16E-6A	F. Burnett	----	−40	----	R	2	----	F	4-62	N	Dom.	----	C
6J	A. Koluvek	1944	−38	616	R	2½	----	F	4-62	N	Dom.	----	C
6P	T. Olesh	----	−50	300	R	2	----	F	3-62	N	Dom., S	5(E)	C
14S/13E-33K	U.S. Geol. Survey	1961	−57	177(M)	A	1¼	124- 126	−13.4	12-61	N	O	----	D, C, W
14S/14E-22G	do	1961	−140	122(M)	A	1¼	82- 84	+0.6	12-61	N	O	----	D, C, W
30N	do	1961	−81	187(M)	A	1¼	124- 126	−13.8	11-61	N	O	----	D, C, W
14S/15E-1B	do	1961	−62	187	A	----	----	----	----	----	O, Des.	75	D, C
6B	Fifield do	----	−132	----	R	2½	----	F	2-62	N	Dom.	20	C
9D	G. Mamer	1920	−113	----	R	2½	----	F	2-62	N	Dom., S	----	C
9N	J. Birger	1940	−113	385	R	1½	----	F	7-61	N	Dom.	5(E)	C
11D	L. Moiola	1953	−88	650	R	3	----	F	7-61	N	Dom.	7(E)	C
12N	M. and F. Feed Lot	1959	−72	1,260	R	2½	1,171-1,233	F	5-62	N	Ind.	----	D, C
15B	Bowman and Jeska	----	−95	1,165	R	4	----	+31(R)	1948	N	U	60(E)	C
23M	J. Birger	1941	−85	750	R	2	----	F	7-61	N	Dom.	5(E)	C
27A	do	----	−88	400	R	4	----	F	7-61	N	Dom., S	4(E)	C
28K	H. A. Foster	----	−100	380	R	1½	----	F	3-62	N	S	15(E)	C
34B	V. Shaw	1935	−88	357	R	2½	----	+19(R)	1948	N	Dom.	30(R)	C
34Q	W. Hansen	1962	−80	610	R	2½	----	F	9-62	N	Dom.	5(E)	C
34R	J. A. Bastanchury	----	−80	----	R	2	----	F	3-62	N	Dom.	4(E)	C
14S/16E-4Q	F. P. Borchard	1958	−15	457	R	2	----	F	7-61	N	S	12(E)	C
16B	Chopenich	----	−17	----	R	1½	----	F	8-61	N	U	3	C
16K	A. Axler	----	−17	400	R	2	----	F	7-61	N	S	1(E)	C
19N	A. Immel	1955	−57	1,135	R	2½	----	F	2-62	N	S	----	C
21B1	S. Stacey	1930	−16	----	R	2	----	F	7-61	N	Dom.	----	C
21B2	do	1961	−16	437(M)	R	3	----	F	9-61	N	S	5	D, C
21D	F. Axler	1954	−25	450	R	2	----	F	7-61	N	Dom.	----	C
22D	C. Singh	----	−7	709	R	2	698- 709	F	7-61	N	U	5(R)	C
34E	A. Jochims	----	−7	----	R	1½	----	F	7-61	N	Dom.	----	C
15S/12E-22G	U.S. Geol. Survey	1961	−46	137(M)	A	1¼	82- 84	−25.2	12-61	N	O	----	D, C
15S/13E-27E	do	1962	−43	117(M)	A	1¼	113- 115	−7.4	2-62	N	O	----	D, C
15S/14E-13E	do	1962	−105	117(M)	A	1¼	92- 94	+6.3	3-62	N	O	----	D, C
18C	Imperial Irrigation District	1958	−64	500	R, G	8	140- 440	−6.3	2-61	N	T	90(R)	D, P, C, W
15S/15E-1H	J. Rohrer	----	−53	580	R	4	560- 580	F	8-61	N	Dom.	----	C
9E	F. Schaffner	----	−88	----	R	2	----	F	9-62	N	U	----	C
9N	E. C. Robinson	----	−88	600	R	1¼	----	F	9-62	N	Dom.	----	C
9Q	R. Schaffner	----	−78	----	R	2½	----	F	3-62	N	Dom.	----	C
10G		----	−74	460	R	2	----	+18.5(R)	1948	N	U	27(R)	C
10K	A. W. Barnes	----	−75	399	R	2	----	+9.8(R)	1948	N	U	21(R)	C
11G	Old Eastside School	----	−51	281	R	2	----	+22.5(R)	1948	N	Dom.	7(E)	C
12H	F. Grinello	----	−48	----	R	----	----	F	7-61	N	Dom.	12(E)	C
13N	K. K. Sharp	----	−36	----	R	2½	----	F	2-62	N	Dom.	----	C
15F	C. D. Allen	1936	−65	864	R	2	----	F	7-61	N	Dom.	10(E)	C
25B	Hazzard and Strangwell Assoc.	1910	−16	873	R	4	400- 700	+5.6(R)	1948	N	Dom.	80(R)	C
25F	Neidiffer Grocery	1936	−18	----	R	2	----	F	7-61	N	Dom.	2(E)	C
35A	Holtville Ice Co.	1926	−18	1,100	R	2	----	+25(R)	1948	N	U	29(R)	C
36D	City of Holtville	----	−15	852	R	2	----	+1.4(R)	1948	N	U	3(E)	C
15S/16E-7F	D. D. Dower	1912	−42	517	R	2½	----	F	8-61	N	S	----	C
7R	J. Asbury	1913	−37	695	R	2	664- 695	F	8-61	N	Dom.	3(E)	C
8E	G. Hoyt	1912	−34	488	R	6	475- 488	F	8-61	N	Dom	1(E)	C
15P	R. S. Garewal	1953	0	800	R	3	----	F	7-61	N	Dom.	----	C
18Q	Imperial Irrigation District	1958	−27	440	C	10	----	+7.9	12-61	N	T	----	D, G, W, C
19E	F. Strahm	1938	−27	834	R	2½	----	F	7-61	N	Dom.	10(E)	C
22F	D. Starr	----	+3	650	R	2	----	F	7-61	N	U	3(E)	C
22L	do	1943	+1	750	R	2	----	F	7-61	N	Dom.	15(E)	C
23F	L. E. Foster	1960	+15	561	R	2½	452- 542	F	2-62	N	Dom., S	25	D, C
27N	C. Martinez	----	−3	----	R	2	----	F	7-61	N	Dom.	2(E)	C
29Q	A. Fusi	1961	−10	616	R	2½	537- 616	F	9-61	N	U	2	D, C
16S/12E-36E	U.S. Geol. Survey	1962	−28	122(M)	A	1¼	103- 105	−11.5	2-62	N	O	----	D, C, W
16S/13E-13N	do	1962	−25	147	A	1¼	145- 147	−11.2	2-62	N	O	----	D, C, W
16S/15E-17L	do	1962	−15	162(M)	A	1¼	145- 147	−3.8	2-62	N	O	----	D, C, W
16S/16E-1M	Imperial Irrigation District	1947	+22	132	R, G	16	----	−4(R)	1961	T, E	U	----	D, C
3C	Date City Store	----	+5	596	R	----	----	F	7-61	N	U	----	D, C
14A	Waltor Labor Camp	1950	+17	800	R	2	----	F	9-61	N	Dom.	----	C
15B	Old Alamo School	1955	+12	1,000	R	4	864- 877	F	9-61	N	Dom.	4(R)	C
33D	Keithmetz	1950	+30	800	R	2½	----	F	9-61	N	S	10	C
35F	Imperial Irrigation District	1958	+41	603	C	10	46- 590	−10.8	10-60	N	T	----	D, G, W, C
16½S/12E-1D	do	1958	−17	517	R	----	----	----	----	----	T, Des.	----	D
17S/13E-20N	U.S. Geol. Survey	1961	−2	162	A	1¼	82- 84	−12.4	5-61	N	O	----	D, W, C
17S/14E-14Q1	do	1961	−35	162	A	1¼	71- 73	+3.8	5-61	N	O	----	D, W, C
14Q3	LCRP 7	1962	−30	1,000(M)	R	----	----	----	----	N	T	----	D, C

TABLE 3. — *Records of selected wells and springs* — Continued

Well location (pl.1)	Owner or name	Year completed	Altitude of land surface (ft)	Depth of well (ft)	Type of well	Diameter (in.)	Perforated interval (ft)	Water level: Feet above (+) or below (−) land surface	Water level: Date measured (month, yr)	Pump and power	Use of well	Discharge (gpm)	Other data available
Central Imperial Valley — Continued													
17S/15E-10N	Imperial Irrigation District	1958	+22	500	R, G	8	110- 450	−9.2	4-63	N	T	90(R)	D, P, W, C
16K	U.S. Geol. Survey	1961	+20	162	A	1¼	150- 152	−9.3	5-61	N	O	----	D, W, C
17S/16E-18B	do	1961	+25	162	A	1¼	150- 152	+2.1	5-61	N	O	----	D, W, C
Eastern Imperial Valley													
10S/16E-5D	Beal Well	----	+1,280	42	D	----	----	−38.5	9-61	N	U	----	C
11S/15E-23M	W. Adams	1958	+120	550	C	12	25- 150	−25(R)	1963	J, E	Dom.	25(R)	C
12S/16E-9A	Southern Pacific Co.	1963	+220	1,000	R, G	12	150-1,000	−154.5	7-63	T, E	Irr.	980	D, E, P, C
12S/18E-11N	E. Van Derpaol	----	+1,180	14	D			−10	8-63	N	U		C
12S/19E-15J	C. Chisman	----	+1,350	39	D	----	----	−31.2	2-63	P	Dom.	----	C
13S/16E-16F	Imperial Irrigation District	1958	0	329	C	10	----	+3.8	1-62	N	T	----	D, G, C
35M	U.S. Geol. Survey	1961	+25	182(M)	A	1¼	134- 136	−12.5	5-64	N	O	----	D, W, C
13S/17E-32N	do	1961	+85	155(M)	A	1¼	113- 115	−40.0	5-64	N	O	----	D, W, C
35P	do	1962	+110	162(M)	A	1¼	155- 157	−6.9	5-64	----	O	----	D, W, C
13S/19E-33Q	Vista Mine	1937	+550	690	C	10	----	−480(R)	1937	T, G	Ind.	800	C
14S/16E-11H		----	+25	287	----	2	----	+4.4	2-63	N	U	30	C
26K	U.S. Geol. Survey	1961	+25	192(M)	A	1¼	155- 157	−12.6	5-64	----	O	----	D, W, C
15S/16E-24G	do	1961	+45	142(M)	A	1¼	113- 115	−29.4	5-64	----	O	----	D, W, C
36E	B. Nussbaum	1961	+40	630	R	6	360- 430	F	7-61	T, E	U	50(E)	C
15S/18E-13B	U.S. Geol. Survey	1964	+135	164	A	1¼	162- 164	−43.5	2-64	N	O	----	D, C
15K	do	1961	+123	142(M)	A	1¼	134- 136	−14.8	5-64	N	O	----	D, W, C
15M	LCRP 11	1963	+120	1,140	R, G	10	309- 894	−28.3	4-63	----	T	1,000	D, E, T, P, W, C
19M	U.S. Geol. Survey	1961	+115	192(M)	A	1¼	155- 157	−39.3	5-64	N	O	----	D, W, C
15S/19E-19H	do	1964	+138	177(M)	A	1¼	155- 157	−43.4	3-64	N	O	----	D
28N	do	1964	+145	172(M)	A	1¼	155- 157	−43.7	2-64	N	O	----	D, C
33R	do	1964	+143	177	A	1¼	155- 157	−35.0	3-64	N	O	----	C
15S/20E-9A	Gold Rock Ranch	1935	+488	521	C	6	----	−404.8	6-62	N	U	----	D, C
23M	American Girl Mine	1936	+440	475	C	12	----	−339(R)	1936	N	Des.	----	D, C
25N	R. K. Foster	1960	+400	493	R	8	----	−291.4	5-62	T, G	Ind.	130	C
33K	Mill site	----	+295	210	----	8	----	−154.5	1-61	N	U	----	C
16S/16E-12Q	U.S. Geol. Survey	1961	+30	142(M)	A	1¼	92- 94	−11.9	5-64	N	O	----	D, W, C
16S/17E-23R	do	1964	+90	177(M)	A	1¼	155- 157	−33.6	2-64	N	O	----	D, C
16S/18E-2R	do	1965	+135	142(M)	A	1¼	134- 136	−35.5	2-65	N	O	----	D, C
6R	do	1965	+119	152(M)	A	1¼	145- 147	−43.9	2-65	N	O	----	D, C
13R	do	1964	+145	157(M)	A	1¼	145- 147	−45.1	4-64	N	O	----	D, C
17R	do	1964	+116	177(M)	A	1¼	155- 157	−32.2	2-64	N	O	----	D, C
23A	U.S. Bur. Reclamation	1964	+127	500	R	1¼	----	−27.8	10-64	N	O	----	D, E, C
29J	U.S. Geol. Survey	1961	+120	192(M)	A	1¼	155- 157	−32.8	5-64	N	O	----	D, W, C
32R	LCRP 18	1964	+118	815(M)	R, G	10	140- 630	−28.2	6-64	N	T	900	D, E, T, P, W, C
16S/19E-2N	U.S. Geol. Survey	1961	+154	142(M)	A	1¼	134- 136	−41.7	5-64	N	O	----	D, W, C
9E	do	1964	+143	136(M)	A	1¼	134- 136	−43.5	2-64	N	O	----	D, C
11D	LCRP 12	1963	+155	1,000(M)	R, G	10	300- 610	−43.5	5-63	N	T	----	D, E, G, T, P, W, C
15Q	U.S. Geol. Survey	1963	+150	147(M)	A	1¼	72- 74	−41.3	5-63	N	O	----	D, C
32G1	Imperial Irrigation District	1958	+142	275	R, G	18	40- 240	−31.5	10-60	N	T	----	D, E, G, W, C
32G2	do	1958	+144	500	R, G	18	69- 273	−32.7	10-60	N	T	1,350(R)	D, E, G, W, C
36P	Gordon's Well	1951	+154	228	----	10	----	−44(R)	7-61	T, E	Dom.	----	D, C
16S/20E-14C	U.S. Geol. Survey	1961	+242	187(M)	A	1¼	150- 152	−128.3	5-64	N	O	----	D, W, C
21P	do	1961	+180	202	A	1¼	87- 89	−50.2	5-64	N	O	----	D, W, C
23B	do	1961	+220	147(M)	A	1¼	134- 136	−97.4	12-61	N	O	----	D
27D	State of California	1925	+170	153	C	12	127- 144	−50.2	6-63	S, E	Dom.	----	D, C
31K	LCRP 6	1962	+155	1,000	C	12	340- 520	−51.2	5-62	N	----	----	
31K	LCRP 6A	1964	+155	2,519	R	12	----	----	----	N	T	1,000	D, E, G, T, P, W, C
32R	U.S. Geol. Survey	1961	+162	142(M)	A	1¼	82- 84	−56.6	5-64	N	O	----	D, W, C
16S/21E-15G	E. Spitzer	1959	+320	276	----	8	----	−190(R)	1959	T, E	Dom.	----	C
15J	E. P. Howard	1960	+315	312	R	8	----	−220(R)	1960	S, E	Dom.	----	C
15K	F. L. Bledsoe	1958	+315	272	C	8	----	−185(R)	1960	S, E	Dom.	----	C
16B	R. G. Winder	1960	+320	847	C	20	598- 806	−195.5	12-62	T, E	Irr.	1,200	D, P, C
19D1	Springer Station	1957	+243	265	----	4	----	−120.9	11-60	S, E	Dom.	----	D, C
19D2	U.S. Geol. Survey	1961	+247	172(M)	A	1¼	166- 168	−124.6	5-64	N	O	----	D, W, C
20J	H. Brommel	1931	+270	293	----	10		−170(R)	1931	N	Des.	----	D
21G	F. Carlson	1962	+290	360	R, G	10	258- 358	−167.4	6-62	----	U	930	C
21P	do	1961	+270	464	R, C	6	----	−144.0	7-61	S, E	Dom.	----	D, C
32R	U.S. Geol. Survey	1961	+195	202(M)	A	1¼	87- 89	−57.7	5-64	N	O	----	D, W, C
17S/17E-3C	Imperial Irrigation District	1948	+92	120	R, G	16	0- 105	−35(R)	1948	T, E	Ind.	600	D, C
17S/18E-4A	do	1952	+117	195	R	12	179- 195	----	----	T, E	Ind.	130	C

TABLE 4.—*Drillers' logs of selected wells*

Lithology	Thickness (feet)	Depth (feet)
Western Imperial Valley		
9S/11E-4J		
Sediment	2	2
Clay, yellow	10	12
Sand, red	15	27
Clay, yellow	10	37
Sand, fine, red	10	47
Clay, soft, sticky	123	170
Clay, blue and yellow	25	195
Clay, yellow	104	299
Sand, red	6	305
Clay, blue and yellow, and thin streaks of shell rock 1–12 in. thick	956	1,261
10S/10E-19K		
Rock, swelling, bentonitic	85	85
Clay, red and green	61	146
Clay; lens of gravel	178	324
Clay, red. Sandstone lens about every 10 feet	149	473
Clay, brown	117	590
Shale, blue	12	602
Clay, red, blue, gray, and pink	48	650
Clay, red, black, and gray	30	680
Shale, gray, hard	11	691
Clay, gray, soft	60	751
Sandstone	3	754
Clay, red stringers, and sandstone	28	782
Clay, red	18	800
Clay, gray; a little gravel	39	839
Sandstone, hard	4	843
Shale, blue, and sand	44	887
Sand; little gravel	46	933
Clay and sandstone	69	1,002
11S/10E-35N		
Sand and sandstone	55	55
Clay	11	66
Clay and sand, alternating	24	90
Sand and sandstone capping	10	100
Clay	158	258
Sand and sandstone	3	261
Clay	30	291
Sandstone	1	292
Clay	28	320
Sand and sandstone	10	330
Clay, and sand streaks	180	510
Sand	17	527
Clay and sand	53	580
Clay, soft	22	602
Clay, hard	15	617
Clay	80	697
Clay, and sand streaks	112	809
12S/8E-9H		
Sand, coarse, and boulders	47	47
Sand, coarse	41	88
Gravel, cemented	14	102
Sand, coarse	3	105
Boulders	7	112
Sand, coarse	3	115
Sand, coarse, and boulders	15	130

TABLE 4.—*Drillers' logs of selected wells*—Continued

Lithology	Thickness (feet)	Depth (feet)
Western Imperial Valley — Continued		
12S/8E-9H — Continued		
Boulders	12	142
Sand, coarse, and thin clay streaks	8	150
Sand, coarse, and gravel	26	176
12S/11E-18J		
Clay, silty, brown, and fine sand	19	19
Sand, coarse to very coarse	14	33
Clay, silty, brown	7	40
Sand, medium to very coarse, and very fine gravel	25	65
Clay, silty, brown, and silt. Few streaks of gray clay	51	116
Silt, brown, and very fine sand	8	124
Clay, silty, brown, and silt. Few streaks of gray clay	29	153
Sand, fine to coarse, and some brown silt	39	192
Clay, silty, brown	20	212
Sand, fine and brown silt	12	224
Clay, silty, brown, and some fine to coarse sand	53	277
Sand, medium to coarse	12	289
Clay, silty, brown and fine sand	13	302
Sand, partly cemented, fine to medium, and brown silty clay	30	332
Sand, fine to very coarse, and small amount of very fine gravel	73	405
Clay, silty, brown, and some gray clay	33	438
Sand, fine to very coarse, and layers of brown silty clay	32	470
Sand, fine to very coarse, and small amount of very fine gravel	18	488
Clay, silty, brown	40	528
Sand, fine to coarse	29	557
Clay, silty, brown and gray, and layers of fine to medium sand	43	600
Sand, fine to very coarse, and partly cemented layers brown and gray silty clay	68	668
Clay, silty, brown and gray, and layers of medium to coarse sand	32	700
Sand, fine to very coarse	25	725
Clay, brown and gray, silty	18	743
Sand, fine to coarse, and some clay	25	768
Clay, gray-brown, silty, and small amount of olive-green clay	45	813
Sand, fine and gray-brown clay	22	835
Sand, fine to very coarse, and some clay	33	868
Clay, gray-brown, silty	11	879
Sand, fine to coarse	9	888
Clay, gray and brown, silty	15	903
Sand, fine to coarse, and silt	21	924
Clay, gray and brown, silty	7	931
Sand, fine to coarse, and gray-brown silty clay	28	959
12S/11E-36K		
Sand, surface, and clay	75	75
Clay	39	114
Sandstone	4	118
Clay	45	163
Clay streaks, and sand	13	176
Rock	2	178

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Western Imperial Valley — Continued		
12S/11E-36K — Continued		
Clay	9	187
Sand	3	190
Clay	4	194
Sand, medium	3	197
Clay	9	206
Clay, and medium sand streaks	12	218
Sand, medium, and clay	24	242
Clay	18	260
Sand, medium	5	265
Clay	2	267
Sand, medium, and clay streaks	27	294
Rock	1	295
Sand, medium to coarse, and clay	62	357
Clay	8	365
Sand, fine, and pebbles; some clay streaks	52	417
Clay	9	426
Boulders	2	428
Clay	4	432
Mix, fine to coarse	6	438
Clay	8	446
Boulders	4	450
Sand, fine to medium, and clay streaks	7	457
Clay and fine sand	46	503
14S/11E-32R		
Sand, very fine to very coarse, and some brown silt	10	10
Sand, very coarse, and very fine subangular gravel	20	30
Clay, brown; some gray; some silt and very fine sand	30	60
Silt, light brown, and very fine sand	30	90
Clay, brown, and silt and very fine to fine sand. Bits of wood	20	110
Sand, very fine to very coarse, angular, and some silt	40	150
Sand, very coarse to coarse, and very fine to fine subangular gravel	20	170
Sand, fine; some very fine and coarse; some brown clay	10	180
Clay, brown; some gray; and brown silty clay and sand	40	220
Sand, very fine to coarse	10	230
Sand, fine, very fine, cemented, and light-brown silt	25	255
Clay, brown, and light-brown silty clay. Pieces of carbonized wood	25	280
Clay, brown, sandy; few gray streaks; some silt and sand	35	315
Sand, medium to very coarse, and silt and very fine sand	20	335
Clay, brown, and fine to coarse sand	10	345
Sand, very fine; some fine to very coarse; very light gray	10	355
Clay, silty, gray, and silt and very fine sand	35	390
Sand, very coarse. Worn fragments of pelecypods and oysters	20	410
Sand, coarse to very coarse, and some very fine subangular gravel	5	415
Clay, brown, silty, and fine to very coarse sand	20	435
14S/11E-32R — Continued		
Sand, coarse, and fine to medium sand; some silt. Worn *Pecten* fragments	10	445
Gravel (50 percent), very fine to fine, and very coarse sand; some silty clay	45	490
Sand, fine to very coarse; small amount very fine gravel	70	560
Clay, silty, light-brown and gray, and very fine to coarse sand	15	575
Sand, very fine; some coarse; and light-brown silty clay	15	590
Clay, silty, light-gray, and light brown silt and very fine sand	15	605
Silt, light-brown, and silty clay; few very fine subangular pebbles	10	615
Sand, medium to very coarse, and very fine to fine gravel (25 percent) and silty clay	30	645
Clay, silty, light-brown and gray, and light-brown silt and very fine to fine sand	30	675
Sand, very fine to coarse	25	700
Clay, brown, and fine sand and silt	15	715
Sand, very fine and fine, partly cemented	40	755
Clay, brown, and silty clay and silt	20	775
Sand, fine; some coarse and very coarse; partly cemented	30	805
Clay, brown, and silty clay and silt	25	830
Sand, fine to coarse, and silt and some light-brown clay	40	870
Sand, very coarse; some fine to coarse	25	895
Sand, coarse to very coarse, and some brown and yellow-brown clay	70	965
Clay, reddish-brown and gray, and medium to very coarse cemented sand	20	985
16S/9E-35M		
Sand and boulders	23	23
Clay, sandy	67	90
Sand, gravel, and clay	10	100
Sand	20	120
Clay, white	34	154
Clay, yellow, and gravel	36	190
Clay, white	19	209
Clay, yellow, and gravel	55	264
Clay, brown	57	321
Clay, yellow, sandy	10	331
Sand, quick	19	350
Mud, silty, black, and clay	7	357
Rock or sandstone	5	362
Clay, sandy, and gravel	4	366
Sand, quick	10	376
Sand and gravel	4	380
Sand, fine, black	27	407
Sand and small gravel	15	422
Clay	6	428
Sand, fine	30	458
Clay, sticky, white	2	460
Rock, dry, and sandy clay	12	472
Sand, fine, and scattered gravel	11	483
Clay and gravel	10	493

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Western Imperial Valley — Continued		
16S/9E-35M — Continued		
Clay, fine, brown	7	500
Clay and gravel	5	505
Silt and sand	7	512
Clay, sticky	13	525
Silt and sand	10	535
16S/9E-36G4		
Surface	17	17
Gravel and some boulders	43	60
Clay	2	62
Gravel and fine sand	43	105
Clay and sand, alternating	28	133
Clay, silty	15	148
Sand and clay	10	158
Shale, yellow	15	173
Clay and streaks of sand	14	187
Clay and silt	18	205
Clay, yellow	29	234
Clay and fine silt	66	300
Sand	2	302
Shale	7	309
Sand	1	310
Shale and clay	49	359
Sand	2	361
Clay, blue	14	375
No log	6	381
Clay	49	430
Clay and streaks of sand	20	450
Sand, coarse	5	455
Clay, blue	7	462
Clay and streaks of sand	21	483
Sand, coarse, and clay	11	494
Clay	8	502
Clay and streaks of sand	59	561
16S/12E-6P1		
Sand, silty to coarse, angular to rounded	10	10
Clay, red-brown to gray-brown and tan, silty, and some fine to medium sand lenses	30	40
Sand and some clay and gravel: fine to coarse sand and some rounded pea grave; red-brown and silty clay	15	55
Gravel, sand, and some silt; pea gravel; coarse to very fine angular to subrounded sand; clayey red-brown silt	5	60
Sand and clay: very fine to coarse rounded to subangular sand; platy shale fragments; red-brown silty clay	25	85
Sand and some clay: very fine to coarse, rounded to subangular sand; silty red-brown clay	35	120
Clay and some sand and gravel: silty red-brown and gray-brown clay; very fine to coarse sand; angular to rounded gravel	25	145
Clay and some sand: gray tough silty clay and tan sandy clay; fine sand, with gastropods	5	150
Gravel and sand: angular to rounded gravel; fine to coarse sand	3	153
Clay, sand, and gravel: tan silty platy clay and gray sandy clay; fine to coarse sand	82	235

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Western Imperial Valley — Continued		
16S/12E-6P1 — Continued		
Sand, clay, and gravel: fine to coarse rounded to subangular gravel and sand; tan platy silty clay and gray clay	30	265
Gravel and sand: pea gravel; fine to coarse rounded to subangular sand. Trace of gray-brown, silty clay	103	368
Clay and sand: interbedded tan to yellow silty clay and gray-brown clay: fine to coarse sand	7	375
Clay: interbedded tan to yellow silty clay and gray-brown silty clay	13	388
Central Imperial Valley		
12S/15E-23M		
Clay	88	88
Silt and clay	32	120
Clay	80	200
Clay and silt	80	280
Sand, fine	10	290
Clay and silt	16	306
Sand, fine, and clay	14	320
Clay	12	332
13S/15E-33A		
Clay	228	228
Clay, shale, and sand	22	250
Clay and fluid sand	21	271
Clay and sand	94	365
Shale, clay, and sand streaks	43	408
Clay, and sand streaks	115	523
Sand, fluid	70	593
Clay	24	617
Shale and clay	20	637
Clay	124	761
Hard cap	9	770
Sand, and clay streaks	31	801
Clay	58	859
Hard cap	10	869
Sand	10	879
Clay	121	1,000
Hard cap	8	1,008
Sand	12	1,020
Clay	83	1,103
Hard cap	8	1,111
Sand and clay	35	1,146
Hard cap	4	1,150
Clay, sandy	14	1,164
Clay	102	1,266
Clay, and sand streaks	84	1,350
Hard cap	8	1,358
Clay, and sand streaks	31	1,389
14S/15E-12N		
Clay	18	18
Sand, fine	6	24
Clay	58	82
Sand, and clay streaks	305	387
Clay, hard	3	390

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thick-ness (feet)	Depth (feet)
Central Imperial Valley — Continued		
14S/15E-12N — Continued		
Sand, fine, and clay	46	436
Clay	69	505
Sand, fine, and clay	171	676
Sand and small streaks of clay	54	730
Clay	143	873
Sand	9	882
Clay, and sand streaks	244	1,126
Sand	4	1,130
Clay	7	1,137
Sand streaks and clay	42	1,179
Sand	4	1,183
Clay	7	1.190
Sand	50	1,240
Clay and streaks of sand	20	1,260
14S/15E-34Q		
Clay	206	206
Sand	97	303
Clay	38	341
Sand, fine, and silt	83	424
Clay	16	440
Sand	21	461
Clay	4	465
Sand	16	481
Clay	5	486
Sand	24	510
14S/16E-21B2		
Sand, fine, and silty clay	20	20
Clay, and gravel streaks	15	35
Sand	35	70
Clay	40	110
Sand	20	130
Clay	27	157
Sand	3	160
Clay	76	236
Sand, coarse	8	244
Clay	70	314
Sand, fine	5	319
Clay, orange-brown, and some very fine sand	33	352
Sand, very fine to fine	27	379
Clay, soft, light-brown	1	380
Sand, very fine	7	387
Sand, very fine, and thin layers of clay	8	395
Sand, very fine	7	402
Clay, soft, light-brown	3	405
Sand	1	406
Clay	3	409
Sand and clay	7	416
Sand, very fine	15	431
Clay	4	435
Sand, very fine	1	436
15S/14E-18C		
Sand, brown, very fine to medium, and clay stringers	30	30
Sand, brown, very fine to medium, and thin stringers of silty clay; some very fine gravel	20	50
Sand, brown, medium; some fine	53	103

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thick-ness (feet)	Depth (feet)
Central Imperial Valley — Continued		
15S/14E-18C — Continued		
Sand, brown, fine to medium, and dark-gray clay	27	130
Sand, brown, fine to coarse, and stringers of brown and gray clay	35	165
Sand, fine to medium, and brown clay; with some coarse sand	75	240
Clay, light-gray, and streaks of hard brown clay; some fine to medium sand	100	340
Sand, fine to medium, and light-gray clay	70	410
Sand, brownish-gray, fine to coarse, and stringers of gray clay	30	440
Sand, fine to coarse, and gray clay	35	475
Clay, gray, and stringers of fine to medium sand	25	500
15S/16E-18Q		
Clay	10	10
Sand, fine to medium	2	12
Clay	5	17
Sand, fine to medium	3	20
Clay	8	28
Sand, fine to medium	2	30
Clay	5	35
Sand, fine to medium	2	37
Clay	6	43
Sand, silty, very fine to medium	7	50
Clay	6	56
Sand, silty, very fine to medium	2	58
Clay	11	69
Sand, silty, very fine to medium	2	71
Clay	1	72
Sand, silty, very fine to medium	3	75
Clay	1	76
Sand, silty, very fine to medium	2	78
Clay	52	130
Sand, fine to medium	5	135
Clay	1	136
Sand, fine to medium	8	144
Clay	2	146
Sand, fine to medium	11	157
Clay	3	160
Sand, fine to medium	7	167
Clay	1	168
Sand, fine to medium	9	177
Clay	2	179
Sand, fine to medium	8	187
Clay	1	188
Sand, fine to medium	5	193
Clay	2	195
Sand, silty, very fine to medium	2	197
Clay	3	200
Sand, silty, very fine to medium	5	205
Clay	2	207
Sand, silty, very fine to medium	5	212
Clay	1	213
Sand, silty, very fine to medium	8	221
Clay	12	233
Sand, silty, very fine to medium	23	256
Clay	2	258
Sand, silty, very fine to medium	2	260

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Central Imperial Valley — Continued		
15S/16E-18Q — Continued		
Clay	3	263
Sand, silty, very fine to medium	2	265
Clay	1	266
Sand, silty, very fine to medium	26	292
Sand, very fine to medium, and clay, alternating	18	310
Clay	4	314
Sand, silty, very fine to medium	4	318
Clay	1	319
Sand, silty, very fine to medium	3	322
Clay	2	324
Sand, silty, very fine to medium	3	327
Clay	3	330
Sand, silty, very fine to medium	2	332
Clay	3	335
Sand, silty, very fine to medium	2	337
Clay	3	340
Sand, silty, very fine to medium	2	342
Clay	3	345
Sand, silty, very fine to medium	2	347
Clay	8	355
Sand, silty, very fine to medium	2	357
Clay	8	365
Sand, silty, very fine to medium	2	367
Clay	7	374
Sand, silty, very fine to medium	3	377
Clay	8	385
Sand, silty, very fine to medium	2	387
Clay	8	395
Sand, silty, very fine to medium	45	440
15S/16E-23F		
Sand, fine	23	23
Clay	3	26
Sand, fine	12	38
Clay	7	45
Sand	13	58
Clay	12	70
Sand	4	74
Clay	247	321
Sand	13	334
Clay	37	371
Sand	9	380
Clay	71	451
Sand	32	483
Clay	48	531
Sand	10	541
Clay and sand	20	561
15S/16E-29Q1		
Clay	155	155
Sand	40	195
Clay, soft	65	260
Sand	40	300
Clay	15	315
Sand	9	324
Clay	20	344
Sand	19	363
Clay	22	385

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Central Imperial Valley — Continued		
15S/16E-29Q1 — Continued		
Sand	5	390
Clay	70	460
Sand, fine, and clay streaks	80	540
Clay	14	554
Sand, and clay streaks	62	616
16S/16E-35F		
Pit	13	13
Clay, reddish-brown, tough, sticky, silty	36	49
Sand, brown, fine, and some clay	6	55
Clay, reddish-brown, silty, and some fine sand	7	62
Sand, brown, silty, fine to medium, and red-brown clay stringers	3	65
Sand, brown, silty, fine to medium, and trace of coarse sand and pebbles	22	87
Sand, brown, silty, fine, and stringers of red-brown clay	4	91
Clay, red-brown, tough, sticky, silty, and some fine sand	9	100
Sand and clay: silt to fine sand; red-brown soft sticky clay	24	124
Clay, dark-brown, tough, sticky, and some silt to fine sand	19	143
Sand, silt to fine sand, and some brown-gray clay	48	191
Clay, dark-brown, sticky, and some silty fine sand	23	214
Sand and clay: silty very fine sand; brown-gray clay	12	226
Sand, silty, fine, and some red-brown clay	28	254
Silt, brown, and clay	3	257
Sand, silty, fine, and some red-brown clay	5	262
Clay, dark-brown, silty	53	315
Sand, silty, very fine, and dark-brown clay	25	340
Clay, dark-brown, tough, sticky, silty	35	375
Sand, very fine, and light-brown clay	3	378
Sand and gravel: light-brown fine to medium sand; rounded granule to pebble gravel; gastropods	11	389
Clay, red-brown, tough, sticky, and thin stringers of pea gravel at 419 and 430 ft	42	431
Sand, silty, fine; gastropods at 435–437 ft	49	480
Sand, silty, fine, and dark-brown clay	13	493
Clay, reddish-brown, and silty fine sand	10	503
Sand, silty, fine, and some red-brown clay	10	513
Clay, reddish-brown, and some silty fine sand	27	540
Clay	5	545
Sand, very fine to medium	5	550
Clay	7	557
Sand, very fine to medium	2	559
Clay	23	582
Sand, very fine to medium	10	592
Clay	11	603
16½S/12E-1D		
Sand, brown, fine to coarse; mica; few gastropods 1-2 mm	26	26
Sand and gravel: coarse to very coarse sand; angular gravel to ⅜ in	11	37
Clay, brown, silty	51	88

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Central Imperial Valley — Continued		
16½S/12E-1D — Continued		
Sand, brown, silty, fine to medium	4	92
Clay, gray, silty	4	96
Sand, brown, silty, fine to medium	9	105
Clay, brown, silty	15	120
Sand, brown, fine to medium	22	142
Clay, brown, silty, and some fine to medium sand	24	166
Sand, brown, silty, fine to medium	7	173
Clay, brown, silty, and some sand	6	179
Sand, brown, silty, fine to medium	13	192
Clay, gray-brown, silty	8	200
Sand, brown, silty, fine to medium	2	202
Clay, gray-brown, silty	7	209
Sand, brown, silty, fine to medium	4	213
Clay, gray, silty	7	220
Sand, brown, silty, fine to medium	4	224
Clay, gray, silty	5	229
Sand, brown, silty, fine to medium	6	235
Sand, light-gray, fine to medium; scattered gastropods	12	247
Sand, light-gray, medium to coarse	2	249
Clay, brownish-gray	11	260
Sand, brown, fine to medium	6	266
Clay, brownish-gray	20	286
Sand, brown, silty, fine to medium	4	290
Clay, gray	6	296
Sand, brown, silty, fine to medium	6	302
Clay, gray	4	306
Sand, light-gray, fine to coarse; some scattered granules; gastropods	12	318
Clay, gray	8	326
Sand, light-gray, medium to coarse	24	350
Sand, light-gray, fine to medium	13	363
Sand, light-gray, silty, fine to medium	9	372
Sand, light-gray, cemented, fine to medium	7	379
Clay, gray	3	382
Sand, light-gray, medium to coarse; scattered gastropods	24	406
Sand, light-gray, silty, fine to medium	6	412
Sand, light-gray, fine to medium	9	421
Sand, light-gray, silty, cemented, fine to coarse	11	432
Clay, brownish-gray, silty	9	441
Sand, light-gray, fine to coarse	9	450
Sand, light-gray, medium to very coarse	22	472
Clay, gray	20	492
Sand, light-gray, fine to coarse	5	497
Clay, light-gray	20	517
17S/15E-10N		
Clay, brown, and scattered medium sand. Gastropods 1-3 mm at 0-30 ft	74	74
Sand and clay: silty very fine sand; blue-gray clay, with mica flakes and black carbonaceous material at clay partings. Shell fragments and gastropods at 82 ft	33	107
Cored. No recovery	25	132
Sand and Clay: very fine to medium sand; brown to gray clay	28	160

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thickness (feet)	Depth (feet)
Central Imperial Valley — Continued		
17S/15E-10N — Continued		
Sand, very fine to medium, and brown to gray clay stringers	60	220
Sand, brown, very fine to medium, and fine platy carbonaceous material	12	232
Sand and clay: brown very fine to medium sand; brown clay stringers. Fine carbonaceous particles	49	281
Clay, dark-gray, silty, very sticky	2	283
Cored. No recovery. Probably fine sand	8	291
Clay, dark-gray, silty, very tough and sticky	2	293
Sand, brown, silty, fine, and scattered fine mica flakes	1	294
Clay, brown, and stringers of very fine to medium sand	19	313
Sand, brown, very fine to medium, and carbonaceous material	11	324
Clay, brown, and stringers of very fine to medium sand	16	340
Sand, fine to medium, and brown clay	50	390
Clay: moderately hard gray claystone and very fine sand, probably interbedded with softer clay	40	430
Clay, brownish-gray	40	470
Clay and Sand: brownish-gray clay; very fine to medium sand (30 percent)	30	500
17S/14E-14Q3		
Sand, fine and very fine	200	200
Clay, brown, and silty clay	85	285
Sand, very fine, silty, and brown clay	25	310
Sand, very fine, and some silty clay	55	365
Clay, brown, hard	10	375
Sand, very fine, silty; alternating with thin layers of gray-brown clay	100	475
Clay, gray	30	505
Sand, very fine, silty, and gray-brown silty clay	65	570
Clay, brown, silty, and some very fine sand	20	590
Clay, brown, and few gray layers; some thin beds of very fine sand	95	685
Sand, very fine, silty, and gray clay	20	705
Clay, gray, and some brown silty clay	60	765
Sand, very fine, silty	10	775
Clay, gray-brown, and thin layers of very fine silty sand	80	855
Sand, very fine and fine, silty	45	900
Clay, brown	5	905
Sand, very fine, silty	15	920
Clay, brown and gray, and very fine and fine cemented sand	25	945
Sand, very fine, silty, and gray clay	25	970
Clay, gray, and few thin beds of very fine silty sand	30	1,000
Eastern Imperial Valley		
12S/16E-9A		
Sand, silty, very fine, and brown clay	10	10
Sand, very coarse to fine, and very fine gravel	102	112

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thick-ness (feet)	Depth (feet)
Eastern Imperial Valley — Continued		
12S/16E-9A — Continued		
Clay, light-brown, and very fine silty sand	5	117
Sand, fine to medium, and silt	14	131
Clay, silty, yellow-brown	5	136
Sand, coarse to very coarse	15	151
Sand, very coarse to coarse, and very fine and larger gravel	45	196
Sand, fine to very coarse, and yellow-brown clay	19	215
Clay, yellow-brown, and fine sand	17	232
Sand, very fine to very coarse, and thin layers of gravel	48	280
Clay, yellow-brown; some light-gray clay	20	300
Clay, light-gray, and yellow-brown clay	40	340
Sand, medium to very coarse, and gravel	3	343
Clay, light-gray	13	356
Sand, fine to medium, and light-gray clay	15	371
Clay, silty, light-gray	13	384
Sand, very fine to medium, and thin layers of gray clay	33	417
Sand, fine to very coarse, and very fine to fine gravel	10	427
Sand, very fine to medium, and thin layers of gray clay	59	486
Clay, light-gray, and fine sand	6	492
Sand, silty, very fine to medium	24	516
Clay, light-gray	31	547
Sand, very fine to medium	15	562
Sand, very fine to medium, and light-gray clay	18	580
Clay, light-gray and yellow-brown	60	640
Sand, fine to very coarse, and light-gray clay	42	682
Clay, light-gray, and layers of fine to very coarse sand	30	712
Sandstone, very fine to medium, and fine to coarse sand	53	765
Clay, light-gray, and very fine to medium sandstone	17	782
Clay, light-gray, and very fine to medium sandstone	17	782
Clay, light-gray; some yellow brown	38	820
Clay, gray and brown, and fine to very coarse sand	46	866
Sand, silty, fine to medium	61	927
Sand, silty, fine, and light-gray clay, in alternating layers	73	1,000
13S/16E-16F		
Levee fill	8	8
Sand, tan, very fine to medium	1	9
Clay, reddish-brown, silty, rather hard	25	34
Sand, light-brown, silty, very fine to medium	9	43
Clay, reddish-brown	7	50
Sand, fine to medium, and blue-gray clay	13	63
Sand, light-brown, silty, very fine to medium	4	67
Sand, very fine to medium, and gray sandy clay	7	74
Clay, gray, tough, and some silty very fine to medium sand	14	88
Sand, very fine to medium, brown, and gray sandy clay	12	100
Sand, light-brown, very fine to fine, and gray to buff clay	4	104
13S/16E-16F — Continued		
Clay, gray, sandy	2	106
Clay, gray, sandy, and beds of tough sticky silty clay	69	175
Clay, gray, silty, and some streaks of fine sand	22	197
Clay, gray, silty, sticky	18	215
Sand, brown, fine, silty	4	219
Clay, gray, silty; alternating beds are soft and tough; some thin stringers of silt	70	289
Clay, brown, sticky, and silt; some siltstone stringers. Gastropods and foraminifera at 295 ft	8	297
Sand, brown, fine to medium, and some coarse sand and subangular to subrounded pebble gravel	28	325
Clay, gray, sandy, silty	4	329
15S/18E-15M		
Clay, silty, tan	3	3
Sand, fine to medium, and silt	21	24
Sand, very coarse, and subangular to subrounded gravel	3	27
Sand, medium, and some fine sand and silt	10	37
Sand, coarse and medium	9	46
Sand, medium to coarse	23	69
Sand, fine to medium, and layers of brown silty clay	22	91
Sand, medium to coarse	21	112
Clay, silty, brown	13	125
Sand, fine to very coarse, and gravel	20	145
Clay, brown; alternating with layers of fine sand	30	175
Sand, fine to medium	19	194
Clay, silty, brown, and layers of fine sand to 5 ft thick	56	250
Sand, fine to coarse	96	346
Clay, silty, brown, and fine sand	11	357
Sand, fine to coarse	63	420
Clay, silty, brown	6	426
Sand, fine to coarse, and silt	21	447
Clay, silty, brown	2	449
Sand, medium to coarse, and few very thin layers of silty clay	108	557
Clay, silty, brown	5	562
Sand, fine to very coarse, and thin layers of brown clay	68	630
Sand, medium to very coarse, and some very fine gravel	13	643
Clay, brown	7	650
Sand, fine to very coarse, and layers of hard brown clay	35	685
Clay, brown, and fine to coarse sand, in alternating layers	11	696
Sand, fine to very coarse, and layers of gravel	37	733
Clay, brown	6	739
Sand, medium to very coarse, and some very fine gravel	14	753
Clay, hard, brown	9	762
Sand, fine to very coarse	16	778
Clay, brown; some blue and orange streaks	4	782

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thick-ness (feet)	Depth (feet)
Eastern Imperial Valley — Continued		
16S/21E-21P — Continued		
Sand, fine, and pea gravel; few streaks of clay	70	310
Sand, medium to very coarse; few angular pebbles to 1/2 in.	16	326
Sand, fine to medium, gray	4	330
Sand, fine and very fine, silty	5	335
Sand, fine and very fine	15	350
Sand, fine, cemented	10	360
Sand, fine, gray	7	367
Sand, fine to medium, and some fine gravel	8	375

TABLE 4. — *Drillers' logs of selected wells* — Continued

Lithology	Thick-ness (feet)	Depth (feet)
Eastern Imperial Valley — Continued		
16S/21E-21P — Continued		
Sand, fine to coarse; few pebbles and cemented sand layers	10	385
Sand, fine to medium	10	395
Clay and fine to coarse sand	9	404
Sand, fine to medium; few volcanic pebbles	11	415
Clay and fine to coarse sand	25	440
Clay and fine to coarse sand; few angular pebbles	10	450
Clay and fine to medium sand	7	457
Sand, fine to medium	3	460
Clay and fine to medium sand	4	464

TABLE 5. — *Chemical analyses of water from selected wells*

[Results in milligrams per liter, except as indicated]

Well location	Interval sampled (ft below land surface)	Analysis No.	Date of sample	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium: Sodium (Na)	Sodium and potassium: Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total dissolved solids	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH
EASTERN IMPERIAL VALLEY — Chocolate Mountains Piedmont Slope																				
10S/16E-5D	38- 42	1a	5-11-50	----	90	17	42		293	36	78	----	----	----	409	294	54	24	720	----
		1b	6-11-52	----	72	15	42	7.4	290	8	71	0.4	0	----	360	242	4	27	581	----
12S/18E-11	----	2	5-10-50	----	195	40	105		262	515	92	----	----	0	1,080	652	436	26	1,590	----
11N	10- 14	3	c 8- 7-63	14	122	29	150		234	475	44	1.0	----	----	952	424	232	44	1,270	7.9
12S/19E-15J	31- 39	4	2-19-63	28	197	17	43		170	432	42	.3	.6	----	849	562	422	14	1,130	8.1
13S/19E-3	----	5	12-13-63	----	186	60	1,320		260	1,400	1,360	----	----	----	4,470	710	497	80	6,910	7.7
5	330- 459	6	10-14-65	16	47	15	422		264	375	345	1.5	----	----	1,350	180	0	84	2,280	7.4
33Q	480- 690	7a	1- 9-62	21	52	2.6	370		85	248	430	3.2	3.1	.68	1,170	140	70	85	2,010	7.7
		7b	6- 6-62	16	57	5.1	357		88	250	414	3.2	----	----	1,140	148	76	84	2,080	7.6
		7c	12- 9-63	24	53	6.1	368	6.1	94	244	430	3.4	3.4	.96	1,180	147	70	84	1,980	7.6
15S/20E-9A	405- 521	8a	1-19-49	----	149	21	384		104	242	667	----	----	.72	1,510	458	373	64	2,740	----
		8b	9-29-68	16	24	5.8	281		84	125	348	1.9	----	----	844	84	15	88	1,590	7.5
23M	339- 475	9	3-36	22	418	15	1,415		37	362	2,680	----	----	.4	4,930	1,110	1,070	74	----	----
25N	291- 493	10	1-19-62	28	62	2	455		82	300	548	----	----	----	1,440	162	95	86	2,500	8.0
15S/21E-18A	74- 78	11	1-19-45	----	91	33	38		354	65	65	----	----	.36	471	362	72	19	790	----
Pilot Knob Mesa-Sand Hills Area																				
12S/16E-9A	150-1,000	12a	7- 8-63	28	22	566	420			217	645	----	----	----	1,750	248	0	83	3,150	7.6
		12b	7- 9-63	34	83	29	663		520	243	765	----	----	1.8	2,080	326	0	82	3,660	7.4
24	454- 475	13	5-12-17	60	8	0	262		185	103	232	----	----	----	756	20	0	97	----	----
15S/20E-33K	155- 210	14	1-27-49	----	17	7	316		317	41	344	----	----	----	830	71	0	91	1,530	----
16S/20E-14C	150- 152	15	7- 5-62	4	40	10	301		116	135	397	----	----	----	945	142	47	82	1,840	6.9
21P	87- 89	16	7- 5-62	10	91	30	135		174	333	111	----	----	----	797	352	210	46	1,240	7.8
27D	127- 144	17a	2-14-41	----	39	12	158		117	166	135	.3	----	.07	568	147	51	70	990	----
		17b	5-13-58	----	100	35	141		168	360	132	----	----	----	852	394	256	44	1,330	7.7
		17c	9-27-61	13	79	30	133		160	317	105	----	----	----	757	320	189	47	1,160	8.0
		17d	9- 4-63	15	95	32	126		174	317	119	.3	----	----	791	368	226	43	1,270	7.5
36R	124- 126	18	2- 5-65	16	90	33	111		164	283	121	.6	----	----	737	360	226	40	1,200	7.7
16S/21E-15G	190- 276	19	9-20-62	21	46	13	188		264	130	160	.6	----	----	691	170	0	71	1,200	7.7
15J	----	20a	7-22-61	----	----	----	233		226	----	231	----	----	----	----	184	0	----	1,380	----
		20b	1961	----	50	16	210		220	127	238	0.4	----	----	751	191	10	71	1,400	----
15K	----	21a	5-13-58	----	62	12	153		190	104	192	----	----	----	618	204	48	62	1,120	7.9
		21b	3-12-60	----	28	11	213		239	141	169	----	0.5	----	682	116	0	80	1,090	8.0
		21c	7-27-61	----	----	----	----	----	240	----	167	----	----	----	----	138	0	----	1,130	----
16B	598- 806	22a	7-19-61	23	24	235	191			157	358	.5	2.6	0.45	977	304	148	63	1,700	8.0
		22b	10-27-62	19	74	25	225		192	140	335	.7	----	----	915	288	130	63	1,700	7.3
19D1	----	23	7-19-61	----	----	----	----	----	156	----	218	----	----	----	----	260	132	----	1,260	7.8
19D2	166- 168	24	7- 5-62	4	64	17	251		140	165	344	----	----	----	915	228	113	70	1,690	7.1
21J	----	25a	1-19-49	----	64	35	11		122	13	160	----	----	.06	370	304	204	----	680	----
		25b	5-13-58	----	74	22	179		168	130	276	----	----	----	765	275	137	59	1,400	7.7
21G	258- 358	26a	6-18-62	24	59	17	99		205	108	107	.5	----	----	576	218	50	50	845	7.3
		26b	6-27-62	----	40	27	102		208	93	120	----	----	.24	513	211	40	51	854	8.0
21P	----	27a	3-12-60	----	36	21	132		188	112	137	----	----	.10	532	178	22	62	826	8.0
		27b	6-21-61	----	----	----	120		186	----	130	----	----	----	----	196	44	----	914	7.8
		27c	6-11-62	15	53	19	129		180	108	165	.3	----	----	579	212	64	57	1,050	7.8
		27d	6-22-62	27	34	28	143		180	100	179	----	----	.12	611	200	52	61	1,100	8.2
32R	87- 89	28	5-12-64	19	18	7.1	265		199	333	100	----	----	----	842	74	0	89	1,290	8.2
East Mesa																				
11S/15E-23M	25- 150	29a	6-13-63	33	106	107	503		212	700	635	1.6	----	----	2,190	705	531	61	3,630	7.4
		29b	9- 4-63	29	105	95	498		216	675	605	1.6	----	----	2,120	654	477	62	3,580	7.4
13S/16E-16F	----	30	8- 6-58	----	20	8	576	4	195	212	721	1.2	3.3	2.3	1,660	84	0	93	2,800	7.9
35M1	134- 136	31	1-16-62	20	82	44	607		128	267	938	----	----	----	2,020	385	280	77	3,910	8.2
35M2	29- 31	32	11- 8-61	34	191	181	2,210		204	1,550	3,010	----	----	----	7,280	1,220	1,050	80	11,300	7.6
13S/17E-32N	113- 115	33	1-16-62	27	88	45	578		147	308	865	----	----	----	1,980	405	284	76	3,620	8.1

TABLE 5. — *Chemical analyses of water from selected wells* — Continued

EASTERN IMPERIAL VALLEY — Continued
East Mesa — Continued

Well location	Interval sampled (ft below land surface)	Analysis No.	Date of sample	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium: Sodium (Na)	Sodium and potassium: Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total dissolved solids	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH
35P1	25- 27	34a	10-13-61	16	97	30	144		163	362	119	----	----	----	850	364	230	46	1,270	7.8
		34b	----	12	99	31	149		166	367	127	----	----	----	870	376	240	46	1,310	8.1
35P2	155- 157	35	5-10-62	7	73	32	121		126	300	113	----	----	----	709	312	208	46	1,150	7.8
14S/16E-11H	----	36a	8-22-62	28	13	5.5	422		193	125	483	1.3	----	----	1,170	55	0	94	2,180	7.6
		36b	2-12-63	26	12	5.4	423		192	130	487	1.3	----	----	1,190	52	0	95	2,150	7.8
26K1	155- 157	37	2- 3-62	22	35	17	841		372	525	805	----	----	----	2,430	157	0	96	4,170	8.2
26K2	19- 21	38a	11-21-62	33	23	17	1,310		472	1,180	965	----	----	----	3,760	126	0	91	5,760	8.2
		38b	2- 3-62	13	19	18	1,330		516	1,150	985	----	----	----	3,770	121	0	96	5,810	8.4
15S/16E-24G1	113- 115	39	1-18-62	5	384	232	2,010		293	217	4,120	----	----	----	7,110	1,910	1,670	70	12,700	8.1
24G2	50- 52	40	1-18-62	40	238	172	2,230		267	500	3,840	----	----	----	7,150	1,300	1,080	79	12,700	7.9
36E	360- 430	41a	7-31-61	14	8.2	1.6	300		450	76	159	3.0	----	----	787	27	0	96	1,360	8.3
		41b	9-17-61	16	6.6	1.1	294		440	80	153	----	----	----	771	21	0	97	1,320	8.2
15S/18E-13B	162- 164	42	2-11-64	21	74	19	325		57	238	478	.6	----	----	1,180	264	218	73	2,210	7.8
15K1	134- 136	43	1-18-62	22	22	7.9	225		155	300	97	----	----	----	752	87	0	85	1,190	8.2
15K2	24- 26	44	12	84	32	135	166			333	109	----	----	----	788	343	207	46	1,220	7.8
15M	309- 894	45a	4- 4-63	30	159	27	554		72	167	1,050	----	----	----	2,020	508	449	70	3,800	7.2
		45b	5-10-63	35	165	28	543		70	170	1,040	.6	3.8	0.68	2,020	525	470	69	3,790	7.5
		45c	1-14-64	23	158	43	504		59	200	1,000	----	----	----	1,960	570	522	66	3,790	7.3
19M1	155- 157	46	1-17-62	26	122	58	411		74	57	935	----	----	----	1,650	545	484	62	3,360	7.9
19M2	94- 96	47	3- 2-64	16	139	63	694		127	250	1,240	.8	----	----	2,470	606	502	71	4,541	7.9
26R	82- 84	48	5-16-63	32	87	32	204		200	317	211	.7	----	----	984	350	186	56	1,600	7.6
15S/19E28N	155- 157	49	2-19-64	39	143	5.6	885		94	225	1,410	1.9	----	----	2,760	380	303	84	5,060	7.8
33R	155- 157	50	3- 6-64	29	111	10	505		98	233	775	1.0	----	----	1,710	320	240	77	3,180	8.6
16S/16E-12Q	92- 94	51	1-22-62	13	101	55	750		265	600	900	----	----	----	2,550	478	263	77	4,340	8.0
16S/17E-23R	155- 157	52	2-24-64	21	49	21	403		296	120	508	.9	----	----	1,270	210	0	81	2,340	8.0
16S/18E-2R	134- 136	53	2-16-65	30	127	49	860		123	412	1,320	----	----	----	2,860	520	419	78	4,900	7.7
6R	145- 147	54	2-16-65	28	94	30	574		120	275	865	----	----	----	1,930	356	258	78	3,480	7.9
13R	145- 147	55	4-22-64	22	47	16	287		104	225	345	1.0	----	----	995	185	100	77	1,780	7.4
17R	155- 157	56	2-19-64	22	26	11	280		150	212	265	1.4	----	----	892	112	0	84	1,530	8.0
23A	58- 60	57a	9-16-64	10	28	7.7	234	4.3	145	175	227	1.1	1.9	.41	761	102	0	82	1,300	8.1
	148- 150	57b	9- 5-64	20	36	16	272	4.3	128	224	289	1.1	3.1	.46	929	156	52	78	1,570	8.2
	298- 300	57c	9-16-64	21	23	7.7	216	5.4	134	171	192	1.3	3.7	0.36	708	89	0	83	1,200	8.1
	498- 500	57d	9-15-64	26	24	7.8	213	13	122	156	211	1.0	3.7	.38	717	91	0	81	1,220	8.2
29J	155- 157	58a	1-22-64	30	16	7	282		186	180	242	----	----	----	850	68	0	90	1,450	8.2
		58b	2-19-64	27	12	7.3	271		192	165	224	1.9	----	----	804	60	0	91	1,370	8.1
32R	140- 630	59	6-30-64	27	23	8.6	272	4.0	208	235	200	1.7	.5	.64	874	93	0	86	1,460	8.0
35P1	----	60	12- 4-17	38	29	17	238		170	158	252	----	.34	----	818	142	3	78	----	----
35P2	----	61	2-14-41	----	12	16	257		96	279	215	1.0	----	----	828	96	18	85	1,440	----
16S/19E-2N1	136- 138	62	2- 3-62	25	65	22	153		136	316	102	----	----	----	751	252	140	57	1,170	7.8
2N2	62- 65	63	2- 3-62	5	58	26	140		70	295	149	----	----	----	688	250	192	55	1,130	7.4
5J	82- 84	64	5-14-63	23	44	12	445		110	350	474	1.6	----	----	1,400	160	70	86	2,390	7.8
9E	134- 136	65	2-13-64	20	41	6.7	278		98	208	308	1.3	----	----	912	130	50	82	1,670	7.8
11D	300- 610	66a	5-14-63	26	52	7.4	253		131	285	216	.6	1.1	.24	905	160	52	77	1,490	7.7
		66b	1-14-64	25	76	8.6	196		145	357	118	----	1.2	.14	854	232	113	64	1,300	7.3
15Q	72- 74	67	5-16-63	24	87	31	316		112	412	438	.6	----	----	1,420	344	252	70	2,390	7.5
32G1	40- 240	68a	5-29-58	19	54	29	202	6.1	163	343	150	5.0	1.2	----	891	255	120	63	----	7.8
		68b	6-19-58	----	63	31	160	12	146	300	160	.8	----	----	800	287	166	54	----	8.0
36P1	----	69	1933	----	38	11	144		156	102	145	0	----	----	518	140	12	69	900	----
36P2	----	70a	3- 3-52	----	84	29	105	.4	176	265	103	.6	2.5	----	679	329	184	41	----	8.3
		70b	5-13-58	----	104	38	140		178	380	140	----	----	----	900	416	270	44	1,400	7.9
		70c	7-18-61	----	82	29	121		163	305	96	----	----	----	715	324	190	45	1,140	7.9
		70d	9- 4-63	----	82	29	120		154	292	109	.5	----	----	730	324	198	45	1,170	7.4
16S/20E-31K	340- 520	71a	5- 2-62	21	78	16	138	5.9	149	293	103	.1	.8	.14	729	259	137	53	1,130	8.0
		71b	6-26-63	21	81	18	142		152	300	104	.3	1.2	.14	743	276	152	53	1,140	7.4
		71c	1-13-64	17	80	20	146		150	312	106	.3	----	----	756	280	157	53	1,150	7.4
32	----	72	12- 4-17	26	32	12	138		134	106	146	----	----	----	501	129	20	70	----	----
32R1	----	73a	1933	----	44	12	138		149	102	155	0	----	----	525	160	38	65	900	----
		73b	2-14-41	----	31	13	137		135	102	146	----	----	.20	498	132	21	69	919	----
32R2	82- 84	74	7- 5-62	3	97	4.4	122		66	250	150	----	----	----	659	260	206	50	1,090	6.9

17S/17E-3C1	----	75a	4- 4-50	----	65	30	126		171	280	91	----	----	----	678	286	146	49	1,080	----
		75b	3-13-52	----	27	31	393		229	116	525	----	----	----	1,210	196	8	81	----	----
3C2	----	76a	6-23-53	----	76	35	116		174	298	96	----	----	----	708	335	192	42	1,150	----
		76b	9-27-61	----	76	32	149		162	342	110	----	----	----	803	320	187	50	1,210	7.8
17S/18E-4A	179- 195	77a	9-27-61	18	21	8.4	226		160	215	158	----	----	----	726	87	0	85	1,190	8.0
		77b	6-15-64	26	23	8.1	213		162	208	143	1.5	----	----	704	91	0	84	1,170	7.8
4K	160- 175	78	11-24-47	----	37	17	159		165	115	179	0.2	----	----	589	162	27	68	1,100	----
17S/19E-4	25- 96	79	4- 2-52	7	102	19	15		195	277	160	----	----	----	820	332	172	----	1,380	5.5
CENTRAL IMPERIAL VALLEY																				
10S/14E-20N	----	80	4-28-61	----	----	----	----	----	210	----	6,050	----	----	----	----	2,440	2,270	----	19,200	8.0
11S/13E-22H	145- 147	81	5-10-62	3	134	49	384		100	275	710	----	----	----	1,600	535	453	61	3,120	7.4
12S/12E-25F1	103- 105	82	2- 1-62	2	107	86	295		79	425	535	----	----	----	1,490	620	555	51	2,710	7.4
25F2	14- 16	83	2- 1-62	1	944	242	4,570		20	1,200	8,530	----	----	----	15,700	3,350	3,330	75	24,700	6.9
12S/13E-15L	113- 115	84	7-10-62	2	476	202	1,300		40	700	2,900	----	----	----	5,600	2,020	1,990	58	9,370	7.2
12S/14E-21J	145- 147	85	7-10-62	18	810	822	3,400		408	4,050	5,850	----	----	----	15,200	5,400	5,060	58	19,800	7.4
12S/15E-23M	285- 325	86a	2-26-58	28	31	25	628	5.1	334	457	568	2.1	0.6	2.62	1,910	178	0	88	3,120	8.1
		86b	4-29-62	24	32	25	635		336	475	562	1.7	----	----	1,920	182	0	88	3,370	7.6
26J	304- 344	87	4-27-62	24	20	11	502		278	275	477	1.4	----	----	1,450	96	0	92	2,620	7.6
27R	----	88a	3-10-36	----	23	12	539		273	301	579	1.4	3.1	2.20	1,530	107	0	92	2,680	7.9
		88b	2-26-58	20	20	11	539	3.9	280	325	575	1.0	----	2.33	1,570	101	0	92	2,640	8.2
		88c	5-18-62	20	20	12	525		268	275	520	----	----	----	1,570	101	0	92	2,690	7.8
12S/16E-31N	----	89	4-27-62	16	36	12	1,110		276	45	1,620	1.4	----	----	2,980	140	0	94	6,030	7.7
13S/13E-22G	145- 147	90	7-10-62	16	564	460	3,100		434	1,250	5,950	----	----	----	11,600	3,300	2,940	67	18,600	7.2
13S/14E-21K	145- 147	91	7-10-62	15	930	608	1,990		294	1,250	5,400	----	----	----	10,300	4,820	4,580	47	16,500	7.1
13S/15E-1B	----	92a	3-10-36	----	46	15	1,112		392	308	1,108	1.2	----	10.1	3,190	174	0	93	5,290	----
		92b	4-16-48	----	20	35	1,132		407	605	1,195	.5	----	8.2	3,190	194	0	93	5,160	----
		92c	8- 1-61	32	36	13	1,120		370	586	1,180	1.4	2.1	9.9	3,160	144	0	94	5,150	7.5
1Q	----	93	4-27-62	19	16	6.8	460		252	110	528	1.4	----	----	1,270	68	0	94	2,530	7.6
2N	----	94	2-21-62	12	12	4.1	491		352	155	428	1.6	----	----	1,320	47	0	96	2,380	7.8
3N	----	95a	9-17-59	----	9.6	0.4	510	3	442	115	430	1.8	0	----	1,290	25	0	97	----	7.8
		95b	3- 1-62	34	9.3	4.1	486	2.9	441	112	445	2.1	.6	2.4	1,320	40	0	96	2,270	7.7
3Q	----	96	2-21-62	23	17	2.6	489		368	115	490	1.5	----	----	1,320	53	0	95	2,540	7.9
5D1	851- 886	97	3- 1-62	27	25	4.3	611		1,240	60	230	1.3	----	----	1,580	80	0	94	2,600	8.2
5D2	----	98	3- 1-62	29	40	2.9	613		1,170	55	302	1.2	----	----	1,630	112	0	92	2,780	8.2
5D3	772- 812	99	11-13-63	23	4.8	10	546		1,150	0	208	1.5	----	----	1,470	54	0	96	2,310	8.0
12R	----	100	11-17-61	23	14	8.3	5$4		314	210	488	----	----	----	1,400	69	0	94	2,520	8.2
15G	----	101	2-16-62	16	13	1	488		508	140	378	1.8	----	----	1,290	38	0	96	2,230	8.2
21Q	----	102	11-15-61	29	8.0	2.7	452		656	92	269	----	----	----	1,180	31	0	97	2,040	8.2
22P	----	103	11-15-61	32	6.2	3.5	504		672	130	312	----	----	----	1,320	30	0	97	2,270	8.3
23Q	----	104	2-21-62	18	31	8.6	952		424	525	915	----	----	----	2,660	113	0	95	4,660	8.1
24E	----	105	2-21-62	15	11	4.0	447		316	125	442	1.7	----	----	1,200	44	0	96	2,230	8.2
24N	----	106	2-21-62	23	10	3.6	481		482	89	422	1.6	----	----	1,270	40	0	96	2,380	8.3
28N	----	107	2-16-62	20	61	50	1,110		534	538	1,240	----	----	----	3,180	356	0	87	5,560	7.7
32D	----	108	9-24-62	21	17	12	883		840	140	835	----	----	----	2,330	92	0	95	4,170	7.7
33A	1,269-1,389	109a	9-27-59	----	29	12	1,052		516	216	1,295	.7	----	----	3,090	123	0	94	----	7.7
		109b	11-15-61	33	27	15	1,090		530	240	1,290	----	----	----	2,960	128	0	95	5,360	7.9
33K	----	110	2-14-62	13	135	77	1,760		530	2,200	1,360	----	----	----	5,710	655	381	85	7,740	7.7
34J	----	111	2-21-62	27	11	4.0	555		748	145	342	1.8	----	----	1,460	44	0	97	2,420	8.2
34K	----	112	2-14-62	29	13	2	562		816	121	328	1.7	----	----	1,460	40	0	97	2,480	8.6
34M	936- 954	113	2-14-62	30	13	2	578		782	132	365	1.8	----	----	1,510	40	0	97	2,560	8.0
13S/16E-6A	----	114	4-27-62	14	14	9	448		268	160	467	1.5	----	----	1,250	72	0	93	2,340	7.8
6J	----	115	4-27-62	13	19	10	512		224	183	588	1.2	----	----	1,440	90	0	92	2,810	7.8
6N	----	116	11-17-61	3	19	9.8	572		210	205	672	----	----	----	1,610	88	0	93	2,950	8.1
6P	----	117	3- 1-62	21	24	8.3	573		264	200	648	.9	----	----	1,610	94	0	93	2,950	8.0
28R	----	118	8- 1-61	----	----	----	593		211	----	608	----	----	----	----	90	0	94	2,760	8.0
14S/13E-33K	124- 126	119	1-23-62	19	68	39	935		278	588	1,080	----	----	----	2,870	330	102	86	4,820	7.9
14S/14E-22G	82- 84	120	1-23-62	16	1,610	1,110	1,770		352	2,050	7,100	----	----	----	13,800	8,580	8,290	31	21,700	7.2
30N	124- 126	121	1-23-62	25	676	417	3,930		416	875	7,580	----	----	----	13,700	3,400	3,060	72	22,900	7.4
14S/15E-1B	----	122	11- 6-61	22	23	13	436		314	105	485	1.6	5.8	1.4	1,250	112	0	89	2,180	8.0
6B	----	123	2-14-62	30	61	11	1,200		810	412	1,220	----	----	----	3,340	197	0	93	5,630	8.0
9D	----	124	2-14-62	21	60	53	1,050		510	575	1,160	----	----	----	3,170	366	0	86	5,250	7.6
9N	----	125	7-25-61	33	61	46	1,030		518	482	1,200	1.1	3.1	2.6	3,110	340	0	87	5,140	7.9
11D	----	126	7-25-61	----	----	----	529		760	79	344	----	----	----	----	41	0	97	2,380	8.2
12N	1,171-1,233	127	5-18-62	25	34	12	947		362	538	945	1.3	----	----	2,680	134	0	94	4,740	7.6
15B1	----	128a	3-10-36	----	15	6.0	628		762	87	510	1.3	4.3	4.13	1,630	61	0	96	2,840	8.1
		128b	2-26-58	34	12	4.1	622	4	762	87	487	1.9	1.2	4.47	1,630	46	0	96	2,740	8.2
		128c	9- 4-63	25	14	2.2	618		756	95	472	1.3	----	----	1,610	44	0	97	2,790	8.0
15B2	----	129	9- 4-63	24	19	6.9	760		692	85	758	1.6	----	----	2,000	76	0	96	3,570	7.9
23M	----	130	7-25-61	34	6.8	4.6	494		700	75	322	1.8	----	----	1,290	36	0	97	2,250	8.0
27A	----	131a	3-10-36	----	27	27	756		847	194	651	2.6	6.8	----	2,090	182	0	90	3,430	----
		131b	7-25-61	24	26	17	530		616	292	342	1.7	6.8	----	1,530	136	0	89	2,450	7.7

TABLE 5. — *Chemical analyses of water from selected wells* — Continued

Well location	Interval sampled (ft below land surface)	Analysis No.	Date of sample	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium: Sodium (Na)	Sodium and potassium: Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total dissolved solids	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH
CENTRAL IMPERIAL VALLEY — Continued																				
28K1	----	132	3-1-62	27	31	21	780		684	250	735	----	----	----	2,190	162	0	91	3,860	8.2
28K2	----	133	3-1-62	20	37	21	800		664	283	765	----	----	----	2,260	178	0	91	3,980	8.2
34B	----	134a	3-10-36	----	69	55	711		658	249	810	1.0	3.1	.98	2,230	398	0	80	3,820	7.7
		134b	9-8-48	----	42	17	745		660	228	692	.6	----	2.2	2,050	175	0	90	3,190	----
		134c	2-26-58	31	45	38	608	3.9	662	194	601	1.3	.6	2.3	1,850	270	0	83	3,150	8.1
		134d	7-25-61	30	----	----	591		668	187	565	.9	.9	2.3	----	256	0	83	2,990	7.8
		134e	9-4-63	24	49	29	602		694	200	545	1.5	----	----	----	240	0	84	3,100	7.8
34Q	----	135a	9-24-62	15	21	20	583		720	250	390	----	----	----	1,640	134	0	90	2,840	7.7
	----	135b	9-4-63	17	39	13	656		580	450	448	----	----	----	1,910	152	0	90	3,200	7.8
34R	----	136	3-1-62	22	74	90	1,180		356	358	1,740	----	----	----	3,640	556	264	82	6,980	8.0
14S/16E-4Q	----	137a	1-3-58	18	7	1	430	5.1	585	165	220	.2	----	2.3	1,140	26	0	97	----	8.6
		137b	7-25-61	----	----	----	----	----	604	----	219	----	----	----	----	24	0	----	1,810	8.2
16B	----	138	8-1-61	29	8	3	385		432	105	284	1.8	----	----	1,030	32	0	96	1,750	8.3
16K	----	139	7-27-61	25	14	3	297		300	60	279	1.5	----	----	832	60	0	92	1,490	8.1
19N	----	140	2-4-62	23	27	6.9	765		332	135	955	----	----	----	2,080	96	0	94	3,870	8.1
21B1	----	141	7-27-61	34	8	2	379		400	105	292	1.8	----	----	1,020	30	0	96	1,750	8.1
21B2	----	142	9-27-61	18	6.0	3.6	392		468	115	268	----	----	----	1,040	30	0	97	1,800	8.1
21D	----	143	7-27-61	23	7.4	4.3	411		528	98	275	2.0	----	----	1,080	36	0	90	1,870	7.9
22D	----	144	7-27-61	18	23	12	932		204	88	1,330	----	----	----	2,510	108	0	95	4,690	7.7
34E	----	145	7-25-61	31	9	4	431		580	155	242	----	----	----	1,160	40	0	96	1,950	8.1
15S/12E-22G	82-84	146	2-1-62	4	432	178	3,250		198	3,100	3,890	----	----	----	10,900	1,810	1,650	80	15,700	7.7
15S/13E-27E	113-115	147	7-10-62	7	700	451	3,090		97	3,900	4,380	----	----	----	12,600	3,600	3,520	65	16,400	6.8
15S/14E-13E	92-94	148	7-10-62	8	560	361	2,300		268	1,200	4,550	----	----	----	9,110	2,880	2,660	64	14,900	7.2
18C	140-440	149a	5-5-58	----	417	199	3,312	58.7	281	452	6,000	0.3	----	----	10,250	1,860	1,630	79	17,750	7.7
		149b	6-9-58	18	386	184	3,200	5.0	281	450	6,071	----	----	----	10,500	1,730	1,500	80	18,400	6.8
15S/15E-1H	----	150	8-2-61	30	9.1	3.5	480		676	65	315	2.6	3.0	3.2	1,240	37	0	97	2,090	8.2
9E1	----	151	7-21-61	41	45	35	865		508	356	960	1.1	7.8	2.2	2,600	268	0	88	4,250	8.0
9E2	----	152a	2-25-58	30	34	29	1,177	5.1	727	175	1,410	1.3	.6	3.6	3,220	204	0	92	5,560	7.8
		152b	9-24-62	26	30	28	1,180		728	180	1,400	----	----	----	3,210	192	0	93	5,570	7.5
9N	----	153	9-24-62	29	54	67	1,790		824	233	2,400	----	----	----	4,990	412	0	90	8,840	7.6
9Q	----	154	3-1-62	25	26	15	650		712	181	545	----	----	----	1,800	128	0	92	3,220	8.2
10E	----	155a	5-16-33	22	21	19	659	9.8	656	200	591	2.5	.4	2.9	1,860	130	0	91	3,090	8.0
		155b	2-25-58	32	23	18	665	4.7	626	204	607	1.9	----	2.7	1,880	133	0	91	3,150	8.0
		155c	7-21-61	----	----	----	----	----	623	----	600	----	----	----	----	124	0	----	3,220	8.2
10K	----	156a	5-17-33	25	24	26	668	10	695	229	582	2.7	----	3.0	1,910	166	0	89	3,150	8.1
		156b	2-25-58	32	24	21	675	5.1	678	226	586	2.1	.6	2.8	1,910	144	0	91	3,170	8.1
		156c	7-21-61	35	22	22	676		664	221	585	2.0	4.7	2.8	1,900	144	0	91	3,120	7.6
11G1	----	157a	5-16-33	24	20	17	453	8.6	610	60	388	2.1	----	2.2	1,280	119	0	88	2,180	8.0
		157b	9-2-48	----	36	32	434		610	101	397	.4	----	----	1,310	226	0	81	2,300	----
11G2	----	158a	2-25-58	26	67	61	855	4.7	439	228	1,206	1.5	.6	2.2	2,670	418	59	81	4,650	7.9
		158b	7-21-61	28	----	----	865		422	231	1,220	1.4	3.2	1.9	----	432	86	81	4,630	7.9
12H	----	159	7-21-61	----	----	----	----	----	618	----	218	----	----	----	----	30	0	----	1,830	8.2
13N	----	160	2-21-62	26	9	3	367		618	134	127	2.8	----	----	978	35	0	96	1,590	8.3
15F	----	161	9-4-63	24	13	68	505		736	90	310	1.8	----	----	1,310	40	0	96	2,250	8.1
25B	----	162	7-27-61	32	18	6.6	794		470	180	870	----	----	----	2,140	72	0	96	3,790	7.9
25D	----	163	2-6-62	22	14	2	517		698	133	322	1.6	----	----	1,360	45	0	96	2,260	8.2
25F	----	164a	3-19-58	----	11	3	470	3	682	92	282	2.4	0	----	1,200	40	0	----	----	7.9
		164b	7-18-61	42	----	----	481		688	105	290	1.9	3.0	----	----	45	0	96	2,080	8.1
25F	----	164c	9-4-64	29	13	1.8	484		692	120	282	1.2	----	----	1,280	40	0	96	2,150	8.0
35F	----	165a	3-29-33	26	20	6.3	763	11	305	129	965	1.7	----	5.0	2,070	80	0	95	3,680	7.8
		165b	2-24-58	26	21	7.4	767	4.7	339	140	945	1.3	0.6	4.9	2,080	82	0	95	3,700	8.2
		165c	7-18-61	31	----	----	771		332	137	945	1.1	2.9	3.8	----	76	0	96	3,630	8.1
36D	----	166a	4-10-51	----	16	11	964		464	78	287	----	3.2	1.2	991	84	0	90	1,680	8.1
		166b	3-19-58	----	17	9	350	3	451	77	288	2.0	----	----	977	78	0	----	----	7.9
		166c	7-18-61	22	16	8	358		442	75	290	1.4	.5	1.3	992	74	0	91	1,710	7.9
15S/16E-7F	----	167	2-3-62	39	8	3	421		644	114	213	----	----	----	1,120	31	0	97	1,820	8.4
7R	664-695	168	8-2-61	----	----	----	----	----	666	----	278	----	----	----	----	38	0	----	2,110	8.0
8E	475-488	169	8-2-61	24	16	9	804		804	128	275	1.4	6.1	3.3	1,380	77	0	93	2,240	7.9

15P	----	170	7-27-61	21	7	3.3	426		552	155	237	3.2	----	----	1,130	31	0	97	1,920	8.0
18Q	----	171a	8-20-58	----	17	7.8	397		671	79	217	1.6	----	1.8	1,070	74	0	92	1,710	7.9
		171b	8-20-58	----	41	31	706		360	220	880	1.9	----	1.6	2,040	230	0	87	3,360	7.8
		171c	12-12-61	21	13	40	729		300	190	951	----	----	----	2,090	198	0	89	3,870	8.8
19E	----	172a	2-25-58	32	7.4	2.9	318	1.6	623	97	79	3.0	----	2.4	852	30	0	96	1,360	8.3
		172b	7-27-61	----	----	----	327		622	110	82	----	----	----	----	28	0	96	1,390	8.1
22F	----	173	7-31-61	21	4.8	1.7	251		336	52	163	1.7	----	----	663	19	0	97	1,180	8.2
22L	----	174a	3-20-58	----	17	6	545	4	390	124	588	2.4	----	----	1,480	68	0	----	----	7.7
		174b	7-31-61	29	17	5	571		404	135	588	1.7	----	----	1,550	64	0	95	2,740	8.2
16E-23F	452- 542	175	2-14-62	11	9	1	385		548	185	151	3.5	----	----	1,020	26	0	97	1,600	8.3
27N	----	176	7-31-61	31	6	1	264		444	80	100	2.0	----	----	706	20	0	97	1,110	8.4
29Q1	537- 616	177	9-27-51	15	7.2	2.2	277		544	120	42	3.0	----	----	735	27	0	96	1,150	8.2
29Q2	----	178	2-14-62	21	1.1	1	385		634	170	115	2.8	----	----	1,020	30	0	96	1,570	8.3
16S/12E-36E	103- 105	179	7- 9-62	11	72	23	461		145	80	762	----	----	----	1,480	275	156	78	2,820	7.8
16S/13E-13N	145- 147	180	7- 9-62	2	362	211	3,020		45	175	5,750	----	----	----	9,540	1,770	1,730	79	16,600	7.3
16S/15E-17L	145- 147	181	7- 9-62	14	376	214	2,920		267	400	5,350	----	----	----	9,410	1,820	1,600	78	16,100	7.4
16S/16E-1M	----	182	6- 1-50	----	81	35	153		189	310	142	----	----	----	811	346	191	49	1,320	----
3C	----	183a	7- 8-61	----	----	----	----	----	458	----	165	----	----	----	----	23	0	----	1,440	8.4
		183b	9- 4-63	25	14	1	327		456	100	187	3.0	----	----	885	38	0	95	1,530	8.2
14A	----	184	9-27-61	17	15	4.4	567		290	145	638	----	----	----	1,530	50	0	96	2,830	8.0
15B	864- 877	185a	2-24-58	24	11	3.9	425	2.0	445	112	345	2.3	1.6	2.2	1,120	43	0	95	1,960	8.3
		185b	7-28-61	29	----	----	426		472	116	320	1.9	1.6	2.2	1,120	39	0	96	1,930	8.3
33D	----	186a	3-20-58	----	20	9	540	3	307	112	646	2.0	----	----	1,480	88	0	93	----	7.7
	----	186b	----	21	17	4.3	576		316	115	662	----	----	----	1,550	60	0	95	2,870	8.0
35F	432- 590	187a	8-18-58	----	21	5.4	349		214	192	320	1.2	9.3	1.1	1,000	72	0	91	1,620	7.8
	320- 400	187b	8-19-58	----	20	4.6	367		228	179	352	1.3	6.8	1.2	1,040	69	0	92	1,680	7.7
	46- 234	187c	8-20-58	----	196	117	1,670		274	1,970	1,650	2.4	11.2	2.9	5,750	970	745	79	8,260	7.6
	46- 234	187d	8-21-58	----	235	144	1,980		299	2,490	1,880	2.9	12.6	3.2	6,890	1,180	934	79	8,930	7.6
16½S/12E-2	----	188	7-31-50	----	97	34	122		198	312	114	----	----	----	791	382	219	41	1,190	----
17S/13E-20N	82- 84	189	1-31-62	29	160	70	766		394	1,000	725	----	----	----	2,960	720	396	70	4,540	8.2
17S/14E-14Q1	71- 73	190	1-31-62	10	448	261	1,720		304	1,350	3,040	----	----	----	6,980	2,190	1,440	63	11,000	7.9
14Q3	----	191	3-62	5	175	122	1,480		199	800	2,240	----	----	----	4,920	940	777	77	8,350	7.7
17S/15E-10N	110- 450	192	4-21-58	18	253	143	1,541	19.4	299	1,450	2,040	----	----	.05	5,610	1,220	975	80	8,500	7.5
16K	150- 152	193	1-30-62	11	244	161	1,530		257	850	2,490	----	----	----	5,410	1,270	1,060	72	8,890	----
17S/16E-18B	150- 152	194	1-30-62	3	103	48	953		198	538	1,280	----	----	----	3,020	455	292	82	4,800	7.5

WESTERN IMPERIAL VALLEY

Lower Borrego Valley

12S/8E-15R	----	195	8- 1-63	24	81	10	482		116	650	365	2.5	----	----	1,670	244	149	81	2,640	7.6
22E	----	196a	1- 8-54	----	16	1.8	177	3.4	96	145	147	----	.3	----	538	48	0	88	936	7.7
		196b	8- 2-63	20	18	.7	171		88	125	145	4.8	----	----	529	48	0	88	911	7.5
22G	----	197	8- 2-63	24	76	7.4	309		88	325	335	3.8	----	----	1,120	220	148	75	1,870	7.6
23G	----	198	8- 1-63	20	82	15	420		96	575	350	4.0	----	----	1,510	268	190	77	2,410	7.6
12S/9E-22A1	312- 412	199	7-29-63	19	450	184	1,360		96	1,850	2,000	1.3	----	----	5,910	1,880	1,880	61	8,630	7.2
22A2	285- 667	200a	9-25-62	20	157	23	372		92	388	578	----	----	----	1,580	486	410	62	2,770	7.3
		200b	7-29-63	19	130	29	383		100	400	550	.8	----	----	1,560	442	360	65	2,630	7.4
23D	250- 580	201a	9-25-62	19	162	31	381		84	388	628	----	----	----	1,650	530	461	61	2,920	7.3
		201b	7-29-63	20	163	31	409		84	425	645	1.3	----	----	1,740	534	465	62	2,900	7.5

San Felipe Creek-Superstition Hills Area

12S/10E-26M	----	202a	1- 8-18	15	56	13	270		98	216	336	----	----	----	995	193	112	75	----	----
		202b	1- 9-49	----	87	34	222		97	284	355	----	----	----	1,030	356	277	58	1,770	----
		202c	9-25-62	15	61	14	292		96	233	370	0.8	----	----	1,030	210	132	75	1,920	7.2
26	----	203	1- 4-49	----	130	38	465		281	396	550	----	----	----	1,720	407	176	71	2,820	----
34G	----	204a	1- 4-49	----	170	67	1,320		104	25	2,310	----	----	----	3,920	495	410	85	----	----
		204b	9-25-62	0	109	46	1,590		66	5	2,740	----	----	2.0	4,520	462	408	88	8,430	6.6
12S/11E-18J1	310- 650	205a	5-20-64	18	39	8.4	470	9.4	200	296	495	1.8	0.1	2.0	1,440	132	0	88	2,470	8.2
		205b	7- 2-64	18	30	9.0	472	9.4	191	285	498	1.2	5.2	2.6	1,420	112	0	89	2,460	8.4
18J2	35- 55	206	5-20-64	19	348	197	2,380		248	2,400	2,950	----	----	----	8,420	1,680	1,480	76	12,600	7.2
21	----	207a	11-20-17	26	30	22	705		207	451	748	----	1.4	----	2,090	165	0	90	----	----
		207b	9-25-62	----	28	32	1,930		567	800	2,200	----	----	----	5,270	202	0	95	9,180	7.8

Coyote Valley

16S/9E-25K	90- 247	208a	5-15-59	----	19	67	79	4.3	157	27	61	.6	3.2	----	279	75	0	68	----	8.3
		208b	3- 6-62	15	20	3.2	73		152	25	49	1.0	----	----	262	63	0	----	509	7.3
25M	----	209	3- 6-62	17	23	4.5	82		152	32	67	1.1	----	----	303	76	0	70	532	7.3
26H	----	210	3- 5-62	29	18	3.9	93		160	30	68	1.1	3.9	----	326	61	0	77	540	7.8
35M	415- 495	211a	7- 2-62	----	1.4	.2	104	8.0	129	14	80	3.8	.1	----	330	4.5	0	94	----	9.3
		211b	1- 9-63	48	1.5	.1	105		123	10	82	2.0	----	----	311	4	0	98	509	8.8

TABLE 5. — *Chemical analyses of water from selected wells* — Continued

Well location	Interval sampled (ft below land surface)	Analysis No.	Date of sample	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium: Sodium (Na)	Sodium and potassium: Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total dissolved solids	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)	pH
WESTERN IMPERIAL VALLEY — Continued																				
Coyote Valley — Continued																				
35N	----	212	1-9-63	35	6.1	2.2	114		162	14	84	2.0	----	----	338	24	0	91	577	7.8
36C1	----	213a	10-27-52	22	20	6	76		143	24	69	.9	2.5	----	292	76	0	76	450	8.2
		213b	2-19-58	----	14	5	102	9	149	30	78	----	3	----	315	56	0	77	582	8.1
		213c	3-5-62	10	14	3.2	106		130	33	94	2.2	0	----	326	48	0	83	583	8.0
36C2	180-300	214a	2-8-61	----	16	4.9	93	43	156	27	69	1.6	4.8	----	299	60	0	76	----	8.3
		214b	3-5-62	14	19	2.6	101		168	28	75	1.5	----	----	325	58	0	79	584	7.3
36G1	199-214	215a	5-27-57	25	5	4	124		178	39	71	.1	----	----	357	30	0	90	608	----
		215b	2-19-58	----	5	1	128	6	177	35	78	----	----	.45	341	17	0	92	622	8.4
		215c	3-5-62	11	5.8	1.5	133		196	32	75	3.5	----	----	356	20	0	94	628	7.7
36G2	----	216	3-5-62	9	5.8	1.6	141		188	39	87	4.0	----	----	381	21	0	94	679	7.7
36R	----	217a	9-17-48	24	7.2	7.8	141		224	69	72	----	----	----	433	50	0	86	----	7.8
		217b	1953	----	12	3	144		207	63	84	----	----	----	410	42	0	88	----	----
		217c	1958	----	10	3	160	10	207	85	85	----	----	----	456	38	0	87	764	8.6
16S/10E-20R	----	218	2-19-58	----	13	12	500	9	308	370	376	----	0	----	1,430	83	0	92	2,300	8.0
28D	----	219	12-16-48	----	3	14	3,140		1,620	,520	2,510	----	----	----	8,000	0	0	99	----	----
30R	----	220a	6-27-59	40	32	12	129	5.3	166	95	128	----	2.5	----	527	130	0	67	910	7.8
		220b	3-5-62	20	25	7.4	108		156	43	109	1.0	----	----	391	93	0	72	711	7.9
West Mesa																				
14S/11E-32R	135-560	221a	4-3-62	16	133	36	445		82	827	365	1.4	.2	1.6	1,870	480	413	67	2,800	7.5
		221b	5-11-62	15	152	33	510		64	1,080	318	----	----	----	2,140	515	463	68	2,920	7.7
15S/11E-13K	93-95	222	4-15-64	15	368	142	1,260		142	1,650	1,700	----	----	----	5,210	1,500	1,380	64	7,970	7.7
15S/11E-32R	138-140	223	3-19-64	2	28	19	1,560		368	2,250	635	----	----	----	4,680	150	0	96	6,500	9.2
16S/12E-6P	262-264	224	8-18-58	----	131	57	726		146	769	866	.6	4.3	0.74	2,620	564	444	74	4,030	8.2
Yuha Desert																				
16S/11E-23B	121-123	225	3-19-64	3	148	96	4,150		184	3,330	4,380	----	----	----	12,200	765	614	92	17,800	8.2
16½S/10E-5D1	----	226	4-23-63	32	8.4	.7	260		272	160	141	2.2	----	----	742	24	0	96	1,220	8.2
5D2	----	227	7-17-62	31	8	2.9	155		220	58	86	2.8	----	----	454	33	0	91	750	8.1
6	----	228a	5-8-52	----	7.0	1.6	183		270	55	95	12.0	4.3	.4	493	24	0	94	876	8.2
		228b	3-4-58	----	4	.5	215	6	265	100	110	----	----	.25	568	11	0	96	980	8.8
16½S/11E-6M1	----	229	8-23-62	----	0	2.4	5,010		5,940	2,700	2,280	----	----	----	13,000	10	0	100	17,600	9.4
6M2	----	230	8-23-62	----	11	2.6	1,010		1,500	400	420	----	----	----	2,630	38	0	98	4,150	8.5
17S/9E-11G	----	231	7-17-62	34	1	.4	124		112	22	106	3.5	----	----	347	4	0	98	590	9.4
17S/10E-2E	----	232	4-22-64	11	23	3	238		137	158	219	.6	----	----	721	70	0	88	1,250	7.4
17S/12E-17A	----	233	3-19-64	15	188	73	690		236	825	865	----	----	----	2,770	770	576	66	4,680	8.0

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