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STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 84

MOJAVE RIVER GROUND WATER BASINS INVESTIGATION

AUGUST 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

FOREWORD

This investigation and report are the result of the recognition by the Mojave Water Agency of its need for reliable information on existing water resources, future water requirements, and sources of additional water supply to meet the needs for growth of the region it serves. Accordingly, the agency, through its legislative representatives, obtained state funds for the Department of Water Resources to undertake this investigation. Appropriation of funds was made under Budget Item 263.2, A. B. No. 1, 1962 Second Extraordinary Session.

To provide interested agencies and persons with information as soon as it was available, informal meetings were held and two progress reports were published by the Department of Water Resources.

The results of this study show that additional water will be required if the Mojave region is to realize its growth potential. The meager rainfall and increasing water demands of the area indicate the need for a plan of basin operation that will take full advantage of existing and potential water resources, including ground water, imported water, and the use of the ground water basins for both storage and distribution of water.

The information provided by this study points out the need and provides a foundation for a ground water basin model simulation and operational and economic studies, leading to the selection by local agencies of an optimum plan of water resources management.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California

June 12, 1967

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Civil and Professional Engineers' Act of the State of California.

Harvey L. Chan
Registered Civil Engineer

Registration No. 16783

Date May 16, 1967

ATTEST:

J.J. Doody
District Engineer
Southern District

Registration No. 6500

Date MAY 17 1967

ABSTRACT

This bulletin presents data on the water resources and water requirements of a part of the Mojave Desert ar consisting of about 3,700 square miles located primarily in San Bernardino County. The study was authorize the Legislature in 1962 for the purpose of providing fundamental geologic and hydrologic information to the State of California and to local water agencies in the Mojave area as the basis for planning for optimum us water supplies and facilities. In this desert region, annual water supply from precipitation is not suffic to meet the needs of existing agricultural and urban developments. The water deficiency that has existed i the area since about 1945 has been met by extraction of ground water. However, with the anticipated contin tion--or acceleration--of the urban growth pattern of recent years, additional water will be required. The future water needs could be met by a combination of ground water and imported water. Control of non-benefi riparian vegetation offers a potential secondary source of increased water supply. The bulletin describes geology, water supply, water quality, and water requirements in the study area. Tables give detailed infor tion on resources and requirements. Figures and plates show the area of investigation, geology and geologi sections, precipitation patterns, hydrographic units, land use, and changes in ground water levels.

CHAPTER I. INTRODUCTION

Recently, residences and industry have grown up over much of the land along the Mojave River in San Bernardino County that formerly supported only agriculture. This development, which has increased the water uses, has caused concern among water agencies over the adequacy of the local supply. Although large amounts of water are known to be stored underground, the scanty rainfall in the vast desert areas surrounding the river raises a question as to the long-term reliability of local supplies and suggests the need for imported water. In addition, the quality of the local supplies is a matter of concern, particularly the possible changes in quality resulting from increased urban development and water use. As one means of relieving the problem, the Mojave Water Agency on June 22, 1963, signed a contract to take delivery of 50,000 acre-feet from the State Water Facility.

In recognition of the need for an analysis of the water resources along the Mojave River, the California Legislature requested the Department of Water Resources to make such an investigation. Studies were started in July 1962.

To provide interested agencies and persons with information as soon as it was available, informal meetings were held and two progress reports were published. This final report summarizes the results of the investigation.

Objectives of Investigation

The major objective of this study is to provide geologic and hydrologic information that can be used by local agencies in managing the surface and ground water resources of the area in the most productive and economic manner.

The specific objectives of this investigation are to:

1. Develop information on boundary conditions of the ground water resources, structures affecting ground water movement, transmissive and storage characteristics of the water-bearing material, and subsurface flow and change in ground water storage.

2. Increase the detail and extent of the knowledge pertaining to the amounts of annual water supply, use, and disposal for each subdivision of the study area for a selected base period. From this information, evaluate the character and amount of deep percolation, determine the average annual water supply surplus or deficiency, estimate the average annual safe yield and overdraft and determine where future imported water supplies must be delivered, by identifying the areas of water supply surplus and deficiency.

Scope of Investigation

The investigation consisted of a comprehensive and detailed geologic and hydrologic study of the area along the Mojave River. The hydrologic study concentrated on the 25-year period of 1936-37 through 1960-61, which was selected as the study base period. The hydrologic study included investigation of the mineral quality of both the surface and ground water supplies.

The geologic investigation consisted of the review of all available geologic data, detailed field mapping, and field transmissibility tests. Basin boundaries and physical properties of the area were then determined.

In the hydrologic investigation, the available reports on the study area were reviewed and data were compiled from reports published by the United States Geological Survey, United States Weather Bureau, and Department of Water Resources. Numerous contacts were made with individual agencies to gather the necessary data regarding the various items of water supply, use and disposal. This information was developed on an annual basis.

The water quality investigation consisted of review and evaluation of existing data and of new data obtained from a limited water sampling program. Areas in which the water quality is relatively consistent were delineated to show the mineral character and total dissolved solids content of the water. A limited salt balance analysis was made.

Conduct of Investigation

Geologic, hydrologic, and water quality studies were conducted to meet the objectives of this investigation. Standard engineering concepts were used to develop hydrologic information and, where necessary, simplifying assumptions were made to facilitate the geologic, hydrologic, and water quality analyses. The major steps in the conduct of this investigation are summarized below:

1. The geologic properties of the study area were determined, the study area was subdivided into convenient workable units, transmissibility and storage factors of the water-bearing sediments were estimated, and historical water level elevations were determined.

2. The annual amounts of water supply, use, and disposal were estimated; water use and disposal were subtracted from the water supply to obtain annual water supply surplus or deficiency for the base period.

3. The change in the amount of ground water in storage during the base period was estimated by the specific yield method.

4. The mineral quality of the water in the area was determined.

5. The total annual amount of water supply or deficiency was compared with the total annual change in the amount of ground water in storage during the base period.

During the first year of the investigation, activities were directed toward establishing, on a preliminary basis, the extent of the local water resources of the area; this information was used by the Mojave Water Agency and the State of California as the basis for a contract to import a supplemental water supply through the California Aqueduct. These activities were summarized in the first progress report.

During the second year of the investigation, the geologic studies of the area were expanded to identify and delineate the extent of the water-bearing materials, to establish the location of structures affecting ground water movement, and to determine the hydraulic characteristics of the water-bearing materials. The refinement of the preliminary estimates of water supply, use, and disposal was commenced; the seasonal amounts of the major components of both surface and subsurface flows within the area were determined; also, a study of the mineral characteristics of both the ground water and surface water was initiated. These activities were summarized in the second progress report.

During the third year of the investigation, the studies to achieve the specific objectives of the program were completed. These studies included a determination of the annual amount of supply, use, and disposal of water during the base period; the annual amount of water supply surplus or deficiency; and estimates of the present and future uses of water in the study area. The local water supplies and future water requirements were compared to ascertain the time, magnitude, and location of delivery of imported supplies. Ground water storage capacities estimates from the preliminary studies were revised, using an electronic digital computer. Change in the amount of ground water in storage during the base period was calculated and compared with water supply surplus or deficiency for the same period. This bulletin summarizes the activities and results of the entire investigation.

Related Investigations and Reports

Previous hydrologic investigations of the Mojave River region have been made and reported on by the Department of Water Resources and its predecessor agencies and by other federal, state, county, and private agencies. Reports of previous major investigations are listed below. Other reports utilized in preparing this bulletin are summarized in Appendix A, Bibliography.

1. Blaney, Harry F., and Ewing, Paul A. "Utilization of the Waters of Mojave River, California." United States Department of Agriculture, Division of Irrigation. August 1935.

2. California State Department of Public Works, Division of Water Resources. "Mojave River Investigation." Bulletin No. 47. 1934.

3. Frye, Arthur H., Jr. "Report on Survey for Flood Control, Mojave River, San Bernardino County, California." United States Corps of Engineers. December 28, 1956.

4. Koebig and Koebig, Incorporated. "Mojave Water Agency-Supplemental Water Report." Volume 1. March 1962.

5. -----. "Mojave Water Agency-Supplemental Water Report." Volume 1, Appendixes A, B, C, and D. March 1962.

6. Thompson, David G. "The Mojave Desert Region, California." United States Geological Survey Water-Supply Paper No. 578. 1929

7. United States Department of the Interior, Bureau of Reclamation. "Report on Victor Project, California." April 1952.

Area of Investigation

The area of investigation, which is outlined in Figures 1 and 2, is located almost entirely in San Bernardino County, with only

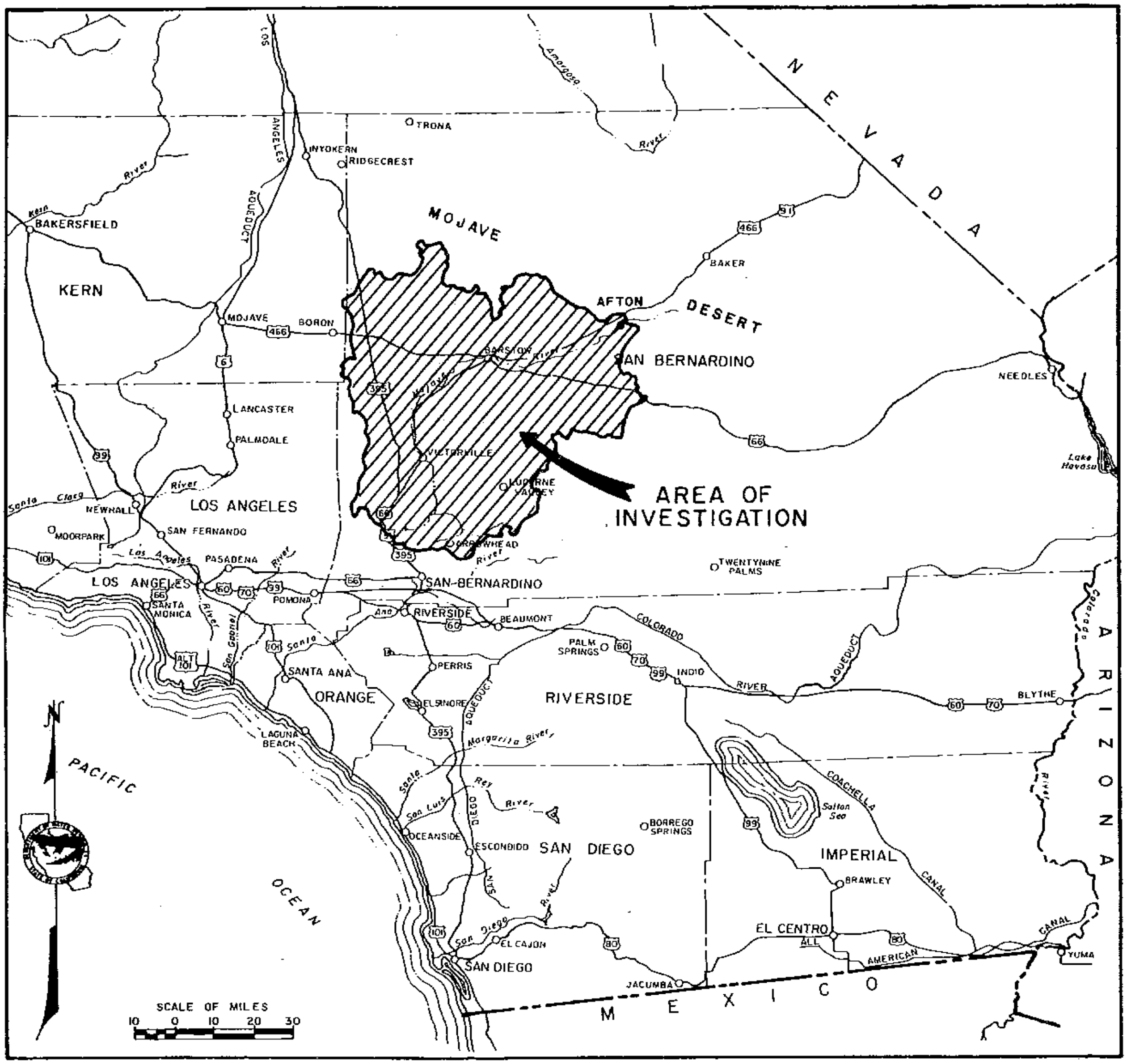

Figure I. LOCATION MAP

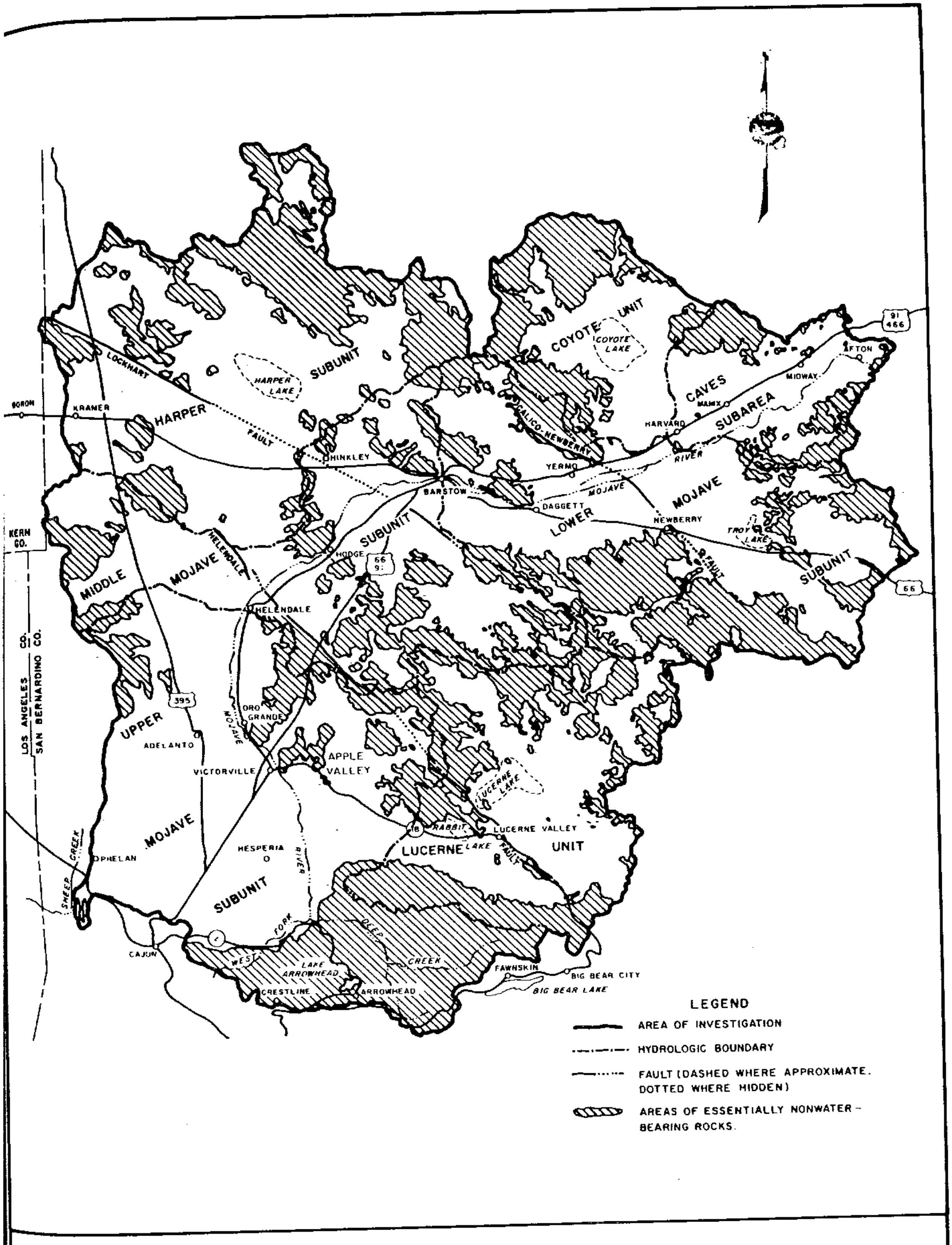

Figure 2 — AREA OF INVESTIGATION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1967

a small portion in Kern County. The study area is part of the Mojave Desert, which covers vast areas of east-central Southern California.

The study area is irregularly shaped and covers about 3,700 square miles in the south-central part of the Mojave Desert. The area extends about 60 miles northerly and easterly along and adjacent to the Mojave River from its source in the San Bernardino Mountains, along the southern border of the study area, to the desert floor near Afton. Although the Mojave River extends beyond Afton, the area downstream from Afton was not included in the study because the use of water there is considered minor in quantity and economic importance to the total study area.

The study area is essentially a plain sloping gently northward and eastward. The plain is made up of small, broad valleys, or closed basins, separated by isolated hills, groups of hills, and low mountains. The bottoms of the closed basins are playas which contain water only following heavy rainfall. The largest playas in the study area are Lucerne Lake, Harper Lake, Coyote Lake, and Troy Lake.

Elevations in the study area range from more than 8,500 feet near Crestline in the San Bernardino Mountains to 2,715 feet at Victorville and 1,408 feet at Afton.

The Mojave River is the major stream traversing the study area. The river originates in the foothills of the San Bernardino Mountains at the junction of the West Fork and Deep Creek and flows north 12 miles to Victorville, then continues 18 miles adjacent to Highway 91 to Helendale. It then turns northeast and continues adjacent to Highway 91 past Barstow to Afton, the study area limit, approximately 90 miles from its beginning.

The river then flows to its terminus in Silver Lake. Flood waters in the Mojave River occasionally reach Silver Lake but soon evaporate. Perennial flow occurs only in the mountains and near Victorville, Harvard, and Afton.

Annual precipitation averages less than 4 inches in the desert area but exceeds 40 inches in the upper regions of the Mojave River watershed. Sixty percent of the precipitation occurs from December through March. The growing period between killing frosts averages about 245 days. The area is also noted for its high summer temperatures and low humidity; temperatures of more than 100° F and relative humidity below 20 percent are not uncommon.

The greater portion of the region is undeveloped. Historically, the development of irrigable lands and centers of population have been primarily along the Mojave River and the adjacent valleys where there has been an easily available supply of surface and/or ground water. Alfalfa and permanent pasture are the chief crops. The larger centers of urban development are the Cities of Barstow and Victorville, with 1960 populations of about 11,500 and 8,000. Other communities include Hesperia, Apple Valley, Lucerne Valley, Adelanto, and Yermo. Mining and the manufacture of cement are the chief industries. Several military installations are located in the study area, with George Air Force Base near Victorville being the largest.

Subdivisions of the Study Area

Because of the size and complexity of the study area and the need for localized information, the area was subdivided for this investigation. The subdivision was based mainly on information in the office report published by the Department, "Names and Areal Code Numbers of Hydrologic Areas in the Southern District", April 1964. The information in the publication is the basis for compiling, filing, and retrieving geologic and hydrologic data with high-speed electronic data processing machines in the Department.

It was found convenient for this study to adopt the names and areal code numbers used in that publication. However, some significant boundary changes were made, which are used in this study. The 1964 report will be updated to reflect these changes. The revised boundaries are a result of analysis of recent topographic and geologic maps of the United States Geological Survey and the Department of Water Resources. These changes are described later in this report. The names and areal code numbers of study area subdivisions are presented in Table 1. The subdivisions are shown on Figure 2, "Area of Investigation".

TABLE 1

NAMES AND AREAL CODE NUMBERS OF HYDROLOGIC AREAS

Areal Code	Designation
W-18.00	Coyote Hydrologic Unit
W-28.00	Mojave Hydrologic Unit
W-28.B0	Upper Mojave Hydrologic Subunit
W-28.C0	Middle Mojave Hydrologic Subunit
W-28.D0	Harper Hydrologic Subunit
W-28.E0	Lower Mojave Hydrologic Subunit*
W-28.G1	Caves Hydrologic Subarea
X-01.00	Lucerne Hydrologic Unit

*Troy Hydrologic Subunit has been combined with Lower Mojave Hydrologic Subunit for this study.

Each subdivision in Table 1 could be further segregated into a nonwater-bearing hill and mountain area and a ground water-bearing valley area. In this report the ground water-bearing valley area is referred to as the "ground water basin" or "basin" to distinguish it from the entire subdivision, which includes portions of the surrounding hills and mountains.

In most locations in this region, water-bearing areas are separated from each other by nonwater-bearing materials of hill and mountain areas and by bedrock highs, which created conditions of alluvial constriction. In some locations, the water-bearing areas are separated by surface drainage divides. The boundary conditions between the water-bearing areas, or basins, of the hydrologic subdivisions are presented in Table 2.

TABLE 2

BOUNDARY CONDITIONS BETWEEN BASINS

Basins	Physical conditions at boundary
Upper Mojave-Lucerne	Drainage divide and alluvial constriction
Lower Mojave-Middle Mojave	Drainage divide and alluvial constriction
Lower-Mojave-Caves	Drainage divide
Caves-Coyote	Drainage divide
Caves Basin at study area boundary	Alluvial constriction
Harper-Middle-Mojave	Drainage divide
Middle Mojave-Upper Mojave	Drainage divide

The most significant changes in boundaries which resulted from the recent topographic coverage were made to boundaries of the Lower Mojave Basin and Lucerne Basin. Previously, the boundary between the Lower Mojave Basin and Troy Basin was represented by a low relief surface drainage divide. Because there is no restriction to ground water movement across this divide, and because restrictions do occur elsewhere in these two divisions, Troy Basin has been included as part of the Lower Mojave Basin for this study. The boundaries of the Caves Basin, Coyote Basin, and Lower Mojave Basin were also revised considerably on the basis of the recent detailed topographic mapping, although the hydraulic characteristics which determine these divisions remain basically the same. The boundary between the Lucerne Basin and the Upper Mojave Basin was also revised on the basis of topographic criteria; the boundary now follows the surface drainage between Apple Valley and Rabbit Lake.

Base Hydrologic Period

In any watershed, precipitation is the original source of local water supply; therefore, the amount of precipitation to a ground water basin and its tributary areas serves as an index of the water supply available to that basin. By analysis of long-time precipitation records, it is possible to select as a "base period" a relatively short and recent period which represents the long-time average water supply. Such a period is needed for study purposes because long-time hydrologic data, other than rainfall records, are generally unavailable.

The base period conditions should be reasonably representative of long-time hydrologic conditions and should include both normal and extreme wet and dry years. Both the beginning and the end of the base period should be preceded by a series of wet years or a series of dry years, so that the difference between the amount of water in transit within the zone of aeration at the beginning and end of the base period would be a minimum. The base period should also be within the period of available records and should include recent cultural conditions as an aid for projections under future basin operational studies.

For this study, the base hydrologic period was determined from analysis of records of a precipitation station in the San Bernardino Mountains, the major area of water supply to the basin. The accumulated departure from the mean precipitation at this recording station appears to start during a dry period (1893-94), and it continues through 1960-61. It includes the 57-year period from 1904-05 through 1960-61, which covers two cycles of wet and dry periods. This 57-year period was selected as that which best represents the long-time hydrologic conditions in the Mojave River region.

On the basis of the criteria stated in preceding paragraphs, the water years 1936-37 through 1960-61 were chosen as the base hydrologic period. This 25-year period includes the most recent pair of wet and dry cycles; has an average annual precipitation (at Squirrel Inn No. 2) of 40.7 inches, which closely approximates the estimated long-time period average of 41.7 inches; begins and ends after a series of dry years; is within the period of available data; and includes recent land use conditions. The precipitation characteristics at the Squirrel Inn No. 2 Station are shown on Figure 3. Because of the similarity of hydrologic conditions (dry trends) preceding 1936-37 and 1960-61 and because valley precipitation averaged less than 6 inches annually, the assumption could be made that there was no significant change in the amount of water in transit at the beginning and end of the base period. In view of this, the difference in the amount of water percolating downward through the

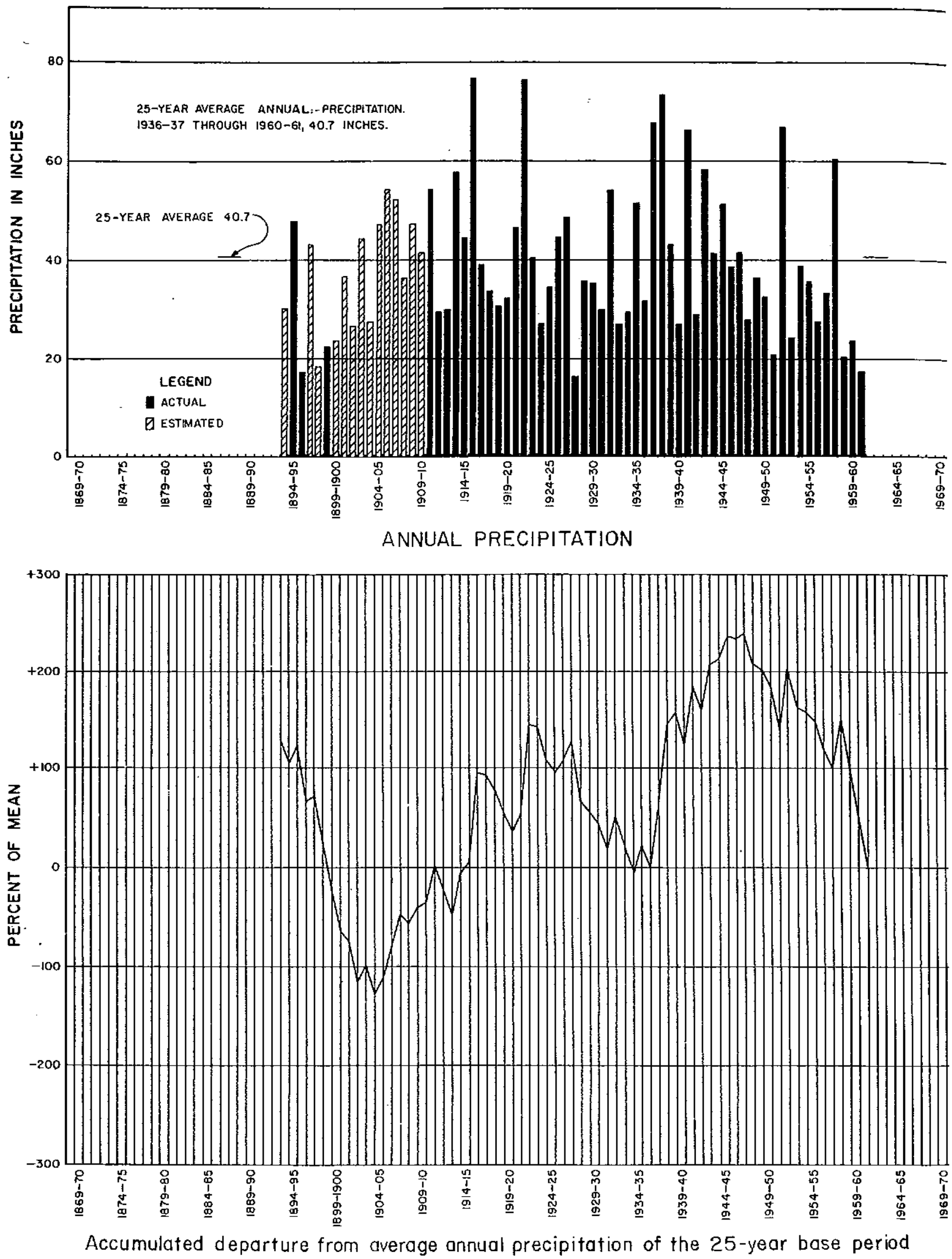

Figure 3. PRECIPITATION CHARACTERISTICS AT SQUIRREL INN NO. 2

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zone of aeration to the zone of saturation was considered to be negligible for both periods. This assumption facilitated computation of changes in the amount of ground water storage during the base period.

CHAPTER II. GEOLOGY

In this investigation, the geology studies included a detailed examination of the physiography, stratigraphy, and structure of the area. The primary objective of these studies was to develop a better understanding of the water-bearing formations of the area and to determine the occurrence, movement, and quality of ground water within the formations. To meet this objective, geologic formations and structures were inspected and were correlated with geologic units delineated by previous studies. An areal geology map of the study area was then prepared and lithologic units were grouped according to general water-yielding characteristics. Water well logs, water quality data, water level data, and aquifer test information were evaluated, along with data obtained from interviews with local water well drillers. The results of these studies are summarized and discussed in the following paragraphs.

Physiography

The Mojave study area is an alluviated plain that slopes gently northward and eastward. Bordering the plain are the San Bernardino Mountains on the south; the Fry, Rodman, and Cady Mountains on the east; the Alvord Mountains, the Paradise Range, the Calico Mountains, the Rainbow Hills, and the Gravel Hills on the north; and the Kramer Hills and the Shadow Mountains on the west.

The high San Bernardino Mountains are essentially nonwater-bearing crystalline and metamorphic rock. These mountains contribute the major amount of runoff to the ground water basin; they also are the source of the bulk of the alluvial debris deposited in the valley areas. Minor amounts of both runnoff and alluvial debris are contributed by the low mountains and hills interspersed throughout and bordering the basin.

The principal stream traversing the study area is the Mojave River, which originates in the San Bernardino Mountains, and flows north and east about 110 miles, terminating in Silver Lake, about 20 miles outside the study area.

Other important features of the study area are the Upper and Lower Narrows of the Mojave River, where rising ground water occurs as the result of constrictions in the cross-sectional area of the water-bearing materials. Physiographic features are shown on Plate 1, "Physiographic Features and Lines of Equal Average Annual Precipitation"; detailed areal geology is shown on Plate 2, "Areal Geology".

The Mojave River ground water basin is the subsurface reservoir which yields water to wells drilled in the area. The ground water basin area, or valley fill area, contains shallow, permeable alluvial deposits, and is underlain and surrounded by relatively impermeable rock. These features are shown on Plate 3, "Geologic Sections".

Stratigraphy

Geologic units of the region are grouped under two broad categories according to their water-yielding characteristics: water-bearing and nonwater-bearing. A crystalline complex of pre-Tertiary igneous and metamorphic rocks that characteristically yields little water to wells forms the major portion of the mountain and hill areas surrounding the water-bearing portions of the study area. These formations, which are considered nonwater bearing, underlie water-bearing sediments. The water-bearing sediments are unconsolidated to semiconsolidated alluvial deposits that are Quaternary in age, continental in origin, and made up primarily of materials ranging in size from coarse gravel to clay. These sediments are generally more consolidated with depth, and commonly exhibit cementation in the older formations. Interspersed within, and overlying these sediments, in local areas are nonwater-bearing volcanic deposits.

Water-Bearing Formations

The water-bearing deposits of the area result primarily from deposition of alluvial material eroded from the adjacent highlands. The streams carry debris onto the valley floor during flood flows, forming alluvial fans at the base of the mountains by dropping the coarse particles first. As the distance from the mountains becomes greater, the sediment-carrying capacity of the stream becomes less, resulting in deposition of finer grained sediments. Usually only the silts and clays reach the central or lowest portions of the basins. Generally, the coarser alluvial fan deposits and deposits within the streambed are more permeable and result in higher yield to wells, whereas the fine-grained deposits do not yield water readily. The older deposits have undergone chemical weathering and compaction and have been cemented to some degree, all of which tends to reduce the permeability of the materials.

The Mojave River has interrupted this general deposition pattern by traversing the study area, cutting a channel through both coarse-and fine-grained materials, and then backfilling with coarse-grained river channel deposits. These latter deposits are highly permeable and contain the major source of the water supply used at present in the study area.

Within the study area, the water-bearing materials include 11 lithologic units that range in age from Recent to Pleistocene; these units include: river deposits, playa deposits, dune sand, younger alluvium, younger fan deposits, old lake and lakeshore deposits, older alluvium, older fan deposits, landslide breccia, Shoemaker gravel, and the Harold Formation. Figure 4, "Generalized Stratigraphic Column of Water-Bearing Sequence, Mojave River Area" shows the stratigraphic sequence of the water-bearing formations or units, their lithology, and the maximum thickness of each formation or unit. The major characteristics of these water-bearing lithologic units are discussed in the following paragraphs.

River Deposits. Boulders, gravel, sand, and silt, with some interbeds of clay and sandy clay, occupy the channel of the Mojave River. The deposits are unconsolidated, unweathered, and range up to 90 feet in thickness. The river deposits form the most important aquifer in the study area. A majority of the irrigation and municipal water wells in the region draw water from this aquifer. These wells yield water at an average rate of 500 gallons per minute, although some wells yield as much as 1,600 gallons per minute. In addition, ground water in the river deposits is a major source of replenishment to the other ground water areas, through subsurface flow.

Playa Deposits. Playa deposits underlie the surfaces of the dry lakes in the study area. The deposits are fine sand, silts, and clays, which range in thickness from a few feet to about 25 feet. These fine-grained materials generally have a low permeability and, even when saturated, will yield only small quantities of water to wells. These materials generally

SYSTEM	SERIES	GEOLOGIC FORMATION	LITHOLOGY	MAXIMUM THICKNESS (FEET)
QUATERNARY	RECENT	RIVER DEPOSITS	Qra	90±
		PLAYA DEPOSITS	Qp	25±
		DUNE SAND	Qds	35±
		YOUNGER ALLUVIUM	Qal	100±
		YOUNGER FAN DEPOSITS	Qyf	75±
	PLEISTOCENE	OLD LAKE & LAKESHORE DEPOSITS	Qol	75±
		OLDER ALLUVIUM	Qoa	1000±
		OLDER FAN DEPOSITS	Qof	1000±
		LANDSLIDE BRECCIA	Qls	100±
		SHOEMAKER GRAVEL	Qs	300±
		HAROLD FORMATION	Qh	1300±

LEGEND

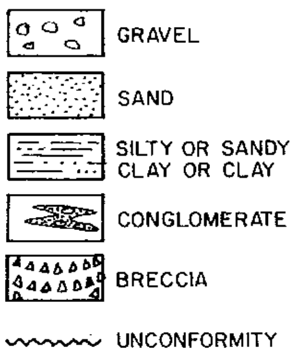

Fig. 4. GENERALIZED STRATIGRAPHIC COLUMN OF WATER-BEARING SEQUENCE, MOJAVE RIVER AREA

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exhibit high concentrations of total dissolved solids, ranging from 380 to 5,300 parts per million.

Dune Sand. Sand dunes are present in all of the basins, commonly near the playas and adjacent to the Mojave River. Typical deposits are found downstream of Hodge and in Hinkley Valley. These deposits range in thickness from a few feet to as much as 35 feet. The dunes are porous and permeable and suitable for storage of ground water; however, they are above the existing water table.

Younger Alluvium. Younger alluvium occurs as a veneer overlying large portions of the older materials, and occupies small stream channels tributary to the Mojave River. The deposits are made up of material ranging in size from very small to large and are usually unweathered sands and silts, plus some gravel and clay. The younger alluvium ranges in thickness from a few inches to about 100 feet. Not only are the deposits less prolific water producers than the river deposits but yields are usually less than 300 gallons per minute. Large portions of the younger alluvium are above the water table, or only partially saturated.

Younger Fan Deposits. Unconsolidated younger fan deposits are located at the base of the highland areas, usually above the water table. These deposits are poorly-sorted gravel and sand with some silt and clay. The younger fan deposits range in thickness from a few inches to about 75 feet. They occur extensively as a thin veneer at the base of the desert mountain ranges, overlying bedrock. Reworked older material has been deposited as alluvial fans at the base of the bluffs adjacent to the Mojave River.

These are partially saturated, and wells penetrating them vary in yield from a few gallons per minute to about 1,200 gallons per minute.

Old Lake and Lakeshore Deposits. Old lake deposits of well-bedded silts, clays, and sands, interbedded with thin fresh-water limestones are exposed at four separate areas along the Mojave River: (1) in the bluffs at Victorville, (2) along the river northwest of Helendale, (3) in the low hills south of Barstow, and (4) in the bluffs of the Mojave River at the Caves Basin near Manix. Water well logs indicate the presence of blue and green clays which suggests that lake deposits underlie Hinkley and Harper Valleys. The Old Lake and Lakeshore deposits range in thickness from a few inches to about 75 feet. Lake deposits yield little water to wells, but may act as confining layers for deeper water-bearing materials.

Lakeshore deposits are remnants of sand and gravel bars of late Pleistocene lakes. These deposits, which are found south and east of Coyote Lake and near Manix, are above the water table.

Older Alluvium. Older alluvium underlies most of the study area. The unconsolidated to moderately consolidated deposits are interbedded gravel, sand, silt, and clay. The deposits are weathered, and some cementation has developed, usually in the form of caliche.

The older alluvium ranges in thickness from a few inches to about 1,000 feet and contains the major portion of ground water in storage in the area. Generally, the alluvium yields water freely to wells; however, in some areas the materials are poor in their water-yielding characteristics. A few wells in the vicinity of Hesperia and near Daggett produce more than 2,000 gallons per minute from older alluvium; in contrast, water wells in older alluvium north of Adelanto characteristically yield 30 gallons per minute or less.

Older Fan Deposits. Deposits of older fans are exposed irregularly throughout the region, but generally occur near the flanks of the highland areas. The deposits include gravels, sands, and silts, which in some areas, are cemented with caliche deposits. The materials are moderately consolidated, and in some places, deeply weathered. Maximum thickness is estimated to be 1,000 feet. Records of the few wells known to penetrate older fan material indicate that the yield varies considerably, but is generally low.

Landslide Breccia. In the southeasterly portion of the Lucerne Basin, on the flank of the San Bernardino Mountains, is a large slide deposit which apparently occurred during Pleistocene time. This area, known as the Blackhawk slide, contains primarily poorly-sorted and partially cemented blocks of limestone. Maximum thickness is estimated to be 100 feet. There are no known water wells in the landslide. If saturated, the breccia would probably have low water-yielding capacity.

Shoemaker Gravel. The Shoemaker gravel is a deposit of poorly-sorted, subangular gravel with lenses of sand and silt that underlies older alluvium and overlies the Harold Formation in depths of as much as 300 feet. Although some unused water wells penetrate the Shoemaker gravel, it generally lies above the water table and there are no known wells extracting from it. However, if it were saturated it probably would yield water freely.

Harold Formation. The Harold Formation is exposed in the bluffs facing south near the crest of Cajon Pass as a series of discontinuous beds of grayish silty sandstone with lenses of conglomerate, and occasional thin beds of clayey silt; it is approximately 1,300 feet thick.

The Harold Formation apparently yields little water to wells, as indicated by two known wells that produce less than 20 gallons per minute.

Nonwater-Bearing Formations

Pre-Tertiary crystalline rocks enclose the entire study area and comprise the major portions of the mountain and hill areas; the area also includes consolidated Tertiary sedimentary and volcanic rocks and Quaternary basalt. The crystalline complex and the Tertiary deposits also underlie the valley areas, but are buried by the unconsolidated Quaternary alluvial deposits that comprise the water-bearing formations.

In the mountain and hill areas, the rocks may be the only source of water; however, because the yield from wells is typically less than 50 gallons per minute, these formations are considered to be essentially nonwater-bearing. In addition to being poor storage reservoirs, these formations also act as impediments to ground water movement. The nonwater-bearing units, listed generally from younger to older, include: Quaternary basalt, Tertiary sedimentary rocks, Tertiary volcanic rocks, and the basement complex. The major characteristics of these nonwater-bearing lithologic units are discussed in the following paragraphs:

Quaternary Basalt. Abundant outcrops of Quaternary volcanic rocks with thicknesses ranging from a few inches to about 265 feet are located in the Black Mountain area north of Harper Lake, in a long belt extending south of Troy Lake, and in the Rodman Mountains. The dominant rock type is basalt, which occurs as vesicular to dense basalt dikes and flows, associated with some cinders, and local deposits of scoriaceous tuff. In the study area, all of these deposits occur above the regional water table. They are not tapped by any known wells, and therefore are not a significant source of ground water. However, water is yielded freely from basalt deposits in other localities through springs.

Tertiary Sedimentary Rocks. The Tertiary continental sedimentary deposits identified in the study area range in age from Miocene to Pliocene and range in thickness from a few inches to about 4,800 feet. Major outcrops occur in the mountain and hill areas northeast of the Lockhart fault and some isolated exposures occur in the Kramer Hills.

These consolidated rocks consist of water-deposited conglomerates, sandstone, siltstone, mudstone, limestone, agglomerates, and volcanic tuffs. In the study area, these formations do include pervious layers, but the water they contain is generally of poor quality and yields from wells are low. Because of their fine grain size and low porosity, the limited recharge they receive in outcrop areas, and the great depths at which they occur in the valleys, these deposits are considered to be nonwater-bearing.

Tertiary Volcanic Rocks. Tertiary volcanic rocks consist of extrusive and intrusive rock of various compositions, interbedded with Tertiary continental sedimentary rocks. These formations occur in large and small outcrop areas in the mountain and hill region predominantly northeast of the Lockhart fault, and in small, isolated areas within the Kramer Hills. These rocks yield little water to wells and are considered to be nonwater-bearing.

Basement Complex. Basement rocks of the study area are a highly complex assemblage of pre-Tertiary crystalline and metamorphic rocks that are exposed in the mountain and hill areas, and underlie the younger deposits of the valley areas. These rocks are generally nonwater-bearing, but locally yield small-to-moderate quantities of water from springs, cracks, and from a few shallow wells in the residuum.

Structures Affecting Ground Water Movement

Geologic structural features, which affect ground water movement, include anticlines, synclines, faults, and valleys or topographic highs formed by folding or faulting. Within the area of investigation, structural features which affect ground water movement are generally obscured by alluvial cover and are not well defined on the surface. The exceptions are the San Bernardino Mountains, a high, rugged east-west trending uplifted block of the San Andreas fault system, and the other more subdued highland areas which generally form the internal and external borders of the Mojave River Ground Water Basin. The general nonlinear alignment of these highlands indicates that, in the main, the alluvial valleys owe their formation to normal erosional processes rather than to faulting, and the irregular, barren hills and mountains are stubborn, erosion resistant remnants. However, the greater depths of fill that occur in certain parts of the basin can be satisfactorily explained only by the assumption of faulting and folding.

At several places along the Mojave River channel, shallow alluvial sections underlain by near-surface, topographically-high masses of bedrock obstruct ground water underflow and serve to perpetuate conditions of rising ground water. This rising ground water condition occurs at four locations: the Upper Narrows, Lower Narrows, near Camp Cady, and at Afton.

The major faults within the study area which impede and affect the flow of ground water significantly are the Helendale fault, the Lockhart fault, and the Calico-Newberry fault. These three northwest-southeast trending faults are associated with, and subordinate to, the dominating San Andreas and Garlock fault systems. The locations of these faults are shown on Plate 2, "Areal Geology". The major characteristics and the principal structural influences of these faults are discussed in the following paragraphs:

Helendale Fault

The active Helendale fault extends northwest from the vicinity north of Baldwin Lake to the southeast flank of the Kramer Hills, a distance of over 45 miles. Directly east of the Kramer Hills and north of the northwest end of the Helendale fault trace is an unnamed fault, which extends in a general northwest direction for over 30 miles. This unnamed fault may be part of the Helendale fault system; however, due to the lack of supporting evidence, definite conclusions cannot be drawn.

Ground water levels in the vicinity of the Helendale fault indicate that it impedes the movement of ground water. This is particularly true in the Lucerne Basin where differences of 48 feet in water levels have been measured in wells 250 feet apart on either side of the fault. Table 3 includes water level data for wells on both sides of the fault.

In Lucerne Basin, the highest water levels are on the western side of the fault. These levels occur near the northwest end of the fault trace where ground water flowing northeasterly spills over the fault. Some flowing wells are in the vicinity, as indicated in Table 3.

In the Middle Mojave Basin, where the Helendale fault crosses the Mojave River, ground water levels indicate that the fault impedes ground water

TABLE 3

WATER LEVEL DATA FOR WELLS ADJACENT TO HELENDALE FAULT IN LUCERNE BASIN

State well number	Date of observation	Depth of well, in feet	Depth to water, in feet	Elevation of water in well, in feet
Southwesterly of the Fault				
4N/1W-10A1	4-15-54	568	4	2,903
4N/1W-10H2	2- 9-54	168	8	2,902
4N/1W-10R2	2-10-54	250	0.2	2,930
4N/1W-11Q3	2-10-54	250	Flowing	Flowing
4N/1W-14B2	2- 2-54	100	10	2,930
4N/1W-14K2	2-16-54	219	Flowing	Flowing
4N/1W-14Q4	2-17-54	129	18	3,012
Northeasterly of the Fault				
4N/1W- 2P1	11-18-54	410	60	2,808
4N/1W-11B1	4-14-54	376	45	2,840
4N/1W-11J1	4-14-54	300	53	2,872
4N/1W-11Q1	3-15-55	85	51	2,882
4N/1W-13M1	11-23-54	--	112	2,803
4N/1W-14A2	2- 3-54	140	74	2,891
4N/1W-14H1	2-16-54	44	44	2,936

movement in the older alluvium, but not within the Recent channel deposits of the Mojave River. Upstream from the fault, rising water contributes to the Mojave River; downstream of the fault this condition is reversed.

Lockhart Fault

In the area of investigation, the Lockhart fault extends northwest from the southwest flank of the Fry Mountains to the extreme northwest portion of the study area, a distance of over 70 miles. The fault trace continues for another 15 miles beyond the study area. The Lockhart fault impedes the movement of ground water in the Harper Basin and in older alluvium within Hinkley Valley in the Middle Mojave Basin. Although the paucity of water wells in the Harper Basin precludes quantitative estimates of this impediment, the generally higher level of the water table southwest of the fault suggests the fault impedes ground water flow. Ground water level data for wells adjacent to the Lockhart fault in the Harper Basin are shown in Table 4.

TABLE 4

WATER LEVEL DATA FOR WELLS ADJACENT TO LOCKHART FAULT

State well number	Date of observation	Depth of well, in feet	Depth to water, in feet	Elevation of water in well, in feet
Southwesterly of the Fault				
10N/4W-8P1	1- 7-59	789	18	2,007
Northeasterly of the Fault				
10N/4W- 4C1	5-27-59	419	160	1,940
10N/4W- 6A1	5-19-59	250	250	1,870
10N/4W-10A1	5-20-59	325	187	1,933

Although there is no surface trace of the Lockhart fault in Hinkley Valley, the extension of the trace from Harper Basin coincides with the southwest flank of a deep pumping hole in Hinkley Valley. The steep gradient of that flank indicates an effective impediment to ground water flow.

Calico-Newberry Fault

The active Calico-Newberry fault trends northwest from the northeast flank of the Rodman Mountains to, and along, the southwest flank of the Calico Mountains, a distance of over 35 miles.

Water level measurements in wells indicate the Calico-Newberry fault impedes the movement of ground water in Lower Mojave Basin except along the northwestern portion of the fault, from the Mojave River to just east of the community of Yermo. In that portion of the fault area, little difference was observed in the water levels on either side of the fault. On the other hand, ground water level elevations measured in wells adjacent to either side of the fault southeast of the Mojave River indicate a marked difference in levels. In this area, the water levels south of the fault are higher than those north of the fault. Representative ground water level data are listed in Table 5.

TABLE 5

WATER LEVEL DATA FOR WELLS ADJACENT TO CALICO-NEWBERRY FAULT

State well number	Date of observation	Depth of well, in feet	Depth to water, in feet	Elevation of water in well, in feet
Southwesterly of the Fault				
9N/2E- 3C1	1-13-60	63	17.5	1,853
9N/2E-11H1	1-12-60	--	17.5	1,848
9N/2E-13Q1	12- 7-60	230	14.6	1,855
9N/3E-19P1	3-24-60	151	8.6	1,847
9N/3E-29G1	3-24-60	--	11.2	1,839
9N/3E-33E1	8- 8-61	304	Flowing	1,830
Northeasterly of the Fault				
9N/2E- 3A2	3-23-60	65	40.1	1,845
9N/3E-18M1	12-16-59	253	54	1,860
9N/3E-20Q1	6- 2-60	390	58	1,845
9N/3E-29A1	3-24-60	90	68.2	1,846
9N/3E-34N1	12-17-59	99	23.1	1,818

CHAPTER III. WATER SUPPLY, USE, AND DISPOSAL

Hydrologic studies of water supply, use, and disposal are essential in evaluating the surplus or deficiency of the water supply and in determining the overdraft and safe yield. These studies, which are discussed and summarized in this chapter, include analyses of precipitation, surface flow, subsurface flow, import-export of water, and consumptive use. For these studies, the 25-year base period from 1936-37 through 1960-61 was used. (The selection of this base period is discussed in Chapter II.)

In the study area, data sufficient for these hydrologic studies are available in areas along the Mojave River and the adjacent valleys that constitute the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Ground Water Basins. The limited amount of data that are available on the other three basins--Harper, Coyote, and Caves--does not permit comparable analyses. Where information is available, it is included in the following text and tables as a matter of interest.

For most items of water supply, use, and disposal, the historical data on the annual amounts for each year of the base period were available for the four major basins. For some items, such as subsurface inflow and outflow across basin boundaries, the surface inflow from the desert mountain area, it was necessary to estimate the average annual amounts.

Water Supply

The ground water basins discussed in this report are equivalent to the water-bearing portions of the study area. Plate 4, "Ground Water

Basins and Effective Base of Fresh Water", shows the boundaries of each of the basins in the study area.

For this study, sources of water supply are considered to be precipitation falling on the ground water basins and surface, subsurface, and import waters flowing into the basins.

Because the basins are interrelated, a part of the surface and subsurface inflow and the imported water supply to one basin may originate as outflow or as exported water from other basins. For this reason, water supply to and within the total study area from these sources is discussed as surface flow, subsurface flow, and import-export water.

Because the amount of pumped ground water which is not consumptively used is assumed to return to the ground water basin, this amount could be considered as water supply. However, because pumped ground water cancels out as a factor in the overall hydrologic equation when surface and ground water supplies are considered together, it is not discussed here as an item of supply, but is included later in this chapter as an item of water use and disposal.

Precipitation

The average annual precipitation in the study area ranges from less than 4 inches on the desert valley floor to over 40 inches in the San Bernardino Mountains. This range in average annual precipitation is shown on Plate 1. The data utilized on this map were prepared by the U. S. Weather Bureau as part of its meteorological studies of the southwestern United States.

Records of two long-term precipitation stations in the study area indicate a similar wide range in average annual precipitation. At Barstow, on the desert valley floor, the average annual rainfall is

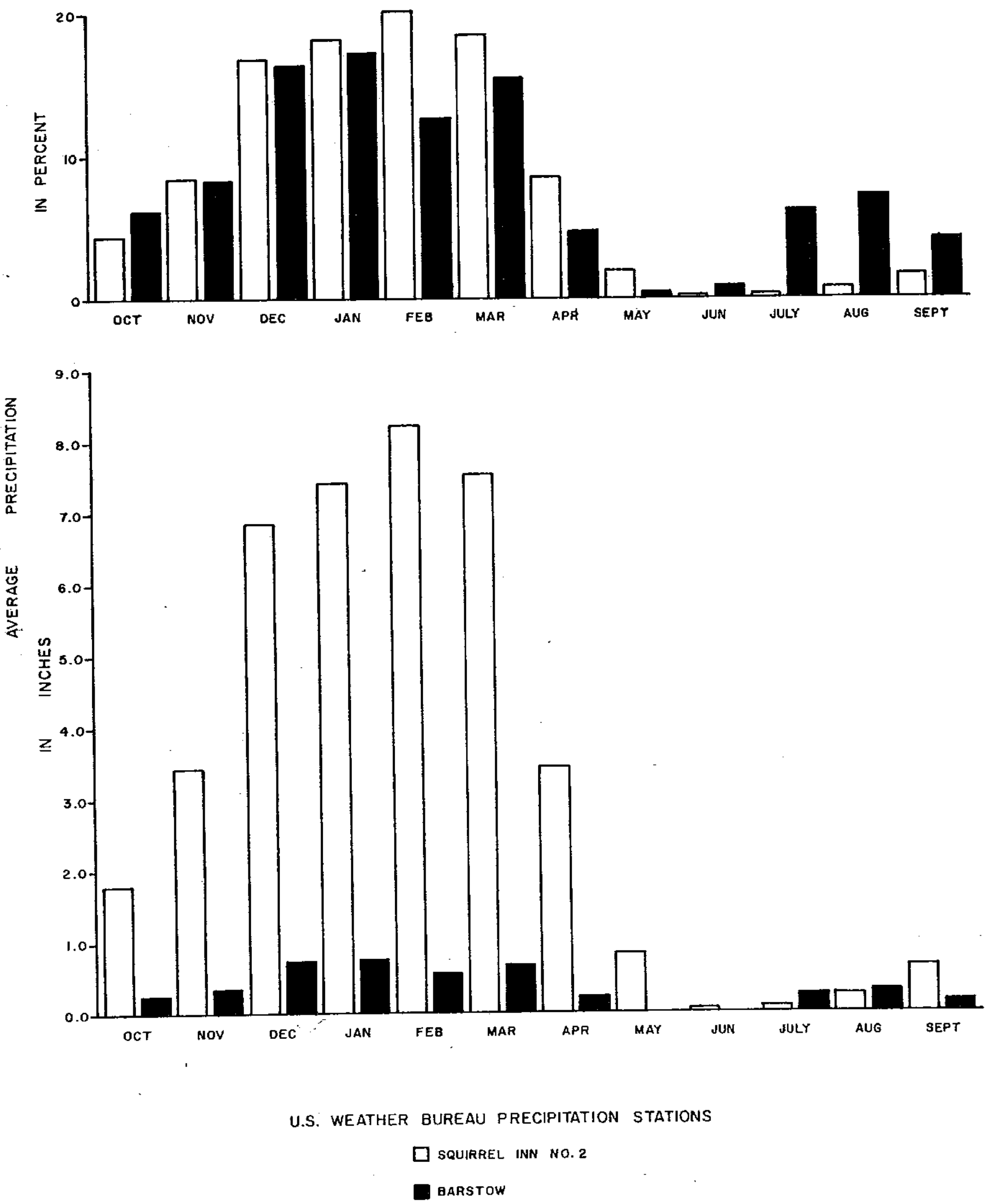

Fig. 5. AVERAGE MONTHLY DISTRIBUTION OF PRECIPITATION AT REPRESENTATIVE STATIONS—1936-37 THROUGH 1960-61

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4.7 inches; at Squirrel Inn No. 2, located in the San Bernardino Mountains, the average annual rainfall is 40.7 inches.

The monthly distribution of the average annual precipitation at these stations is shown on Figure 5, "Average Monthly Distribution of Precipitation at Representative Stations, 1936-37 through 1960-61". At both stations, the major source of rainfall is the storms that usually occur in this area during the period from December through April. However, comparison of the winter and summer rainfall patterns shows that a higher percentage of the rainfall from summer convectional storms falls on the desert area.

Table 6 lists the selected stations in the study area, their elevations, length, and source of records, and the amount of average annual precipitation during the period 1930-31 to 1959-60. In addition, the table gives the average annual precipitation during the 25-year base period (1936-37 through 1960-61) for those stations for which adequate records were available. Comparison of these records shows that the precipitation for both periods is essentially the same. Therefore, the isohyetal map, Plate 1, is considered to represent both the period of historical record and the base period.

Table 7 shows the estimated average annual precipitation to the hill and mountain areas and to the valley areas of each basin. The portion of precipitation to hill and mountain areas that becomes water supply to the basins is discussed later in this chapter as surface inflow.

The valley areas are primarily desert, with extensive growths of native vegetation which are not cultivated and are not controllable as to water use. For this study, all precipitation less than 8 inches annually was considered to be used in satisfying the growth and transpiration requirements of this native vegetation and, therefore, was not considered an item of water supply or consumption.

Precipitation that is consumed by agricultural crops is beneficial to man, and thus is included in the total amount of water supply from precipitation. In addition, although precipitation consumed by riparian native vegetation is not beneficial to man at this time, the amount of precipitation used by these plants is included here, because this water may be partially recovered and beneficially used in the future through elimination and control of riparian growths.

TABLE 6

SELECTED* PRECIPITATION STATIONS IN THE STUDY AREA

Plate 1 reference No.	Station	Elevation of station, in feet, USGS datum	Period of record: From	Period of record: To	Missing or incomplete years: During period of record	Missing or incomplete years: During base period	Average seasonal precipitation, in inches: 25-year base period	Average seasonal precipitation, in inches: Isohyetal map 1930-60	Source of record[a]
1	Adelanto	2,845	1943-44	1960-61	1	7	5.5	4.9	USWB
2	Ash Meadows	4,650	1904-05	1914-15	1	25		21.6	DWR
3	Barstow	2,142	1888-89	1960-61	24	3	4.7	5.1	USWB
4	Big Bear Lake Dam[c]	6,815	1883-84	1960-61	0	0			USWB
5	Daggett FAA Airport	1,922	1939-40	1960-61	3	6	4.0	3.9	USWB
6	Deep Creek	5,200	1892-93	1914-15	6	25		28.0	DWR
7	Fleming's Mill	5,010	1893-94	1899-00	0	25		39.5	DWR
8	Fork of Mojave	3,000	1904-05	1919-20	0	25		13.5	DWR
9	Grass Valley	5,190	1893-94	1914-15	10	25		31.9	DWR
10	Hesperia	3,195	1942-43	1960-61	0	6	7.8	8.0	USWB
11	Lake Arrowhead	5,250	1929-30	1960-61	3	2	42.8	41.0	USWB
12	Lucerne Valley 1 SSW	3,040	1952-53	1960-61	0	16		5.6	USWB
13	Morse's[b]	5,350	1892-93	1917-18	5	25		49.2[e]	DWR
14	Squirrel Inn No. 2	5,680	1892-93	1960-61	12	0	40.7	40.9	USWB
15	Talmadge[b]	5,090	1893-94	1899-00	1	25		44.8[e]	DWR
16	Victorville Pumping Plant	2,858	1938-39	1960-61	1	3	5.9[d]	5.8	USWB

a. USWB--United States Weather Bureau; DWR--Department of Water Resources.
b. Former Arrowhead Company stations. Records published in DWR Bulletin No. 47, "Mojave River Investigation", 1934.
c. Outside of study area.
d. Estimated.
e. Computed by USWB in preparing isohyetal map shown on Plate 1.
* On the basis of representative location and completeness of records.

TABLE 7

ESTIMATED AVERAGE ANNUAL PRECIPITATION
BY AREA*

Location	Area, in acres	Precipitation, in inches
Mountain Areas		
San Bernardino Mountains	169,600	24.6
Desert Mountains		
Upper Mojave Basin	46,800	6.4
Middle Mojave Basin	107,500	6.1
Lower Mojave Basin	136,900	6.9
Lucerne Basin	71,600	7.6
Harper Basin	100,800	6.7
Coyote Basin	66,100	7.8
Caves Basin	34,000	5.7
Valley Areas		
Upper Mojave Basin	371,100	6.3
Middle Mojave Basin	260,500	5.0
Lower Mojave Basin	259,200	4.2
Lucerne Basin	190,100	6.4
Harper Basin	297,200	4.5
Coyote Basin	99,900	5.0
Caves Basin	94,000	4.5

*For the base period

Rainfall in the area south of the town of Hesperia is -- in some years -- in excess of 8 inches and, therefore, contributes to the ground water supply. In this area, the average annual amount of precipitation exceeding 8 inches during the base period of the study was sufficient to provide to the land surface an estimated 4,500 acre-feet of water supply annually. The average annual amount of deep percolation from precipitation to the valley floor was estimated by applying a technique used by the Department in previous investigations. This technique relates deep percolation to the amount of precipitation, the evapotranspiration requirements and soil moisture deficiency that must be satisfied above the selected 8 inch value, and the residual amount of runoff. The technique was developed from data used in 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 in U. S. Department of Agriculture publication, "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data", by Harry F. Blaney and Wayne D. Criddle of the Soil Conservation Service, dated August 1950.

Based on this technique, the amount of precipitation that may percolate was determined to be 3,850 acre-feet. However, to make allowances for any loss of this water as it passes from the root zone to ground water due to vapor transport, the amount of precipitation that percolates and becomes ground water was assumed to be 3,500 acre-feet.

Table 8 summarizes the estimated annual deep percolation of precipitation on the valley floor south of Hesperia during the base period. The occurrence of perched ground water in the same region confirms the occurrence of deep percolation as a source of water supply. However, the available data were not sufficient to define the magnitude and areal extent of the perched ground water body or to check the seasonal amounts of deep percolation from this source during the base period.

Surface Flow

Surface flow has two sources: base flow from the discharge of ground water to the stream channels and storm runoff from precipitation on the tributary hill and mountain areas. Base flow is found in four

TABLE 8

ESTIMATED SEASONAL DEEP PERCOLATION OF PRECIPITATION ON THE VALLEY FLOOR SOUTH OF HESPERIA DURING THE BASE PERIOD

In acre-feet

Water year	Deep percolation	Water year	Deep percolation
1936-37	3,500	1950-51	0
38	2,000	52	7,450
39	350	53	0
40	0	54	1,450
		55	0
1940-41	30,150	1955-56	0
42	0	57	0
43	5,600	58	5,400
44	30,550	59	0
45	1,000	60	0
1945-46 through 1948-50	0	1960-61	0
		25-year average	3,500

reaches of the Mojave River. At the point of origin of the Mojave River, the confluence of the West Fork of the Mojave River and Deep Creek, base flow results from the perennial supply available from the drainage area of Deep Creek. At Victorville, Camp Cady, and Afton, base flow, or rising water results from constrictions in the alluvial section of water-bearing materials, which force the ground water to the surface of the stream channel.

Runoff enters the study area through stream channels or as overland flow. The sources of runoff from precipitation are the San Bernardino Mountains and the desert mountains on the valley floor, shown on Table 7. In addition, as discussed earlier in the chapter, runoff from precipitation on the valley floor is a source of water supply in the area south of Hesperia.

Those stream gaging stations in the study area from which data were obtained for use in this report are presented in Table 9, by station name, length of record, and drainage area. In addition, the gaging station from the diversion site on Deep Creek to Hesperia is also listed. Although the records of the station at Beacon Creek near Helendale were not utilized in this study, it is part of the United States Geological Survey program to determine runoff characteristics for small drainage areas, which may provide valuable information in the future. Location of these stations is shown on Plate 1.

The principal surface flow in the study area is the Mojave River. The two major streams in the San Bernardino Mountains are Deep Creek and the West Fork of the Mojave River. These streams combine at the base of the mountains to form the Mojave River. This confluence is referred to as the forks. The flows in these streams are gaged by the U. S. Geological Survey about 1 mile upstream of their confluence. The records of the combined flow of the two streams and the diversion on Deep Creek are indicative of the flow of the Mojave River at the forks into the Upper Mojave Basin. The average annual flow at the forks during the base period was about 62,000 acre-feet, including diversion above the forks.

The major sources of surface inflow, or water supply to the basin, are the two forks of the Mojave River: Deep Creek and West Fork.

TABLE 9

STREAM GAGING STATIONS

Index No.*	Name[a]	Period of record: From	Period of record: To	Period of record: Incomplete or missing years	Drainage area, in square miles
Active Stations					
1[b]	Deep Creek near Hesperia	1904-05	1960-61	9	137.0
2[c]	West Fork Mojave River near Hesperia	1904-05	1960-61	9	74.8
3[d]	Mojave River at Lower Narrows, near Victorville	1898-99	1960-61	17	530.0
4	Mojave River at Barstow	1930-31	1960-61	0	f
5	Mojave River at Afton	1929-30	1960-61	21	f
6	Beacon Creek at Helendale	1959-60	1960-61	0	0.7
7	Cushenbury Creek near Lucerne Valley	1956-57	1960-61	1	6.4
Inactive Stations					
8	Deep Creek Diversion	1950-51	1958-59	0	---
9[e]	Mojave River at Point of Rocks	1908-09	1910-11	2	f
10	Mojave River at Hodge	1930-31	1931-32	0	f

a. USGS gaging station unless otherwise noted.
b. Lake Arrowhead Company records as East Fork of Mojave River from 1904-05 through 1921-22; USGS records from 1929-30 through 1960-61.
c. Lake Arrowhead Company records from 1904-05 through 1960-61; USGS records from 1929-30 through 1960-61.
d. Lake Arrowhead Company records from 1904-05 through 1914-15; USGS records from 1898-99 through 1905-06 and from 1930-31 through 1960-61.
e. Lake Arrowhead Company records.
f. Not available.
* These index numbers are as shown on Plate 1.

The flows in these forks are gaged about 1 mile upstream of their confluence at the forks, and the records of the combined flow of the two streams and the diversion on Deep Creek are considered indicative of the flow of the Mojave River at the forks. The flow at the forks essentially occurs at the boundary of the water-bearing material, although a portion of the area above the gage on the West Fork is underlain with water-bearing material. Consequently, some of the runoff from the San Bernardino Mountains has an opportunity to infiltrate and percolate to the ground water reservoir before it reaches the gage.

The average annual runoff at the forks during the base period was computed to be 62,000 acre-feet. The amount is about 16 percent less than the average annual amount for the entire period of record, which begins in 1904, and about 26 percent less than for the period 1904-05 through 1936-37 that includes one wet and one dry period. This shows that the runoff during the earlier time was more than during the base period. However, in previous studies of the selection of the base period, the average annual precipitation for these same periods was determined to be about equal. Because of this condition, it is reasonable to expect that the average annual runoff for the base period and the longer time would be about equal.

To determine whether or not the streamflow records should be adjusted to account for the difference in runoff, the records of the gaged stations at the forks were checked against records of other streams by applying a double mass curve technique commonly used by hydrologists.

The results showed that the data plot is a straight line and that the amounts of runoff at the forks are proportional to the amounts occurring in other streams. Therefore, two conclusions were arrived at: first, the runoff records of the Mojave River at the forks are accurate over the entire period of record; second, the difference in the amounts of runoff from comparable amounts of precipitation is apparently due to the changing physical conditions and precipitation characteristics affecting the precipitation runoff relationship of the drainage area above the forks. Accordingly, the average annual runoff at the forks during the base period is considered representative of the amount of water supply to the basin under present physical conditions and precipitation characteristics.

Because a small portion of the water-bearing material is above the gage on the West Fork of the Mojave River, some of the runoff from the San Bernardino Mountains percolates and becomes ground water before it reaches the gage. The amount that becomes ground water is considered as part of the surface flow of the Mojave River in this study. During the year, the average annual amount of ungaged runoff above the gage contributing to the water supply of the basin was estimated to be 1,150 acre-feet. This amount was determined by comparing the estimate of runoff for the West Fork drainage area with the gaged record at the forks. The estimate of runoff was based on the precipitation-runoff relationship discussed hereinafter and the amount of precipitation over the drainage area which was obtained from the isohyetal map.

For the balance of the ungaged portion of the San Bernardino Mountains, the average annual surface inflow from runoff was estimated to be 50 acre-feet to the Upper Mojave Basin and 600 acre-feet to the

Lucerne Basin. These estimates were determined by applying precipitation-runoff relationships discussed later in this chapter.

Although there is a gage on a 6.4 square mile drainage area of Cushenbury Creek, which is tributary to Lucerne Basin, the average annual amount of runoff in this area during the base period could not be determined from the short period of record. Therefore, the estimate of runoff from the San Bernardino Mountains to Lucerne Basin includes the amount from the Cushenbury Creek drainage area.

From the San Bernardino Mountains to Afton, the Mojave River crosses the boundaries between ground water basins, which are identified and discussed in Chapter II. At the basin boundaries, the flow of the Mojave River is surface outflow from the upstream basin or surface inflow to the downstream basin. There are four of these boundaries along the river: Helendale, Barstow, Camp Cady site, and Afton. Except at Barstow, the flow is a combination of storm flow and base flow. At Barstow, the flow is entirely storm flow from runoff originating in the San Bernardino Mountains.

There is no record of a stream-gaging station at the boundary between the Upper and Middle Mojave Basins which is near Helendale. However, flow data are available for stations at two nearby locations: less than three years of record at Point of the Rocks, about $1\frac{1}{2}$ miles downstream from the boundary, and two years of record at Hodge. These data were used to check the estimates of flow at the boundary.

The estimates of flow at the basin boundary near Helendale were based on: (1) a correlation developed from the flow data of the

Lower Narrows station and the Barstow station to be discussed next; (2) the criteria that, for the same amounts of annual flow entering the initial reach, the total amount of annual riverbed percolation in any number of reaches must equal the amount of riverbed percolation in the entire reach; and (3) the assumption that there is no change in the amount of storm flow in the reach between Victorville and Helendale because the majority of the storm flow occurs when there is base flow at Helendale. This correlation shows the relationship between the annual amounts of riverbed percolation and the annual amounts of flow at the Lower Narrows station, with riverbed percolation being computed as the difference in the annual amounts of gaged flow at the two stations. Therefore, knowing the annual flows at the Lower Narrows station, the annual amounts of riverbed percolation in the reach between the station and the boundary were determined. The annual amounts of flow at the boundary were determined by deducting percolation from flows at the Lower Narrows station. The average annual flow at the basin boundary during the base period was estimated to be 35,500 acre-feet.

The flow of the Mojave River is gaged at Barstow, about one-half mile downstream of the boundary between the Middle and Lower Mojave Basins. For study purposes, the flow at the gage is considered representative of flow at the boundary. The flow of the Mojave River at Barstow consists entirely of storm flow, 96 percent of which occurs from January through April. This storm flow originates as storm runoff in the San Bernardino Mountains above the forks and occurs when the storm runoff is of sufficient magnitude to reach Barstow. During the base period, the record of the gage at Barstow indicates no flow occurred at the station during 13 of the 25 years of the base period.

Based on these records, the average annual flow of the Mojave River at Barstow was computed to be 21,450 acre-feet during the base period. The seasonal flow ranged from zero to 130,000 acre-feet in 1937-38. In addition, the records at the station were used for estimating the flow of the Mojave River at the basin boundary near Helendale, previously discussed, and at the basin boundary at the Camp Cady site, to be discussed next.

The Mojave River crosses the boundary between the Lower Mojave and Caves Basins near the abandoned Camp Cady which is approximately 5 miles southeast of Harvard. The flow in the river at this point comprises base flow (rising water at the constriction in the alluvial section) and storm flow. During the base period, the average annual flow at the boundary was estimated to be 12,200 acre-feet and comprised 11,300 acre-feet storm flow and 900 acre-feet base flow.

In determining the average annual flow, it was first necessary to estimate the average annual storm flow by applying the same technique used in analyzing the flow of the Mojave River near Helendale. Where, (1) knowing the annual flows at the Barstow station, (2) based on a correlation developed from the flow data of the Barstow station and Afton station to be discussed next, and (3) based on the same criteria presented in analyzing the flow of the Mojave River near Helendale, the annual amounts of storm flow were estimated and the average annual storm flow determined to be 11,300 acre-feet.

The paucity of data precludes an analysis to determine the base flow at the boundary and, therefore, the average seasonal amount of base flow was assumed to be the same amount as at the Afton gage.

The flow of the Mojave River is gaged at the basin boundary at Afton. The flow at the station is the amount leaving the study area and comprises base flow (rising ground water at the constriction in the cross-sectional area of water-bearing materials at Afton Canyon) and storm flow. The storm flow at the station is a combination of runoff originating in the San Bernardino Mountains and runoff from local summer storms. The major portion of the storm flow originates in the San Bernardino Mountains. During the base period, flow at Afton was recorded only for the years 1952-53 through 1960-61; therefore, it was necessary to estimate the flow for the other 16 years of the base period. Flow data prior to the base period, from January 1930 through September 1932, and ground water level data during the missing 16 years of record between the Barstow and Afton stations aided in estimating the annual flow during the base period. Based on these data, the annual amounts for the 16 years of missing record were determined, and the average annual storm flow at Afton from the runoff originating in the San Bernardino Mountains was estimated to be 8,650 acre-feet. In addition, the average annual storm flow at Afton due to local summer storms was determined by a study of the magnitude and frequency of the amounts found in the 9 years of record at the station. From this study, the average annual storm flow from local summer storms was determined to be 50 acre-feet.

The annual base flow during the missing years of record was estimated by establishing a relationship between the base flow for the years of record and ground water level data at nearby wells. Based on this relationship, the base flow for the 16 years of missing record was determined, and the average annual base flow was estimated to be 900 acre-feet. Combined with the storm flow at the station, the average annual flow at the boundary where the Mojave River leaves the study area was estimated to be 9,600 acre-feet.

The average annual flows of the Mojave River at the various basin boundaries are shown in Table 10.

TABLE 10

AVERAGE ANNUAL FLOWS AT THE BASIN BOUNDARIES

Basin boundary	In acre-feet
At the Forks	62,000
Near Helendale	35,500
At Barstow*	21,450
Camp Cady Site	12,200
At Afton*	9,600

*Stream-gaging station.

The ungaged desert mountains on the valley floor contribute runoff to the water supply of the basins. This runoff constitutes about five percent of the total water supply of the study area. However, it is an important source of water supply to the basins that do not border the Mojave River. Estimated average annual runoff to these three basins -- Lucerne, Harper, and Coyote -- amounted to 450 acre-feet, 550 acre-feet, and 450 acre-feet during the base period. This is the only source of surface inflow to Harper and Coyote Basins; Lucerne receives additional runoff from the San Bernardino Mountains.

The amount of runoff from the ungaged desert mountains to the basins was estimated from an average seasonal precipitation-runoff relationship which was developed by adjusting a curve of the relationship for various streams in Southern California to reflect local conditions in the Mojave Desert region. The adjustment was made by creating a curve parallel to the original curve. The amount of offset from the original curve was based on the relationship of the average annual precipitation and runoff of the Deep Creek drainage area to the average of various streams in Southern California. Values of percent runoff for different depths of average annual precipitation used in estimating the runoff from ungaged drainage areas in the current studies and in the preliminary studies are presented in Table 11. By applying these values to the average annual precipitation on the various ungaged areas, the average annual surface inflow to the basins could be determined.

TABLE 11

AVERAGE PRECIPITATION-PERCENT RUNOFF VALUES

Average annual precipitation, in inches	Average annual runoff, in percent of precipitation
10	3.1
9	2.6
8	2.1
7	1.7
6 or less	1.0

As discussed earlier in the chapter, runoff from precipitation on the valley floor south of Hesperia percolates and becomes ground water. This is a source of water supply and, for this study, is considered surface inflow to the Upper Mojave Basin. The estimate of the average annual amount was based on the precipitation-runoff relationship discussed previously, modified for slope and soil conditions. The area of the valley floor south of Hesperia is flatter and composed of more permeable older alluvium than the steep and crystalline rock drainage areas used in originally developing the curve; therefore, it is reasonable to expect less runoff to occur in this area for equal amounts of precipitation. Analysis of limited data suggests that the amount of runoff is about half the amount determined from the precipitation-runoff relationship. On this basis, the average annual runoff from precipitation on the valley floor south of Hesperia during the base period was estimated to be 1,350 acre-feet. Most of this amount percolates in the many natural channels and becomes ground water in the area. However, because small amounts may be consumptively used by native vegetation, the amount of this runoff that becomes water supply to the Upper Mojave Ground Water Basin was assumed to be 1,000 acre-feet.

The flow of the Mojave River at the basin boundaries, the runoff from desert mountains on the valley floor, and runoff from precipitation on the basin as surface inflow to the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins are summarized in Table 12.

TABLE 12

ESTIMATED SURFACE INFLOW DURING THE BASE PERIOD

In acre-feet

Water year	To Upper Mojave Basin: From: San Bernardino Mountains: At the forks	Above West Fork	Other areas	From: Desert Mountains	Valley Area	Total	To Middle Mojave Basin: From: Mojave River	Desert Mountains	Total	To Lower Mojave Basin: From: Mojave River	Desert Mountains	Total	To Lucerne Basin: From: San Bernardino Mountains	Desert Mountains	Total
1936-37	169,250	1,150	50	250	2,800	173,500	125,200	550	125,750	103,900	800	104,700	600	450	1,050
38	218,900	1,150	50	250	3,700	224,050	159,150	550	159,700	138,100	800	138,900	600	450	1,050
39	40,600	1,150	50	250	500	42,550	17,250	550	17,800	550	800	1,350	600	450	1,050
40	31,250	1,150	50	250	350	33,050	15,350	550	15,900	0	800	800	600	450	1,050
1940-41	161,200	1,150	50	250	2,800	165,450	118,950	550	119,500	96,000	800	96,800	600	450	1,050
42	26,100	1,150	50	250	400	27,950	13,700	550	14,250	100	800	900	600	450	1,050
43	150,000	1,150	50	250	2,800	154,250	104,700	550	105,250	91,000	800	91,800	600	450	1,050
44	86,850	1,150	50	250	1,900	90,200	60,300	550	60,850	36,250	800	37,050	600	450	1,050
45	70,850	1,150	50	250	1,150	73,450	39,500	550	40,050	22,100	800	22,900	600	450	1,050
1945-46	54,550	1,150	50	250	700	56,700	29,350	550	29,900	12,550	800	13,350	600	450	1,050
47	50,350	1,150	50	250	1,150	52,950	17,150	550	17,700	2,900	800	3,700	600	450	1,050
48	16,750	1,150	50	250	150	18,350	10,550	550	11,100	0	800	800	600	450	1,050
49	26,150	1,150	50	250	400	28,000	8,350	550	8,900	0	800	800	600	450	1,050
50	15,550	1,150	50	250	250	17,250	7,650	550	8,200	0	800	800	600	250	1,050
1950-51	4,350	1,150	50	250	0	5,800	7,200	550	7,750	0	800	800	600	450	1,050
52	106,450	1,150	50	250	2,150	110,050	35,200	550	35,750	12,550	800	13,350	600	450	1,050
53	13,000	1,150	50	250	100	14,550	7,850	550	8,400	0	800	800	600	450	1,050
54	57,400	1,150	50	250	850	59,700	13,500	550	14,050	0	800	800	600	450	1,050
55	21,050	1,150	50	250	200	22,700	8,150	550	8,700	0	800	800	600	450	1,050
1955-56	19,100	1,150	50	250	100	20,650	7,750	550	8,300	0	800	800	600	450	1,050
57	23,750	1,150	50	250	150	25,350	7,100	550	7,650	0	800	800	600	450	1,050
58	151,950	1,150	50	250	2,200	155,600	54,150	550	54,700	20,050	800	20,850	600	450	1,050
59	20,850	1,150	50	250	200	22,500	6,800	550	7,350	0	800	800	600	450	1,050
60	8,750	1,150	50	250	0	10,200	6,350	550	6,900	0	800	800	600	450	1,050
1960-61	4,500	1,150	50	250	0	5,950	6,300	550	6,850	0	800	800	600	450	1,050
25-year average	61,980	1,150	50	250	1,000	64,430	35,500	550	36,050	21,442	800	22,242	600	450	1,050

Estimated average annual inflow to: Harper Basin -- 550 acre-feet. (desert mountains)
Coyote Basin -- 450 acre-feet. (desert mountains)
Caves Basin -- 12,350 acre-feet. (12,200 acre-feet from Mojave River; 150 acre-feet from desert mountains)

Subsurface Flow

Primarily, ground water movement within the study area occurs parallel and adjacent to the Mojave River in a south to north direction. Minor subsurface movement occurs in alluvium adjacent to the hills and mountains. The prevailing ground water gradients generally conform to the regional slope of the land surface; however, in portions of the study area, the gradients are reversed. This reversed gradient is caused by pumping from ground water in storage.

Ground water can move across the boundaries of the basins within the study area and its subdivisions when the permeability of the subsurface materials, the hydraulic gradient, and the cross-sectional area are sufficient for movement to occur and provided there is no subsurface barrier. At some of the boundaries, data on the permeability, hydraulic gradient, and cross-sectional area were not available for computing the amount of subsurface flow. However, it is believed the limited extent of alluvial materials at these boundaries prohibits the movement of significant quantities of water.

There is no subsurface outflow from the study area. However, subsurface inflow into the study area apparently occurs at the southwest boundary of the study area, which is also the west boundary of the Upper Mojave Basin. Because information on the depth and nature of the alluvial materials and the hydraulic gradient at this location is lacking, no direct determination of the amount of this flow was possible. However, on the basis of analysis of the natural recharge to the ground water basin west of the Upper Mojave Basin (primarily from Sheep Creek which is outside the study area), it appears reasonable that some ground water moves into the study area across this boundary. For this study, it was assumed that one-third of the estimated average seasonal runoff of Sheep Creek, less the average seasonal diversion to Phelan, percolated and moved easterly into the study area and the Upper Mojave Basin.

The amounts of underflow across the basin boundaries were determined from estimates of the factors in the equation, Q=TIW, which is based on Darcy's Law. In this equation, the subsurface flow (Q) is equal to the transmissibility (permeability times saturated aquifer depth) (T) of the subsurface materials, multiplied by the width of the cross-sectional area (W) through which the flow passes, and the slope, or the hydraulic gradient, (I) of the ground water at the cross-sectional area.

The estimates of underflow for each of the selected boundaries are listed in Table 13.

TABLE 13

ESTIMATED AVERAGE ANNUAL SUBSURFACE INFLOW

In acre-feet

Basin	Average annual amount during the base period	
Upper Mojave from:		
West Boundary	850	
Lucerne	100	
TOTAL		950
Middle Mojave from Upper Mojave		2,000
Lower Mojave from Middle Mojave		2,000
Harper from Middle Mojave		1,000
Coyote from Lower Mojave		1,000
Caves from Lower Mojave		1,000

Import-Export of Water

A small amount of water is imported from outside the study area to the town of Phelan, in the Upper Mojave Basin. Some water supply, as well as sewage, crosses the boundary from the Middle to Lower Mojave Basins within the City of Barstow.

The water supply for Phelan is imported by pipeline from the Sheep Creek drainage area which is in the San Gabriel Mountains just outside the study area. Although the major purpose of the imported water is for urban and suburban use, a portion may overflow into another pipeline for agricultural use when there is no available storage in the tank.

Records of the amount of water imported are fragmentary until late 1963, when a meter was installed. From this recent information, the average annual amount of imported water to Phelan during the base period was estimated to be 250 acre-feet.

The boundary between the Middle and Lower Mojave Basins passes through the City of Barstow, which is supplied with water pumped from wells in the two basins. The water is distributed by the Southern California Water Company. Based on information on the amounts pumped and the demand by population in each basin, it was established that some of the water extracted in the Middle Mojave Basin is transported across the basin boundary to service areas in the Lower Mojave Basin. The estimate of the average annual amount of water supply transported across the basin boundary during the base period was 700 acre-feet.

A second source of water exported from the Middle Mojave Basin is sewage that originated from the City of Barstow and was transported across the boundary to a treatment plant in the Lower Mojave Basin. The smaller portion of the City is in the Middle Mojave Basin. The average annual amount of sewage exported from the basin is estimated to be 100 acre-feet. This estimate is based on the amount of applied water and its consumptive use, the population in the two basins, and the amount of flow through the treatment plant in 1961.

Table 14 summarizes the amounts of water imported to the Upper Mojave Basin from outside the study area and to the Lower Mojave Basin from Middle Mojave Basin.

TABLE 14

ESTIMATED AVERAGE ANNUAL AMOUNTS OF WATER IMPORTED TO THE UPPER AND LOWER MOJAVE BASINS

In acre-feet

Basin		Average annual amount during the base period
Upper Mojave		250
Lower Mojave from Middle Mojave:		
Water	(700)	
Sewage	(100)	
TOTAL		800

In Table 15 is shown the annual supply and the 25-year average annual supply from each source of supply to each of the four main basins: Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne. The estimated annual supply to each of the other three basins -- Harper, Coyote, and Caves -- is also indicated by footnote. Although there is insufficient hydrologic data available in these last three basins to make definite determinations of the amounts of water supply, estimates were made to provide an indication of existing conditions.

TABLE 15

ESTIMATED WATER SUPPLY DURING THE BASE PERIOD

In acre-feet

Water year	Upper Mojave Basin					Middle Mojave Basin				Lower Mojave Basin					Lucerne Basin		
	Precipi-tation*	Surface inflow	Subsur-face inflow	Imported water	Total	Precipi-tation*	Surface inflow	Subsur-face inflow	Total	Precipi-tation*	Surface inflow	Subsur-face inflow	Imported water	Total	Precipi-tation*	Surface inflow	Total
1936-37	8,600	173,500	950	250	183,300	1,250	125,750	2,000	129,000	900	104,700	2,000	800	108,400	150	1,050	1,200
38	6,850	224,050	950	250	232,100	1,350	159,700	2,000	163,050	950	138,900	2,000	800	142,650	150	1,050	1,200
39	4,800	42,550	950	250	48,550	1,500	17,800	2,000	21,300	1,250	1,350	2,000	800	5,400	150	1,050	1,200
40	4,000	33,050	950	250	38,250	1,350	15,900	2,000	19,250	950	800	2,000	800	4,550	150	1,050	1,200
1940-41	36,950	165,450	950	250	203,600	2,000	119,500	2,000	123,500	1,850	96,800	2,000	800	101,450	150	1,050	1,200
42	4,100	27,950	950	250	33,250	1,650	14,250	2,000	17,900	1,400	900	2,000	800	5,100	150	1,050	1,200
43	11,650	154,250	950	250	167,100	1,500	105,250	2,000	108,750	1,100	91,800	2,000	800	95,700	150	1,050	1,200
44	36,850	90,200	950	250	128,250	1,350	60,850	2,000	64,200	850	37,050	2,000	800	40,700	150	1,050	1,200
45	6,350	73,450	950	250	81,000	1,700	40,050	2,000	43,750	1,300	22,900	2,000	800	27,000	150	1,050	1,200
1945-46	4,250	56,700	950	250	62,150	1,150	29,900	2,000	33,050	450	13,350	2,000	800	16,600	150	1,050	1,200
47	4,850	52,950	950	250	59,000	1,250	17,700	2,000	20,950	500	3,700	2,000	800	7,000	350	1,050	1,400
48	4,800	18,350	950	250	24,350	1,500	11,100	2,000	14,600	700	800	2,000	800	4,300	550	1,050	1,600
49	6,150	28,000	950	250	35,350	2,050	8,900	2,000	12,950	1,450	800	2,000	800	5,050	700	1,050	1,750
50	4,550	17,250	950	250	23,000	2,050	8,200	2,000	12,250	1,300	800	2,000	800	4,900	850	1,050	1,900
1950-51	5,300	5,800	950	250	12,300	2,100	7,750	2,000	11,850	1,250	800	2,000	800	4,850	1,000	1,050	2,050
52	15,150	110,050	950	250	126,400	2,300	35,750	2,000	40,050	2,450	13,350	2,000	800	18,600	1,200	1,050	2,250
53	5,850	14,550	950	250	21,600	2,300	8,400	2,000	12,700	1,650	800	2,000	800	5,250	1,250	1,050	2,300
54	7,300	59,700	950	250	68,200	2,400	14,050	2,000	18,450	1,800	800	2,000	800	5,400	1,250	1,050	2,300
55	7,500	22,700	950	250	31,400	2,450	8,700	2,000	13,150	1,750	800	2,000	800	5,350	1,250	1,050	2,300
1955-56	5,300	20,650	950	250	27,150	2,350	8,300	2,000	12,650	1,500	800	2,000	800	5,100	1,300	1,050	2,350
57	5,250	25,350	950	250	31,800	2,000	7,650	2,000	11,650	900	800	2,000	800	4,500	1,300	1,050	2,350
58	11,900	155,600	950	250	168,700	2,850	54,700	2,000	59,550	2,050	20,850	2,000	800	25,700	1,250	1,050	2,300
59	4,500	22,500	950	250	28,200	2,250	7,350	2,000	11,600	1,050	800	2,000	800	4,650	1,250	1,050	2,300
60	4,900	10,200	950	250	16,300	2,500	6,900	2,000	11,400	1,400	800	2,000	800	5,000	1,200	1,050	2,250
1960-61	4,700	5,950	950	250	11,850	2,250	6,850	2,000	11,100	1,050	800	2,000	800	4,650	1,150	1,050	2,200
25-year average	8,896	64,430	950	250	74,526	1,896	36,050	2,000	39,946	1,272	22,242	2,000	800	26,314	694	1,050	1,744

Estimated average annual supply to: Harper Basin -- 1,550 acre-feet.
Coyote Basin -- 1,450 acre-feet.
Caves Basin -- 13,350 acre-feet.

*The amount of precipitation on the basin consumptively used by native vegetation is not included.

Water Use and Disposal

The use and disposal of water during the base period, 1936-37 through 1960-61, are discussed here under the headings of surface outflow, subsurface outflow, exported water, and consumptive use.

The figures shown below for surface outflow, subsurface outflow, and exported water were arrived at by the methods described in the previous section for determining the flows at basin boundaries within the study area.

Surface Outflow

Surface outflow from the study area takes place only at the northeast boundary near Afton. The average annual amount of surface outflow during the base period was estimated to be 9,600 acre-feet.

Amounts of average annual surface outflow from each of the basins within the study area during the 25-year base period are given below.

Basins	Average annual surface outflow in acre-feet
Upper Mojave to Middle Mojave	35,500
Middle Mojave to Lower Mojave	21,450
Lower Mojave to Caves	12,200

There is no surface outflow from the Lucerne Basin.

Subsurface Outflow

There is no subsurface outflow from the study area. The amount of average annual subsurface outflow from basins during the 25-year base period was:

Basins	Average annual subsurface outflow in acre-feet
Upper Mojave to Middle Mojave	2,000
Middle Mojave to Lower Mojave	2,000
Middle Mojave to Harper	1,000
Lower Mojave to Caves	1,000
Lower Mojave to Coyote	1,000

Exported Water

The only export of water is from the Middle Mojave Basin to the Lower Mojave Basin, an estimated average annual amount of 700 acre-feet.

Consumptive Use

Water is consumptively used by vegetation and by man and his associated activities. Water is consumed by vegetation through the transpiration processes and building of plant tissues and by evaporation from the soil, from free water surfaces, and from foliage. Water consumptively used by man and his activities includes water used for agriculture, domestic uses, industrial purposes, and water evaporated by urban and nonvegetative types of land use. Water for consumptive use is obtained from natural sources and from man-made facilities.

Applied water from man-made sources meets the consumptive use requirements not supplied through natural sources and is usually in excess of the consumptive use requirements. The portion of the applied water that is not consumed replenishes the basin by becoming ground water through deep percolation.

In the following discussion of beneficial and nonbeneficial uses of water in the study area, the land use data was obtained from a comprehensive survey of the Mojave River region, conducted by the Department of Water Resources in 1961. The results of this survey are shown on Plate 5, "Land Use, 1961".

The three kinds of plant growth in the study area are: native vegetation, which covers much of the desert; riparian native vegetation, which grows in and near streams; and agricultural crops. Consumptive use of both precipitation and ground water by agriculture is a beneficial use. In addition, consumptive use of water by man in urban or suburban developments and industry is a beneficial use. Consumption of precipitation by native vegetation and consumption of both precipitation and ground water by riparian native vegetation are nonbeneficial uses.

The studies of beneficial consumptive use include determining the total amount of water used by the various crops and the amounts of water used by the population of the study area and its associated commerce and industry.

Agriculture. Estimates of consumptive use of precipitation and applied water by agriculture during the base period were based on the mean annual unit consumptive use values and acreages of the various types of crops. The unit use values for the Mojave River region are presented in State Water Resources Board Bulletin No. 2, "Water Utilization and Requirements of California", 1955. These unit use values are derived by the "Blaney-Criddle Method". Briefly, this method uses an empirical consumptive use coefficient, the average monthly temperature, the monthly percent of daylight hours, and the length of growing season to arrive at the unit use values.

In applying these unit use values to the base period, the values were modified to reflect the average monthly temperature in the Upper Mojave Basin as recorded at the climatological station at Victorville, and the temperature in the Middle and Lower Mojave Basins based on temperature data at the station at Barstow. The modified, or average, annual unit consumptive use values of precipitation and applied water for various types of crops are shown in Table 16.

As shown in Table 16, the amount of precipitation consumptively used by crops is equal to the small amount of precipitation that occurs during the nongrowing season. This is based on precipitation observed at stations in Victorville and Barstow. These records confirm that the average annual precipitation during the nongrowing season is too small to permit runoff from the tilled area. This amount of rainfall is also well within the moisture-holding capacity of the soil, where it is retained until the growing season. During the growing season, this water is consumptively used; thus, the moisture-holding capacity of the soil was assumed to be depleted at the beginning of the water year.

A description of the various classifications of crops used in this study is presented in Appendix C. These groupings are similar to those used in State Water Resources Board Bulletin No. 2.

TABLE 16

ESTIMATED AVERAGE SEASONAL UNIT CONSUMPTIVE USE VALUES FOR AGRICULTURAL CROPS DURING THE BASE PERIOD

In acre-feet per acre

Agricultural crop	Unit consumptive use values					
	Upper Mojave and Lucerne Basins			Middle and Lower Mojave Basin		
	Precipitation	Ground water*	Total	Precipitation	Ground water*	Total
Alfalfa	0.5	3.0	3.5	0.4	3.3	3.7
Pasture	0.5	2.8	3.3	0.4	3.1	3.5
Truck crops	0.5	1.6	2.1	0.4	1.7	2.1
Field crops	0.5	1.6	2.1	0.4	1.7	2.1
Deciduous fruits and nuts	0.5	2.3	2.8	0.4	2.5	2.9
Small grains	0.5	1.0	1.5	0.4	1.2	1.6
Vineyards	0.5	2.5	3.0	0.4	2.7	3.1

*Pumped ground water that is applied to crops.

The total acreage and the acreages of the various types of crops in the study area were obtained from federal, state, and county land and water use surveys. These included Department of Water Resources surveys in 1929, 1950, 1957, and 1961, a United States Bureau of Reclamation survey in 1946, and United States Bureau of Census surveys in 1934, 1939, and 1949. County crop reports for the Mojave Desert portion of the San Bernardino County were also available for 15 years of the base period, beginning with 1946.

The data for only two of the surveys -- those conducted by the Department in 1957 and 1961 -- included acreages of all the various crops in each basin. Data from the balance of the surveys are of lesser detail, and crop acreage by basin was partially estimated. Based on the data from these surveys, the total acreage and the acreage of the various types of crops in each basin during each year of the base period were determined. Total acreage for each was interpolated from a curve of the plotted data that shows the variation of the acreage of agriculture from 1929 through 1961. Acreages of the various types of crops were assumed to follow the percentage distribution of the three distinct periods of agricultural development in the study area, for which data on the types of crops are available. The three distinct periods of agricultural development are from 1936-37 to 1946-47, 1946-47 to 1959-60, and 1959-60 to end of the base period 1960-61. The estimated land use in 1961 in each basin is shown in Table 17.

TABLE 17

ESTIMATED LAND USE IN THE BASINS IN 1961

In acres

Nature and class of land use[a]	Mojave Basins			Lucerne Basin	Harper Basin	Coyote Basin	Caves Basin
	Upper	Middle	Lower				
WATER SERVICE AREA							
Urban and Suburban							
Residential	5,850	800	1,200	b	0	0	0
Recreational residential	3,250	0	0	b	0	0	0
Commercial	550	100	250	b	0	0	0
Industrial	100	0	50	b	0	0	0
Unsegregated urban and suburban area	1,850	700	650	b	150	0	50
Subtotal	11,600	1,600	2,100	b	150	0	50
Included Nonwater Service Area	29,050	2,550	3,200	b	250	0	0
Gross Urban and Suburban Area	40,650	4,150	5,300	b	400	0	50
Irrigated Agriculture							
Alfalfa	4,050	3,100	1,750	850[c]	300	400	650
Pasture	1,300	900	300	800[c]	200	0	0
Truck crops	200	0	0	0[c]	0	0	0
Field crops	400	200	150	0[c]	0	50	0
Deciduous fruits and nuts	50	0	150	0	0	0	0
Small grains	900	1,350	50	300[c]	0	0	0
Subtotal	6,900	5,550	2,400	1,950[c]	500	450	650
Fallow	150	50	0	0[c]	50	0	0
Included Nonwater Service Area	350	300	100	100[c]	50	50	50
Gross Irrigated Agriculture	7,400	5,900	2,500	2,050[c]	600	500	700

a. Described in Appendix C.
b. Data not available.
c. Estimated.

Estimates of the annual and average annual amounts of consumptive use of precipitation and applied water during the base period for the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins are presented in Table 18.

TABLE 18

CONSUMPTIVE USE OF WATER BY AGRICULTURE DURING THE BASE PERIOD

In acre-feet

Water year	Upper Mojave Basin			Middle Mojave Basin			Lower Mojave Basin			Lucerne Basin		
	Precipi-tation	Ground water*	Total	Precipi-tation	Ground water*	Total	Precipi-tation	Ground water*	Total	Precipi-tation	Ground water*	Total
1936-37	1,950	9,300	11,250	750	5,200	5,950	150	1,050	1,200	150	900	1,050
38	1,950	9,250	11,200	750	5,200	5,950	150	1,050	1,200	150	900	1,050
39	1,950	9,250	11,200	750	5,150	5,900	150	1,050	1,200	150	900	1,050
40	2,000	9,450	11,450	750	5,300	6,050	150	1,100	1,250	150	900	1,050
1940-41	2,050	9,750	11,800	800	5,450	6,250	150	1,100	1,250	150	900	1,050
42	2,150	10,100	12,250	800	5,600	6,400	150	1,150	1,300	150	900	1,050
43	2,200	10,400	12,600	850	5,800	6,650	150	1,200	1,350	150	900	1,050
44	2,300	10,750	13,050	850	6,000	6,850	150	1,250	1,400	150	900	1,050
45	2,400	11,300	13,700	900	6,300	7,200	200	1,300	1,500	150	900	1,050
1945-46	2,500	11,850	14,350	950	6,600	7,550	200	1,350	1,550	150	900	1,050
47	2,800	14,200	17,000	1,150	8,400	9,550	350	2,700	3,050	350	1,800	2,150
48	3,050	15,550	18,600	1,350	9,950	11,300	550	4,100	4,650	550	2,700	3,250
49	3,300	16,750	20,050	1,550	11,500	13,050	750	5,450	6,200	700	3,600	4,300
50	3,550	18,150	21,700	1,750	12,900	14,650	900	6,900	7,800	850	4,500	5,350
1950-51	3,800	19,450	23,250	1,950	14,450	16,400	1,100	8,200	9,300	1,000	5,400	6,400
52	4,050	20,750	24,800	1,950	14,300	16,250	1,250	9,600	10,850	1,200	6,300	7,500
53	3,950	20,150	24,100	1,950	14,300	16,250	1,200	9,200	10,400	1,250	6,550	7,800
54	3,800	19,500	23,300	1,900	14,150	16,050	1,100	8,300	9,400	1,250	6,600	7,850
55	3,700	19,850	23,550	1,900	14,150	16,050	950	7,350	8,300	1,250	6,750	8,000
1955-56	3,600	19,350	22,950	1,900	14,000	15,900	850	6,450	7,300	1,300	6,800	8,100
57	3,550	18,850	22,400	1,850	13,750	15,600	700	5,450	6,150	1,300	6,900	8,200
58	3,500	18,750	22,250	1,950	14,450	16,400	750	5,600	6,350	1,250	6,750	8,000
59	3,500	18,750	22,250	2,050	15,100	17,150	800	6,100	6,900	1,250	6,550	7,800
60	3,500	18,200	21,700	2,150	14,300	16,450	900	6,650	7,550	1,200	6,300	7,500
1960-61	3,500	18,200	21,700	2,200	14,950	17,150	950	7,200	8,150	1,150	6,150	7,300
25-year average	2,984	15,114	18,098	1,428	10,290	11,718	588	4,434	5,022	694	3,706	4,400

Estimated (1961 land use conditions):

	Precipitation	Ground water	Total
Harper Basin	200	1,600	1,800 acre-feet
Coyote Basin	200	1,400	1,600 acre-feet
Caves Basin	250	2,150	2,400 acre-feet

*Pumped ground water that is applied to crops.

Urban-Suburban and Industry. In the study area, because of the lack of historic urban and suburban land use surveys and the minor amounts of heavy industry in the basins, it was appropriate to estimate urban-suburban water use on the basis of a per capita use of water and population data.

The population of the study area is concentrated in the four major basins. Estimates of population in these basins from 1930 through 1960 are presented in Table 19 and are based on federal census surveys of 1950 and 1960, supplemented by information from earlier state reports. Detailed estimates of the population of the other three basins, Harper, Caves, and Coyote, are not available; however, they are sparsely settled areas and constitute approximately 2 percent of the total study area population.

TABLE 19

ESTIMATED POPULATION
1930 TO 1960

Year	Population				
	Mojave Basin			Lucerne Basin	Total
	Upper	Middle	Lower		
1930	2,650	2,300	1,100	150	6,200
40	3,250	1,550	3,800	200	8,800
50	8,400	4,100	9,750	450	22,700
60	25,000	8,100	18,300	1,600	53,000

The amount of applied, or delivered, water that is consumptively used by the population in the study area was determined from data in Department of Water Resources Bulletin No. 78, "Investigation of Alternative Aqueduct Systems to Serve Southern California", Appendix D, "Economic Demand for Imported Water", 1960. Based on information in the report, the average per capita applied water in the study area was estimated to have increased from about 130 gallons per capita per day at the start of the base period (1936-37) to 200 gallons per capita per day at the end (1960-61). The information in the report was also the basis for the assumption that 50 percent of the applied water is consumptively used.

The annual and average annual amounts of consumptive use of water during the base period by urban and suburban areas in the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins are presented in Table 20.

Industrial use of water in the study area is by a railway maintenance yard, a steam power generating plant, and three cement plants.

TABLE 20

CONSUMPTIVE USE OF WATER BY URBAN AND SUBURBAN AREAS DURING THE BASE PERIOD

In acre-feet

Water year	Mojave River			Lucerne Basin
	Upper	Middle	Lower	
1936-37	200	100	250	--
38	200	100	250	--
39	250	100	250	--
40	250	100	300	50[a]
1940-41	300	150	350	--
42	350	150	400	--
43	400	200	450	--
44	450	200	500	--
45	500	250	550	100[b]
1945-46	550	250	650	--
47	600	300	700	--
48	650	300	750	--
49	700	350	850	--
50	800	400	900	200[b]
1950-51	850	400	950	50
52	950	450	1,050	50
53	1,050	450	1,100	50
54	1,150	500	1,150	50
55	1,250	500	1,200	100
1955-56	1,400	550	1,200	100
57	1,500	550	1,250	100
58	1,850	600	1,500	100
59	2,300	750	1,750	150
60	2,750	900	2,000	200
1960-61	2,950	900	2,050	200
25-year average	968	384	894	60

a. Four-year total.
b. Five-year total.

Water consumption by these industries was computed from records of metered pumping of wells and records of the amounts used in the industrial process. Where these records were not complete, additional data on water purchases and plant production (computed in terms of use of water per product) were also used for estimating the water consumption. Table 21 shows the amounts of consumptive use of water by industry.

Nonbeneficial Consumptive Use

Throughout most of the undeveloped portions of the study area, the consumptive use of water by native vegetation is assumed equal to the precipitation. However, vegetation along the banks of the Mojave River derives only a small part of its water supply from precipitation, but consumes large quantities of ground water that might be beneficially used by man if the vegetation were eliminated and controlled. Estimates of nonbeneficial consumptive use of water by this riparian native vegetation were based on the "Blaney-Criddle Method" applied to the acreages of the four classifications of riparian native vegetation considered in this study. These classifications are based on the Department's 1961 land use survey modified by field correlation. The classifications provide a direct means of determining an individual consumptive use value for each type of riparian native vegetation, as shown in Table 22.

As shown in Table 23, the acreages of riparian native vegetation were classified according to areal (surface) density and kind of plants, taking into account the areas of high ground water and minor areas of free water surfaces. The amounts in each basin were determined from aerial photos of the Mojave River area taken in 1929, 1939, and 1959.

TABLE 21

CONSUMPTIVE USE OF WATER BY INDUSTRY
DURING THE BASE PERIOD

In acre-feet

Water Year	Upper Mojave Basin	Lower Mojave Basin	Lucerne Basin
1936-37	250	200	0
38	200	200	0
39	200	200	0
40	200	200	0
1940-41	300	200	0
42	350	200	0
43	250	200	0
44	250	200	0
45	250	200	0
1945-46	350	200	0
47	350	200	0
48	350	200	0
49	350	200	0
50	450	200	0
1950-51	500	200	0
52	550	200	0
53	550	200	0
54	650	200	0
55	1,250	200	0
1955-56	1,450	200	0
57	1,500	200	250
58	1,450	200	400
59	1,450	200	400
60	1,300	200	450
1960-61	1,400	700	500
25-year average	646	220	80

The 1929 photos were used for coverage along the river from the forks to the Lower Narrows near Victorville where 1939 photos were not available. The 1959 survey was considered to approximate conditions in 1961, the end of the base period for this study.

TABLE 22

AVERAGE ANNUAL UNIT CONSUMPTIVE USE VALUE OF
RIPARIAN NATIVE VEGATATION

In acre-feet per acre

Classification of riparian native vegetation	Unit consumptive use value					
	Upper Mojave Basin			Middle and Lower Mojave Basin		
	Precipitation	Ground water	Total	Precipitation	Ground water	Total
Trees, 80 percent areal density or greater	0.4	4.7	5.1	0.3	5.1	5.4
Trees, 79 percent areal density or less	0.4	4.2	4.6	0.3	4.6	4.9
Brush and meadowland	0.4	2.9	3.3	0.3	3.2	3.5
Swamp	0.4	6.8	7.2	0.3	7.3	7.6

Table 23 shows the classifications of riparian native vegetation and the acreages of each in the Upper, Middle, and Lower Mojave Basins in 1960-61.

TABLE 23

AREAS DEVOTED TO
RIPARIAN NATIVE VEGETATION IN 1960-61

In acres

Classification of riparian native vegetation	Mojave Basin		
	Upper	Middle	Lower
Trees, 80 percent areal density or greater	1,790	170	1,010
Trees, 79 percent areal density or less	1,350	1,110	680
Brush and meadowland	1,320	70	180
Swamp	600	0	0

Utilizing the Blaney-Criddle method and the estimated acreage and assigned consumptive use coefficient for each classification of riparian native vegetation, the unit water use values and the amounts of consumptive use were determined for each year of the base period.

The annual and average annual amounts of consumptive use of precipitation and ground water by riparian native vegetation in the Upper, Middle, and Lower Mojave Basins during the base period, is shown on Table 24.

Estimated amounts of water use and disposal during the base period are presented in Table 25 for each of the main basins: Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne. Estimates for the other three basins -- Harper, Coyote, and Caves -- are also indicated by footnote.

TABLE 24

CONSUMPTIVE USE OF WATER BY RIPARIAN NATIVE VEGETATION DURING THE BASE PERIOD

In acre-feet

Water year	Upper Mojave Basin			Middle Mojave Basin			Lower Mojave Basin		
	Precipitation	Ground water	Total	Precipitation	Ground water	Total	Precipitation	Ground water	Total
1936-37	3,100	20,450	23,550	500	7,300	7,800	750	11,250	12,000
38	2,900	20,850	23,750	600	7,300	7,900	800	11,200	12,000
39	2,500	21,500	24,000	750	7,200	7,950	1,100	10,900	12,000
40	2,000	22,200	24,200	600	7,400	8,000	800	11,200	12,000
1940-41	4,750	19,650	24,400	1,200	6,850	8,050	1,700	10,300	12,000
42	1,950	22,650	24,600	850	7,250	8,100	1,250	10,750	12,000
43	3,850	20,950	24,800	650	7,500	8,150	950	11,050	12,000
44	4,000	19,700	23,700	500	7,550	8,050	700	11,050	11,750
45	2,950	21,800	24,750	800	7,650	8,450	1,100	11,100	12,200
1945-46	1,750	23,350	25,100	200	8,550	8,750	250	12,300	12,550
47	2,050	23,100	25,150	100	8,500	8,600	150	12,100	12,250
48	1,750	22,600	24,350	150	8,050	8,200	150	11,500	11,650
49	2,850	21,500	24,350	500	7,400	7,900	700	10,450	11,150
50	1,000	24,100	25,100	300	7,850	8,150	400	11,250	11,650
1950-51	1,500	23,950	25,450	150	8,000	8,150	150	11,450	11,600
52	3,650	20,750	24,400	350	7,400	7,750	1,200	9,850	11,050
53	1,900	22,600	24,500	350	7,300	7,650	450	10,500	10,950
54	2,050	22,750	24,800	500	7,150	7,650	700	10,300	11,000
55	3,800	20,250	24,050	550	6,750	7,300	800	9,700	10,500
1955-56	1,700	22,750	24,450	450	6,800	7,250	650	9,800	10,450
57	1,700	23,200	24,900	150	7,000	7,150	200	10,100	10,300
58	3,000	21,250	24,250	900	6,100	7,000	1,300	8,800	10,100
59	1,000	23,950	24,950	200	6,850	7,050	250	9,950	10,200
60	1,400	23,500	24,900	350	6,550	6,900	500	9,450	9,950
1960-61	1,200	23,150	24,350	50	6,700	6,750	100	9,600	9,700
25-year average	2,412	22,100	24,512	468	7,318	7,786	684	10,636	11,320

Estimated (1961 land use conditions):	Precipitation	Ground water	Total
Caves Basin	negligible	1,150	1,150 acre-feet

TABLE 25

ESTIMATED WATER USE AND DISPOSAL DURING THE BASE PERIOD

In acre-feet

Water year	Upper Mojave Basin				Middle Mojave Basin					Lower Mojave Basin				Lucerne Basin		
	Surface outflow	Subsurface outflow[a]	Consumptive use	Total	Surface outflow	Subsurface outflow[a]	Exported water	Consumptive use	Total	Surface outflow	Subsurface outflow[a]	Consumptive use	Total	Subsurface outflow[a]	Consumptive use	Total
1936-37	125,200	2,000	35,250	162,450	103,900	3,000	800	13,850	121,550	54,950	2,000	13,650	70,600	100	1,050	1,150
38	159,150	2,000	35,350	196,500	138,100	3,000	800	13,950	155,850	109,050	2,000	13,650	124,700	100	1,050	1,150
39	17,250	2,000	35,650	54,900	550	3,000	800	13,950	18,300	1,050	2,000	13,650	16,700	100	1,050	1,150
40	15,350	2,000	36,100	53,450	0	3,000	800	14,150	17,950	1,050	2,000	13,750	16,800	100	1,100	1,200
1940-41	118,950	2,000	36,800	157,750	96,000	3,000	800	14,450	114,250	50,550	2,000	13,800	66,350	100	1,050	1,150
42	13,700	2,000	37,550	53,250	100	3,000	800	14,650	18,550	1,050	2,000	13,900	16,950	100	1,050	1,150
43	104,700	2,000	38,050	144,750	91,000	3,000	800	15,000	109,800	48,050	2,000	14,000	64,050	100	1,050	1,150
44	60,300	2,000	37,450	99,750	36,250	3,000	800	15,100	55,150	8,800	2,000	13,850	24,650	100	1,050	1,150
45	39,500	2,000	39,200	80,700	22,100	3,000	800	15,900	41,800	5,650	2,000	14,450	22,100	100	1,150	1,250
1945-46	29,350	2,000	40,350	71,700	12,550	3,000	800	16,550	32,900	3,600	2,000	14,950	20,550	100	1,050	1,150
47	17,150	2,000	43,100	62,250	2,900	3,000	800	18,450	25,150	1,950	2,000	16,200	20,150	100	2,150	2,250
48	10,550	2,000	43,950	56,500	0	3,000	800	19,800	23,600	1,050	2,000	17,250	20,300	100	3,250	3,350
49	8,350	2,000	45,450	55,800	0	3,000	800	21,300	25,100	1,050	2,000	18,400	21,450	100	4,300	4,400
50	7,650	2,000	48,050	57,700	0	3,000	800	23,200	27,000	1,050	2,000	20,550	23,600	100	5,550	5,650
1950-51	7,200	2,000	50,050	59,250	0	3,000	800	24,950	28,750	1,050	2,000	22,050	25,100	100	6,450	6,550
52	35,200	2,000	50,700	87,900	12,550	3,000	800	24,450	40,800	3,600	2,000	23,150	28,750	100	7,550	7,650
53	7,850	2,000	50,200	60,050	0	3,000	800	24,350	28,150	1,000	2,000	22,650	25,650	100	7,850	7,950
54	13,500	2,000	49,900	65,400	0	3,000	800	24,200	28,000	950	2,000	21,750	24,700	100	7,900	8,000
55	8,150	2,000	50,100	60,250	0	3,000	800	23,850	27,650	900	2,000	20,200	23,100	100	8,100	8,200
1955-56	7,750	2,000	50,250	60,000	0	3,000	800	23,700	27,500	900	2,000	19,150	22,050	100	8,200	8,300
57	7,100	2,000	50,300	59,400	0	3,000	800	23,300	27,100	750	2,000	17,900	20,650	100	8,550	8,650
58	54,150	2,000	49,800	105,950	20,050	3,000	800	24,000	47,850	4,900	2,000	18,150	25,050	100	8,500	8,600
59	6,800	2,000	50,950	59,750	0	3,000	800	24,950	28,750	600	2,000	19,050	21,650	100	8,350	8,450
60	6,350	2,000	50,650	59,000	0	3,000	800	24,250	28,050	700	2,000	19,700	22,400	100	8,150	8,250
1960-61	6,300	2,000	50,400	58,700	0	3,000	800	24,800	28,600	650	2,000	20,600	23,250	100	8,000	8,100
25-year average	35,500	2,000	44,224	81,724	21,442	3,000	800	19,884	45,126	12,196	2,000	17,456	31,652	100	4,540	4,640

a. Estimated average annual outflow.

Estimated total use and disposal:

Harper Basin 1,800 acre-feet -- 1961 land use conditions.
Coyote Basin 1,600 acre-feet -- 1961 land use conditions.
Caves Basin 13,150 acre-feet (3,550 acre-feet -- 1961 land use conditions and 9,600 acre-feet, estimated average annual surface outflow at Afton)

Water Supply Surplus or Deficiency

A balance must exist between the sum of water entering and leaving the water-bearing portion of the study area and change in storage within that portion. A quantitative statement of this balance for any increment of time is provided by the equation of hydrologic equilibrium which, expressed in its general form, is:

Inflow-Outflow = $\pm$ Change in Storage.

In this report, the water-bearing area, from the base of the alluvium to and including the ground surface, is considered as the free body, as shown in Figure 6, and the equation of hydrologic equilibrium is expressed as:

Water Supply - Water Use and Disposal =
Water Supply Surplus or Deficiency.

Based on the water year as the increment of time, the annual water supply surplus or deficiency for each year of the 25-year base period was determined, using this equation.

In each of the four main basins, Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins, the total water supply during the base period was less than the total water use and disposal. In each basin, this resulted in a water supply deficiency which was met by using ground water in storage.

The amount of annual water supply, annual water use and disposal, and the resulting annual and accumulated deficiency during the base period for each basin is presented in Table 26. The accumulated deficiencies -- 179,950 acre-feet, 129,500 acre-feet, 133,450 acre-feet, and 72,400 acre-feet for the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins -- represent the reduction in ground water in storage during the base period in each of these basins. The total water supply, use and disposal, and deficiency is shown in the following tabulation:

Basin	In acre-feet		
	Water Supply	Water Use and Disposal	Deficiency
Upper Mojave Basin	1,863,150	2,043,100	179,950
Middle Mojave Basin	998,650	1,128,150	129,500
Lower Mojave Basin	657,850	791,300	133,450
Lucerne Basin	43,600	116,000	72,400
Totals	3,563,250	4,078,550	515,300

Due to lack of complete data, it is not possible to compute comparable water supply, use and disposal amounts for the other three basins -- Harper, Coyote, and Caves. However, it is apparent from the limited information available that a water deficiency also existed in these basins during the base period, and that future development of these areas will require supplemental water.

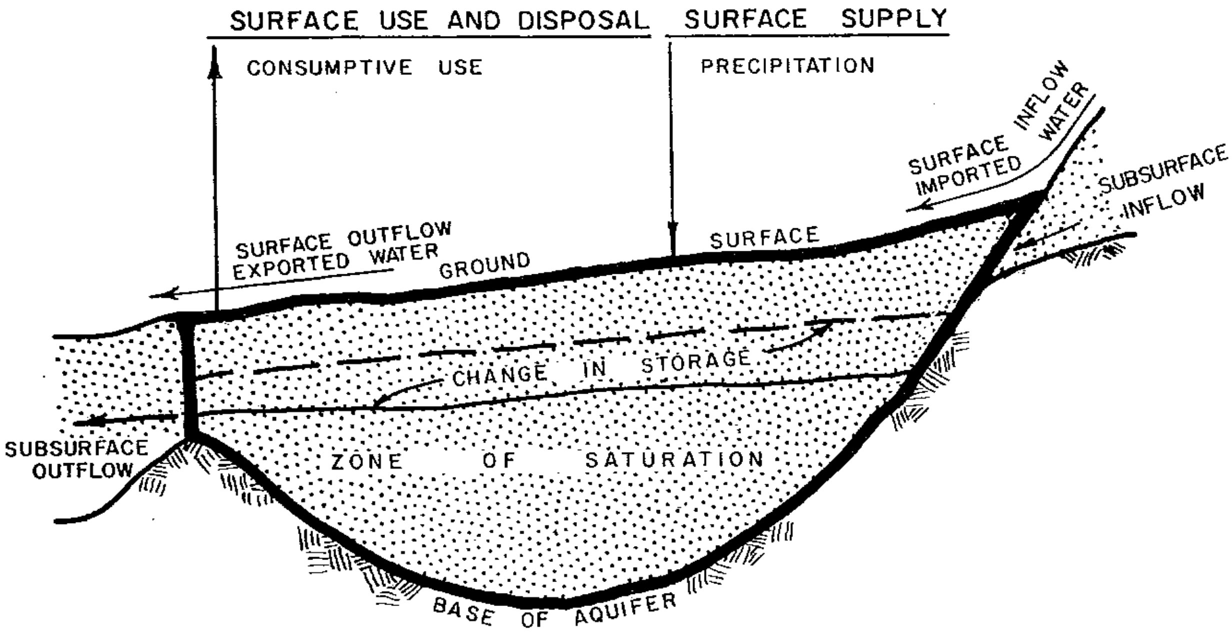

Fig. 6. THE GROUND WATER BASIN AS A FREE BODY

TABLE 26

ESTIMATED WATER SUPPLY, USE AND DISPOSAL, AND WATER SUPPLY SURPLUS OR DEFICIENCY DURING THE BASE PERIOD

In acre-feet

Water year	Upper Mojave Basin				Middle Mojave Basin				Lower Mojave Basin				Lucerne Basin			
	Water supply	Water use and disposal	Surplus or deficiency		Water supply	Water use and disposal	Surplus or deficiency		Water supply	Water use and disposal	Surplus or deficiency		Water supply	Water use and disposal	Surplus or deficiency	
			Annual	Accumulated			Annual	Accumulated			Annual	Accumulated			Annual	Accumulated
1936-37	183,300	162,450	20,850	20,850	129,000	121,550	7,450	7,450	108,400	70,600	37,800	37,800	1,200	1,150	50	50
38	232,100	196,500	35,600	56,450	163,050	155,850	7,200	14,650	142,650	124,700	17,950	55,750	1,200	1,150	50	100
39	48,550	54,900	- 6,350	50,100	21,300	18,300	3,000	17,650	5,400	16,700	-11,300	44,450	1,200	1,150	50	150
40	38,250	53,450	-15,200	34,900	19,250	17,950	1,300	18,950	4,550	16,800	-12,250	32,200	1,200	1,200		150
1940-41	203,600	157,750	45,850	80,750	123,500	114,250	9,250	28,200	101,450	66,350	35,100	67,300	1,200	1,150	50	200
42	133,250	53,250	-20,000	60,750	17,900	18,550	- 650	27,550	5,100	16,950	-11,850	55,450	1,200	1,150	50	250
43	167,100	144,750	22,350	83,100	108,750	109,800	- 1,050	26,500	95,700	64,050	31,650	87,100	1,200	1,150	50	300
44	128,250	99,750	28,500	111,600	64,200	55,150	9,050	35,550	40,700	24,650	16,050	103,150	1,200	1,150	50	350
45	81,000	80,700	300	111,900	43,750	41,800	1,950	37,500	27,000	22,100	4,900	108,050	1,200	1,250	- 50	300
1945-46	62,150	71,700	- 9,550	102,350	33,050	32,900	150	37,650	16,600	20,550	- 3,950	104,100	1,200	1,150	50	350
47	59,000	62,250	- 3,250	99,100	20,950	25,150	- 4,200	33,450	7,000	20,150	-13,150	90,950	1,400	2,250	- 850	- 500
48	24,350	56,500	-32,150	66,950	14,600	23,600	- 9,000	24,450	4,300	20,300	-16,000	74,950	1,600	3,350	-1,750	- 2,250
49	35,350	55,800	-20,450	46,500	12,950	25,100	-12,150	12,300	5,050	21,450	-16,400	58,550	1,750	4,400	-2,650	- 4,900
50	23,000	57,700	-34,700	11,800	12,250	27,000	-14,750	- 2,450	4,900	23,600	-18,700	39,850	1,900	5,650	-3,750	- 8,650
1950-51	12,300	59,250	-46,950	- 35,150	11,850	28,750	-16,900	- 19,350	4,850	25,100	-20,250	19,600	2,050	6,550	-4,500	-13,150
52	126,400	87,900	38,500	3,350	40,050	40,800	- 750	- 20,100	18,600	28,750	-10,150	9,450	2,250	7,650	-5,400	-18,550
53	21,600	60,050	-38,450	- 35,100	12,700	28,150	-15,450	- 35,550	5,250	25,650	-20,400	- 10,950	2,300	7,950	-5,650	-24,200
54	68,200	65,400	2,800	- 32,300	18,450	28,000	- 9,550	- 45,100	5,400	24,700	-19,300	- 30,250	2,300	8,000	-5,700	-29,900
55	31,400	60,250	-28,850	- 61,150	13,150	27,650	-14,500	- 59,600	5,350	23,100	-17,750	- 48,000	2,300	8,200	-5,900	-35,800
1955-56	27,150	60,000	-32,850	- 94,000	12,650	27,500	-14,850	- 74,450	5,100	22,050	-16,950	- 64,950	2,350	8,300	-5,950	-41,750
57	31,800	59,400	-27,600	-121,600	11,650	27,100	-15,450	- 89,900	4,500	20,650	-16,150	- 81,100	2,350	8,650	-6,300	-48,050
58	168,700	105,950	62,750	- 58,850	59,550	47,850	11,700	- 78,200	25,700	25,050	650	- 80,450	2,300	8,600	-6,300	-54,350
59	28,200	59,750	-31,550	- 90,400	11,600	28,750	-17,150	- 95,350	4,650	21,650	-17,000	- 97,450	2,300	8,450	-6,150	-60,500
60	16,300	59,000	-42,700	-133,100	11,400	28,050	-16,650	-112,000	5,000	22,400	-17,400	-114,850	2,250	8,250	-6,000	-66,500
1960-61	11,850	58,700	-46,850	-179,950	11,100	28,600	-17,500	-129,500	4,650	23,250	-18,600	-133,450	2,200	8,100	-5,900	-72,400
25-year average	74,526	81,724			39,946	45,126			26,314	31,652			1,744	4,640		

CHAPTER IV. WATER QUALITY

Surface and ground waters contain dissolved minerals that vary in amount and composition. Surface water character is primarily dependent upon mineral composition of rocks within the upper source areas of a stream. As the stream proceeds to lower levels, the basic water character continues to be influenced by mineral characteristics of materials through which it flows and by secondary contributions of other water types from tributaries and rising ground water.

Concentrations of mineral constituents in ground water are influenced primarily by the quality and quantity of water which percolates to the ground water basin. The sources of this replenishment by percolation include surface flow, precipitation, sewage and industrial waste waters, and irrigation waters. Ground water quality is also influenced by the lithologic type and relative age of water-bearing materials; the hydrologic and geologic conditions that govern rates of ground water movement; well construction and destruction techniques; the season of the year; changes in water level elevations; and duration and rate of pumping prior to sampling of the ground water.

Regional and local correlation of the quality of extracted ground water is, therefore, dependent on the knowledge of geology, hydrology, well drilling practices, duration, and rates of ground water extractions and drawdowns, and water use. Such information is vital to the identification and comprehension of factors that produce water of dissimilar qualities from closely spaced wells, or water of similar quality from wells in widely separated regions within the study area.

In the vast and remote Mojave region, however, collection of adequate data is a major problem. Wells are scarce--in some areas, non-existent. There are few records of well construction or water production rates; for this reason, interpretation of conditions which produce waters of varying qualitites in the area can only be based on approximations.

From such records as are available, it is apparent that there is a wide variation in the mineral character and quality of ground water within the individual basins of the Mojave study area. The existence of marked differences of water quality in certain basins necessitated the grouping of individual water types into broader more general categories to facilitate description and discussion. This procedure resulted in the identification of some relatively consistent and distinct ground water quality characteristics within each basin. Moreover, these characteristics made it possible to identify those basin areas that were influenced by flows from the Mojave River and to locate restrictions to ground water movement.

As a general guide on the acceptability and use of various water supplies in the Mojave River region, water quality criteria are presented in Appendix D.

Sampling and Analyses

A regular water quality monitoring program in the area of investigation has been conducted by the Department since 1952 in cooperation with the San Bernardino County Flood Control District. Additional samples were taken during this investigation to confirm previous data. Samples

TABLE 27

MINERAL ANALYSES OF REPRESENTATIVE SURFACE WATERS

Constituent	Heath Canyon-tributary to Sheep Creek Sec.9 T3N/R7W		Mojave River: West Fork (floodflow) Sec.32 T3N/R4W		The Forks Sec.18 T3N/R3W		Victorville Sec.29 T6N/R4W		Helendale Sec.31 T8N/R4W		Barstow (floodflow) Sec.31 T10N/R1W		Barstow Sec.31 T10N/R1W		Harvard Crossing (floodflow) Sec.34 T10N/R3E		Afton Canyon Sec.18 T11N/R6E	
	epm[a]	ppm[b]	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm
Ca	2.37	47	1.00	20	1.05	21	2.15	43	2.30	46	1.24	25	1.63	33	2.19	44	1.20	24
Mg	0.47	6.0	0.41	5	0.33	4	0.75	9	0.74	9	0.44	5	0.34	4	0.77	9	0.30	4
Na	0.15	3.0	0.39	9	1.22	28	1.83	42	2.39	55	0.64	15	2.93	68	4.26	98	12.65	291
K	0.16	6.4	0.08	3	0.05	2	0.08	3	0.118	4.6	0.046	1.9	0.25	9.6	0.02	0.8	0.26	10.2
CO_3	0	0	0	0	0	0	0	0	0.32	10	0	0	0	0	0	0	0.80	24
HCO_3	1.45	88	1.19	73	1.69	103	3.18	194	3.24	198	1.30	79	3.48	212	4.59	280	6.60	403
Cl	0	0	0.17	6	0.37	13	0.79	28	0.87	31	0.28	10	0.73	26	1.30	46	4.65	165
SO_4	1.68	81	0.32	15	0.55	26	0.83	40	1.02	49	0.70	33.6	0.94	45	1.42	68	2.55	122
NO_3	0	0	0.13	8	0.02	1	0.05	3	0.029	1.8	0.03	1.63	0.04	1.54	0.032	2.0	0.09	5.6
F	0.02	0.4	0.02	0.4	0.09	1.8	0.03	0.6	0.041	0.78			0.021	0.40		0.16	0.04	0.8
Boron		0		0.07						0.145		0.20		0.40				1.12
Silica		4.0										26		5				64
TDS[c] by Evaporation	262		132		171		283		310		139		293		455		916	
Percent Na	48		21		46		38		43		27		57		59		88	
Total hardness	142		71		68		145		153		84		99		148		75	
Sampled by[d]	DWR		DWR		DWR		DWR		SBCFCD		DWR		DWR		SBCFCD		DWR	
Data sampled	3/28/63		4/2/65		2/5/65		2/5/65		2/4/64		4/4/58		8/28/58		3/27/58		10/25/61	
Discharge (cfs)	3		135		18		31				1500		40				1.5	
Temperature	45° F.		46° F.		50° F.		51° F.				50° F.						57° F.	
pH	7.5		7.2		7.6		8.0		8.1		7.6		7.1		7.6		8.5	
EC x 10^6	320		194		272		476		493		216		484		700		1520	

a. Chemical equivalents per million.
b. Parts per million by weight.
c. Total dissolved solids.
d. SBCFCD-San Bernardino County Flood Control District; DWR-Department of Water Resources

were also drawn from wells in areas not previously covered by the monitoring program. Another major source of water quality data was information compiled by the United States Geological Survey, and published by the Department of Water Resources in the Bulletin 91 series. In addition, useful information was obtained from the Department's Bulletin No. 106-1, "Ground Water, Occurrence and Quality, Lahontan Region", June 1964.

Representative analyses of surface water within the individual basins are presented in Table 27. Ground water analyses are presented in Table 28.

Mineral Character and Quality of Surface and Ground Water

The mineral character and quality of water in the study area depends upon the geologic composition of the study area, the movement and occurrence of surface and ground waters, and the use of these waters. Surface and ground waters exhibit several distinct types of mineral character and ranges of total dissolved solids.

Surface Water

Available mineral analyses depicting surface water character and quality within the study area are primarily confined to the flows of the Mojave River, the main source of water supply to the region. Average of all data shows that storm flow of the Mojave River is primarily calcium bicarbonate in character and has less than

TABLE 28

MINERAL ANALYSES OF REPRESENTATIVE GROUND WATERS FROM WELLS

Constituent	Lucerne Basin						Upper Mojave Basin						Middle Mojave Basin					
	South of Lucerne Lake 4N/1W-1P		Lucerne Valley 5N/1W-29R2		Near Fifteenmile Valley 4N/2W-20K1		Near Apple Valley 4N/3W-23D1		Apple Valley 5N/3W-33R1		Near Adelanto 6N/5W-9B1		Stoddard Valley 7N/1W-9E1		Near Helendale 8N/4W-30E1		Hinkley Valley 10N/3W-23H4	
	epm[a]	ppm[b]	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm
Ca	3.52	70	2.77	55	2.40	48	6.14	123	2.54	51	0.41	8.2	1.59	32	4.20	84	0.66	13
Mg	4.82	59	1.22	15	1.34	16	1.00	12	1.24	15	0.18	2.2	0.59	7.2	0.52	6.3	0.06	0.7
Na	2.05	47	27.43	631	1.87	43	8.44	194	2.83	65	5.00	115	1.95	45	10.43	240	5.20	120
K	0.06	2.3	0.10	4.0	0.06	2.5	0.14	5.4	0.06	2.4	0.02	0.8	0.05	1.9	0.09	3.5	0.03	1.3
CO_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HCO_3	2.50	152	3.20	195	2.36	144	0.66	40	2.35	143	2.83	173	2.28	139	2.81	172	4.50	274
SO_4	4.73	227	11.60	557	1.87	90	13.93	668	2.82	135	2.36	113	0.86	41	4.85	233	0.71	34
Cl	3.01	106	16.00	567	1.16	41	1.18	42	1.32	47	0.19	6.8	0.77	27	7.57	269	0.70	25
NO_3	0.39	24	0.16	10	0.06	3.8	0.02	1.2	0.06	3.6	0.02	1.3	0.12	7.3	0.01	0.5	0.02	1.4
F	0.01	0.2	0.20	4.0	0.13	2.4	0.17	3.3	0.04	0.8	0.06	1.2	0.06	1.2	0.02	0.4	0.08	1.6
Boron		0.08		1.2		0.09		1.90		0.46		0.27		0.20		0.52		1.62
Silica		18		32		31		30		23		15		24		24		25
TDS[c] by Evaporation	732		1,934		305		1,105		412		342		252		924		346	
Percent Na	20		87		33		54		42		89		47		69		88	
Total hareness	417		200		187		357		189		30		109		236		36	
Sampled by[d]	DWR		DWR		DWR		DWR		DWR		DWR		DWR		DWR		DWR	
Date sampled	8/23/63		7/17/63		6/13/63		6/14/63		3/28/63		1/10/64		4/27/64		1/22/64		1/8/64	
Temperature	68° F.										68° F.				74° F.		68° F.	
pH	7.6		7.6		7.8		8.1		7.9		7.9		8.0		7.6		8.2	
EC x 10^6	990		3,000		557		1,529		650		550		400		1,460		570	

a. Chemical equivalents per million.
b. Parts per million by weight.
c. Total dissolved solids.
d. DWR-Department of Water Resources.

MINERAL ANALYSES OF REPRESENTATIVE GROUND WATERS FROM WELLS
(continued)

Constituent	Harper Basin						Lower Mojave Basin						Coyote Basin		Caves Basin	
	South of Harper Lake 11N/4W-33G1		Northwest of Harper Lake 32S/43E-28K1		Near Lockhart 11N/4W-30N2		West of Yermo 10N/1E-33P1		Near Toomey 10N/2E-25P1		South of Troy Lake 8N/4E-7E1		near Coyote Lake 12N/2E-32G1		near Harvard 10N/3E-14J1	
	epm[a]	ppm[b]	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm
Ca	1.30	26	1.70	34	3.49	70	1.75	35	1.13	23	0.49	9.9	1.88	38	2.62	52
Mg	0.20	2	0.60	7	0.83	10	0.43	5	0.80	10	0.53	6.4	0.46	5.6	0.68	9
Na	10.70	246	8.75	201	15.60	359	2.97	68	3.17	73	5.35	123	10.65	245	3.60	83
K	0.12	5	0.13	5	0.20	8	0.06	2	0.03	1	0.11	4.4	0.06	2.5	0.03	1
CO_3	0	0	0	0	0	0	0	0	0.32	10	0.40	12	0	0	0	0
HCO_3	2.45	211	1.15	70	3.36	205	2.48	151	2.92	178	3.15	192	1.86	114	2.44	148
SO_4	3.74	180	6.89	331	5.60	269	1.19	57	0.97	46	1.19	57	5.47	262	1.57	75
Cl	6.00	213	3.00	106	10.69	379	1.41	50	0.90	32	1.35	48	5.73	203	2.71	96
NO_3	0.18	11	0.09	5.6	0.06	4	0.02	1	0	0	0.01	0.7	0	0	0.03	2
F	0.043	0.8	0.060	1.1		1.8	0.03	0.5	0.01	0.2	0.10	1.90	0.10	2.0	0.03	0.6
Boron		0.32		1.73				1.4		0.29		1.0		0.82		0.46
Silica		60		24										28		
TDS[c] by Evaporation	804		763		1,221		301		296		426		848		402	
Percent Na	87		79		78		57		62		82.6		82		52	
Total hardness	75		115		216		109		96		51		117		165	
Sampled by[d]	DWR		DWR		DWR		DWR		DWR		SBCFCD		DWR		DWR	
Date sampled	7/25/61		7/25/61		4/7/65		4/6/65		6/24/64		4/22/64		4/29/64		6/24/64	
Temperature	78° F.		78° F.										67° F.		78° F.	
pH	7.7		8.0		7.7		8.0		8.5		8.3		8.0		7.9	
EC x 10^6	1,315		1,205		2,076		533		475		61.35		1,220		670	

a. Chemical equivalents per million.
b. Parts per million by weight.
c. Total dissolved solids
d. DWR-Department of Water Resources; SBCFCD-San Bernardino County Flood Control District.

400 parts per million (ppm) total dissolved solids (TDS) before it percolates into the ground water basins of the region. Mineral analyses of samples of ground water rising to the stream channel at Victorville indicate that the rising water is higher in TDS, about 300 ppm, and has a larger percent of sodium than its source of replenishment, the storm flow of the Mojave River. At Afton, where rising water maintains a perennial stream, the water character is primarily sodium bicarbonate-chloride and is significantly poorer in quality than the rising water at Victorville. At Afton, the total dissolved solids were about 900 ppm in 1962.

Ground Water

The classification of ground water quality is based upon water samples obtained from pumped wells. For study purposes, the quality of ground water in the study area was grouped into four broad, general water types. The first type is generally relatively low in total dissolved solids, with calcium, sodium, or a combination of the two being the major dissolved cation, and bicarbonate the major dissolved anion constituent. A second general type contains a relatively high total dissolved solids content that is either sodium, calcium sulfate, or sodium or calcium sulfate-chloride in character. A third distinct type is high in total dissolved solids and is either sodium chloride or sodium-calcium chloride in character. A fourth general type has a relatively high total dissolved solid content and consists of a mixture of bicarbonate-sulfate water or bicarbonate-chloride water with either sodium, calcium, or a combination of both as the predominant cation.

For illustrative purposes, and for more detail, 13 distinct ground water types have been identified and are shown on Plate 6, "**Water Quality Conditions". These are the results of selective data reduction** and condensation of the wide range of water type variations which are present in the study area. Each of these 13 types, however, falls into at least one of the four broad categories previously outlined, which are discussed in detail in the following paragraphs:

Bicarbonate Ground Water. Ground water within the area influenced by surface waters of the Mojave River is predominantly bicarbonate in character, with the dominant cations being either sodium, calcium, or a mixture of sodium and calcium. The bicarbonate characteristic of the ground water is believed to be derived from runoff from the bordering granitic rocks that occur in the San Bernardino Mountains to the south. Ion exchange within the area influenced by percolating stream waters is indicated by the change from a predominantly calcium bicarbonate character in the Upper Mojave Basin to a predominantly sodium bicarbonate character downstream in the Middle and Lower Mojave Basins. This ion exchange phenomena is believed to occur between water and clay within the water-bearing materials.

A magnesium bicarbonate type water occurs in the southern portion of Lucerne Basin adjacent to the Helendale fault. The magnesium cation is derived principally from dolomitic limestone outcrops that occur in the mountains to the south and from dolomitic limestone detritus that is contained in the sediments.

Mineral analyses indicate that for the study area as a whole, the average total dissolved solids (TDS) content of the bicarbonate type ground water is approximately 300 parts per million (ppm), although the range of TDS is from 90 to 2,000 ppm. Fluoride concentrations found in bicarbonate type ground water throughout the study area are commonly less than 1 ppm; however, a few isolated wells at scattered locations in the Middle Mojave Basin have revealed fluoride concentrations up to 4.0 ppm. Mineral analyses also indicate that the boron content in the area as a whole is commonly less than 1 ppm; however, excessive boron concentrations have been recorded in a few isolated wells, predominately in areas where wells have penetrated older sediments. This penetration allows a mixing between poorer quality water from the older sediments and better quality water from the younger sediments.

Sulfate and Sulfate-Chloride Ground Water. In areas where there is a predominance of older alluvium (particularly older alluvium whose source rocks include the Tertiary sedimentary deposits) or where portions of the ground water basin receive very little recharge and have only a slight amount of ground water movement, ground water typically has a sulfate or sulfate-chloride anion content. The dominant cation is usually sodium, although calcium occurs occasionally as the dominant cation constituent. In addition, where the ground water basins are intersected by or closely related to faults, ground water is dominantly sodium-calcium sulfate in character and usually has a relatively high total dissolved solids concentration. Total dissolved solids content in the area's sulfate or sulfate-chloride type water ranges from 200 to more than 3,000 parts per million (ppm), although it is typically 700 to 1,000 ppm.

Mineral analysis of ground water extracted from one well in the extreme southwest portion of Harper Basin, in a structural wedge southwest of the Lockhart fault and northeast of the Helendale fault, revealed a TDS concentration of nearly 15,000 ppm and a water character of sodium sulfate-chloride. This concentration and water type, together with the proximity to the Helendale fault and the evidence of very little recharge and ground water movement in the immediate area, lend credence to the assumption that ground water in this particular locale is connate water and has probably been virtually static since entrapment. However, this condition could also result from meteoric water that has been concentrated by evaporation. Phenomenon of this sort presumably exists in other areas within the basins; however, the lack of adequate well data renders it impossible to determine the extent and frequency of the condition.

Analyses also indicate that the concentration of fluoride in the sulfate or sulfate-chloride type ground water ranges from less than 1 part per million to almost 4.0 ppm; the average fluoride content ranges between 1 and 2 ppm. Boron concentrations are typically between 1 and 2 ppm in Upper Mojave and Lucerne Basins; however, the downstream basins contain water that has a boron content that is commonly greater than 2 ppm. In one particular area in Harper Basin, it ranges from 0 up to 35 ppm.

Sodium Chloride Ground Water. The third general ground water type present in the area of investigation contains sodium as the dominant cation and chloride as the dominant anion. Calcium occasionally occurs with sodium in nearly equal concentrations; however, predominance of this condition is limited to the Lower Mojave Basin in an area directly northwest of Troy Dry Lake. Examples of modifications in water type resulting from significant amounts of the sulfate ion are also found in the study area. Such modifications are rare and are prevalent in only one small area of Lucerne Basin.

Sodium chloride type ground water occurs consistently in the study area, being typically present in the fine-grained playa deposits found at lower elevations of the basins and in the older lake deposits. The total dissolved solids content ranges from 380 ppm to more than 5,300 ppm; the average is approximately 1,200 ppm.

Fluoride and boron concentrations are commonly between 1 and 2 ppm. However, in the Middle Mojave Basin, fluoride content frequently ranges from 4 to 8 ppm; boron, from 4.9 to 10 ppm. In the Harper Basin these ranges are: fluoride, 0.5 to 1.6 ppm; and boron, 0.32 to 8.7 ppm.

Ground Water of More Than One Type. Ground water, in which two or more of the four major water types are present, is pumped in some isolated places in the study area. This condition, which has also been observed during investigations of other regions, indicates that ground water quality types may be related to the formations in which they occur, rather than to areal distribution. In the Mojave region, for example, where older alluvium is overlain by channel deposits of the Mojave River, a well penetrating both of these formations would yield a combination of bicarbonate water from the channel deposits and sulfate water from the underlying alluvium. This appears to be one explanation for the combinations of water types that are pumped in some areas.

Total dissolved solids concentrations of these combined water types tend to be moderately high, in the 600 to 900 ppm range, while the fluoride and boron content varies from 0 to 1 ppm from basin to basin. There are very few instances where fluoride and boron reach a high level of concentration in these waters. In the Barstow-Daggett area, however, well log data indicate that some water wells penetrate volcanic material, which is known to contribute significant amounts of boron and increased mineral content to the water.

Changes in Ground Water Character and Quality. It is difficult to trace any distinct trend in ground water character and quality because of the lack of historical data in the major portion of the study area. In general, available data indicate that the character and quality of water in and adjacent to the downstream reaches of the Mojave River have declined. At Afton, the total dissolved solids content has increased from about 650 ppm in 1950 to about 900 ppm in 1962. The mineral character of ground water has also changed in various areas of the basins. In some of these areas, domestic and agricultural uses have increased the total dissolved solids content by 300 to 1,000 ppm. Along the Mojave River, ground water impairment may be attributed to waste waters derived from man's agricultural, urban and suburban, and industrial activities. The natural recycling of these "used" waters to and from the ground water basin reservoir, slowly but continually increases the total dissolved solids concentration, thereby decreasing the water quality. The change in ground water characteristics may also reflect types of water encountered in the various water-bearing formations as the ground water levels throughout the basins declined.

In addition, the sources of water supply are continually adding salts to the basins that far exceed the amounts removed by water disposal. A limited study of the amount of salts added to the water-bearing portion of the study area shows that water supply contributed an average of 21,000 tons of salts during the base period, 1936-37 through 1960-61, and that water disposal by surface outflow removed an average of 3,000 tons of salts. With man's activities in the basins contributing an additional average of 4,000 tons of salt during the base period, an adverse salt balance, or accumulation of salts, at the rate of 22,000 tons per year exists in the basin.

At present, there are only scattered areas in the basin where water quality is a problem because of the undesirable character and high TDS of the water. A more comprehensive study may be needed in the future to provide specific information on the water quality conditions in the Mojave River area.

CHAPTER V. GROUND WATER STORAGE, OVERDRAFT, AND SAFE YIELD

The ground water basins, or water-bearing portions, of the study area contain millions of acre-feet of storage space. These provide for natural regulation of the water supply, use, and disposal. During periods of heavy precipitation, when there is a surplus of water supply, water levels rise and ground water in storage increases. However, in dry periods, the deficiency in water supply is met by extraction and use of ground water, which in time lowers water levels and decreases the amount of ground water in storage.

Ground Water Storage

The ground water in storage in each basin of the study area is many times greater than the average annual water supply to the basin. These natural reservoirs are the primary water resource in the study area. Most of the wells that pump ground water are located along the river and in adjacent valleys where, historically, there has been a readily available supply of ground water. Generally, as the distance from the river increases, the depth at which ground water occurs also increases. Thus, although there are vast amounts of ground water in storage, only limited use has been made of this water resource.

For studies on ground water storage, some of the ground water basins were subdivided into smaller units, on the basis that geologic faults and alluvial constrictions limit the movement of ground water from one portion of the basin to another. These limited areas of the basins are referred to as storage units. These storage units were used in computing the ground water storage capacity and the change in storage for each basin discussed here. The storage units are shown on Figure 7.

Storage Capacity

For the basins in the study area, the storage capacity is defined as the amount of storage space between the ground surface and the 1961 water levels. The ground water in storage is considered to be the amount contained in the zone between the 1961 water levels and the base of the water-bearing materials. Plate 7, "Ground Water Level Contours, 1961", shows the ground water levels at the end of the base period. The most recent water levels for this study are shown on Plate 8, "Ground Water Level Contours, Spring 1964".

Although the base of the water-bearing materials in the study area was not well known, estimates were made, based primarily on well logs that extend to the nonwater-bearing materials, and on gravity surveys conducted by the United States Geological Survey. Materials were considered to be water-bearing if they produced a minimum yield of 50 gallons per minute. This limit was assumed to provide a reasonable estimate of the base of the water-bearing materials, which lie at great depths and are generally considered to be too consolidated to yield water readily. Estimates of the elevation of the base of the water-bearing materials are shown on Plate 4.

The total thickness of the water-bearing materials from the ground surface to the base of these materials ranges from a foot at its contact with nonwater-bearing crystalline rock to over 1,000 feet near Phelan, with an average total thickness of about 300 feet for the

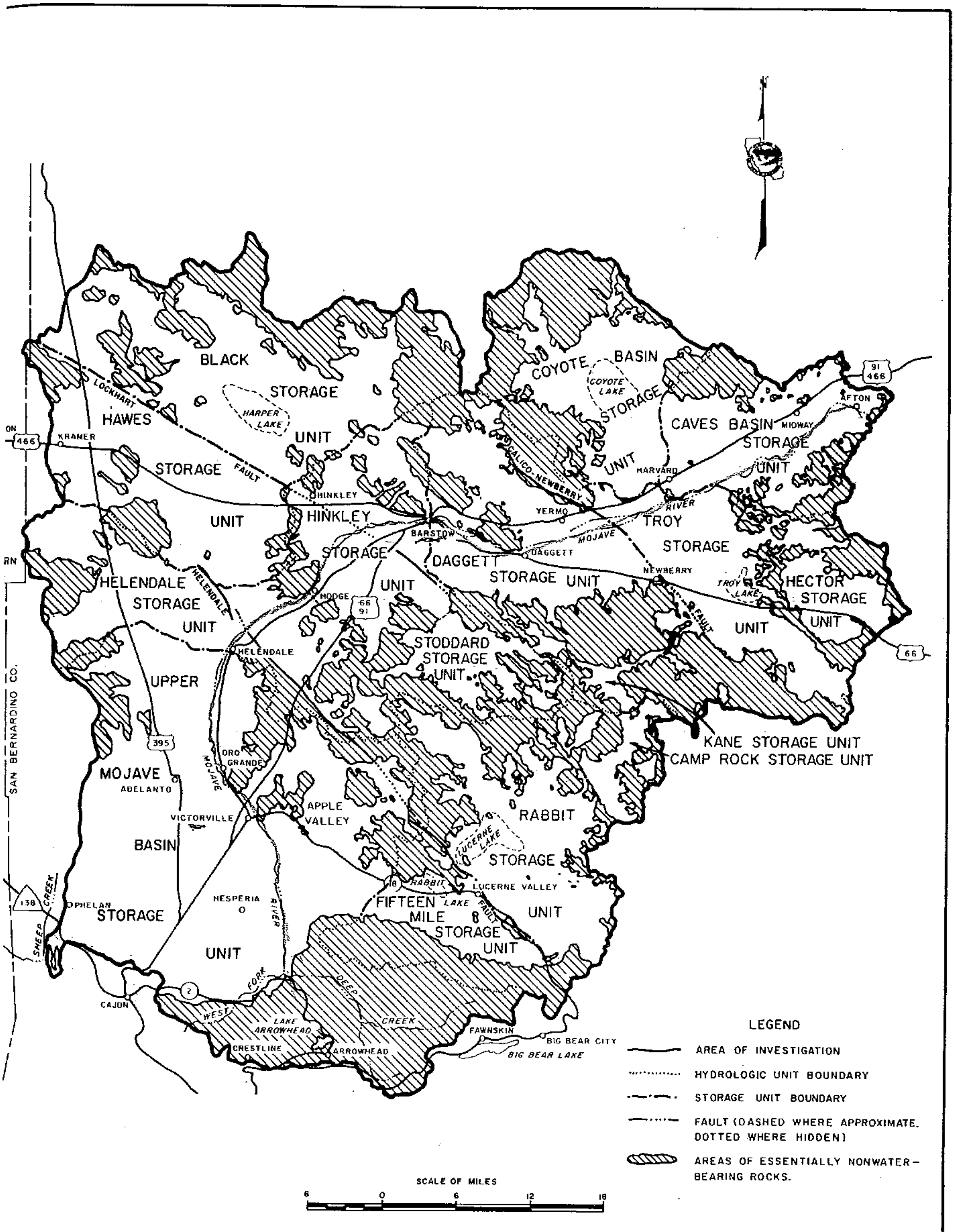

FIGURE 7 - GROUND WATER STORAGE UNITS

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alluviated portion of the study area. Overall, the average saturated thickness, based on the 1961 water levels, is approximately 230 feet. For the portion of the basins that receive surface and/or subsurface inflow from the Mojave River, the average saturated thickness, based on the 1961 water levels, is approximately 275 feet, in an average total thickness of 360 feet. In general, as the distance from the river increases the average saturated thickness becomes smaller in proportion to the total thickness of the water-bearing materials.

To estimate the volume of water stored in the interstices within the water-bearing sediments, the volume of sediments is multiplied by its specific yield value. The specific yield of water-bearing materials is defined as the ratio of the volume of water that saturated materials will yield by gravity drainage over a period of time to the total volume of the saturated materials, prior to draining; it is usually expressed as a percent. Specific yield values of these materials, as described in water well driller's logs, were determined in a cooperative study by the Department and the United States Geologic Survey. Specific yield values and representative driller's terms are presented in Appendix E. These values range from 3 to 35 percent.

The average specific yield from the ground surface to the base of the water-bearing materials varies according to the lithologic composition of the materials, resulting in a wide range (4 to 25 percent) and wide distribution of the average specific yield values in the study area. In those portions of the basins in which surface and/or subsurface inflow from the Mojave River constitutes the most important source of ground water supply, the average specific yield was found to be 14 percent.

The average specific yield for the other areas was estimated to be about 10 percent.

The storage capacity of each basin and storage unit is shown in Table 29. As presented in the table, total storage capacity consists of available storage space and the ground water in storage, in relation to the 1961 water levels.

TABLE 29

ESTIMATED GROUND WATER STORAGE CAPACITY, AVAILABLE STORAGE, AND GROUND WATER IN STORAGE

In acre-feet

Basin	Total storage capacity		Available storage space, above 1961 water levels		Ground water in storage, below 1961 water levels	
Upper Mojave		26,532,000		8,212,000		18,320,000
Middle Mojave						
Helendale storage unit	5,649,000		1,907,000		3,742,000	
Hinkley storage unit	1,792,000		936,000		856,000	
Stoddard storage unit	607,000		174,000		433,000	
		8,048,000		3,017,000		5,031,000
Lower Mojave						
Daggett storage unit	3,919,000		1,465,000		2,454,000	
Troy storage unit	4,035,000		973,000		3,062,000	
Hector storage unit	643,000		575,000		68,000	
Kane storage unit	105,000		53,000		52,000	
		8,702,000		3,066,000		5,636,000
Lucerne						
Fifteen Mile storage unit	1,307,000		792,000		515,000	
Rabbit storage unit	2,861,000		1,463,000		1,398,000	
Camp Rock storage unit	568,000		328,000		240,000	
		4,736,000		2,583,000		2,153,000
TOTAL		48,018,000		16,878,000		31,140,000
Harper						
Black storage unit	3,791,000					
Hawes storage unit	3,184,000					
		6,975,000		*		*
Coyote		7,530,000		*		*
Caves		4,152,000		*		*

* Data not available.

Change in Storage

Change in the amount of ground water in storage over a specified period is reflected by the change in ground water levels. One method to compute changes in storage is by use of the equation of hydrologic equilibrium (Inflow-Outflow = $\pm$ change in storage). Storage changes during the base period using this method are shown in Table 26 as water supply surplus or deficiency.

The change in storage during the base period was also determined by use of the Specific Yield Method:

(Specific yield value) x (thickness of saturated water-bearing materials) x (area) = ground water in storage.

The results of this computation substantiate the results obtained by the use of the hydrologic equation. The amounts of surplus and deficiency computed by the Specific Yield Method are shown in Table 30.

TABLE 30

ESTIMATED CHANGE IN AMOUNTS OF GROUND WATER IN STORAGE DURING THE BASE PERIOD

In acre-feet

Basin	Ground water in storage					
	Below 1936 water levels		Below 1961 water levels		Change in 25-years	
Upper Mojave		18,506,000		18,320,000		-186,000
Middle Mojave						
Helendale storage unit	3,772,000		3,742,000		30,000	
Hinkley storage unit	952,000		856,000		96,000	
Stoddard storage unit	433,000		433,000		0	
		5,157,000		5,031,000		-126,000
Lower Mojave						
Daggett storage unit	2,522,000		2,454,000		68,000	
Troy storage unit	3,124,000		3,062,000		62,000	
Hector storage unit	68,000		68,000		0	
Kane storage unit	52,000		52,000		0	
		5,766,000		5,636,000		-130,000
Lucerne						
Fifteen Mile storage unit	516,000		515,000		1,000	
Rabbit storage unit	1,477,000		1,398,000		79,000	
Camp Rock storage unit	240,000		240,000		0	
		2,233,000		2,153,000		- 80,000

When the annual amounts of water supply surplus or deficiency from Table 26 are accumulated and plotted, as shown on Figure 8, "Cumulative Water Supply Surplus or Deficiency", the general trend corresponds to the hydrographs of the wells numbers 4N/3W-18E1, 10N/2W-19P1, and 9N/1E-13E2 shown on Figure 9, "Hydrographs of Ground Water at Representative Wells". These wells are in areas where substantial changes in storage have occurred. Figure 9 also shows hydrographs of wells in outlying areas, where a smaller reduction in storage occurred during the base period.

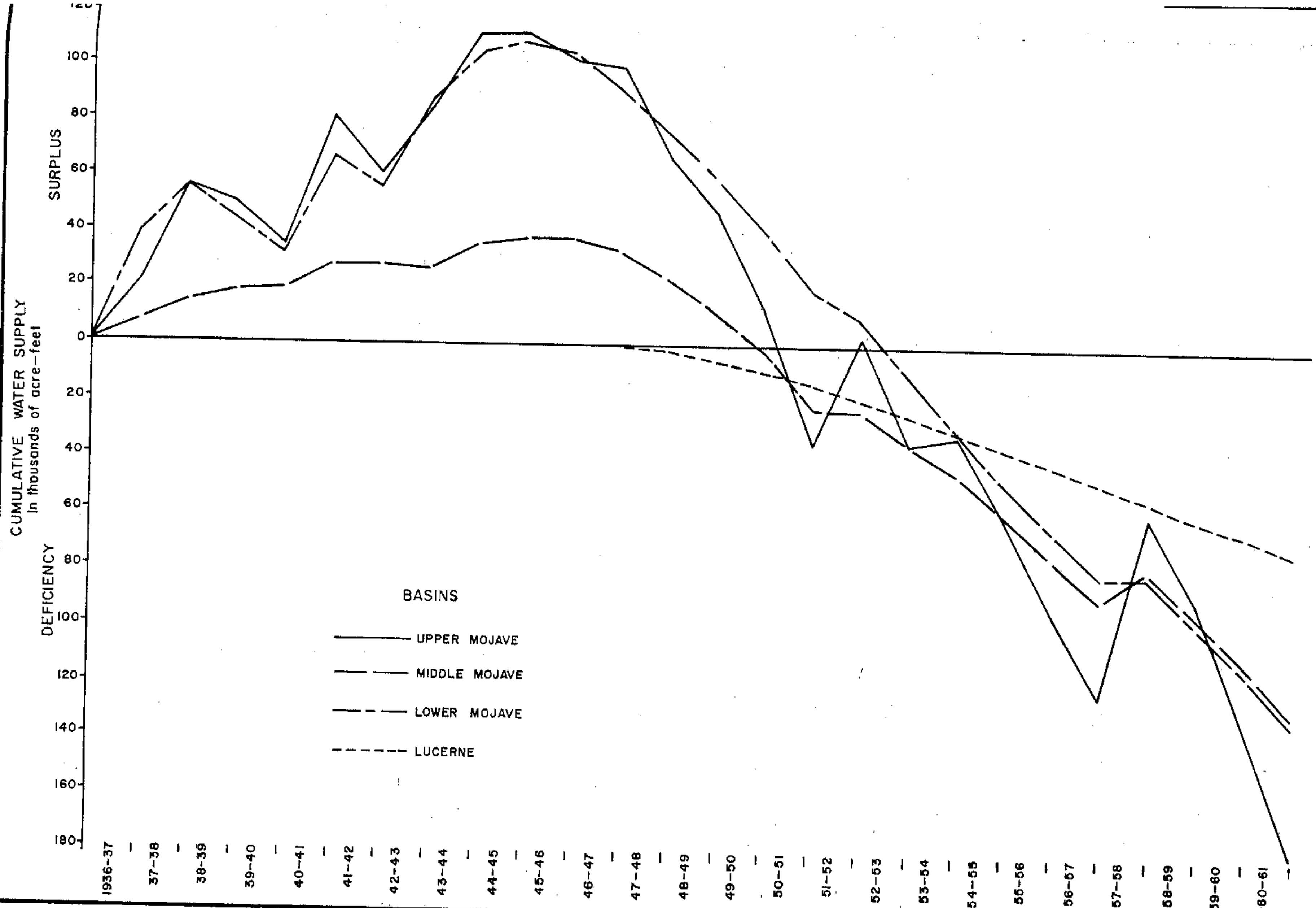

Fig. 8. CUMULATIVE WATER SUPPLY SURPLUS OR DEFICIENCY

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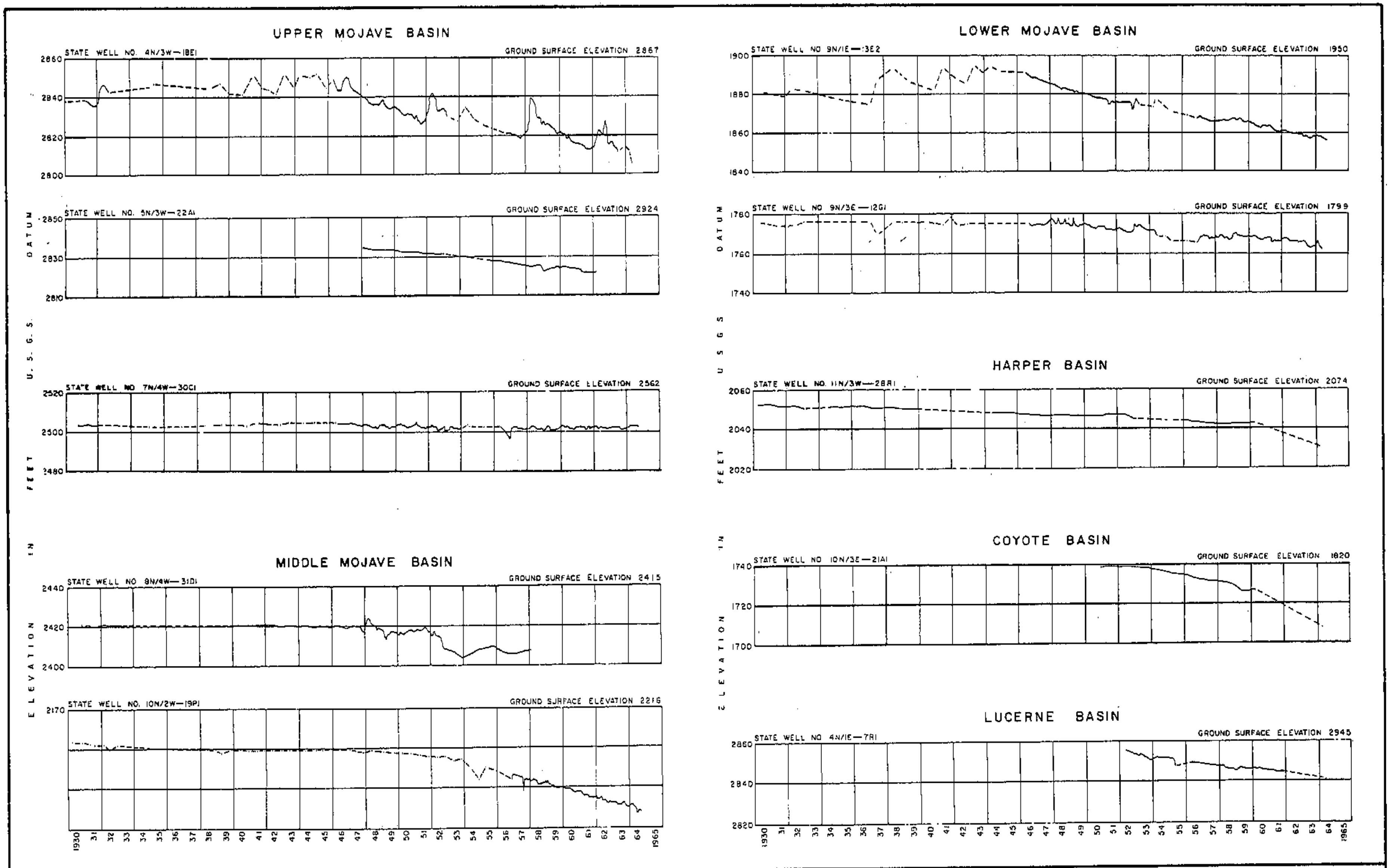

Figure 9. HYDROGRAPHS OF GROUND WATER AT REPRESENTATIVE WELLS

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Comparison of the two figures shows that, in general, water levels in the study area increased from 1936-37 to about 1945, but decreased from 1945 to 1961, the end of the study base period. This trend has continued to 1966. The distribution and amounts of pumping in the basins in 1961 is shown in Table 31.

TABLE 31

PUMPAGE OF GROUND WATER IN 1961*

In acre-feet

Basin	Pumpage	
Upper Mojave		
San Bernardino Mountains to Upper Narrows	33,737	
Upper to Lower Narrows	4,291	
Lower Narrows to Helendale	14,173	
		52,201
Middle Mojave		
Helendale to Hodge	9,111	
Hodge to Barstow	17,264	
		26,375
Lower Mojave		
Barstow to Daggett	4,698	
Daggett to Calico-Newberry fault	9,208	
East of Calico-Newberry fault	5,963	
		19,869
Lucerne		
Southwest of Helendale fault	667	
Northeast of Helendale fault	9,876	
		10,543
TOTAL		108,988

Estimated:	Harper	1
	Coyote	5,601
	Caves	2,861

*The amounts of pumpage were estimated from State Water Rights Board's records. However, currently a detailed verification of pumpage is being made by the Mojave Water Agency. Preliminary figures from this determination indicate the pumpage within the area served by the Agency in 1961 to be on the order to 180,000 acre-feet.

Because, after use, a substantial portion of water extracted from wells returns by deep percolation to the zone of saturation, amounts pumped from wells should not be construed as reduction in ground water sotrage.

Plate 9 depicts the amounts of change in water levels in wells in the study area during the base period, 1936-37 to 1960-61.

Ground Water Overdraft and Safe Yield

In this report, the value assigned to ground water overdraft is equal to the mean annual decrease in the amount of ground water in storage over a longtime period, under a particular set of physical conditions affecting the supply, use, and disposal of water.[1] The value assigned to ground water safe yield is equal to the mean annual amount of ground water that can be pumped from the ground water basin, under the same specific physical conditions, without causing a longtime net change in the amount of ground water in storage.

As was pointed out earlier, the water supply and climatic conditions during the 25-year base period were considered to be equivalent to those conditions during the longtime period.

The set of physical conditions used in the determination of overdraft and safe yield were those that existed in the study area in 1960-61, the last year of the base period. These physical conditions were assumed fixed throughout the base period. In other words, this assumption established the annual amount of water supply, use, and disposal to sustain the 1960-61 physical conditions under mean water supply and climate the entire base period; it also established the places and ways in which the fixed amounts of water supply were applied, used, and disposed.

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[1] See Chapter III for specific items on water supply, use, and disposal.

Ground water overdraft was computed to be the average annual water supply deficiency under actual conditions plus the difference between the average annual consumptive use during the base period and the mean annual consumptive use under 1960-61 physical conditions. This is true because the mean annual amounts of water supply, use, and disposal were found to be the same as the average amounts of the corresponding hydrologic items, except the amount of consumptive use which increased significantly.

The values of ground water basin overdraft for each of the four major basins are derived in Table 32.

TABLE 32

ESTIMATED ANNUAL OVERDRAFT UNDER
1960-61 LAND USE CONDITIONS AND PUMPAGE

In acre-feet per year

Basin	Average annual water supply deficiency under actual conditions	Consumptive Use: Average annual under actual conditions	Consumptive Use: Mean annual under 1960-61 conditions	Consumptive Use: Increase	Ground water overdraft
Upper Mojave	7,200	44,200	50,400	6,200	13,400
Middle Mojave	5,200	19,900	24,800	4,900	10,100
Lower Mojave	5,350	17,450	20,600	3,150	8,500
Lucerne	2,900	4,550	8,000	3,450	6,350
Totals	20,650	86,100	103,800	17,700	38,350

Estimates of annual safe yield were obtained by subtracting the estimates of annual overdraft from estimates of the annual amounts of ground water pumpage that would have been necessary to sustain the

1960-61 physical conditions under mean water supply and climate over a longtime period. Values of safe yield for the four major basins are presented in Table 33.

TABLE 33

ESTIMATED MEAN ANNUAL SAFE YIELD
UNDER 1960-61 LAND USE CONDITIONS AND PUMPAGE*

In acre-feet per year

Basin	Estimated annual pumpage under 1960-61 conditions	Ground water	
		Overdraft	Safe yield
Upper Mojave	57,000	13,400	43,600
Middle Mojave	32,000	10,100	21,900
Lower Mojave	22,000	8,500	13,500
Lucerne	12,000	6,350	5,650
Totals	123,000	38,350	84,650

*The amounts of pumpage were estimated from State Water Rights Board's records. However, currently a detailed verification of pumpage is being made by the Mojave Water Agency. Preliminary figures from this determination indicate the pumpage within the area served by the Agency in 1961 to be on the order of 180,000 acre-feet. Using this figure, the estimated mean annual safe yield would be on the order of 140,000 acre-feet.

It should be pointed out again that two basic assumptions were made in the determination of overdraft and safe yield in this study: (1) a particular set of physical conditions affecting the supply, use, and disposal (including pumpage) of water in the ground water basin was assumed, and (2) it was further assumed that these conditions remained constant at the 1960-61 level throughout the 25-year base period. These assumptions then fixed the amounts of the items of supply, use, and disposal of water at one level for the entire base period; they also held constant the place and manner in which the fixed amount of water supply was applied, used, and disposed. These assumptions were hypothetical, of course, since this situation did not occur in the past and will probably not occur in the future.

In the management of ground water basins in the Mojave area, an understanding of these assumptions and the manner in which they are used is necessary, if the estimates of safe yield and overdraft obtained by this method are to be used as guides in controlling the amounts of pumpage from the ground water basins and in estimating the needs for imports to the area. For example, should it be deemed necessary to reduce the amounts of pumpage by the amount of the overdraft in order to achieve safe yield, the amount of such reduction would have to be made up by an equal amount of supplemental water, such as water obtained by removal of riparian native vegetation or by importing water. This supplemental water would have to be applied in the same place and manner as the extracted water for which it is being substituted, if the estimates of safe yield of the basin determined under constant conditions are to remain unchanged.

The amounts of annual overdraft and safe yield would be different for different sets of physical conditions. Sufficient changes could be made to eliminate overdraft and maintain safe yield. Man has control over, and could change, such physical conditions as (a) urban, suburban, industrial, agricultural land use; (b) intensity of native vegetation, especially riparian native vegetation; and (c) water conservation featues such as reclamation of waste water and artificial recharge of water. In turn, these will change the amounts of water supply, use, and disposal.

An example by which the amount of annual overdraft could be reduced and the annual amount of safe yield could be increased significantly would be by economically removing and controlling the amount of riparian native vegetation. Assuming that the set of physical conditions previously used would have been the same, except that 50 percent of the riparian native vegetational use would have been removed, the annual amount of overdraft would have decreased from about 38,000 acre-feet to 19,000 acre-feet and the annual amount of safe yield would have correspondingly increased from 79,000 acre-feet to 98,000 acre-feet.

There are major flood control and water supply features under way that could affect the physical conditions of the basin. The U. S. Army Corps of Engineers is currently designing the federally authorized flood control dam at the fork site, at the confluence of Deep Creek and the West Fork of the Mojave River. Also, the U. S. Bureau of Reclamation has investigated a multiple-purpose dam and reservoir project at the same site. Principally, it would reduce peak floodflows, decreasing the amount of surface outflow from the study area. In turn, the annual overdraft would decrease and the annual safe yield would increase.

The amounts of ground water overdraft and safe yield are dependent upon the set physical conditions used in their determination, one of which is pumpage. Accordingly, the amounts of ground water overdraft and safe yield are subject to redetermination whenever major changes occur in these conditions. Such a reevaluation may be necessary periodically in the future to provide a continuing guide to the use of ground water in storage.

CHAPTER VI. FUTURE SUPPLEMENTAL WATER REQUIREMENTS AND SOURCES

The San Bernardino Mountains separate the Mojave River desert region from the coastal metropolitan area of Southern California but the region is affected by the social and economic trends of the coastal area. The future expansion in the developed coastal area will tend to spill over into the inland Mojave desert and should have a profound effect on the economy of the study area.

Although the major portion is undeveloped, the study area is strategically located in relation to the great Southern California market with its center in Los Angeles. It is traversed by major transcontinental rail and highway routes, and a dependable supply of electricity and natural gas. Land is available at much lower prices than in coastal Southern California and in its present relatively undeveloped state, the study area could easily accommodate additional agricultural, urban and suburban, and industrial development.

The development of the study area will be limited by the local, social and economic factors affecting agriculture, urban and suburban areas, and industry. Agriculture is influenced by the economic feasibility of producing particular crops under certain market conditions, the availability of land, the pressure for land for other developments, and the availability of low-cost water. In general, farming is marginal and is affected by the late spring and early fall frosts which, in contrast to other more productive and desirable areas, limit production of most crops to the summer months when market prices are lowest. The number of crops that can be produced annually is also limited. In addition, any significant increase in the cost of water would make it uneconomical for the farmer to continue. Therefore, assuming that future agricultural water costs will remain close to the current levels and that the cost of imported water to the Mojave Water Agency would be recovered by increased urban and suburban water rates and by ad valorem taxation, the total gross agricultural acreage is expected to decrease only slightly -- to 16,800 acres in 1970, 15,600 acres in 1980, and 14,500 acres in 1990.

The present urban-suburban areas will continue to be the center for most of the future social and economic activity. Under the influence of the current trend toward development of recreational and retirement areas in the desert regions and the closely associated growth in commercial activity to support these areas, the population of the Mojave region is expected to increase. However, the magnitude of growth will probably not be as great as the growth anticipated in other regions of Southern California.

Population projections to the year 1990 are given in the Department's Bulletin 119-12, "Feasibility of Serving the Mojave Water Agency from the State Water Project", printed in December 1965. This bulletin updates the population figures given in Bulletin 78, "Investigation of Alternative Aqueduct Systems to Serve Southern California", Appendix D, "Economic Demand for Imported Water", published in March 1960.

The current estimates of future population of the Mojave Water Agency (which is essentially the population of the study area) are: 90,000 in 1970, 211,000 in 1980, and 393,000 in 1990. The per capita population demand is estimated to increase from the 200 gallons per capita per day in 1960-61 to 213 gpcd in 1970, 222 gpcd in 1980, and 228 gpcd in 1990.

Industrial activity is not expected to increase in the same proportions as the population. Although the area has the potential for industrial development, the initial investment required to install utilities and other services may deter industries from locating in the area. Furthermore, the study area will be competing with other areas of Southern California for industry. However, the growth of cement production can be expected to continue. The basic raw materials are in abundant supply and the demand will continue to grow and be stimulated by the projected growth of California, generally, and Southern California, specifically. Cement production, however, is not a labor-intensive industry and it has become increasingly mechanized in recent years. For this reason, the expected further expansion of the capacity of the present plants and the probable construction of new plants will not necessarily lead to a proportionate increase in employment within the industry and in demand for water. On this basis, industrial use of water was assumed to increase from 2,600 acre-feet in 1960-61 to 5,000 acre-feet in 1970.

Amounts of water use and disposal, water supply, and water deficiency under 1960-61 land use conditions, and projected amounts for the years 1970, 1980, and 1990 are presented in Table 34.

The water deficiency of 1960-61 and earlier years was met by use of ground water in storage. However, the anticipated growth of the area will result in increased need for supplemental water in future years. To meet these needs, the Mojave Water Agency has contracted with the State of California Department of Water Resources for importation of Northern California water through the State Water Project. These deliveries are to begin in 1972.

TABLE 34

WATER REQUIREMENTS AND SOURCES OF SUPPLY
(Total Study Area)

In acre-feet

Study area	1960-61	1970	1980	1990
Water Use and Disposal:				
Surface Outflow[a]	9,600	9,600	9,600	9,600
Consumptive use				
Agriculture	60,100	51,000	48,000	44,000
Riparian Native Vegetation[b]	41,950	41,950	41,950	41,950
Urban and Suburban	6,200	11,000	26,000	50,000
Industry	2,600	3,000	4,000	5,000
TOTAL	120,450	116,550	129,550	150,550
Existing Sources of Water Supply:				
Precipitation	12,750	12,750	12,750	12,750
Surface inflow	68,000	68,000	68,000	68,000
Subsurface inflow	850	850	850	850
Imported water	250	250	250	250
TOTAL	81,850	81,850	81,850	81,850
Water Supply Deficiency	38,600	34,700	47,700	68,700
Supplemental Sources of Water Supply:				
State Water Project Annual Entitlement[c]			27,200	50,800
Water Deficiency[d]	38,600	34,700	20,500	17,900

a. May be reduced if a proposed dam is constructed at the Forks site.
b. Water salvage could result from a program of elimination and control of riparian native vegetation.
c. Delivery scheduled to begin in 1972 with importation of 8,400 acre-feet.
d. To be met by use of ground water. Amount could be reduced under conditions a and b above.

Consideration was also given to the possibility of additional inflow occurring in future years as the result of importation of water into the mountain area by the Crestline-Lake Arrowhead Water Agency, which has contracted for 5,800 acre-feet of water annually from the State Water Project. Deliveries are scheduled to begin in 1972.

The Crestline-Lake Arrowhead region is primarily a recreation and resort area. Small streams, springs, and shallow wells are the current sources of water. Currently, about 30 percent of the total area within the water agency service area is sewered and this treated sewage is disposed of through evaporation ponds. The remaining portion of the sewage is disposed of through individual septic tank cesspool systems.

About 85 percent of the consumptive use of water by man occurs during the summer months, when consumptive use of water by vegetation and evaporation is also highest. Assuming that the current rate of development continues and that present weather cycles also continue, the amount of imported water supply from the State Water Project will be sufficient only to meet the future additional water demands; there will be no increase in inflow to the study area due to the application of imported water in the mountain area.

As shown in Table 34, a significant possible source of supplemental water is water salvaged as a result of a program of elimination and control of riparian native vegetation. Based on the limited amount of available information, the approximate cost of such a program would be about $50 per acre for clearing, plus about $10 per acre for control by spraying or burning. These amounts include the direct cost of equipment, operating expenses, and salaries and wages.

Because these areas are along the river, where free water surface and high ground water conditions may exist, it may be necessary to collect and distribute the recovered water to other areas to prevent loss by evaporation. If collection and distribution facilities are included in the program, there would be additional cost. Management costs should also be included in determining the total cost of a program to eliminate and control areas of riparian native vegetation to provide a source of supplemental water.

In meeting the future water demands by identifying the above mentioned sources of supplemental water supplies, consideration could be given to a planned reduction of ground water in storage since approximately 30,000,000 acre-feet of ground water exists within the basins and the average annual deficiency is in the order of 38,000 acre-feet.

CHAPTER VII. SUMMARY OF FINDINGS AND CONCLUDING STATEMENTS

In this chapter, the results of the geologic, hydrologic, and water quality studies are summarized as findings. The concluding statements evaluate the objectives achieved and indicate the further application of the findings.

Summary of Findings

Geology

The area of investigation is irregularly shaped, covers about 3,700 square miles, and contains about 2,500 square miles of water-bearing area. It is essentially an alluviated plain made up of small, broad valleys, separated by hills, groups of hills, and low mountains.

Structurally, the study area is dissected by three major northwest-southeast trending faults, which have an important influence on ground water flow: the Helendale, Lockhart, and Calico-Newberry faults. These faults exhibit very little surface expression, primarily because of burial by alluvium. Ground water levels are higher on the southwest side of each of these faults than on the northeast side. Water level differences range from a few feet to about 60 feet.

The water-bearing portion of the study area comprises seven ground water basins: Upper, Middle, and Lower Mojave Basins, and Harper, Coyote, Caves, and Lucerne

Basins. All except Lucerne Basin receive the major portion of their water supply from the Mojave River. The major source of water supply to the Lucerne Basin is from surface inflow from the mountain area.

The heterogeneous, water-bearing alluvial deposits that constitute the ground water basins are primarily the result of stream erosion of the adjacent highlands. These alluvial deposits average about 300 feet in thickness, within a range of a few feet to over 1,000 feet. The saturated portion of these deposits, over the entire study area, averages about 230 feet in depth. However, in those portions of the area that receive inflow from the Mojave River, the average saturated thickness is 275 feet, in an average total thickness of 360 feet.

The specific yield of the water-bearing alluvial deposits varies throughout the basins. The average specific yield for areas influenced by inflow from the Mojave River is approximately 14 percent. For the entire water-bearing portion of the study area, the specific yield ranges from 3 to 25 percent; for the other areas, the average is 10 percent.

Hydrology

Historical Conditions.

The amounts of annual water supply, water use and disposal, and water supply deficiency during the 25-year base period

(1936-37 through 1960-61) were determined for the Upper, Middle, and Lower Mojave Basins, and Lucerne Basin, where adequate geologic and hydrologic data were available. Data for the other three basins -- Harper, Coyote, and Caves -- were limited; however, the findings in the four major areas of record are indicative of conditions throughout the study area.

Water supply sources consist of precipitation, surface inflow, subsurface inflow, and imported water. Precipitation on the valley floor is not sufficient to contribute to the water supply of the basins, except in a portion of the Upper Mojave Basin, south of the town of Hesperia, where the average annual precipitation is greater than eight inches. The average annual amount of water from this source that percolates to the ground water body is about 4,500 acre-feet. The existence of perched ground water in the same general area confirms the addition of water to the ground water body in this area.

Surface inflow to the study area from the surrounding hills and mountains averaged about 68,000 acre-feet annually during the base period. Subsurface inflow to the study area from bordering regions occurs only at the southwest boundary, where inflow to the Upper Mojave Basin contributes about 900 acre-feet annually to the water supply.

During the study base period, imported water was a minor source of supply. About 300 acre-feet of domestic water was imported annually from outside the study area to the town of Phelan.

Surface or subsurface flow between basins within the study area and water piped across these basin boundaries are items of inflow or imported water supply to the receiving basin. However, because this water originates as outflow or exported water from adjacent basins within the study area, these amounts balance out and do not increase the overall water supply.

Water use and disposal is by surface outflow, subsurface outflow, exported water, and consumptive use. Surface outflow from the study area occurs at the northeast boundary, an average annual amount of 9,600 acre-feet from Caves Basin at Afton.

There is no subsurface outflow or water export from the study area to the outlying regions.

The average annual amounts of consumptive use in the study area could only be determined for the four major basins. These amounts were about 44,000 acre-feet for the Upper Mojave Basin, 20,000 acre-feet for the Middle Mojave Basin, 17,000 acre-feet for the Lower Mojave Basin, and 4,500 acre-feet for Lucerne Basin.

The average annual water supply, disposal, and deficiency are as follows:

AVERAGE ANNUAL AMOUNTS

In acre-feet

Basin	Supply	Disposal	Deficiency
Upper Mojave	74,500	81,700	7,200
Middle Mojave	39,900	45,100	5,200
Lower Mojave	26,300	31,600	5,300
Lucerne	1,700	4,600	2,900

The average annual deficiency in water supply, about 21,000 acre-feet, was met by use of pumped ground water.

The deficiency in water supply was the result of increased urbanization and development of the area and the prolonged drought conditions that have prevailed in southwestern United States since about 1945.

If 1961 physical conditions had prevailed throughout the 25-year base period, the average annual overdraft would have been about 38,000 acre-feet and the corresponding average annual safe yield would have been about 85,000 acre-feet for these four basins.

The principal regions where quantitative estimates of ground water storage could be made are the Upper Mojave, Middle Mojave, Lower Mojave, and Lucerne Basins. These basins have a total storage capacity, between the ground surface and the base of the water-bearing materials, of about 48,000,000 acre-feet. There was a net decrease of 522,000 acre-feet in the amount of ground water in storage between the beginning and the end of the 25-year base period. At the close of the base period, in 1961, about 31,100,000 acre-feet of ground water remained in storage in these four basins.

Future Conditions

The study area is primarily desert, and development of farms and communities has been limited to areas along the Mojave River and the adjacent valleys where water has been readily available. However, the study area is strategically located in relation to the expanding Southern California market and will be influenced by the social and economic trends of the region, in general, and of Los Angeles, in particular.

The population of the study area is expected to increase from 55,300 in 1960-61 to 393,000 in 1990. Urban and suburban water use will rise from 6,200 acre-feet in 1960-61 to 50,000 acre-feet in 1990. Agricultural land use is expected to decline during this period, from 18,650 acres to 14,500 acres, resulting in a decrease in agricultural water use, from 60,100 acre-feet to 44,000 acre-feet annually. Conversely, water use and disposal by industry will require 5,000 acre-feet annually by 1990 -- almost double the 2,600 acre-feet needed by industry in 1960-61. These changes in population and occupation will result in a net increase in water use from about 120,000 acre-feet in 1960-61 to about 151,000 acre-feet in 1990.

Historical climatic and hydrologic conditions are assumed to continue in the future; thus, water supply from natural sources will remain at about the same level as it was during the 25-year base study period. In view of the anticipated increase in water needs under future conditions of growth and development in the study area, water supply deficiency will amount to about 68,700 acre-feet annually by 1990, as compared to the 1960-61 deficiency of 38,600 acre-feet.

In order to provide supplemental water to meet the future needs, the Mojave Water Agency has entered into a contract with the State of California for water from the State Water Project. Deliveries of imported water are scheduled to begin in 1972. Use of this water will reduce the 1990 water deficiency from 68,700 acre-feet to 17,900 acre-feet. The remaining water supply deficiency can be met by use of pumped ground water.

Consideration was also given to possible future sources of supplemental water supply. In the event that a dam is constructed at the forks site, as proposed by the U. S. Army Corps of Engineers and studied by the U. S. Bureau of Reclamation, outflow at Afton could be reduced. The water thus conserved would be available for use in the study area. An additional potential supply of supplemental water could be developed by elimination and control of riparian native vegetation or by introduction of a planned program of reduction of ground water storage.

Water Quality

There is a wide variation in the quality and mineral character of the water in the study area. This variation is related to the source of replenishment, the geological formation in which the ground water is found, and use of water by man. Ground water influenced by the Mojave River is typically bicarbonate, with an average total dissolved solids content of about 300 parts per million. Ion exchange is indicated by a change in the character of the water from predominately calcium bicarbonate in the Upper Mojave Basin to predominately sodium bicarbonate in the downstream Middle and Lower Mojave Basins. The other most common type of ground water found in the study area is related to older alluvium. This water is typically sulfate or sulfate-chloride in character with a total dissolved solids range from 700 to 1,000 ppm.

Sodium chloride type ground water is consistently present in the fine-grained playa deposits found at lower elevations of the basins and in the older lake deposits. The total dissolved solids content ranges from 380 ppm to more than 5,300 ppm. The average is approximately 1,200 ppm.

Inflow of salts to the study area exceeds the outflow of salts at the rate of 22,000 tons per year. However, there are only a few areas in which problems due to the accumulation of salts occur. These are in the vicinity of dry lakes and near Afton.

Concluding Statements

Studies leading to this report were conducted to determine the location, amount and quality of local water supply in the basins along the Mojave River, to evaluate the adequacy of the local water supply to meet present and future water requirements, and to indicate potential sources of supplemental water.

The geologic and hydrologic information provided by this study can be used by local agencies in planning for effective use of existing surface and ground water resources of the study area and in developing supplemental sources of water. The information provided by this study points out the need and provides a foundation for a ground water basin model simulation and operational economics studies, leading to the selection by local agencies of an optimum plan of water resources management.

APPENDIX A

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APPENDIX B

DEFINITION OF TERMS

DEFINITION OF TERMS

Acre-foot - The volume of water required to cover one acre one foot in depth (43,560 cubic feet or 325,829 gallons).

Applied Water - The water delivered to a farmer's headgate or to an urban individual's meter, or its equivalent. Excludes precipitation.

Blaney-Criddle Method - Based on an empirical formula developed by Harry F. Blaney and Wayne D. Criddle for the U.S. Department of Agriculture. Used to obtain estimates of evapotranspiration. (For a detailed description, see California State Water Resources Board Bulletin No. 2 and U.S. Department of Agriculture Technical Bulletin No. 1275.)

Character of Water - A classification of water based on predominant anion and/or cation in equivalents per million (epm). Identified by the name of the ion which constitutes one-half or more of the total ions for that water group.

Connate Water - Water entrapped in the interstices of a sedimentary rock at the time it was deposited. These waters may be fresh, brackish or saline in character. Because of the dynamic geologic and hydrologic conditions in California, this definition has been altered in practice to apply to water in older formations, even though in these the water may have been altered in quality since the rock was originally deposited.

Consumptive Use of Water - Water consumed by vegetative growth in transpiration and building plant tissue, and water evaporated from adjacent soil, from water surfaces, and from foliage. It also includes water similarly consumed and evaporated by urban and nonvegetative types of land use.

Darcy's Equation - An equation applied to ground water studies, based on Darcy's Law (the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path). Expressed as Q = PIA, where the subsurface flow (Q) is equal to the permeability (P) of the subsurface materials, times the cross-sectional area (A) and the slope or the hydraulic gradient (I) of the ground water at the cross-sectional area.

P = gallons per day square foot

I = feet per foot

A = square feet

Q = gallons per day

Deep Percolation - See Percolation, Deep.

Ground Water - Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

Ground Water Basin - As used in this report, an area underlain by water-bearing sediments capable of storing and yielding a ground water supply.

Ground Water Overdraft - For this study, the value is equal to average annual decrease in the amount of ground water in storage that occurs during a longtime period, under a particular set of physical conditions affecting the supply, use, and disposal (including pumpage) of water in the ground water basin.[1/]

[1/] See Chapter III for specific items of water supply, use, and disposal.

Ground Water Safe Yield - For this study, the value is equal to average annual amount of ground water that could be pumped from a ground water basin over a long-time period without causing a long-time net change in storage of ground water. The extractions must occur under a particular set of physical conditions affecting the supply, use, and disposal of water in the ground water basin.[1/]

Ground Water Storage - That stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation.

Ground Water Table - See Water Table.

Hydraulic Gradient - Under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

Hydrology - The applied science concerned with the waters of the earth, their occurrences, distribution, use, and circulation through the unending hydrologic cycle of precipitation; consequent runoff, infiltration, storage, use, and disposal; eventual evaporation; and reprecipitation. It is concerned with the physical and chemical reaction of water with the rest of the earth, and its relation to the life of the earth.

Hydrology, Ground Water - The branch of hydrology that treats of subsurface water -- its occurrence, movement, and storage and its replenishment and depletion -- also, of the properties of unconsolidated materials and rocks that control the occurrence, movement,

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[1/] See Chapter III for specific items of water supply, use, and disposal.

and storage of subsurface water and of the method of investigation and utilization of subsurface water.

Impermeable - Impervious; having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Infiltration - The flow, or movement, of water through the soil surface into the ground.

Overdraft - See Ground Water Overdraft.

Perched Ground Water - Ground water occurring in a saturated zone separated from the main body of ground water by unsaturated rock or by an impervious formation.

Percolation - The movement or flow of water through the interstices, or the pores, of a soil or other porous media.

Percolation, Deep - The movement of water entering the zone of saturation, below the root zone.

Period - A specified division or portion of time.

a. Average. An arithmetical average relating to a period other than a mean period.

b. Base. A period chosen for detailed hydrologic analysis, because prevailing conditions of water supply and climate are approximately equivalent to mean conditions and because adequate data for such hydrologic analysis are available.

c. Mean. A period chosen to represent conditions of water supply and climate over a long series of years.

d. Annual. Any 12-month period other than the calendar year. In this study, annual period is synonymous with the runoff period, October 1 through September 30.

Permeability - The permeability (or perviousness) of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size, shape, and extent of their interconnections.

Permeable - Pervious, having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Physical Conditions - For this study, the state of man's activities, particularly land use -- agriculture, urban, suburban, and industrial -- and the resulting physical structures affecting the supply, use, and disposal of water.

Rising Water - Ground water from the zone of saturation which appears at the ground surface, usually to a streambed, when the ground surface is at a lower elevation than the ground water table or the piezometric surface of a confined aquifer.

Safe Yield - See Ground Water Safe Yield.

Specific Yield - The ratio of the volume of water a saturated sediment will yield by gravity drainage to the total volume of the sediment and water prior to draining, customarily expressed in percent.

Total Dissolved Solids (TDS) - The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Transmissibility, Coefficient of - The rate of flow of water, expressed in gallons per day, at the prevailing water temperature through each vertical strip, 1 foot wide, having a height equal to the thickness of the aquifer, and under a unit hydraulic gradient.

Transpiration - The exhalation of water vapor from the stomata of plant leaves and other surfaces.

Unconfined Ground Water - Ground water that is not immediately overlain by impervious materials and that moves under control of the water table slope.

Unconformity - A surface or erosion or nondeposition, usually the first, that separates younger strata from older rocks.

Vapor Transport - The loss of percolating water in the zone of aeration in areas of low annual precipitation, infrequent high annual precipitation, and great depth to the zone of saturation.

Water Quality - Those physical, chemical, biological, and radiological characteristics of water which affect its suitability for beneficial uses.

Water Table - The surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

Water Supply Surplus or Deficiency - For this study, the difference between the inflow to and the outflow from a ground water basin during any given period. The outflow of water includes the consumptive use of water. A water supply surplus results when the inflow is greater than the outflow; a water supply deficiency results when the inflow is less than the outflow.

APPENDIX C

CLASSIFICATION OF LAND USE

WATER SERVICE AREA

Urban and Suburban Category

Class of Land Use	Type of Land Use
Residential	Single and multiple family houses and apartments, institutions, motels, 1- and 2-story hotels, trailer parks, and residential subdivisions under construction at time of survey.
Recreational residential	Weekend and summer home tracts within a primarily recreational area.
Commercial	All classes of commercial enterprises, including strip commercial, downtown commercial, and schools, but excluding 1- and 2-story hotels, motels, and institutions.
Industrial	All classes of industrial land uses involving manufacturing, processing, and packaging, but excluding extractive industries (oil, sand, and gravel), air fields, and storage, distribution, and transportation facilities.
Unsegregated urban and suburban area	Farmsteads, dairies, livestock ranches, parks, cemeteries, and golf courses.
Included nonwater service area	Oil fields, tank farms, vacant lots, quarries, gravel pits, warehouses and storage yards, railroads, public streets, landing strips of airfields, and subdivisions with streets and utilities in place but with no buildings constructed.

Irrigated Agriculture Category

Class of Land Use	Type of Land Use
Alfalfa	Alfalfa raised for hay, seed, or pasture

Class of Land Use (continued)	Type of Land Use
Pasture.	Irrigated grasses and legumes other than alfalfa used for livestock forage.
Truck crops	Vegetables of all varieties, melons, flower seed, and nursery crops.
Field crops	Cotton, sorghum, sugar beets, and field corn.
Deciduous fruits and nuts .	All varieties.
Small grains	Barley, wheat, and oats.
Fallow	Tilled, between crops.
Included nonwater service area	Public highways and roads, farm access roads, canals, and other inclusions not devoted to crop production, including idle and abandoned lands.

APPENDIX D

WATER QUALITY CRITERIA

WATER QUALITY CRITERIA

Criteria presented in the following sections can be utilized in evaluating mineral quality of water relative to existing or anticipated beneficial uses. It should be noted that these criteria are merely guides to the appraisal of water quality. Except for those constituents which are considered toxic to human beings, these criteria should be considered as suggested limiting values. Water which exceeds one or more of these limiting values need not be eliminated from consideration as a source of supply, but other sources of better quality water should be investigated.

Criteria for Drinking Water

Criteria for appraising the suitability of water for domestic and municipal use in connection with interstate quarantine have been promulgated by the United States Public Health Service. The limiting concentrations of chemical substances in drinking water have been abstracted from these criteria and are shown in Table 35. Other organic or mineral substances may be limited if their presence renders the water hazardous for use.

Interim standards for certain mineral constituents have been adopted by the California State Board of Public Health. Based on these standards, temporary permits may be issued for drinking water supplies failing to meet the United States Public Health Service Drinking Water Standards, provided the mineral constituents in Table 36 are not exceeded.

TABLE 35

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS
1962

Chemical Substance	Mandatory limit in ppm
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Hexavalent chromium (Cr^{+6})	0.05
Cyanide (CN)	0.2
Lead (Pb)	0.05
Salenium (Se)	0.01
Silver (Ag)	0.05

	Nonmandatory, but recommended limit in ppm
Alkyl benzene sulfonate (detergent)	0.5
Arsenic (As)	0.01
Carbon chloroform extract (exotic organic chemicals)	0.2
Chloride (Cl)	250
Copper (Cu)	1.0
Cyanide (CN)	0.01
Fluoride (F) (See Table 37)	
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3)	45
Phenols	0.001
Sulfate (SO_4)	250
Total dissolved solids (TDS)	500
Zinc (Zn)	5

TABLE 36

UPPER LIMITS OF TOTAL SOLIDS AND SELECTED MINERALS IN DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit
Total solids	500 (1000)*	1500 ppm
Sulfates (SO_4)	250 (500)*	600 ppm
Chlorides (Cl)	250 (500)*	600 ppm
Magnesium (Mg)	125 (125)	150 ppm

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* Numbers in parentheses are maximum permissible, to be used only where no other more suitable water is available in sufficient quantity for use in the system.

The relationship of infant methemoglobinemia (a reduction of oxygen content in the blood, constituting a form of asphyxia) to nitrates in the water supply has led to limitation of nitrates in drinking water. The California State Department of Public Health has recommended a tentative limit of 10 ppm nitrogen (44 ppm nitrates) for domestic water. Water containing higher concentrations of nitrates may be considered to be of questionable quality for domestic and municipal use.

The California State Board of Public Health has defined the maximum safe amounts of fluoride ion in drinking water in relation to mean annual temperature. These relationships are shown in Table 37.

TABLE 37

RELATIONSHIP OF TEMPERATURE TO FLUORIDE CONCENTRATION IN DRINKING WATER

Mean Annual Temperature	Mean monthly fluoride ion concentration
50°F	1.5 ppm
60°F	1.0 ppm
70°F - above	0.7 ppm

Criteria for Hardness

Even though hardness in water is not included in the foregoing standards, it is of importance in domestic and industrial uses. Excessive hardness in water used for domestic purposes causes increased consumption of soap and formation of scale in pipe and fixtures. Table 38 showing degrees of hardness in water has been suggested by the United States Geological Survey.

TABLE 38

HARDNESS CLASSIFICATION

Range of hardness, expressed as $CaCO_3$ in ppm	Relative classification
0 - 60	Soft
61 - 120	Moderately hard
121 - 200	Hard
Greater than 200	Usually requires softening

Criteria for Irrigation Water

Criteria for mineral quality of irrigation water have been developed by the Regional Salinity Laboratories of the United States Department of Agriculture in cooperation with the University of California. Because of diverse climatological conditions and the variation in crops and soils in California, only general limits of quality for irrigation waters can be suggested. The department uses three broad classifications of irrigation waters as listed below and in Table 39.

Class 1 - Regarded as safe and suitable for most plants under most conditions of soil and climate.

Class 2 - Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 - Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

TABLE 39

QUALITATIVE CLASSIFICATION OF IRRIGATION WATERS

Chemical properties	Class 1 Excellent to good	Class 2 Good to injurious	Class 3 Injurious to unsatisfactory
Total dissolved solids, in ppm	Less than 700	700 - 2000	More than 2000
Conductance, in micromhos at 25°C	Less than 1000	1000 - 3000	More than 3000
Chlorides, in ppm	Less than 175	175 - 350	More than 350
Sodium, in percent of base constituents	Less than 60	60 - 75	More than 75
Boron, in ppm	Less than 0.5	0.5 - 2.0	More than 2.0

These criteria have limitations in actual practice. In many instances, water may be wholly unsuitable for irrigation under certain conditions of use and yet be completely satisfactory under other circumstances. Consideration also should be given to soil permeability, drainage, temperature, humidity, rainfall, and other conditions that can alter the response of a crop to a particular quality of water.

Criteria for Industrial Uses

It is beyond the scope of this report to present water quality requirements for the various types of industry found in the Mojave River region or for the diverse processes within these industries, since such criteria are as varied as industry itself. In general, where a water supply meets drinking water standards, it is satisfactory for industrial use, either directly or following a limited amount of treatment or softening by the industry.

APPENDIX E

SPECIFIC YIELD VALUES

AND REPRESENTATIVE DRILLERS' TERMS

3 Percent (Clay)

Black rock
Black schist
Blue shale
Boulders, chunk rock
Boulders, hard
Caliche
Cemented boulders
Clay
Clay cobblestones
Hard pan
Hard shelf
Hillside clay conglomerate
Lime "shelves"
Rotten granite
Soft granite

Sticky clay

Tight clay
White quartz & Black shale

5 Percent (Sandy Clay)

Basalt
Basaltic sandstone
Cemented conglomerate
Clay - scattered gravel
Clay - scattered lime
Clay - with embedded rock

Crumbly clay
Crushed rock
Decomposed granite
Fractured granite
Gravelly clay
Hard lime shale
Kaolin
Limerock & Biotite clay
Muck
Nodules
Rotten Ledge rock
Sandy clay
Sandy Muck
Sandstone reefs
Silty clay
Volcanic rock
White limestone

10 Percent (Silt)

Black swamp mud & silt
Cemented gravels
Clay - embedded gravel
Coarse granulated water-bearing kaolin
Limy silt
River silt
Silt
Soft silt
Soil (Topsoil)
Talc

12 Percent (Cemented Sand)

Cemented sand
Cemented sand & gravel
Conglomerate sand
Hard cemented sand
Hard sand
Sandy clay & cobbles
Water gravel with cement reef

15 Percent (Sandy Silt)

Granulated kaolin
Kaolin with grit
Mucky sand, gravel & bits
Sandy silt

18 Percent (Coarse, Medium, or Undiff. Gravel)

Alluvial fill boulders
Brittle conglomerate - water
Brittle FM - water
Coarse, medium, or undifferentiated gravel
Cobblestone - coarse sand - some gravel
Loose "Granite" formation
Sand w/clay ribs

20 Percent (Silty Sand)

Dirty sand
Hilldrift
Silty sand
Soft sand

22 Percent (Fine Gravel)

Fine gravel
Pea gravel

26 Percent (Fine Sand)

Blow sand
Dune sand
Fine sand
Quicksand

32 Percent (Sand-Undifferentiated)

Lava sand
Loose sand
Sand-undifferentiated

33 Percent (Coarse Sand)

Coarse sand

35 Percent (Medium Sand)

Dry sand
Medium sand
Water sand

Note: Source of information: U. S. Geological Survey, Water Resources Division, "Compilation of Specific Yield for Various Materials," Open file report. 1966.