State of California
THE RESOURCES AGENCY OF CALIFORNIA
Department of Water Resources

BULLETIN No. 108

COACHELLA VALLEY INVESTIGATION

JULY 1964

HUGO FISHER	EDMUND G. BROWN	WILLIAM E. WARNE
Administrator	*Governor*	*Director*
The Resources Agency of California	State of California	Department of Water Resources

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STATE OF CALIFORNIA—RESOURCES AGENCY

EDMUND G. BROWN, Governor

DEPARTMENT OF WATER RESOURCES
P. O. BOX 388
SACRAMENTO

April 20, 1964

Honorable Edmund G. Brown, Governor,
and Members of the Legislature of the
State of California
State Capitol
Sacramento, California

Gentlemen:

I have the honor to transmit herewith Department of Water Resources Bulletin No. 108 entitled "Coachella Valley Investigation." The report has been prepared as part of the cooperative agreement between the State and the Coachella Valley County Water District as authorized in the Budget Act of 1960-61, Item 254.1.

Bulletin No. 108 includes a description of the physical characteristics of the Coachella Valley Ground Water Basin and its subdivisions, and contains an inventory of the surface and underground water resources within the basin. In addition, the quality and character of the waters in the basin are discussed and the hydrologic budget, under fixed 1958 cultural conditions, is evaluated.

The results of the study indicate Coachella Valley Ground Water Basin has a storage capacity for about 39,000,000 acre-feet of ground water. Under present cultural conditions the amount of water extracted from the basin has caused an overdraft in excess of 100,000 acre-feet each year. Although importation of Colorado River water has supplemented the water available for agricultural use, ground water extractions continue to exceed the water supply replenishing the ground water basin. Ground water of good quality exists in the major portion of the basin. However, poor quality water present in the semiperched zone, coinciding with a high ground water table, has hindered the full agricultural development of the basin.

Considering the increasing need for water in Coachella Valley, the data presented in this report will be a guide for planning and developing a basin management program, as well as in determining the participation by residents of the valley in statewide planning and construction of water resources developments.

Sincerely yours,

William E. Warne

Director

AUTHORIZATION

Certain provisions of the State Water Resources Law of 1945 (Water Code Sections 12616-12634) authorize the State to make investigations of the water resources of the State and make reports thereon, as deemed expedient and economically feasible. The State is further authorized to enter into cooperative agreements under Section 12611 of the code, when requested by local agencies, in accomplishing the purpose of the law. Accordingly, the Budget Act of 1960 (1961 California Statutes, Chapter 11, page 73, Item 254.1) provided:

> "For groundwater investigation studies in Coachella Valley, comprising the alluvial fill area of the Whitewater River watershed extending from the drainage divide in the San Gorgonio Pass on the north to Riverside County line on the south, and bounded on the northeast by the San Bernardino Mountains, Little San Bernardino Mountains, Mecca Hills, and Orocopio Mountains, and on the southwest by the San Jacinto Mountains and Santa Rosa Mountains, Department of Water Resources, payable from the California Water Fund------- 50,000 provided, that the moneys hereby appropriated may be expended from time to time, but no expenditure shall be made unless and until moneys equal to or in excess of the amount then proposed to be expended for such work shall be made available (by a political subdivision, public district, municipality, county or public agency, including agencies of local government but excluding agencies which are a part of the executive department of the state government) for expenditure by the department for such work, to the end that any sums expended from this appropriation from time to time shall be matched by like or greater amounts from public sources other than the State Treasury or funds of any agency which is a part of the executive department of the state government. The appropriation made by this item shall remain available for expenditure until June 30, 1962."

In keeping with the statutory authorization and the legislative financing, Cooperative Agreement No. 851033 was executed on July 1, 1960, by the department and the Coachella Valley County Water District. This agreement, reproduced in Appendix A of this report, provided for the contribution of funds equally by the State and the district, with "the objective of completing the investigation and report by June 30, 1962, or as nearly thereafter as possible." Under the provisions of Government Code Section 16304 (c) the funds so contributed were then available for completion of the study. A total of $100,000 was jointly deposited in the Water Resources Revolving Fund by the two participating agencies for financing the complete study and report.

ACKNOWLEDGMENT

Valuable assistance and data used in this investigation were contributed by numerous federal, state, and local agencies, and by private companies and individuals. This cooperation is gratefully acknowledged.

Special mention is made of the helpful cooperation of the following:

Coachella Valley County Water District
Robert Spencer, Research Engineer

City of Indio, Water Department

County of Riverside, Office of the Agricultural Commissioner

Dr. Gordon Eaton, Geology Department, University of California at Riverside

United States Geological Survey
Hydrologic Laboratory, Denver, Colorado
Lower Colorado River Project Staff, Yuma, Arizona
Thomas W. Dibblee Jr., Menlo Park, California

United States Weather Bureau, Weather Forecast Unit, Salt Lake City, Utah
Eugene Peck, Hydrologist in Charge

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

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Rainfall-runoff analyses were conducted by

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COACHELLA VALLEY COUNTY WATER DISTRICT

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CHAPTER I. INTRODUCTION

Coachella Valley lies in the northwestern apex of the hot, arid Colorado Desert of California, in the central portion of Riverside County. The warm dry climate, proximity to the Los Angeles metropolitan area, and the availability of an adequate water supply have been the basis for flourishing agricultural and winter resort economies in the valley. Future expansion of these desert lands will be largely dependent on the continued availability of an adequate water supply, as has been recognized by the Coachella Valley County Water District, the major water service agency in the area.

The rapid expansion of both irrigated agricultural and urban lands in this area during the past twenty years, and the corresponding increase in water use, had accentuated the need for a thorough study of the water resources in the valley. The Coachella Valley County Water District, in January 1960, inquired of the Department of Water Resources regarding the possibility of such an investigation being made. Subsequently, an investigation was authorized and conducted.

The studies were conducted by personnel of the Department of Water Resources and the investigation was completed by June 30, 1962. An interim report which summarized the findings was issued at that time.

Scope and Conduct of Investigation

The agreement under which this study was initiated by the two cooperating agencies set forth certain general objectives. These objectives were stated to be as follows:

1. Delineation of the boundaries and the geology of the ground water basin or basins of the study area.

2. Investigation of the physical factors affecting ground water occurrence.

3. Evaluation of the hydrologic characteristics of the study area.

4. Investigation of the water quality characteristics of the surface and ground waters in the area.

5. Determination of the amount of ground water in storage, and the underground storage space available.

A work program was developed to achieve the objectives through a two-phase approach. Initially, the physical makeup of the area under study and the geologic conditions affecting ground water movement and storage were determined. Based on these physical characteristics, an evaluation was made of the hydrologic aspects of the study area, including the storage capacity and change in storage of ground water basins, historical utilization of ground water, and annual recharge of the ground water basins.

A field office at the headquarters of the Coachella Valley County Water District was established for department personnel during the first year of the investigation. Field studies were conducted to determine the nature and extent of water-bearing materials and to evaluate geologic conditions affecting the recharge and movement of ground water in the valley.

Approximately 600 water well logs were collected and analyzed in determining the characteristics and distribution of the water-bearing materials and the storage capacities therein. Department geologists interviewed water well drillers and observed water wells being drilled to aid in an evaluation of the water-bearing materials. In addition, the department cooperated with the United States Geological Survey in the drilling of two exploratory holes in Coachella Valley. Undisturbed soil samples and water samples were obtained for laboratory analysis.

A gravity survey, consisting of three line traverses of the valley area, was made with the assistance of Dr. Gordon Eaton and students of the Geology Department of the University of California at Riverside, for the purpose of aiding in the determination of subsurface structure of the basin.

The transmissibility of water-bearing materials was computed for nine locations in the study area through well pumping tests.

Information and basic data of prior studies by the Department of Water Resources, other public agencies, and individuals were reviewed. Since previous data did not adequately cover the valley, additional data were collected during the course of the investigation. For example, water level measurements of wells throughout the study area were made in the spring of 1961 to determine the direction of movement of ground water and to aid in the detection of subsurface barriers.

Studies were made of the mineral quality of surface and ground waters in order to determine the sources and types of water occurring within the area of investigation. To supplement previous data, more than forty ground water samples were collected during the study period for chemical analysis.

Basic hydrologic data, including precipitation, streamflow and ground water level records, were compiled from records of the department and the Coachella Valley County Water District, as well as the United States Army Corps of Engineers, the United States Weather Bureau, the Riverside County Flood Control and Water Conservation District, and local agencies in the area of investigation. The records of 33 precipitation stations and 7 stream-gaging stations were collected. Use was made of the United States Weather Bureau's precipitation studies presently being conducted for the United States Geological Survey's Lower Colorado River Project.

Interviews with private and municipal water service agencies in the area were conducted in order to supplement water use and ground water extraction data compiled from State Water Rights Board records. A canvass of sewage disposal plants was also conducted.

Use was made of data from a land use survey conducted during 1958 by the department as part of its statewide land use survey program. Agricultural land use surveys conducted by the Coachella Valley County Water District and the County of Riverside Agricultural Commissioner's Annual Crop Reports were utilized in determining the amounts and trends in land use within the study area.

Hydrologic studies made included determination of the sources and amounts of water supply available to the area of investigation, the present means of disposal of the water supply, and evaluation of the present annual extractions from the ground water basin.

The studies and work accomplished in achieving the objectives of the investigation were done during the period from June 1960 through July 1962. Compilation of these data into this report was completed during fiscal year 1962-63. Expenditures of the funds allotted for the investigation were distributed as follows:

Fiscal year 1960-61	$ 47,600
Fiscal year 1961-62	45,000
Fiscal year 1962-63	4,600
Fiscal year 1963-64	2,800
Total	$100,000

Results of the Coachella Valley Investigation are presented following this introduction in the following chapters. Chapter II, "Geologic Studies," describes the geologic development (history) and the land forms (physiography) of the area of investigation; the materials present in the area and their distribution (stratigraphy); and the folds and faults of the area (structure). Chapter III, "Coachella Valley Ground Water Basin," describes the occurrence and movement of ground water within the study area and the water storage capacities. Chapter IV, "Water Quality," describes the water quality and character of the ground water in the Coachella Valley Ground Water Basin. Chapter V, "Hydrologic Studies," presents analyses of the hydrologic characteristics of the area of investigation through a presentation of a hydrologic budget which weighs the items of water supply against the items of water disposal. Chapter VI, "Summary," presents a summary of the investigation and conclusions thereon.

Location and Description of Study Area

As shown on Plate 1, "Location of Investigational Area," the study area is primarily located in central Riverside County, with small portions in San Bernardino County on the north and San Diego and Imperial Counties on the south. Coachella Valley is about 65 miles long on a northwest-southeast trending axis and covers approximately 440 square miles. The high, precipitous San Jacinto-Santa Rosa Range, and San Bernardino Mountains border the valley on the west and north, respectively. Separating these two mountain ranges is San Gorgonio Pass, an entrance to the Southern California coastal area. Along the eastern margin of the valley are rugged and barren mountain ranges of the Colorado Desert. The valley is drained primarily by the Whitewater River system which empties southward into the Salton Sea, a saline sink cut off from the Gulf of California by the delta of the Colorado River. The watershed of the study area encompasses 1,600 square miles.

Rugged relief and extremes of climatic conditions are characteristic of the study area. The watershed ranges in elevation from over 10,000 feet above sea level at San Gorgonio and San Jacinto Peaks to more than 200 feet below sea level at the Saltbn Sea. Seasonal temperatures vary from about 120 degrees Fahrenheit in the summer to below freezing in the winter. Climate in the valley area is typical of a desert. The high mountains bordering the valley to the west and north are an effective barrier against the easterly moving coastal storms. The average annual rainfall on the valley floor is less than five inches. In contrast, average annual rainfall at the crest of the mountains to the west and north of the valley ranges from 30 to 40 inches. Although some precipitation on the mountains occurs as snow, extensive snowpacks are seldom sustained.

Since precipitation on the valley floor contributes very little to the directly usable water supply of the area, agriculture is wholly dependent on irrigation. The main natural source of water in the valley is ground water that is replenished by surface runoff from the mountains to the west and north. Minor amounts of runoff are contributed from the mountain ranges to the east.

Cultural History of the Area

The San Gorgonio Pass and the Coachella Valley have supported Indian tribes for many centruies. Natural radiocarbon measurements of charcoal remnants found in the Salton Sea area (Hubbs, C. L., 1960) indicate Indians have lived there for at least 1,500 years. The first known visit to the area by a European occurred in 1539 when the Spanish explorer Ulloa traveled there. However, for the next three centuries further knowledge of the area was limited to Spanish missionaries who frequently visited or passed through the area. The best known of these was Father Eusebio Kino who, between 1699 and 1702, made four trips from Northern Mexico to Southern California through the Coachella Valley and the San Gorgonio Pass.

The area became better known in the nineteenth century. A freight team route was established in the valley and through the pass in the 1840's to carry goods between San Bernardino and Yuma, Arizona. In 1853, the first thorough investigation of the region was made by a United States Army expedition, which explored the area for a feasible railroad route. Later, the Southern Pacific Company constructed a railway through the area, putting it into operation in 1879.

The modern history of the Coachella Valley began with the completion of the railroad. The railroad utilized artesian wells and as settlement of the area began, farmland was put under irrigation. Irrigation development did not advance rapidly, however, because of the prohibitive cost of drilling and operating the wells necessary for irrigation water. The development of economical well-drilling methods and pumping machinery about 1900, however, considerably lessened the cost of water supply development, and farming received a new impetus. By 1906, 400 wells had been developed to nourish the beginnings of a flourishing agricultural economy. The irrigated land in Coachella Valley increased to 7,000 acres by 1916.

The limitations of the natural supply of water became evident as ground water levels in the valley declined when more and more agricultural lands were developed. Thus, in 1918, the Coachella Valley County Water District was formed, primarily for the purpose of securing imported water supplies. Since the break in the Alamo Canal in Baja California, Mexico in 1905, there had been agitation for a completely American canal to serve water from the Colorado River to the Imperial and Coachella Valleys. This agitation culminated in the Swing-Johnson bills, several of which were introduced in the Congress between 1922 and 1927. In 1928, the last Swing-Johnson bill was approved by the Congress and signed by the President, authorizing the Boulder Canyon Project and the All-American Canal.

The Coachella Valley County Water District executed a contract with the United States in 1934 for the construction of the Coachella Branch of the All-American Canal, and construction began in 1938. At that time, there were about 14,000 acres of land under irrigation in the Coachella Valley. Construction of the canal was interrupted by World War II, but was resumed in 1944 and completed in 1948. By that time about 23,000 acres were under irrigation. Since 1948, irrigated farming has increased rapidly. Today there are over 50,000 acres under irrigation. Urban development and population have grown commensurately with the development of farming.

Today, two distinct economies are present in the area. In the lower portion of the valley is a complex agricultural economy in which artificial drainage has become of paramount importance. Over 50,000 acres of land are under cultivation. Principal crops grown in the area include citrus, dates, and grapes. Alfalfa and other field crops and a wide variety of truck crops are also grown. Grains and fruits are the principal agricultural products in the San Gorgonio Pass. A second economy, which evolved rapidly since the end of the World War II, is based on the exploitation of the area's dry and warm winter climate for urban resorts. Primarily situated in the upper portion of the valley, the resort areas have become an important facet of the valley's economy, along with the basic agricultural developments.

Population in the area of investigation today is over 50,000, of which the majority reside in the incorporated cities of Banning, Cabazon, Palm Springs, Indio, and Coachella. Important unincorporated communities of the valley include Cathedral City, Desert Hot Springs, Mecca, Rancho Mirage, Palm Desert, Thermal, and La Quinta.

Hydrology Study Unit

A hydrologic investigation of an area such as the Coachella Valley area necessitates definition and delineation of the units to be studied and their relationship to adjacent areas. The State of California has been subdivided by the department in a systematic order to aid in coding hydrologic data and in identifying areas for hydrologic study. The basic unit in this system is the hydrologic unit. The area of investigation is part of the Coachella Valley Hydrologic Unit, as shown on Plate 1. This unit is essentially defined by the watershed that encloses all surface drainage emptying into the north end of the Salton Sea. This includes the Whitewater River and its tributaries.

Within the Coachella Valley Hydrologic Unit are three topographic lows that are filled with alluvial debris and constitute ground water storage basins. They are: Morongo Valley, Shavers Valley, and Coachella Valley. Morongo Valley and Shavers Valley are smaller than, and drain into, the larger, lowermost Coachella Valley. The area described in this report is the Coachella Valley Ground Water Basin and the highland areas that drain immediately into that basin. Morongo and Shavers Valleys and the highland areas draining immediately into them are not part of the study area; however, outflow from these valleys contributes to the supply of the Coachella Valley Ground Water Basin. Within the ground water basin, further subdivisions were made and are described in Chapter III of this report.

Previous Investigations and Reports

The earliest published investigations of the Coachella Valley area were made as a result of the exploration for a railroad route from the Mississippi River to the Pacific Ocean in the 1850's. William F. Blake, a geologist assigned to the Williamson expedition that explored the route through the San Gorgonio Pass, reported on the geologic and hydrologic character of the valley. He predicted at that time that artesian water would probably be found in the area.

In 1909, the U.S. Geological Survey published Water Supply Paper No. 225, "Ground Waters of the Indio Region," by W. C. Mendenhall. It includes a geologic study of the region, a description of the development and use of ground water and its occurrence and movement in the valley. In 1922 an investigation published as U.S. Geological Survey Water Supply Paper No. 497, entitled "The Salton Sea Region," by John S. Brown, included the area of study.

Several hydrologic investigations conducted within the study area during the period from 1919 through 1923 were primarily concerned with the surface water supply of the Whitewater River, its allocation and control. The investigations were essentially motivated by the Whitewater River Adjudication Proceedings, which were instigated during this period. The proceedings resulted in the allocation of surface water.

Geologic studies of the area became more intense in the 1940's due to increased interest of major oil companies in its potential as a source of oil. Hydrologic studies of the valley area since World War II included water quality studies in relation to irrigation and drainage practices in the agricultural areas and studies by the State Water Resources Board in relation to the Statewide Water Resources Investigation commenced in 1947.

A bibliography of related studies reviewed during the investigation is presented in Appendix B.

CHAPTER II. GEOLOGIC STUDIES

In the Coachella Valley Investigation, the geologic studies included a critical examination of the physiography, stratigraphy, structure, and geologic history of the area. From these studies, the boundaries of the Coachella Valley Ground Water Basin and the storage capacity of the ground water basin were determined. In addition, the conditions under which ground water occurs in the basin, the direction of ground water movement, and the amount of ground water in storage in the basin were also established. The results of the geologic studies are summarized and discussed in this chapter.

Physiography

Coachella Valley occupies the northwestern part of a great structural trough that includes the Gulf of California. The Colorado River discharges into this trough and has formed a deltaic barrier between the gulf and the spoon-shaped depression to the north. The depression, which is the main portion of the Colorado Desert of southeastern California, contains Imperial Valley, the Salton Sea, and Coachella Valley. The water level of the Salton Sea is currently maintained almost entirely by agricultural drainage discharged from Imperial Valley on the south and Coachella Valley on the north.

Coachella Valley, comprising the principal valley floor area of this investigation, is bounded by a series of rugged and steep mountain ranges and outlying hills, except to the southeast, where the valley drains into the Salton Sea. The physiographic features of the study area, shown on Plate 2, "Physiographic Features and Lines of Equal Mean Seasonal

Precipitation," may be grouped according to the following categories: bordering highlands, hills and benchlands, intermontane areas, central plain, and drainage system. The bordering highlands are primarily nonwater-bearing rocks, the hills and benchlands are underlain by semiwater-bearing materials, and the intermontane and central plain areas are generally underlain by water-bearing materials.

Bordering Highlands

The physiographic relationship of Coachella Valley to the bordering highlands is characterized by sharp contrasts. This is not only exemplified in relief and topographic expression, but also in varying climatic conditions. The highlands of the study area include the Santa Rosa and San Jacinto Mountains of the Peninsular Ranges, the San Bernardino and Little San Bernardino Mountains of the Transverse Ranges, and the Orocopia Mountains of the Colorado Desert.

Peninsular Ranges. Bold high mountains trending northerly to northwesterly border the valley on the southwest. Included are the Santa Rosa Mountains and the San Jacinto Mountains. Highest elevations are at Toro Peak, in the Santa Rosa Mountains at 8,716 feet above sea level, and at San Jacinto Peak in the San Jacinto Mountains at 10,804 feet above sea level. Both mountain ranges consist of large blocks of an igneous and metamorphic complex that have been uplifted by faulting. The Peninsular Ranges act as an effective barrier to the eastward-moving storms and cooler air masses of the Southern California coastal area.

Transverse Ranges. North of the San Jacinto Mountains, the east-west trending San Bernardino Mountains of the Transverse Ranges continue the barrier of high mountains bordering Coachella Valley. San Gorgonio Peak, in the San Bernardino Mountains, at 11,502 feet above sea level is the highest elevation in Southern California. Although similar in other respects to the Peninsular Ranges, the Transverse Ranges, however, have been uplifted along axes trending generally east-west.

The northeast flank of Coachella Valley is determined by the Little San Bernardino Mountains. They are the eastern extension of the Transverse Range province and, to the northeast, are transitional into highlands of the Mojave Desert. Maximum elevation above sea level of the drainage divide in this range is 5,500 feet. The mountains are a fault block complex made up of crystalline rocks similar to those found in the San Bernardino Mountains. The absence of vegetal cover is indicative of the aridity of the mountains.

Orocopia Mountains. Southeast of Coachella Valley are the Orocopia Mountains, a mountain block of the Colorado Desert. Separated from the Coachella Valley by the Mecca Hills, the Orocopia Mountains are of minor significance in this investigation.

Hills and Benchlands

Within the Coachella Valley study area a series of hills, ridges, and a topographic bench, occurs along the northeast flank of the valley and at the base of the San Bernardino Mountains. Associated with the San Andreas fault zone, these features include the Mecca Hills, Indio Hills, Edom-Garnet belt of hills, Miracle Hill, and Banning Bench.

Mecca Hills. The Mecca Hills separate Shavers Valley from the study area. Rising to elevations over 1,800 feet above sea level, the deeply eroded barren hills merge northerly into the alluvial slope at the base of the Little San Bernardino Mountains and southeasterly with the Orocopia Mountains. The San Andreas fault zone determines the southwest base of the hills. Box Canyon traverses the entire width of the hills, draining Shaver Valley and emptying into Coachella Valley.

Indio Hills. The Indio Hills, located in the east central portion of Coachella Valley, is the largest unit of hills within the valley area. These hills are very similar in aspect to the Mecca Hills, and are bordered on the southwest by the San Andreas fault. The hills are divided in their central portion by Thousand Palms Canyon. Maximum elevation of the hills is about 1,740 feet in the southern portion and about 1,380 feet in the northern portion.

Edom-Garnet Belt of Hills. From the northwest end of the Indio Hills to the base of the San Bernardino Mountains near Whitewater River is a series of small structural hills associated with the Banning and Garnet Hill faults. These hills include, from southeast to northwest, Edom Hill, Flat Top Mountain, Seven Palms Ridge, Garnet Hill, Devers Hill and Whitewater Hill. Other than Edom Hill, none rise more than 500 feet above the valley floor. Devers Hill, an almost imperceptible rise above the alluvial slope, is on the northeast side of the Banning fault, whereas the other hills all lie between the Banning and Garnet Hill faults.

Banning Bench. North of the City of Banning, a surface of low relief, distinctly higher than the alluvial fill of the San Gorgonio Pass area, interrupts the rugged foothills of the San Bernardino Mountains.

The Banning Bench is 160 feet above the stream channel at the mouth of San Gorgonio River Canyon. Triangular in shape, the bench is 1-1/2 miles wide along the southeast facing scarp west of San Gorgonio River. It narrows northward, and rises in elevation. The surface is covered by a red soil and underlain by deeply weathered fanglomerate materials. The bench surface apparently is a remnant of erosional processes that were interrupted. Streams were consequently incised below the elevation of the bench in the present channels.

Miracle Hill. Just southeast of the town of Desert Hot Springs, a small, asymmetric northwest-trending ridge about two miles in length has been uplifted on the northeast side of the Mission Creek fault. Named Miracle Hill, it is one of the locales of natural hot water that occurs in the vicinity.

Intermontane Areas

Intermontane areas include San Gorgonio Pass and Dillon Road Piedmont Slope. They are generally higher in elevation than the central plain of Coachella Valley and both areas are filled with coarse alluvial fan debris, the finer-grained debris having been carried away to be deposited in the lower central plain.

San Gorgonio Pass. San Gorgonio Pass is an east-west trending, narrow defile between the San Jacinto and San Bernardino Mountains. The pass proper contains a coarse sandy alluvial fill throughout most of its extent. West of the community of Banning, the pass is underlain by a deeply weathered, coarse, alluvial soil that is being eroded by present-day streams. To the east of Banning, the pass is an area of deposition.

Approximately 15 miles long, San Gorgonio Pass provides Coachella Valley access to the coastal plains to the west. The summit within the pass is near the western end at an elevation of 2,600 feet, making drainage within most of the pass area tributary to Coachella Valley. The town of Beaumont is at the western end of the pass, just outside the drainage divide of the study area. Within the pass and study area are the communities of Banning and Cabazon.

Dillon Road Piedmont Slope. Between the Little San Bernardino Mountains and the Indio and Mecca Hills extends the Dillon Road Piedmont Slope, a narrow lowland filled with coarse alluvial material which slopes steeply to the southwest. Streams debauching from the base of the Little San Bernardino Mountains have formed a series of coalescing alluvial fans that terminate against or merge with the Indio and Mecca Hills. Fine-grained deposits which would normally occur at the distal ends of the fans are carried through and around the hills to be deposited elsewhere. The portion of the piedmont slope between the Indio and Mecca Hills merges southwesterly with the central alluvial plain. The Dillon Road Piedmont Slope extends from Desert Hot Springs at the northwest end, southeast 30 miles to the Mecca Hills.

Central Plain

The central plain area consists of the area in which the streams discharge the load of eroded material carried down from the adjoining mountain slopes and is the floor of the Coachella Valley. The central plain is subdivided into the main Indio Plain, the Mission Creek Upland, the Oasis Piedmont Slope, and the Palm Springs Sand Ridge.

Indio Plain. The narrow lowland extending from San Gorgonio Pass southeastward to the Salton Sea is a gently sloping area of little relief that is over 65 miles in length. Maximum width of the lowland is less than 15 miles near the Salton Sea. From the City of Indio south, the plain is predominantly a flat valley of fine-grained deposits. Northwest of Indio, there is a broad zone of transition; the valley materials become predominantly sandy and coarse. Coalescing alluvial fans form the marginal limits of the plain. North and west of Indio, windblown deposits form prominent dunes in the central portion of the plain.

Mission Creek Upland. The portion of the floor of Coachella Valley north of the Edom-Garnet belt of hills is designated the Mission Creek Upland. Alluvial fans along the eastern base of the San Bernardino Mountains merge with those of the westernmost Little San Bernardino Mountains to form a sandy alluvial plain that slopes southeastward at a moderate gradient. The area is triangular in shape with the Edom-Garnet belt of hills on the south being the base along which the area merges with the central plain.

Oasis Piedmont Slope. The portion of the valley on the southeast flank of the Santa Rosa Mountains between Travertine Rock and Martinez Canyon is a series of coalescing alluvial fans comprising the Oasis Piedmont Slope. The slope is a relatively uniform piedmont that merges northeastward into the central alluvial plain. Although the slope consists predominantly of recent alluvial fan deposits, in the upper reaches dissected older alluvial fans are present. These fans are indicative of the probability that the line of transition between areas of erosion and areas of deposition is migrating eastward.

Palm Springs Sand Ridge. The strong prevailing winds continually move sand and debris in a southeasterly direction down the valley. In San Gorgonio Pass and the northwest portion of the valley, windblown deposits occur only in the leeward areas of ridges, canyons, and bushes. However, southeastward, where the energy of the wind dissipates, sand dunes have developed on the valley floor. The coarser fraction of the windblown material is dropped first and has formed a broad, low ridge, elongate southeastward, in the northwest central portion of the valley. Emerging east of Palm Springs, the ridge continues to Point Happy. The leeward end of the ridge is broken into an irregular topography of sand hills. The height of these dunes ranges from 5 to 30 feet. South of Indio there is also much surface material which is wind deposited and, locally, small dunes are present. However, only the area north of Indio that is predominantly covered by sand dunes is defined as the Palm Springs Sand Ridge.

Drainage System

The Whitewater River and its tributaries, including the San Gorgonio River, Mission Creek, and Little and Big Morongo Creeks, and Box Canyon Wash, drain the major portion of the study area. Other important streams of the drainage network include Snow, Chino, Tahquitz and Andreas Creeks in the San Jacinto Mountains, and Palm Canyon, which separates the San Jacinto and Santa Rosa Mountains.

The Whitewater River originates in the San Bernardino Mountains to the north, enters the valley at the east end of San Gorgonio Pass, and flowing southeastward, empties into the Salton Sea. The San Gorgonio River and its tributaries drain San Gorgonio Pass, joining the Whitewater River at the east end of the pass. Little and Big Morongo Creeks drain Morongo Valley north of the study area, and, joined by Mission Creek in the Coachella Valley, they drain the Mission Creek Upland.

Streams which are not tributary to the Whitewater River, but which empty directly into the Salton Sea, include a series of small streams draining the northeasterly slope of the Santa Rosa Mountains, southeast of Martinez Canyon, and the streams draining the southeast portion of the Mecca Hills. Box Canyon Wash, the largest of these streams, drains Shavers Valley which is east of the study area, and also drains a portion of the Mecca Hills.

Several small perennial streams exist in the San Jacinto and San Bernardino Mountains; however, upon reaching the valley floor they seldom persist, usually percolating immediately into the alluvial fill, except during periods of infrequent maximum flows. Typical of desert basins, the valley floor is characterized by braided networks of indeterminate channels.

Stratigraphy

Within the area of investigation a crystalline complex of pre-Tertiary igneous and metamorphic rocks comprise the mountain ranges and underlie the basin area at substantial depths. In the depressions, thick deposits of Tertiary and Quaternary sediments overlie the crystalline bedrock. The sedimentary materials are of continental origin, with the exception of some Pliocene marine sediments. The Tertiary and Quaternary sediments generally consist of coarse, clastic fanglomerates on the periphery of the basin, grading basinward into fine-grained deposits laid down in an alluvial plain and shallow-lake environment. The areal distribution of the geologic formations is shown on Plates 3A, 3B, and 3C, entitled "Areal Geology."

The names and delineation of geologic formations in this report are, for the most part, based on previous work in the area. Formational names used are those described and mapped by Allen (1957), Dibblee (1954), and Fraser (1931), as listed in the bibliography. The delineation of these formations is essentially as mapped by the above authors. The exceptions to this are the delineation of upper portions of the Ocotillo conglomerate in the Indio Hills as a separate unit, and redefinition of materials northeast of the Mecca Hills fault as part of the Ocotillo conglomerate. Unpublished theses by Hays (1957), Popenoe (1959), and Ware (1958), in addition to field mapping by state personnel during the course of the investigation, are the bases for these revisions. The four units of Recent deposits delineated on the geology map are based on field work conducted during the investigation.

The geologic formations of the investigational area have been grouped according to their ground water storage characteristics. Although the areal location and degree of structural deformation are factors in determining the hydrologic significance of a formation, the ability of the unit to contain, transmit, and yield ground water is of prime consideration in such a classification. The formations have been grouped in three categories: nonwater-bearing, semiwater-bearing, and water-bearing.

Nonwater-Bearing Group

The pre-Tertiary crystalline rocks enclosing the basin and the older consolidated Tertiary sediments contain little or no water within their interstices, but do yield small quantities, primarily from cracks and fractures. These formations are here classified as nonwater-bearing. In addition to being poor storage reservoirs, nonwater-bearing rocks act as barriers to ground water movement. In the surrounding mountains, however, these rocks may be the only source of water, although the yield from wells drilled in these rocks is generally small.

Pre-Tertiary Crystalline Rocks. Basement rocks of the San Bernardino, Little San Bernardino, and Orocopia Mountains are a complex assemblage of gneisses and schists, Precambrian in age, intruded by younger granitic rocks associated with the Southern California batholith of Cretaceous age. This igneous-metamorphic complex includes the San Gorgonio igneous-metamorphic complex, the Chuckwalla complex, and the Orocopia schist.

Metamorphic rocks exposed in the San Jacinto and Santa Rosa Mountains are considered younger than either the gneissic complexes or the Orocopia schist of the mountains to the north and east of the valley. Originally sedimentary rocks of probable Paleozoic age, they underwent extensive metamorphism and were ultimately intruded by granodiorite and tonalite intrusives of the Southern California batholith. The core of the San Jacinto Mountains also consists of these intrusives.

Consolidated Tertiary Sediments. Sedimentary rocks of early Tertiary age considered as nonwater-bearing include the pre-Pliocene

Coachella fanglomerate and Hathaway formation, and the lower Pliocene Imperial and Mecca formations. The Imperial formation is the only known marine deposit in Coachella Valley. Other than the Imperial formation, the nonwater-bearing Tertiary deposits are continental in origin and of small areal extent.

The Coachella fanglomerate is a well-indurated, massive conglomerate exposed on the east flank of the San Bernardino Mountains along the upper Whitewater River. Interlayered within the formation are flows of olivine basalt.

Small exposures of deformed continental sandstones, siltstones, and conglomerates north of Cabazon are included in the Hathaway formation.

Exposures of the Imperial formation occur throughout Coachella Valley and represent the last extensive marine environment in the valley. The formation includes interbedded tan to yellow fossiliferous sandstone, siltstone, and shale. Exposures in Coachella Valley appear tight and nonwater-bearing, and the formation probably underlies the greater part of the valley at depth.

The Mecca formation is a coarse basal conglomerate, exposures of which underlie the Palm Spring formation, a semiwater-bearing formation, in the Mecca Hills. It is apparently limited in extent and low in permeability.

Semiwater-Bearing Group

A series of semiconsolidated Plio-Pleistocene formations which are present within the study area consist generally of materials low in permeability and water-yielding capabilities. Although water is present in the interstices of these rocks, it is limited in supply and is not extracted or replenished readily. Characteristically, these formations have been highly contorted and faulted, which further limits their effectiveness as ground water storage reservoirs.

Included in this group are continental Plio-Pleistocene formations which are stratigraphically correlative and similar in lithologic characteristics. They include the San Timoteo, Painted Hill, Palm Spring, Borrego, and Canebrake formations.

San Timoteo Formation. The San Timoteo formation, more extensive outside the investigational area, crops out in the west end of San Gorgonio Pass. It consists of tan to grey sandstone, grey-green siltstone, and some interbeds of conglomerate. Exposures in San Gorgonio Pass indicate a formation thickness of at least 1,800 feet. Water wells on the Banning Bench may partially penetrate the San Timoteo formation.

Painted Hill Formation. Along the east base of the San Bernardino Mountains, the Painted Hill formation conformably overlies the Imperial formation. It consists of up to 3,400 feet of continental light brown to grey conglomerate and sandstone. The semiconsolidated nature and poor sorting of the materials indicate low permeability. No water wells were found in the formation during the course of this investigation.

Palm Spring Formation. The thick series of compacted continental beds extensively exposed in the Mecca and Indio Hills is named the Palm Spring formation. It includes grey to tan arkosic sandstones interbedded with red and green siltstones and clays. The formation generally lies unconformably beneath the water-bearing Ocotillo formation and is estimated to be over 5,000 feet thick. It is most probable that the Palm Spring formation underlies the greater part of Coachella Valley. No water wells in the Palm Spring formation were located during this investigation.

Borrego Formation. The fine-grained, lake deposited facies of the Palm Spring formation is named the Borrego formation. Exposures of yellow-grey claystone at the base of the Santa Rosa Mountains and red to grey-green clay and siltstone adjacent to the San Andreas fault in the Mecca Hills are included in this formation. The exposures in Coachella Valley unconformably underlie beds of the Ocotillo conglomerate. Drillers' logs of water wells near Mortmar suggest tight clays of the Borrego formation underlie the alluvium at depths of less than 100 feet.

Canebrake Conglomerate. Extensive exposures of compacted grey to tan, silty conglomerate and sandstone, present in the Indio Hills and on the east slope of the Santa Rosa Mountains, are included in the Canebrake conglomerate. They represent the coarse, torrentially deposited facies of the Palm Spring formation. Although more permeable than the Palm Spring formation, the Canebrake conglomerate would probably yield only limited supplies of water. No wells that extracted water from the Canebrake conglomerate were located during the investigation.

Water-Bearing Group

Relatively undisturbed and unconsolidated Recent and late Pleistocene alluvial deposits are the principal reservoirs of ground water within the study area. It is within these water-bearing materials that storage of ground water occurs and from which water is readily extracted.

Similar materials are being deposited in the study area today in much the same manner as the earlier materials were deposited during Recent and late Pleistocene time.

The valley area receives detritus eroded from the surrounding mountain ranges. When the streams carrying the eroded materials pass from the confined, steep channels of the mountains, and reach the gentler slopes of the valley, the coarse materials are deposited heterogeneously as piedmont alluvial fans. Further away from the mountain fronts, toward the central part of the valley, slopes are nearly flat and the materials deposited are finer grained. In the central portion of the basin, playas and shallow lakes have occurred periodically; these have been similar to the Salton Sea, but often were larger.

Stratification of the materials increases with distance from the mountain front, although, in general, individual beds are lenticular in shape, and not extensive. As stream-carrying power varies from wet to dry years, coarse and fine-grained deposits often alternate and changes in the stream channel result in erosion and redeposition of previous deposits.

The water-bearing deposits have undergone little weathering. Fine-grained materials are predominantly silt-sized particles; however, deposits in the central portion of the basin are interspersed with lenses of lacustrine clays. The presence of these tabular bodies of impermeable materials tends to direct the movement of ground water parallel to the bedding planes.

Units included in the water-bearing group are: Ocotillo conglomerate, Cabezon fanglomerate, older alluvium and terrace deposits, and

Recent alluvial and dune sand deposits. These units were identified and their stratigraphic relationships were determined primarily from observation of surface exposure. Correlation of subsurface materials was based largely on stratigraphic sequence and lithologic similarities observed from drill cuttings. Electrical resistivity logs obtained during the drilling of water wells and exploration holes were also used in identifying these units.

Ocotillo Conglomerate. The Ocotillo conglomerate consists of poorly consolidated sandstones and conglomerates with thin grey-green and red-brown silts and clays as lens-like interbeds. Exposures in the Mecca and Indio Hills indicate the Ocotillo conglomerate overlies the Palm Spring formation unconformably, and that it also underlies upper Pleistocene and Recent fanglomerates unconformably. In addition to the several exposures in the Mecca and Indio Hills, the formation underlies, at depth, the Central Plain and the Dillon Road Piedmont Slope areas.

A characteristic "break," or increase in the resistivity of the electric logs of water wells, at depths ranging from 300 to 400 feet below the surface, was identified as signifying the top of the Ocotillo conglomerate, underlying the basin. Well log data also indicate that the first 100 to 200 feet of material below the top of the conglomerate, underlying the area of the Central Plain southeast of Point Happy, consist predominately of lake-deposited materials. Below this zone, however, the materials are characteristic of the Ocotillo conglomerate.

This unit is at least 2,400 feet thick, and is the principal water-bearing unit in the area of investigation.

Cabezon Fanglomerate. Stratigraphically correlative with the Ocotillo beds, the Cabezon fanglomerate was deposited along the base of the San Bernardino Mountains and underlies at depth the Mission Creek Upland. It is essentially a coarse and heterogeneous, poorly consolidated fanglomerate that unconformably overlies the Painted Hill formation. Apparently the formation is the primary source of ground water in the Mission Creek Upland area. The maximum thickness is approximately 1,000 feet.

The deformed gravels of the Whitewater River, which consist of tilted beds of sandstone and gravels, are considered a basal portion of the Cabezon fanglomerate, as defined by Allen, 1957.

Older Alluvial Fan and Terrace Deposits. An unconformity in upper Pleistocene sediments exposed on the periphery of the basin commonly separates coarse angular fanglomerates that are underlain by interbeds of sandstone, conglomerate and siltstone. The overlying fanglomerates embrace several mappable units that have been grouped for this report under older alluvial fan and terrace deposits. Included in this group are Heights fanglomerate, upper portions of the Ocotillo conglomerate, terrace deposits, older alluvium in San Gorgonio Pass, and a portion of the Bautista formation.

Exposed portions of these deposits occur on the periphery of the Coachella Valley basin in San Gorgonio Pass and the Indio and Mecca Hills. The deposits have a maximum thickness at the Indio and Mecca Hills and thin out toward the northwest, the thickness ranging from 0 to 400 feet. The shallow water-bearing zones in the Central Plain and the Mission

Creek Upland are probably correlative with the older alluvial fan and terrace deposits.

Relatively undeformed gravels unconformably overlying the Cabezon fanglomerate as exposed north of Cabazon are mapped as Heights fanglomerate. More extensive exposures overlie the San Timoteo formation on the Banning Bench. The fragments consist of thoroughly decomposed metamorphic rocks. Maximum exposed thickness is 240 feet.

In the Indio and Mecca Hills, the upper portion of the Ocotillo formation, as defined by Dibblee, 1954, is a greyish angular fanglomerate that unconformably overlies typical Ocotillo sandstones and conglomerates. Maximum exposed thickness of the formation is 400 feet. It is stratigraphically equivalent to the older alluvial fan and terrace deposits.

Undifferentiated terrace deposits present in the Mecca Hills and along the flanks of the Santa Rosa Mountains consist of grey to tan heterogeneous gravels, sands, and silts.

Outcrops of the Bautista formation (?) are present along State Highway 74 at the crest of the San Jacinto Mountains. Composed primarily of arkosic grey to tan sands with lenses of gravel, the deposits are a southeast extension of a larger body of the formation present outside the area of investigation in Hemet Valley. The latter is on the westerly slope of the San Jacinto Mountains. Because the areal extent of the Bautista formation in the area of investigation is relatively small, and the water-bearing materials would best be considered a part of the Hemet Valley Ground Water Basin, the formation was not evaluated in the hydrologic analysis.

Recent Deposits. Four units of Recent age have been delineated within the study area and are shown on Plates 3A, 3B, and 3C. They represent different processes or environments of deposition on the valley floor. The four units are: active channel deposits, alluvial fan and stream-wash deposits, alluvial plain and lake deposits, and dune sand.

Coarse alluvial debris within the present channels of the Whitewater River and its main tributaries is identified as active channel deposits. Downstream, the particle size decreases and the channels become less distinct. The most permeable deposits are found in these channels and infiltration is highest in these areas.

Coarse, poorly sorted sands and gravels of the many desert washes make up the alluvial fan and stream-wash deposits. As individual piedmont fans coalesce laterally and form relatively uniform alluvial slopes, stream channels become indistinct. Particle size decreases toward the distal portions of the fans where they merge with the alluvial plain. Infiltration is high in these materials.

Fine-grained sand, silt, and clay deposited by streams at the distal portions of the Whitewater River system and in lakes in the lowest part of the basin are the alluvial plain and lake deposits. A large lake, the Salton Sea, has been present at the lower end of Coachella Valley since 1905. An earlier lake, Lake Cahuilla, extended as far north as the City of Indio, as indicated by the remnants of gravel beach bars, travertine deposits and prolific fresh-water gastropod shells present on the margins. The predominant silts and clays present in the first 50 to 100 feet of depth in this portion of the valley were deposited in this earlier lake. Percolation of water through these deposits is retarded by the fine-grained and layered nature of the materials. When large quantities of water are applied over these deposits, semiperched ground water conditions develop.

Windblown sand deposits, including both active and stabilized dunes, are grouped under dune sand. They are well sorted, fine to medium-grained, micaceous sands overlying fanglomerate, alluvial plain, and lacustrine deposits. Only the more extensive deposits are shown on Plates 3A, 3B, and 3C. Minor dune sand deposits are present elsewhere on the valley floor.

Structure

Geologic structures within the area of investigation have a marked influence on the occurrence and movement of ground water. Principal structural features of Coachella Valley are faults of the northwest-trending San Andreas fault system, and associated drag and compressional folds.

Faults of the San Andreas fault system act as partial barriers to ground water movement, affecting both water quality conditions and the depth at which ground water occurs. Thermal waters in Coachella Valley are related to faulting. Folding of sedimentary formations in the hills and along the mountains has exposed Tertiary formations which generally limit ground water movement. Pleistocene formations structurally uplifted above the water table have been dewatered, reducing the area of effective ground water storage and yield. Structural features of the area of investigation are shown on Plates 3A, 3B, and 3C, and Plate 4, "Geologic Sections."

As a part of the investigation, a gravity survey was conducted to aid in determining the configuration of the structural trough underlying the basin and other aspects of the subsurface conditions of the valley. Three gravity profiles were run transverse to the valley axis. The calculated residual gravity profile for Section C-C' of the geologic sections is shown on Plate 4 along with the computed configuration of the trough. The trough is a narrow, asymmetrical basin, in which the deepest portion is just southwest of the Banning and San Andreas faults. With the gravity data, it was estimated that at maximum depth, the basement rock is in excess of 12,000 feet below the surface at Section C-C'.

San Andreas Fault Zone

Large subparallel and branching faults present in Coachella Valley are part of the San Andreas fault zone. They have developed from a general north-south regional stress that began in late Tertiary time and is continuing today. Although movement within the San Andreas fault zone is predominantly right lateral, (the southwest block moving northwest relative to the northeast block) vertical displacement has also depressed the southwest block. Faults of the San Andreas system, which are partial barriers to ground water movement within Coachella Valley, include the San Andreas, Mission Creek, Banning, Garnet Hill, Indio Hills and Mecca Hills faults. In addition, buried faults probably account for the localized quality differences and high temperature of the ground water in some areas. Several related faults are present in the highland and hill areas.

San Andreas Fault. From Point Arena north of San Francisco, the San Andreas fault extends to the southeast about 450 miles where it splits into several major branches northwest of the study area. The branch fault given the parent name terminates in the San Bernardino Mountains northeast of Banning. Continuing southeast, in Coachella Valley, it is questionable whether any one of the remaining branches deserves the parent name. However, the prominent fault that extends from the junction of the Banning and Mission Creek faults in the central Indio Hills southeast along the base of the Indio and Mecca Hills is generally identified as the San Andreas fault. The fault trace is nearly straight, indicating that dominant horizontal displacement has occurred here along an essentially vertical plane. The break consists of a crushed and sheared zone encrusted with gypsum. Exposures in the Mecca Hills indicate a crushed zone up to 350 feet wide. Palm tree oases along the southwest flank of the Indio Hills and abrupt changes in vegetation southeast of the Indio Hills, are indicative of the effectiveness of this zone as a barrier to ground water movement. Water levels measured in the spring of 1961 on either side of the fault trace indicate a difference in elevation of over 50 feet.

Southeast of the Mecca Hills the trace of the fault is obscured by recent alluvium, although a noticeable vegetation change may be identified from aerial photos.

Mission Creek Fault. The Mission Creek fault extends northwest from the junction with the Banning and San Andreas faults, crossing the Indio Hills. Continuing northwest the fault trace passes from the valley area into the Little San Bernardino Mountains at the mouth of Little

Morongo Canyon. Between the junction with the Banning fault and Little Morongo Canyon the fault is a fracture zone made up of a principal northwesterly break and several splinter breaks that fray off toward the Little San Bernardino Mountains on the northeast. This zone is nearly vertical as shown on Section C-C', Plate 4. Miracle Hill consists of Recent alluvium that has been uplifted between the main trace of the Mission Creek fault along the southwest flank and a splinter fault on the northeast flank of the hill.

The fault trace curves gently to the west beyond Little Morongo Canyon. Branches of the San Gorgonio and Whitewater Rivers follow the large east-west crushed zone of the fault trace in the San Bernardino Mountains. The dominant direction of movement on the Mission Creek fault has probably been lateral, although evidence of some vertical displacement is seen at Miracle Hill and in the Indio Hills. The Indio Hills indicate upward movement of the southwest block relative to the northeast block; however, the younger Miracle Hill is apparently a reversal of this relative vertical movement and a similar topographic pattern could have resulted from lateral displacement alone. The fault, which has apparently existed since late Miocene time, is active in the study area; the Desert Hot Springs earthquake in 1948 centered on this fault.

The Mission Creek fault is an effective ground water barrier where it crosses the alluvial basin between the Little San Bernardino Mountains and the Indio Hills. Water levels measured in the spring of 1961 show differences on either side of the fault ranging from 260 to 130 feet between Little Morongo Canyon and the Indio Hills. In addition, fault springs and cienegas at Miracle Hill and along the traces of the several branch faults in the Indio Hills are evidence of an impediment to the movement of ground water. Ground water temperatures ranging up to 200° F. have been measured in the vicinity of Miracle Hill along the northeast side of the Mission Creek fault.

<u>Banning Fault</u>. From the west end of San Gorgonio Pass to the Whitewater River, the Banning fault is an east-west trending reverse fault that dips steeply to the north. Crystalline basement rocks on the north side are in contact with Quaternary sedimentary formations. A crushed zone up to several thousand feet wide is present in the pass area.

East of Whitewater River the Banning fault curves to the southeast and its trace through valley fill extends into the Indio Hills. Southeast of Thousand Palms Canyon it merges with the Mission Creek fault. Movement along the portion of the fault east of the Whitewater River Canyon appears to be a transition from the vertical displacement in the pass area to the dominant right lateral movement of the San Andreas fault. Movement on the Banning fault dates from pre-Pliocene time and has been recurrent during Recent time.

The Banning fault is an effective barrier to ground water movement where it offsets Pleistocene and Recent formations within Coachella Valley and San Gorgonio Pass. A difference of 200 feet in the ground water levels on either side of the fault between Whitewater River and the Indio Hills is indicated from water level measurements made during the spring of 1961. Shallow water levels, springs and cienegas in Whitewater River Canyon and Seven Palms Valley, on the northeast side of the fault trace, result from the barrier effects to ground water movement.

The fault trace through these areas is sharply defined by the southern limit of dense vegetation sustained by the shallow ground water. The barrier effect is also indicated by differences in quality of ground water on either side of the fault.

Garnet Hill Fault. The Garnet Hill fault is located about 1- 1/2 miles south of and generally parallel to the Banning fault between Flat Top Mountain and Whitewater Hills. The surface expression of the fault is two en echelon faults along the south flank of the hills west of Whitewater River Canyon. Elsewhere, the structure is buried by Recent alluvium. Southeast of Flat Top Mountain the fault is undetermined. It does not show as an anomaly on the gravity profile, as delineated on Plate 4, Section C-C', and probably dies out along the southwest flank of Edom Hill. The fault is probably a branch of the Banning fault. Apparent vertical displacement on the fault is suggested by the topographic highs of Garnet Hill, Edom Hill and Flat Top Mountain aligned on the northeast block. Exposures of Imperial formation on Garnet Hill suggest a stratigraphic displacement of several thousand feet.

It is believed that the fault has not displaced Recent alluvium but is effective as a ground water barrier below depths of 100 feet, based on water level measurements at the fault. Measurements made in the spring of 1961, west of Garnet Hill, indicated that water levels on the northeast side of the fault were at least 100 feet below the surface. On the southwest side of the fault, however, water levels were found to be 130 to 180 feet lower than those of the northeast side of the fault.

Indio Hills Fault. The northeast facing flank of the southeasternmost Indio Hills is the trace of the Indio Hills fault. It is one to two miles northeast of and generally parallel to the San Andreas fault. Continuing northwest, the fault trace curves away from the Indio Hills and apparently borders the east flank of Fan Canyon in the Little San Bernardino Mountains. In the Indio Hills, the southwest block apparently has been uplifted in relation to the northeast block. However, the east block is up relative to the west block in the Little San Bernardino Mountains, suggesting either a scissors movement, or possibly a lateral displacement.

The structure apparently acts as a barrier to ground water movement where it crosses valley fill between the Indio Hills and the Little San Bernardino Mountains. Water levels measured on either side of its projected trace in this area indicate a difference of 35 feet. The extension of the fault beyond the southeast end of the Indio Hills may be traced, and ground water barrier effects are indicated by the change in vegetation on the northeast side of the fault trace. However, this surface evidence disappears approximately two miles southeast of the Indio Hills and further extension of the fault can only be inferred.

It is likely that the Indio Hills fault is an effective ground water barrier in formations of late Pleistocene and older age, but does not disrupt Recent alluvium.

Mecca Hills Fault. The Mecca Hills fault is located about two miles northeast of and parallel to the San Andreas fault through most of the Mecca Hills. It consists of two principal en echelon breaks that split into several branches to the northwest. These structures bring into contact crystalline basement rock on the northeast block with Tertiary and Quaternary sedimentary formations on the southwest block. They may be traced by fault scarps, rift valleys, and the contact between steeply tilted beds on the southwest and gently dipping beds on the northeast. Recent displacement along the faults includes components of upward thrust of the southwest block and right lateral offset.

There is no direct evidence that the Mecca Hills fault acts as a barrier to ground water movement. The fault northwest of Thermal Canyon would probably affect ground water movement, but the nature of ground water storage, or movement, in this area, is undetermined and the ground water resources are unexploited.

Buried Faults. Agua Caliente Spring, a warm-water spring located in Palm Springs, is believed associated with a buried fault or faults. The temperature and quality of the spring water indicate local ground water has probably encountered a zone of faulting in which it has been heated and, as a result, has absorbed dissolved minerals and carbon dioxide gas. The spring is aligned with the projected north extension of a fault which displaces crystalline basement rock along Palm Canyon. The sharp topographic rise of the mountains to the west is best explained by uplift along such a fault.

The lineal distribution of water wells with a sodium chloride character water and the generally aligned warm-water wells between Oasis and Travertine Rock suggest the presence of a buried fault. This inferred break is located approximately one-half mile northeast of and trends northwest nearly parallel to U.S. Highway 99. It apparently extends from the edge of the Salton Sea near Travertine Rock northwest to the vicinity of Oasis. Northwest of Oasis, ground water data do not indicate any such structural break. The structure has no surface expression and does not offset water levels.

Faults of the Highland and Hill Areas. Several named and unnamed faults are present in the highland and hill areas, such as the northwest trending fault southeast of Box Canyon in the Mecca Hills, the Lawrence fault in the western San Jacinto Mountains, and several faults in the San Bernardino Mountains. They are significant to the geologic development of the study area. However, since they do not affect water-bearing materials, their significance to the occurrence and movement of water in the Coachella Valley Ground Water Basin is considered negligible.

Folds Associated with the San Andreas Fault Zone

Structural deformation of sedimentary formations beneath the floor of the valley is apparently limited to tilting and compression caused by downwarping of the trough and the loading of younger alluvial deposits on older sediments.

Along the northeast flank of Coachella Valley disrupted and highly contorted Tertiary and early Pleistocene beds are present in the hills associated with the San Andreas rift zone. Folding and disruption of the beds are a result of drag and compression associated with fault displacement. Tertiary formations are most intensely folded and have suffered repeated deformation. Early Pleistocene sediments are steeply tilted adjacent to faults. Late Pleistocene beds have been gently folded within the San Andreas rift zone.

Sedimentary formations in the Indio Hills have been compressed between the Banning and Mission Creek faults and are folded along axes trending generally northwest-southeast. Highly contorted Plio-Pleistocene formations are exposed along breached anticline axes in the northwestern portion of the hills. Sediments in the southeastern portion of the hills are exposed along the western limb of an anticline whose axis is parallel to and immediately adjacent to the Indio Hills fault. Folding and tilting of late Pleistocene beds have resulted in the dewatering of potentially water-bearing materials in the Indio Hills.

Plio-Pleistocene formations between the Mecca Hills fault and the San Andreas fault in the Mecca Hills are intensely contorted and faulted. Northeast of the Mecca Hills fault and southeast of Box Canyon in the Mecca Hills, sediments are folded in a series of discontinuous gentle folds, generally parallel to the faults in the area. Immediately adjacent to the faults, however, the folds become tight and are contorted. Potential water-bearing materials north and east of the San Andreas fault in the Mecca Hills are above the general level of ground water occurrence.

Whitewater Hill and Edom Hill are domical anticlines resulting from movement on the Banning fault in Recent time. Devers Hill and Seven Palms Valley Ridge are probably topographic expressions of drag or compressional folds along the Banning fault. The significance of these folds to the occurrence of ground water is the disruption or diversion of flow of ground water due to the placement of impermeable materials in the path of ground water movement.

Geologic History

The rock formations in the Coachella Valley study area range in age from pre-Cambrian to Recent. Geologic events prior to the Cenozoic era, represented by the igneous-metamorphic complexes of the surrounding highlands, are only generally understood. The last of these events was the intrusion of the Southern California batholith in Cretaceous time, followed by a period in which processes of erosion and leveling of the lands predominated. Geologic events since the beginning of the Cenozoic era are more clearly understood and are discussed in the following paragraphs.

The initial rise of the positive areas present today began in early Tertiary time. A structural trough developed along the San Andreas rift zone, and Coachella Valley, the northwestern termination of the trough, began receiving detrital material eroded from the young highland areas surrounding it. The Gulf of California marine embayment inundated the trough as far north as San Gorgonio Pass in early Pliocene time.

With the close of the Tertiary period the young Colorado River began to form a deltaic barrier in the gulf that effectively stopped marine invasion to the north. Coachella Valley became a lowland containing shallow ponds of fresh water. Except for minor and short-lived occurrences, the barrier has remained to this day. At the same time, the surrounding highlands increased in height and Coachella Valley became much drier.

By mid-Pleistocene time the present day San Jacinto and San Bernardino Mountains existed, and the Indio and Mecca Hills were present. Torrential alluvial fan and playa deposits became the characteristic mode of deposition in the valley. Since deposition in the gulf trough north of the Colorado delta did not keep up with the rate of sinking, the Salton depression, an area below sea level, resulted. Periodically, as the Colorado River changed its course over the delta, flow would be directed northward into the sink and a large, shallow fresh-water lake would exist until the Colorado River again changed course and flowed directly into the gulf.

Short-lived stages of this fresh-water lake have occurred periodically in the Salton depression since mid-Pleistocene time. The red silts and clays of the Colorado River interfingered with the coarse, heterogeneous alluvial deposits. One stage of this ancient lake which ended several thousand years ago, persisted for an extended period of time. It is represented by a thick section of predominantly fine-grained deposits interbedded in the alluvium of Coachella Valley.

The last inundation of the sink by this ancient lake disappeared less than 1,000 years ago. Wave-cut benches and sand bars of this stage remain today. The ancient lake was first named Lake LeConte. However, a later name, Lake Cahuilla, has become more familiar. In this report, the name Lake Cahuilla has been used in reference to the last stage of Lake LeConte. Lake Cahuilla apparently did not extend significantly beyond the present location of Indio on the north. Deposition north of Indio fluctuated between moist, near-shore alluvial flood plains and dry, windblown deposits with the successive advance and retreat of Lake Cahuilla. The strong prevailing winds moving southeast from San Gorgonio Pass have undoubtedly influenced the mode of deposition in the valley since mid-Pleistocene time, and continue to do so today.

CHAPTER III. COACHELLA VALLEY GROUND WATER BASIN

The Coachella Valley Ground Water Basin is that part of the investigational area underlain by water-bearing and semiwater-bearing formations, generally coinciding with the valley floor area. The basin extends from the surface drainage divide at the west end of San Gorgonio Pass to the Salton Sea on the southeast. It includes over 690 square miles, and has an estimated maximum depth to consolidated rocks in excess of 12,000 feet. Surface elevations within the basin range from 2,600 feet above sea level west of Banning, to 235 feet below sea level at the Salton Sea. The ground water basin boundaries and subdivisions are shown on Plate 5, "Coachella Valley Ground Water Basin." Locations of wells are shown on Plates 6A, 6B, and 6C, "Ground Water Basin Subdivisions and Well Locations."

Ground Water Basin Boundary

The ground water basin is bounded on the north and east by nonwater-bearing crystalline rocks of the San Bernardino and Little San Bernardino Mountains. Crystalline rocks of the Santa Rosa and San Jacinto Mountains border the basin on the south and west. The basin boundary was generalized across the mouths of canyons to exclude thin tongues of alluvium that would not contain appreciable amounts of ground water in storage. The trace of the Banning fault on the north side of San Gorgonio Pass is the basin boundary across stream channels and where it is the contact between crystalline rocks and water-bearing or semiwater-bearing materials.

At the west end of San Gorgonio Pass, between Beaumont and Banning, the basin boundary is defined by a surface drainage divide separating the Coachella Valley Ground Water Basin from the Beaumont Ground Water Basin of the Upper Santa Ana drainage area.

The southeastern boundary of the basin is formed primarily by the watershed of the area of investigation in the Mecca Hills and by the northwest shoreline of the Salton Sea. Between the Little San Bernardino Mountains and Mortmar the boundary is formed by either the watershed or the contact between nonwater-bearing and semiwater-bearing materials. Between the Salton Sea and Travertine Rock at the base of the Santa Rosa Mountains, the boundary coincides with the Riverside-Imperial county line.

Southeast of the boundary, at Mortmar and at Travertine Rock, the subsurface materials are predominantly fine-grained and low in permeability; although ground water is present, it is not readily extractable. A zone of transition exists at these boundaries, however, and to the north the subsurface materials are coarser and yield water more readily.

Ground Water Basin Subdivisions

Although there is interflow of ground water throughout the basin fault barriers, constrictions in the basin profile, and the formation permeability limit and control the movement of ground water. Based on these factors, the Coachella Valley Ground Water Basin has been subdivided into four subbasins and four areas, as shown on Plate 5.

The four subbasins are the San Gorgonio Pass, Mission Creek, Indio, and Desert Hot Springs subbasins. Boundaries of subbasins define usable ground water storage reservoirs within the ground water basin. They delineate areas underlain by formations which readily yield the stored water through water wells, and offer natural reservoirs for the regulation of water supplies in the area. These underground reservoirs are the prime source of urban water supply in the valley, and, until the advent of the Coachella Canal, were practically the only source for irrigation water.

The boundaries between subbasins within the Coachella Valley Ground Water Basin are generally based upon faults that are effective barriers to the lateral movement of ground water. Minor subareas have also been delineated within three of the subbasins, based on one or more of the following geologic or hydrologic characteristics: type of water-bearing formations, water quality, areas of confined ground water, forebay areas, ground water divides and surface divides.

Subdivisions of the ground water basin which are not classified herein as subbasins include the Banning Bench, Indio Hills, Mecca Hills, and Barton Canyon areas. These are areas which are underlain by semiwater-bearing formations, or by potential water-bearing formations that are at elevations above the water levels of the ground water basin. Accordingly, it may be difficult to extract a substantial supply of water from the formations in these areas.

The several subdivisions of the Coachella Valley Ground Water Basin are shown below in outline form for reference purposes, and are further described in the text. The boundaries of the basin subdivisions are delineated on Plates 5 and 6A, 6B, and 6C.

San Gorgonio Pass subbasin

    Beaumont subarea

Mission Creek subbasin

Indio subbasin

    Palm Springs subarea
    Thermal subarea

Garnet Hill subarea
Thousand Palms subarea
Oasis subarea

Desert Hot Springs subbasin

Miracle Hill subarea
Sky Valley subarea
Fargo Canyon subarea

Banning Bench area

Indio Hills area

Mecca Hills area

Barton Canyon area

San Gorgonio Pass Subbasin

The portion of the Coachella Valley Ground Water Basin that lies entirely within San Gorgonio Pass is described as the San Gorgonio Pass subbasin. The limits of the subbasin coincide with the basin boundaries except at the east end of San Gorgonio Pass, and north of the community of Banning. The Banning Bench area borders the subbasin north of Banning. The eastern boundary separates the San Gorgonio Pass subbasin from the Indio subbasin.

A gravity survey conducted during the investigation confirmed that the prominent bedrock ridge projecting from the flank of San Jacinto Peak, and located approximately one mile west of the junction of State Highway 111 and U.S. Highway 99, persists northward beneath the basin deposits. This ridge creates a constriction in the basin, reducing the cross-sectional area of alluvial fill. Accordingly, the subbasin boundary at the east end of San Gorgonio Pass was drawn to coincide with the suballuvial extension of the bedrock ridge.

The sparse water level data in the area indicate a ground water cascade over this bedrock constriction. A drop in water level of over 500 feet in a distance of 8,000 feet was measured in the area in April 1961.

Drillers' logs indicate very coarse and poorly sorted materials with little or no fines present throughout most of the pass area. These materials are more than 1,000 feet thick. West and south of Banning, however, reddish-brown clayey sands and gravels are present. No wells that reached bedrock were located within the San Gorgonio Pass subbasin.

Beaumont Subarea. The San Gorgonio Pass subbasin contains one subunit, the Beaumont subarea, which is located southwest of Banning. The sparse data available suggest that the subarea is a southeastern extension of a larger unit west of the area under investigation. The northeast boundary of this subarea may be a fault barrier, as suggested by a difference of 120 feet in water levels on either side. However, since no surface expression of a fault is evident, the difference in water levels might be explained by changes in permeability due to a lithologic difference. A small area of semiwater-bearing materials is exposed along the southwest boundary of the subarea and the alluvium may only be a thin veneer over these materials elsewhere in the Beaumont subarea.

Water Levels in San Gorgonio Pass Subbasin. Depth to water within the San Gorgonio Pass subbasin ranges from 100 feet to over 500 feet. Water apparently occurs as an unconfined ground water body throughout the subbasin. Movement of ground water is from west to east. Underflow spills out of the subbasin over the suballuvial bedrock constriction at the east end of the pass into the Indio subbasin. However, the lack of wells in the greater portion of the San Gorgonio Pass subbasin precludes a detailed description of the water table configuration. Hydrographs of wells 3S/1W-12D1 and 3S/3E-8M1, located within the subbasin, are presented on Plate 7, "Ground Water Level Fluctuations at Selected Wells." The hydrographs indicate the historic steady decline of the water table and the apparent lack of seasonal fluctuation in the basin.

Mission Creek Subbasin

Water-bearing materials underlying the Mission Creek upland comprise the Mission Creek subbasin of the Coachella Valley Ground Water Basin. The subbasin is bounded on the south by the Banning fault and on the north and east by the Mission Creek fault. The subdivision is bordered on the west by nonwater-bearing rocks of the San Bernardino Mountains. To the southeast, the subbasin merges with the Indio Hills. The boundary selected in this area reflects the estimated limit of effective storage within the subbasin.

A narrow strip of semiwater-bearing rocks is exposed along the west boundary just north of the Banning fault. Although these materials do not contribute to the effective ground water storage capacity, delineation of subareas within the Mission Creek subbasin was not attempted. The exposed semiwater-bearing materials most probably extend beneath the water-bearing materials of the subbasin.

Both the Mission Creek fault and the Banning fault are effective barriers to ground water movement as evidenced by offset water levels, fault springs, and changes in the vegetation. Water level measurements in the spring of 1961 between wells 3S/5E-4L2 and 3S/5E-4M1 indicated a vertical difference in the ground water table elevation of 255 feet in a horizontal distance of 1,600 feet across the Mission Creek fault. Similar measurements of wells 3S/4E-13H1 and 3S/4E-13N1 on either side of the Banning fault indicated a vertical difference of 250 feet in water elevation in a horizontal distance of 4,900 feet. Water levels are higher on the north side of both faults.

All known wells drilled in the basin were begun in Recent sands and gravels. At depths ranging from 20 to 170 feet, the wells pass through unconsolidated Recent material and encounter semiconsolidated and interbedded sands, gravels and silts similar to exposures of the Octillo conglomerate in the Indio Hills or the Cabezon fanglomerate exposed at Whitewater Hill. Although the Pleistocene deposits are the main source of water, water also occurs in Recent alluvium where the water table is sufficiently shallow.

Water Levels in the Mission Creek Subbasin. Measured depths below ground surface to water in Mission Creek subbasin range from a maximum of 425 feet in the northwestern portion to flowing wells, as a minimum, in a narrow strip along the Banning fault northwest of Seven Palms Ridge. Although semiconfined ground water is present, as indicated by the flowing wells, it is believed that the greater portion of the ground water body is unconfined. Movement of water within the subbasin is generally southward. However, in spite of the moderate to high permeability of the water-bearing materials, the flat gradient suggests the rate of movement is not great. Historic water levels, as represented by the hydrograph of well 3S/5E-17K1 on Plate 7, indicate a general rise in water levels within the subbasin between 1938 and 1952. Since 1952 a steady decline has been experienced.

Indio Subbasin

The Indio subbasin comprises the major portion of the floor of Coachella Valley and encompasses 400 square miles. Beginning at the eastern boundary of San Gorgonio Pass subbasin, located approximately one mile west of the junction of State Highway 111 and U.S. Highway 99, the Indio subbasin extends southeast approximately 60 miles to the Salton Sea. Bordered on the southwest by the Santa Rosa and San Jacinto Mountains, the subbasin is separated from Mission Creek and Desert Hot Springs subbasins to the north and east by the Banning and San Andreas faults and the Indio Hills.

The limit of the Indio subbasin along the base of the San Jacinto Mountains and the northeast portion of the Santa Rosa Mountains coincides with the Coachella Valley Ground Water Basin boundary. Southwest of Oasis the subbasin is bordered by the Barton Canyon area. The Indio subbasin in this vicinity includes only the Recent terraces and alluvial fans. The Banning fault, which extends southeastward from the north side of San Gorgonio Pass to the Indio Hills, is an effective barrier to ground water movement from Mission Creek basin into the Indio basin. The San Andreas fault, extending southeastward from the junction of the Mission Creek and Banning faults in the Indio Hills and continuing out of the basin on the east flank of the Salton Sea, also is an effective barrier to ground water movement.

Structurally elevated hills reduce the area of ground water storage in the Indio subbasin. These include Garnet Hill, Edom Hill, a...

an exposure of semiwater-bearing materials on the southwest flank of the Mecca Hills. Garnet Hill, capped by a veneer of Cabezon fanglomerate, is underlain by the nonwater-bearing Imperial formation. The Ocotillo formation exposed on Edom Hill is above the ground water levels of the basin. On the southwest flank of the Mecca Hills, the Borrego formation is exposed in the Indio subbasin along the San Andreas fault. The boundary between the water-bearing materials and those which are less permeable was selected as the subbasin boundary inasmuch as it defines the limit of major ground water storage within the subbasin.

The Indio subbasin is divided into five subareas: Palm Springs, Thermal, Garnet Hill, Thousand Palms, and Oasis subareas. Palm Springs subarea is the forebay or main area of recharge to the subbasin. Thermal subarea comprises the pressure area within the basin. The other three subareas are peripheral areas having unconfined ground water conditions.

Palm Springs Subarea. The triangular area between the Garnet Hill fault and the east slope of the San Jacinto Mountains southeast to Cathedral City is designated the Palm Springs subarea, and is an area in which unconfined ground water occurs. The valley fill materials within the subarea are essentially heterogeneous alluvial fan deposits exhibiting little sorting and with little content of fine-grained material. Thickness of these water-bearing materials is not known; however, it exceeds 1,000 feet. Although no lithologic distinction is apparent from water well logs, the probable thickness of Recent deposits suggests that Ocotillo conglomerate underlies Recent fanglomerate in the subarea at depths ranging from 300 to 400 feet.

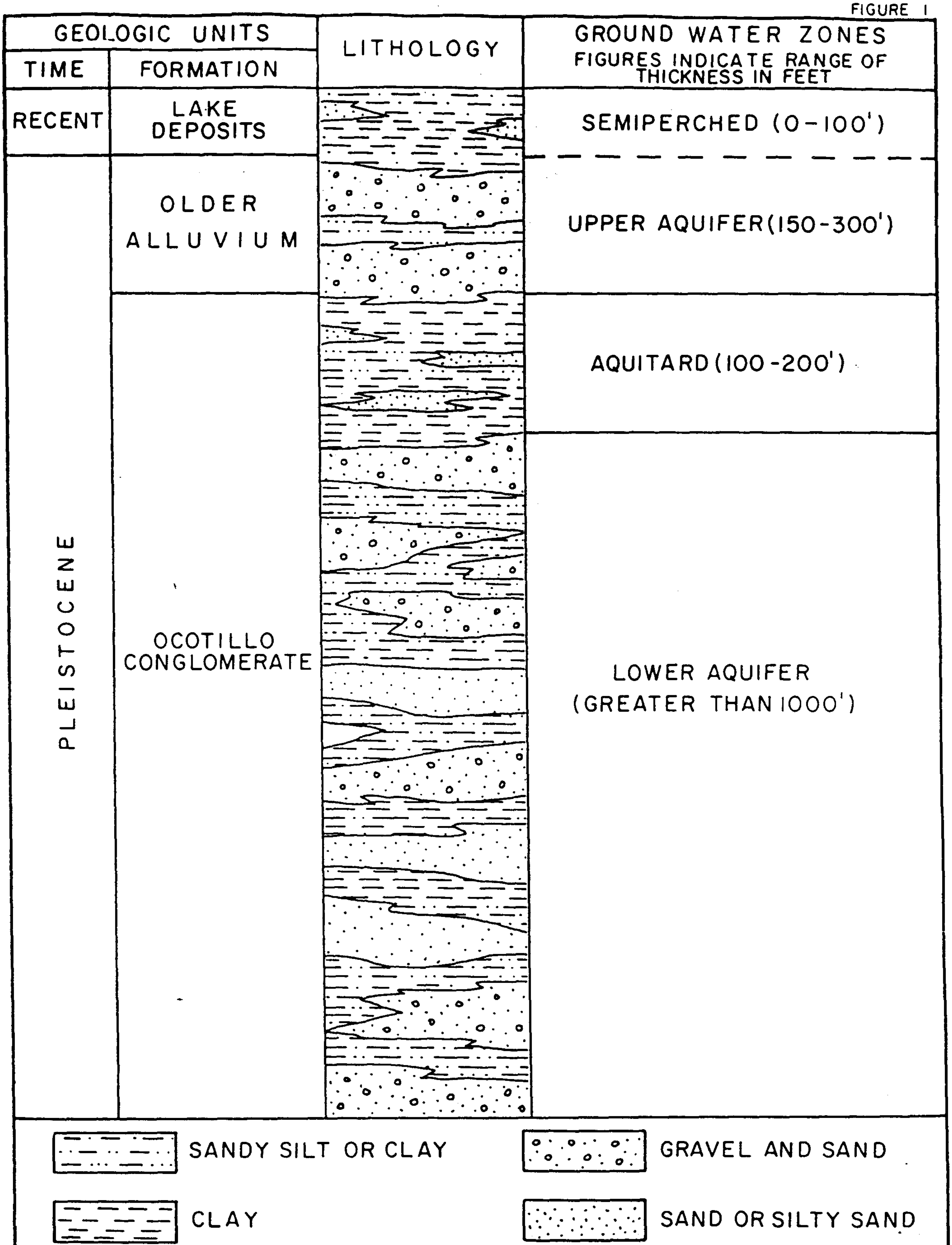
Recharge of ground water to the aquifers in the Indio subbasin occurs primarily in the Palm Springs subarea. The major sources include infiltration of stream runoff from the San Jacinto Mountains and the Whitewater River, and subsurface inflow from the San Gorgonio Pass subbasin. Deep percolation of direct precipitation on the Palm Springs subarea is considered negligible.

Depth to water in the subarea ranges from 100 feet below the surface near Cathedral City to over 500 feet at the northwestern apex of the subbasin.

Thermal Subarea. Ground water of the Palm Springs subarea moves southeastward into the interbedded sands, silts, and clays underlying the central portion of the Indio Plain. The permeabilities parallel to the bedding of these deposits are several times the permeabilities normal to the bedding and, as a result, movement of ground water parallel to the bedding predominates. Confined, or semiconfined, ground water conditions are present in the major portion of the Thermal subarea. Movement of water under these conditions is caused by differences in piezometric levels or head. Unconfined, or free water conditions, are present in the alluvial fans at the base of the Santa Rosa Mountains, as in the fans at the mouth of Deep Canyon and in the La Quinta area.

Sand and gravel lenses underlying this subarea are discontinuous and clay beds are not extensive. However, two aquifer zones separated by a zone of finer-grained materials as illustrated on Figure 1 were identified from well logs. The fine-grained materials within the intervening zone are not tight enough, or persistent enough, to completely restrict vertical interflow of water, nor to assign the name aquiclude in refere

FIGURE 1



GENERALIZED STRATIGRAPHIC COLUMN
THERMAL SUBAREA

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1964 to it. Therefore, the term aquitard is used for this zone of less permeable material which separates the upper and lower aquifer zones. Capping the upper aquifer at the surface are tight clays and silts with minor amounts of sand. Semiperched ground water occurs in this capping zone, which is up to 100 feet thick. The areal limits of the aquitard, the extent of the semiperched ground water body, and depth to the top of the lower aquifer zone are shown on Plate 5.

The lower aquifer zone, composed of part of the Ocotillo conglomerate, consists of silty sands and gravels with interbeds of silt and clay. It is the most important source of ground water in the Coachella Valley Ground Water Basin. The top of the lower aquifer zone is present at a depth ranging from 300 to 600 feet below the surface. Thickness of the zone is undetermined as the deepest wells present in the valley have not penetrated it in its entirety. The available data indicate that the zone is at least 500 feet thick and may be in excess of 1,000 feet thick.

The aquitard overlying the lower aquifer zone is generally 100 to 200 feet thick, although in small areas on the periphery of the Salton Sea it is in excess of 500 feet in thickness. North and west of Indio, in an arcuate zone approximately one mile wide, the aquitard is apparently lacking and no distinction is made between upper and lower aquifer zones.

The upper aquifer zone in the Thermal subarea is similar in lithology to the lower aquifer, although it is only 150 to 300 feet thick. Subsurface inflow to the upper zone is less than that to the lower aquifer zone. As the water levels in the Palm Springs subarea continue to drop, the cross sectional area available for recharge from the Palm Springs subarea is reduced.

Capping the upper aquifer zone in the Thermal subarea is a shallow fine-grained zone in which semiperched ground water is present. This surficial zone consists of Recent silts, clays, and fine sands and is relatively persistent southeast of Indio. It ranges from zero to 100 feet thick and is generally an effective barrier to deep percolation. However, north and west of Indio, the zone is composed mainly of clayey sands and silts and its effect in retarding deep percolation is limited. The low permeability of the materials southeast of Indio has contributed to the irrigation drainage problems of the area. Semiperched ground water has been maintained by the excess irrigation water applied to control salt balance in the soil. Water in this zone is high in salt content and considered unusable.

Discharge of ground water from the Coachella Valley Ground Water Basin occurs in the Thermal subarea by underflow southeast to the Salton Sea. Semiperched ground water discharges from the Thermal subarea as surface outflow in the drainage ditches and by evaporation. A small number of uncontrolled flowing wells present around the edge of the Salton Sea contribute to the discharge.

Garnet Hill Subarea. The area northeast of the Garnet Hill fault in the Indio subbasin, named the Garnet Hill subarea, was separated within the subbasin because of the effectiveness of the Garnet Hill fault as a barrier to ground water movement. This is illustrated by a difference of 170 feet in water level elevation in a horizontal distance of 3,200 feet between well 3S/4E-17K1 and well 3S/4E-21D1, as measured in the spring of 1961. The fault does not reach the surface and is probably effective as a barrier to ground water movement only below a depth of 100 feet.

Only five water wells were present within the subarea at the time of the investigation. Because of the lack of direct information deductions as to the hydrologic characteristics of the area are necessarily generalized. Water is encountered in sands and gravels that are probably part of the Cabezon fanglomerate. Depth to water is greater than 170 feet. Movement of ground water is apparently southeasterly from Whitewater Hill. Passing around Garnet Hill, a constriction in the alluvial section has caused a small ground water cascade.

Although some recharge to the subarea may come from Mission Creek and other streams which pass through the subarea during periods of high flood flows, the chemical character of the ground water, plus the direction of movement of ground water, indicate that the main source of recharge to the subarea comes from the Whitewater River through the permeable deposits which underlie Whitewater Hill.

Thousand Palms Subarea. The narrow strip along the southwest flank of the Indio Hills is named the Thousand Palms subarea. The southwest boundary of the subarea was determined by tracing the limit of distinctive ground water chemical characteristics. Whereas a bicarbonate water is characteristic of the major aquifers of the Indio subbasin, water in the Thousand Palms subarea is sulfate-bicarbonate in character.

The water quality differences suggest that recharge to the Thousand Palms subarea comes primarily from the Indio Hills and is limited in supply. The relatively sharp boundary between chemical characteristics of water derived from the Indio Hills and ground water in the Thermal subarea suggests there is little intermixing of the two.

The configuration of the water table north of the community of Thousand Palms, as shown on Plate 11, is such that the generally uniform, southeast gradient in the Palm Springs subarea diverges and steepens to the east along the base of Edom Hill. This steepened gradient suggests a barrier to the movement of ground water, or a reduction in permeability of the water-bearing materials. A southeast extension of the Garnet Hill fault would also coincide with this anomaly. However, there is no surface expression of such a fault, and the gravity measurements taken during the investigation do not suggest a subsurface fault. The residual gravity profile and structure section of Section C-C', Plate 4, illustrate these observations. The steepened gradient is therefore attributed to lower permeability of the materials to the east.

Oasis Subarea. A second peripheral zone of unconfined ground water that is different in chemical characteristics from water in the major aquifers of the Indio subbasin is found underlying the Oasis Piedmont slope. This zone, named the Oasis subarea, extends along the base of the Santa Rosa Mountains. Water-bearing materials underlying the subarea consist of highly permeable fan deposits. Although ground water data suggests that the boundary between the Oasis and Thermal subareas may be a buried fault extending from Travertine Rock to the community of Oasis, the remainder of the boundary is a lithologic change from the coarse fan deposits of the Oasis subarea to the interbedded sands, gravels and silts of the Thermal subarea. Little information is available as to the thickness of water-bearing materials, but it is estimated that they are in excess of 1,000 feet thick.

Although several wells are present along the boundary adjacent to the Thermal subarea, only three wells located during the investigation were within the Oasis subarea. The limited hydrologic data which were available indicate that a source of recharge is the aquifers of the Thermal subarea in the vicinity of Martinez Canyon. Surface runoff from the Santa Rosa Mountains also contributes to the recharge of the subarea. The marked differences in water quality characteristics between water in the Oasis subarea and the Thermal subarea, similar to that experienced in the Thousan Palms subarea, plus the apparent flat gradient of the water table indicate that movement of ground water in the subarea is small.

Depth to water in the subarea ranges from near the ground surface along the boundary with the Thermal subarea to over 160 feet at well 8S/8E-31R1.

Water Levels in Indio Subbasin. The historic fluctuations of water levels within the Indio subbasin indicate a steady decline in the levels throughout the subbasin prior to 1949, as illustrated by the hydrographs of wells shown on Plate 7. Since 1949, levels in the Thermal subarea, where imported Colorado River water is applied, have risen sharply, although elsewhere in the subbasin water levels have continued to decline.

This condition of rising levels in the Thermal subarea is due to percolation of applied imported water replenishing the semiperched zone. Pressure levels in the deeper aquifers have correspondingly risen, and will probably continue to do so until water levels in the forebay areas are lowered sufficiently to reverse the southeast gradient of the ground water pressure levels, or until water levels in the semiperched zone are lowered again.

Desert Hot Springs Subbasin

The coalescing alluvial fan deposits underlying the Dillon Road Piedmont Slope are the water-bearing materials of the Desert Hot Springs subbasin.

The northeasterly boundary of the subbasin along the base of the Little San Bernardino Mountains from Little Morongo Canyon southeast to Thermal Canyon coincides with the northeasterly boundary of Coachella Valley Ground Water Basin. The southwest boundary of the subbasin is set by the Mission Creek, the Indio Hills, and the San Andreas faults. The Mission Creek fault forms the boundary from Little Morongo Canyon southeast to Pushawalla Canyon in the Indio Hills. Semiwater-bearing materials of the Indio Hills border the subbasin along the south margin of Pushawalla Canyon, from the Mission Creek fault east to the Indio Hills fault. From Pushawalla Canyon to the southeast end of the Indio Hills, the boundary is defined by the Indio Hills fault. The San Andreas fault separates the Desert Hot Springs subbasin and the Indio subbasin between the Indio Hills and Thermal Canyon in the Mecca Hills. Between the Indio Hills fault and the San Andreas fault at the southeast end of the Indio Hills the subbasin boundary is the contact between Recent alluvium and Plio-Pleistocene formations. The subbasin merges with the Mecca Hills to the southeast and the boundary is the southeastern side of Thermal Canyon from the San Andreas fault to the Mecca Hills fault. The boundary continues along the southeast wall of a tributary wash easterly to outcrops of crystalline basement rock of the Little San Bernardino Mountains near U.S. Highway 60.

The water-bearing materials in the subbasin are primarily coarse-grained and poorly sorted alluvial fan deposits, principally of the Ocotillo formation, but also including the overlying Recent deposits. In the vicinity of Thousand Palms Canyon, fine-grained interbeds are present in the Recent deposits. Although Recent fanglomerates cover most of the land surface, exposures of the Ocotillo conglomerate are present throughout the basin. Principal exposures occur at Miracle Hill, along the northeast flank of the Indio Hills and near the southeast end of the subbasin. Recent alluvium in the subbasin ranges in thickness from a thin edge to over 100 feet. The thickness of the underlying Ocotillo conglomerate is estimated to be in excess of 700 feet. Drillers' logs commonly describe the material as being cemented.

The Desert Hot Springs subbasin is not extensively developed except in the vicinity of the town of Desert Hot Springs. Hot water from springs along the northeast side of the Mission Creek fault supplies several hot-water spas in the area. However, the relatively poor quality of the ground water throughout the subbasin has limited its use for drinking and agricultural purposes.

The subbasin has been divided into three subareas called, from northwest to southeast, the Miracle Hill, Sky Valley, and Fargo Canyon subareas.

<u>Miracle Hill Subarea</u>. The portion of the Desert Hot Springs subbasin along the Mission Creek fault in which there is extensive development of hot-water wells is called the Miracle Hill subarea. It covers approximately 12 square miles and includes the northeastern portion of the community of Desert Hot Springs. A principal use of ground water i

this area is to provide the hot mineral water available at several spas. The boundary separating the subarea from the Sky Valley subarea is a surface drainage divide. Ground water levels indicate that underflow across this boundary moves from Miracle Hill subarea southeastward into the Sky Valley subarea.

More than 130 water wells have been drilled in the Miracle Hill subarea. Approximately half of these are active and pump water for domestic use or for spas. Depth to water ranges from 12 feet below ground surface near the Mission Creek fault to over 300 feet in the southeast portion of the subarea.

Water level data in the Miracle Hill subarea suggest several barriers to ground water movement. The barriers appear to trend parallel to the Mission Creek fault with which they are probably associated. Structural conditions within the subarea are complex and the barrier effects are not well understood. Movement of ground water in the subarea is generally southeastward except within the narrow strip between the main Mission Creek fault and the secondary parallel fault that follows the northeast flank of Miracle Hill. The probable barriers to ground water movement in the Miracle Hill area are shown on Plate 8, "Contours of Ground Water Levels, Spring 1961."

The water temperatures in 34 wells of the Miracle Hill subarea were measured in the spring of 1961, and the values ranged from 82° F. to 200° F. The average value was 118° F. Water temperatures measured in 16 wells along the southwest side of the Mission Creek fault in the Mission Creek subbasin ranged in value from 74° F. to 86° F. This difference is probably a reflection of the barrier effect of the fault and suggests that ground water is heated on the northeast side of the fault with very little movement across the fault.

Sky Valley Subarea. The central portion of the Desert Hot Springs subbasin, in which ground water movement is toward Thousand Palms Canyon, is the Sky Valley subarea. The subarea extends 11 miles from the Miracle Hill subarea southeasterly to the trace of the Indio Hills fault and covers approximately 35 square miles. The trace of the Indio Hills fault is the boundary of the Sky Valley and Fargo Canyon subareas. The fault coincides with a ground water divide and is probably an effective barrier to ground water movement.

Ground water and other hydrologic data in the Sky Valley subarea are sparse. Only 15 water wells were located during the course of the investigation and of these, 8 were active, pumping only small quantities of ground water for domestic use. Movement of water within the subarea is southeasterly from the Miracle Hill subarea and southwesterly from the vicinity of Fan Canyon, converging on Thousand Palms Canyon, where rising water is present throughout the year. The gradient of the water table is moderate. Ground water is probably unconfined in the greater part of the subarea.

Fargo Canyon Subarea. The portion of the Desert Hot Springs subbasin south and east of the Indio Hills fault is called the Fargo Canyon subarea. It covers approximately 57 square miles and extends 17 miles from the Sky Valley subarea to the southeast limit of the subbasin. The northwest half of the area is underlain by coarse, alluvial fans of Recent age. To the southeast, Recent deposits are confined to stream channels cut into the Ocotillo conglomerate.

Data on the occurrence of ground water within the Fargo Canyon subarea is even less than in the Sky Valley subarea. Nine wells drilled in the Fargo Canyon subarea were located during the investigation, all in the vicinity of Dillon Road. Two of these wells were active, pumping water for domestic use and for irrigation of approximately 200 acres of young citrus trees.

Water levels measured in these wells during the spring of 1961 are shown on Plate 8. Although the data are not sufficient to determine the configuration of the water table, the measured levels along Dillon Road suggest that ground water movement in the northwest portion of the subarea moves southeasterly, and the ground water is probably unconfined.

Water Levels in Desert Hot Springs Subbasin. The fluctuations and trends of the water table in the Desert Hot Springs subbasin cannot be exactly determined due to the lack of historic data and the paucity of wells outside the Miracle Hill subarea. However, the available data represented by hydrographs on Plate 7 indicate that water levels are declining in the Miracle Hill subarea, but that elsewhere, little change has occurred.

Banning Bench Area

The portion of the Banning Bench south of the Banning fault is within the Coachella Valley Ground Water Basin and is designated the Banning Bench area. Heights fanglomerate almost completely covers the bench. However, exposures of the San Timoteo formation underlying the fanglomerate indicate that the latter is only a veneer; accordingly, ground water storage in this area is limited. During the course of the present investigation, there were no water wells found in the area. However, it was reported that a domestic well had been drilled but was abandoned due to lack of production.

Indio Hills Area

The semiwater-bearing Palm Spring formation is the predominant unit underlying the Indio Hills area. Where it is not exposed, it is at relatively shallow depths. In those areas in which younger, water-bearing materials occur, they are either above the water table, or are of such limited extent as to preclude the existence of any substantial water supply. The extensive faulting that occurs throughout the hills further limits the easily extractable supply of ground water.

The oases associated with the San Andreas fault on the southwest flank of the hills are indicative of the presence of ground water within the hills, although any water movement through the hills would be small. Only one well is known to have been drilled within the Indio Hills. At the time of the present investigation, the well had no pump and was apparently abandoned.

Mecca Hills Area

Although the northwestern, relatively low-lying portion of the Mecca Hills is considered water-bearing, and has been included within a subbasin, the larger portion of the hills southeast of Thermal Canyon is not water-bearing. The Mecca Hills is a structurally complex unit that includes all three categories of formations based on ground water storage characteristics.

The southwest flank of the hills is intensely faulted and underlain by the Palm Spring, Borrego and Mecca formations. Northeast of the Mecca Hills fault, exposures of crystalline bedrock underlying Ocotillo sandstone and siltstone indicate that potential water-bearing formations in the Mecca Hills occur above ground water storage levels. In those areas in which the crystalline rocks are not exposed, they are apparently at shallow depths, thus precluding the possibility that any large ground water storage exists in the area.

Three wells were located during the investigation in the Mecca Hills area. The wells were either dry, or the water was of such poor quality that they were abandoned.

Barton Canyon Area

The southeastern flank of the Santa Rosa Mountains west of Oasis is underlain by a large erosional remnant of the Canebrake conglomerate. Although many of the coarse sands and gravels of the remnant appear relatively permeable, their location on the side of the Santa Rosa Mountains is well above ground water levels within the basin, and so are included in the Barton Canyon area.

Along the base of the mountains are small remnants of younger, water-bearing formations that are underlain at relatively shallow depths by the semiwater-bearing Borrego and Palm Spring formations. Since the permeable formations are above ground water storage levels, they also have been included within the Barton Canyon area. Should a sufficient amount of precipitation be intercepted to saturate the water-bearing materials, the steep gradient indicates such ground water would be quickly transmitted to ground water reservoirs at lower elevations outside the area and not become stored therein.

Ground Water Occurrence and Movement

The major source of ground water replenishment in the basin at the present time is percolation of streamflow from the adjacent mountain areas. Other significant sources of replenishment include deep percolation of precipitation in the San Gorgonio Pass area and subsurface inflow at the west end of San Gorgonio Pass. Deep percolation of imported Colorado River water applied in agricultural areas is not considered as a source of replenishment because of water quality considerations; this will be discussed in detail in Chapter V.

The general direction of movement of these percolating waters, after becoming part of the ground water body, is southeastward to the Salton Sea. Plate 8, "Contours of Ground Water Levels, Spring 1961," illustrates the configuration of the water table or piezometric surface in the basin.

Both unconfined and confined ground water conditions are present in the basin. Ground waters in the northwest portion and on the flanks of the valley are unconfined, but southeast of Indio the ground water is confined. Depths to ground water vary widely. While some wells extract water in excess of 500 feet below the surface, such as in the San Gorgonio Pass area, other wells in the southeast portion of the valley deliver artesian flows.

A useful term in estimating subsurface flow from field data is the coefficient of transmissibility. It is defined as the average field coefficient of permeability of the water-bearing materials multiplied by the saturated thickness of the materials. The transmissibility of water-bearing materials in Coachella Valley was measured at several locations through water well pumping tests. The results of these tests are presented in Table 1.

TABLE 1

SUMMARY OF TRANSMISSIBILITY DATA

Area	Pumping Well	Date of Test	Calculated Transmissibility[a]
Palm Springs	4S/5E-15R2	4-25-61	175,000
Desert Hot Springs	3S/6E-28D1	4-29-61	1,000
Indio	5S/7E-24L1[b]	5- 3-61	250,000
	5S/8E-29K1	4- 7-61	60,000
Thermal	6S/7E-13K2	4-27-61	220,000
Oasis	8S/9E-29H1	10-10-60	24,000
	8S/9E-33R1	10-12-60	5,000
	8S/9E-31A1	10-20-60	750,000
	8S/9E-31R1	10-21-60	1,500,000

a. Values in gallons per day per foot width of aquifer under unit hydraulic gradient
b. Cooperative pumping test with United States Geological Survey

Extractions of ground water by wells from the Coachella Valley Ground Water Basin currently amount to over 150,000 acre-feet annually. Although water wells exist throughout the basin, the major portion of them are present southeast of Indio. The location of water wells and their distribution within the several subdivisions of the ground water basin are shown on Plates 6A, 6B, and 6C.

Ground Water Storage

The amount of readily-extractible water a ground water basin can store depends on the volume of the water-bearing formations and their specific yield. The ground water storage capacity of the Coachella Valley Ground Water Basin between the 1935-36 water table levels and 1,000 feet below ground surface was calculated to be over 39,000,000 acre-feet. Within the several subdivisions of the basin the amount of ground water in storage has fluctuated from year to year, depending upon the amount of the replenishing supply, and the items of disposal, including ground water extractions and outflow.

Storage Capacity

The volume of the water-bearing formations in a ground water basin and the specific yields of the materials making up these formations, as stated above, are the bases for determining the storage capacity. Since the maximum depth of water-bearing materials in the basin is not well known and exceeds a practical depth of extraction, other criteria were needed to determine the volume of water-bearing materials. Therefore, for the purposes of this investigation, the total storage capacity of the basin was defined as that which occurs between the spring 1935-36 ground water elevations and a depth below the ground surface of 1,000 feet or the base of water-bearing materials, whichever is smaller. The 1935-36 ground water elevations are used as a practical upper limit for ground water storage. Attempts to utilize storage space to the ground surface everywhere in the basin would undoubtedly cause waterlogging problems in the lower portion of the valley, and it may be reasonably expected that water levels will not recover above the 1935-36 levels under present or future physical conditions.

The specific yield of water-bearing materials is the ratio of the volume of water that saturated materials will yield to gravity to the total volume of the saturated materials, and is expressed as a percent.

Specific-yield values of the water-bearing formations of the Coachella Valley Ground Water Basin, and representative drillers' terms, are listed in Table 2. The Hydrologic Laboratory of the United States Geological Survey, in cooperation with the Department of Water Resources, is currently investigating the specific-yield values of subsurface materials in California. Although tentative results of that investigation indicate that some of the values shown on Table 2 may be subject to revision, the values given are believed to be sufficiently valid for purposes of the present study.

Specific-yield values were compiled from available data including work done by the State Water Rights Board for the San Fernando Valley Reference, and from Bulletin 45 (Calif. DWR 1934). Allowances were made for the differences in depositional characteristics between coastal valleys (for which data were compiled in the reference study, and Bulletin 45) and desert valleys, such as Coachella Valley. Interviews of well drillers in the area of study and observation of drilling in Coachella Valley aided in assigning specific-yield values to drillers' terms. These specific-yield values were assigned to the materials listed in over 600 drillers' logs of wells in the basin. Based on these data, storage capacities of the ground water basin and subbasins were determined and are shown in Table 3. Also listed in Table 3 is the water in storage between the ground water levels of spring 1961 and depths below those levels of 20 feet and 60 feet. Storage capacity available above the spring 1961 ground water levels is listed in the last column of Table 3. These latter capacities are limited by the 1935-36 high ground water levels, or a maximum of 20 feet above the spring 1961 ground water levels, whichever is the smaller.

TABLE 2

SELECTED SPECIFIC YIELD VALUES FOR USE IN COACHELLA VALLEY

Specific yield value	Description of material	Representative terms used by drillers to describe material	
3 percent	Clay	Clay and silt Clay streak Gumbo Hard pack Hard shale	Ledge Shale and clay Shell Slum Sticky formation
5 percent	Clayey sand	Clay and sand Clay and sand streaks Clay and slummy sand Fine in and out Hill formation	Medium fine sand and shale streaks Medium fine shaley Medium fine to clay streaks Slime sand
7 percent	Clayey gravel	Cemented gravel Comented rock Clay and gravel streaks Clay and rock	Conglomerate and shale Gravel and sand cemented Slummy gravel
10 percent	Silty sand	Clay and mix Coarse in and out In and out Medium in and out Sand and clay	Silty sand Slummy sand Surface soil Tight gravel Tight sand and gravel
18 percent	Fine sand	Blow sand Boulders Dirty sand Fine fair loose sand Fine sand	Hard packed sand Medium fine and pebbles Running sand Sand cutting type Sugar sand
22 percent	Gravel	Clear rock Coarse gravel Fairly coarse sand mixed with fine sand Free gravel Light white water gravel	Medium to conglomerate Rocky pebbles Sand and gravel Sand and rock Surface rocks
25 percent	Medium sand	Alluvial deposits Clean sand Dry wash sand Medium and coarse sand	Medium coarse and medium sand Sand Water Water gravel
28 percent	Coarse sand	Coarse sand Fairly coarse sand	Match head gravel Medium coarse sand

TABLE 3

ESTIMATED GROUND WATER STORAGE CAPACITY AND AMOUNT OF GROUND WATER IN STORAGE
COACHELLA VALLEY GROUND WATER BASIN
(In acre-feet)

Area	Total storage capacity[a]	Storage capacity available in first 20 feet above spring 1961 water levels[b]	Ground water in storage, spring 1961: Amount stored in first 20 feet below water table	Ground water in storage, spring 1961: Amount stored in first 60 feet below water table
San Gorgonio Pass Subbasin	2,700,000	81,000	81,000	245,000
Mission Creek Subbasin	2,600,000	32,000	80,000	254,000
Desert Hot Springs Subbasin				
Miracle Hill subarea	400,000	--[c]	13,000	40,000
Sky Valley subarea	1,400,000	--[c]	47,000	141,000
Fargo Canyon subarea	2,300,000	--[c]	112,000	336,000
	4,100,000	--[c]	172,000	517,000
Indio Subbasin				
Garnet subarea	1,000,000	33,000	34,000	100,000
Palm Springs subarea	4,600,000	225,000	220,000	670,000
Thousand Palms subarea	1,800,000	33,000	29,000	90,000
Oasis subarea	3,000,000	--[c]	82,000	247,000
Thermal subarea	19,400,000			
Semiperched ground water		--[c]	309,000	374,000
Aquifers (unconfined)		160,000	211,000	600,000
	29,800,000	451,000	885,000	2,581,000
COACHELLA VALLEY GROUND WATER BASIN	39,200,000	564,000	1,218,000	3,597,000

a. Capacity to store ground water between 1935-36 high ground water elevations and 1,000 feet below the ground surface.

b. Limited by 1935-36 high ground water levels.

c. Storage capacity between 1935-36 high ground water levels and spring 1961 ground water levels negligible or undetermined.

Change in Storage

Changes in the amount of ground water in storage within an unconfined ground water basin over a specified time are a function of the change in free ground water levels during the time period, and the specific yield of the materials through which the water level changes occur. Piezometric level fluctuations in areas of confined ground water are the result of changes in pressure and do not necessarily reflect a change in storage.

Determination of the seasonal change in storage in the Coachella Valley Ground Water Basin during the 22-year base period, 1935-36 through 1956-57, was based on data from historical ground water level measurements, well hydrographs, and the specific-yield values assigned the materials listed in the drillers' logs of water wells in the valley. Annual changes of the unconfined ground water table were estimated for each year of the base period. In the portion of the Thermal subarea southeast of Indio, changes in the semiperched water table were used for change in storage calculations. Plates 9, 10, and 11, "Contours of Ground Water Levels," indicate the magnitude and direction of changes in ground water levels of the semiperched and main water tables during the base period. Elevation contours of the main water table are depicted for fall 1938 on Plate 9, fall 1948 on Plate 10, and fall 1957 on Plate 11. Contours of depth below ground surface of the semiperched water table are shown for winter 1939 on Plate 9, spring 1949 on Plate 10, and spring 1957 on Plate 11.

The accumulated change in storage for the subbasins, subareas, and the total accumulated change in storage for the ground water basin are presented graphically on Plate 12, "Estimated Accumulated Change in Storage During Base Period 1935-36 through 1956-57."

As noted from Plate 12, the total amount of ground water in storage in the basin generally declined during the early part of the base period. However, since the importation of Colorado River water, a reversal of this trend has occurred. Ground water levels in those portions of the basin receiving Colorado River water have risen rapidly since 1949 when the first deliveries of this water were made. Even though water levels in areas not receiving imported water have continued to decline, the change in storage of the basin as a whole reflects the application of Colorado River water.

Imported Colorado River water is applied primarily to the portion of the basin in the Thermal subarea below Indio. Percolation of this applied water replenishes the semiperched ground water body. Plate 12 shows that a very large increase in the amount of ground water in the semiperched zone has occurred since 1949. However, the poor quality of the semiperched ground water precludes consideration of its reuse for beneficial purposes.

Determination of the usable water supply within the Coachella Valley Ground Water Basin includes a consideration of the quality of the waters. On this basis, the semiperched ground water body is not a source of supply. Although the gross amount of ground water in storage is increasing within the Coachella Valley Ground Water Basin, the amount of usable supply in storage is decreasing.

CHAPTER IV. WATER QUALITY

Naturally occurring ground water contains dissolved solids that vary in amount and composition; its quality depends upon the source of the water, the type of water-bearing materials in which it occurs, and the hydrologic conditions governing rates of movement of the ground waters. Additional dissolved material may be added to ground water by percolation of irrigation water, sewage, and other waste waters.

Ground waters of the subbasins of the Coachella Valley Ground Water Basin exhibit marked variations in character and quality. However, within each subbasin and subarea, the ground water type and quality characteristics are distinct. These distinct characteristics were utilized in delineating the basin subareas and in locating barriers to ground water movement.

Sampling and Analyses

General sampling and mineral analyses of waters in the area of investigation has been conducted since approximately 1952 through the department's statewide water quality monitoring program. About 500 water analyses in the department's files were reviewed and a total of 36 samples were taken from representative wells during the investigation to cover peripheral areas not previously covered.

Water analyses were also used in this study that were developed by the Coachella Valley County Water District, the Riverside County Flood Control District, and other water agencies within the Coachella Valley. Especially useful during the investigation of water quality was the report, "Hydrologic Studies in Coachella Valley" by M. R. Huberty, A. F. Pillsbury, and V. P. Sokoloff, University of California College of Agriculture, June 1948.

Representative analyses of ground water within the subbasins and subareas are listed in Table 4. Analyses of surface waters contributing to the valley are shown in Table 5. An analysis of imported Colorado River water is also included for comparison. The surface water analyses are representative of the main sources of ground water supply for the valley. Also listed is an analysis of agricultural drainage water from the Whitewater River Storm Water Channel.

Mineral Character of Coachella Valley Ground Water

Four general types of ground water are present in the Coachella Valley Ground Water Basin. The first type is relatively low in dissolved solids having calcium, or sodium, and bicarbonate as the major dissolved constituents. A second type contains a relatively high total dissolved solids content that consists predominantly of sodium and sulfate. Relatively equivalent amounts of calcium and sodium, bicarbonate and sulfate are characteristic of the third type. The fourth distinct type is high in total dissolved solids and is characterized by sodium and chloride.

Calcium-Sodium Bicarbonate Ground Water

Calcium as the dominant cation and bicarbonate as the dominant anion is characteristic of the San Gorgonio Pass subbasin and the Palm Springs subarea of the Indio subbasin. The sources of these waters undoubtedly are the surface streams of the San Bernardino and San Jacinto Mountains, which carry water of similar character. However, as the ground water moves from the northwest to the southeast portion of the Indio

TABLE 4

MINERAL ANALYSES OF REPRESENTATIVE GROUND WATERS
COACHELLA VALLEY INVESTIGATION

Area well number	(1) San Gorgonio Pass 3S/2E-7D1		(2) Palm Springs 4S/4E-1N1		(3) Thermal deep zone 7S/8E-20l		(4) Thermal shallow zone 6S/8E-7P1		(5) Garnet Hill 3S/4E-15R1		(6) Miracle Hill 3S/5E-10J1		(7) Sky Valley 3S/6E-28A1		(8) Fargo Canyon 4S/8E-31R1		(9) Thousand Palms 4S/6E-8L1		(10) Mission Creek 3S/4E-2E1		(11) Oasis 8S/9E-31R1		(12) Thermal semi-perched water CVCWD:F-23	
Constituents	epm[1]	ppm[2]	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm
Ca	2.59	52	1.6	32	0.44	9	2.8	56	0.40	8	2.2	44	1.80	36	2.2	44	2.69	54	2.40	48	2.70	54	10.75	215
Mg	1.40	17	0.58	7	0	0	0.45	6	0.58	7	0.50	6	0.35	4	0.05	1	1.37	17	0.82	10	0.92	11	4.72	57
Na	0.83	19	0.48	11	1.74	40	1.50	34	2.65	61	12.17	280	12.25	282	7.90	182	4.92	113	2.35	54	8.35	192	33.96	782
K	0.05	1.8	--	--	(.038	1.5	0.09	4	--	--	--	--	0.16	6.3	0.20	7.8	0.23	8.8	0.22	8.6	0.36	14	0.17	6.6
CO_3	0	0	0.15	5	0	0	0	0	0.20	6	0.10	33	0	0	0	0	0	0	0	0	0	0	0	0
HCO_3	4.24	259	1.95	119	1.48	90	2.09	128	1.3	79	0.65	40	0.85	52	1.75	107	2.14	131	2.20	134	3.60	220	1.65	101
SO_4	0.36	17	0.31	15	0.62	30	1.07	51	1.15	55	10.42	500	10.40	500	5.91	284	5.76	276	2.95	142	4.68	225	17.24	828
Cl	0.23	8	0.30	11	0.28	10	1.44	51	0.15	18	4.00	142	3.00	106	2.10	74	1.10	39	0.54	19	4.00	142	30.93	1097
NO_3	0.05	3.0		trace	0.024	1.5	0.04	2		trace	0	0	0.10	6.2	0.43	27	0.03	2.1	0.02	1.5	0.10	6	trace	
F	0.04	0.8		0.45		0.9	0.03	0.54		0.20		8.5	0.46	8.7	0.33	6.3	0.06	1.2	0.03	0.6		1.0	0.200	
Boron		0.02		trace		0.02		0		trace		1.6		0.69		0.17		0.09		0.04		0.5		1.22
Silica		—		—		—		18		—		—		14		18		18		—		—		33
Total Dissolved Solids		285				147		355						962		692		624		300		786		3180
Solids by Summation		247		149		138		287		194		1005		1016		697		594		352		755		3121

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Percent Na	18	18.0	78	31	73	82	84	76	53	41	68	68
Total hardness	199	109	22	163	49	135	108	113	203	161	181	773
Sampled by[3]	DWR	P.S.Wat.Co.	DWR	DWR	RCFCD	RCFCD	DWR	DWR	DWR	DWR	CVCWD	CVCWD
Date sampled	2-23-55	10-15-57	4-9-52	12-16-59	9-25-57	10-30-57	3-21-61	2-18-61	2-1-61	2-23-55	6-1960	6-24-49
Temp.	—	—	70° F.	71° F.	81° F.	109° F.	94° F.	90° F.	—	76° F.	—	—
pH	7.7	8.1	8.2	7.9	8.5	8.2	7.6	7.6	8.2	7.8	7.8	7.5
EC x 10^6	413	268	208	546	353	1487	1545	1055	913	554	1246	4880

1. Chemical equivalents per million.
2. Parts per million by weight.
3. DWR-Department Water Resources; P.S. Wat. Co.-Palm Springs Water Company; RCFCD-Riverside County Flood Control District; CVCWD-Coachella Valley County Water District.

TABLE 5

MINERAL ANALYSES OF REPRESENTATIVE SURFACE WATERS
COACHELLA VALLEY INVESTIGATION

Stream	Whitewater River Sec. 2 T 3S/R3E		San Gorgonio River Hwy 99 Bridge nr. Banning		Snow Creek at P.S. Water Co. diversion intake Sec. 33 T 3S/R3E		Tahquitz Creek at USGS gage Sec. 22 T 4S/R5E		Mission Creek above Indian Spg. Ctr. Sec. 12 T 2S/R3E		Mission Creek at Hwy 99 bridge NW-1/4 Sec. 24 T 3S/R5E		Imported Colorado River Water at Ave. 52 & Canal		Drainage water Whitewater River Storm Channel at Lincoln St.	
Constituents	epm[1]	ppm[2]	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm
Ca	1.75	35	1.62	32	0.50	10	0.85	17	4.29	86	1.30	26	3.97	79	9.08	181
Mg	0.90	11	1.06	13	0.0	0	0.15	2	3.04	37	0.71	9	2.31	28	3.74	45
Na	0.62	14	0.62	14	0.47	11	0.52	12	2.13	49	0.26	6	4.78	110	32.58	749
K	0.108	4.2	0.07	2.8	0.041	1.6	0.07	2.7	0.218	8.5	0.058	2.4	0.11	4.3	0.39	15
CO_3	0	0	0	0	0	0	0	0	0	0	0	0	trace	0	0	0
HCO_3	2.4	146	2.62	160	0.75	46	1.3	79	4.54	283	1.85	113	2.35	143	5.73	350
Cl	0.1	4	0.34	16	0	0	0.10	4	0.48	17	0.17	6	6.01	213	15.96	566
SO_4	0.86	4	0.33	12	0.17	8	0.04	2	4.16	200	0.36	17	2.70	129	24.10	1157
NO_3	0.049	3.0	0.0195	1.21	0.010	0.6	0.01	0.9	0.056	3.5	0.02	1.15	trace		--	--
F	0.033	0.6	0.005	0.08	0.050	1.0	0.01	0.1			0.005	0.11		0.15		
Boron		0.02		1		0.0		0.06		0.05		0		--		--
Silica				12		17		20		--		20				
Br		0.1														
I		0														
PO_4				0.0												
Total Dissolved Solids		201		209		55		84		585		118		727		2983
Solids by Summation		186		194		73		100		543		144		705		3065
Percent Na	18		18		47		33		22		11		43		74	
Total hardness	132		134		20		50		366		100		314		641	
Sample by[3]	RCFCD		DWR		RCFCD		RCFCD		DWR		DWR		CVCWD		CVCWD	
Date sampled	5-3-57		4-7-58		2-28-58		3-16-60		3-26-52		4-7-58		8-12-58		7-16-59	
Discharge: cfs	7+		100		10		2+		almost dry		ponded					
Temp.	64° F.		52° F.		42° F.		58° F.		60° F.		--					
pH	8.1		7.8		7.8		7.9		8.2		7.3		8.1			
EC x 10^6	333		320		81		140		765		182		1080		4230	

1. Chemical equivalents per million.
2. Parts per million by weight.
3. RCFCD-Riverside County Flood Control District; DWR-Department of Water Resources; CVCWD-Coachella Valley County Water District.

subbasin, an increase in sodium is evident, as illustrated by the representative ground water analyses of the Thermal subarea aquifers in Table 4. This is apparently caused by ion exchange phenomena between the water and minerals in the clay lenses of the water-bearing materials. A similar condition apparently exists in the Garnet Hill subarea. The clay gouge present in the fault zones bounding the latter subarea would be a source for ion exchange.

Sodium Sulfate Ground Water

The portions of the ground water basin that receive very little recharge have only a slight amount of ground water movement; where these basins are intersected by or closely related to faults they usually contain ground waters of relatively high total dissolved solids which are dominantly sodium sulfate in character. These conditions are present in the Desert Hot Springs subbasin and the Thousand Palms subarea.

Ground waters adjacent to the Mission Creek fault in the Miracle Hill subarea contain the largest amounts of sodium and sulfate ions and are also of abnormally high temperature. Gypsum, which is a significant source of sulfate, is present in the exposures of the Mission Creek fault and in the semiwater-bearing materials of the Indio and Mecca Hills. This would be a possible source of the sulfate ions in ground water in these areas.

Calcium-Sodium Bicarbonate-Sulfate Ground Water

The Mission Creek subbasin and the Oasis subarea contain ground water that is characterized by relatively equivalent amounts of calcium, sodium, bicarbonate and sulfate ions. These ground waters are replenished by water sources that are different, or variable, in character. In addition, the replenishment to and the movement of ground water in these areas is small.

An illustration of the variable character of the supply to the Mission Creek subbasin is provided by the surface water analyses of Mission Creek listed in Table 5.

The chemical analysis of water sampled above Indian Spring represents the type of water in the stream during periods of low flow. It is essentially a calcium-magnesium bicarbonate-sulfate type water. However, the second analysis of water sampled approximately ten miles downstream from Indian Spring, at the highway bridge, which is representative of spring runoffs, is a calcium bicarbonate type water. The variability in water quality illustrated by the analyses of samples from Mission Creek is probably representative of the intermittent runoff of streams draining the southeast portion of the Santa Rose Mountains where rock types and the amount of rainfall is similar to that present within the drainage of Mission Creek.

In addition to runoff from the adjacent mountains, the Oasis subarea apparently receives recharge from the Thermal subarea in the vicinity north and east of Martinez Canyon. The Mission Creek subbasin probably receives a limited amount of recharge from the Desert Hot Springs subbasin.

A mixing of the different types of waters replenishing the Mission Creek subbasin and the Oasis subarea may explain, at least partially, the character of the ground waters present.

Sodium Chloride Ground Water

The fourth ground water type present in the area of investigation contains sodium as the dominant cation and chloride as the dominant anion, modified by a significant amount of sulfate ion. The semiperched ground water of the Thermal subarea contains water of this type. Evaporation from the shallow water table, consumptive use of vegetation, and leaching of salts from the soil by return irrigation water has resulted in a high concentration of minerals in this type of ground water.

Presence of the significant amount of sulfate ion can be attributed to mixture with waters from the Colorado River. The initial filling of the Salton Sea by the Colorado River in 1906 inundated the central portion of the Thermal subarea and provided an opportunity for the mixing of Colorado River water with the semiperched ground water. Similar floodings of the Salton depression undoubtedly occurred in prehistoric times. Since 1948, imported Colorado River water has been applied in the Thermal subarea for irrigation purposes.

Changes in Ground Water Character

The agricultural and urban development of Coachella Valley has changed the natural regimen of the ground water basin. Ground water extractions and the importation of Colorado River water have changed the conditions which had developed for disposal of the water supply. A general evaluation of water quality in the Coachella Valley Ground Water Basin was undertaken to see if any changes in water quality have also occurred with time. Water analyses collected by the department since 1952 were compared to those collected prior to 1940. These comparisons showed little change in the quality of the ground water in any of the subareas except the Thermal subarea.

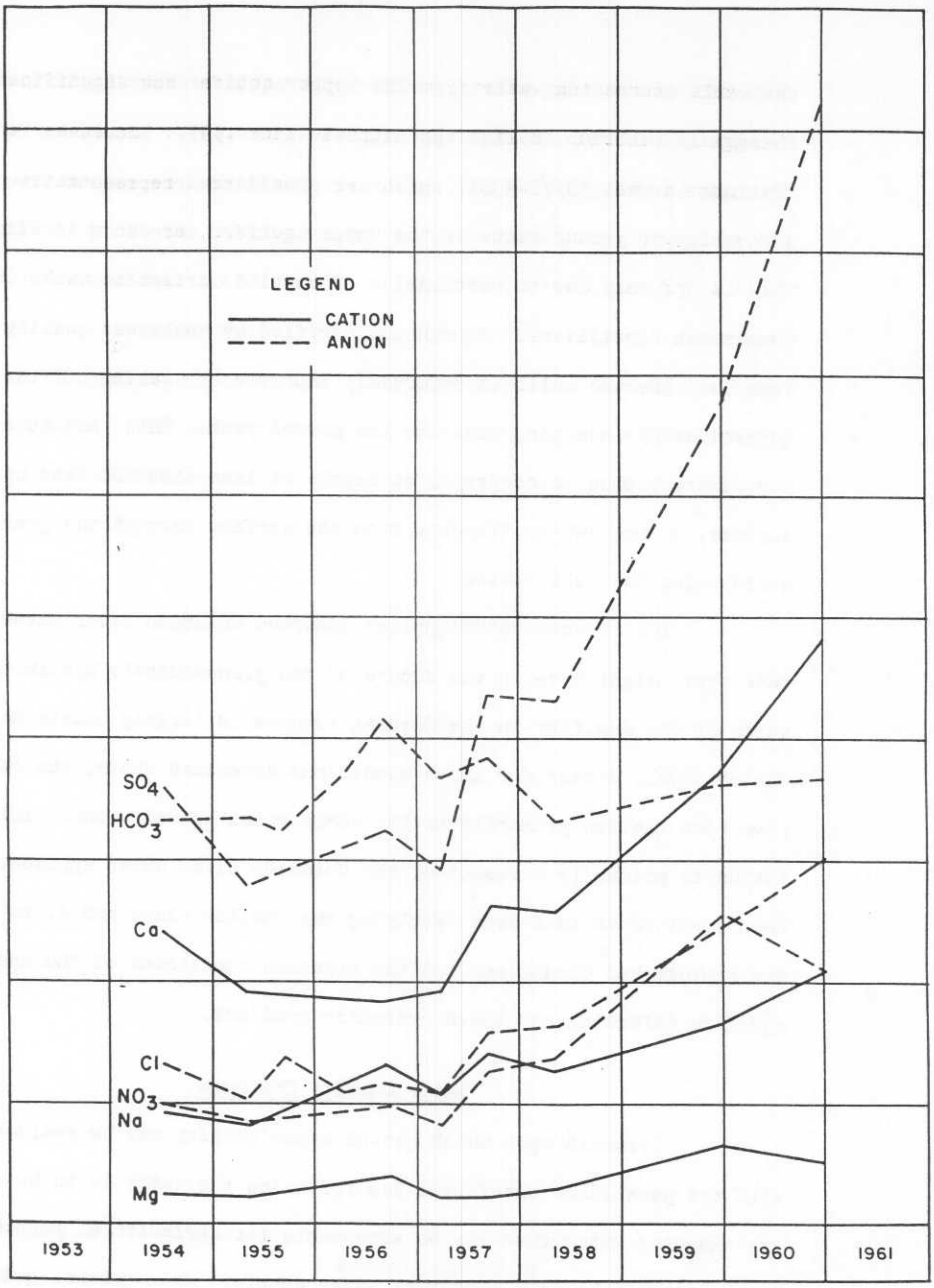
Within the Thermal subarea, the general character of the ground water types appears to be little altered since 1940. However, a few of the wells extracting water from the upper aquifer show significant quality changes in calcium, sulfate and nitrate since 1957. Increases in concentrations in well 5S/7E-33C1, which are considered representative of changes in quality of ground water in the upper aquifer, are shown in Figure 2. This is probably due to percolation of applied irrigation water carrying commercial fertilizers. Though not verified by analyses, quality of water from the affected wells is reportedly improved by sealing off the shallow formations by injecting mud into the gravel pack. This indicates the quality deterioration is occurring at depths of less than 200 feet below the surface, or by leakage directly from the surface through the gravel pack surrounding the well casing.

The effects which applied imported Colorado River water, a sulfate type, might have in the future on the predominantly bicarbonate type water of the aquifers in the Thermal subarea is largely undetermined. Through 1961, except for those conditions discussed above, the effects have been limited primarily to the semiperched ground water. This limitation is primarily a result of the Colorado River water application having been confined to that area overlying the shallow clays and silts causing the semiperched condition, and the pressure conditions of the underlying aquifers effecting an upward hydraulic gradient.

Water Quality Criteria

Criteria upon which ground water quality may be evaluated vary with the particular beneficial use for which the water is to be used. For example, water that may be acceptable for agricultural purposes may not be acceptable as a municipal water supply. As a general guide to the acceptability of various water supplies in Coachella Valley, drinking

FIGURE 2



INCREASE IN MINERAL CONCENTRATION OF GROUND WATER, 1954 THROUGH 1960 STATE WELL NO. 5S/7E-33C1

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1964 water standards and some pertinent criteria for irrigation waters are presented.

Criteria for Drinking Water

The most widely used criteria for determing the suitability of water for domestic and municipal use are the U. S. Public Health Service Drinking Water Standards. Limits for mineral and other constituents in water are divided into two groups: (1) concentrations which constitute grounds for rejection of the supply, and (2) recommended maximum concentrations. These criteria, as revised in 1962, are shown in Table 6.

The California Department of Public Health has established maximum safe limits of fluoride concentrations. The limitation of fluoride content is based on studies that have shown that amounts in excess of the limitation on the fluoride ion in drinking water may cause a complete or partial arrest in the development of the tooth enamel. Maximum safe limits of fluoride ion concentrations are related to mean annual temperature, and are defined by the State Department of Public Health as follows:

Mean Annual Temperature	Mean Monthly Fluoride Ion Concentration
50° F.	1.5 ppm
60° F.	1.0 ppm
70° F.	0.7 ppm

Total hardness is a significant factor in the determination of the suitability of water for domestic or municipal use. Waters containing 100 ppm or less of hardness (as $CaCO_3$) are considered "soft"; those containing 101 to 200 ppm are considered "moderately hard"; and those with more than 200 ppm are considered "very hard."

TABLE 6

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS

Dissolved constituent	Concentration which constitutes grounds for rejection*	Recommended maximum concentration*
Arsenic (As)	0.05	0.01
Barium (Ba)	1.0	
Cadmium (Cd)	0.01	
Chromium (Hexavalent) (Cr^{+6})	0.05	
Cyanide (CN)	0.2	0.01
Lead (Pb)	0.05	
Selenium (Se)	0.01	
Silver (Ag)	0.05	
Chloride (Cl)		250
Copper (Cu)		1.0
Iron (Fe)		0.3
Manganese (Mn)		0.05
Nitrate (NO_3)		45
Sulfate (SO_4)		250
Zinc (Zn)		5
Phenols		.001
Total dissolved solids, desirable		500
Alkyl Benzene Sulfonate		0.5
Carbon Chloroform Extract (CCE)		0.2

*Concentrations of the dissolved constituents in water are expressed in parts per million by weight.

Criteria for Agricultural Use

Variability of soil type, crops grown, and climate have resulted in numerous classifications of water for agricultural use. In any such classification, three types of deleterious effects should be considered. The first is the adverse effects caused by high concentrations of dissolved solids in the water. Plants, in order to absorb soil water must have a tissue fluid of higher osmotic pressure and, therefore, of higher salt content than the soil water. Thus, the high salt content within the plant tissues required to absorb soil water of high mineral content may be injurious to the plant.

The second type of effect is due to substances in the soil water that are toxic to the plants, even in low concentrations. An example of the substances that fall in this category is boron. Although boron is essential in minute quantities for normal plant growth, it becomes injurious to boron-sentitive plants when it is present in concentrations of as little as 1.0 part per million. There is a wide range of boron sensitivity among crop types. A listing of crops according to boron sensitivity and related classes of irrigation water are given in Table 7.

The third type of effect, which is due to the relative proportions of cations present in the water, produces undesirable properties in the soil. As an example, water containing sodium as the dominant cation tends to reduce the tilth and permeability of clayey soils through a base exchange process. A guide to the classification of irrigation waters, relating these effects to the usability of water for irrigation, is presented in Table 8. The guide was originally proposed by Dr. L. D. Doneen of the University of California.

TABLE 7

CROPS GROUPED ACCORDING TO BORON TOLERANCE AND CLASSES OF IRRIGATION WATER FOR GROUPS BASED ON BORON CONCENTRATIONS[1]

Boron tolerance of crop group and representative crops in group[2]	Boron concentration in parts per million	Class of irrigation water for crop group
Sensitive to Boron	0.33	Excellent
	0.33-0.67	Good
Lemon, grapefruit, avocado, orange, thornless blackberry, apricot, peach, cherry, persimmon, kadota fig, grape (sultanina and malaga), apple, pear, plum, American elm, navy bean, Jerusalem artichoke, Persian (English) walnut, black walnut, pecan	0.67-1.00	Permissible
	1.00-1.25	Doubtful
	Above 1.25	Unsuitable
Semitolerant to Boron	0.67	Excellent
	0.67-1.33	Good
Lima bean, sweet potato, bell pepper, tomato, pumpkin, zinnia, oat, milo, corn, wheat, barley, olive, Ragged Robin rose, field pea, radish, sweet pea, Pima cotton, Acala cotton, potato sunflower (native)	1.33-2.00	Permissible
	2.00-2.50	Doubtful
	Above 2.50	Unsuitable
Tolerant to Boron	1.00	Excellent
	1.00-2.00	Good
Carrot, lettuce, cabbage, turnip, onion, broad bean, gladiolus, alfalfa, garden beet, mangel, sugar beet, palm (Phoenix canariensis), date palm (P. dactylifera), asparagus, tamarix or athel (Tamarix aphylla and T. gallica)	2.00-3.00	Permissible
	3.00-3.75	Doubtful
	Above 3.75	Unsuitable

1. U. S. Department of Agriculture Technical Bulletin No. 962, "The Quality of Water for Irrigation Use, 1948." L. V. Wilcox.
2. In each group, the crops are listed in order of decreasing sensitivity to boron concentration in irrigation waters.

TABLE 8

QUALITY CRITERIA FOR IRRIGATION WATER[a]

Criterion	Class 1[b] Excellent to good	Class 2[c] Good to injurious	Class 3[d] Injurious to unsatisfactory
Conductance[e] EC x 10^6 at 25° C	Less than 1,000	1,000-3,000	More than 3,000
Chloride, epm[f]	Less than 5	5-10	More than 10
Percent sodium[g]	Less than 60	60-75	More than 75
Boron, ppm[h]	Less than 0.5	0.5-2.0	More than 2.0

a. The values shown should be used as a guide only, since permissible limits vary widely with different crops, soils, and climatic conditions.
b. Class 1. Excellent to good--regarded as safe and suitable for most plants under any condition of soil and climate.
c. Class 2. Good to injurious--regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.
d. Class 3. Injurious to unsatisfactory--regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.
e. Specific electrical conductance (K x 10^6 at 25° C). This measurement is reported in reciprocal ohms per cm., multiplied by 10^6 (1,000,000), and provides an index of total dissolved electrolytes or total salinity. Dividing the conductance (EC x 10^6 at 25° C) by 10 gives an approximation of the salt content in milligram equivalents per liter. Multiplying the conductance (EC x 10^6 at 25° C) by 0.7 gives a rough estimate of parts per million (ppm) total salts.
f. Chloride is expressed as equivalents per million.
g. Sodium percentage is computed by the formula $\frac{Na \times 100}{Na+Ca+Mg}$, when these are expressed as equivalents per million.
h. Boron content is expressed in parts per million.

Water Quality Considerations in Coachella Valley

The major problem in considering the use of ground water in Coachella Valley for domestic and municipal purposes is the content of fluoride ion. The mean annual temperature determined from the records at the U. S. Date Gardens at Indio is 73° F. Using this as a guide, the maximum limit of fluoride concentration in water considered safe for public use in Coachella Valley would be 0.7 parts per million. The chemical analyses listed in Table 4 indicate that ground water in Coachella Valley tends to be relatively high in fluoride concentration. Many areas contain waters that far exceed the maximum limit quoted above. For example, wells listed in Table 4 for the Desert Hot Springs subbasin have fluoride concentrations of 6 to 8 parts per million fluoride, about 10 times the maximum limit.

The hardness of most ground waters in the area of investigation would be classed as moderately hard. One exception to this is the ground water in the deep aquifer zone of the Thermal subarea, which would be termed soft under criteria quoted herein. Hardness of the ground water in Coachella Valley is not considered a major problem, because the hardness, generally, is not significantly high, and because of the relative case with which high degrees of hardness can be decreased to acceptable limits for most domestic and municipal uses.

The ground waters presently being applied to agricultural crops in Coachella Valley would not all be classed as excellent to good, although little of the agriculture in the valley is irrigated by water injurious to the crops grown.

Agricultural lands in the Thermal subarea, where more than 80 percent of the agriculture in Coachella Valley exists, are underlain by shallow, semiperched ground water. The shallow ground water is undesirable for agricultural use, primarily because of its high mineral concentration. In addition, the shallow semiperched ground water table must be kept at a sufficient depth below the root zone in order that accumulated salts in the soil derived from the applied water may be leached out. Because the amount of rainfall is insufficient to wash accumulated salts from the soil, the irrigation water applied to agricultural crops must be in excess of plant requirements to provide for leaching of the salts.

The importation of Colorado River water has provided a larger supply of applied water to these lands than the natural drainage conditions can handle, thus resulting in a steady rise in the semiperched ground water table. Control of the shallow water table below the root zones of the crops is presently accomplished through the placement of underground drainage systems. Laterals of farm tile drainage systems discharge into a main outlet drainage system that is provided and maintained by the Coachella Valley County Water District. All of the drainage water eventually discharges into the Salton Sea.

Ground water below the semiperched ground water in the Thermal subarea generally contains sodium as the dominant cation. Applied waters with a high sodium percentage (the ratio of sodium in equivalent parts per million to the total cations) affect the tilth and permeability characteristics of the soil. Soil clays undergo a cation exchange reaction and deflocculate. As the irrigation water becomes more concentrated in the fine-grained soils, there is a tendency for the water to produce an alkali soil. When the application of these ground waters is interspersed with applications of imported Colorado River water, the relatively high content of calcium of the latter water tends to counteract the development of an alkali soil. However, it has been necessary on much of the farmland in the valley to counteract the sodium in the applied ground water with the application of calcium sulfate.

Presently irrigated lands of the investigational area outside the Thermal subarea are, with little exception, in the San Gorgonio Pass subbasin. Ground water here would be classified as excellent for agricultural purposes.

Ground water in the Mission Creek and Desert Hot Springs subbasins would be classed as good to injurious for agricultural purposes. Locally, such as in the Miracle Hill subarea, the high mineral concentrations and the presence of boron in toxic concentrations make the ground water less desirable.

Relatively high boron concentration also exists in the ground water of the Thermal subarea in the vicinity of Oasis and Travertine Rock near the northwest shore of the Salton Sea.

CHAPTER V. HYDROLOGIC STUDIES

The manner in which the water supply reaches a ground water basin, the utilization of the supply in the basin, and the disposal of the supply make up the hydrologic characteristics of the basin. The several factors affecting a basin's water supply, utilization and disposal are commonly evaluated in the hydrologic equation: supply of water to the basin minus water disposal equals change in ground water storage. Thus, when the supply of water to the basin exceeds the disposal of water from the basin, the amount of ground water in storage in the basin increases. Conversely, when the supply is less than the disposal, the amount of ground water in storage decreases. Presented in this chapter are estimates of seasonal amounts of each item of supply and each item of disposal, and an evaluation of the water supply surplus or deficiency in the Coachella Valley Ground Water Basin.

The factors studied in the hydrologic equation for the basin were grouped into the following items of water supply and disposal:

Items of Supply

1. Precipitation on area of investigation
   a. Deep percolation of direct rainfall on valley areas
   b. Mountain runoff to the valley (directly related to precipitation in the mountains)
2. Surface inflow (from outside the area of investigation)
3. Subsurface inflow (from outside the area of investigation)
4. Imported water

Items of Disposal

1. Net water use, which includes:
   a. Agricultural consumptive use
   b. Urban and suburban consumptive use
   c. Native vegetation consumptive use
   d. Applied waters irrecoverably lost
   e. Evaporation from free water surfaces

2. Surface outflow

3. Subsurface outflow

4. Exported water

As a first step in determining the hydrologic characteristics of the basin, a base period was selected that would be representative of average conditions of water supply in the area of investigation.

Determination of the Study Base Period

Total seasonal precipitation in the study area, the source of the natural water supply, varies widely in magnitude from season to season. At Banning, for example, during the period of record from 1906 through 1961, the precipitation ranged from a seasonal low of 6.02 inches in 1960-61 to a seasonal high of 30.30 inches in 1940-41. The ground water basin functions as a natural regulatory reservoir of this fluctuating supply, sorting quantities of water during periods of surplus supply that are then available during periods of deficient water supply. Therefore, the average amount of supply over a long-time period that includes both wet and dry years is considerably more significant in determining the hydrologic characteristics of the ground water basin than the supply over shorter wet or dry periods.

A base period of 22 years, from 1935-36 through 1956-57, was selected for the hydrologic studies because this period includes typical seasonal fluctuations in the precipitation over the area of investigation and because the available data indicate that average precipitation during the base period and the period of record are comparable. The precipitation records of the stations at Indio, Beaumont, and Raywood Flat, listed in Table 9, illustrate the fluctuations in seasonal rainfall in the region of the study area.

The 1935-36 season was the end of a generally dry period. As a result, the amount of water in transit (the water percolating from the ground surface to the ground water table) was at a minimum at this time. Similar conditions of relative dryness and amount of water in transit were also true for the 1956-57 season. Selecting these similar years for the beginning and end of the 22-year base period permits the important assumption to be made that the net change in the amount of water in transit to the ground water table was minimal.

TABLE 9

PRECIPITATION RECORDS AT
INDIO, BEAUMONT, AND RAYWOOD FLAT

Season	Total seasonal precipitation, in inches		
	Indio	Beaumont	Raywood Flat
1878-79	1.90		
80	0.40		
81	4.65		
82	1.50		
83	3.40		
84	5.60		
85	0.80		
86	0.90		
87	1.35		
88	0.95		
89	3.83	18.18	
1889-90	5.56	25.10	
91	2.42[a]	18.43	
92	4.24	14.92	
93	1.63	19.30	
94	1.01	9.46	
95	6.01	27.04	
96	0.92	7.87	

PRECIPITATION RECORDS AT
INDIO, BEAUMONT, AND RAYWOOD FLAT
(continued)

Season	Total seasonal precipitation, in inches		
	Indio	Beaumont	Raywood Flat
1896-1897	1.29	19.36	
98	2.50	8.71	
99	1.70	7.48	
1899-1900	2.35		
01	3.04		
02	0.60		
03	2.35[a]		
04	2.05[a]		
05	5.18[a]		
06	4.70		
07	5.83	25.94	
08	3.18	17.16	
09	3.13	24.35	
1909-10	3.60	14.49	
11	2.44	19.89	
12	3.15	17.56	
13	3.01	10.23	
14	2.45	27.48	
15	5.43	28.61	
16	4.34	26.19	
17	3.54	19.44	
18	1.51	17.08	
19	1.09	15.68	
1919-20	5.63	22.93	
21	4.84	16.88	29.51
22	7.03	32.89	59.55
23	0.18	17.21	28.95
24	0.74	13.77	31.26
25	0.89	13.29	22.33
26	5.53	24.52	47.49
27	7.09	27.75	48.75
28	5.00	13.16	27.78
29	0.42	13.94	30.46
1929-30	4.20	21.94	49.13
31	2.67	13.81	27.22
32	3.79	26.03	60.76
33	2.44	15.36	25.27

PRECIPITATION RECORDS AT
INDIO, BEAUMONT, AND RAYWOOD FLAT
(continued)

Season	Total seasonal precipitation, in inches		
	Indio	Beaumont	Raywood Flat
1933-34	0.35[a]	11.75	23.56
35	2.67	20.53	45.76
36	2.26	15.65	31.39
37	6.67	34.00	58.34
38	1.88	22.89	54.07
39	3.65	18.20	29.36
1939-40	11.50	18.04	41.18
41	6.81	30.25	49.74
42	5.53	14.44	28.74
43	5.75	23.79	25.68
44	6.05	20.08	53.30
45	2.06	18.69	34.21
46	4.43	15.39	33.78
47	1.94	17.64	32.87
48	0.85	11.54	22.69
49	3.81	14.63	24.97
1949-50	0.76	12.93	21.47
51	0.91	9.34	21.90
52	5.22	23.66	29.79
53	4.06	14.00	20.06
54	1.55	17.75	25.61
55	3.23	14.07	22.07
56	0.57	12.07	19.55
57	1.58	14.71	23.24
58	4.53	27.32	64.41
59	0.38	9.21	23.25
1959-60	3.02	13.37	
Average seasonal precipitation[b]	3.15	18.30	34.60
Average seasonal precipitation[c]	3.69	17.90	32.00
Maximum seasonal precipitation[b]	11.50	34.00	64.41
Maximum seasonal precipitation[c]	11.50	34.00	58.34
Minimum seasonal precipitation[b]	0.18	7.48	20.06
Minimum seasonal precipitation[c]	0.57	9.34	20.06

a/ Partially estimated
b/ Of record
c/ Of base period, 1935-36 to 1956-57

Estimates of the amounts of water supply and disposal for each season of the base period were attempted even though several of the factors could only be evaluated on an average basis because of the lack of basic data. However, these estimates are believed to be sufficiently accurate for verifying the water supply surplus or deficiency, and were used as a basis for checking the reasonableness of the change in storage that was determined from the geologic studies.

Items of Water Supply

The major source of water supply to the Coachella Valley Ground Water Basin is imported Colorado River water. The amounts of imported water brought into the basin through the Coachella Canal far exceed those derived from the sources of natural water supply: surface runoff from the surrounding mountains, deep percolation of precipitation on the valley floor, and subsurface inflow.

The contributions to the water supply of the basin from the various items of supply, including precipitation, surface inflow, subsurface inflow, and imported water are discussed in this section.

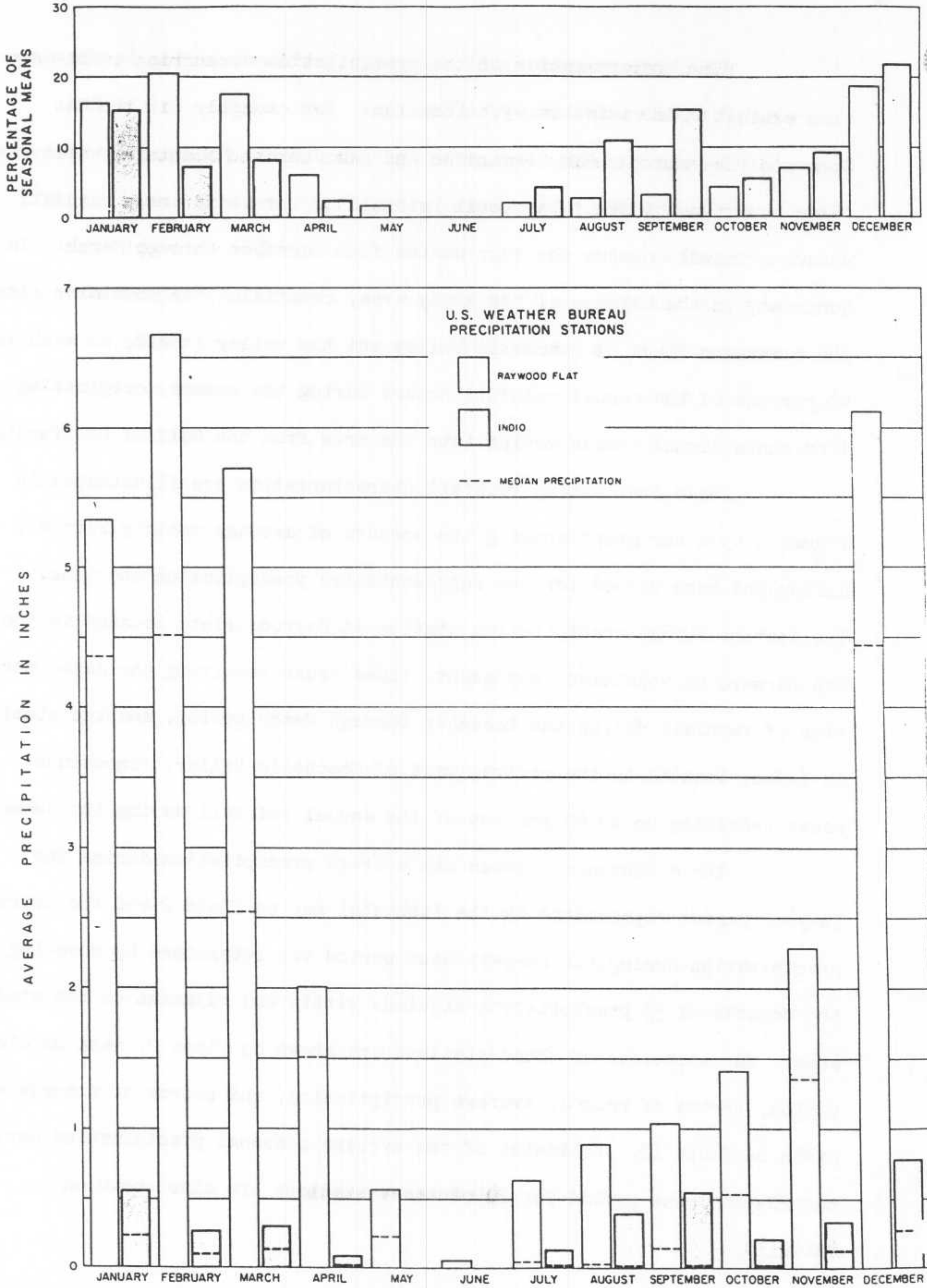
Precipitation

The average seasonal precipitation within the study area varies markedly with location, ranging from less than 4 inches at Indio to over 35 inches at the crests of the San Bernardino and San Jacinto Mountains. This variation in the average seasonal precipitation is shown by the isohyetal map on Plate 2, which indicates the average precipitation for the 30-year period 1930-31 to 1960-61. This map was obtained from the U. S. Weather Bureau and is part of the precipitation study made for the U. S. Geological Survey for the Lower Colorado River Project.

The characteristics of the precipitation occurring in the area also exhibit wide variation with location. For example, in the San Gorgonio Pass and the San Bernardino and San Jacinto Mountains, which receive over two-thirds of the total rainfall of the study area, rainfall occurs primarily during the four months from December through March. In contrast, in the balance of the study area, comprising the mountains along the northeast flank of Coachella Valley and the valley itself, as much as 40 percent of the annual rainfall occurs during the summer, originating from convectional storms moving into the area from the Gulf of California.

These contrasting rainfall characteristics are illustrated in Figure 3 by a bar graph showing the amounts of average monthly rainfall during the base period for two representative precipitation stations. The Weather Bureau precipitation station at Raywood Flat, located in the San Bernardino Mountains, represents those areas receiving the major portion of rainfall during the December through March period, and the station in Indio, located in the central part of Coachella Valley, represents areas receiving up to 40 percent of the annual rainfall during the summer.

The difference between the average precipitation during the 30-year period represented by the isohyetal map on Plate 2 and the average precipitation during the 22-year base period was determined by checking the records of 33 precipitation stations within and adjacent to the study area. The locations of these stations are shown on Plate 2; data on elevation, period of record, average precipitation, and source of records are given on Table 10. Estimates of the average seasonal precipitation during the 22-year base period for 20 of these stations are also shown on Table 10.



MONTHLY DISTRIBUTION OF PRECIPITATION 1935-36 THROUGH 1956-57

TABLE 10

PRECIPITATION STATIONS

Map reference number[a]	Station	Elevations of stations, in feet, USGS datum	Period of record: From	Period of record: To	Missing or incomplete years: Record	Missing or incomplete years: Base period	Average annual precipitation, in inches: Period from 1935-36 through 1956-57[b]	Average annual precipitation, in inches: Period from 1930-31 through 1959-60[c]	Source of record[d]
1	Banning Water Company	2305 & 2340	1906-07	1960-61	12	12	16.41	15.87	USWB
2	Beaumont	2560 & 2580	1888-89	1960-61	7		17.89	17.70	USWB
3	Beaumont 1E	2589 & 2630	1939-40	1960-61		3	17.47		USWB
4	Beaumont Pumping Plant	3045	1911-12	1960-61			20.91		USWB
5	Berdoo Camp	1875	1933-34	1936-37		21			USWB
6	Cabazon	1790 & 1815	1898-99	1960-61	31	8	12.42	12.28	USWB
7	Cathedral City	320	1948-49	1960-61		13	4.01		RCFCD
8	Deckers Ranch	5550	1920-21	1940-41		16			USWB
9	Deep Canyon Taylor	3650	1936-37	1945-46	7	20			CE[d]
10	Desert Hot Springs	1100	1948-49	1960-61		13	5.05	5.52	RCFCD
11	Hemet Reservoir	4350 & 4400	1910-11	1960-61			18.23		USWB & LHWCo
12	Idyllwild Ranger Station	5250 & 5400	1901-02	1960-61	21	4	27.93	28.87	USWB
13	Indio State Forestry	-8	1950-51	1960-61		15			RCFCD
14	Indio U. S. Date Garden	-20 & -11	1878-79	1960-61			3.68	3.36	USWB
15	La Quinta Fire Control Station	90	1952-53	1960-61		18			RCFCD
16	Mecca	-197 & -175	1905-06	1960-61	7	6	3.46		USWB & RCFCD
17	Morongo Valley	2580	1942-43	1960-61		7	9.86		USWB
18	North Palm Springs	890	1958-59	1960-61		22			RCFCD
19	Oasis	-170	1957-58	1960-61		22			RCFCD
20	Palm Desert	263	1955-56	1960-61		21			USWB

PRECIPITATION STATIONS
(continued)

Map reference number[a]	Station	Elevations of stations, in feet, USGS datum	Period of record: From	Period of record: To	Missing or incomplete years: Record	Missing or incomplete years: Base period	Average annual precipitation, in inches: Period from 1935-36 through 1956-57[b]	Average annual precipitation, in inches: Period from 1930-31 through 1959-60[c]	Source of record[d]
21	Palm Springs	411 & 685	1899-90	1960-61	7		6.33	6.03	USWB
22	Poppet Flat	3540	1936-37	1951-52		6	23.49		MWD
23	Raywood Flat	6620	1920-21	1960-61			32.00	33.28	USWB
24	Salton Sea Evaporation Station	-235	1959-60	1960-61		22			CVCWD
25	Simms Ranch	2140	1937-38	1960-61	3	5	15.63	15.74	USWB
26	Snow Creek	1275	1920-21	1937-38		20			USWB
27	Snow Creek Upper	1940	1931-32	1960-61	1	1	12.79	12.66	USWB
28	Thermal Airport (FAAAP)	-120 & -70	1948-49	1960-61		13	2.88		USWB
29	Thousand Palms	240	1958-59	1960-61		22			RCFCD
30	Twin Pines (Hurley Flat)	3440	1919-20	1960-61	10	10	20.93		USWB & RCFCD
31	Vista Grande Ranch	5000	1938-39	1942-43		17	26.05		MWD
32	Whitewater Canyon	1600	1919-20	1923-24		22			USWB
33	Whitewater Ranch	1200	1919-20	1922-23		22			USWB

a. Precipitation station locations shown on Plate 2
b. 22-year base period
c. 30-year period used on isohyetal map, Plate 2
d. USWB - United States Weather Bureau; RCFCD - Riverside County Flood Control and Water Conservation District; CE - United States Army, Corps of Engineers; LHWCo - Lake Hemet Water Company; MWD - Metropolitan Water District; CVCWD - Coachella Valley County Water District

Comparisons between the average precipitation for the 30-year period derived from the isohyetal map and the average precipitation for the 22-year base period at 10 of these stations (selected on the basis of location and completeness of records) were made. As shown on Table 10, the difference between the averages of the two periods was found to be negligible for the purposes of the study; therefore, average seasonal precipitations obtained from the isohyetal map were used for the base period. The weighted average seasonal depths of precipitation over the mountain and valley areas, as estimated from the isohyetal map, are listed in Table 11.

TABLE 11

ESTIMATED AVERAGE SEASONAL DEPTH OF PRECIPITATION ON MOUNTAIN AND VALLEY AREAS

Area	Area, in acres	Weighted average seasonal precipitation, in inches
Mountain Areas		
San Jacinto Mountains	138,500	14.9
San Bernardino Mountains	110,700	23.0
Little San Bernardino Mountains	170,600	7.2
Santa Rosa Mountains	159,800	7.7
Valley Areas		
Mecca Hills	39,100	3.7
Indio Hills	27,100	4.0
San Gorgonio Pass Subbasin	28,600	15.4
Mission Creek Subbasin	27,200	6.3
Desert Hot Springs Subbasin	66,300	4.5
Indio Subbasin	256,400	4.5
Total for Study Area	1,024,300	9.2

In order to determine the average seasonal water supply to the ground water basin from precipitation in the area of investigation, deep percolation of water resulting from precipitation directly on the valley floor was evaluated. All precipitation falling on the mountainous regions surrounding the valley was also evaluated to determine the amount of resulting surface runoff reaching the basin.

Precipitation on the Valley Areas. A portion of the rain falling directly on the valley areas overlying the ground water basin may reach the ground water table by deep percolation. The amount of deep percolation depends on several factors including the condition of the soil, the slope of the surface, the vegetal cover, and the distribution and amount of rainfall. From season to season, the last item will vary more than the others over a specific area. Consequently, the amount of deep percolation will reflect the fluctuations in the rainfall. In years of low rainfall, little or no deep percolation will occur; in years of high rainfall, when evapotranspiration requirements and the soil moisture deficiency have been satisfied, there will be deep percolation.

In determining the water supply derived from deep percolation, the paucity of rainfall records in the valley areas precluded estimating seasonal amounts during the base period. Therefore, only average seasonal amounts of deep percolation were estimated based on the average seasonal rainfall during the base period. In those areas where the average seasonal rainfall is less than 12 inches, deep percolation is negligible. This estimate is based on the results of deep percolation studies reported in Department of Water Resources Bulletin No. 33, "Rainfall Penetration and Consumptive Use of Water - in Santa Ana River Valley and Coastal Plain," 1930, and from studies by the U. S. Department of Agriculture which evaluated the effectiveness of rainfall in relation to irrigated crops ("Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data" by Harry F. Blaney and Wayne D. Criddle of the U. S. Department of Agriculture, Soil Conservation Service, August 1950).

It can be seen from Plate 2 that only in the San Gorgonio Pass area does the average seasonal rainfall exceed the 12 inches required for deep percolation. For the San Gorgonio Pass area, the mean annual supply from deep percolation was determined from a correlation with an earlier study of rainfall penetration in the Beaumont-Yucaipa area ("Rainfall and Irrigation Water Penetration and Consumptive Use in the Beaumont-Yucaipa area, Riverside County, California" by Dean C. Muckel and V. S. Aronovici, United States Department of Agriculture, Soil Conservation Service, March 1950). The Beaumont-Yucaipa area is immediately adjacent to the west end of San Gorgonio Pass. The climatological conditions of the two areas are quite similar, as are the soils, the types of land use, and the topographic characteristics. Therefore, it was assumed that a correlation of the results of deep percolation studies in the Beaumont-Yucaipa area could be applied to data in the San Gorgonio Pass region.

The average values of seasonal depth of rainfall deep percolation for each type of land use determined by Muckel and Aronovici for the period 1927-28 through 1947-48, were assigned to the land use acreages in the San Gorgonio Pass area. The total average seasonal deep percolation of rainfall in the San Gorgonio Pass area would be 13 percent of the average seasonal rainfall, based on a straight correlation with results derived in the Beaumont-Yucaipa area studies. However, the actual percentage of rainfall in San Gorgonio Pass which would go to deep percolation would be somewhat less because the total average rainfall is less in the San Gorgonio Pass area. Thus, the estimate of deep percolation in San Gorgonio Pass during the base period was computed on the assumption that it was 11 percent of the total average rainfall. Based on these assumptions, the average seasonal supply to the ground water basin from deep percolation of rainfall in San Gorgonio Pass was estimated to be 4,000 acre-feet.

In the areas outside San Gorgonio Pass, some deep percolation undoubtedly has occurred, at least in exceptionally wet years. However, the long term average amount is considered negligible. The total average seasonal water supply to the basin from deep percolation of rainfall on the valley areas, therefore, was estimated to be 4,000 acre-feet.

Mountain Runoff. Surface runoff from the adjacent mountain slopes percolates to the ground water table and is the main source of natural water supply to the basin. Streams which drain the San Jacinto and San Bernardino Mountains are the main contributors to this source of the water supply. Runoff from these streams is variable, responding to the monthly and seasonal fluctuations of rainfall. Little to no snowpack is carried over from winter to winter in the high mountains so that ground water in the areas tributary to the streams is the only source that can provide perennial streamflow, but the few perennial streams usually have only a meager flow.

In order to determine the seasonal and average seasonal amounts of water supply resulting from mountain runoff during the 22-year base period, a relationship between the seasonal rainfall and the seasonal runoff from the drainage areas of gaged streams was first developed. The streams of the study area for which recorded flow measurements were available are presented in Table 12 which lists these stations, the length of record at each station, and the drainage area above the station. In addition, a gaging station on a diversion ditch from Snow Creek is also listed. Locations of the stations are shown on Plate 2.

TABLE 12

STREAM GAGING STATIONS

Station number*	Stream	Period of record: From	Period of record: To	Period of record: Years missing	Drainage area, in square miles
10.2560	Whitewater River	1948	1961		57.4
10.2565	Snow Creek	1921	1961	28	11.0
10.2570	Southern Pacific Ditch	1921	1934	3	Diversion from Snow Creek
10.2575	Falls Creek	1922	1931		4.1
10.2580	Tahquitz Creek	1947	1961		16.7
10.2585	Palm Canyon Creek	1930	1961	5	94.0
10.2590	Andreas Creek	1948	1961		8.8

*U. S. Geological Survey gaging station number

Estimates of the seasonal precipitation on the gaged drainage areas during the base period were determined, using the average seasonal precipitation represented by the isohyetal map shown on Plate 2, and the precipitation records of selected stations for analysis of seasonal precipitation. A Thiessen polygon network, using nine selected stations for control, was superimposed over the isohyetal map shown on Plate 2. It was assumed that the degree of wetness or dryness, or the index of wetness, of the precipitation station would correspond to that of the polygon. The index of wetness is defined as a ratio of the seasonal precipitation to the 22-year average seasonal precipitation. The seasonal average depths of precipitation over a drainage area were then computed by multiplying the 22-year average seasonal precipitation of the polygon, or portion of a polygon, overlying the drainage area by the indexes of wetness of the controlling station.

Rainfall-runoff curves were constructed for each gaged drainage area using the estimated seasonal average depths of precipitation, plotted against the corresponding recorded seasonal depths of runoff. The seasonal runoff from each of the gaged drainage areas during each season of the base period was estimated from these curves and the 22-year average was computed from the total of measured and estimated runoffs.

Estimates of the runoff of ungaged areas were based on direct correlations with gaged areas of similar characteristics, or determined from an average rainfall-percent runoff curve, which was constructed from the rainfall-runoff curves of Palm Canyon Creek, draining a relatively dry watershed, and Tahquitz Creek, located in a relatively wet watershed.

For the entire basin, the average seasonal mountain runoff during the 22-year base period was estimated to be 72,000 acre-feet. The average seasonal mountain runoff estimated as contributed to each subbasin is presented in Table 13. Seasonal runoff during the base period was estimated to range from a minimum of about 27,000 acre-feet in 1955-56 to a maximum of about 173,000 acre-feet in 1936-37.

TABLE 13

ESTIMATED DISTRIBUTION OF AVERAGE SEASONAL MOUNTAIN RUNOFF TO COACHELLA VALLEY GROUND WATER BASIN SUBDIVISIONS

Area	Average seasonal tributary runoff in acre-feet
San Gorgonio Pass subbasin	25,000
Mission Creek subbasin	6,000
Desert Hot Springs subbasin	2,900
Indio subbasin	38,100
TOTAL - Coachella Valley Ground Water Basin	72,000

Surface Inflow

Three streams draining areas outside the boundaries of the area of investigation enter the area and are tributary to the Whitewater River system. These are Big Morongo Creek, Little Morongo Creek, and Box Canyon Wash. None of these streams are perennial within the study area, although rising ground water flow has occurred periodically where they enter the study area.

Big and Little Morongo Creeks enter the study area on the north side of the Little San Bernardino Mountains. The points of entry are the discharge areas of the Morongo Valley ground water basins. Prior to 1950, water levels in the Morongo Valley basins were high enough that rising ground water discharged to these streams. However, these flows quickly percolated into the alluvial fill of the stream channels and entered the Coachella Valley as subsurface flow. Any surface flow in Big or Little Morongo Creeks entering Coachella Valley would be from infrequent flash floods or storm runoff.

Box Canyon Wash drains Shavers Valley, entering the study area on the east flank of the Mecca Hills. Although ground water has been observed near the surface at this point, evidence of surface flow from rising ground water is lacking. Surface flow into the Coachella Valley Ground Water Basin from Box Canyon would be from flash floods or storm runoff.

Because there are no stream-gage records in either Morongo or Shavers Valleys, rainfall-runoff relationships determined for the Little San Bernardino and Santa Rosa Mountains in the study area were selected as representative of these areas. Applying these relationships to the apparent low average precipitation in Morongo and Shavers Valleys, and considering the large alluviated basins that any surface flow would need to cross before entering Coachella Valley, it was estimated that the average seasonal surface inflow to the Coachella Valley Ground Water Basin from these valleys is negligible.

Subsurface Inflow

The estimates of seasonal subsurface inflow to the study area were made by using the equation, Q = TIW, which was derived from the fundamental Darcy equation. In this equation, the subsurface flow (Q) is equal to the rate of transmissibility (T) of the subsurface materials, multiplied by the width of the cross-sectional area (W) through which the flow passes, and the hydraulic gradient (I) of the ground water at the cross-sectional area.

Subsurface inflow into the study area through water-bearing materials was determined to occur at three places; at the west end of San

Gorgonio Pass, and through the alluvial fill in Big and Little Morongo Canyons. In these areas, values of transmissibility were estimated from pump discharge-drawdown (specific capacity) data correlated with transmissibility determinations listed in Table 1. The hydraulic gradient was estimated by determining the slope of the water table or pressure surface taken from water level elevation contour maps, or by correlation to the slope of the stream channel.

Some subsurface inflow may be derived from the nonwater-bearing materials underlying the mountains surrounding the basin, but, due to the low permeability of the materials, it is assumed the amount of underflow is negligible.

Based on these analyses, it was estimated that the average seasonal subsurface inflow to the San Gorgonio Pass subbasin is 4,000 acre-feet. This underflow originates in the alluvium between the western end of the San Gorgonio Pass subbasin and a ground water divide, trending southwest, that underlies the City of Beaumont farther to the west, out of the study area.

The subsurface inflow through the alluvial fill in Big and Little Morongo Canyons has been decreasing in recent years. Prior to 1950, when high ground water conditions in Morongo Valley were present, the ground water discharged to these canyons provided a source for subsurface flow in the alluvial fill of the stream channels. However, as this source was depleted by increased use in Morongo Valley, the subsurface inflow to Coachella Valley was correspondingly reduced. Based upon historic water well data in Big and Little Morongo Canyons, the average seasonal subsurface inflow from Morongo Valley during the base period was estimated to be 200 acre-feet.

The total average seasonal amount of subsurface inflow to the Coachella Valley Ground Water Basin is estimated to be about 4,200 acre-feet. Nearly all of this inflow enters the basin at the western end of the San Gorgonio Pass, with minor amounts contributed through the alluvial fill in Big and Little Morongo Canyons.

Imported Water

Colorado River water has been imported to the Coachella Valley since 1948 by the Coachella Valley County Water District. The federal Boulder Canyon Project Act, passed in 1928, provided for the construction of the All-American Canal and its branch, the Coachella Canal. Construction of the Coachella Canal was substantially completed in June 1948, and the first imported Colorado River water was delivered to farms in Coachella Valley by the district in that year. The imported water delivered each season to the valley is listed in Table 14.

TABLE 14

SEASONAL IMPORTS OF COLORADO RIVER WATER TO COACHELLA VALLEY
1948-49 THROUGH 1959-60

Season	Import in acre-feet*
1948-49	28,400
1949-50	95,800
1950-51	230,700
1951-52	301,100
1952-53	298,800
1953-54	338,700
1954-55	356,100
1955-56	367,300
1956-57	331,000
1957-58	324,300
1958-59	345,100
1959-60	333,100

*Total acre-feet based on periodic measurements taken by the Coachella Valley County Water District at mile post 87.0 on the Coachella Canal

The imported water is used solely for irrigation purposes in the southeast portion of the Thermal subarea. The Coachella Canal, shown on Plates 6B and 6C, essentially encircles the area served by the imported water. The major portion of the construction of a nine-unit distribution system in the area served by the canal was completed by the end of 1953. Since 1953-54, the total imported water delivered each year has remained relatively constant. Although the irrigated acreage has steadily increased, the corresponding increase in demand for water has been met by increasing efficiencies in the distribution of the water by the district and in the application of water on the fields, as well as by increasing the rate of extractions from the ground water basins.

The importation of Colorado River water has brought about marked changes in the hydrologic conditions of Coachella Valley. The present rate of import, at more than 330,000 acre-feet each season, has increased the total water supply nearly fourfold. The increased water supply applied to the valley floor for irrigation of agricultural crops has caused drainage problems and high ground water table conditions in that part of the valley overlying the semiperched ground water body. To control these problems, a complex network of farm tile drains and outlet works has steadily increased in size as more and more lands are either put into agriculture or are affected by the rising water levels in the semiperched zone.

Items of Water Disposal

The surface water supply that arrives at the valley floor, as discussed previously, either flows over the surface to the Salton Sea, is consumptively used by evaporation and plant transpiration, or percolates to the ground water reservoir. Ground water may flow out of the basin as either surface or subsurface flow, may be extracted by water wells for use or, in areas of high water table conditions, may be disposed of by evaporation or by consumptive use of riparian vegetation. The items of water disposal in the Coachella Valley Ground Water Basin were evaluated as net water use (which includes consumptive use and applied waters irrecoverably lost), surface outflow, subsurface outflow, and exported water.

Net Water Use

Water is consumed in many different ways, both by nature under native conditions, and by man in his modifications of native conditions. Water is consumed by vegetation in the building of plant tissues and transpiration processes, by evaporation from the soil, from free water surfaces, and from foliage. Water is also consumed or evaporated by urban or nonvegetative types of use such as food processing and air conditioning. The water for consumptive use is generally obtained from either natural sources that include direct percipitation, surface runoff, and, in localized areas, high ground water table, or applied water sources, meaning water available through the activities of man.

The water applied by man is to meet consumptive use requirements not supplied from natural sources. In practice, the applied water is usually in excess of these consumptive use requirements, and that portion of the applied water that is not consumed may remain a part of the basin water supply through deep percolation to the ground water. However, applied water not consumed may be deteriorated in quality to the point where the water is unsuitable for reuse. Such water may be considered as irrecoverably lost and as not remaining a part of the usable water supply. The term "net water use" in this report, therefore, includes all waters used to meet the consumptive use requirements plus any irrecoverable losses of applied water.

In the area overlying the semiperched ground water, any applied water that percolates to the semiperched ground water must be considered irrecoverably lost because the ground water in that zone is of such poor quality as to preclude its reuse for beneficial purposes. Therefore, net water use in the area overlying the semiperched ground water may be considered equivalent to the applied water. On the other hand, net water use in the remainder of the ground water basin is equal to the sum of the consumptive uses.

Seasonal water consumption was evaluated under the two general land use categories of agricultural use and urban and suburban use. Consumptive use of water on undeveloped lands was also estimated and evaporation from free water surfaces in the valley was evaluated.

<u>Land Use</u>. The areal distribution of the lands in the valley subject to agricultural and urban and suburban land uses during the base period was analyzed from land and water use surveys conducted by the Department of Water Resources in 1950 and 1958, and from an agricultural land use survey conducted in 1937 by the University of California and the Coachella Valley County Water District. The land use was classified in these surveys on the basis of various types of water use. Thus, it was possible to assign appropriate unit values of consumptive use of water to each classification and thereby estimate the total amount of water used.

The most recent and comprehensive land use survey in Coachella Valley was that conducted in 1958. The results of that survey are shown on Plate 13 "Land Use - 1958."

The specific classifications of land use that were included in each of the two general categories of land use used in this study are similar to those used in the State Water Resources Board Bulletin No. 2, "Water Utilization and Requirements in California," 1955, and are as follows:

<u>Urban and Suburban</u>

Residential	Single and multiple family houses and apartments, rest homes, trailer parks, and residential subdivisions under construction at time of survey.
Recreational-residential	Weekend and winter homes within a primarily recreational area.
Commercial and industrial	All classes of commercial enterprises and industrial land uses, including sand and gravel processing operations, feed lots, transportation facilities, schools, and hospitals.
Included nonwater service area	Gravel pits, vacant lots, warehouses and storage yards, railroads, streets, and landing strips of airfields.

<u>Irrigated Agriculture</u>

Citrus	Grapefruit, lemons, tangerines, oranges, and miscellaneous citrus.
Subtropical	Date palms and olives.
Vineyards	All varieties.
Truck crops	Vegetables of all varieties, melons, tomatoes, sweet corn, carrots.
Alfalfa	Hay, seed and pasture.

Irrigated Agriculture (continued)

Pasture	Irrigated grasses and legumes, other than alfalfa, used for livestock forage. Includes golf courses, parks, and cemeteries.
Field crops	Cotton, sorghums, flax, sugar beets, and field corn.
Small grains	Barley, wheat, and oats.
Deciduous fruits and nuts	All varieties.
Included nonwater service area	Highways and roads, farm access roads, canals, drainage ditches and other inclusions not devoted to crop production, including idle and abandoned lands.

In delineating land use areas in the field, no attempt was made to exclude nonwater-using lands such as streets, railroads, etc. Instead, these land uses are classified as "Included nonwater-service areas," as noted on the above tabulation. An appropriate percentage determined from prior surveys conducted by the department was applied to the gross areas of each of the water-using land use classifications to determine the amount of nonwater-using lands.

The results of the 1958 land use survey of the study area are shown in Table 15. The net acreage values shown in the table are the gross acreage values minus the included nonwater-service areas. A land use comparison for years 1937, 1950 and 1958 in the study area is shown in Table 16. The total number of irrigated agricultural acres in Coachella Valley doubled during each of the intervals between the surveys tabulated in Table 16. The type of crops grown in the valley has remained essentially the same, although, since 1950, the trend has been toward putting new acreage in vineyards, citrus groves, field and truck crops, all of which have more than tripled in acreage since 1950. Although both dates

TABLE 15

SUMMARY OF 1958 LAND USE SURVEY
(in acres)

Nature and class of land use	Coachella Valley	San Gorgonio Pass	Area of investigation
Urban and Suburban			
Residential	4,800	1,040	5,840
Recreational residential	2,850		2,850
Commercial and industrial	1,680	270	1,950
Subtotal	9,330	1,310	10,640
Included Nonwater-Service Area	3,788	532	4,320
Gross Urban and Suburban Area	13,118	1,842	14,960
Irrigated Agriculture			
Citrus	9,110		9,110
Date palms and olives	5,430	110	5,540
Deciduous fruit and nuts	70	250	320
Vineyards	12,330		12,330
Truck crops			
Small truck	4,920	30	4,950
Melons	860		860
Sweet corn	5,100		5,100
Tomatoes	960		960
Field crops			
Alfalfa	5,690	210	5,900
Cotton	5,670	10	5,680
Grains	2,730	120	2,850
Sorghum	400		400
Miscellaneous	3,450		3,450
Permanent pasture	2,600	250	2,850
Subtotal	59,320	980	60,300
Included Nonwater-Service Area	7,340	60	7,400
Gross Irrigated Agriculture	66,660	1,040	67,700

and cotton are still important products, the number of acres devoted to these crops has remained nearly constant since 1950. Possibly the most significant present trend in the development of Coachella Valley is the increase of urban and suburban lands. The data shown in Table 16 indicate that gross urban and suburban acreages more than tripled, increasing from 4,900 acres in 1950 to 15,000 acres in 1958.

Because the land use surveys were few in number and incomplete, except for the 1958 survey, they were supplemented by other data in determining seasonal use of water during the base period. Those other data included annual crop reports of the Riverside County Agricultural Commissioner, population data from the United States Bureau of the Census, and information collected from water service agencies in the study area.

Agricultural Consumptive Use. Estimates of the seasonal unit consumptive use of water by agricultural crops were determined primarily by the method developed by Harry F. Blaney and Wayne D. Criddle of the Soil Conservation Service, United States Department of Agriculture, as described in their report entitled "Determining Water Requirements in Irrigated Areas from Climatological Data" published in August 1950. A discussion of the techniques employed in the derivation of unit values of consumptive use of water is contained in the State Water Resources Board, Bulletin No. 2. Briefly, the method is based on the correlation of consumptive use with average monthly temperatures, monthly percentage of daytime hours, and the length of the growing season. However, this basic method was modified when warranted by other data. These modifications were particularly significant in the consumptive use of dates and truck crops.

TABLE 16

HISTORICAL LAND USE SURVEYS COMPARISON
(Nearest one hundred acres)

Nature and class of land use[a]	1937[b]	1950[c]	1958[c]
Gross Urban and Suburban Area	--[d]	4,900	15,000
Irrigated Agriculture			
Alfalfa	1,500	2,400	5,900
Cotton	1,500	4,400	5,700
Citrus	2,700	2,500	9,100
Dates	2,900	5,700	5,600
Deciduous fruits and nuts	100	1,400	300
Truck crops	3,700	4,100	11,900
Field crops and grains	--	1,100	6,700
Pasture	900	1,500	2,800
Vineyards	2,300	7,100	12,300
Subtotals, Net Irrigation	15,600	30,200	60,300
Included Nonwater-Service Area	--[d]	900	7,400
Gross Irrigated Agriculture			67,700

a. 1958 land use classes grouped to correspond with previous surveys
b. Crop survey by University of California and Coachella Valley County Water District (does not include San Gorgonio Pass area)
c. Land use surveys by Department of Water Resources
d. Value not available

The seasonal water use of date palms, as determined by the Blaney-Criddle Method, was adjusted on the basis of studies conducted at the United States Date Field Station at Indio between 1953 and 1955, and studies conducted by A. F. Pillsbury in Coachella Valley.

The multiple cropping practices that are utilized in Coachella Valley were considered in estimating the seasonal water use by truck crops. Multiple cropping, or the practice of growing more than one crop during a season, is possible in Coachella Valley because of the warm climate and the resulting year-around growing season. Because the annual county crop reports used in the determination of seasonal water use during the base period reported only the total acreage of each crop, and not the number of crops per acre, it was assumed that the reported truck crop acreage was used for the full growing season. The growing seasons of crops in Coachella Valley were determined from data provided by the Agricultural Commissioner of Riverside County and from studies conducted for the State Water Resources Board, Bulletin No. 2.

Consumptive use of water by agricultural crops was determined for each year of the base period to provide the most representative estimate for the hydrologic budget analysis. Because of the considerably different climatological conditions in the San Gorgonio Pass subbasin, agricultural consumptive use in this area was evaluated separately from the remainder of the study area. In the pass area, the climate is cooler and the growing season is not as long as in Coachella Valley, consequently, consumptive use is less, and multiple cropping is not a significant factor in the agricultural practices in the pass area.

Individual monthly and seasonal unit values of consumptive use of agricultural crops in Coachella Valley were derived, based upon climatological data for each season of the base period. The average estimated seasonal unit values of consumptive use of agricultural crops in Coachella Valley during the base period are listed in Table 17. Estimates of agricultural consumptive use in San Gorgonio Pass, utilized average seasonal unit values taken from the report "Rainfall and Irrigation Water Penetration and Consumptive Use in the Beaumont-Yucaipa Area," by D. C. Muckel of the United States Department of Agriculture, published in 1950. The

TABLE 17

AVERAGE SEASONAL UNIT CONSUMPTIVE USE VALUES
FOR AGRICULTURAL CROPS, 1935 THROUGH 1957
(in feet)

Agricultural crops	Unit consumptive use values: Coachella Valley	Unit consumptive use values: San Gorgonio Pass[1]
Citrus	3.9	--
Date palms	5.0	--
Vineyards	2.8	2.1
Deciduous fruits and nuts	3.6	2.1
Olives	--	2.6
Truck crops[2]		2.0
Small crops	2.9	
Melons	2.1	
Sweet corn	2.8	
Tomatoes	2.8	
Sweet potatoes	1.3	
Field crops		
Alfalfa	5.1	3.5
Cotton	2.7	2.0
Small grain	1.6	2.1
Sorghum	2.3	
Permanent pasture	4.8	
Mixed pasture	--	2.9
Miscellaneous	1.5	

1. Unit Consumptive Use Values from Muckel, D. C., "Rainfall and Irrigation Water Penetration and Consumptive Use in the Beaumont-Yucaipa Area, Santa Ana River Valley, California." U.S.D.A. Report - 1950
2. Truck crops in the San Gorgonio Pass area were grouped in one class. Truck crop values listed for Coachella Valley include effects of multiple cropping

unit values are an arithmetic average of the amounts of seasonal consumptive use determined for each crop type during the period 1927 through 1948, and are listed in Table 17.

Determination of agricultural consumptive use in the pass area was not done in greater detail because of its relatively small portion of the total agricultural consumptive use in the area of investigation. Use of water by agriculture in San Gorgonio Pass during the base period was approximately 10 percent of that in Coachella Valley.

The estimates of seasonal total agricultural consumptive use in the area of investigation ranged from 61,000 acre-feet in 1938 to 202,000 acre-feet in 1958. The average seasonal agricultural consumptive use during the base period was 107,000 acre-feet, which includes 11,500 acre-feet in San Gorgonio Pass and 95,500 acre-feet in Coachella Valley. However, it should be emphasized that net water use is equivalent to the consumptive use only on those lands outside the area underlain by the semiperched ground water. As stated previously, net water use on lands overlying the semiperched ground water is equivalent to the water applied.

Consequently, in order to determine total net water use of agricultural lands, it was necessary to separate that portion of lands in Coachella Valley overlying the semiperched ground water from those lands outside the semiperched zone. Estimates of the areal distribution of agricultural lands during the base period were determined from the land use surveys of 1950 and 1958, described previously, and from the seasonal agricultural crop surveys conducted from 1956 through 1960 by the Coachella Valley County Water District. From these data, it was estimated that from 13 to 15 percent of the total agricultural consumptive use in Coachella Valley was by crops outside the semiperched zone.

Net water use of agricultural crops overlying the semiperched ground water was estimated as the total applied water to those lands. This includes all of the applied imported water and a portion of the ground water extractions in Coachella Valley. The amount of imported water applied to agriculture in the valley was estimated as the total imported supply less the regulatory discharges described under surface outflow.

The seasonal amounts of ground water extractions applied on lands overlying the semiperched ground water were estimated from the ground water extraction records of the State Water Rights Board, and from estimates of total ground water extractions reported by M. R. Huberty, et al., (1948) and H. B. Lynch (1949).

Based on these data, the amount of ground water extractions applied on lands overlying the semiperched ground water for agricultural purposes during the base period was estimated to range from 58,000 acre-feet in 1935-36 to more than 115,000 acre-feet in 1955-56. Ground water extractions applied on agricultural land overlying the semiperched ground water in 1958 were estimated to be 95,000 acre-feet.

Urban and Suburban Consumptive Use. The per capita use of water in urban areas is frequently used to estimate total water use. Its use in the study area was particularly appropriate as there is no heavy industry in the study area, and the existing commercial development is closely related to the area's population.

Because of the lack of historic urban and suburban land use surveys, it was necessary to correlate urban water use to an index other than area of land in use. Accordingly, the total use of water in homes, farmsteads, multiple dwellings and commercial buildings was estimated as a per capita rate developed from data on applied water, sewage, and population.

Historic population data for the study area, based on United States Bureau of the Census surveys, are shown in Table 18. Data on delivered water for urban and suburban use were collected from the several water agencies in the study area, and were correlated to the estimated populations served. From these data, it was determined that the per capita applied water during 1960, in the study area, ranged from a low of about 150 gallons per day to a high of almost 600 gallons per day, depending upon the type of area served, and the relative portion of tourist population represented. The estimated average per capita applied water in the area of investigation was about 300 gallons per day.

TABLE 18

POPULATION DATA

Year	Population			
	Banning	Palm Springs	Indio	Coachella Valley
1930	2,700	2,300	1,900[a]	11,500
1940	3,900	3,400	2,300	17,700
1950	7,000	7,700	5,300	36,000
1960	10,200	13,500	9,700	66,700

a. Estimated population

Many factors contribute to this high rate of per capita water use, including the high consumption of water by urban ornamental plants, the long growing season, the dry, hot climate, and the relatively high personal income status of the area's communities. Also, because of the heavy seasonal use of water for persons visiting the resort centers in the study area, the per capita water use is higher than usual because only the permanent population data were used in estimating these figures. The estimates of per capita water use are believed reliable, even under this method of computation, because the relative proportion of tourists to permanent population has remained relatively constant. Thus, water use by tourists is included with that of the permanent population in the estimates of average seasonal per capita water use.

Estimates of the urban and suburban consumptive use were based on the differences between water delivered and sewage effluent. Records of the amounts of sewage flows from the City of Indio sewage disposal plant and the amounts of water delivered to the area served by the plant were used for these determinations. The City of Indio provides a cross section of urban and suburban types of water use that includes essentially all types found in the area of investigation and was considered representative of the study area. It was assumed that sewage line losses were less than 10 percent of the recorded sewage effluent for the estimates of consumptive use. The average urban and suburban consumptive use of water in the area of investigation, based on these data, was estimated to be 45 percent of the applied water.

In determining the urban and suburban net water use in the area of investigation, it was necessary to estimate that portion of the population which received water in the area overlying the semiperched ground water. As discussed previously, net water use in that area is equivalent to the applied water since any water that percolates to the semiperched ground water must be considered irrecoverably lost. It was estimated from data on the areal distribution of population that the number of people in the study area living in the portion overlying the semiperched ground water increased from 8,500 in 1930 to 30,400 in 1960. Seasonal urban and suburban net water use in this area was estimated to range from 2,600 acre-feet in 1935-36 and 9,600 acre-feet in 1956-57.

The estimates of net water use of the population in that area outside the semiperched ground water zone is equivalent to the consumptive use. The average urban and suburban consumptive use of those areas not overlying the semiperched ground water are believed to correspond to those determined for the City of Indio. Based on this assumption, the net urban and suburban water use in these areas was estimated to range between 500 acre-feet in 1935-36 and 4,400 acre-feet in 1956-57 during the base period.

The total estimated seasonal urban and suburban net water use during the base period varied from about 3,100 acre-feet in 1935-36 to about 14,000 acre-feet in 1956-57.

Net Water Use on Undeveloped Lands. Water use on undeveloped lands overlying the ground water basin was evaluated in one of two categories; either undeveloped land on which native vegetation receives its water supply only from direct precipitation, or undeveloped land underlain by a shallow water table.

Water use on lands in the first classification was treated in the discussion of water supply from direct precipitation. The lands were subgrouped into those lands where precipitation equalled the consumptive use of native vegetation, and those lands where precipitation exceeded the consumptive use of native vegetation. Outside of San Gorgonio Pass, precipitation on the valley floor lands is meager and, except where the lands are underlain by a shallow water table, consumptive use was assumed to be equal to the precipitation of those areas. However, in San Gorgonio Pass, the consumptive use of water on undeveloped lands is less than the direct precipitation and that portion of precipitation in excess of the consumptive use requirements percolates past the root zones into the water table area of the ground water basin.

Because many phreatophytes, or plants that use ground water for a large portion of their water supply, can effectively extract water to depths of ten feet or more, such areas have been segregated in the second classification as areas of shallow water table. In these areas, the vegetation is not wholly dependent on direct precipitation, and comsumptive use exceeds that amount. In areas adjacent to and northerly from the Salton Sea, there are large acreages of undeveloped lands where the depth to the ground water table is 10 feet or less. However, in these areas the undeveloped lands are underlain by the semiperched ground water. Thus, the existence of a shallow water table does not affect the net water use relationship previously established for such areas. As discussed earlier, net water use in these areas was considered equivalent to the applied water because of the degradation of the excess applied water to an unusable quality.

On the other hand, in areas of the valley where lands are not underlain by the semiperched zone, net water use is directly related to the type and density of native vegetation and the depth to the water table. Where large masses of phreatophytes are present they consume relatively large quantities of water through growth and transpiration. Also, where the depth to the water table is such that the capillary fringe intercepts the ground surface, the rate of evaporation from the area of interception is approximately equivalent to that from a free water surface in the same locale.

These conditions exist in the oases which are present along the Mission Creek and Banning faults. Based on the density of the vegetation and the estimated average depth to ground water in these areas, the net water use was estimated to be equivalent to the evaporation from a free water surface in Coachella Valley. The average seasonal consumptive use in areas of shallow water table that are undeveloped, and are not underlain by the semiperched zone, was estimated to be about 5,000 acre-feet.

Consumptive Use by Evaporation from Free Water Surfaces. Evaporation data in Department of Water Resources Bulletin No. 54A, "Evaporation from Water Surfaces in California," and preliminary estimates of the evaporation rate of the Salton Sea by the United States Geological Survey Lower Colorado River Project were the bases for the estimated average seasonal depth of evaporation of 75 inches from water surfaces in Coachella Valley.

Free water surfaces in the Coachella Valley include the Coachella Canal, open irrigation drains, farm storage reservoirs, duck ponds, and swimming pools. However, the majority of these surfaces are present in the area overlying the semiperched ground water, and since they are replenished by applied water, evaporation from them does not affect the net water use relationship. The swimming pools are nearly all served by urban or suburban water supplies and, therefore, are a part of urban and suburban consumptive use.

Therefore, the amount of water consumed by the few farm reservoirs outside the semiperched ground water zone and the few swimming pools not served by domestic water service is considered to be negligible.

Net Water Use Under 1958 Land Use Conditions. In review, the items of disposal that are included in net water use may be grouped under consumptive uses in areas outside the semiperched ground water zone and under applied waters in the area overlying the semiperched ground water body. For purposes of estimating the average annual overdraft of the Coachella Valley Ground Water Basin, as will be explained under Water Supply Surplus or Deficiency, and to illustrate present rates of water use, the estimated amount of each item of disposal included in net water use during the year 1958 is presented.

	Acre-feet
Consumptive Uses Outside Semiperched Ground Water Zone	
Agriculture in San Gorgonio Pass area	12,100
Agriculture in Coachella Valley	25,000
Urban and suburban use	4,600
Consumptive use on undeveloped lands overlying shallow water table	5,000
Subtotal	46,700
Applied Waters in Area Overlying the Semiperched Ground Water	
Agricultural use	
Imported water	320,500
Ground water extractions	95,800
Urban and suburban use	9,300
Subtotal	425,600
TOTAL NET WATER USE DURING 1958	472,300

Surface Outflow

The average seasonal runoff to the Salton Sea is comprised of infrequent flood flows of the Whitewater River system, uncontrolled flowing wells on the periphery of the sea, and drainage and regulating waters from irrigated agricultural areas of the valley.

Flood Flows. Normally, discharge of the streams flowing into Coachella Valley infiltrates into the alluvium and becomes part of the ground water supply. Only during the infrequent peak flood flows are the infiltration rates of stream channels exceeded and surface runoff reaches the Salton Sea. Unfortunately, measurements of flood flows discharging into the Salton Sea are not available.

Floods in Coachella Valley have generally been of short duration, usually lasting three days or less. Although most flood flows are due to high intensity storms, a general relationship exists between annual flood waste to the Salton Sea and the total rainfall over the study area. Generally, more mountain runoff reaches the Salton Sea during wet years than during dry years, but on occasion, intense storms in dry years produce large quantities of runoff to the Salton Sea.

The discharge rates, duration of flows, and frequency of peak discharges of the gaged streams in Coachella Valley were studied. Infiltration rates of the stream channels crossing the valley floor were estimated in order to determine what portion of the surface runoff from the mountains reaches the Salton Sea. Reports of eye witnesses also gave an indication of the frequency and duration of flood flows reaching the Salton Sea.

Based on these studies, it was estimated that the average seasonal flood runoff to the Salton Sea during the base period was 3,600 acre-feet per year, amounting to about 5 percent of the average seasonal mountain runoff.

Flowing Wells. A field investigation of uncontrolled flowing wells which tap ground water below the semiperched zone on the periphery of the Salton Sea was made during the summer of 1961. Twenty-one wells and three springs were located that flowed unchecked directly into the Salton Sea. The amount of flow was either measured or estimated at the time of investigation. The aggregate surface outflow from these wells was estimated to be about 1,500 gallons per minute, or 2,400 acre-feet per year.

Agricultural Drainage and Regulatory Discharge. The artificial drains carry off as much water as is necessary to maintain adequate salt balance in the soil and to maintain the water table below the root zones of the crops. The surface flow to the Salton Sea in these drains, 19 of which empty directly into the Salton Sea, has been measured by the Coachella Valley County Water District. The Whitewater River storm water channel, shown on Plates 6B and 6C, is the largest of these drains and carries over 90 percent of the drainage discharge. The flows in the storm-water channel are measured at the Salton Sea weekly and the remainder of the drains discharging to the Salton Sea are measured each month.

The drainage channels carry regulatory discharges from the Coachella Canal and from field headgates in addition to drainage water. These discharges occur when demand for imported water on the field is less than the available supply. There is a differential of several days betwe... the time imported water is ordered and the time the water arrives in Coachella Valley. During this interval, marked changes from the anticipated demand frequently occur, resulting in quantities flowing in the canal that must be wasted. Consequently, a portion of the canal flows are discharged directly into the drains. Regulatory discharge from field headgates is also discharged into the drains, occasionally, by farmers in their irrigation operations.

Seasonal amounts of drainage water and regulatory spills discharging into the Salton Sea are listed in Table 19. Because drainage water originates from water applied over the semiperched zone, it does not enter the hydrologic equation directly, but is included in the figures on net water use. Regulatory discharge, on the other hand, is not a part of the applied irrigation water, but is included as part of the surface outflow item of posal.

TABLE 19

SEASONAL OUTFLOW OF AGRICULTURAL DRAINAGE
AND REGULATORY DISCHARGE TO SALTON SEA
(in acre-feet)

Season	Drainage outflow	Regulatory discharge[a]	Total surface outflow of Coachella Drains[b]
1948-49	0	17,700	17,700
1949-50	0	30,600	30,600
1950-51	300	89,000	89,300
1951-52	2,200	108,600	110,800
1952-53	5,300	66,400	71,700
1953-54	7,400	56,300	63,700
1954-55	21,000	57,300	78,300
1955-56	31,600	60,800	92,400
1956-57	36,100	16,500	52,600
1957-58	44,400	14,500	58,900
1958-59	49,800	4,800	54,600
1959-60	59,800	2,400	62,200
1960-61[c]	73,100	2,800	75,900

a. Regulatory discharge since 1952-53 based on records of the Coachella Valley County Water District. Prior to 1952-53, regulatory discharge estimated.
b. Total acre-feet based on periodic measurements taken by the Coachella Valley County Water District at the Salton Sea discharge points of the drainage system.
c. 1960-61 seasonal flows partially estimated.

It may be seen therefore, that the amount of surface water outflow, as an item of disposal from the area of investigation, is contributed from three main sources. These include: flood flows reaching the Salton Sea, estimated to be an average of 3,600 acre-feet per year; the discharge of flowing wells near the periphery of the Salton Sea, estimated to be 2,400 acre-feet per year; and the regulatory discharges of imported Colorado River water, recorded as 9,300 acre-feet in 1958. The total of these items of surface outflow is 15,300 acre-feet.

It should be pointed out, however, that a continued reduction in the amount of regulatory discharge has occurred since 1955 as can be seen in Table 19. This is due to increased efficiency in the regulation of imported water and better evaluation of anticipated demands. Since 1959-60, the seasonal regulatory discharge has remained at approximately one percent of the seasonal imported water.

Subsurface Outflow

Ground water in the Coachella Valley Ground Water Basin moves generally southeastward toward the Salton Sea. As discussed above, discharge of semiperched ground water to the Salton Sea is by surface flow in the drains. In addition, ground water in the lower aquifers of the Indio subbasin moves out of the basin as subsurface outflow.

The estimates of seasonal subsurface outflows were made in the same manner employed for determining the subsurface inflows; that is, using the equation, Q = TIW. Again, the paucity of data did not permit accurate estimates of seasonal amounts of subsurface outflow. The poor distribution of water level measurements gave correspondingly poor control on the determination of the hydraulic gradient. However, data were sufficient to indicate that subsurface outflow persisted throughout the base period, and is continuing today, but the magnitude of underflow has decreased as the hydraulic gradient has decreased. The change in the hydraulic gradient during the base period is illustrated by the differences in the spacings between the ground water level contours shown on Plates 9, 10, and 11.

Based on the available data, estimated seasonal subsurface outflow to the Salton Sea during the base period decreased from 33,000 acre-fee in 1935-36 to 27,800 acre-feet in 1956-57. The average seasonal outflow during the base period was 30,800 acre-feet.

Exported Water

Well water is exported from Coachella Valley in tank trucks by the Triple A Water Company and Ben Laflin Ranches. The water is hauled to the Imperial Valley where it is sold for drinking purposes. Although this export had decreased to approximately 18,000 gallons per day by 1961, during the study base period an average of about 35,000 gallons a day, or about 40 acre-feet per year, was exported.

The Southern Pacific Company also hauls water from wells at Indio and Mecca to railroad siding camps south of Coachella Valley. The amount of this export, however, has never been more than 10 acre-feet per year. Therefore, the average total seasonal amount of exported water during the base period was less than 50 acre-feet. For purposes of the hydrologic budget, this amount may be considered negligible.

Water Supply Surplus or Deficiency

As discussed earlier in this chapter, even though several of the items of the hydrologic budget could be evaluated only on an average seasonal basis because of the paucity of basic data, seasonal estimates were made of the major items of supply and disposal during the base period. With this limitation, a seasonal hydrologic budget was estimated for the purpose of comparing annual surpluses, or deficiencies, with changes in ground water storage as determined from geologic considerations. A summary of the findings developed from these estimates of the annual hydrologic balance and the comparison with changes in total ground water storage is presented in the following paragraphs.

The difference between the sums of the items of supply and items of disposal is the water supply surplus or deficiency in the ground water basin hydrologic balance. Hydrologic studies conducted during this investigation indicate that during the 22-year base period, 1935-36 through 1956-57, replenishment to the Coachella Valley Ground Water Basin was less than the water use. These studies indicate that the accumulated total deficiency in the usable water supply of the basin during the 22-year base period was nearly 1,500,000 acre-feet. This deficit in the hydrologic balance takes water quality into consideration and represents a gradual depletion of the usable ground water supply that is continuing today.

A comparison of this total accumulated water supply deficiency with the total accumulated change in storage shown on Plate 12, indicates the existence of an apparent anomaly. The total water supply deficiency, based on estimates of change in storage only, is less than 600,000 acre-feet. However, the total accumulated change in storage shown on Plate 12 does not take into account the quality of water in storage. The poor quality of water in the semiperched zone precludes its recovery for beneficial uses; thus, changes in ground water storage within that zone should not be considered in evaluating the usable ground water supply.

The difference between the total change in storage, and the total water supply deficiency during the base period is approximately 900,000 acre-feet, made up primarily of an increase in the amount of poor quality, semiperched ground water.

Even though factors such as the assignment of low specific yield values to materials in the valley could have affected the change in storage computations somewhat; such factors cannot reasonably account for a significant portion of this difference of 900,000 acre-feet.

In the areas of the valley where water levels give a true indication of the change in storage of the usable ground water supply, the levels have steadily declined during the base period, and continue to do so today. The rate of decline has increased steadily as well, reflecting the increase in ground water extractions. Therefore, since the extractions from the ground water basin that are either consumptively used, or irrecoverably lost, exceed the average annual replenishment to the usable supply, the Coachella Valley Ground Water Basin must be considered in a condition of overdraft.

Estimate of Annual Overdraft. Use of land overlying the Coachella Valley Ground Water Basin steadily increased during the base period, and probably will continue to do so. Since the seasonal values of water supply and disposal fluctuate with changing land uses, the average annual value of overdraft during the base period has no utility in evaluating continued use of the water supply. Therefore, an estimate of average annual overdraft was made on the basis of the cultural conditions of 1958, in conjunction with the average seasonal water supply to the ground water basin.

The computation of overdraft under the 1958 cultural conditions is illustrated in Table 20. The items of supply and disposal are those discussed in the report. The hydrologic budget indicates than an average seasonal overdraft of about 100,000 acre-feet of usable water would exist for the study area under the conditions of development extant in 1958, assuming average natural water supply conditions.

TABLE 20

ESTIMATED HYDROLOGIC BUDGET UNDER
1958 LAND USE CONDITIONS

Items of Hydrologic Budget	Acre-feet
Water Supply	
Precipitation on the valley areas	4,000[a]
Mountain runoff to the valley (from precipitation in the mountain areas)	72,000[a]
Surface inflow (from outside the area of investigation)	0[b]
Subsurface inflow (from outside the area of investigation)	4,200[a]
Imported water in 1958	329,800
Total Supply	410,000
Water Disposal	
Net water use in 1958	
Areas outside semiperched zone (consumptive use)	46,700[c]
Lands overlying semiperched zone (applied water)	425,600[d]
Surface outflow to the Salton Sea	15,300[e]
Subsurface outflow	27,500
Exported water	0[b]
Total Disposal	515,100
Seasonal water supply deficiency	105,100
Say	100,000

a. Estimated average seasonal amount during the period 1935-36 through 1956-57

b. Although some surface inflow does occur occasionally, and there is a certain amount of water exported from the basin, the amounts are considered negligible for the hydrologic budget.

c. Includes consumption by agricultural, urban and suburban, and native vegetation uses

d. Includes the applied portions of imported water and ground water extractions

e. Includes estimated average seasonal flood flows, discharge of flowing wells, and regulatory discharge of imported water during 1958

It should be reiterated that this estimate of overdraft assumes that any applied water percolating to the semiperched ground water body must be considered irrecoverably lost because ground water in that zone is presently of such poor quality that it cannot be used for beneficial purposes. Should the mineral content of the ground water in the semi-perched zone decrease in the future (there was little evidence of such change during the study period), the hydrologic budget would have to be recomputed and the values given on Table 20 would undoubtedly be revised.

CHAPTER VI. SUMMARY

On the basis of this analysis of the available data, it appears that the entire Coachella Valley floor area is underlain by a ground water basin, which has been designated the Coachella Valley Ground Water Basin. This basin is divided into four major areas and four subbasins, as shown on Plate I, based on the water-bearing characteristics of the underlying materials, fault barriers which restrict the movement of ground water, or other geologic and hydrologic criteria.

It is estimated that between the high ground water elevations that occurred during the 1935-36 season and a depth of 1,000 feet below the ground surface, the Coachella Valley Ground Water Basin has a capacity for storing about 39,000,000 acre-feet of ground water.

The amount of ground water in storage in the Coachella Valley Ground Water Basin decreased by about 770,000 acre-feet between 1935 and 1951; then increased by about 190,000 acre-feet between 1951 and 1957. The increase in the amount of ground water in storage, which is continuing today, has occurred since imported Colorado River water has been available for irrigation.

The application of imported water is essentially limited to the area underlain by the semiperched zone in the lower end of the basin near the Salton Sea. This has provided a larger supply of applied water than the natural drainage conditions can handle, resulting in a steady rise in the semiperched ground water table. When the water table reaches the root zones of the crops, further rise is controlled through the placement of underground drainage systems that carry the excess semiperched ground water off to the Salton Sea. As a result of the excess applied water, the total storage of ground water in the area overlying the semiperched zone increased during the base period by 350,000 acre-feet, while the storage in areas outside of the semiperched zone continued to decline by about 160,000 acre-feet, indicating the above-cited net increase of 190,000 acre-feet between 1951 and 1957.

The ground water in the semiperched zone, however, is of such poor quality that it cannot be considered a source of supply. Thus, excess applied water entering the semiperched zone is irrecoverably lost. On the other hand, ground water of good quality occurs in the remainder of the Indio subbasin, and in the San Gorgonio Pass subbasin. The quality of the ground water is poor in the Desert Hot Springs subbasin, and it is only marginal for most beneficial uses in the Mission Creek subbasin, and the Thousand Palms and Oasis subareas of the Indio subbasin.

In the areas of the valley where water levels are an indication of the change in storage of the usable ground water supply, the levels have steadily declined during the base period, and continue to do so today. Thus, the amount of usable water in the ground water basin has continued to decrease.

The sum of all items of water disposal in the basin, including water entering storage in the semiperched zone, exceeded the sum of all items of water supply in almost every year of the base period. The resulting usable water supply deficiency amounted to a total of about 1,500,000 acre-feet over the 22-year base period, 1935-36 through 1956-57. A comparison of this deficit with the total change in storage indicated the amount of poor quality water in the semiperched zone has increased by about 900,000 acre-feet during the base period.

It is estimated that the continued use of the usable water supply under fixed 1958 cultural conditions would result in an average seasonal overdraft of that supply of about 100,000 acre-feet. It is expected that the current steady increase in the use of land overlying the Coachella Valley Ground Water Basin will continue and, correspondingly, the use of water will increase.

The responsible local water agencies have recognized this problem and, in an effort to alleviate this deficit, have completed contracts with the State of California, Department of Water Resources, for the importation of Northern California water through the State Water Facilities. These agencies and their respective contractual annual quantities of water are: Coachella Valley County Water District, 20,000 acre-feet; Desert Water Agency, 33,000 acre-feet; and San Gorgonio Pass Water Agency, 15,000 acre-feet.

The effects which continued application of imported water might have in the future is largely undetermined. Through 1961, however, the effects have been limited to increasing the quantities of the semiperched groundwater. This is primarily a result of the Colorado River water application having been confined to the area overlying the semiperched zone, and the existence in the underlying aquifers of pressure conditions creating an upward hydraulic gradient.

APPENDIX A

COOPERATIVE AGREEMENT NO. 851033

APPENDIX A

COOPERATIVE AGREEMENT NO. 851033
BETWEEN
THE STATE OF CALIFORNIA, DEPARTMENT OF WATER RESOURCES
AND THE
COACHELLA VALLEY COUNTY WATER DISTRICT

This agreement, entered into by and between THE STATE OF CALIFORNIA, DEPARTMENT OF WATER RESOURCES, hereinafter referred to as the STATE, and the COACHELLA VALLEY COUNTY WATER DISTRICT, hereinafter referred to as the DISTRICT:

W I T N E S S E T H

WHEREAS, by The State Water Resources Law of 1945 the State is authorized to make investigations of the water resources of the State, formulate plans for the control, conservation, protection, and utilization of such water resources, including solutions for the water problems of each portion of the State as deemed expedient and economically feasible, and may render reports thereon; and

WHEREAS, by said law the State is authorized to cooperate with any county, city, state agency or public district on such water resources investigations and when requested by any thereof may enter into a cooperative agreement to expend money on behalf of any thereof to accomplish the purposes of said law; and

WHEREAS, the District has requested the State to make a cooperative investigation and report on the ground water basin and ground water resources of Coachella Valley;

NOW, THEREFORE, it is mutually agreed, subject to the availability of funds, as follows:

1. The State shall perform the work provided for by this agreement and shall prepare the report and otherwise advise and assist in formulating solutions to the water problems of the area.

2. The work program shall be as set forth in the attached sheet, entitled "Work Program," marked "Exhibit A," and incorporated herein by this reference.

3. The District shall contribute $25,000, which shall be transmitted to the State prior to commencement of the work.

4. The State shall contribute $25,000 from funds appropriated to the Department of Water Resources by Item 254.1 of the Budget Act of 1960.

5. Funds contributed by the parties shall be deposited in the Water Resources Revolving Fund in the State Treasury for expenditure by the State in performance of the work provided for in this agreement.

6. The State shall, under no circumstances, be obligated to expend for, or on account of, the work provided for under this agreement any amount in excess of the funds made available hereunder.

7. A statement of expenditures for the fiscal year beginning July 1, 1960, and ending June 30, 1961, shall be furnished the District by the State as soon as practicable after the close of the fiscal year.

8. Upon completion and final payment for the work provided for in this agreement, the State shall furnish to the District a statement of expenditures made under this agreement, and any balance which may remain of the sum or sums advanced by the District shall be returned to the District.

9. It is mutually understood that the sum of Fifty Thousand Dollars ($50,000) to be made available as hereinbefore provided, is adequate to cover the cost of performing that portion of the work scheduled by the State for performance during the fiscal year 1960-61, and it is further understood that the District will make an additional sum of Twenty-five Thousand Dollars ($25,000) available at the commencement of the fiscal year 1961-62 to be matched by an equal contribution by the State for the completion of said work, said State funds being available in Item 254.1 of the Budget Act of 1960.

10. During the progress of this investigation, all maps, plans, information, data, and records pertaining thereto which are in possession of either party hereto, shall be made fully available to the other party for the due and proper accomplishments of the objectives hereof.

11. The work to be done under this agreement shall be diligently prosecuted with the objective of completing the investigation and report by June 30, 1962, or as nearly thereafter as possible.

IN WITNESS WHEREOF, the parties hereto have executed this agreement as of the date hereof.

DATED: July 1, 1960

COACHELLA VALLEY COUNTY WATER DISTRICT

By /s/ Leon Kennedy
President

Approved as to form and legal sufficiency:

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

/s/ Mark C. Nosler, Acting
Chief Counsel
Department of Water Resources

HARVEY O. BANKS
Director of Water Resources

By /s/ Roy Kidner
For Paul L. Barnes, Chief
Division of Administration

Approved - Department of Finance

WORK PROGRAM

The work to be performed under this agreement shall consist of the following ground water investigation studies in Coachella Valley:

1. Delineation of the boundaries and the geology of the ground water basin or basins of Coachella Valley, comprising the alluvial fill area of the Whitewater River watershed within Riverside County which extends from the drainage divide in the San Gorgonio Pass on the north to the southerly boundary of Riverside County, and is bounded on the northeast by the San Bernardino Mountains, Little San Bernardino Mountains, Mecca Hills, and Orocopia Mountains, and on the southwest by the San Jacinto Mountains and Santa Rosa Mountains.

2. Investigation of the physical factors affecting ground water occurrence and movement in the basin or basins, and between basins.

3. Evaluation of the hydrologic characteristics of the basin or basins and the tributary area.

4. Investigation of the water quality characteristics of the surface and ground waters in the area.

5. Determination of the amount of ground water in storage and the underground storage space available.

6. Formulation of a report on the results of this work.

Exhibit A

APPENDIX B

BIBLIOGRAPHY

APPENDIX B

BIBLIOGRAPHY

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