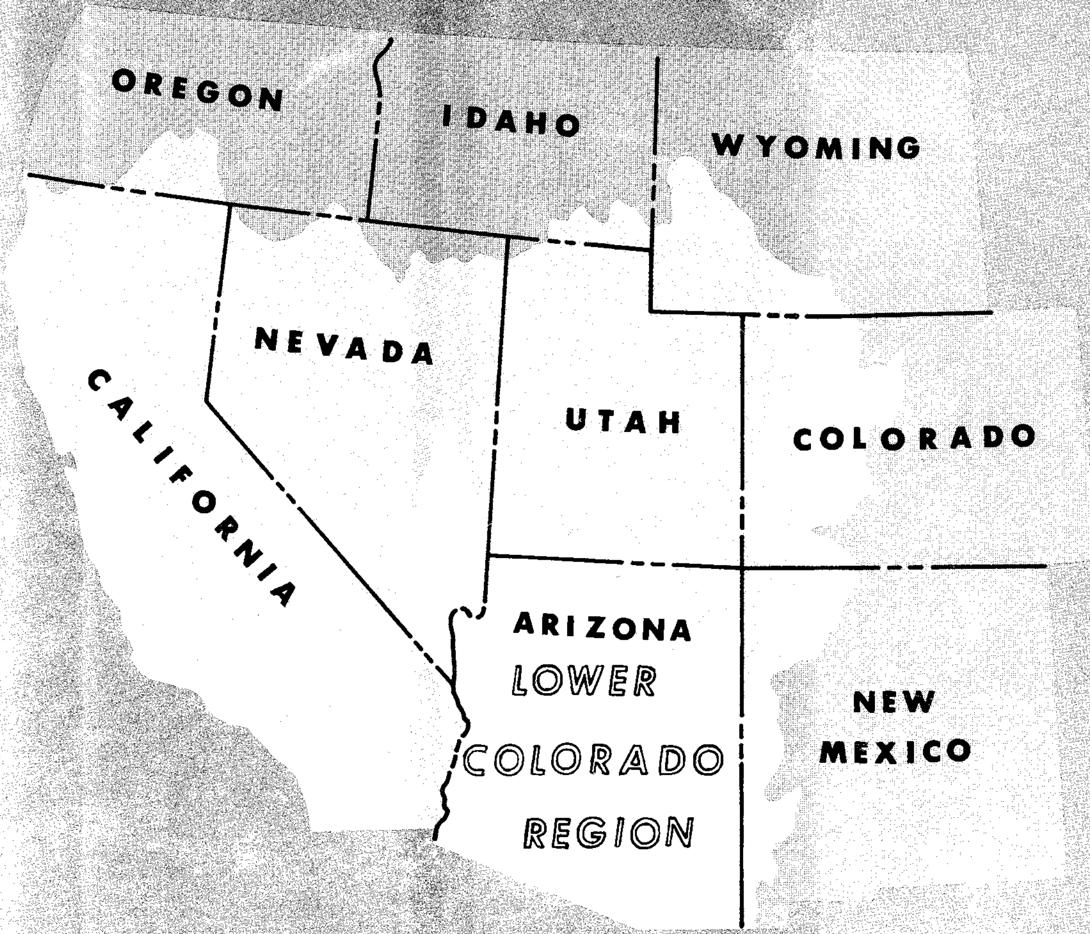
VER COLORADO REGION
Comprehensive Framework Study

APPENDIX V
WATER RESOURCES
JUNE 1971



PREPARED BY:

LOWER COLORADO REGION STATE – FEDERAL
INTERAGENCY GROUP FOR THE
PACIFIC SOUTHWEST INTERAGENCY COMMITTEE

The Water Resources Appendix is one of 16 appendixes supporting the "Main Report." The details of various categories discussed in this appendix are found in companion appendixes as follow:

APPENDIX I - HISTORY OF STUDY

APPENDIX II - THE REGION

APPENDIX III - LEGAL AND INSTITUTIONAL ENVIRONMENT

APPENDIX IV - ECONOMIC BASE AND PROJECTIONS

APPENDIX V - WATER RESOURCES

APPENDIX VI - LAND RESOURCES AND USE

APPENDIX VII - MINERAL RESOURCES

APPENDIX VIII - WATERSHED MANAGEMENT

APPENDIX IX - FLOOD CONTROL

APPENDIX X - IRRIGATION AND DRAINAGE

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LOWER COLORADO REGION

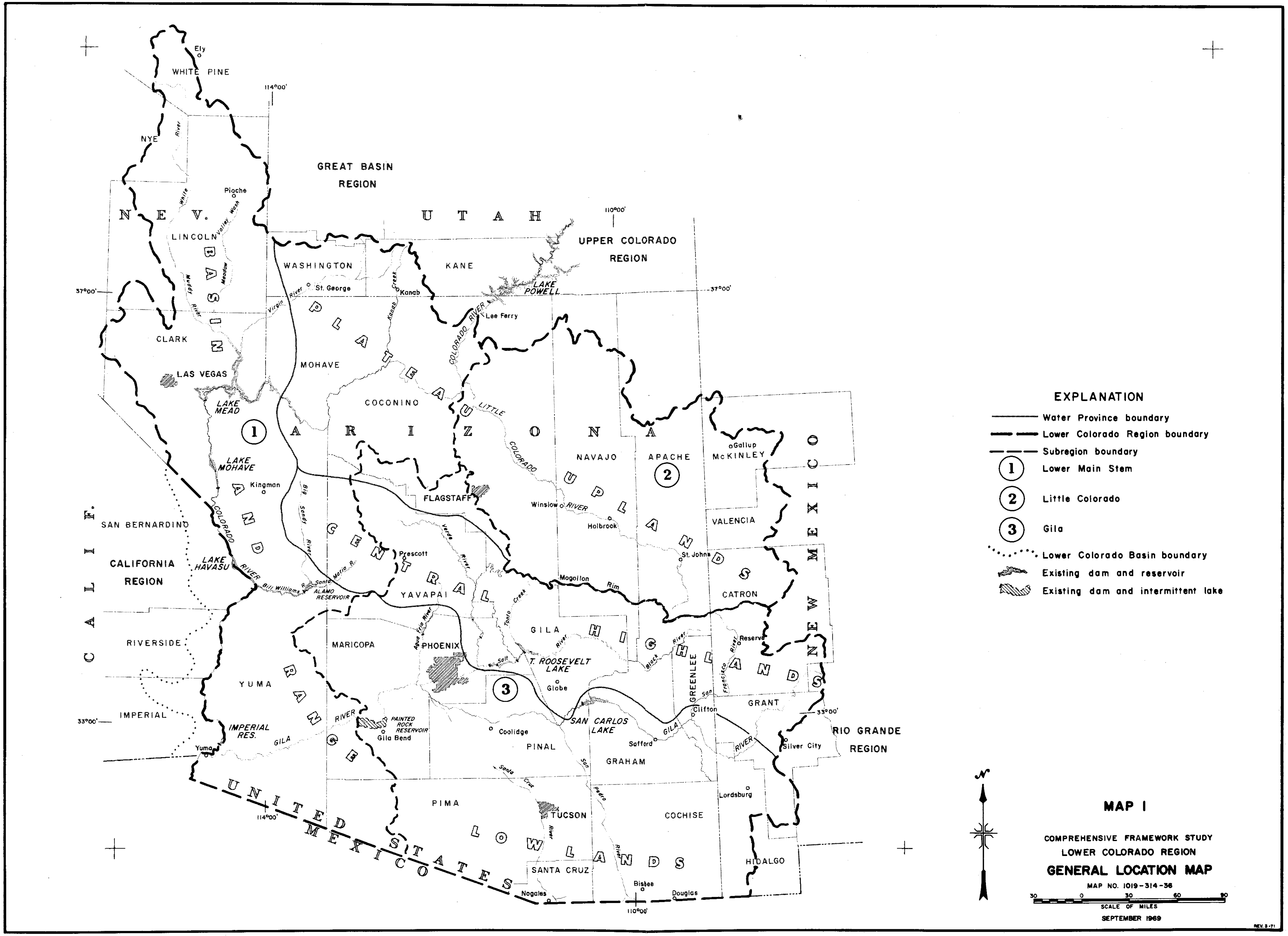
COMPREHENSIVE FRAMEWORK STUDY

APPENDIX V

WATER RESOURCES

This report of the Lower Colorado Region Framework Study State-Federal Interagency Group was prepared at field level and presents a framework program for the development and management of the water and related land resources of the Lower Colorado Region. This report is subject to review by the interested Federal agencies at the departmental level, by the Governors of the affected States, and by the Water Resources Council prior to its transmittal to the Congress for its consideration.

June 1971



EXPLANATION
Water Province boundary
Lower Colorado Region boundary
Subregion boundary
1 Lower Main Stem
2 Little Colorado
3 Gila
Lower Colorado Basin boundary
Existing dam and reservoir
Existing dam and intermittent lake
GREAT BASIN REGION
UPPER COLORADO REGION
CALIFORNIA REGION
RIO GRANDE REGION
U T A H
N E V.
C A L I F.
A R I Z O N A
N E W M E X I C O
U N I T E D S T A T E S
M E X I C O
BASIN AND RANGE
PLATEAU UPLANDS
CENTRAL HIGHLANDS
LOWLANDS
WHITE PINE
NYE
LINCOLN
CLARK
WASHINGTON
KANE
MOHAVE
COCONINO
NAVAJO
APACHE
McKINLEY
VALENCIA
CATRON
YAVAPAI
GILA
GREENLEE
GRANT
MARICOPA
YUMA
PINAL
GRAHAM
PIMA
COCHISE
SANTA CRUZ
HIDALGO
SAN BERNARDINO
RIVERSIDE
IMPERIAL
Ely
Pioche
St. George
Kanab
Lee Ferry
LAS VEGAS
Kingman
FLAGSTAFF
Winslow
Holbrook
St. Johns
Gallup
Reserve
Prescott
PHOENIX
Globe
Clifton
Silver City
Coolidge
Gila Bend
Safford
TUCSON
Lordsburg
Nogales
Bisbee
Douglas
Yuma
LAKE MEAD
LAKE MOHAVE
LAKE HAVASU
LAKE POWELL
ALAMO RESERVOIR
PAINTED ROCK RESERVOIR
T. ROOSEVELT LAKE
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IMPERIAL RES.
COLORADO RIVER
LITTLE COLORADO RIVER
GILA RIVER
Virgin River
Kanab Creek
White River
Meadow Valley Wash
Muddy River
Big Sandy River
Santa Maria R.
Bill Williams R.
Verde River
Agua Fria River
Salt
Tonto Creek
Black River
San Francisco River
San Pedro River
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Mogollon Rim
114°00'
110°00'
37°00'
33°00'
MAP I
COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION
GENERAL LOCATION MAP
MAP NO. 1019-314-36
30 0 30 60 90
SCALE OF MILES
SEPTEMBER 1969
REV. 3-71

This Appendix Prepared by the

WATER RESOURCES WORK GROUP

of the

LOWER COLORADO REGION STATE-FEDERAL INTERAGENCY GROUP

for the

PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE

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SUMMARY OF FINDINGS

This appendix presents the evaluation of water resources of the Lower Colorado Region and summarizes the requirements for the use of water under present (1965) and projected future (1980, 2000, and 2020) conditions leading to the formulation of framework plans to provide a broad guide to the best use, or combinations of uses, of water resources to meet foreseeable short- and long-term needs of the Region.

The Lower Colorado Region includes most of Arizona and parts of Nevada, New Mexico, and Utah, comprising a total area of over 141,000 square miles. For purposes of analysis and planning, the Lower Colorado Region has been divided into three subregions comprising the major drainage areas of the Lower Main Stem, the Little Colorado River, and the Gila River above Painted Rock Dam.

The Region is richly endowed with favorable climate, abundant land, mineral, and other resources, and leads the Nation in population growth rate. Though other resources are abundant, the Region probably comes closer than most any other to using the last available drop of water resources for man's needs. Water is used for irrigation, municipal-industrial-domestic purposes, livestock watering, thermal and hydroelectric power generation, mineral activity, fish and wildlife facilities, and recreation. Large amounts of water are also exported from the Lower Colorado River to the adjoining California Region and to Mexico for multiple-purpose uses.

The Region's economy is sustained by utilizing ground-water reserves, especially in the areas of population concentration such as central Arizona and the Las Vegas area in Nevada. The depletion rate of these reserves has reached well over 2 million acre-feet annually due largely to the imbalance between location of supply and location of demand, and to the lack of facilities which would enable the Region to utilize its unused share of Colorado River water. The Southern Nevada Water Project, currently under construction, the Dixie Project in Utah, and the Central Arizona Project would enable the Region to utilize its remaining available water supplies.

The regional water supply deficiency, even with the above projects, is projected to exceed 4 million acre-feet by year 2020. Expansion of water conservation management practices, more intensive water reuse, vegetative management for increased water yields, and treatment of brackish water are all possible ways to lessen the effects of rising water deficiencies until augmentation of the Region's water supplies can be accomplished in sufficient amounts to meet future water requirements and reduce ground-water overdraft.

Several possible sources are being explored to augment the existing water supplies of the Lower Colorado Region and the remainder of the Pacific Southwest. These sources include weather modification, geothermal resources, inter-regional transfers of water, and desalting of sea water.

The following table provides a summary of present water supplies and present and future requirements indicating the extent of present and projected future regional water supply deficiencies.

Summary Table of Water Resources Development
Lower Colorado Region

Units: Million ac-ft

	Modified OBE-ERS Level of Development			
	1965	1980	2000	2020
SURFACE-WATER SUPPLY				
Depleted Colorado River at Lee Ferry (1906-65)	11.64	10.26	8.97	8.54
Undepleted subregional supply	3.12	3.12	3.12	3.12
Total	14.76	13.38	12.09	11.66
DEPLETION REQUIREMENTS				
By type of use				
Irrigation	5.23	5.97	5.31	5.38
Municipal and industrial	0.20	0.36	0.68	1.15
Electric power	0.01	0.04	0.11	0.43
Minerals	0.05	0.09	0.13	0.19
Fish, wildlife, and recreation	0.11	0.15	0.25	0.43
Reservoir and stockpond evaporation	0.23	0.28	0.33	0.36
Subtotal	5.83	6.89	6.81	7.94
By States				
Arizona	5.42	6.28	6.00	6.90
Nevada	0.25	0.38	0.53	0.72
New Mexico	0.09	0.13	0.18	0.20
Utah	0.07	0.10	0.10	0.12
Subtotal	5.83	6.89	6.81	7.94
Main Stem Reservoir evaporation and spills	1.85	1.72	1.35	1.35
Channel and conveyance losses 1/	0.76	0.48	0.45	0.43
Exports to California Region	5.00	4.40	4.40	4.40
Mexican Treaty	1.50	1.50	1.50	1.50
Subtotal	9.11	8.10	7.70	7.68
Total requirements	14.94	14.99	14.51	15.62
DEFICIENCY IN SURFACE SUPPLY	-0.18	-1.61	-2.42	-3.96

1/ Includes main stem and lower Gila River channel losses, and estimated nonrecoverable losses from the Central Arizona Project aqueduct.

LOWER COLORADO REGION COMPREHENSIVE FRAMEWORK STUDY

APPENDIX V

WATER RESOURCES

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INTRODUCTION

CHAPTER A - INTRODUCTION

The Lower Colorado Region is one of four regions in the Pacific Southwest assigned to the Pacific Southwest Inter-Agency Committee by the Water Resources Council for comprehensive framework study. Guidelines for the framework studies state: "The basic objective in the formulation of framework plans is to provide a broad guide to the best use, or combination of uses, of water and related land resources of a region to meet foreseeable short- and long-term needs." The studies are reconnaissance in nature and rely largely on existing data and the reasoned judgment of competent planners.

The purposes of this appendix are to evaluate the existing surface- and ground-water resources of the Lower Colorado Region, to summarize the requirements for the use of water under base conditions (1965) and projected future conditions, and to summarize available hydrologic data for this and other Work Groups preparing companion appendixes, all leading to the formulation of plans and programs of the "Main Report." In line with the reconnaissance nature of these framework studies, existing studies, inventories, reports, and other publications were relied upon in assembling much of the material for this appendix.

The Lower Colorado Region includes the Colorado River drainage in the United States below Lee Ferry, Arizona, except that occurring in California and Mexico (see map 1). In addition, it includes several closed basins in Arizona, Nevada, and New Mexico, and some areas in southern Arizona and New Mexico that drain into Mexico. The Colorado River drainage in California, shown as a dotted line, is included in the California Region. Although the Region includes many hydrologic subbasins, it is naturally divided into three major drainage areas--the Lower Main Stem, Little Colorado, and Gila--which have been designated as hydrologic subregions. These subregions provide a logical basis for water resource analysis and planning.

Projections of growth in the Lower Colorado Region in major economic sectors and in population were provided by the Office of Business Economics and the Economic Research Service (OBE-ERS) for the years 1980, 2000, and 2020. These projections are based on an extension of past national and regional development. The various States of the Region, upon review of the OBE-ERS projections, presented several modifications to them. The main body of the appendix concerns itself with these Modified OBE-ERS projections. The OBE-ERS data are treated in condensed form in the last section of this appendix.

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REGIONAL SUMMARY

CHAPTER B - REGIONAL SUMMARY

HYDROLOGIC FRAMEWORK

The total area of the Lower Colorado Region is about 141,000 square miles and is composed of the topographic drainage areas within the States of Arizona, Nevada, New Mexico, and Utah, shown in table 1.

Table 1 - Drainage Areas by Subregions

	Units in 1,000 square miles			
	Subregions			
	1 (Lower Main Stem)	2 (Little Colorado)	3 (Gila)	Region
Colorado River - Southerly International Boundary to Lee Ferry, Compact Point, 1 mile below the Paria River	52.2	26.9	49.6	128.7
Closed Basins - Southwestern New Mexico and southeastern Nevada and Arizona	3.2		4.0	7.2
Mexican Drainage - Southern Arizona and New Mexico	1.2	—	4.0	5.2
	56.6	26.9	57.6	141.1

Streamflow is contributed to the upper reaches of the San Pedro and Santa Cruz Rivers from drainage areas totaling 1,100 square miles in Mexico, to the Lower Colorado River from the 3,600 square miles in adjoining California, and from the Upper Colorado Region at Lee Ferry.

Average annual runoff varies widely, as do the precipitation, temperature, and terrain in the Lower Colorado Region. Runoff averages 0.05 inches or less in the desert to as much as 8 inches in mountainous areas. Variations in annual runoff are illustrated in table 2 by comparing a wet year, 1916, and a dry year, 1934.

Table 2 - Regional Variations in Runoff

Station	Estimated Runoff 1916 (maf)	1916 (inches)	1934 (maf)	1934 (inches)
Little Colorado River at Grand Falls, Arizona	0.91	0.80	0.12	0.11
Virgin River at Littlefield, Arizona	0.57	2.10	0.11	0.40
Bill Williams River at Planet, Arizona	0.32	1.17	0.01	0.04
Gila River at Gillespie Dam, Arizona	5.98	2.26	0.31	0.12
Colorado River at Lee Ferry, Arizona	19.20	3.29	5.64	0.97

Most authorities conclude that the Lower Colorado Region entered a severe drought period in the 1930's. However, the length of reliable record may be insufficient to substantiate this conclusion. Various periods of record have been recommended for use in Type I studies. The selection of a historic period of record on which to base the representative long-term water supply is generally a matter of the availability of record and judgment on what represents a fair long-term average. Considering the available information on undepleted runoff, historic streamflow records, ground-water data, depletions, and available studies and reports, the 60-year period, 1906-65, was selected as representative of long-term conditions to determine the average annual virgin flow of the Colorado River at Lee Ferry. Periods other than 1906-65 have been used in other investigations, however. The effect of using two of these other periods has been analyzed in this study. These periods are 1914-65, adopted by the Upper Colorado Region as its base period; and 1922-65, representing the period beginning with measured flow at Lee Ferry.

The 52-year period, 1914-65, was selected as representative of the long-term conditions on which to base runoff originating within the boundaries of the Lower Colorado Region. This period coincides with the beginning of most hydrologic data within the Region. Based on the limited information available prior to 1914, there is no reason to suspect that a longer study period, such as 1906-65, would materially change the average annual runoff occurring within the Subregions.

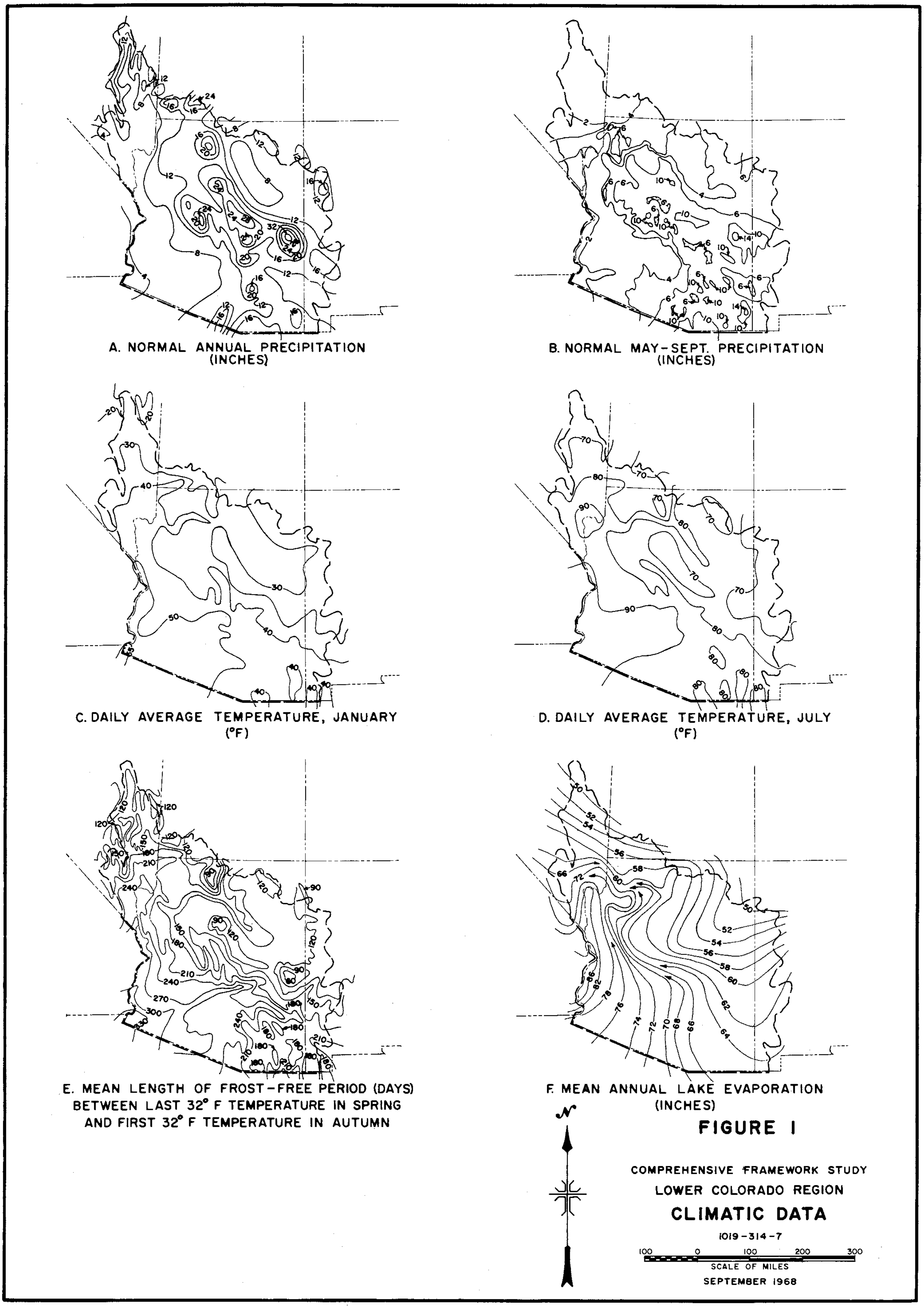
There would be practically no farming if it were not for irrigation. Lands suitable for irrigated agriculture are plentiful, totaling some 36.2 million acres, of which about 1.2 million acres were irrigated in the Region in 1965. The climate is conducive to the growth of a wide variety of crops and provides long growing seasons, especially in the desert portions of the Region. However, a limited surface-water supply has restricted the area's irrigation development. The shortage of surface water has resulted in the extensive use of ground water to the extent that the total water supply for irrigation is now comprised of over 60 percent ground water resulting in declining ground-water levels.

Population in the Region totaled nearly 1.9 million in 1965, an increase of more than 220 percent over the 1940 population. Nevada and Arizona rank first and second nationally in the rate of population growth. Most of the regional growth has occurred in the cities of Phoenix, Tucson, and Las Vegas. The problem of water supply in the urban centers is especially critical where ground water is the only source. With the population growth has also come demands for increased water-oriented recreational opportunities.

CLIMATE

One of the chief characteristics of the climate of the Lower Colorado Region is its variety. The wide range in climatic conditions is the result of large differences in altitude, a considerable range in latitude, and the distribution of mountain ranges and highlands (see figure 1).

Because of the different topographical features and elevation variations throughout the Region, a number of different climatic classifications are present. Most of the Region falls into Steppe climate, which stretches from the southeastern corner of the Gila Subregion northwestward into northwestern Arizona and the Nevada portion of the Region. With the exception of the higher elevations on the southern and western borders, all of the Little Colorado Subregion is also a Steppe climate. Desert climate predominates over the southwestern quarter of Arizona. The area south of the Mogollon Rim classifies as Warm Temperate climate while the higher elevations along the Rim have a Cold Snow Forest type of climate. North from the Mogollon Rim and at slightly lower elevations is a transitional zone between the Cold Temperate and Steppe climates. Southern Utah and the portion of Arizona north of the Colorado River have a Temperate climate.



A. NORMAL ANNUAL PRECIPITATION (INCHES)

B. NORMAL MAY-SEPT. PRECIPITATION (INCHES)

C. DAILY AVERAGE TEMPERATURE, JANUARY (°F)

D. DAILY AVERAGE TEMPERATURE, JULY (°F)

E. MEAN LENGTH OF FROST-FREE PERIOD (DAYS) BETWEEN LAST 32° F TEMPERATURE IN SPRING AND FIRST 32° F TEMPERATURE IN AUTUMN

F. MEAN ANNUAL LAKE EVAPORATION (INCHES)

FIGURE I

COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION

CLIMATIC DATA

1019-314-7

SEPTEMBER 1968

Precipitation

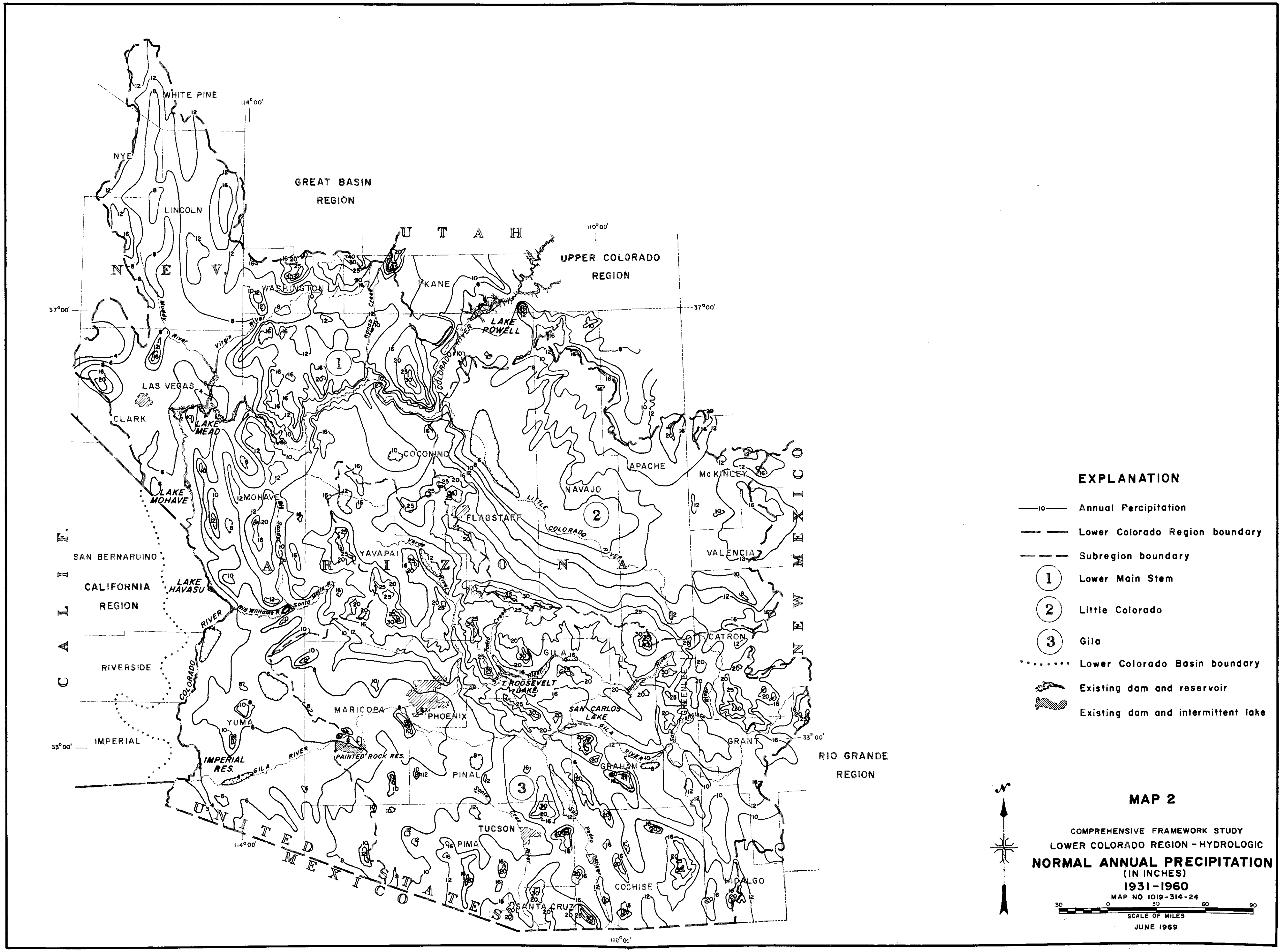
Approximately 100 million acre-feet of precipitation falls annually upon the Region. About 40 percent of the Region receives an average of 10 inches or less of precipitation per year, and a large part of the remainder receives less than 20 inches per year. In a few small areas, representing about one-half of one percent of the Region, the average annual precipitation is more than 30 inches (see map 2).

The southwestern part of the Region is the most arid. Near Yuma, Arizona, some areas receive less than 5 inches of precipitation per year. The mountain ranges that form the headwaters of the Verde, Salt, Little Colorado, and Gila Rivers, are the areas of highest precipitation. There are two distinct moisture sources. Winter precipitation is associated with moisture moving into the area from the Pacific Ocean, while the Gulf of Mexico is the source for much of the summer rainfall.

The desert areas of the Region are typified by meager summer precipitation, usually from thunderstorms, combined with low winter precipitation, which makes this area one of the driest in the United States. In the Steppe regions of Nevada, winter storms produce more precipitation than in the Yuma area, but nearly all mean annual totals are no more than 5 to 10 inches. Precipitation during the winter in the Desert and Steppe regions is usually in the form of rain, but snow is common in the mountains north of the Grand Canyon and on the Kaibab Plateau where snow accumulations during some winters can be considerable. In 1949, 86 inches of undrifted snow were measured on the ground at the Bright Angel Ranger Station on the North Rim of the Grand Canyon and maximum accumulations on the Kaibab Plateau may occasionally reach 100 inches.

Winter precipitation on the vast plateau of northeastern Arizona is usually light and about one-half of it falls as snow. From the middle of July until the end of August, thundershowers develop somewhere in the area almost every day. Many of these storms are of moderate to heavy intensity.

Precipitation in the transitional zone between Steppe and Cold Temperate climate is somewhat greater during the summer than on the Plateau itself because of the nearby mountains. During the winter, the portion of this zone along the Mogollon Rim does not get much more precipitation than the Steppe regions, because the nearby steep slopes



WHITE PINE
NYE
LINCOLN
GREAT BASIN REGION
UTAH
UPPER COLORADO REGION
NEVADA
WASHINGTON
KANE
LAKE POWELL
LAS VEGAS
CLARK
LAKE MEAD
COCONINO
APACHE
McKINLEY
NAVAJO
LAKE MOHAVE
MOHAVE
FLAGSTAFF
LITTLE COLORADO RIVER
CALIF.
SAN BERNARDINO
YAVAPAI
ARIZONA
VALENCIA
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EXPLANATION
Annual Percipitation
Lower Colorado Region boundary
Subregion boundary
1 Lower Main Stem
2 Little Colorado
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Lower Colorado Basin boundary
Existing dam and reservoir
Existing dam and intermittent lake
MAP 2
COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION - HYDROLOGIC
NORMAL ANNUAL PRECIPITATION
(IN INCHES)
1931-1960
MAP NO. 1019-314-24
SCALE OF MILES
JUNE 1969

of the Rim and the White Mountains intercept the flow of moisture from the southwest. As a result of these terrain effects throughout the year, nearly three-quarters of the annual average precipitation falls during the 6-month period May-October. The majority of the precipitation received during November through March falls as snow.

In the cold Temperate climate of the higher elevations along the Mogollon Rim and in the mountains of north-central Arizona, normal precipitation supports abundant natural vegetation. During the period July through the middle of September scattered afternoon thundershowers occur almost daily over the mountains. In some years during the warmer months, moderately heavy rain showers may persist for 2 or 3 days in a row. These showers are nearly always associated with the remnants of tropical disturbances moving northeastward from the Pacific Ocean. Most of the rest of the yearly precipitation falls during the winter months when middle-latitude storms move eastward from the Pacific Ocean. Most of this precipitation falls as snow, usually in light to moderate showers which may continue for several days. Snow accumulations may reach a depth of several feet during the colder winters, particularly on the northern slopes.

For most of the Gila Subregion, the summer rainy season produces more precipitation than the winter season. Precipitation during the summer comes in the form of thundershowers, some of which can be accompanied by strong winds, blowing dust, locally heavy rains and, occasionally by hail. Winter precipitation is frequently in the form of snow above the 4,000-foot level. Snow accumulations at higher elevations can be considerable.

There is usually a relatively dry period during May and June, between the winter and summer precipitation regimes, and again during the late fall, between the summer and winter precipitation seasons. Heavy rains, lasting several days, sometimes fall in August or September and are associated with tropical storms which inject moisture into the area from the southwest. Only five or six major storms of this nature have been observed in the past 50 years.

Temperature

Temperatures show a great deal of variability over the Region, depending mostly on elevation. In the Desert sections there is a long hot season beginning in April and ending in October. Maximum temperatures in excess of 100° F. are the rule during much of the summer. Predominately clear skies permit intense surface heating during the day and active radiational cooling at night, a process enhanced by the characteristic atmospheric dryness. These conditions produce a large diurnal temperature range, averaging 30° and sometimes exceeding 40°. Maximum temperatures in much of the Steppe region are in the 90's but there is still a large diurnal fluctuation in temperature. Mean annual temperatures range from 43.7° at Alpine in the mountaineous area of eastern Arizona to 72.4° at Gila Bend, Arizona, in the desert area.

At elevations above about 7,000 feet, the summer is relatively cool. During the warmest months, temperatures normally vary from the low 40's near daybreak to the middle or upper 70's in the early afternoon, with readings above 90° extremely rare. On the other hand, freezing temperatures may occur at night even in the warmest months. Readings below zero occur regularly in midwinter and have been reported in early November and in late March. Temperatures may fall as low as 30° below zero in parts of the White Mountains during extremely cold spells.

Summers in the Steppe climate are relatively mild and readings above 100° are uncommon. The diurnal variation of temperature is quite large, approaching 40° in May and June when the air is dry and skies are clear. Winters in this section are chilly. The average temperature in the coldest month is near freezing; however, readings as low as 20° below zero have been recorded. In general, temperatures usually rise from subzero to the upper forties; however, afternoon temperatures exceeding 70° may occur on unusually mild midwinter days.

In the transitional zone between the Steppe and Cold Temperate climate, winter temperatures are somewhat lower than those in the Steppe region. Temperatures as low as zero are recorded nearly every year, and occasionally temperatures as low as 10° below zero are recorded. Summers have comfortably warm afternoons and cool nights. Average maximum temperatures during the hottest part of the summer are in the low eighties and, on the average, the temperature reaches 95° or more in only one summer out of ten (see figure 1, inserts C. and D.).

Wind

Winds throughout this entire Region are greatly affected by the slope and character of the terrain, and mountain-valley winds are quite pronounced in many areas. Normally the wind blows uphill during the hotter part of the day and then reverses from sunset until midmorning. Strongest winds usually occur during the summer months during intense thunderstorm activity, and peak gusts of 75 to 100 miles per hour have been observed during such severe activity. The direction of these extreme winds is random in most areas throughout the Region.

Relative Humidity

Relative humidity shows large diurnal and seasonal variations, being highest near the time of occurrence of the minimum temperature and lowest when the maximum temperature is observed. In general, over most of the Region, the relative humidity reaches a peak in December and January, decreasing steadily as summer approaches and reaching a low point in May and June. In July and August there is a humidity increase which is more marked in the southern sections, followed by a gradual decrease in September and October, then an upswing to the peak in early winter.

Evaporation

The combination of high temperatures and low humidity causes high rates of evaporation and transpiration within the Region. In the desert areas where the need for water is greatest, precipitation is least and potential evapotranspiration is greatest. The gross annual evaporation rate varies from about 50 inches in the north to 86 inches along the Lower Main Stem (see map 3 and figure 1, insert F.).

Length of Growing Season

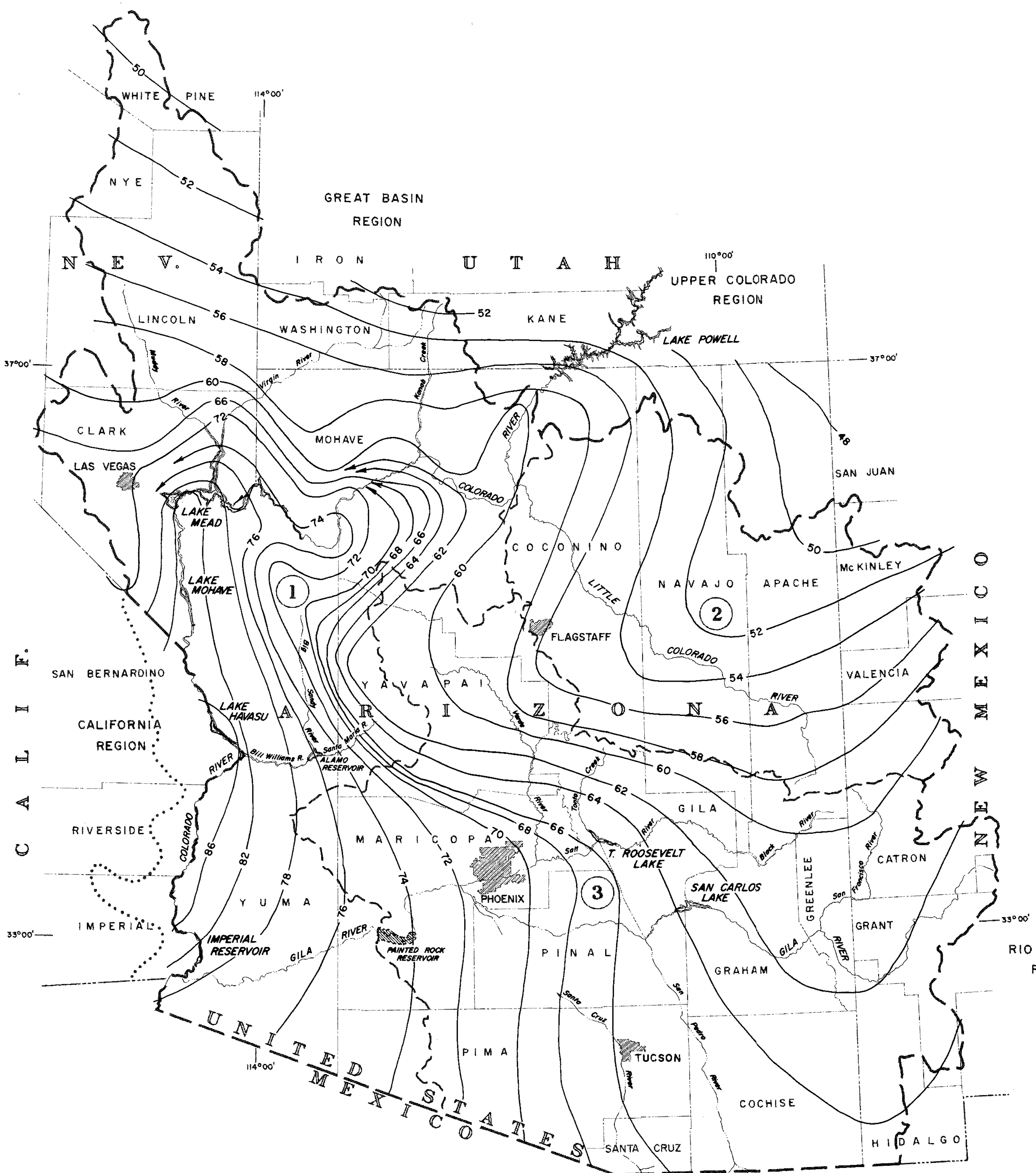
Like the temperature, the length of growing season in the Region is quite variable and depends on the local elevation and also on the nature of the surrounding terrain. Based on the 32-degree threshold, the mean growing season in the Yuma area can be 300 days or longer. In the mountainous areas of the Region the growing season may be as short as 60 days (see figure 1, insert E.).

WATER SUPPLY

Introduction

There are three sources of water supply presently available for use in the Lower Colorado Region: (a) the portion of Colorado River flows delivered at Lee Ferry, (b) local runoff originating within the regional boundaries, and (c) local ground-water.

Flows originating in the Upper Colorado Region and released through Glen Canyon Dam constitute a major source of supply to the Lower Colorado Region. If sufficient Colorado River main stem water is available for release to satisfy 7,500,000 acre-feet of annual



EXPLANATION

- 66 — Evaporation contour
- Lower Colorado Region boundary
- Subregion boundary
- (1) Lower Main Stem
- (2) Little Colorado
- (3) Gila
- Lower Colorado Basin boundary
- Existing dam and reservoir
- Existing dam and intermittent reservoir

MAP 3

COMPREHENSIVE FRAMEWORK STUDY

LOWER COLORADO REGION – HYDROLOGIC

MEAN ANNUAL LAKE EVAPORATION

(IN INCHES) (Gross)

MAP NO. 1019-314-23

30 0 30 60 90

SCALE OF MILES

APRIL 1969

consumptive use in the three Lower Colorado River Basin States, Arizona, Nevada, and California are apportioned 2,800,000, 300,000, and 4,400,000 acre-feet, respectively. The Mexican Treaty of 1944 provides for delivery of 1,500,000 acre-feet of water annually to Mexico. The surface-water supply available for use within the Lower Colorado Region is distributed according to the many State and Federal laws, acts, and decrees applying to water rights. The use of ground water is controlled by State laws in most of the developed areas of the Region.

The usable capacity of the principal reservoirs in the Lower Colorado Region whose function is the conservation and regulation of the surface-water supply is about 32,000,000 acre-feet. These reservoirs control and regulate the orderly use of most of the available surface-water supply in the Lower Colorado Region. Spills which are lost to the Region occur infrequently. Tributary floods on the Colorado River below Lake Havasu and the occasional regulated release of flood waters from Painted Rock Dam, a flood control structure at the Gila Subregion outflow point, are the primary causes of these spills. It should be noted, however, that the historic runoff of the Colorado River prior to 1930, if repeated, could cause large spills from the Region.

The history of water development in the Lower Colorado Region is one of deficient surface-water supplies being supplemented by the ground-water resources. As the ground-water development intensified, water levels declined. The exploitation of this resource brings with it a multitude of problems, some of which are economical and some physical. Land subsidence and degradation of water quality have occurred in some areas as a result of the overdraft of ground-water reservoirs.

Conservation of the limited surface-water supply is practiced on all fronts. Water losses are being reduced through the lining of conveyance systems, automated water control for better management, and a number of programs aimed at increasing the irrigation efficiency of the farmer. Significant progress has been made in increasing the planned use of municipal and industrial waste water and brackish water. Evaporation suppression and soil treatment in watershed areas hold considerable promise. One program which frequently encounters opposition is the selective removal or manipulation of vegetation in river channels and flood plains to increase water yields. The existence of opposition points out the necessity for assigning priorities for water use.

Surface Water

Undepleted runoff is streamflow unaffected by manmade diversions, imports, storage, or other works of man. Sometimes referred to as natural or virgin flow, its derivation is a function of the historic streamflow and the manmade depletion of that streamflow. Where the depletion is nonexistent or very small the historic streamflow approaches undepleted or natural flow. Although the historic streamflow may be measured with a relatively high degree of accuracy, manmade depletions are most often subject to estimates derived from theoretical procedures, indirect measurements, and considerable judgment. Many ephemeral streams in the Lower Colorado Region are essentially undeveloped; however, only a few of these have ever been measured.

Colorado River

The average annual undepleted flow of the Colorado River as it enters the Lower Colorado Region is estimated at about 15.09 million acre-feet for the 60-year period 1906-65. In its natural state the river would gain an average of about 1 million acre-feet of water during its journey through the canyons to the site of Hoover Dam, then lose more than the million acre-feet gained in the upper reaches as the river continues its course toward the Gulf of California. With the contribution of the Gila River near the Mexican border, the Colorado River's average annual undepleted flow into Mexico would be about 15.9 million acre-feet. Various estimates of virgin flow of the Colorado River at Lee Ferry have been developed by experts using varying periods of record for consideration. Estimates of these flows and annual historic flows as shown on figure 2 conform with those established as legislative history during congressional hearings concerning the Lower Colorado River Basin Project.

The Colorado River today is almost completely controlled by the Upper Colorado River Basin storage projects and Lake Mead, having a combined storage capacity of about 60 million acre-feet. The release of water from Glen Canyon Dam, 17 miles upstream from the Compact Point, is dependent on many variables. However, Article IIId of the Colorado River Compact provides that the river at Compact Point will not be depleted below an aggregate of 75 million acre-feet for any period of 10 consecutive water years.

FIGURE 2

VIRGIN FLOW
COLORADO RIVER AT COMPACT POINT
LEE FERRY

AVERAGE VIRGIN FLOW

PERIOD	MAF
1896-1968	14.82
1906-1965	15.09
1914-1965	14.64
1922-1965	13.87
1931-1965	13.09

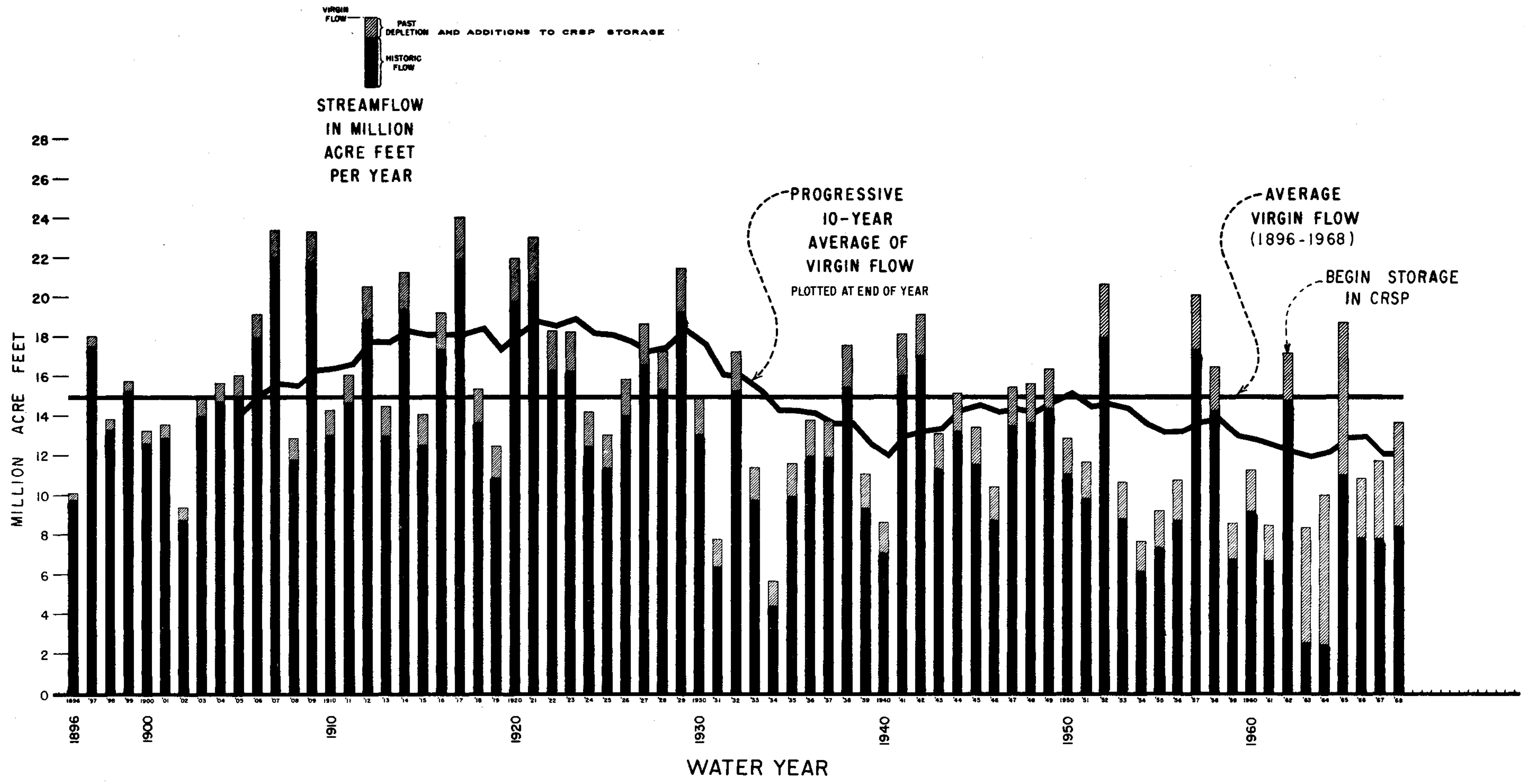


FIGURE 2

The Boulder Canyon Project Act, among other things, authorized the construction of Hoover Dam and the All-American Canal. Hoover Dam storage began in 1935 and brought the first control to the Colorado River. Since then various other surface-water control works have been built providing flood control, electrical power, and reregulation for benefit of downstream irrigators and Mexican Water Treaty commitments.

Local Runoff

There is a wide variation in annual runoff within the Region. In the desert areas, where runoff is directly dependent on rainfall, the bulk of the flow, if any, occurs during the summer--July through September. Above the major storage reservoirs, peak monthly runoff generally occurs during the March-June period as a result of snowmelt in the high mountains.

The distribution by Subregion of average annual runoff (undepleted water supply) for the period 1914-1965 is estimated as follows:

	Million Acre-Feet
Subregion 1 (Lower Main Stem)	0.90
Subregion 2 (Little Colorado)	0.42
Subregion 3 (Gila)	1.80
	3.12

The average undepleted water supply contributed by the tributaries of the Lower Colorado River, exclusive of the Little Colorado and Gila Rivers, is estimated as about 0.9 million acre-feet annually. Tributary development is not extensive and most of this supply is consumed by uses along the main stem, including channel losses. Major water storage features on the main stem with a usable capacity of about 28.6 million acre-feet include Hoover, Davis, and Parker Dams. Headgate Rock, Palo Verde, Senator Wash, and Imperial Dams, also on the main stem, are primarily control and diversion structures without holdover storage.

Under the natural environment, the Little Colorado River contributed an average of about 0.42 million acre-feet annually to the Colorado River. A large portion of this supply is produced from springs near the mouth. Most of the water resource development in the Little Colorado Subregion is at and above Winslow, Arizona. Major reservoirs include Lyman Reservoir near St. Johns, Daggs Reservoir on Silver Creek, and Lakeside, Lone Pine, and Fools Hollow Reservoirs on Show Low Creek. Transbasin diversions to the Gila Subregion are made from Lake Show Low and from Blue Ridge Reservoir on East Clear Creek.

The average annual undepleted water supply of the Gila River is estimated as about 1.8 million acre-feet in the upstream area of central Arizona, 1.3 million acre-feet at the site of Painted Rock Dam, and about 1.1 million acre-feet at the Colorado River. Channel losses through the desert reduced the flow considerably. Almost 90 percent of the estimated local water supply originates from the Salt River and the Gila River above Kelvin. Eight major reservoirs having a combined usable storage capacity of 3.2 million acre-feet almost completely control the flows entering central Arizona. Six of these reservoirs are located on the Salt River and its major tributary, the Verde River. Perhaps the most notable is Roosevelt Lake with a storage capacity of about 1.4 million acre-feet. Completed in 1911, Roosevelt Dam was one of the first projects begun under the Reclamation Act of 1902. The other Salt River reservoirs are Apache Lake, Canyon Lake, and Saguaro Lake; and on the Verde River are Horseshoe and Bartlett Reservoirs. San Carlos Reservoir, with a present storage capacity of about 1 million acre-feet, controls the available water supply originating in the upper reaches of the Gila River. Waddell Dam on the Agua Fria River provides a reservoir with a storage capacity of about 0.16 million acre-feet. Painted Rock Reservoir, located on the Gila River at the subregional outflow point, provides protection from floods originating above the reservoir site to the intensively developed irrigated lands on the lower Gila River and the Colorado River near Yuma. Developments above the major reservoirs are limited usually to small surface-water diversions and to ground-water development.

Ground Water

The Lower Colorado Region is divided into three parts based on physiographic, geologic, and hydrologic characteristics, as shown on map 1. These are the Basin and Range Lowlands, the Plateau Uplands, and the Central Highlands. A discussion of the relation of the physiographic and geologic setting to the occurrence of ground water follows.

Basin and Range Lowlands

The Basin and Range Lowlands is characterized by isolated mountain blocks separated by broad alluvial-floored basins; the altitudes of the basin surfaces range from about 100 to as much as 4,500 feet above mean sea level. The altitudes of the mountain blocks are as much as 10,000 feet above mean sea level and usually are between 1,000 and 4,000 feet above the floors of the subjacent basins. Most of the valleys in the Basin and Range country trend north to northwest, and the predevelopment undisturbed movement of ground water within them was parallel to the flow direction of the present major streams in the valleys. These alternating mountains and valleys were produced by large-scale faulting in which the mountain blocks were pushed upward and the basins were dropped. Subsequent to the faulting, the valleys were filled with alluvial material eroded from the mountain masses. The mountain masses are composed chiefly of granite, gneiss, schist, and quartzite, and some are capped with volcanic rocks.

The occurrence of ground water in the Basin and Range Province is related directly to the geologic history of the rocks of the area. Subsequent to the major faulting that formed the mountains and valleys, several stages of erosion and sedimentation filled the valleys with the materials that now form the major aquifers in the Region. This older alluvial fill consists of lenses of gravel, sand, clay, and silt in varying thicknesses; locally, it may be as much as 3,000 feet thick. In general, the deposits grade in texture from large boulders near the mountains to fine-grained sediments along the axes of the valleys.

In some basins, where clay beds form a confining layer, the ground water beneath is under artesian pressure. Ground water in the coarse materials above the clay beds is under water-table conditions. Localized clay beds within the upper coarse materials sometimes support widespread perched or semiperched water bodies.

The present drainages cut on the older alluvium have been filled to various depths with unconsolidated deposits of gravel, sand, and silt. In many basins this younger alluvial fill along the flood plains of the present streams in the Basin and Range Lowlands provides large amounts of ground water. The amount of ground water that can be obtained from the younger fill in any particular area depends upon the depth and areal extent of the deposits.

Other rock types store and transmit small quantities of ground water in the Basin and Range Lowlands, but they are insignificant in comparison to the amount obtainable from the alluvial-fill materials.

Plateau Uplands

The Plateau Uplands includes a variety of landforms--canyons, buttes, mesas, and volcanic mountains. The altitude ranges from about 4,000 to over 12,000 feet above mean sea level but is mostly between 5,000 and 7,000 feet. The most spectacular physiographic feature of the Plateau Uplands is the Grand Canyon of the Colorado River, which cuts across the northwest corner of the area.

Although all three of the principal rock types--igneous, sedimentary, and metamorphic--are present, the sedimentary rocks are the most important to the occurrence of ground water in the area. These include sandstone, siltstone, claystone, and limestone. The siltstone and claystone are highly impermeable and form confining beds throughout most of the area. Where the water-bearing sandstone and limestone formations alternate with these confining beds, water in the aquifers is under artesian pressure.

The main withdrawal of water in the Plateau Uplands is from four multiple-aquifer systems, the C, N, D, and W aquifer systems. The C multiple-aquifer system includes the Coconino Sandstone and its lateral equivalents the De Chelly Sandstone in the Defiance Plateau and the De Chelly Sandstone Member of the Cutler Formation in the Monument upwarp. It may include the overlying Kaibab Limestone and the topmost beds of the underlying Supai Formation in the Mogollon Mesa-Kaibab Plateau area. The N multiple-aquifer system is in the northern part of Coconino, Navajo, and Apache Counties in Arizona and Washington and Kane Counties in Utah and consists of the Navajo Sandstone, the Kayenta Formation, and the Lukachukai Members of the Wingate Sandstone. The D multiple-aquifer system is composed chiefly of the Dakota Sandstone and is well developed in Black Mesa and along the Arizona-New Mexico State line, where the Dakota Sandstone overlies the Cow Springs Sandstone or sandstone beds of the Morrison Formation. The W multiple-aquifer system includes the Wahweap Sandstone, Straight Cliffs Sandstone, Wasatch Formation, and Kaiparowits Formation and occurs in that part of the Region drained by the Virgin River from the Kolob Terrace east to Pink Cliffs in Washington and Kane Counties in Utah. In parts of the area, volcanic materials yield small amounts of ground water where underlain by impervious materials. In other areas these volcanic materials are porous and water percolates downward into the underlying formations. Along the Little Colorado River and its principal tributaries, shallow alluvium stores some ground water. However, the alluvium usually also is fine grained and does not yield or store large amounts of ground water.

Central Highlands

The Central Highlands is composed of all types of rocks--sedimentary, igneous, and metamorphic--and each type has distinctive water-bearing characteristics. The geologic structure of the province is also an important feature in appraising its water resources.

The most prominent structural feature of the Central Highlands is the Mogollon Rim. The intrusive igneous rocks, mostly granites, which form the core of the Central Highlands and are exposed extensively, are impervious and contain little space for the storage of water. However, in places they are fractured and faulted and small amounts of water are stored in these fracture openings. Where these fractures are at the surface, ground water may issue as springs. Volcanic rocks, which form a large part of the surface area, are permeable and water moves downward into the underlying rocks. In a few small valleys alluvial sediments provide storage for minor amounts of ground water.

Depth to Water

Map 4 depicts depth to ground water, in feet below land surface, in wells tapping the main aquifers in the Lower Colorado Region for the base year 1965. For purposes of this presentation, depth to water is divided into four ranges--less than 200 feet, 200 to 500 feet, greater than 500 feet, and from 0 to 500 feet below land surface. Where data are lacking, mainly in remote or mountainous areas, no depth symbol is shown on the map.

The map presents a very generalized picture, and local exceptions occur. In some areas in Arizona, as parts of the San Simon Valley and the Safford Valley, the upper San Pedro River Basin near St. David, and part of the Navajo Indian Reservation, wells flow at land surface.

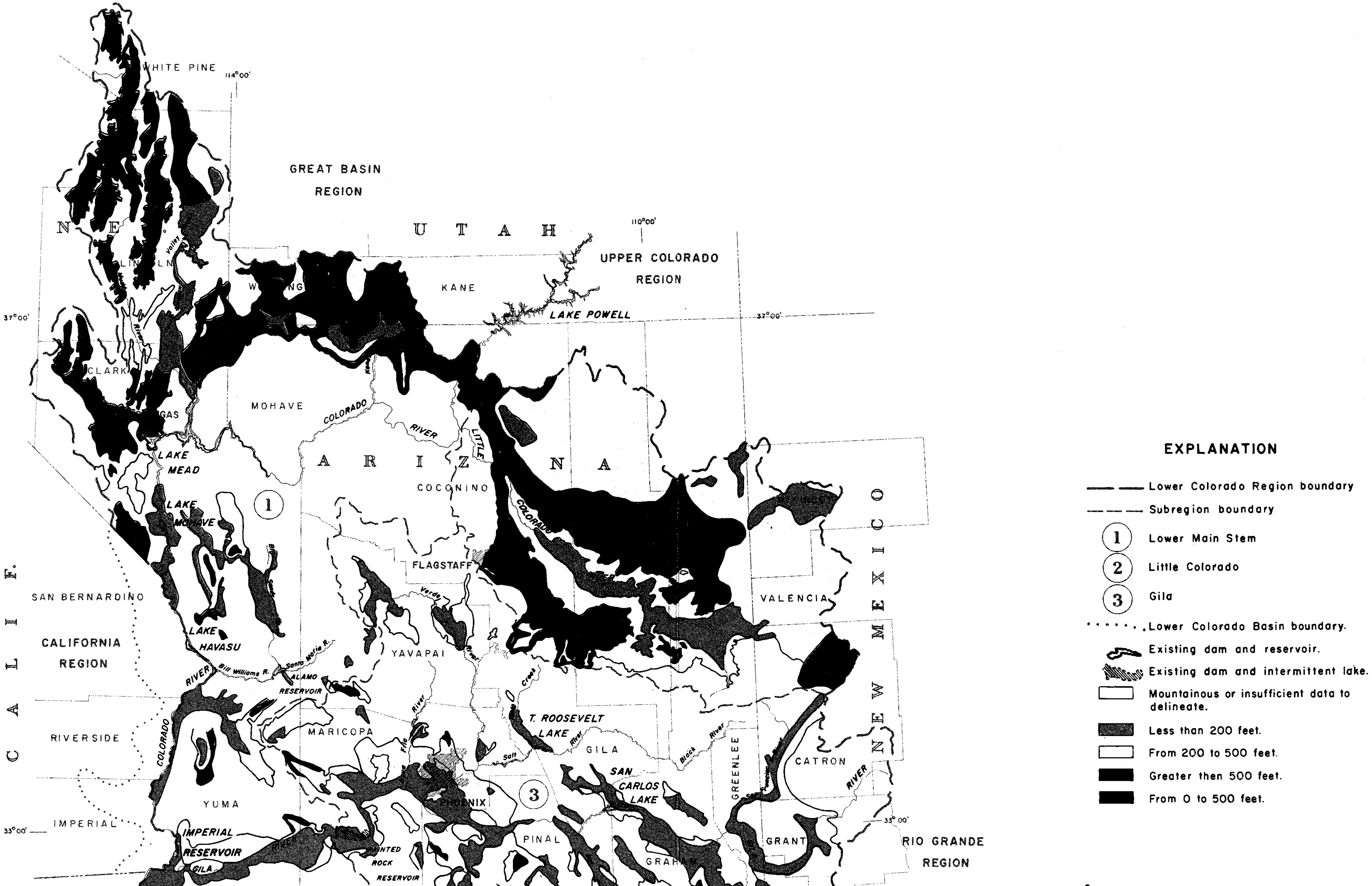
Change in Depth

Map 5 depicts changes in water levels in wells in the Lower Colorado Region from 1960 to 1965. The general picture is one of almost continuous water-level decline except in a few areas. Declines have been more than 60 feet in the 5-year period in the San Simon, Willcox, lower Santa Cruz, and Phoenix basins in Arizona and in the Las Vegas basin in Nevada. Rises in water levels in wells have been associated with areas where drainage of applied surface water for irrigation is a problem, where pumping of ground water for irrigation has decreased, or where recharge from streamflow has been above average.

Ground Water in Storage

As used in this appendix, usable or recoverable ground water is that portion of total water in storage which could be extracted with equipment and methods now available, but without regard to economic, physical, legal, and environmental factors. These factors are discussed in the following section of this appendix, "Constraints on Ground-Water Developments." Under this definition the volume of recoverable ground water to depths of 200, 700, and 1,200 feet below land surface in the main alluvial aquifers in the Lower Colorado Region is shown on table 3. No estimate was made for the alluvial aquifers in the Plateau Uplands of Utah or northern Arizona, since these aquifers, though locally important as sources of some domestic and minor amounts of irrigation water, do not contain large amounts of ground water in storage.

Also shown on table 3 is the amount of ground water in storage in the upper 100 feet of saturated thickness of the main alluvial aquifers in the Lower Colorado Region.



MAP 4

COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION-HYDROLOGIC

DEPTH TO WATER

1965

MAP NO. 1019-314-37

30 0 30 60 90
SCALE OF MILES

OCTOBER 1969

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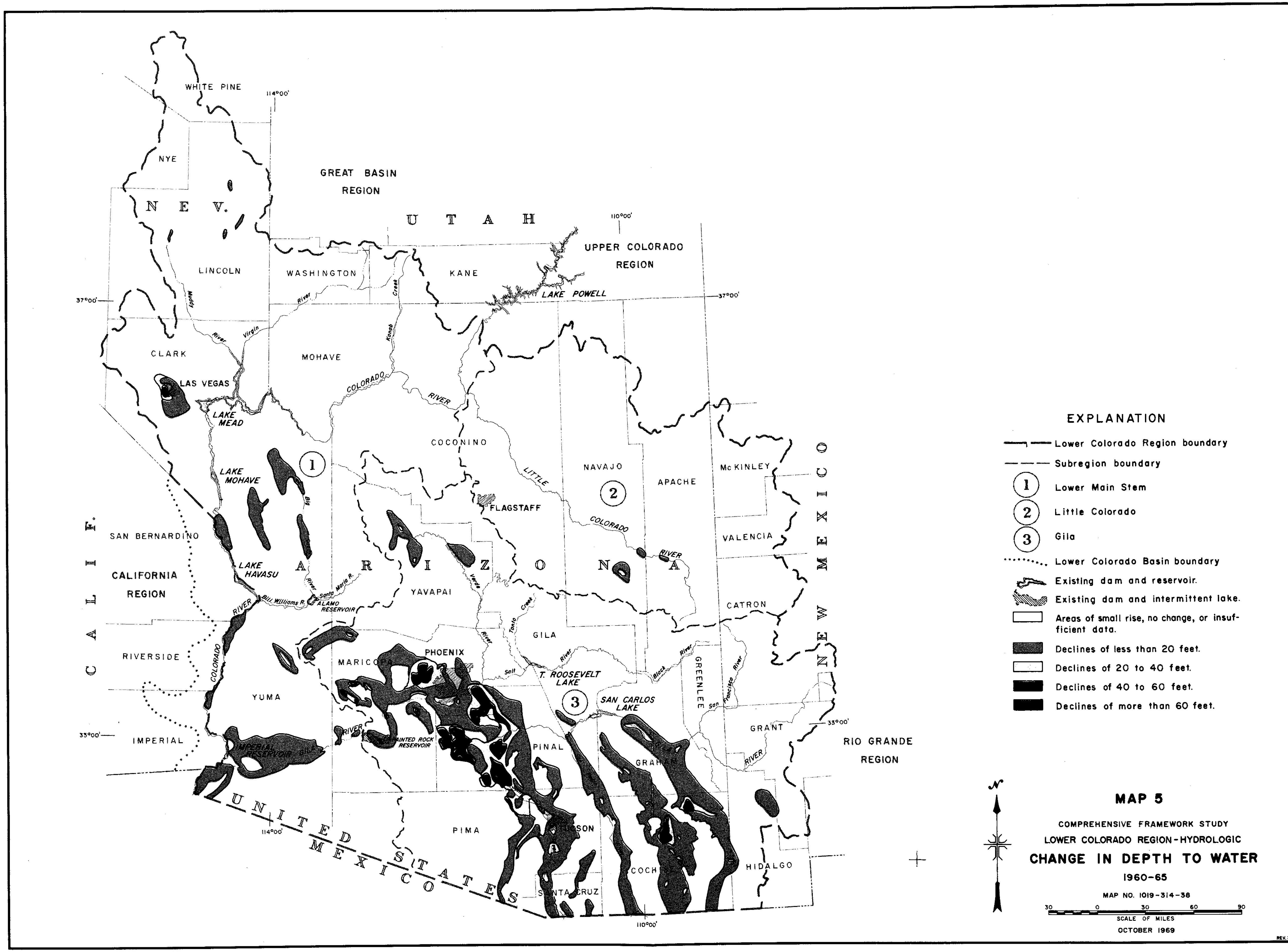


MAP 5

COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION - HYDROLOGIC

CHANGE IN DEPTH TO WATER
1960-65

MAP NO. 1019-314-38

OCTOBER 1969

Table 3

Amounts of Ground Water in Storage in Main Alluvial Aquifers--Lower Colorado Region

Units: Million ac-ft

Area	Amounts of Ground Water in Storage: At depths to water below land surface equal to or less than 200 ft	700 ft	1,200 ft	In upper 100 ft of saturated thickness
Main Stem Subregion				
Nevada	12	140	190	53
Arizona	27	290	430	56
Utah 1/	--	--	--	--
Subtotal	39	430	620	109
Little Colorado Subregion 1/	--	--	--	250
Gila Subregion				
New Mexico	12	80	90	18
Arizona	58	480	720	96
Subtotal	70	560	810	114
Regional Total	109	990	1,430	473

1/ Quantity of ground water stored in alluvial aquifers in Utah and Little Colorado River basins is minor.

In the Little Colorado Subregion the N, C, D, and W multiple-aquifer systems, which are made up of sandstones and limestones, are greater potential sources of water than the alluvial aquifers. About 16 million acres are underlain by these systems, and about 250 million acre-feet of recoverable ground water are stored in a 100-foot-thick section of aquifer.

Although the amount of ground water available from storage in all of the alluvial and multiple aquifers of the Region is tremendous, the environmental and economic soundness of further exploiting this resource is of real concern. Long-range water resource planning concepts do not normally include, except where dictated by localized circumstances, the deliberate and ultimate depletion of a nonrenewable resource. Most efforts are being directed toward achieving a reasonable balance between man's need and the renewable resource.

Constraints on Ground-Water Development

Much of the present economic development of the Region has been made possible through the mining of the Region's ground-water reserves. Even though these reserves are still large, many problems attendant to its extraction and use may preclude the further economical development in the Region of much of this resource. Continuing dependency on ground water to sustain or expand the Region's economy must be analyzed carefully.

In most areas in the Lower Colorado Region where ground water is being pumped, it is being used far in excess of the rate of replenishment; consequently, water levels are declining, and pumping lifts and costs are increasing. Additionally, in some areas in central Arizona and Nevada where large amounts of water have been pumped from the alluvial aquifers, land subsidence has occurred. This subsidence has caused earth cracks which disrupt natural drainage, has caused sheared and collapsed well casings, misalinement of highways, railroads, and irrigation canals, and has endangered structures such as buildings and bridges. Continued pumping from alluvial aquifers in areas already affected by this condition can only aggravate an already troublesome problem. Continued dewatering of alluvial aquifers in areas not yet affected will certainly result in many more cases of land subsidence. Another environmental effect of water table declines has been the dewatering of marshes and other wetland resources which are important as wildlife nesting and feeding grounds.

A part of the recoverable ground water in storage is highly mineralized and would require treatment before it is suitable for either irrigation or domestic use. In other areas objectionable fluoride and boron concentrations preclude its use for many purposes.

Other factors which make development of remaining ground-water reserves impractical or uneconomical include legal constraints, degrading quality, remote location, low aquifer yield, pumping depth, and location in basins of relatively small storage capacity. Although wells of high yields can still be drilled in some of the deeper basins, much of the untapped reserves are at depths of more than 500 feet. Efficient mining of this water, as well as much of the ground water located closer to the land surface, would require detailed well design and spacing, and the installation of much deeper wells than currently exist in most areas.

If properly controlled, managed, and integrated with the other sources of water available to the Lower Colorado Region, ground water reserves can continue to serve future generations. If exploitation and development continue at or near current levels, the nonrenewable ground-water reserves of the Region will be impaired as a water management resource.

Recharge of Ground Water

Recharge is new water added to the ground-water system. The ground-water reservoirs in the alluvial basins are recharged from several sources: (1) runoff from precipitation in adjacent mountain ranges, (2) infiltration of excess applied irrigation water and canal seepage from surface-water sources, (3) underflow from upstream basins, and (4) direct penetration of precipitation.

A large part of the precipitation on the mountain ranges adjacent to the valleys in the Basin and Range Lowlands is lost to the atmosphere by evaporation and transpiration by native vegetation. A part becomes runoff and reaches the coarse alluvial materials at the mountain fronts where it recharges the ground-water reservoir. Data from the upper Santa Cruz River Basin indicate that from 3 to 6 percent of the precipitation on the mountains may become recharge to ground water. These percentages would not be exact for all the alluvial basins but they probably are in the right order of magnitude.

A part of the water applied to the land for irrigation in the valleys is returned to the ground-water reservoir by infiltration. In some areas possibly as much as 25 percent of the water applied to irrigated fields may infiltrate to the ground-water reservoir but in other areas the amount from this source probably is negligible. The amount of return for any given time interval is a function, not only of the amount of water applied but also of the rate at which the water percolates toward the zone of saturation. The rate at which this water moves downward depends upon the permeability of the materials through which it must pass. Other factors, as depth of root zone, capillarity, soil moisture, temperature, and amount of direct sunlight on the ground, influence the return to ground water from this source. Some water also is returned to the ground-water reservoir where unlined canals are used from the source to the point of use. Infiltration from canals and water applied to fields is recharge to the ground-water system only if the source of the water is surface water. If the water applied is pumped ground water, then the part that returns to the ground-water reservoir by infiltration only serves as a credit against pumpage.

The ground-water reservoir in some basins is recharged by the movement of water by underflow from upstream areas through permeable materials underlying stream channels or other areas not completely obstructed by the hard-rock barriers that separate the basins. This movement of water between basins is recharge to the lower basin, but at the same time it is discharged from the upper basin. From the point of view of the Subregion, underflow can be recharge only once; it cannot be counted more than once in reference to the total system.

Most of the rain that falls on the valley floors in the Basin and Rand Lowlands evaporates directly from the soil zone or is transpired by vegetation. Some water seeps downward to the ground-water reservoir where the precipitation falls directly on the coarse-grained materials along the washes that traverse the valley floor, but the amount probably is negligible. In the mountain areas most of the precipitation either becomes runoff or is evaporated because of the steep slopes and impermeable character of the rocks. Direct recharge from precipitation probably is small over most of these areas.

Recharge to the ground-water reservoirs in the Lower Main Stem is very small due to low rainfall and high evaporation and transpiration losses. Only along the Colorado River where surface water can be recharged to the alluvium along the river does recharge occur regularly and predictably.

A part of the water applied to the land for irrigation is returned to the ground-water reservoir by infiltration. In some areas a large part of the water applied to irrigated fields appears to infiltrate to the ground-water reservoir as in the Wellton-Mohawk and Yuma Mesa areas of southwestern Arizona, but in other areas the amount from this source probably is negligible.

Ground-water recharge in the Little Colorado Subregion is from precipitation that falls on the upturned rocks exposed in the highlands. The principal recharge areas probably contribute more than 80 percent of the ground-water recharge to the aquifers. These areas are generally above 6,000 feet and usually receive more than 15 inches of precipitation annually.

Movement of Ground Water

Under natural conditions the direction of movement of ground water in the alluvial basins is generally from the margins toward the axis of the basin and along the axis in the direction of the slope of the land gradient. The rate of movement of ground water in alluvial basins probably ranges from only a few feet to several hundred feet per year. Within a basin the most rapid movement probably is toward the axis from sources of recharge along the margins of the basin. Development of ground water in an area modifies both the direction and rate of movement; the amount and nature of the modification depends on the volume of ground water removed and the pattern of removal.

Ground-water movement in the Lower Main Stem Subregion is, except where disturbed by pumping, generally parallel to the axes of the basins and toward the Colorado River. In 13 Nevada basins of interior surface drainage, which apparently constitute a unified hydrologic system, ground-water movement is southward and, in some places, water apparently moves through the faults in the consolidated rocks of the mountains to basins that are downgradient but across topographic divides.

Regional movement of ground water in the C, N, and D multiple-aquifer systems in the Arizona part of the Little Colorado Subregion is toward the Little Colorado River. In the New Mexico part of the Subregion the general direction of ground-water movement is northward toward the San Juan River, but south and west of Gallup, movement is toward the Puerco River. South of Kayenta and east of Black Mesa, ground water moves northeastward to the San Juan River. In the Colorado Plateaus west of Flagstaff the general direction of ground-water movement is toward the Colorado River and its tributaries.

Ground-water movement in the Gila Subregion generally conforms to that discussed in the opening paragraph of this section.

Natural Discharge of Ground Water

Ground water is discharged from the alluvial basins by both natural and artificial means. Natural means of discharge include: (a) evaporation, (b) transpiration, (c) underflow out of the basin, (d) effluent seepage, and (e) spring discharge.

Locally, small amounts of ground water may be discharged by direct evaporation in areas where the water table is near the surface. However, in many of the alluvial basins in the southern part of the Basin and Range Province, the water table is now sufficiently below the surface to prevent any significant amount of discharge in this manner. As the depth to water approaches 10 feet, the discharge of ground water by evaporation becomes negligible. However, evaporation takes a large part of the precipitation that might otherwise become ground water.

Large amounts of ground water are transpired from ground-water reservoirs by vegetation. In many areas the vegetation is quite dense, and uses thousands of acre-feet of groundwater each year. Several studies are being conducted on possible increase of water yield by replacing selected deep-rooted vegetation with grass or other shallow-rooted species.

In some basins ground water is discharged as underflow to downstream basins through permeable materials underlying stream channels, or through the saturated material lying between the hardrock barriers that separate the basins.

Some ground water is discharged by effluent seepage into stream channels where the water table intersects the streambed. Ground water provides the base flow of some streams, and during periods of high runoff these same streams may supply water to the ground-water reservoir.

Ground water is discharged by springs where the water table intersects the land surface or where water from deep artesian aquifers finds an outlet through fractures or fault zones. Two-thirds of the ground water moving through the Black Mesa area, about 225,000 acre-feet annually, discharges from many springs near the confluence of the Little Colorado and Colorado Rivers. The yield from Blue Spring is chiefly from the C multiple-aquifer system. Ground-water discharge from the N multiple-aquifer system and other aquifers is evaporated or used for irrigation near the points of discharge. Other major areas of ground-water discharge from springs are between St. Johns and Springerville, the source of Silver Creek, between Winslow and Holbrook, and near Tuba City.

Yields of Wells

Well production in the Region ranges from less than 1 gpm in the hard rock of the mountains to more than 2,500 gpm in the extensive alluvial aquifers of the basins and along the major rivers. Highest potential well production occurs in the Basin and Range Lowlands where thick extensive alluvial aquifers provide highly permeable reservoirs capable of yielding large quantities of water to properly constructed wells which tap the full thickness of the aquifer. Wells near the margins of the basins and the shallower basins in the Central Highlands can yield as much as 500 gpm, and most properly located and constructed wells tapping the full thickness of the aquifer are capable of producing at least 100 gpm. Most wells in the Plateau Uplands are capable of yielding at least 10 gpm; generally, yields of 50 gpm can be obtained and in a few places wells can yield as much as 500 gpm. In some of the less productive areas well production in the 0 to 50 gpm range could be increased by drilling below depths of more than 2,000 feet.

Of the multiple-aquifer systems the most extensive is the C system, which underlies the entire Little Colorado River Basin. In general, wells tapping the C multiple-aquifer system yield from 5 to 600 gpm of water, but in the Hunt-St. Johns area in Arizona some irrigation wells yield from 800 to 2,000 gpm. The greatest yields are obtained from zones of extensive fracturing.

Potential well yields in the St. Johns-Joseph City-Showlow area range from 50 to more than 2,500 gpm, and most wells should be capable of producing 1,000 gpm, assuming that the well is favorably located and is sufficiently deep to tap the full thickness of the aquifer. In the northern part of the basin the N multiple-aquifer system is the major aquifer. Wells tapping this system obtain from 50 to 400 gpm. Potential yields of wells tapping the full thickness of the aquifer range from 10 to 500 gpm, and most wells yield about 100 gpm. Yields of wells that tap the D multiple-aquifer system are low and generally range from 0 to 50 gpm. Most wells will yield 10 gpm.

Potential for Artificial Recharge

The potential for artificial recharge in the Lower Colorado Region is high. Dewatering of aquifers by pumping in excess of natural recharge has created additional potential reservoir space for ground-water storage and has increased ground-water gradients from recharge areas to centers of pumping. Existing stream channels are exceptionally efficient modes of recharge. Data indicate that in the Santa Cruz River Basin as much as 86 percent of the total inflow to the river system may be recharged to the ground-water reservoir. Conjunctive use of surface water and ground water is possible by managing riverflow and depth to water near stream channels so that all streamflow infiltrates to recharge the ground-water reservoir. If flow is regulated to increase infiltration along a streambed having alluvium of limited storage capacity, the ground-water system must be managed as an integral part of the operation and wells must pump ground water from the aquifer so that storage is available for infiltrating surface water. Even though conjunctive management of a surface- and ground-water system could locally increase ground-water recharge, the net increase within the Region would be small.

Artificial recharge through wells, though technically feasible, is fraught with problems which include silt- and bacteria-laden water, chemical incompatibility of recharge water with native ground water, air entrainment and dissolved gases in the recharge water, incomplete recovery of recharged water, short well life, and high cost of recovered water. Under favorable circumstances, however, recharge pits and spreading grounds can be successful.

Direct recharge of large quantities of water to the C, D, and N multiple-aquifer systems through wells is precluded by the fine-grained character of the material and its generally low hydraulic conductivity. In a few places where extensive fracturing of the aquifer has occurred and hydraulic conductivity is relatively high, artificial recharge through wells may be technically feasible; but in these few places depth to water is great, and technical difficulties could be encountered in attempting recharge of water under high heads.

WATER QUALITY

Regionally, mineral water quality as expressed by total dissolved solids (TDS) concentrations, is generally poor in contrast to that in many other parts of the Nation. With few exceptions, most surface- and ground-water supplies have mineral concentrations exceeding 500 mg/l (milligrams per liter), and many exceed 1,000 mg/l.

Surface Water

The Colorado River enters the Region at concentrations exceeding 500 mg/l and varies between 600 and 900 mg/l at major diversion points. The percent sodium in this supply varies from about 28 percent at Lee Ferry to about 50 percent at Imperial Dam. Boron concentrations of 0.4 mg/l, the critical level for citrus crops, have been observed at Imperial Dam. Colorado River water has a hardness varying from about 330 mg/l at Parker Dam to about 370 mg/l at Imperial Dam. (Hardness of water is expressed in terms of calcium carbonate.) As a result, about 30 percent of the homes in the Yuma area have water softeners.

In the headwaters of the Gila River, water quality is generally good with total dissolved solids concentrations less than 500 mg/l. However, in the middle reaches below points of major diversions, water quality generally deteriorates to a range of 500 to 1,000 mg/l. This pattern of increasing TDS in a downstream direction is largely due to the consumption of water and to the salts added by pickup from point sources, irrigation, and other uses of water. The effect is to concentrate the dissolved solids in the remaining water, thus resulting in a degradation of stream quality in a downstream direction. This concentrating effect continues into lower reaches of the same stream, until successive uses have consumed the entire streamflow. This situation is observed on the Gila River below Phoenix where highly saline flows are diverted to leave a dry streambed between Gillespie Dam and Painted Rock Dam, a distance of 60 miles.

The fluoride content, normally about one mg/l in most parts of the Region, is relatively high. This level of natural fluoride concentration persists even during flooding on some upstream portions of the Gila River.

Biological quality, characterized by nutrients, dissolved oxygen, and bacterial concentrations, is considered reasonably good except for some local problems. For example, the presence of nutrients from manmade sources has caused excessive algae growths in localized areas of Lake Mead, a major recreation area. In isolated cases, bacterial concentrations have exceeded desirable levels in streams below smaller communities and resort areas.

Sediment concentrations range from very high to moderate in the Region; the areas of greatest sediment yield are located in northern Arizona and southwestern Utah where sediment concentrations as great as 700,000 ppm have been measured and 500,000 ppm observations are not unusual. On Basin and Range Lowlands, the yields are moderate with concentrations averaging about 20,000 ppm. The annual average sediment yield in most areas stays within moderate bounds due to infrequent occurrence of heavy rainfall; however, the control and removal of sediment constitutes a major operational problem in many areas.

Ground Water

The mineral quality of ground water ranges from excellent to unsuitable for any purpose. Ground water in the alluvial deposits of the Basin and Range Lowlands, for example, contains from less than 100 to more than 100,000 mg/l of dissolved solids. In most of these deposits, however, dissolved solids concentrations are less than 1,000 mg/l. Concentrations vary not only areally but also with depth. As a result, the concentrations of dissolved solids for a given well will change abruptly and so will the ionic makeup. In contrast, major sandstone aquifers in the Plateau Uplands of northern Arizona contain water having consistently more than 10,000 mg/l dissolved solids. In the same overall area the dissolved solids content ranged from 90 to more than 60,000 mg/l.

The ground water ranges from soft to very hard, from less than 60 mg/l to more than 180 mg/l of calcium carbonate. The concentrations of the minor constituents such as iron, magnesium, and silica vary considerably throughout the Region but, except for fluoride and nitrate, are not objectionable for most uses. Though concentrations of nitrate are generally small in water from drilled wells, in northern Arizona water from dug wells may contain more than 45 mg/l of nitrate. More than 4 mg/l of fluoride is common in ground waters of northern Arizona. Water from many wells in the Basin and Range Lowlands will contain in excess of 2 mg/l of fluoride. Fluoride content in excess of the amount allowed by U.S. Public Health Service Drinking Water Standards is found in waters at numerous locations throughout the Lower Colorado Region.

More detailed information on surface- and ground-water quality is contained in Appendix XV--Water Quality, Pollution, and Health Factors.

WATER RIGHTS

The philosophy underlying most legal controls and enactments within the Lower Colorado Region is the appropriation doctrine. The doctrine as generally applied establishes a legal right for the first beneficial use of unappropriated water, or "first in time is first in right." Thus, later developments may not interfere with the continued use of water. Virtually all streamflow within the Region has been appropriated under this system.

The multitude of legal documents applicable to the Colorado River is referred to as the "Law of the River." These documents and other water rights in the Lower Colorado Region is one of the subjects of Appendix III, Legal and Institutional Environments, and reference is made to that appendix for discussion of the various water right documents and of the "Law of the River." Some of the major documents concerning the Colorado River are briefly summarized below.

Colorado River Compact (1922)

One of the major purposes of the Colorado River Compact is to provide for the division of the waters from the Colorado River system. The dividing point, designated as Lee Ferry, is located about 1 mile downstream from the Paria River. Among other things, the Compact apportioned in perpetuity to the Upper Basin and to the Lower Basin, respectively, the exclusive beneficial consumptive use of 7.5 million acre-feet annually (Article III(a)) and in addition granted to the Lower Basin the right to increase its beneficial consumptive use by 1 million acre-feet annually (Article III(b)). The Compact further provided for the sharing of any burden which might arise because of a water treaty with Mexico (Article III(c)). It also established a preference for agriculture and domestic uses over uses for power generation.

The Colorado River Compact presents a number of problems. The principal cause for difficulties arises from the fact that the water supply of the Colorado River system seems to be less than that anticipated by the Commissioners who negotiated the Compact.

Boulder Canyon Project Act (1928)

This Act authorized the construction of Hoover Dam and Powerplant and the All-American Canal. The Act also authorized the States of Arizona, California, and Nevada to enter into an agreement whereby the 7.5 million acre-feet of water that was apportioned to the Lower Basin by Article III(a) of the Colorado River Compact would be apportioned as follows: to California, 4.4 million acre-feet; to Arizona, 2.8 million acre-feet; and to Nevada, 0.3 million acre-feet. Before becoming effective, the Act required that California agree to limit her consumptive use to 4.4 million acre-feet. The California Limitation Act of 1929 met this requirement. Provisions were also made for sharing by the States of surplus waters. The Act also authorized the Secretary of the Interior to execute contracts for water made available by the Boulder Canyon Project, subject to the terms of the Colorado River Compact.

Upper Colorado River Basin Compact (1948)

The Compact apportioned the Upper Basin share of the Colorado River waters between the States within that basin.

Mexican Treaty (1944)

The Treaty allocated to Mexico 1.5 million acre-feet of Colorado River system waters annually, to be increased in years of surplus to 1.7 maf and also provided for a proportionate reduction during extraordinary drought.

U.S. Supreme Court Decree in Arizona v. California (1964)

The Supreme Court held that the Boulder Canyon Project Act applied only to the main stream of the Colorado River and confirmed the discretionary power of the Secretary of the Interior to allocate shortages, after satisfying "present" perfected rights, subject to the plenary power of Congress to create its own shortage formula. The court reaffirmed the apportionment of the waters of the Colorado River as provided by the Boulder Canyon Project Act and contracts between the Secretary of the Interior and entities within the Lower Basin States. The Supreme Court did not interpret the Colorado River Compact.

Colorado River Basin Project Act (1968)

The Act authorized the Central Arizona Project, the Dixie Project in Utah, and five projects in the Upper Basin. The Central Arizona Project will provide the conveyance and storage facilities to import Arizona's remaining share of Colorado River water into the Gila River Basin. The Act also directs the Secretary of the Interior to prepare long-range water resources studies directed toward the augmentation of the Colorado River, to prepare criteria for the coordinated long-range operation of the Colorado River reservoirs, and to undertake programs for water salvage and ground-water recovery along and adjacent to the main stream of the Colorado River.

PRESENT UTILIZATION

The principal water control facilities in the Region, as previously discussed, provide for the orderly and efficient use of the Region's water supplies. Spills which are lost to the Region occur infrequently. Outflow from the Little Colorado Subregion becomes an inflow to the Lower Main Stem to be stored and consumed downstream. Under 1965 conditions there was essentially no outflow to Mexico beyond that required to meet the Mexican Treaty obligation.

The major utilization of water within the Lower Colorado Region is for agricultural, municipal, and industrial purposes. Minor quantities of water are used for cooling in thermal power generation, rural domestic needs, fish and wildlife, and for livestock. Other uses which are primarily nonconsuming are hydroelectric power and recreation.

At the present time about 94 percent of the total regional water withdrawal from ground-water pumpage and surface-water diversion is used for irrigated agriculture and 6 percent for municipal, industrial, and other uses. The municipal and industrial uses are increasing with the Region's growing population.

One of the large consuming uses of water in the Lower Colorado Region is water-surface evaporation. The high rate of evaporation and the essential requirements for storage produce an estimated annual lake evaporation loss of over 1.4 million acre-feet, 1.2 million acre-feet of which occurs on the major reservoirs of the Lower Colorado River. These losses are, in effect, the price paid to make possible the orderly use of water for on-site and downstream purposes, including generation of hydroelectric power, and, of considerable importance, for providing recreational opportunities for ever-increasing numbers of people.

Actual use of water in the Region, with a few exceptions, can only be approximated. A field of alfalfa will consume water in proportion to how, when, and amounts of water applied, among other things. These parameters are not normally measured and recorded at each farm or field. Therefore, a discussion of use of water must be general and subject to many reasoned approximations. Tables 4 and 5 show the relative relationship between sources of water in the Region and how this water is used. Of significance is the ratio of consumption to total withdrawal, which shows a Region-wide efficiency of nearly 65 percent. This high efficiency is due, in large measure, to the multiple reuse of existing supplies.

As shown on table 4, over 60 percent of all withdrawals in the Region come from ground water. Historically, annual ground-water pumpage in the Lower Colorado Region has increased from less than 1 million acre-feet in the early 1930's to 3 million acre-feet following World War II, and to about 5 million acre-feet at the present time. Conclusions can be drawn that the present annual overdraft, the amount of water by which the net pumping draft exceeds the perennial yields for the ground-water basins, is about 2.5 million acre-feet, most of which occurs in central Arizona.

The areas of the greatest water demand, the desert lowlands of Arizona and the Las Vegas Valley in Nevada, must rely substantially on the ground-water resources. In these areas, ground-water levels decline as much as 20 feet annually. The results of this continued mining of ground water have already been felt in some areas. Once productive lands are being retired as wells go dry, or as pumping costs rise to a point of no economic gain. Until the introduction of other sources of water, or in some cases the economic means to better utilize the present sources, ground-water overdraft remains as the only alternative to fully meet the demands for water.

The subregional tables 19, 23, and 28 list ground-water pumpage and surface-water withdrawals for the entire period of record.

Table 4

Estimated Annual Water Withdrawal 1/
1965 Level of Development
Lower Colorado Region

Units: 1,000 acre-feet

Subregion and State	Estimated Annual Water Withdrawal: Ground-Water Pumpage	Surface-Water Diversion	Total Withdrawal
Subregion 1 (Lower Main Stem)			
Arizona	400	1,650	2,050
Nevada	115	155	270
Utah	10	90	100
Total	525	1,895	2,420
Subregion 2 (Little Colorado)			
Arizona	72	57	129
New Mexico	2	21	23
Total	74	78	152
Subregion 3 (Gila)			
Arizona	4,400	1,200	5,600
New Mexico	65	31	96
Total	4,465	1,231	5,696
Lower Colorado Region			
Arizona	4,872	2,907	7,779
New Mexico	67	52	119
Nevada	115	155	270
Utah	10	90	100
Total	5,064	3,204	8,268

1/ Gross: Ground water at pump head, surface water at the point of diversion. These values are not necessarily those experienced in 1965, but rather, are normalized amounts which could be expected to be withdrawn under average conditions with the 1965 level of development.

Table 5

Utilization of Water Withdrawals
1965 Level of Development
Lower Colorado Region

Units: Million ac-ft

TOTAL REGIONAL WITHDRAWALS				8.27
Beneficial Depletions 1/				
Subregion 1	0.95			
Subregion 2	0.09			
Subregion 3	3.03			
Total		4.07		
Other Depletions 2/				
Subregion 1	0.13			
Subregion 2	0.01			
Subregion 3	1.03			
Total		1.17		
Subtotal			5.24	
Nonconsumptive Withdrawals 3/				
Subregion 1	1.34			
Subregion 2	0.05			
Subregion 3	1.64			
Total		3.03		
Subtotal			3.03	
REGIONAL TOTAL				8.27

1/ Does not include reservoir and stockpond evaporation losses.

2/ Includes vegetal and evaporative depletions in canals and laterals, etc., and in-transit losses.

3/ Net return flow--difference between withdrawals and depletions.

PRESENT AND FUTURE WATER REQUIREMENTS

Tables 6 through 13 are summaries by hydrologic areas of depletion and withdrawal requirements for the various water-oriented activities in the Lower Colorado Region at the four levels of development, 1965, 1980, 2000, and 2020. Future requirements are based on Modified OBE-ERS projections.

For purposes of this appendix, depletion requirement is defined as the quantity of water consumptively required in the process of vegetative growth, food processing, industrial processes, etc.; or, in other ways, removed as an available water source. Withdrawal requirement is defined as the total quantity of water at the point of diversion, required under present or projected efficiencies to satisfy the depletion requirement.

Depletion and withdrawal requirements for the use of water have been prepared by the appropriate Work Groups as noted by appendix number on the requirement tables, 6 through 13. Reference should be made to these appendixes to find details concerning their derivation.

Reservoir and stockpond evaporation loss estimates were prepared by the Water Resources Work Group and includes all natural and manmade water bodies. Data on location, number, and size of stockponds were received from the Municipal and Industrial Work Group. Data on location and average surface area of other natural and manmade water bodies within the Region were received from the appropriate State. Net evaporation losses (depletion) are computed as annual rate of lake evaporation from map 3, minus normal annual precipitation taken from map 2.

Evaporation losses for the major storage features of the Colorado River, such as Lakes Mead, Mohave, and Havasu, are not included in the requirement tables, since these depletions are interregional in nature. However, main stem evaporation losses were evaluated for use in the Lower Colorado Region framework studies with evaporation rates and average surface areas by time frames being supplied by the Bureau of Reclamation. Net depletion by evaporation from main stem reservoirs is estimated to total 1.2 million acre-feet annually.

No attempt was made to allocate present evaporation losses to specific functions, although many water bodies have been created or are used for only one or two purposes. Future in-Region evaporation losses include expected additional losses from construction of authorized projects such as the Central Arizona Project, the Dixie Project in southern Utah, projections of future stockpond requirements, and estimates based on data received from the General Program and Alternatives Work Group to reflect the possible losses to evaporation associated with other required storage as developed in Appendix XVIII for the regulation and management of augmentation supplies.

Table 6

Lower Colorado Region
Estimated Depletion Water Requirements
1965 Level of Development
Hydrologic Subregions

1970 Level of Dev. (From Tom Burbey 8-27-71)

Units: 1,000 acre-feet

State	Hydrologic Subregion	Annual Depletion Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X) 2/	Municipal and Industrial (XI)	Recreation 3/ (XII) 4/	Fish and Wildlife (XIII) 3/	Electric Power (XIV)	Total
Arizona	1	16.8	2.0 2.6	866.6 1115.4 *	15.5 17.5	0.3	70.0	0.0	971.2 1222.6
	2	31.7	0.3 1.7	48.9	6.9 7.0	0.4	4.0	0.8	93.0 5/ 94.5
	3	154.4	47.7 55.4	3,997.9	139.2 166.1	2.0	5.6	6.0	4,352.8 4387.4
	Total	202.9	50.0 59.7	4,913.4 5162.2	161.6 190.6	2.7	79.6	6.8	5,417.0 5704.5
Nevada	1	12.1	0.6 1.2	174.3	30.3 54.7	0.8	30.0	2.8 4.3	250.9 277.4
New Mexico	2	7.7	0.3 0.5	9.7	1.9 2.3	0.1	0.3	0.0	20.0 20.6
	3	4.3	0.6 2.6	61.9	1.7 1.9	0.0	0.4	0.0	68.9 71.1
	Total	12.0	0.9 3.1	71.6	3.6 4.2	0.1	0.7	0.0	88.9 91.7
Utah	1	3.4	0.0 0.0	66.2	2.4 2.5	0.0	0.0	0.0	72.0 72.1
Lower Colorado Region	1	32.3	2.6 3.8	1,107.1 1355.9	48.2 74.7	1.1	100.0	2.8 4.3	1,294.1 1572.1
	2	39.4	0.6 2.2	58.6	8.8 9.3	0.5	4.3	0.8	113.0 5/ 115.1
	3	158.7	48.3 58.0	4,059.8	140.9 168.0	2.0	6.0	6.0	4,421.7 4458.5
	Total	230.4	51.5 64.0	5,225.5 5474.3	197.9 252.0	3.6	110.3	9.6 11.1	5,828.8 6145.7

Interpolate 65 to 80   chart

1/ Exclusive of Colorado River mainstream.

2/ Includes the irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 15 percent of the computed irrigation requirement for noncrop consumption associated with irrigation. Also includes an estimated 600,000 acre-feet per year of water losses in-transit in the central Arizona area of Subregion 3.

3/ Represents requirements exclusive of existing lake and reservoir evaporation.

4/ Prorated to States by the Water Resources Work Group based on population.

5/ Excludes normal annual export of 15,000 acre-feet to the Gila Subregion.

* Increased mostly on Indian lands. (64,000 acres)

Table 7

Lower Colorado Region
Estimated Withdrawal Water Requirements
1965 Level of Development
Hydrologic Subregions

Unit: 1,000 acre-feet

State	Hydrologic Subregion	Annual Withdrawal Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X)	Municipal and Industrial (XI)	Recreation (XII) 2/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	16.8	4.9	2,084.7	34.2	0.9	107.0	0.0	2,248.5
	2	31.7	0.5	112.1	15.4	1.2	5.5	0.8	167.2 3/
	3	154.4	96.9	6,210.1	312.4	5.9	47.0	6.0	6,832.7
	Total	202.9	102.3	8,406.9	362.0	8.0	159.5	6.8	9,248.4
Nevada	1	12.1	1.5	433.1	76.4	2.3	33.0	2.8	561.2
New Mexico	2	7.7	0.5	24.1	4.1	0.3	0.5	0.0	37.2
	3	4.3	0.8	109.7	2.7	0.0	3.0	0.0	120.5
	Total	12.0	1.3	133.8	6.8	0.3	3.5	0.0	157.7
Utah	1	3.4	0.0	164.6	5.0	0.0	0.0	0.0	173.0
Lower Colorado Region	1	32.3	6.4	2,682.4	115.6	3.2	140.0	2.8	2,982.7
	2	39.4	1.0	136.2	19.5	1.5	6.0	0.8	204.4 3/
	3	158.7	97.7	6,319.8	315.1	5.9	50.0	6.0	6,953.2
	Total	230.4	105.1	9,138.4	450.2	10.6	196.0	9.6	10,140.3

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 8

Lower Colorado Region
Estimated Depletion Water Requirements
1980 Level of Development
Modified OBE-ERS
Hydrologic Subregions

Unit: 1,000 acre-feet

State	Hydrologic Subregion	Annual Depletion Requirements							Total
		Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X) 2/	Municipal and Industrial (XI)	Recreation (XII) 3/	Fish and Wildlife (XIII)	Electric Power (XIV)	
Arizona	1	17.0	3.9	1,131.0	19.1	0.3	72.8	0.2	1,244.3 4/
	2	33.0	4.6	56.0	12.2	0.7	8.1	0.1	114.7
	3	187.0	70.7	4,409.0	214.1	3.6	18.9	4.4	4,907.7
	Total	237.0	79.2	5,596.0	245.4	4.6	99.8	4.7	6,266.7
Nevada	1	12.0	2.3	193.0	102.7	2.0	39.8	31.9	383.7
New Mexico	2	8.0	1.0	16.0	3.5	0.2	1.4	0.0	30.1
	3	9.0	6.7	83.0	3.0	0.0	1.4	0.0	103.1
	Total	17.0	7.7	99.0	6.5	0.2	2.8	0.0	133.2
Utah	1	20.0	0.0	78.0	3.1	0.1	0.0	0.0	101.2
Lower Colorado Region	1	49.0	6.2	1,402.0	124.9	2.4	112.6	32.1	1,729.2 4/
	2	41.0	5.6	72.0	15.7	0.9	9.5	0.1	144.8
	3	196.0	77.4	4,492.0	217.1	3.6	20.3	4.4	5,010.8
	Total	286.0	89.2	5,966.0	357.7	6.9	142.4	36.6	6,884.8

1/ Exclusive of Colorado River mainstream.

2/ Includes the irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 15 percent of the computed irrigation requirement for noncrop consumption associated with irrigation. Also includes an estimated 600,000 acre-feet per year of water losses in-transit in the central Arizona area of Subregion 3.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 9

Lower Colorado Region
Estimated Withdrawal Water Requirements
1980 Level of Development
Modified OBE-ERS
Hydrologic Subregion

Unit: 1,000 acre-feet

		Annual Withdrawal Requirements							
State	Hydro-logic Subregion	Reservoir Evapo-ration (V) 1/	Mineral Resources (VII)	Irrigated Agricul-tural (X)	Municipal and Industrial (XI)	Recre-ation (XII) 2/	Fish and Wildlife (XIII)	Elec-tric Power (XIV)	Total
Arizona	1	17.0	12.4	2,236.0	43.5	1.1	108.5	0.2	2,418.7 3/
	2	33.0	5.0	110.0	28.3	2.2	9.7	0.1	188.3
	3	187.0	143.6	6,370.0	498.3	10.7	47.3	4.4	7,261.3
	Total	237.0	161.0	8,716.0	570.1	14.0	165.5	4.7	9,868.3
Nevada	1	12.0	4.6	381.0	272.7	5.8	43.2	31.9	751.2
New Mexico	2	8.0	1.5	31.0	8.2	0.6	1.7	0.0	51.0
	3	9.0	10.4	147.0	4.9	0.0	3.1	0.0	174.4
	Total	17.0	11.9	178.0	13.1	0.6	4.8	0.0	225.4
Utah	1	20.0	0.0	154.0	7.0	0.2	0.0	0.0	181.2
Lower Colorado Region	1	49.0	17.0	2,771.0	323.2	7.1	151.7	32.1	3,351.1
	2	41.0	6.5	141.0	36.5	2.8	11.4	0.1	239.3 3/
	3	196.0	154.0	6,517.0	503.2	10.7	50.4	4.4	7,435.7
	Total	286.0	177.5	9,429.0	862.9	20.6	213.5	36.6	11,026.1

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 10

Lower Colorado Region
Estimated Depletion Water Requirements
2000 Level of Development
Modified OBE-ERS
Hydrologic Subregions

Unit: 1,000 acre-feet

State	Hydrologic Subregion	Annual Depletion Requirements							
		Reservoir Evaporation (V)	Mineral Resources (VII)	Irrigated Agricultural (X) 2/	Municipal and Industrial (XI)	Recreation (XII) 3/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	18.0	5.2	1,100.0	24.3	0.4	86.7	8.0	1,242.6 4/
	2	37.0	5.0	57.0	18.8	1.2	9.9	0.0	128.9
	3	215.0	104.2	3,780.0	388.5	7.2	49.5	76.8	4,621.2
	Total	270.0	114.4	4,937.0	431.6	8.8	146.1	84.8	5,992.7
Nevada	1	12.0	3.4	185.0	229.1	4.5	79.8	19.0	532.9
New Mexico	2	8.0	1.6	15.0	6.9	0.4	3.5	0.0	35.4
	3	18.0	16.0	95.0	5.0	0.0	2.8	2.7	139.5
	Total	26.0	17.6	110.0	11.9	0.4	6.3	2.7	174.9
Utah	1	20.0	0.0	80.0	3.9	0.1	0.2	0.0	104.2
Lower Colorado Region	1	50.0	8.6	1,365.0	257.3	5.0	166.8	27.0	1,879.7 4/
	2	45.0	6.6	72.0	25.7	1.6	13.4	0.0	164.3
	3	233.0	120.2	3,875.0	393.5	7.2	52.3	79.5	4,760.7
	Total	328.0	135.4	5,312.0	676.5	13.8	232.5	106.5	6,804.7

1/ Exclusive of Colorado River mainstream.

2/ Includes irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 10 percent of the computed irrigation requirement for noncrop consumption associated with irrigation.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 11

Lower Colorado Region
Estimated Withdrawal Water Requirements
2000 Level of Development
Modified OBE-ERS
Hydrologic Subregions

Unit: 1,000 acre-feet

State	Hydro-Logic Subregion	Annual Withdrawal Requirements: Reservoir Evapo-ration (V) 1/	Mineral Resources (VII)	Irrigated Agricul-tural (X)	Municipal and Industrial (XI)	Recre-ation (XII) 2/	Fish and Wildlife (XIII)	Elec-tric Power (XIV)	Total
Arizona	1	18.0	15.0	1,961.0	56.4	1.4	126.5	8.0	2,186.3
	2	37.0	5.3	102.0	46.3	3.7	11.9	0.0	206.2 3/
	3	215.0	211.4	5,774.0	945.8	21.7	84.7	76.8	7,329.4
	Total	270.0	231.7	7,837.0	1,048.5	26.8	223.1	84.8	9,721.9
Nevada	1	12.0	6.6	329.0	618.9	13.3	92.8	19.0	1,091.6
New Mexico	2	8.0	2.3	27.0	16.9	1.1	4.2	0.0	59.5
	3	18.0	23.4	159.0	9.4	0.0	4.7	2.7	217.2
	Total	26.0	25.7	186.0	26.3	1.1	8.9	2.7	276.7
Utah	1	20.0	0.1	144.0	9.0	0.2	0.2	0.0	173.5
Lower Colorado Region	1	50.0	21.7	2,434.0	684.3	14.9	219.5	27.0	3,451.4
	2	45.0	7.6	129.0	63.2	4.8	16.1	0.0	265.7 3/
	3	233.0	234.8	5,933.0	955.2	21.7	89.4	79.5	7,546.6
	Total	328.0	264.1	8,496.0	1,702.7	41.4	325.0	106.5	11,263.7

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 12

Lower Colorado Region
Estimated Depletion Water Requirements
2020 Level of Development
Modified OBE-ERS
Hydrologic Subregions

Unit: 1,000 acre-feet

		Annual Depletion Requirements							
State	Hydro-logic Subregion	Reservoir Evapo-ration (V) 1/	Mineral Resources (VII)	Irrigated Agricul-tural (X) 2/	Municipal and Industrial (XI)	Recre-ation (XII) 3/	Fish and Wildlife (XIII)	Elec-tric Power (XIV)	Total
Arizona	1	18.0	6.6	1,187.0	36.5	0.7	100.4	30.3	1,379.5
	2	37.0	2.6	57.0	27.3	1.7	16.0	0.0	141.6 4/
	3	245.0	138.2	3,767.0	706.5	12.8	164.7	345.6	5,379.8
	Total	300.0	147.4	5,011.0	770.3	15.2	281.1	375.9	6,900.9
Nevada	1	12.0	3.5	180.0	351.4	7.2	110.6	50.6	715.3
New Mexico	2	8.0	4.1	15.0	14.0	0.9	8.2	0.0	50.2
	3	19.0	30.6	86.0	7.7	0.1	4.9	4.4	152.7
	Total	27.0	34.7	101.0	21.7	1.0	13.1	4.4	202.9
Utah	1	20.0	0.0	89.0	5.6	0.1	0.3	3.8	118.8
Lower Colorado Region	1	50.0	10.1	1,456.0	393.5	8.0	211.3	84.7	2,213.6
	2	45.0	6.7	72.0	41.3	2.6	24.2	0.0	191.8 4/
	3	264.0	168.8	3,853.0	714.2	12.9	169.6	350.0	5,532.5
	Total	359.0	185.6	5,381.0	1,149.0	23.5	405.1	434.7	7,937.9

1/ Exclusive of Colorado River mainstream.

2/ Includes irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 10 percent of the computed irrigation requirement for noncrop consumption associated with irrigation.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 13

Lower Colorado Region
Estimated Withdrawal Water Requirements
2020 Level of Development
Modified OBE-ERS
Hydrologic Subregions

Unit: 1,000 acre-feet

State	Hydro-logic Subregion	Annual Withdrawal Requirements: Reservoir Evapo-ration (V) 1/	Mineral Resources (VII)	Irrigated Agricul-tural (X)	Municipal and Industrial (XI)	Recre-ation (XII) 2/	Fish and Wildlife (XIII)	Elec-tric Power (XIV)	Total	
Arizona	1	18.0	18.3	1,953.0	79.8	2.0	161.7	30.3	2,263.1	
	2	37.0	3.0	94.0	68.8	5.1	19.2	0.0	227.1	3/
	3	245.0	281.1	5,756.0	1,704.0	38.5	215.8	354.6	8,586.0	
	Total	300.0	302.4	7,803.0	1,852.6	45.6	396.7	375.9	11,076.2	
Nevada	1	12.0	6.9	296.0	862.3	21.8	129.6	50.6	1,379.2	
New Mexico	2	8.0	5.3	26.0	36.0	2.7	11.6	0.0	89.6	
	3	19.0	42.5	133.0	15.3	0.1	17.9	4.4	232.2	
	Total	27.0	47.8	159.0	51.3	2.8	29.5	4.4	321.8	
Utah	1	20.0	0.1	147.0	12.2	0.2	0.3	3.8	183.6	
Lower Colorado Region	1	50.0	25.3	2,396.0	954.3	24.0	291.6	84.7	3,825.9	
	2	45.0	8.3	120.0	104.8	7.8	30.8	0.0	316.7	3/
	3	264.0	323.6	5,889.0	1,719.3	38.6	233.7	350.0	8,818.2	
	Total	359.0	357.2	8,405.0	2,778.4	70.4	556.1	434.7	12,960.8	

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Irrigated agriculture requirements have been adjusted by the Water Resources Work Group to include estimates of noncrop consumption associated with irrigation and estimates of in-transit losses, where appropriate. Further discussion of the latter item can be found in this appendix under the "Present Requirements" section, Chapter E. Present noncrop consumption associated with irrigation is estimated as 15 percent of the irrigation requirement and includes uses on nonagricultural areas such as water surfaces and vegetation on right-of-way for canals, laterals, roads, etc. These losses are projected to decrease to 10 percent by the year 2000 and after to reflect the greater use of lined and enclosed conveyance facilities as discussed in Appendix X, Irrigation and Drainage.

PRESENT MODIFIED WATER SUPPLY

Table 14 summarizes the subregional modified water supply analyses presented in tables 20, 24, and 29, and assumes complete control and distribution of the total water supply within each Subregion and within the Region.

The principal use of the water supply as derived is to provide a broad concept of the relationship between the total water supply, the present water requirement, and the remaining supply within the basin. Whether any remaining water supply is physically or economically available for further water development is subject to more refined and specific studies.

Table 14

Present Modified Water Supply

	1965 Modified Water Supply--Million ac-ft		
	Runoff Period		
	1906-65	1914-65 1/	1922-65 1/
Subregion 1	2.53	2.08	1.31
Subregion 2 2/	(0.29)	(0.29)	(0.29)
Subregion 3 (deficiency)	-2.71	-2.71	-2.71
Region Total (deficiency)	-0.18	-0.63	-1.40

1/ Assumes no change in subregional runoff due to change in runoff period.

2/ Included in Subregion 1 modified water supply.

Table 14 illustrates, from a broad regional point of view, that the water supply available to the Lower Colorado Region is inadequate to meet present demands even if facilities were available to distribute the supply from areas of surplus to areas of deficiency, principally the Gila Subregion.

PRESENT SUFFICIENCY

There are many ways to evaluate and many criteria by which to measure the adequacy of supplies to meet demands. Many considerations must be weighed which make the above simple presentation only partially conclusive. However, if results show little or no excess water for future growth or for water quality control, as in the preceding section, then the supply must be considered as insufficient. Given the facilities of the authorized Southern Nevada Water Project and the Dixie and Central Arizona Projects with which to convey current local excess supplies to areas of deficiencies, the total picture is still one of regional deficiency.

Much of the present development has been possible through the mining of ground water. The future is less than optimistic, for as upper basin depletions increase, the total regional water supply will decrease resulting in even greater demands on the ground water. Even though the ground-water reserves of the Region are large, declining water levels, degrading quality, legal constraints, and other factors of location, low yield, etc., preclude the economical development of much of this resource. Therefore, further dependency on ground-water development to sustain and expand the present economy would need to be weighed carefully.

The United States Congress said, in Title I of the Colorado River Basin Project Act [1] , "It is the object of this Act to provide a program for the further comprehensive development of the water resources of the Colorado River Basin and for the provision of additional and adequate water supplies for use in the Upper as well as in the Lower Colorado River Basin." Pursuant to this, "the Congress declares that the satisfaction of the requirements of the Mexican Water Treaty from the Colorado River constitutes a national obligation which shall be the first obligation of any water augmentation project plan pursuant to section 201 of this Act...."

FUTURE MODIFIED WATER SUPPLY

Future water requirements in the Lower Colorado Region are presented in tables 8 through 13. Most of the water-consuming sectors of the economy will require more water in the future and total depletion requirements are projected to increase from 5.8 million acre-feet at the current level of development to nearly 8.0 million acre-feet by year 2020. In addition, the Mexican Water Treaty obligation, California entitlement, Colorado River evaporation and conveyance losses, and system spills are expected to be a minimum of 7.6 million acre-feet in the future. The average annual undepleted water supply within the Lower Colorado Region, exclusive of ground-water overdraft, has been estimated as about 3.1 million acre-feet, leaving a demand from the Colorado River at Lee Ferry of about 12.8 million acre-feet in year 2020. As shown on table 15, the Lower Colorado Region water supply will be deficient by at about 4 million acre-feet in satisfaction of projected water needs by year 2020. This table shows a simplified relationship between the projected water requirements and water supply and the apparent regional water supply deficiencies in years 1980, 2000, and 2020.

Projected water requirements do not include water losses that may be associated with future water quality control nor the necessary losses which would be incurred to totally develop the Region's water supply. The existing and authorized water resource projects within the Region accomplish, to a large extent, the concept of total development. The ability to further develop in-Region supplies is severely restricted by the economic law of diminishing returns, legal, institutional, political, physical, and environmental restraints.

FUTURE SUFFICIENCY

As shown on table 15 the Lower Colorado Region faces a shortage of undepleted water supply to satisfy the Modified OBE-ERS projected levels of development. The Gila Subregion, even after construction of the Central Arizona Project, shows large water supply deficiencies. As authorized, the Central Arizona Project would have a conveyance capacity of 3,000 cfs (2.17 maf per year) with which to transport Colorado River water into the Gila Subregion. Should future new water supplies come from an augmented Colorado River, this capacity would be inadequate to transport all the water needed in the Subregion.

Table 15

Future Modified Water Supply
Lower Colorado Region

Units: Million ac-ft

Item	Development Year 1965	1980	2000	2020
Virgin Flow - Colorado River at Lee Ferry (1906-1965) (figure 2)	15.09	15.09	15.09	15.09
Depletions - Upper Colorado Region 1/	3.45	4.83	6.12	6.55
Modified Flow Colorado River at Lee Ferry	11.64	10.26	8.97	8.54
Modified Outflow - Subregion 2 (table 25)	0.29	0.26	0.24	0.21
Tributary Inflow - Subregion 1	0.90	0.90	0.90	0.90
Lower Basin Water Supply	12.83	11.42	10.11	9.65
Lower Basin Export and Depletion Requirements				
Subregion 1	1.29	1.73	1.88	2.21
California Region	5.00	4.40	4.40	4.40
Main Stem Reservoir Evaporation	1.20	1.20	1.20	1.20
System Spills [3-35]	0.65	0.52	0.15	0.15
Main Stem Channel Losses [2-33] (page 81)	0.66	0.39	0.39	0.39
Mexican Water Treaty	1.50	1.50	1.50	1.50
Exports to Subregion 3 2/	--	1.76	1.12	0.87
Subregion 3 Deficiency (table 30)	2.71	1.53	1.89	2.89
Total	13.01	13.03	12.53	13.61
Lower Colorado Region Water Supply Excess or Deficiency (-)	-0.18	-1.61	-2.42	-3.96

1/ Regionally interpreted OBE-ERS from the Water Resources Appendix, Upper Colorado Region.

2/ Diverted by the Central Arizona Project. Interpolated from data for a 3,000-cfs aqueduct [3-35].

Other areas of localized shortages would also exist, such as the Las Vegas area, the Gallup-Zuni area, and the many small, scattered developments dependent on the whims of erratic seasonal streamflow. Some of these problem areas are discussed in more detail in the subregional portions of this appendix, Chapters C, D, and E.

Several alternate means are possible to partially or fully offset major future shortages, some of which are discussed in this appendix under "Technological Advancements." These include weather modification; desalting of brackish, geothermal, or sea water; importation from other basins; conservation and salvage measures; soil and vegetative management to increase runoff; and evaporation suppression. Other means include the transposition of the economic structure from predominately high water-consuming activities to activities of less consumption. Each of these possibilities has attendant legal, political, economic, ecological, and/or technological shortcomings. Some of these problems are well known, such as opposition by some groups to certain salvage and management practices, or the political opposition to importation from other basins. Transfer of water from presently low-value, high-use activities to other uses of higher value is beyond the scope of this appendix since the future economic structure for these studies is given by the Modified OBE-ERS projections.

The following section investigates some of the potentials and, in some cases, the problems associated with the various means to increase water supplies.

TECHNOLOGICAL ADVANCEMENTS

Introduction

The following are brief descriptions of several potential advancements which could occur in the foreseeable future in the fields of water management techniques and water supply augmentation. These summaries were prepared by the Water Resources Work Group of the lower Colorado Region from materials furnished by various experts in each field under the direction of the Pacific Southwest Inter-Agency Committee.

Since most of these potential advancements are of a relatively unproven nature, requiring more research and understanding before concluding their feasibility, this section is included in the appendix for informational purposes only. As such, the Water Resources Work Group does not necessarily approve of or recommend any of the following as sound planning methods for use in comprehensive framework planning.

No particular attempt was made to relate each advancement to this Region since the expertise to do so was not felt to exist within the Work Group. Therefore, most of the discussions are general in nature and may or may not be applicable to the physical environment of this Region, now or in the future.

Hydrometeorological Forecasting

Hydrometeorological forecasting is primarily a management tool aimed at increasing man's foresight and understanding of the factors which influence the occurrence and distribution of water. As such, forecasting cannot increase the amount of renewable water in the Lower Colorado Region, but allows for better utilization, management, and control of existing supplies.

One of the greatest impacts to hydrometeorological forecasting in the last few years has been the advent of the satellite program. A multitude of experiments are currently in progress, including the measurement of vertical distribution of temperature in the atmosphere, the collection, via satellite, of surface data from remote land-based stations, attempts to relate radar data to rainfall, and many others. Strides are also being made in automated surface data collection systems which would provide more varied and timely data from existing data sites and from presently data-sparse areas. Many other potentials for future investigations are also possible.

The ability to collect selected data when and where needed, coupled with the use of computers to rapidly evaluate and correlate these data, promises many improvements in the field of hydrometeorological forecasting.

Weather Modification

Weather modification as an operational tool represents a source of new or additional water for a basin by producing runoff from precipitation that normally would not have fallen on the basin. Research into precipitation management is being actively pursued in the Western United States to develop methods for beneficially modifying weather elements important to the area's water resources. Current techniques involve adding proper quantities of minute particles to selected clouds to change cloud composition and help form more raindrops or snowflakes. Commonly called "cloud seeding," it is usually done by burning silver iodide mixtures. The expected increases in precipitation combined with probable low operational costs, program flexibility, and the high quality of water produced, make precipitation management a unique method for increasing the water supply. More research is needed to develop a better understanding of the physical mechanisms of precipitation and the statistical effects of cloud seeding operations, and to improve existing techniques. Of great importance are the legal, environmental, and economic aspects that must be considered before large-scale modification of precipitation can be relied upon as an additional water source. The effect of a successful weather modification program for the Lower Colorado Region would be to reduce, but not replace, the need for other augmentation measures.

Evaporation Suppression

Controversy exists concerning the ultimate benefits to be derived from evaporation-reduction operations. Work done by the Bureau of Reclamation and others during the past several years indicates that it may be feasible to increase the usable water supply by evaporation-reduction techniques under favorable conditions. However, technical problems exist and work continues on improving the methods for applying, maintaining, and evaluating the effectiveness of evaporation retardants on water surfaces.

Various chemicals and compounds have been utilized in the form of solid chunks, flakes, finely-divided powders, molten sprays, solutions, and emulsions to form monomolecular films on water surfaces to retard evaporation. Each form has been found to have its advantages and its disadvantages, and none has proved to be a panacea for solving the myriad problems encountered in field applications, particularly that of maintaining a film on the water surface in the presence of wind or waves.

Large-scale tests performed or sponsored by the Bureau of Reclamation indicate a capability of reducing lake evaporation losses by 8 to 14 percent at an operational cost of about $60 to $70 per acre-foot. Future improvements in techniques and the efficiency of operation could reduce costs to a point where such operations would be justified for municipal and industrial uses.

Nuclear Explosives

The controlled use of nuclear explosions offers a significant potential for dollar savings in the future construction of large-scale water resource development projects. Its future role will likely be to complement conventional chemical explosives and mechanical excavation and placement methods. Potential applications in this capacity are numerous. Other possibilities are the forming of underground water storage facilities, thereby reducing evaporative losses associated with surface storage. Liquid wastes might also be stored in these underground cavities. One of the disadvantages of the use of nuclear devices is the current lack of control over radioactive contamination of water in such underground storage reservoirs.

Subsurface Water Storage

The use of subsurface storage conjunctively with surface storage is necessary for the maximum development of the water resource. Withdrawals from the ground-water reservoirs during a cycle of dry years would be offset by planned recharge during the ensuing wet years. Conjunctive use of storage requires that surface reservoirs impound streamflow which is then transferred at an optimum rate to ground-water storage. Present knowledge of ground-water reservoirs is far less than adequate for efficient water management and is dependent largely upon inferences from data that can be obtained from drilling wells, pump tests, etc. Further research and development are needed in sensors that penetrate below the land surface in the principles of sedimentation, and in other determinants of permeability that will enable extrapolation and interpolation of scattered point data. Development of an adequate technology for artificial recharge is also needed. In addition to the technical problems of ground-water management, present social and legal concepts will require modernization. Understandably, artificial recharge of ground water is not practiced extensively in the Lower Colorado Region since water demands exceed the renewable water supply by several times and little water is available for planned recharge. In the future, planned waste water disposal of treated sewage effluent downstream from the major cities within the Region could include the artificial replenishment of ground water. The Central Arizona Project may also provide an opportunity to occasionally recharge ground water with excess Colorado River water or local flood runoff.

Desalting

Desalting, whereby sea, brackish, or other chemically charged waters are converted to fresh water, shows promise of becoming a major source of augmenting existing fresh water supplies. Certain basic methods of desalting have long been known and others are being developed. The problem is to produce large quantities of fresh water at a cost that is competitive with that for water obtained from other sources.

Recent investigations have indicated that in large plants (50 million gallons daily or larger) the water cost would be in the order of 30 cents per thousand gallons. That cost is competitive in some areas for domestic and industrial use, but is far higher than the current prices for irrigation supplies, which generally range from $2 to $30 per acre-foot. Future cost reductions are anticipated from improvements in desalting process and materials, and from the economics of larger plants. As the cost of developing new conventional sources rises, desalted water could become increasingly competitive as an alternate source of water supply.

The Bureau of Reclamation has explored the potential of augmenting the Colorado River by desalting sea water to establish the expected feasibility of such a plan. Plans were analyzed for dual-purpose plants located on the coast of southern California and the Gulf of California and relied upon projected techniques for combined nuclear-desalting and thermal-electric plants. The base plan called for staged plants with an annual capacity of 2 million acre-feet by year 2010 [4].

Geothermal Resources

Pure water resulting from the desalting of geothermal brines underlying the Imperial Valley in southern California and possibly other areas of the Pacific Southwest appears to offer considerable possibilities for augmenting the water resources of the Pacific Southwest.

The University of California at Riverside, in cooperation with the Bureau of Reclamation and its Western United States Water Plan, has initiated studies to assess the geothermal potential of the Imperial Valley. The studies indicate the possibility of developing the deep-seated geothermal steam as a source of thermal energy for the operation of electrical generating plants; thus, providing both the water and the energy to operate large desalting plants to convert geothermal brines into fresh water.

Although much work remains to fully inventory and evaluate geothermal resources, scientists foresee a potential of up to 6 million acre-feet of distilled water a year and electrical power output 15 times greater than that of Hoover Dam from geothermal development.

Other Advancements

Although the preceding discussions cover the major foreseeable areas of potentially new water sources and management practices, many other possibilities may be forthcoming. Several already proven and demonstratable techniques involving watershed and vegetative management are available which could, if implemented, produce significant quantities of high quality water. These are discussed in some detail in Appendix VIII, Watershed Management and Appendix XIII, Fish and Wildlife.

Of particular significance to better management of water will be the continuing trend to wider use of more sophisticated, automated devices to aid in forecasting, measuring, routing, and regulating the water supplies.

AVAILABLE HYDROLOGIC DATA

Planning for effective development and use of the Region's water resources requires a continuing supply of basic hydrologic data. The principal objective of this section is to show the relative location and density of such data and to present, pictorially or graphically, a summary of some of these data.

Basic hydrologic and meteorologic data have been collected in the Region for nearly a century. The earliest climate stations were established at Prescott, Arizona, in 1865 and at Phoenix in 1878. Also in 1878, the collection of streamflow data was initiated on the Colorado River at Yuma.

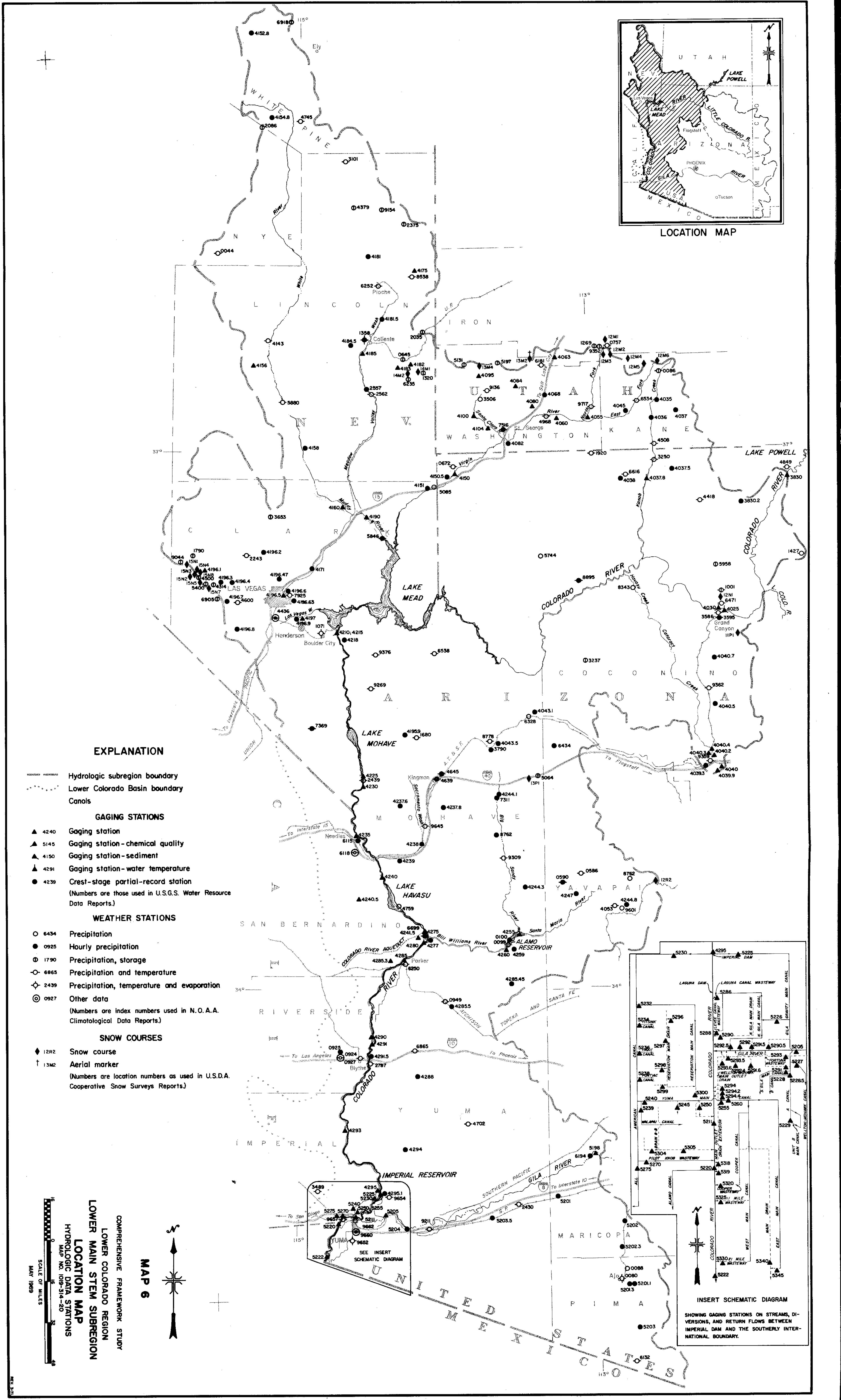
Today's network of data collection stations includes over 450 streamflow stations, some 400 climate stations, 65 snow course and soil moisture stations, and numerous ground-water sampling and depth measurement wells. This net work extends to all corners of the Region and provides the backbone of information needed for sound water resource management and planning. Maps 6, 7, and 8 are subregional location maps of the above stations, except ground water. Complete inventories for these data are available from the various responsible Federal agencies as follow:

Snow Course Data

The Soil Conservation Service is the coordinating agency for snow course and soil moisture sampling used primarily in runoff forecasting.

Ground-Water Data

The U.S. Geological Survey coordinates the collection of most ground-water data. Much of the available data are summarized in the form of various ground-water maps. Presented in this appendix as maps 4 and 5 are depth to water and change in water level, respectively. Also available but not presented are large-scale regional maps of location and thickness of aquifers, potential well production, basins for which estimates of ground water in storage have been made, and areas for which ground-water pumpage is estimated. All of these are available from the Arizona District, Water Resources Division, USGS, in Tucson, Arizona, and are to be published by the USGS in a hydrogeologic atlas of the Lower Colorado River Basin.

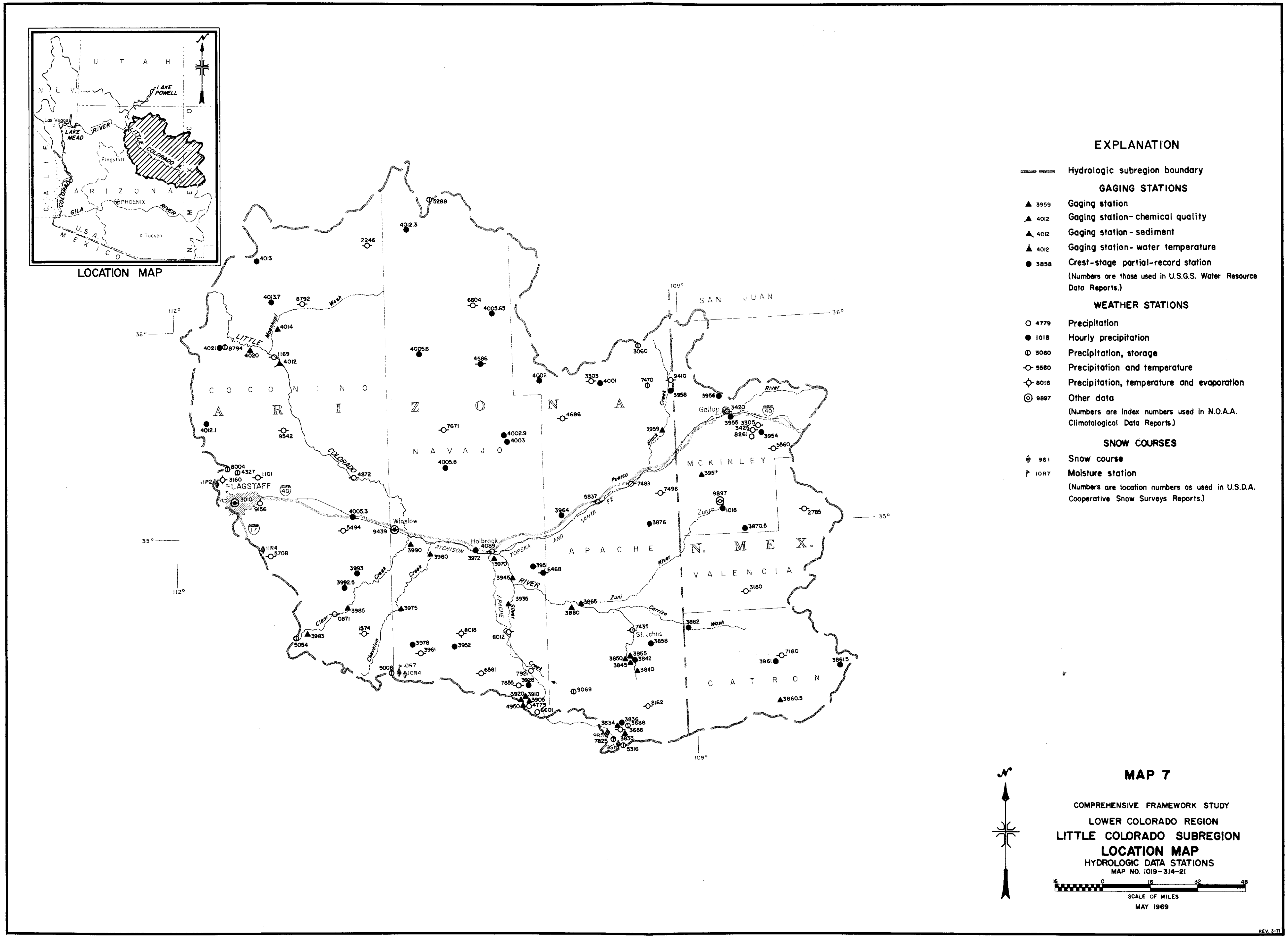


MAP 6

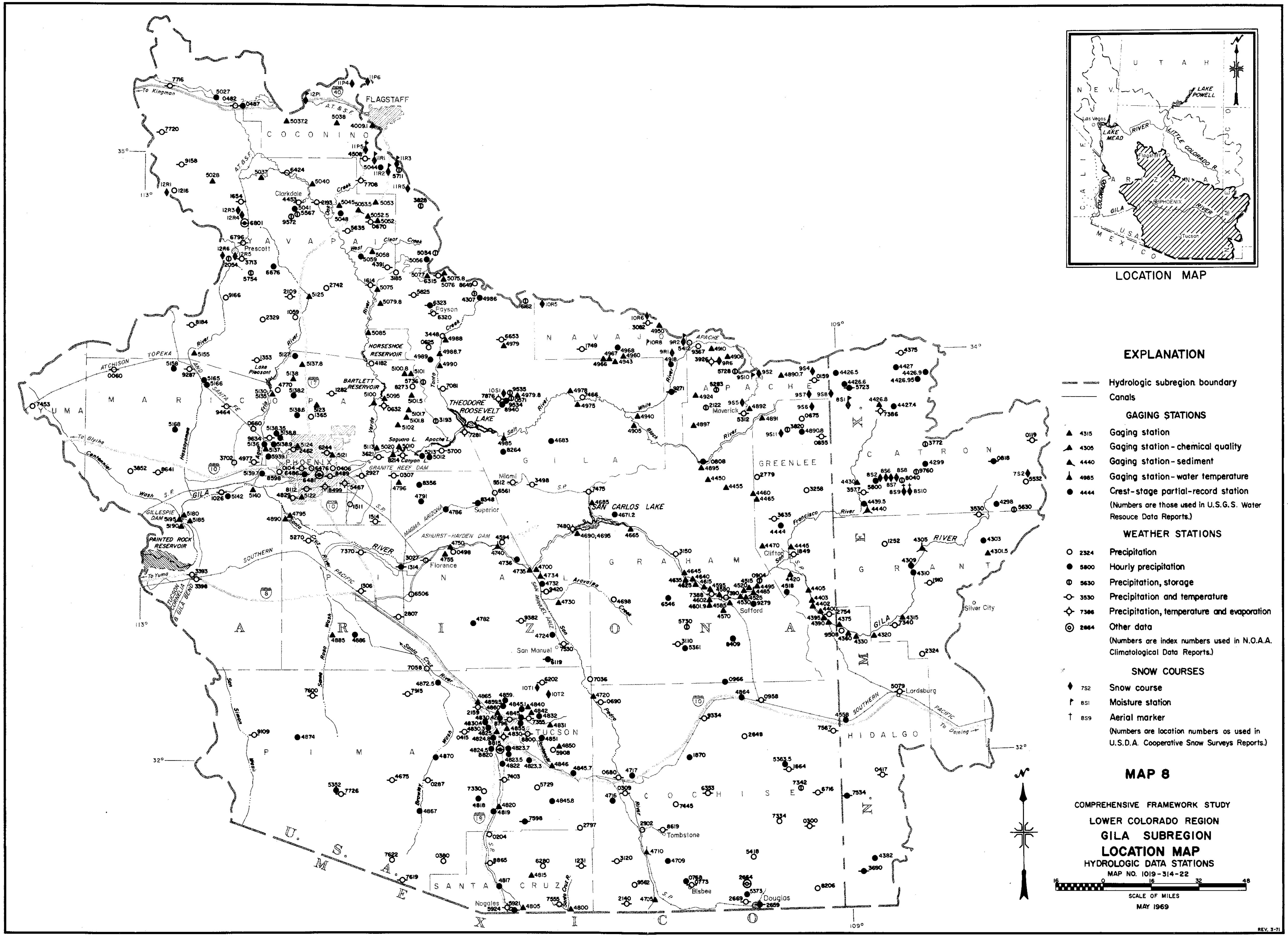
COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION
LOWER MAIN STEM SUBREGION
LOCATION MAP
HYDROLOGIC DATA STATIONS
MAP NO. 1019-314-20

SCALE OF MILES

MAY 1969



LOCATION MAP
UTAH
NEV
LAKE POWELL
Las Vegas
LAKE MEAD
RIVER
LITTLE COLORADO R.
Flagstaff
CALIF.
COLORADO
ARIZONA
GILA
RIVER
PHOENIX
Tucson
U.S.A.
MEXICO
N. MEX.
COCONINO
ARIZONA
NAVAJO
APACHE
FLAGSTAFF
Winslow
Holbrook
St. Johns
Gallup
Zuni
SAN JUAN
MCKINLEY
VALENCIA
CATRON
N. MEX.
LITTLE COLORADO
RIVER
Puerco
Zuni
Carrizo
Wash
Clear Creek
Chevelon
Silver Creek
Black Creek
ATCHISON TOPEKA AND SANTA FE
EXPLANATION
Hydrologic subregion boundary
GAGING STATIONS
3959 Gaging station
4012 Gaging station - chemical quality
4012 Gaging station - sediment
4012 Gaging station - water temperature
3858 Crest-stage partial-record station
(Numbers are those used in U.S.G.S. Water Resource Data Reports.)
WEATHER STATIONS
4779 Precipitation
1018 Hourly precipitation
3060 Precipitation, storage
5560 Precipitation and temperature
8018 Precipitation, temperature and evaporation
9897 Other data
(Numbers are index numbers used in N.O.A.A. Climatological Data Reports.)
SNOW COURSES
951 Snow course
10R7 Moisture station
(Numbers are location numbers as used in U.S.D.A. Cooperative Snow Surveys Reports.)
MAP 7
COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION
LITTLE COLORADO SUBREGION
LOCATION MAP
HYDROLOGIC DATA STATIONS
MAP NO. 1019-314-21
16 0 16 32 48
SCALE OF MILES
MAY 1969
REV. 3-71


LOCATION MAP
EXPLANATION
Hydrologic subregion boundary
Canals
GAGING STATIONS
4315 Gaging station
4305 Gaging station - chemical quality
4440 Gaging station - sediment
4985 Gaging station - water temperature
4444 Crest-stage partial-record station
(Numbers are those used in U.S.G.S. Water Resouce Data Reports.)
WEATHER STATIONS
2324 Precipitation
5800 Hourly precipitation
5630 Precipitation, storage
3530 Precipitation and temperature
7386 Precipitation, temperature and evaporation
2864 Other data
(Numbers are index numbers used in N.O.A.A. Climatological Data Reports.)
SNOW COURSES
7S2 Snow course
8S1 Moisture station
8S9 Aerial marker
(Numbers are location numbers as used in U.S.D.A. Cooperative Snow Surveys Reports.)
MAP 8
COMPREHENSIVE FRAMEWORK STUDY
LOWER COLORADO REGION
GILA SUBREGION
LOCATION MAP
HYDROLOGIC DATA STATIONS
MAP NO. 1019-314-22
SCALE OF MILES
MAY 1969
REV. 3-71

Climate Data

Meteorologic data are collected and published by the National Oceanic and Atmospheric Administration. A discussion of the climate is presented in an earlier section of this chapter.

Surface-Water Data

Collection of surface-water data is coordinated by the Geological Survey and is a result of a cooperative program involving many private, State, and Federal organizations.

Prerequisite to comprehensive planning for the development of the water resources in a river basin is knowledge of the flow characteristics in the basin. To fill this need, historic streamflow records, summarized in a graphical format that emphasizes variability characteristics, are presented herein for 15 selected streamflow stations within the Lower Colorado Region.

For each selected station there is presented a graph of historic annual flow volumes. Estimates of annual flows for those years of missing or incomplete records were taken from various published and unpublished sources to give complete coverage for the period 1914-1965. These graphs demonstrate the erratic annual runoff experienced in the Lower Colorado Region. Also shown graphically with the annual flows is a trend line representing the 10-year moving mean of annual flows to show wet and dry cycles as well as effects on streamflow by upstream development such as storage facilities. The first year of operation of the various major storage features in the Region is indicated, where appropriate, by placement of the name of the dam above that year.

The two remaining graphs depict recorded daily flow (flow duration) and average monthly flows. Flow duration graphs were prepared from USGS computer data and are limited to those data available at the time of preparation of this portion of the appendix, usually ending with 1963 records.

The selected stations and the associated figures for each are as follow:

1. Colorado River at Compact Point, near Lees Ferry, Arizona, figure 3.

2. Colorado River at northerly international boundary, above Morelos Dam, near Andrade, California, figure 4.

3. Virgin River at Littlefield, Arizona, figure 5.

4. Bill Williams River near Alamo, Arizona, figure 6.

5. Little Colorado River above Lyman Reservoir, near St. Johns, Arizona, figure 7.

6. Little Colorado River near Cameron, Arizona, figure 8.

7. San Francisco River near Glenwood, New Mexico, figure 9.

8. Gila River below Blue Creek, near Virden, New Mexico, figure 10.

9. San Pedro River at Palominas, Arizona, figure 11.

10. Santa Cruz River near Nogales, Arizona, figure 12.

11. Salt River near Roosevelt, Arizona, figure 13.

12. Tonto Creek above Sun Creek, near Roosevelt, Arizona, figure 14.

13. Verde River below Tangle Creek, above Horseshoe Dam, Arizona, figure 15.

14. Gila River at Gillespie Dam, Arizona, figure 16.

15. Gila River below Gillespie Dam, Arizona, figure 17.

These streamflow characteristics data may be useful in evaluating the impact of past developments on streamflow, in determining the suitability of remaining water resources for specific purposes, for developing generalized relationships to basin and hydrometeorological data, and for other purposes in the development of the comprehensive framework plan.

Selection of stations for inclusion in the appendix was based on obtaining an adequate coverage of representative streamflow throughout the Region, as well as depicting historic subregional inflow and outflow. Flow conditions vary from nearly undepleted (Tonto Creek and San Francisco River) to nearly fully depleted (Gila River below Gillespie Dam). Both extremes, as noted above, as well as intermediate flow conditions, are represented.

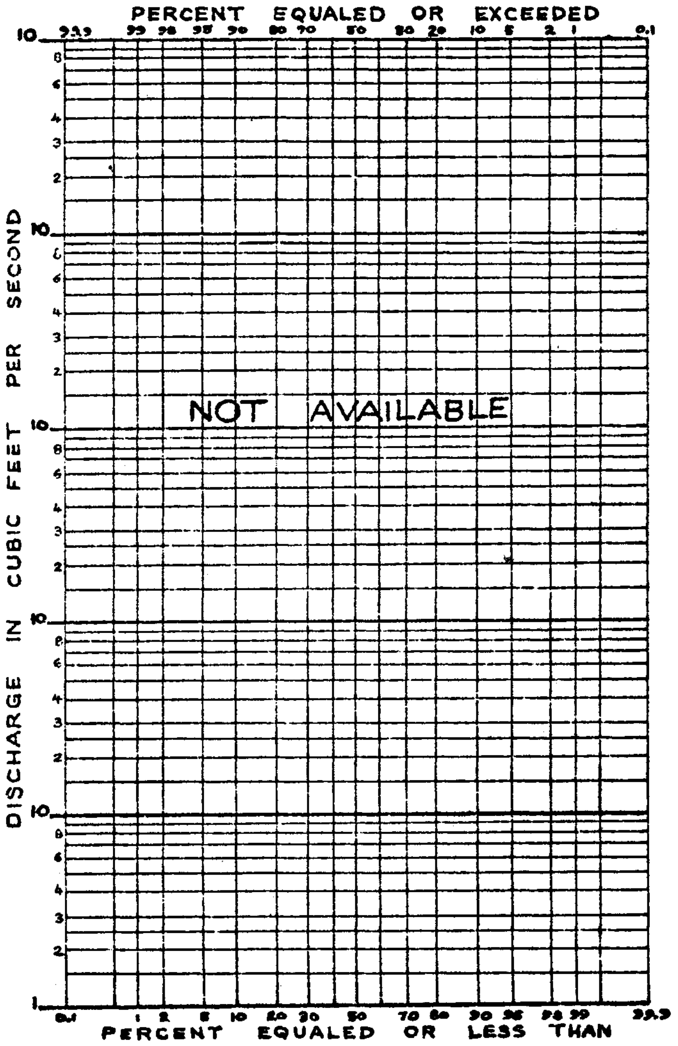
Needs for Additional Data

The existing network of hydrologic and meteorologic stations in the Lower Colorado Region is, generally, adequate for the purposes of comprehensive framework planning. Additions to this network may be proposed from time to time to meet specific needs in localized areas.

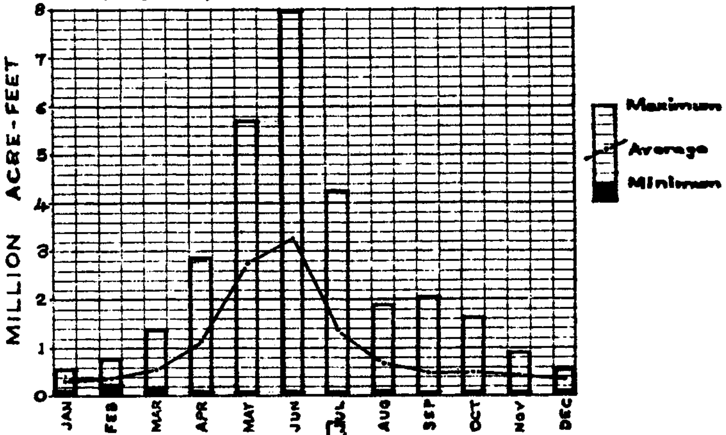
The available data could be strengthened somewhat by the addition of more evaporation and sediment data, especially in the more remote areas of the Region, and the Little Colorado Subregion in particular.

HISTORIC STREAMFLOW CHARACTERISTICS
COLORADO RIVER AT COMPACT POINT NEAR LEES FERRY, ARIZONA

FLOW DURATION



MONTHLY DISTRIBUTION



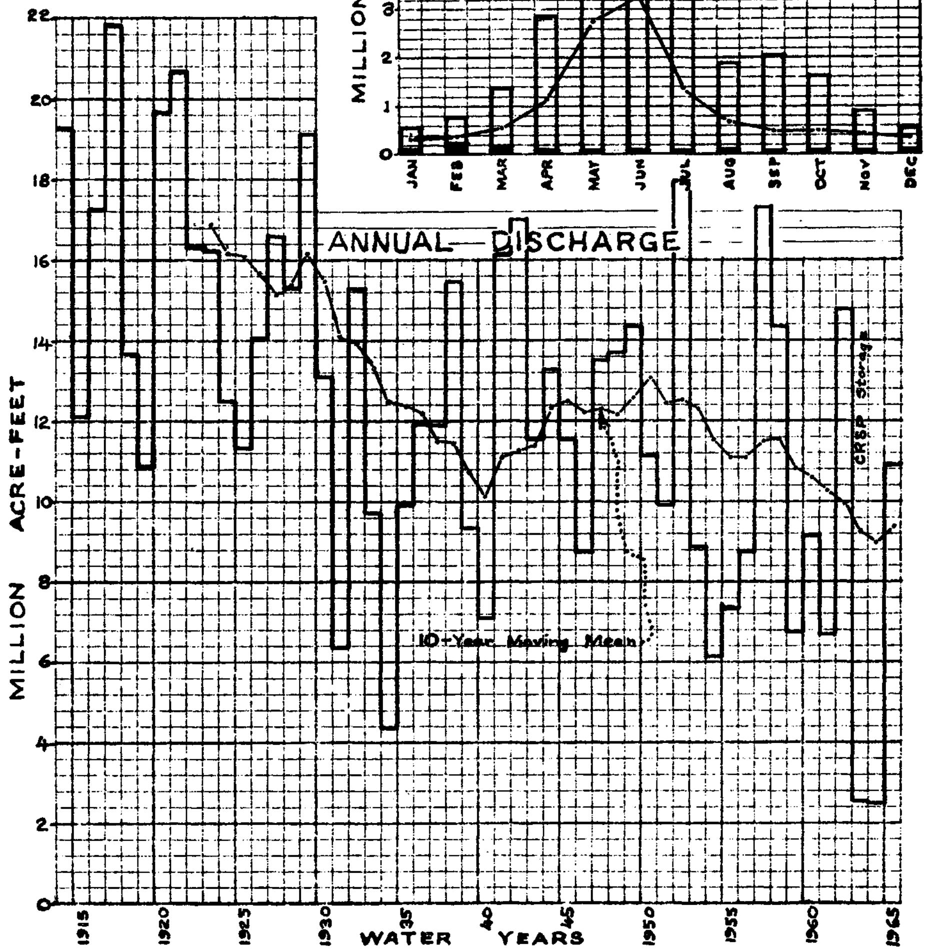
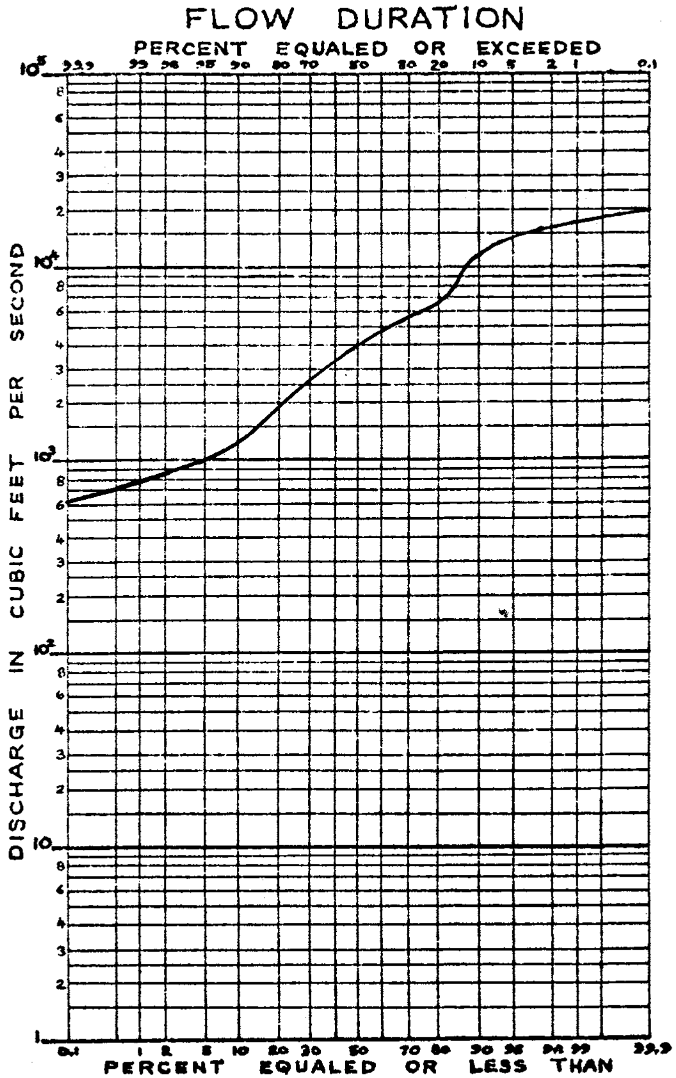
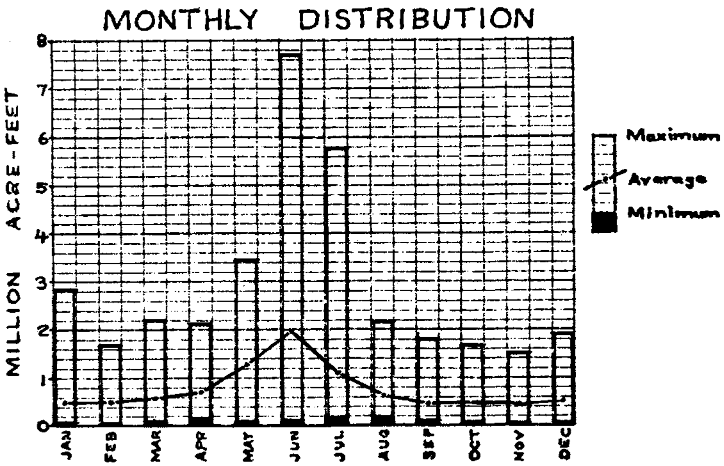


FIGURE 3

HISTORIC STREAMFLOW CHARACTERISTICS

COLORADO RIVER AT NORTHERLY INTERNATIONAL BOUNDARY ABOVE MORELOS DAM, NEAR ANDRADE, CALIF.





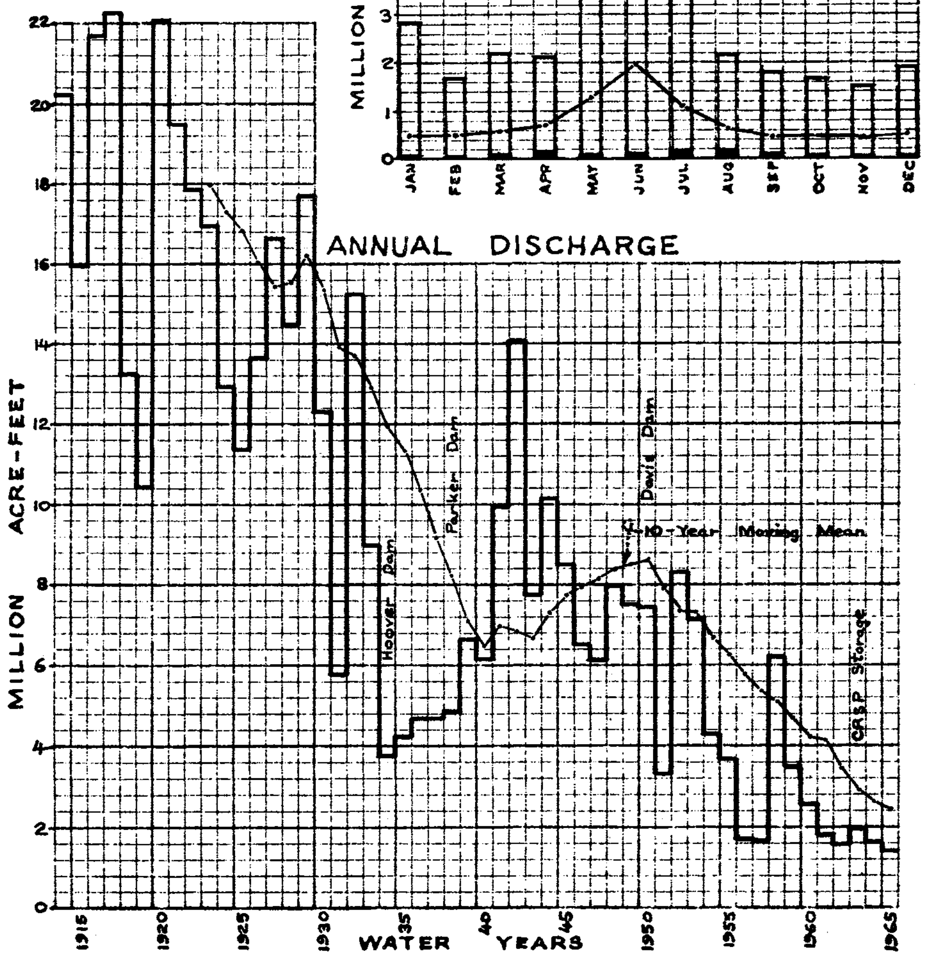


FIGURE 4

HISTORIC STREAMFLOW CHARACTERISTICS
VIRGIN RIVER AT LITTLEFIELD, ARIZONA

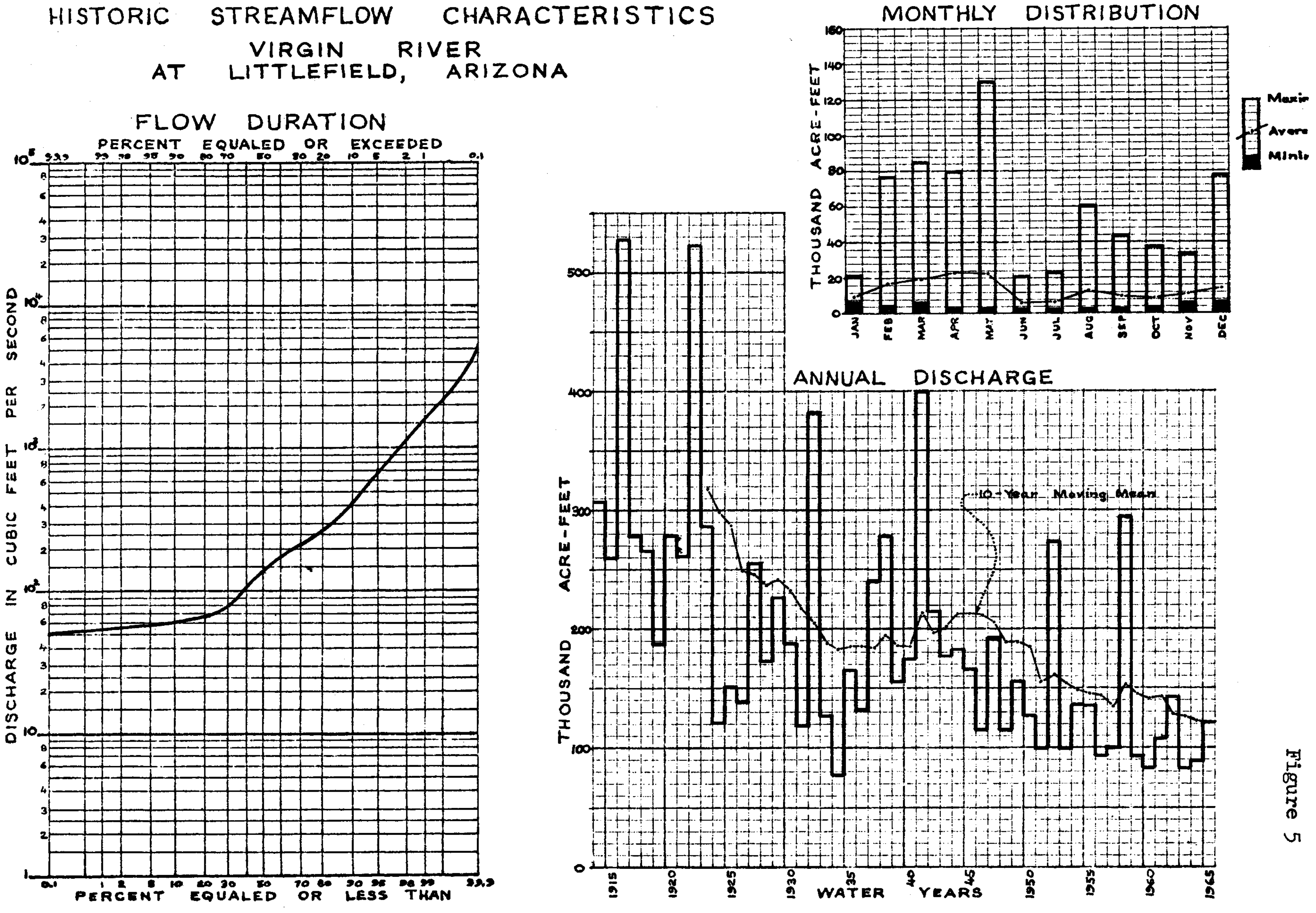
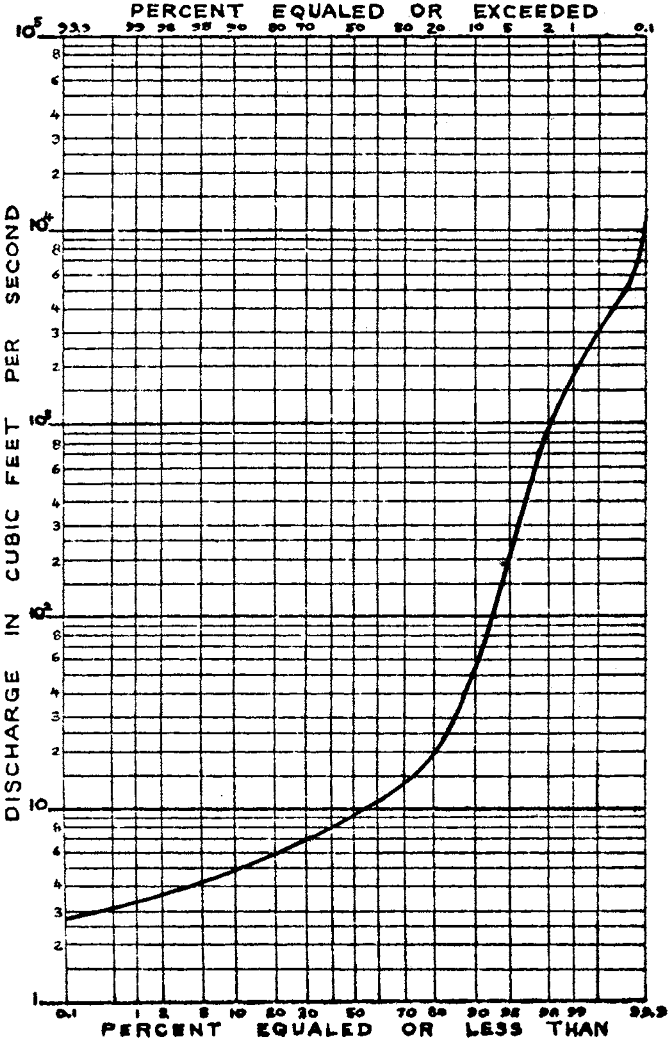


Figure 5

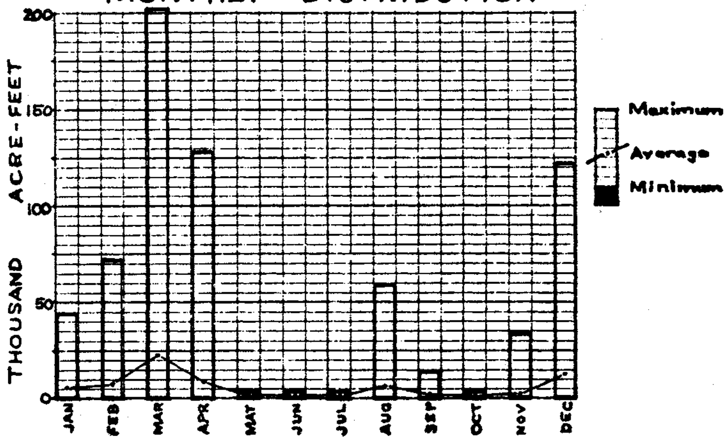
HISTORIC STREAMFLOW CHARACTERISTICS

BILL WILLIAMS RIVER
NEAR ALAMO, ARIZONA

FLOW DURATION



MONTHLY DISTRIBUTION



ANNUAL DISCHARGE

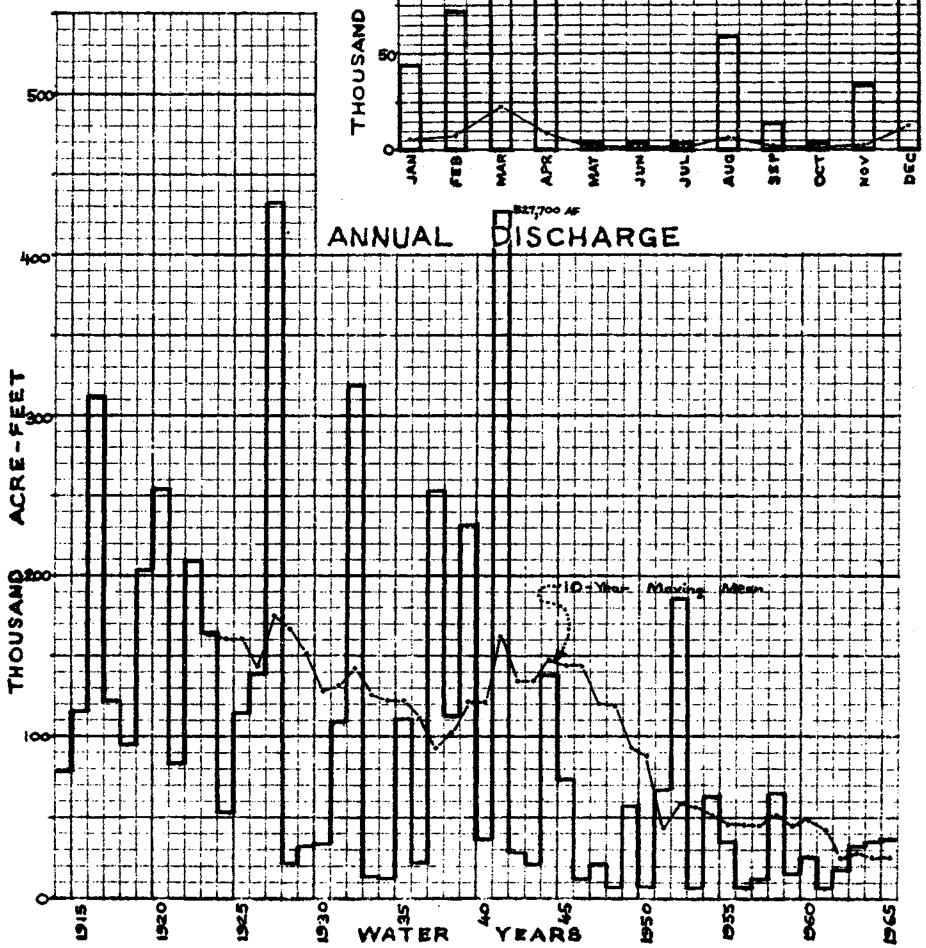
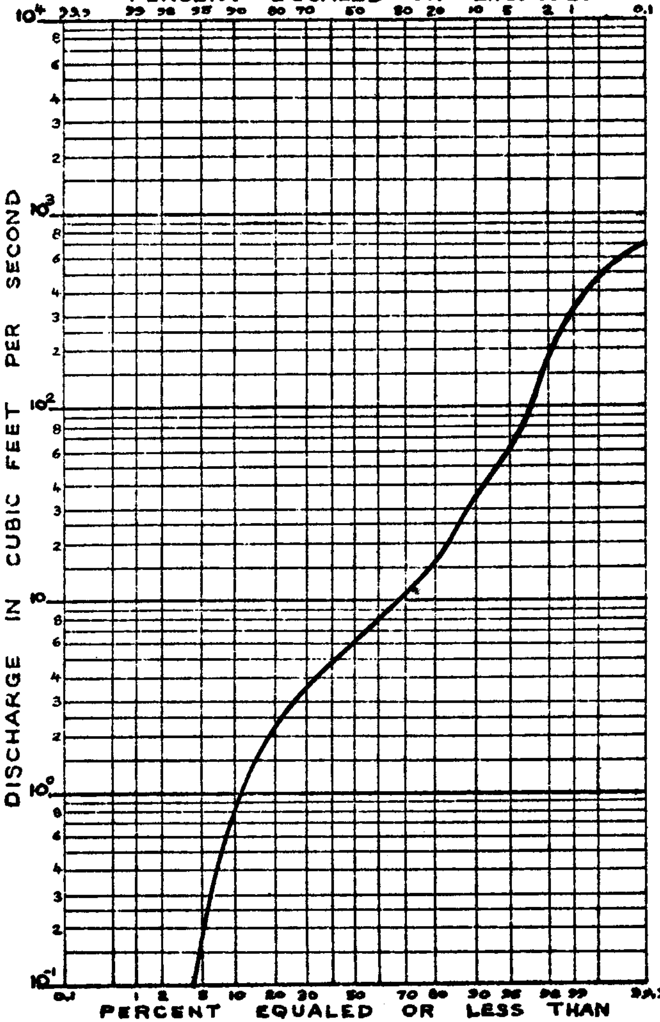


FIGURE 6

HISTORIC STREAMFLOW CHARACTERISTICS

LITTLE COLORADO RIVER ABOVE LYMAN RESERVOIR, NEAR ST. JOHNS, ARIZONA

FLOW DURATION



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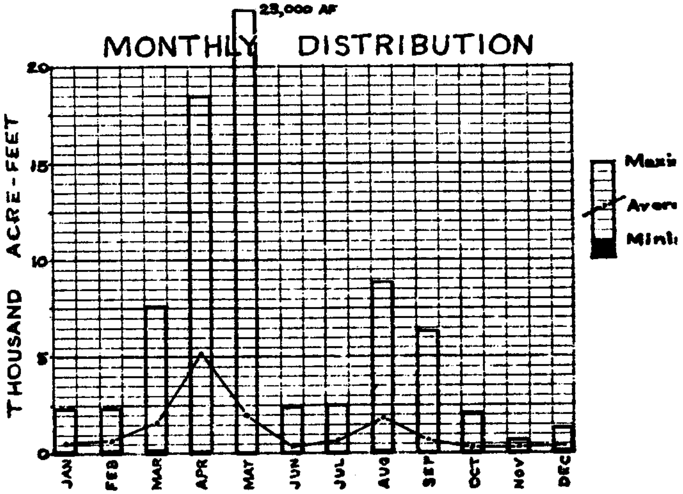

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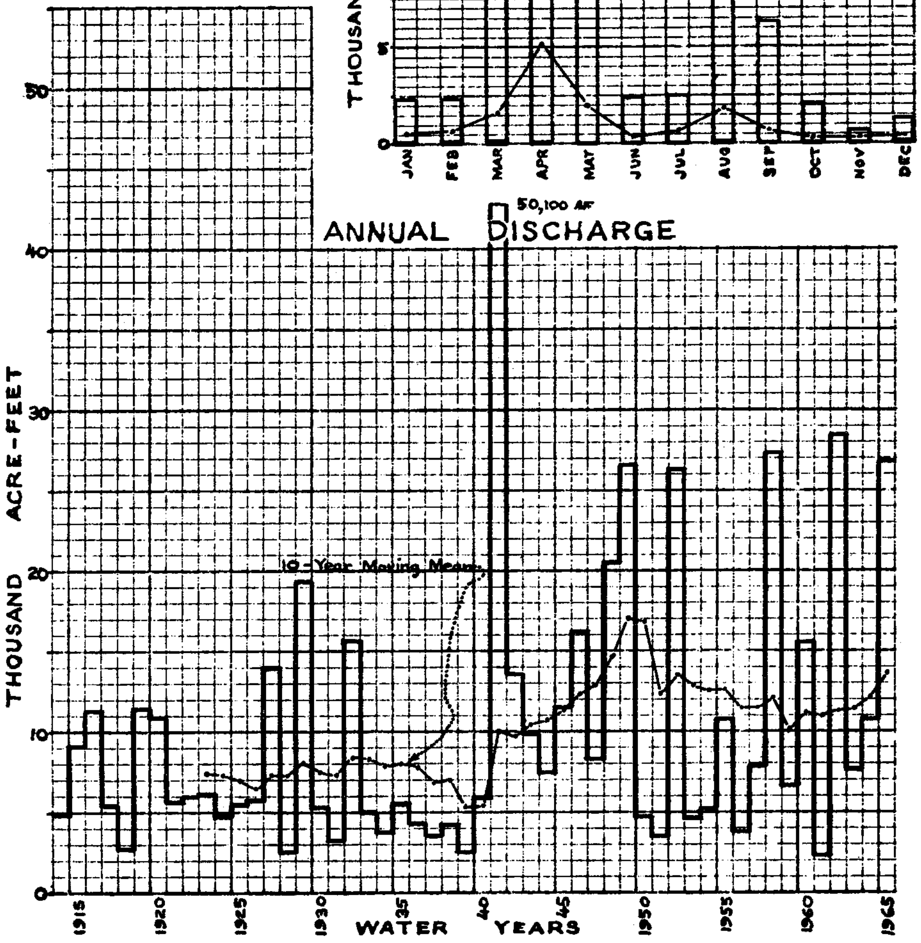


Figure 7

HISTORIC STREAMFLOW CHARACTERISTICS
LITTLE COLORADO RIVER NEAR CAMERON, ARIZONA

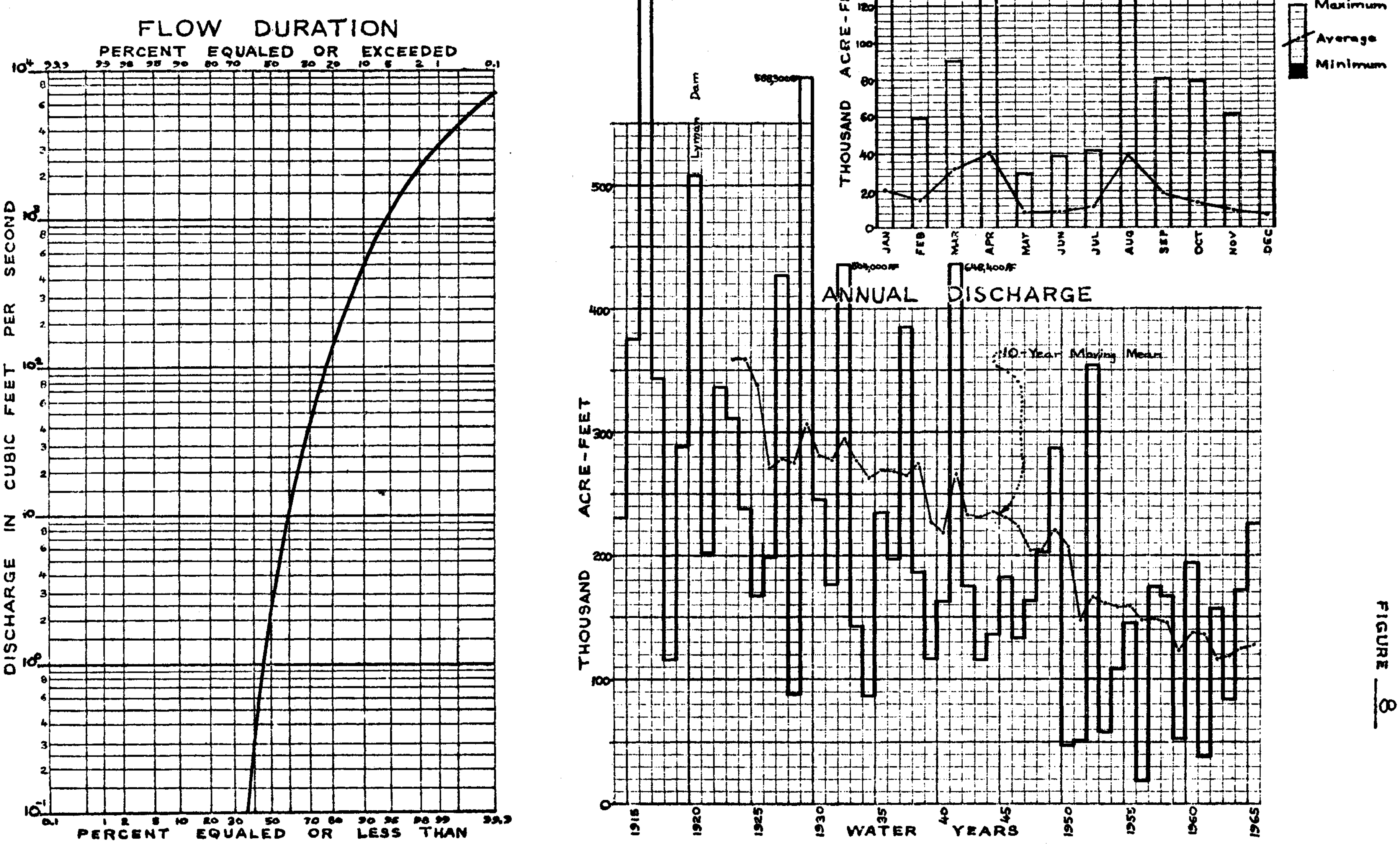
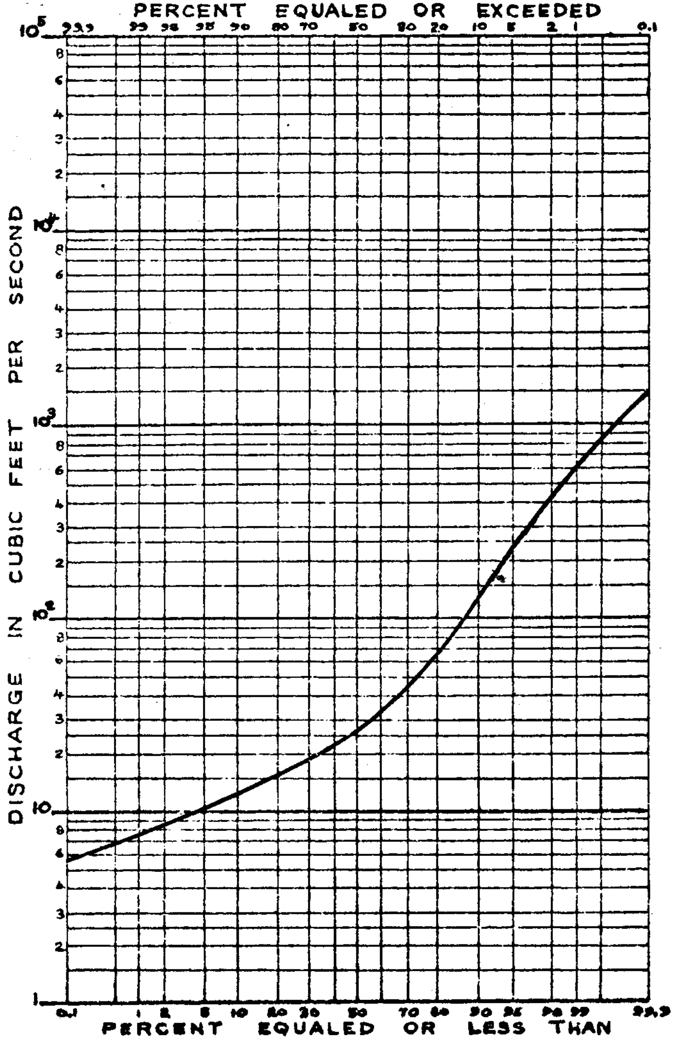


FIGURE 8

HISTORIC STREAMFLOW CHARACTERISTICS

SAN FRANCISCO RIVER
NEAR GLENWOOD, NEW MEXICO

FLOW DURATION



MONTHLY DISTRIBUTION

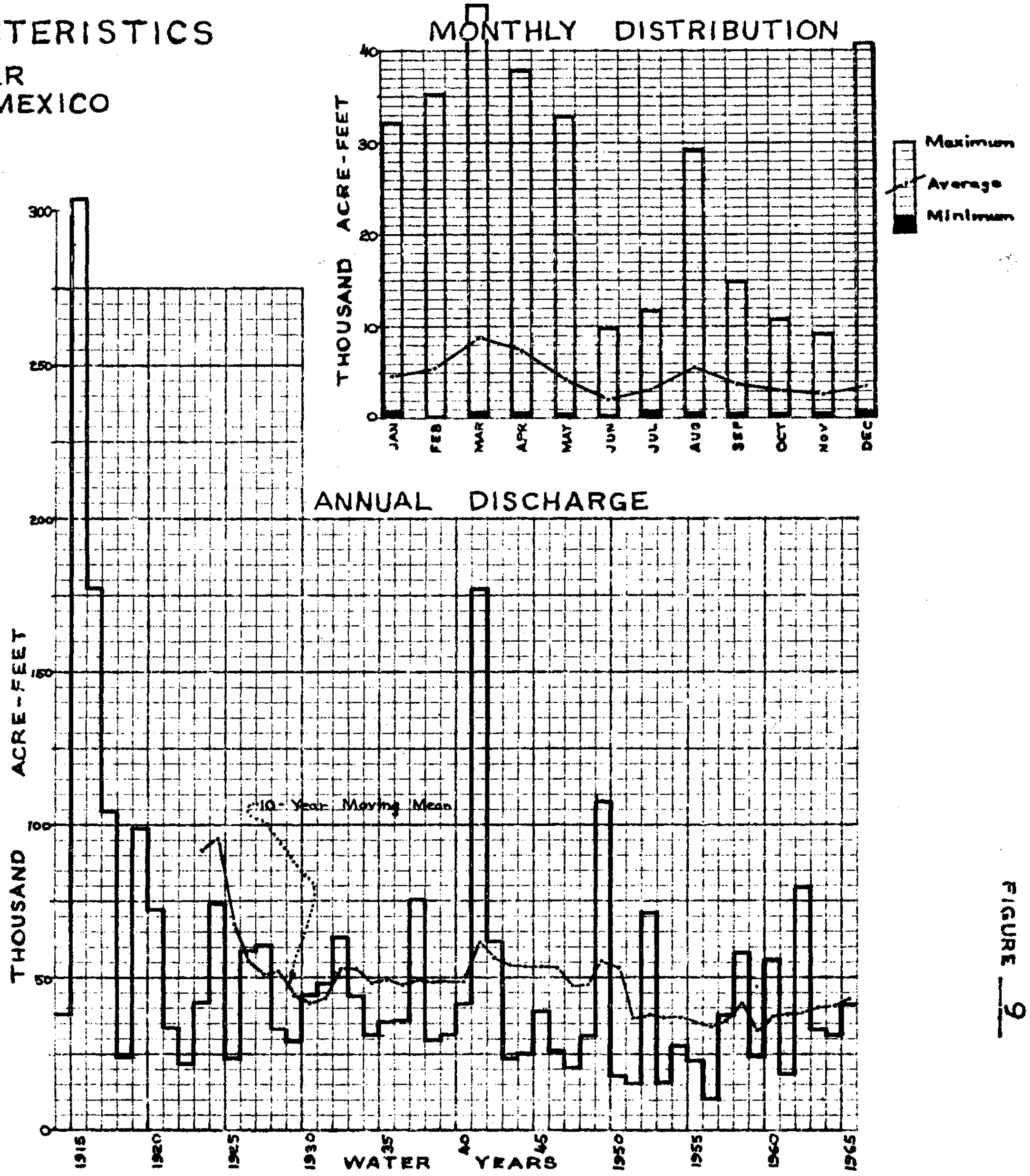
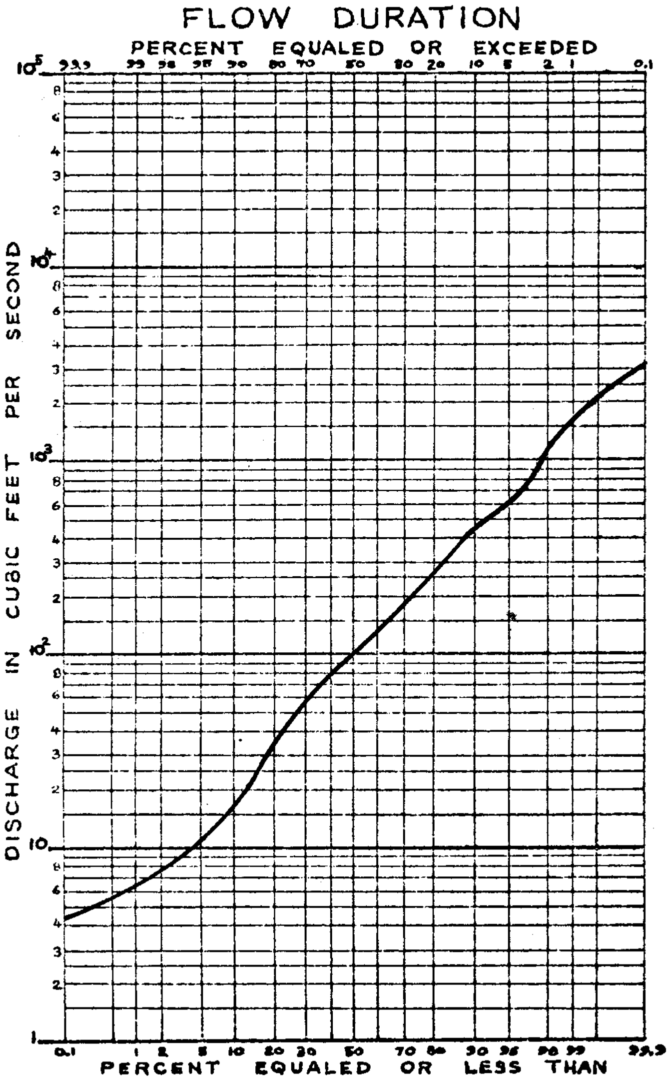
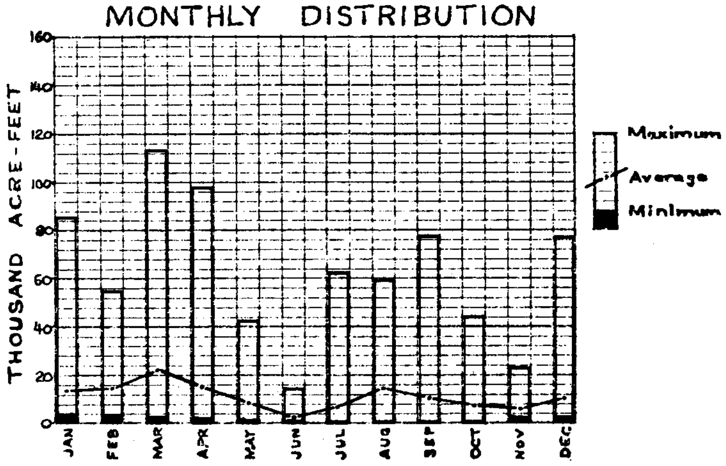


FIGURE 9

HISTORIC STREAMFLOW CHARACTERISTICS

GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NEW MEXICO





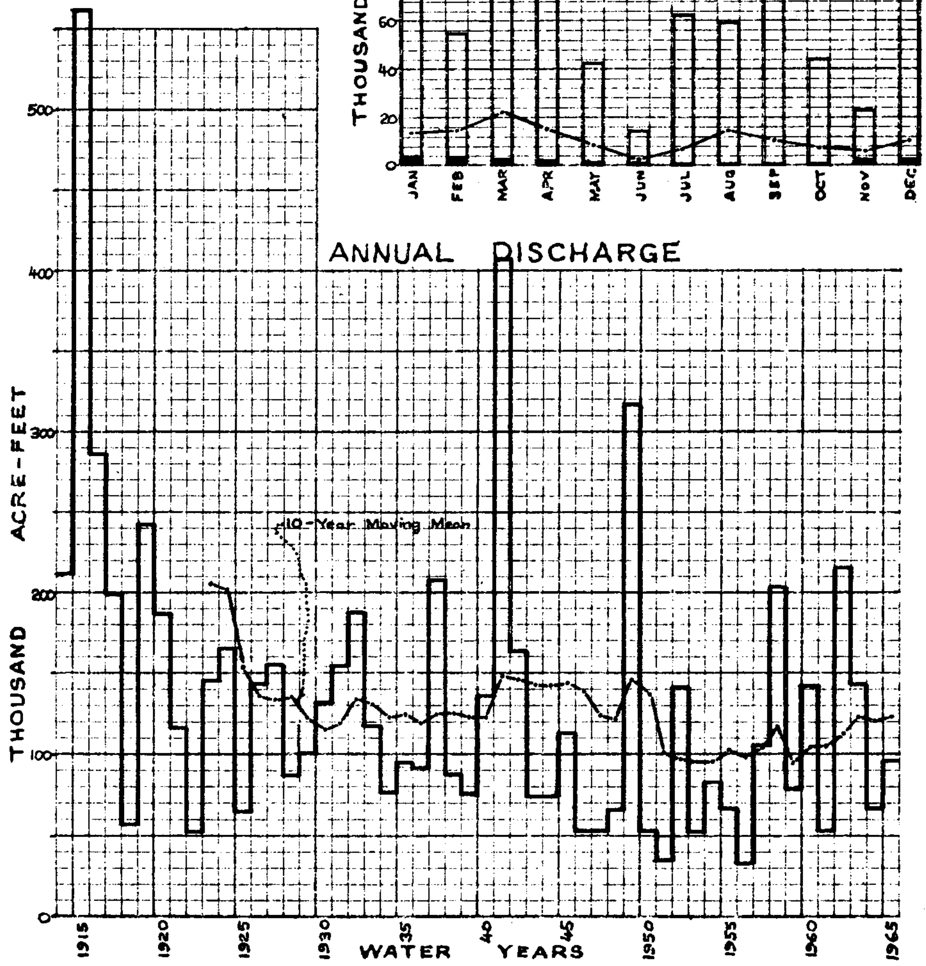
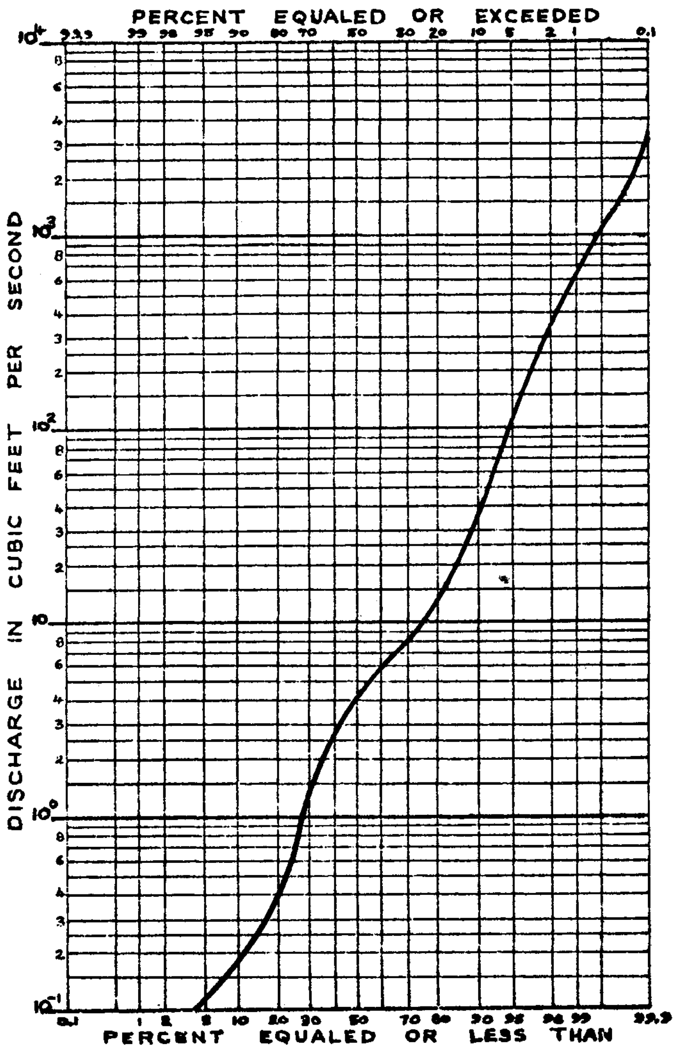


FIGURE 10

HISTORIC STREAMFLOW CHARACTERISTICS

SAN PEDRO RIVER AT PALOMINAS, ARIZONA

FLOW DURATION



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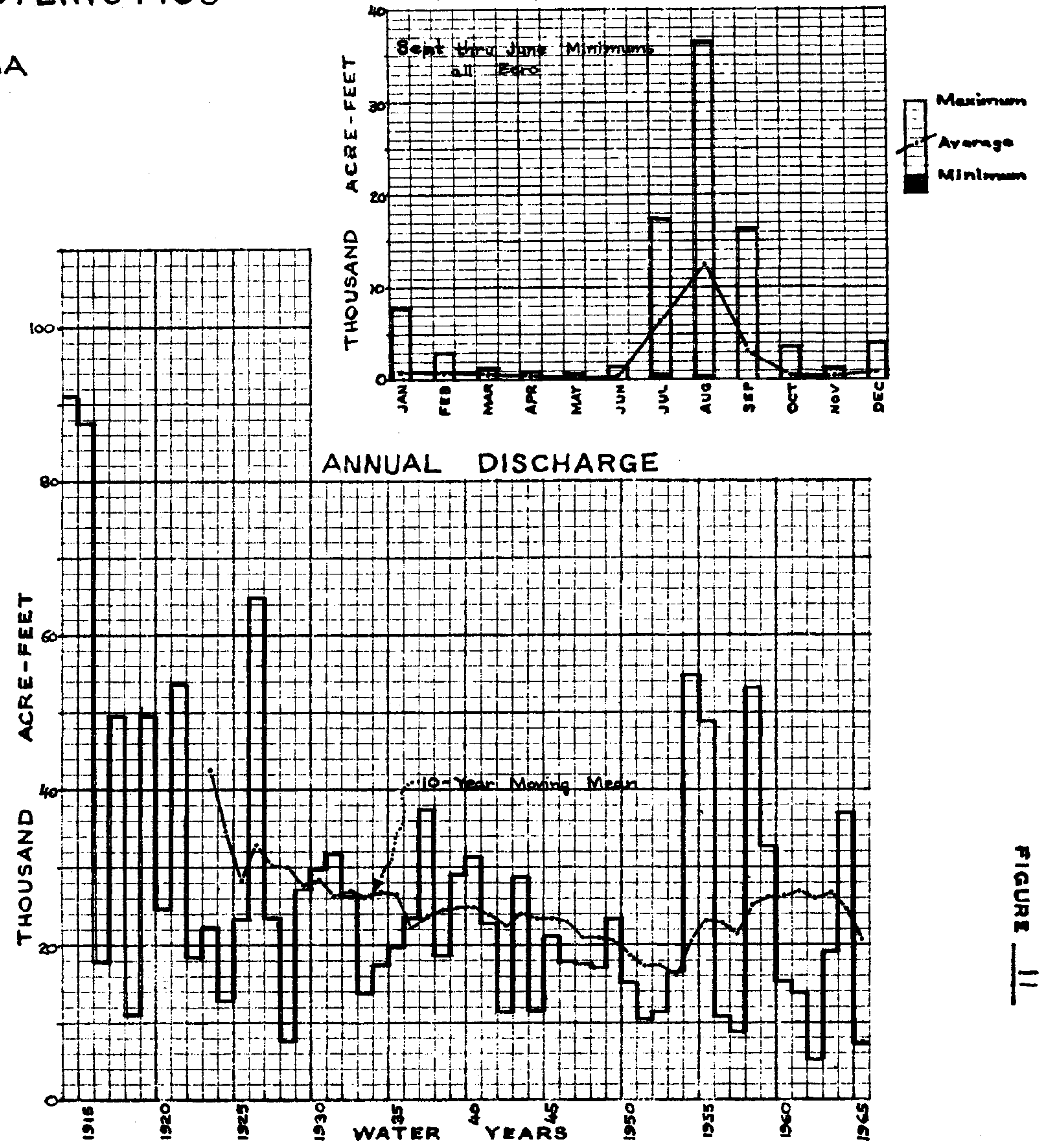
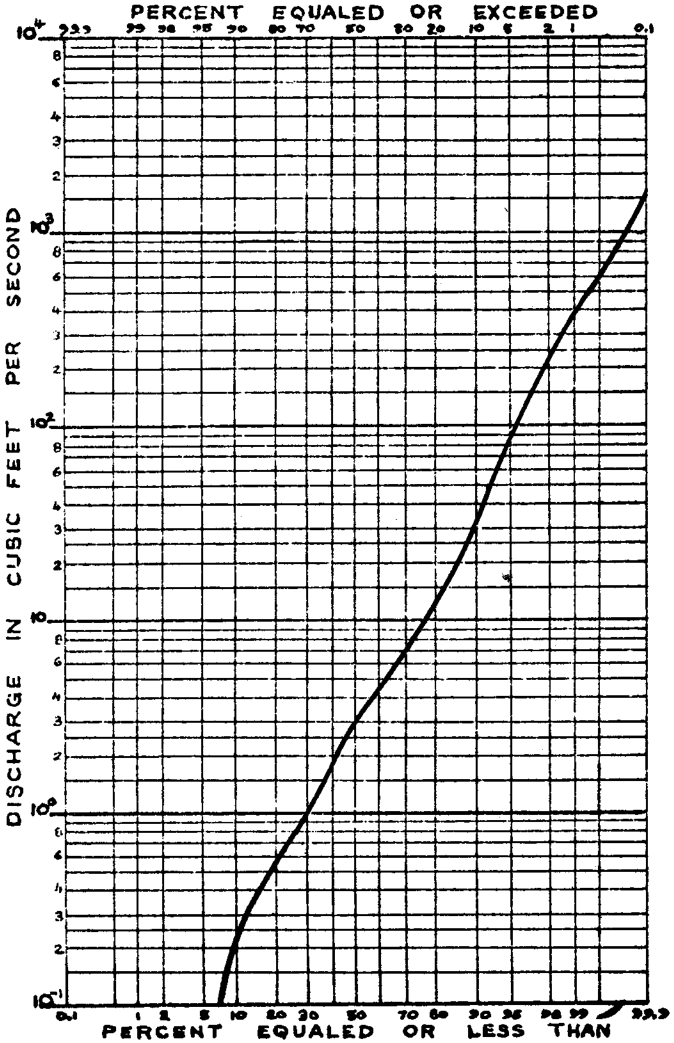


FIGURE 11

HISTORIC STREAMFLOW CHARACTERISTICS

SANTA CRUZ RIVER
NEAR NOGALES, ARIZONA

FLOW DURATION



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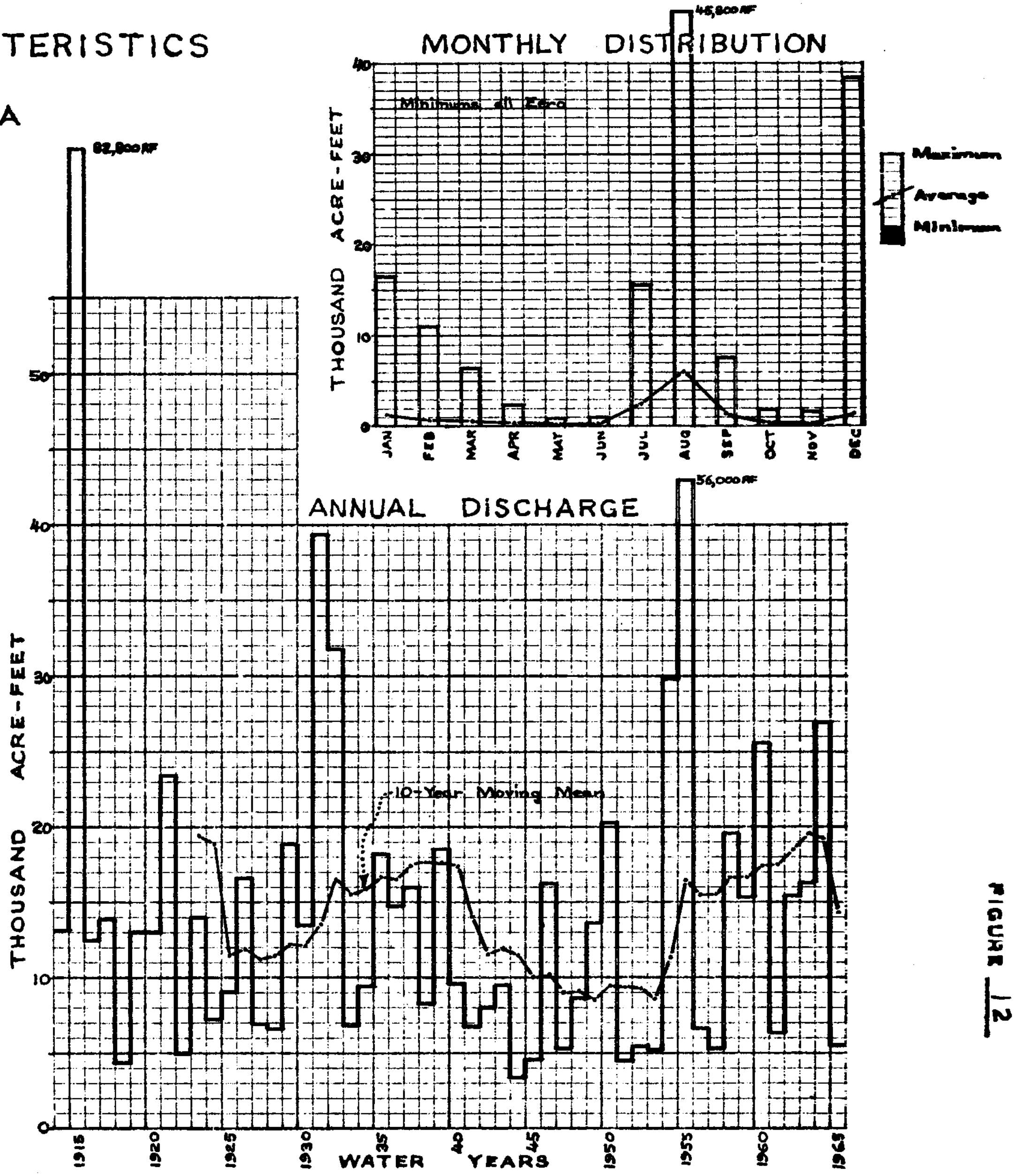
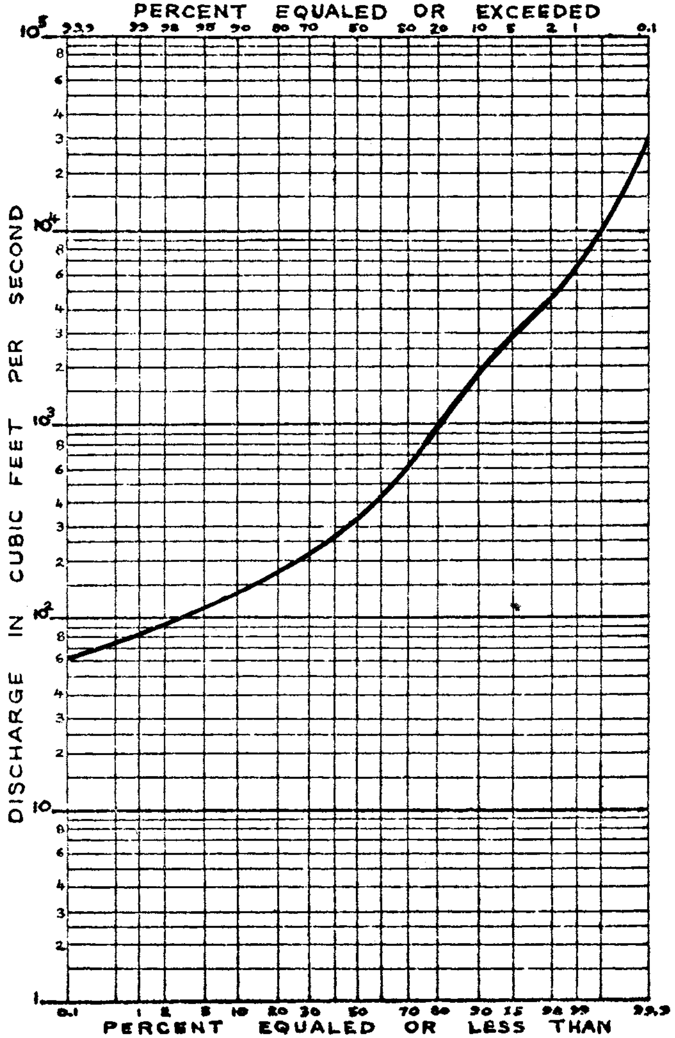


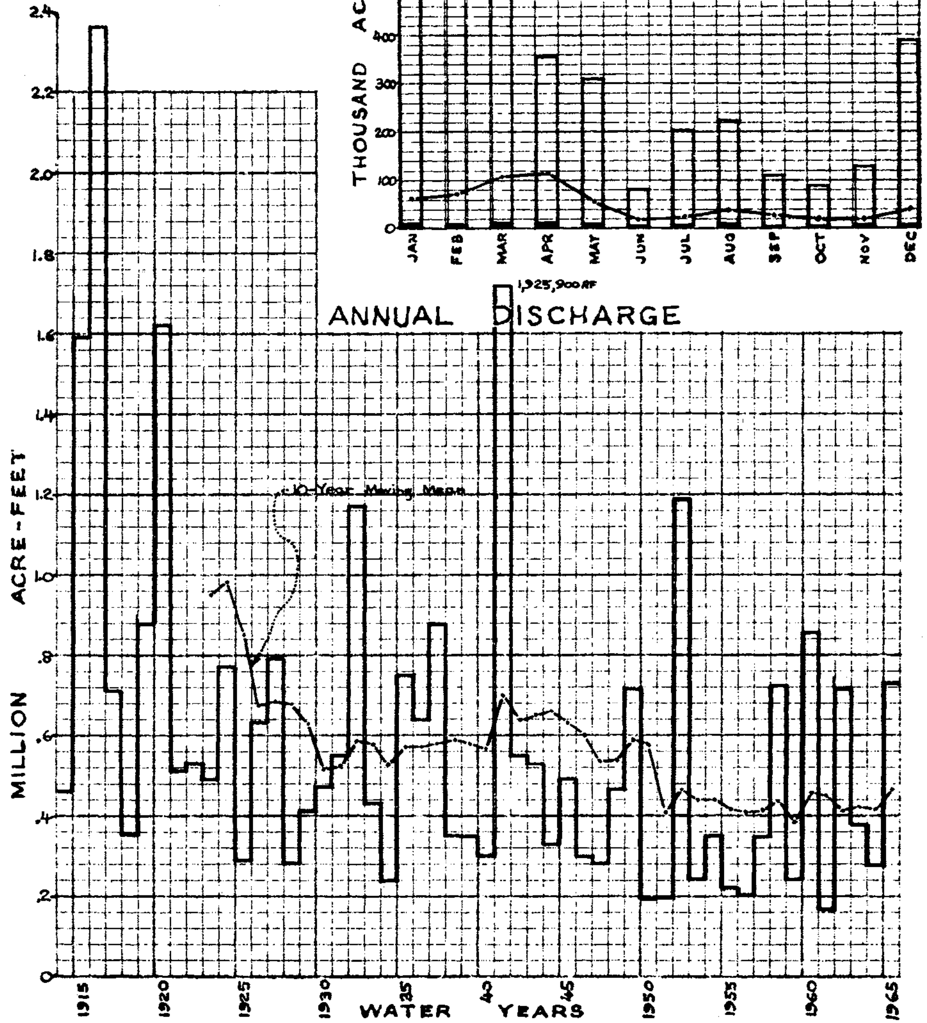
ANNUAL DISCHARGE

FIGURE 12

HISTORIC STREAMFLOW CHARACTERISTICS
SALT RIVER
NEAR ROOSEVELT, ARIZONA

FLOW DURATION





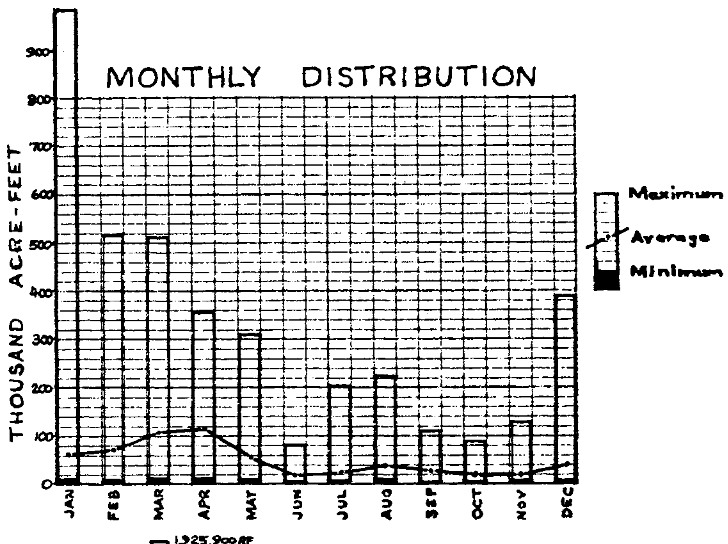
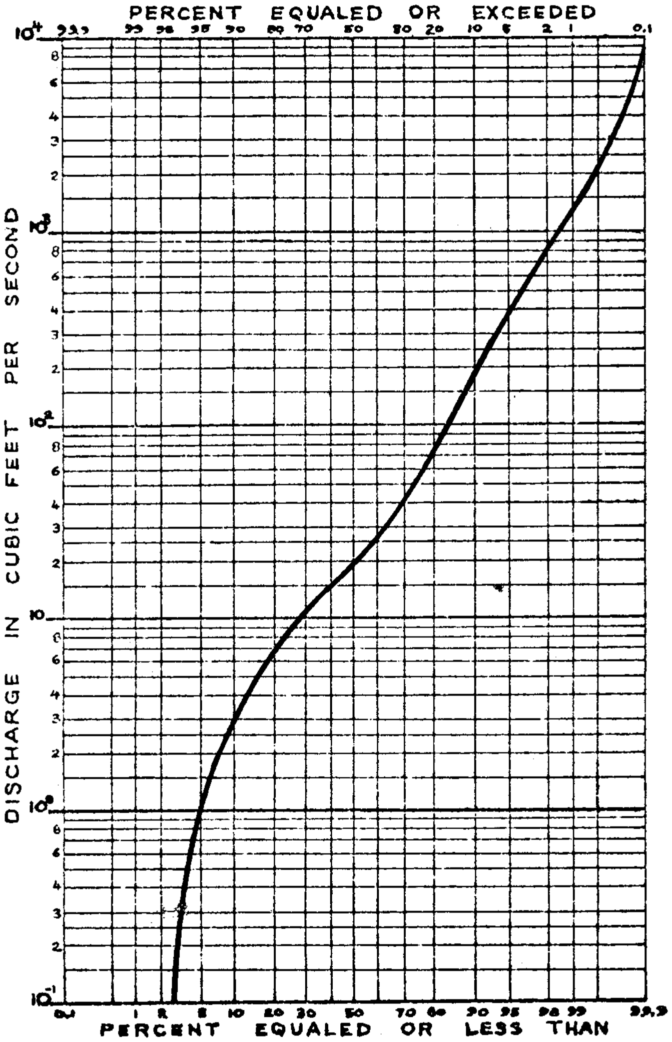


FIGURE 13

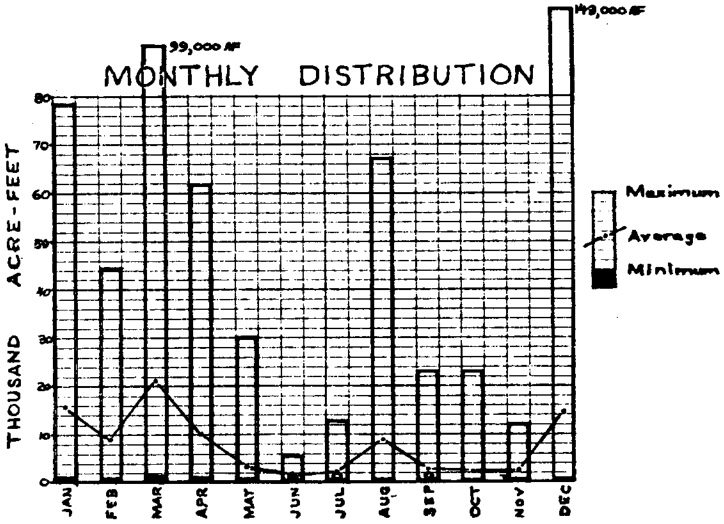
HISTORIC STREAMFLOW CHARACTERISTICS

TONTO CREEK ABOVE GUN CREEK NEAR ROOSEVELT, ARIZONA

FLOW DURATION



MONTHLY DISTRIBUTION



ANNUAL DISCHARGE

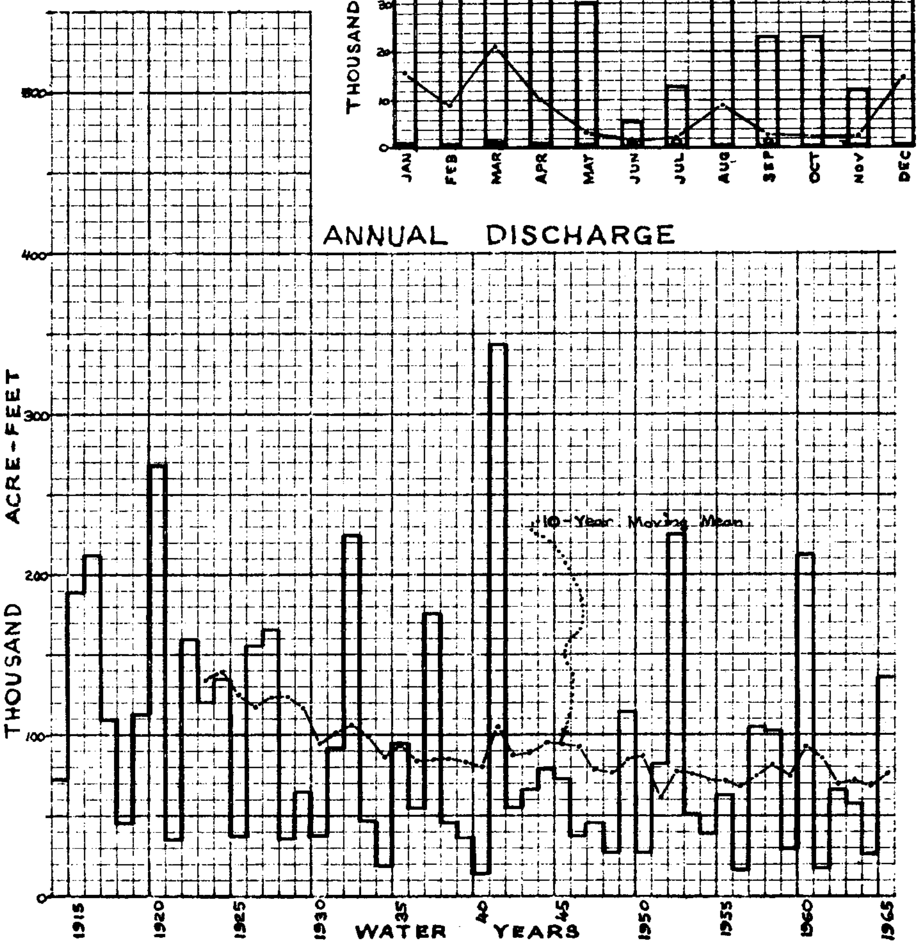


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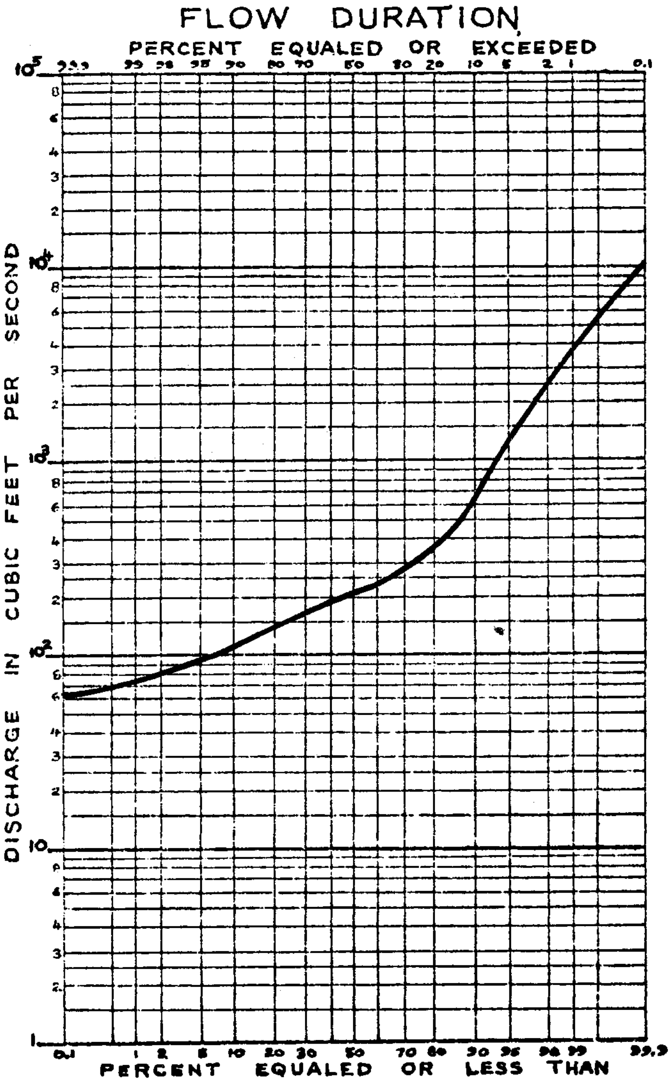
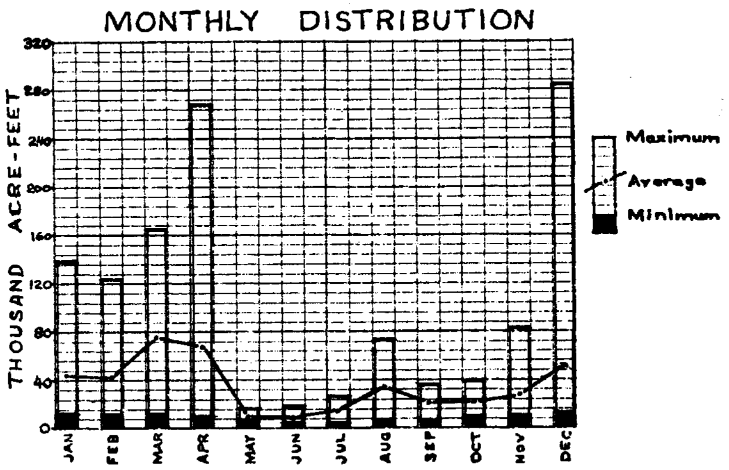
FIGURE 14

HISTORIC STREAMFLOW CHARACTERISTICS

VERDE RIVER BELOW TANGLE CREEK
ABOVE HORSESHOE DAM, ARIZONA





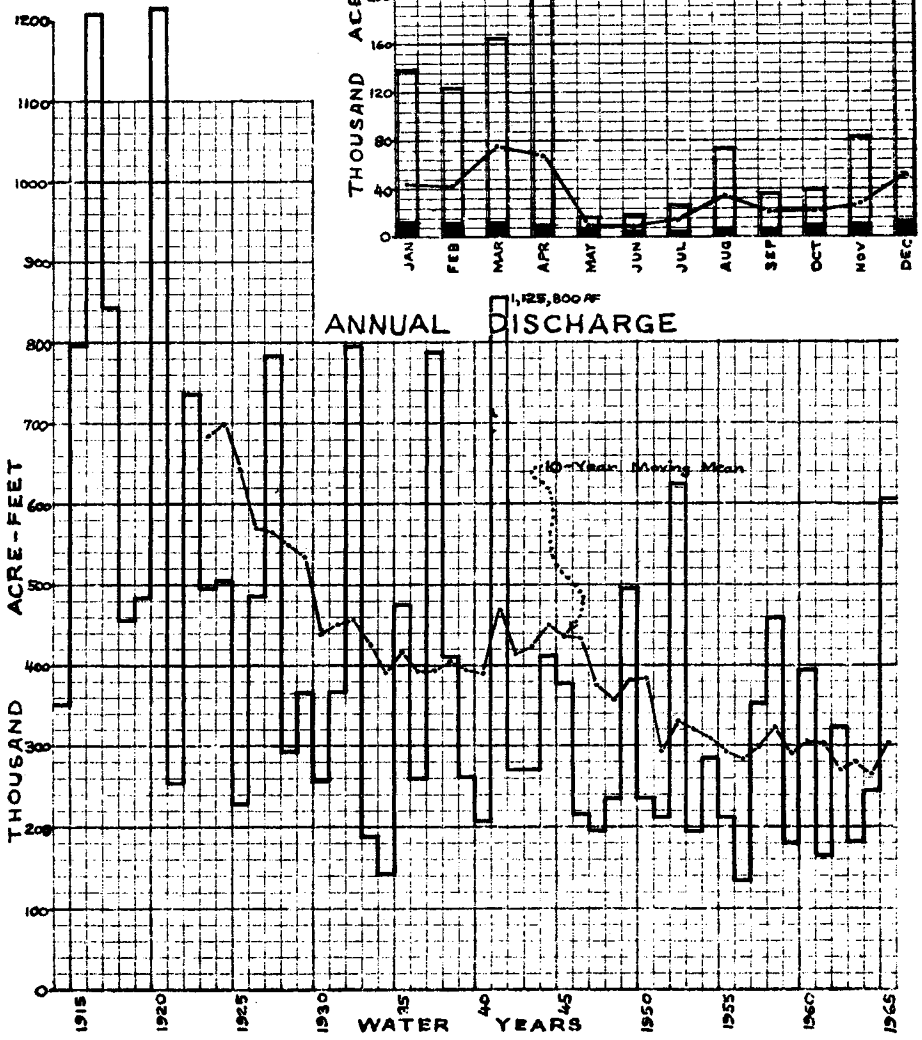
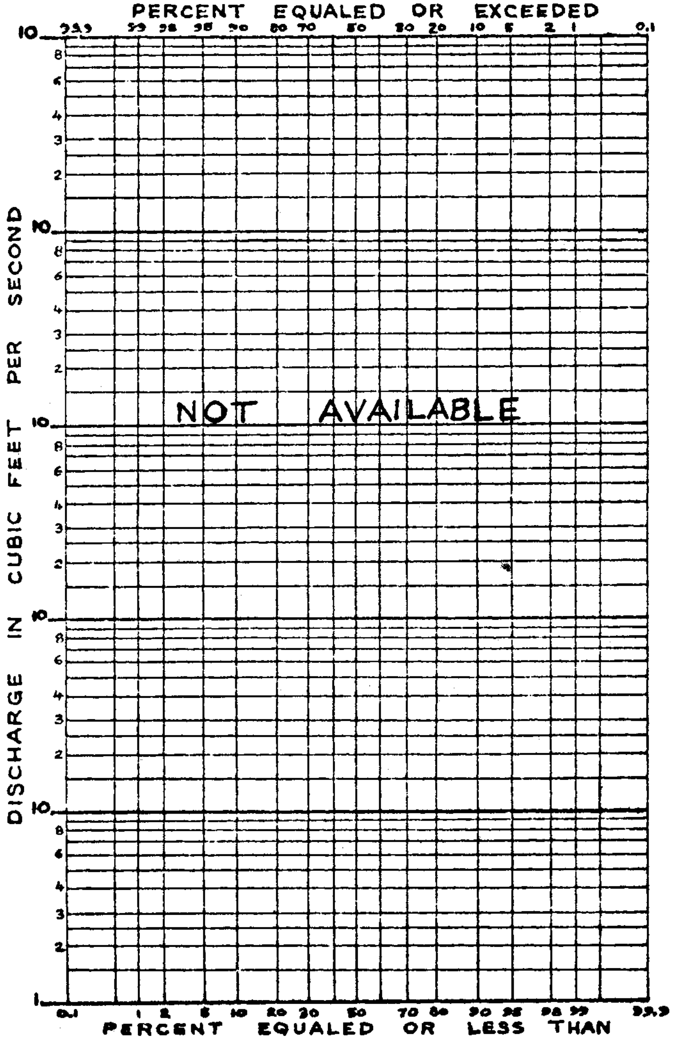


FIGURE 15

HISTORIC STREAMFLOW CHARACTERISTICS

GILA RIVER
ABOVE GILLESPIE DAM, ARIZONA

FLOW DURATION



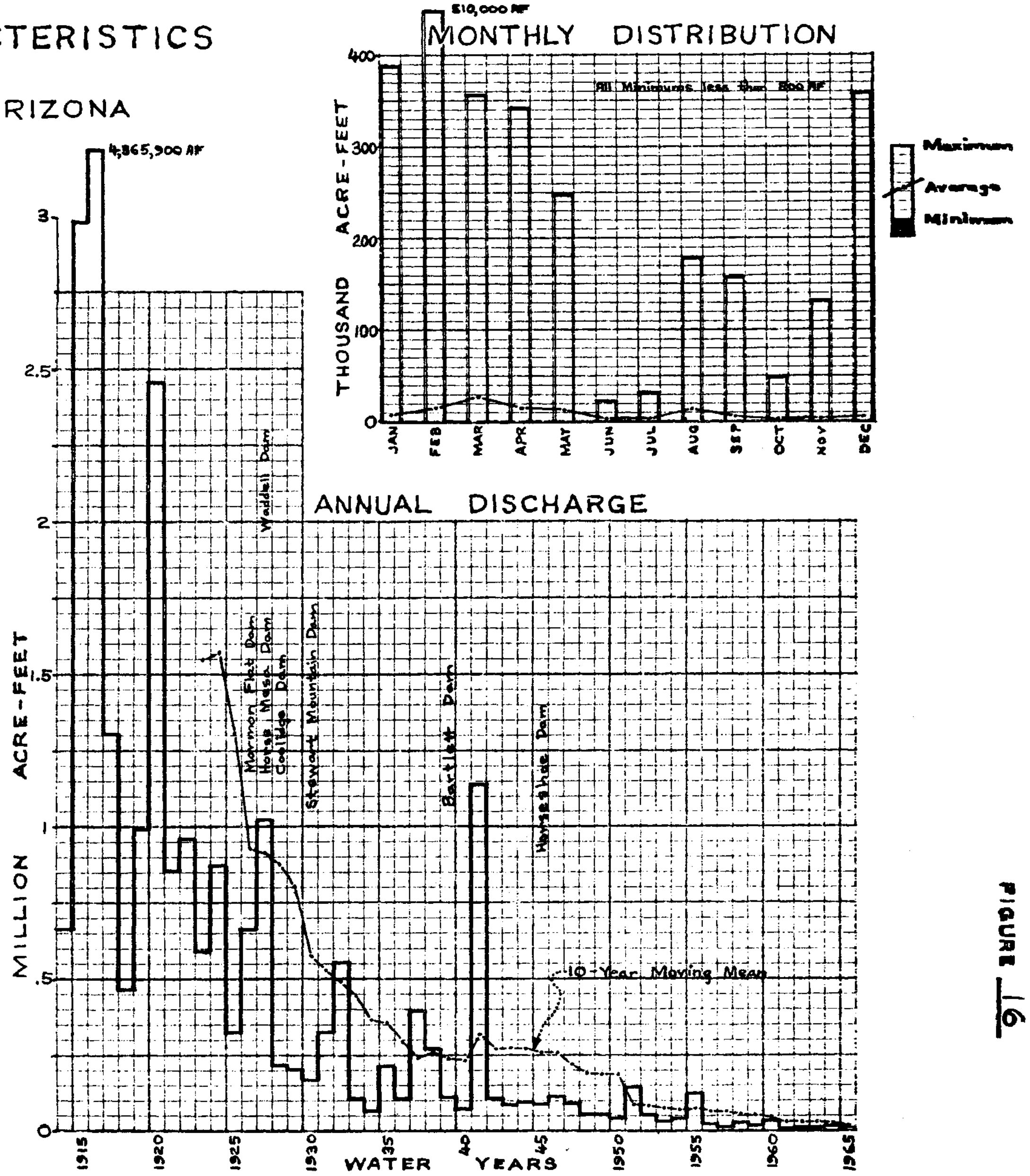


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FIGURE 16

HISTORIC STREAMFLOW CHARACTERISTICS

GILA RIVER
BELOW GILLESPIE DAM, ARIZONA

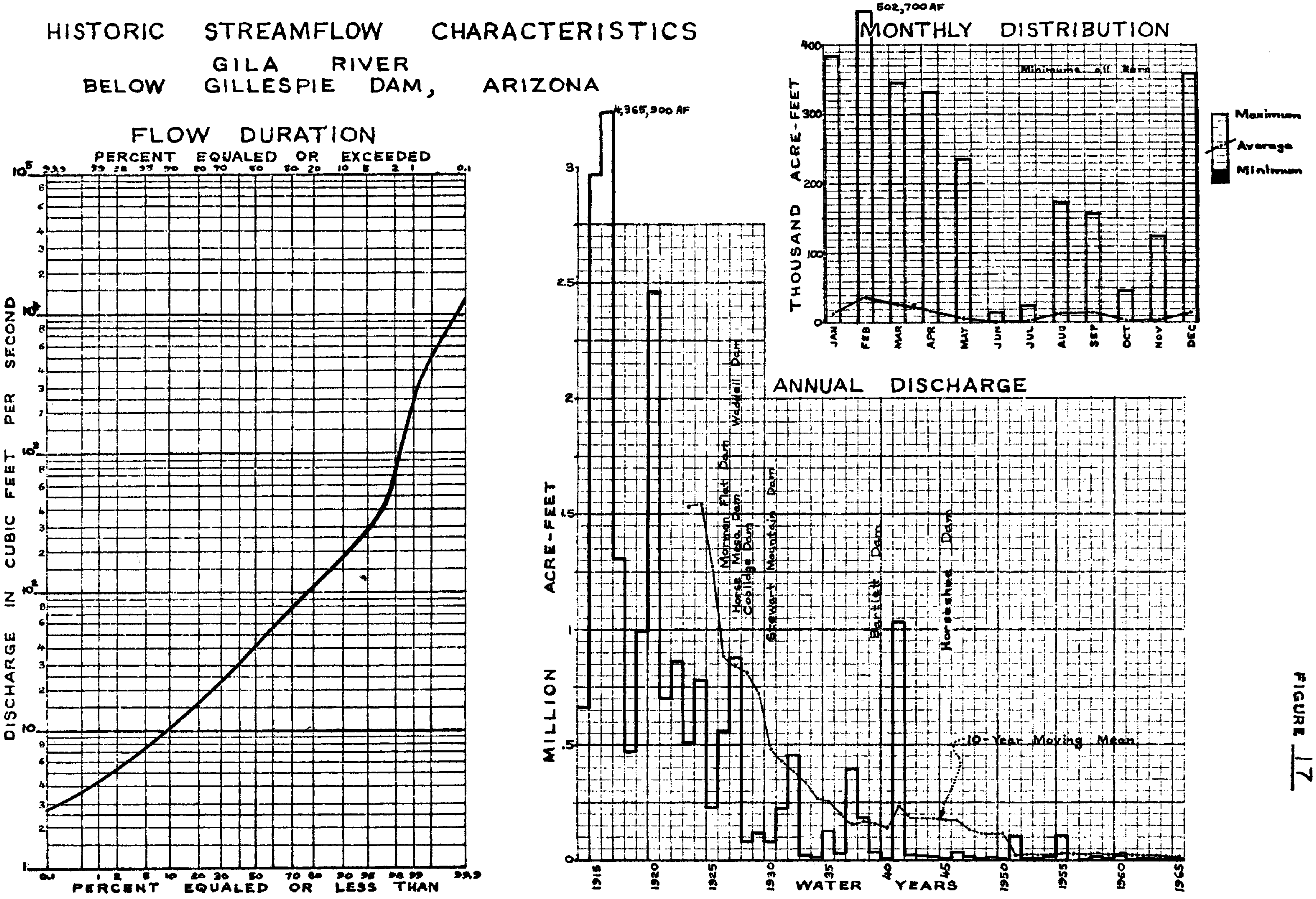

FIGURE 17

LOWER MAIN STEM SUBREGION

CHAPTER C - LOWER COLORADO MAIN STEM SUBREGION

HYDROLOGIC FRAMEWORK

The Lower Main Stem Subregion, as shown on maps 1 and 6, includes the Colorado River drainage basin from Lee Ferry (1 mile downstream from the Paria River) to the southerly international boundary with Mexico, with the exception of the Little Colorado River Basin, the Gila River Basin above Painted Rock Dam, and the California portion of the Colorado River Basin. In addition, the Subregion includes Mexican drainage west of Lukeville, Arizona, and closed basins in southeastern Nevada. The total area is 56,554 square miles, of which 17,310 square miles are in Nevada, 3,490 square miles are in Utah,and 35,754 square miles are in Arizona. About 52,100 square miles of the area contribute to the Colorado River.

	Unit: 1,000 (sq mi)
Drainage area contributing to the Colorado River	52.2
Mexican drainage - west of Lukeville	1.2
Closed basin - southeastern Nevada	3.2
	56.6

The Colorado River follows a generally westerly course from Lee Ferry through the Grand Canyon and into Lake Mead. Below Lake Mead, it flows southward forming the border between the States of Arizona and Nevada and further south, Arizona and California. Elevations range from near 12,000 feet at Charleston Peak near Las Vegas to about 75 feet at the southerly international boundary. As shown on figure 1, average annual precipitation varies from 25 inches or more along the north rim of the Grand Canyon to 5 inches or less along the Colorado River below Lake Mead. The eastern and northern portions of the Subregion are characterized by relatively cold winters and cool summers while the western and southern portions have mild winters and hot summers. Summer temperatures average in the midseventies at Grand Canyon and 90 degrees at Parker, Arizona. Major cities in the Subregion are Las Vegas and Boulder City in Nevada, Yuma and Kingman in Arizona, and St. George in Utah. Between Lee Ferry and Hoover Dam (353 river miles) the principal tributaries are the Little Colorado River (Subregion 2), the Virgin River, Bright Angel, Tapeats, Kanab, and Havasu Creeks, and Las Vegas Wash. Springs contribute about 300,000 acre-feet annually in this reach [5-43]. Below Hoover Dam, the Gila and Bill Williams Rivers are major tributaries.

Table 27

1/ Includes drainage areas in Mexico.

2/ Average annual undepleted runoff, 1914-58, is available from the Report on Water Supply of the Lower Colorado River Basin, Project Planning Report, November 1952; its two supplements of November 1953 and October 1963 and supporting data, Bureau of Reclamation. The available runoff was extended through 1965 by reconnaissance methods and is not intended as an updating of cited report.

3/ Estimated average annual undepleted runoff near the mouth of the Gila River near Dome, Arizona, is 1,050,000 acre-feet.

The Gila River once contributed an annual average flow of over 1 million acre-feet to the Colorado River, however, water-resource development in the basin has reduced the flow to near negligible amounts. The remaining drainage area below Hoover Dam is made up of numerous desert washes that rarely contribute appreciable quantities of water except from occasional heavy storms. The total long-term average annual undepleted tributary runoff to the Colorado River is estimated at nearly 2.4 maf, including over 1 maf from the Gila River and 0.4 maf from the Little Colorado River. The undepleted net gain of the Colorado River from Lee Ferry (15.09 maf) to the international boundary (15.94 maf) is about 0.85 maf annually. Since the undepleted inflow to the main stem is estimated as about 2.4 maf, an apparent river loss of 1.5 maf under the natural environment is indicated.

Present water requirements in the Subregion, shown on table 6, are estimated as 1.3 maf annually. Additional demands on the supply of the river below Lee Ferry are for main stem reservoir evaporation and spills, channel losses, exports to the California Region, and Mexican Treaty obligations. These demands presently total about 9 maf annually.

WATER SUPPLY

Introduction

The water supply available for use in the Lower Main Stem Subregion consists of (a) natural runoff originating in the Subregion, (b) a portion of the main stem Colorado River water released from the Upper Colorado Region at Glen Canyon Dam under the provisions of the Colorado River Compact, and (c) ground water. Most of the presently available runoff originating in the Subregion occurs between Lee Ferry and Hoover Dam. Runoff below Hoover Dam is primarily dependent on a sparse rainfall averaging about 6 inches annually. The Gila River has long been developed and presently contributes only infrequent flow to the Subregion. Releases from Glen Canyon Dam constitute the Subregion's major water source. Completed in 1963, Glen Canyon Dam provides the storage required to meet downstream water requirements under the Colorado River Compact of 1922, storage requirements for Upper Colorado Region water development, and for power production.

In 1965, gross ground-water pumpage provided over one-half million acre-feet to satisfy uses in the Subregion. Ground-water overdraft occurs in some areas, notably in Nevada. The Southern Nevada Water

Project, under construction, will provide the facilities to develop the major portion of Nevada's Colorado River entitlement and will reduce the rate of overdraft in Las Vegas Valley. Refer to Chapter B for further discussion of ground-water resources.

The surface-water supply of the Lower Main Stem Subregion depends almost entirely on releases from Glen Canyon Dam, and on the operational criteria governing releases of water from Lake Mead. The estimated annual virgin flow (1896-1967) of the Colorado River at Lee Ferry is shown on figure 2. Annual virgin flow has varied from 5.6 maf in 1934 to 24.0 maf in 1917. For the purpose of these studies the 60-year period, 1906-65, was selected as representative of the future natural water supply of the Colorado River, although other periods have been analyzed. Average virgin flow for three different periods are shown on table 16, below. Averages for other periods are shown on figure 2, page V-12.

Table 16

Average Annual Virgin Flow
Colorado River at Lee Ferry

Period	Million ac-ft
1906-65 (60 years)	15.09
1914-65 (52 years)	14.64
1922-65 (44 years)	13.87

The estimated average annual undepleted runoff for major Colorado River tributaries below Lee Ferry is shown on table 17. Inflow, exclusive of Subregion 2 (Little Colorado) and Subregions 3 (Gila) is estimated as about 900,000 acre-feet annually. Under the natural environment, the net gain (tributary inflow less river losses) of the Colorado River from Lee Ferry to the international boundary averaged about 850,000 acre-feet annually, 1906-65.

Between Lee Ferry and the head of Lake Mead many of the tributaries flow only during periods of heavy rainfall; however, several are fed by springs and are perennial. Tributary runoff varies widely from 0.3 inches for the Little Colorado River to about 5 inches for Bright Angel Creek on the north side of the Colorado River. Below Hoover Dam the runoff from the two major tributaries, the Bill Williams and Gila Rivers, averages about 0.35 inches annually. The remaining drainage area is made up of numerous desert washes that rarely contribute appreciable quantities of water. The average annual undepleted tributary runoff under the natural environment is estimated as about 3 percent of the Subregion precipitation.

Table 17

Estimated Average Annual Undepleted Runoff
Subregion 1 (Lower Main Stem)

Gaging Station or Point	Drainage Areas 1/ (Approximate) (sq mi)	Average Annual Undepleted Runoff: 2/ Mainstream (1,000 ac-ft)	Average Annual Undepleted Runoff: Tributary 3/ Inflow to Mainstream (1,000 ac-ft)	Average Annual Undepleted Runoff: Runoff Depth (Rounded) (inches)
Colorado River at Lee Ferry, Arizona	109,500	15,090		2.60
Little Colorado River at Mouth, Arizona (Subregion 2 outflow)	26,900		420	0.30
Virgin River at Littlefield, Arizona	5,090		230	0.85
Bill Williams River near Planet, Arizona	5,140		100	0.35
Gila River at Painted Rock Dam, Arizona (Subregion 3 outflow)	50,900		1,320	0.50
Remaining drainage area, Colorado River at Lee Ferry to international boundary	45,470		570	0.25
Colorado River at international boundary, Arizona-California-Mexico	243,000	15,940		1.25

1/ Drainage area below Lee Ferry includes about 3,600 square miles in the California Region and 1,150 square miles in Mexico.

2/ Mainstream runoff based on 1906-65 period.

3/ Average annual undepleted runoff, 1914-58, is available from the Report on Water Supply of the Lower Colorado River Basin, Project Planning Report, November 1952, its two supplements of November 1953 and October 1963 and supporting data, Bureau of Reclamation. The available runoff was extended through 1965 by reconnaissance methods and is not intended as an updating of cited report.

Present Modified Water Supply (1965)

The present annual modified water supply for three periods of record is shown on table 18. As shown, the 1906-65 modified water supply available to the Lower Main Stem Subregion is estimated as about 12.8 million acre-feet, of which 90 percent is derived from the outflow of the Upper Colorado Region at Lee Ferry. Present annual modified flow of the Colorado River at Lee Ferry takes into account an annual depletion of 3.45 maf caused by the use of water in the Upper Colorado Region.

Table 18

1965 Modified Water Supply--Lower Colorado River

Units: million ac-ft

Item	Runoff Period 1906-65	1914-65	1922-65
Virgin Flow - Colorado River at Compact Point (figure 2)	15.09	14.64	13.87
1965 Normalized Depletions Upper Colorado Region 1/	3.45	3.45	3.45
Present Modified Colorado River at Lee Ferry	11.64	11.19	10.42
1965 Modified inflow from			
Subregion 2 (table 24) 2/	0.29	0.29	0.29
Subregion 3 3/	--	--	--
Undepleted Tributary Runoff Subregion 1 2/	0.90	0.90	0.90
Modified Water Supply	12.83	12.38	11.61

1/ Regionally interpreted OBE-ERS from Water Resources Appendix, Upper Colorado Region.

2/ Assumes no change in Subregional runoff due to change in study period.

3/ Subregion 3 outflow is not considered usable since its occurrence is erratic, resulting from rare abnormal flood discharges.

The Utah portion of the Subregion utilizes the surface waters of the Virgin River Basin as its primary source of supply. Utah has no entitlement to water from the Lower Basin's share of Colorado River flows. Nevada, on the other hand, has little usable surface water; its primary sources of water being ground-water reserves and the Southern Nevada Water Project, currently under construction. The first phase of the Southern Nevada Water Project, nearing completion, will provide 132,000 acre-feet annually by pumping Colorado River water from Lake Mead for municipal and industrial uses in the Las Vegas area. Completion of the second stage construction should occur before year 2000 and would utilize most of the remainder of Nevada's 300,000 acre-feet per year share of Colorado River water.

Demands in the Arizona portion of the Subregion are served primarily by diversions from the Colorado River which forms most of the western boundary of the State. Some ground water is also used, mostly in the lower Gila drainage.

PRESENT UTILIZATION

The historic annual water withdrawals in the Lower Main Stem Subregion are shown on Table 19 For the 1965 level of development, gross diversions are estimated at about 2.42 million acre-feet annually, including more than a half-million acre-feet from ground-water pumpage. Seventy percent of these diversions are made below Imperial Dam. About 6 percent of the total withdrawals are identified with uses other than irrigation. The average annual irrigation diversion in Utah and Nevada is estimated at about 4 acre-feet per irrigated acre. In Arizona most of the irrigated lands are located along the Colorado River where abundant and economical water supplies are readily available. The present average annual diversion is over 8 acre-feet per irrigated acre. This is a result of a year-long growing season and the need of water for leaching. Much of the diversion is returned to the river for reuse downstream.

Surface Water

Nearly all of the present diversions of water from the mainstream of the Colorado River are measured. Off-stream diversions, principally from the Virgin, Muddy, and White Rivers, and Kanab Creek, are small and were estimated on the basis of the available information. Surface-water diversions to the Las Vegas-Henderson-Boulder City area and to the city of Yuma represent the bulk of uses for municipal and industrial purposes.

Table 19

Estimated Annual Water Withdrawal
Lower Main Stem Subregion

Units: 1,000 acre-feet

State Area and Source	Estimated Annual Water Withdrawal											
	Historic											
	1915-1919	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965	Normalized 1965 Level
ARIZONA												
Ground-Water Pumpage												
Gila Valley (Yuma area)	3	4	7	12	17	20	40	60	59	68	102	
Gila Valley above Yuma	4	7	17	17	23	32	52	62	36	203	251	
Others	--	--	--	--	--	--	--	13 1/	15	49	48	
	7	11	24	29	40	52	92	135	110	320	401	400
Surface-Water Diversion	256	301	352	381	405	497	692	978	1,319	1,659	1,634	1,650
Subtotal	263	312	376	410	445	549	784	1,113	1,429	1,979	2,034	2,050
NEVADA												
Ground-Water Pumpage												
Las Vegas Valley	--	3	18	18	18	20	30	34	44	46 2/	72	
Other	--	--	--	--	--	--	--	5	13	26	41	
	--	3	18	18	18	20	30	39	57	72	113 3/	115
Surface-Water Diversion	29	29	29	29	32	42	35	39	48	50	153	155
Subtotal	29	32	47	47	50	62	65	78	105	122	266	270
UTAH												
Ground-Water Pumpage	--	--	--	--	--	--	--	--	--	--	10 3/	10
Surface-Water Diversion	48	52	54	59	59	63	65	74	77	78	84	90
Subtotal	48	52	54	59	59	63	65	74	77	78	94	100
LOWER MAIN STEM SUBREGION												
Ground-Water Pumpage	7	14	42	47	58	72	122	174	167	392	524	525
Surface-Water Diversion	340	382	435	469	496	602	792	1,091	1,444	1,787	1,871	1,895
Total	347	396	477	516	554	674	914	1,265	1,611	2,179	2,395	2,420

1/ Data inadequate in some areas to estimate amount of ground water used before 1955.

2/ Partial record.

3/ Data inadequate to estimate amount of water used before 1965.

Ground Water

Current ground-water pumpage in the Subregion is estimated at about 525,000 acre-feet annually of which 250,000 acre-feet was pumped in the Lower Gila River Valley and 72,000 acre-feet in the Las Vegas Valley. Total pumpage in 1965 was about 10,000 acre-feet in Utah, about 110,000 acre-feet in Nevada, and 400,000 acre-feet in Arizona. From 1915 to 1965, about 5,900,000 acre-feet of ground water have been pumped in the entire Subregion. Table 19 is an itemization of surface-water diversions and ground-water pumpage by general area and State. As shown, most of the pumpage is in the lower and south Gila Valleys and includes the drainage wells in the Yuma Mesa and Wellton-Mohawk areas. Ground-water mounds had developed in these areas making necessary the drainage systems which were established in 1961. This drainage is returned to the Colorado River and is used in partial satisfaction of the Mexican Treaty requirements.

About 80,000 acre-feet annually are pumped for municipal and industrial use, of which 72,000 acre-feet occur in the Las Vegas Valley in Nevada, where pumpage exceeds the probable recharge of 25,000 to 35,000 acre-feet annually [6-31]. Other areas of localized overdraft also exist.

PRESENT WATER REQUIREMENTS

Present depletion requirements for the Subregion are presented on table 6 and total nearly 1.29 million acre-feet annually. Water withdrawal requirements, see table 7, total about 2.98 million acre-feet, of which some 90 percent is for irrigated agriculture. Over 75 percent of these requirements occur in the Arizona portion of the Subregion, about 19 percent in Nevada, and the remainder in Utah.

With the exception of reservoir evaporation quantities, all water requirements were estimated and supplied by the Work Groups responsible for the various appendixes, and additional information is presented therein.

PRESENT MODIFIED WATER SUPPLY

Demands on the supply of the Colorado River below Lee Ferry, in addition to the 1.3 million acre-feet of present water requirements within the Subregion, are for main stem reservoir evaporation, channel losses, system spills, exports to the California Region, and Mexican Treaty obligations. These demands are itemized on table 20.

Table 20

1965 Modified Water Supply
Lower Main Stem Subregion

Units: Million ac-ft

Item	Runoff Period 1906-65	1914-65	1922-65
Modified Water Supply--Lower Colorado River (table 18)	12.83	12.38	11.61
Export and Depletion Requirements			
Subregion 1	1.29	1.29	1.29
California Region 1/	5.00	5.00	5.00
Main Stem Evaporation	1.20	1.20	1.20
Channel Losses 2/ [2-33]	0.66	0.66	0.66
System Spills [3-35]	0.65	0.65	0.65
Mexican Treaty	1.50	1.50	1.50
Total	10.30	10.30	10.30
Apparent Remaining Water Supply	2.53	2.08	1.31

1/ 1965-1967 average for California diversions less return flows.

2/ Includes consumptive use by native riparian vegetation and evaporation from the river water surfaces other than reservoirs.

PRESENT SUFFICIENCY

As shown on table 20, the Subregion has a total water supply in excess of its own present requirements. Supplies exceed depletion requirements by 1.3 to 2.5 million acre-feet annually, dependent upon the runoff period inspected. Seasonal water shortages do occur, however, principally on the developed tributaries of the Colorado River. These shortages are due to the erratic nature of the water supply and to lack of adequate storage and conveyance facilities.

Water requirements in the Utah portion of the Subregion are well within the surface-water supplies in that area. The authorized Dixie Project, located on the Virgin River, will, through construction of distribution and storage features, provide water supplies to new and existing irrigated lands, as well as municipal and industrial supplies. Other areas in Utah may require additional facilities to promote future development, but these would probably be highly localized in scope.

The authorized Southern Nevada Water Project will shortly provide the facilities to convey a part of Nevada's allocation of Colorado River water into the area of greatest demand, the Las Vegas-Eldorado Valley. This development should be adequate to meet Nevada's rapidly growing water requirements into the immediate future. Continuation of the present rapid growth, however, could exceed the capability of the present systems to meet demands much beyond 1980.

The Arizona portion presently has adequate water and the facilities to meet demands. Additional facilities are necessary, however, to allow full development of existing Federal and Indian projects and to provide the necessary land and water developments to meet the increasing recreation pressures along the Lower Colorado River.

FUTURE REQUIREMENTS

Water requirements in the Subregion for the Modified OBE-ERS projected levels of development (1980, 2000, and 2020) are shown on tables 8 through 13. These tables show depletion requirements increasing by about a million acre-feet between 1965 and 2020, the largest increases occurring in agriculture and municipal and industrial demands. Significant increases also occur in electric power and fish and wildlife needs.

By 2020 Nevada's requirements are projected to rise from 251,000 acre-feet per year to over 715,000 acre-feet, a threefold increase, due primarily to a rapidly growing population. Arizona's increased demands are principally for agriculture.

FUTURE MODIFIED WATER SUPPLY

The future water supply available to the Subregion, without augmentation, is almost entirely dependent on the depletions caused by water resource development in the Upper Colorado River Basin. Table 21 estimates the water supply available for the 1906-65 runoff period to the Lower Colorado River and the modified outflow from the Region in 1980, 2000, and 2020. For subregional analysis only, no consideration is given to future exports to the Gila Subregion via the Central Arizona

Table 21

Future Modified Water Supply--Lower Main Stem Subregion

Units: Million ac-ft

Item	Development Year 1980	2000	2020
Virgin Flow - Colorado River at Lee Ferry (1906-1965)	15.09	15.09	15.09
Estimated Depletions - Upper Colorado Region	4.83	6.12	6.55
Future Modified Inflow from:			
Colorado River at Lee Ferry	10.26	8.97	8.54
Little Colorado Subregion (table 25)	.26	.24	.21
Subregion 1 Tributaries (undepleted)	.90	.90	.90
Future Modified Water Supply	11.42	10.11	9.65
Export and Depletion Requirements 2/			
Subregion 1 (tables 8, 10, and 12)	1.73	1.88	2.21
California Region (page 81)	4.40	4.40	4.40
Main Stem Reservoir Evaporation	1.20	1.20	1.20
Channel Losses (page 81)	0.39	0.39	0.39
System Spills [3-35]	0.52	0.15	0.15
Mexican Treaty	1.50	1.50	1.50
Total	9.74	9.52	9.85
Apparent Remaining Water Supply	1.68	0.59	-0.20

1/ Regionally interpreted OBE-ERS from the Water Resources Appendix, Upper Colorado Region.

2/ Exclusive of future exports to the Gila Subregion via the Central Arizona Project. These are included in the analysis shown on table 15.

Project aqueduct. Further, uses of Colorado River water in California are assumed, as a basic Lower Region study assumption, to be limited to the 4.4 million acre-feet entitlement [7].

Future main stem reservoir evaporation can be expected to decline without augmentation, but not by great amounts through the 2020 level of development. No estimates of reductions are included on table 21. Main stem channel losses are also projected to decline as a result of the authorized Bureau of Reclamation Colorado River program for increasing water yield. The present losses of 660,000 acre-feet (see table 20) were accordingly reduced by 100,000 acre-feet from selective phreatophyte control and by 170,000 acre-feet from river channelization.

FUTURE SUFFICIENCY

As shown on table 21, the future water supplies available to the Subregion decline from 11.42 maf in 1980 to 9.65 maf in 2020. Water requirements, exclusive of the Central Arizona Project, exceed the available water supply in year 2020, even under a favorable runoff period.

The analysis on table 21 does not limit Nevada to its entitlement from the Colorado River of only 300,000 acre-feet per year. Such a restriction would show Nevada grossly short of water to meet demands, but would also show more available main stem water for use downstream. The Nevada problem would need to be solved through development of sources other than the Colorado River, be it augmentation or by further use of Nevada ground-water resources.

LITTLE COLORADO SUBREGION

CHAPTER D - LITTLE COLORADO SUBREGION

HYDROLOGIC FRAMEWORK

The Little Colorado Subregion, shown on maps 1 and 7, encompasses the Little Colorado River drainage basin extending from the Continental Divide in New Mexico to the Lower Main Stem Subregion boundary near Flagstaff, Arizona. Of the 26,977 square miles within the Subregion, 5,310 square miles are in west-central New Mexico, and 21,667 square miles are in northeastern Arizona. The Little Colorado River drains the Subregion and flows northwestward, joining the Colorado River on the east boundary of Grand Canyon National Park about 78 miles downstream from Glen Canyon Dam. It rises on the north slopes of the White Mountains about 20 miles above Springerville, Arizona, and has a total main stem length of about 356 miles. The elevation in the Subregion ranges from 12,640 feet at San Francisco Peaks north of Flagstaff to about 2,700 feet at the mouth of the Little Colorado River.

In the upper river reaches the main channel flows through a canyon which widens at intervals to form areas susceptible to irrigation. Below St. Johns, Arizona, the river has a generally broad, flat sandy channel with steep sidewalls throughout the greater part of its length. At Grand Falls the river flows into a deep gorge and the lower 50 miles of its length are in an arm of the Grand Canyon of the Colorado. Almost all the perennial tributaries of the Little Colorado River flow from the south and west originating in the mountains along the Mogollon Rim. Winter snows prolong the flow of these streams, but during the summer most of the streams flow only after rain. Chief tributaries from the south and west are Silver, Chevelon, Clear, and Salt Creeks, and Canyon Diablo.

Tributaries from the north and east flow in deep steep-sided canyons or washes and their lower reaches are usually flat, sandy channels with almost vertical sidewalls. These northern tributaries produce most of the large sediment load carried by the Little Colorado River. Major tributaries are Carrizo, Dinnebito, and Moenkopi Washes, Zuni and Puerco Rivers, and Corn Creek.

The climate of the Little Colorado River Basin is cool with a normal July temperature of 65-75 degrees and a January temperature of about 30 degrees. The growing season is short, averaging about 4 months between killing frosts. Except along the Mogollon Rim and parts of the Navajo Indian Reservation, the country is arid. Average annual precipitation ranges from over 25 inches near Flagstaff to about 10 inches along the Little Colorado River. Evaporation is high and most of the streams yield little water in proportion to the size of their drainage areas.

Undepleted outflow from the Subregion is estimated to be about 2.5 percent of the average annual precipitation. Springs near the mouth are the principal natural discharge for ground water in the uplands and are estimated to contribute over one-third of the Subregion's average annual outflow. Streamflow is erratic and subject to flash floods of considerable magnitude. Holdover storage is considered a prerequisite to any orderly irrigation development.

The principal ground-water aquifer in the basin is the Coconino Sandstone. Most of the ground-water resource is difficult to extract and remains undeveloped. Present development is principally from the shallow alluvium along the Little Colorado River, Silver Creek, and the upper Puerco River in New Mexico, where depths to water are less than 200 feet. Storage capacity is limited by the character and extent of the alluvium material and well yields range from a few gallons to as high as 2,000 gallons per minute. For small local areas where limited, but concentrated ground-water development has occurred, changes in the depth to water ranged from zero to 40 feet during the 1960-65 period (see map 5). In the remaining areas of the Subregion, large amounts of ground water are stored but unfavorable permeability, yields, quality, and depth to water counter the hope for developing large supplies from this source.

Agriculture water use in the Subregion has remained relatively constant since early in the century, although the erratic water supply has made frequent adjustment necessary. Other uses have increased slowly but steadily from the rising municipal and industrial demands, evaporation losses from recreational impoundments, and recently from exports to the Gila River Basin for industrial purposes.

WATER SUPPLY

The Little Colorado River is one of the major contributors to the Colorado River within the Region. Springs near the mouth contribute a nearly constant amount, currently estimated as about 220 cubic feet per second. Historic annual discharge near Cameron, Arizona, is subject to wide fluctuations varying from 19,340 acre-feet in 1956 to over 600,000 acre-feet in 1941. Within the Subregion a large part of the annual runoff is from the southern tributaries with watersheds in the heavily vegetated highlands of the Mogollon Rim. Runoff from the northern tributaries occurs principally from rainfall during the summer months. Although ground-water storage in the Subregion is great, only minor development has occurred because of low yields and poor quality. Further discussions of the ground-water resources of the Subregion are located in Chapter B.

The average annual undepleted water supply for the Subregion is estimated as about 420,000 acre-feet at the mouth of the Little Colorado River, of which one-third is contributed by springs near the mouth in the Little Colorado Arm of the Grand Canyon. Table 22 shows undepleted runoff at various points within the Subregion.

The annual water supply at or near the New Mexico-Arizona State line has been estimated by the New Mexico State engineer as about 63,900 acre-feet based on the 1914-45 period of runoff [8-223]. The representative period chosen for the Framework Studies, however, includes the dry years 1946-65. For the longer period the average annual undepleted water supply for the New Mexico portion of the Subregion is estimated as about 56,000 acre-feet, excluding partially closed areas.

Undependable and erratic streamflow makes holdover storage essential for most water using developments within the Subregion. A significant portion of the Arizona development has occurred in the Springerville-St. Johns vicinity and on Silver Creek. Flash floods producing large volumes of sediment have hindered water development particularly on the main stream and the northern tributaries. The springs in the deep rock canyon near the mouth of the Little Colorado River produce consistent flows and large volumes of water, but are of poor quality, high in sodium and chloride, and their location further complicates use within the basin. Subregion runoff, in terms of depth, varies from 0.1 inch to probably as high as 5 inches. Estimated outflow at the river's mouth is about 2.5 percent of the Basin's average annual precipitation.

PRESENT UTILIZATION

Depletions in the Little Colorado Subregion vary from year to year principally due to dependency on a somewhat erratic streamflow and the lack of holdover storage. The estimated net annual average depletion has increased from about 50,000 acre-feet in the twenties to current depletions of well over 100,000 acre-feet. The agricultural depletion has remained relatively constant, the increase occurring from export water, reservoir evaporation, and a small but continuing increase in the municipal and industrial water uses. Nearly 20 percent of the depletion occurs in the New Mexico portion of the Subregion.

The present normal annual water withdrawal in the Subregion, shown on table 23, is estimated at about 152,000 acre-feet, of which nearly half is withdrawn from ground water. Included are about 15,000 acre-feet exported from Lake Show Low and Blue Ridge Reservoir to the Gila Subregion for industrial uses in the Clifton-Morenci area.

Table 22

Estimated Average Annual Undepleted Runoff
Subregion 2 (Little Colorado)
1914-1965

Gaging Station or Point	Drainage Areas (Approx) (sq mi)	Average Annual Undepleted Runoff 2/ Main-stream (1,000 ac-ft)	Tributary Inflow to Mainstream (1,000 ac-ft)	Runoff Depth (Rounded) (inches)
Little Colorado River above 1/ Zuni River near Hunt, Arizona	3,680	32		0.15
Zuni River at Mouth, Arizona	2,577		18	0.15
Silver Creek near Woodruff, Ariz.	942		28	0.55
Remaining Drainage Area, Little Colorado River - above Zuni River to Woodruff	901		15	0.30
Little Colorado River at Woodruff, Arizona	8,100	90		0.20
Puerco River at Mouth, Arizona	3,107		50	0.30
Chevelon Creek near Winslow, Ariz.	1,010		41	0.75
Clear Creek near Winslow, Ariz.	607		65	2.00
Moenkopi Wash near Tuba, Arizona	2,500		15	0.10
Remaining Drainage Area, Little Colorado River at Woodruff to near Cameron	11,176		90	0.15
Little Colorado River near Cameron Arizona	26,500	290		0.20
Drainage Area, Little Colorado River near Cameron to Mouth (including Blue Spring)	400		160	--
Little Colorado River at Mouth, Arizona	26,900	420		0.30

1/ About 2,100 square miles are noncontributing, except during years of high runoff.

2/ Average annual undepleted runoff, 1914-58, is available from the Report on Water Supply of the Lower Colorado River Basin, Project Planning Report, November 1952; its two supplements of November 1953 and October 1963 and supporting data - Bureau of Reclamation. The available runoff was extended through 1965 by reconnaissance methods and is not intended as an updating of cited report.

Table 23

Estimated Annual Water Withdrawal

Little Colorado Subregion

Units: 1,000 acre-feet

State and Sources	Estimated Average Annual Withdrawal					
	Historic					Normalized 1965 Level
	1945-1949	1950-1954	1955-1959	1960-1964	1965	
Arizona						
Ground-Water Pumpage	20	44	44	64	72	72
Surface-Water Diversion	40	35	33	40	51	57 1/
Total	60	79	77	104	123	129
New Mexico						
Ground-Water Pumpage	--	1	1	2	2	2
Surface-Water Diversion	13	11	12	12	21	21
Total	13	12	13	14	23	23
Little Colorado Subregion	73	91	90	118	146	152

1/ Includes exports to the Gila Subregion from Lake Show Low and from Blue Ridge Reservoir.

Currently, about 118,000 acre-feet is used for irrigation, representing a withdrawal of about 4 acre-feet per irrigated acre. The remainder is withdrawn for municipal, industrial, power generation, and other minor uses.

Within the Little Colorado River Basin, withdrawals for the forest-associated industry constitute a significant portion of the industrial use of water. Normal annual evaporation loses from lakes and stockponds are estimated as about 40,000 acre-feet.

Surface Water

The historic annual surface-water diversions, as shown in table 23, were based on a meager measured record and estimates of diversions. Although the cities of Flagstaff and St. Johns receive a substantial portion of their water supply from surface water, nearly all remaining municipal and industrial use within the Basin is supplied from ground-water pumpage. Current normal transbasin diversions from Lake Show Low and Blue Ridge Reservoir have been estimated as about 15,000 acre-feet annually, although large year to year fluctuations occur.

All lands irrigated in New Mexico are supplied by surface-water diversions, and frequent water shortages occur. Principal diversions are from the Zuni River and its tributaries at and above Black Rock Dam. In Arizona, the major diversion from the main stream is at Lyman Reservoir for irrigation in the vicinity of St. Johns. Runoff above Lyman Reservoir is regulated by a number of small reservoirs, and no surplus waters are available for development. Significant diversions are also made from Silver Creek and its tributaries.

The surface-water supply in the Little Colorado River Basin has been generally inadequate for the purposes intended. Irrigated acreage has been adjusted to fit the available supply. Sedimentation affecting diversion works and quality of water problems plague many areas.

Ground Water

The 1965 annual ground-water pumpage is estimated as 72,000 acre-feet in Arizona and 2,000 acre-feet in New Mexico. Pumpage in New Mexico is used principally in the city of Gallup. In Arizona 13,000 acre-feet, or 18 percent of the total estimated pumpage, is used for purposes other than irrigation. A considerable portion is used by the timber, pulp, and paper industries. The remaining Arizona withdrawal is used primarily for supplementing the inadequate irrigation surface-water supply.

PRESENT WATER REQUIREMENTS

Within the Little Colorado Subregion, annual depletion requirements total about 128,000 acre-feet with 108,000 acre-feet of this amount in Arizona (see table 6). Withdrawal requirements are shown on table 7 and are estimated to be 219,000 acre-feet, of which 83 percent is in Arizona and 17 percent in New Mexico. Included in the requirements are the normal exports to the Gila Subregion for mining development. These exports are estimated to average 15,000 acre-feet per year under 1965 development conditions.

Irrigated agriculture accounts for the largest water requirement within the Subregion. Depletion requirements are estimated at 58,600 acre-feet, averaging about 2 acre-feet per irrigated acre. Municipal and industrial depletion and withdrawal requirements comprise less than 10 percent of the total Subregion requirements. Others include reservoir evaporation, mineral, recreation, fish and wildlife, and electric power.

With the exception of reservoir evaporation and export water quantities, all water requirements were estimated and supplied by the Work Groups responsible for the various appendixes, and additional information is presented therein.

PRESENT MODIFIED WATER SUPPLY

The undepleted water supply modified for present water requirements indicates the amount of water which remains for possible future development. The average annual undepleted water supply, present depletion requirements, and 1965 modified water supply for the Little Colorado Subregion are summarized on table 24

Table 24

1965 Modified Water Supply
Little Colorado Subregion

Unit: 1,000 ac-ft

	Average Annual Undepleted Water Supply	Present Depletion Requirements	1965 Modified Outflow
Subregion 2 (Little Colorado) - Outflow	420	128	292
New Mexico - State Line	56	20	36

Some 46 miles upstream from the mouth, near Cameron, Arizona, but below all known man-made depletions, the present modified water supply is about 162,000 acre-feet.

Except for infrequent spills from Lyman Reservoir, no water remains for further development above St. Johns, Arizona. Below St. Johns a substantial amount of runoff remains to be developed. Concurrent historic streamflow records, 1948-1965, at the Little Colorado River gaging stations above Zuni River near Hunt and near Cameron, show an average net gain of about 140,600 acre-feet annually. A large portion of this gain is from the contributions of Clear and Chevelon Creeks and the Puerco River. Below the station near Cameron, Blue Spring and other springs near the mouth currently contribute an estimated 160,000 acre-feet annually to the Subregion outflow.

The average annual outflow of 292,000 acre-feet after satisfaction of the 1965 requirements joins the Colorado River and is ultimately consumed by the many demands along the main stream in the United States and Mexico.

PRESENT SUFFICIENCY

From a broad subregion base, the water supply of the Little Colorado River Subregion appears more than adequate to meet present demands. In local areas, however, frequent irrigation water shortages occur with subsequent adjustments in cropped acreage. Municipal and industrial demands are dependent primarily on ground-water pumpage and the quality of water is often less than desirable.

Water demands tend to locate and adjust to the available water supply. Water use in the Little Colorado River Basin occurs principally in the upper third of the basin where the supply is most dependable. The wide fluctuation of the annual surface-water supply and its monthly distribution requires a storage capability in order to meet any continuous demands from this source. However, adequate surface-water storage is frequently curtailed by excessive sedimentation and geologic conditions conducive to excessive seepage. Inadequate surface supplies are supplemented by ground-water pumpage, but quality and productivity have limited the development of this resource.

A comparison of the undepleted water supply and the current water requirements indicates about one-third of the water supply has presently been developed. The occurrence of water within the Subregion would seem to indicate that future development of surface water is limited to the areas along the Mogollon Rim where supplies are small, but of good quality and of fair dependability. Chevelon and Clear Creeks, producing an average annual flow of over 100,000 acre-feet, appear particularly suited to meeting future increased demands in the central portion of the Subregion.

In New Mexico, problems of water shortage, sedimentation, and quality plague maximum utilization of the available water supply. Of the three urban communities (over 2,800 inhabitants) in the New Mexico portion of the Lower Colorado Region, two--Gallup and Zuni Pueblo--are located in Subregion 2. A major problem in this area is the development of an adequate water supply for the city of Gallup.

FUTURE WATER REQUIREMENTS

Water requirements for development years 1980, 2000, and 2020, in the Little Colorado Subregion are shown on tables 8 through 13. Total annual depletion requirements are projected to increase from the present 128,000 acre-feet to over 200,000 acre-feet in year 2020. Except for power, increases in depletion and withdrawal requirements are expected in all sectors of the economy.

FUTURE MODIFIED WATER SUPPLY

Present average annual outflow from the Subregion has been estimated as about 292,000 acre-feet. Projected water requirements in the Subregion, as shown on table 25, indicate the future outflow will decline to 213,000 acre-feet by the year 2020. About 160,000 acre-feet of this outflow are from springs near the mouth of the Little Colorado River. Therefore, the indicated 2020 modified water supply above the springs is only 53,000 acre-feet annually.

Table 25

Future Modified Water Supply--Little Colorado Subregion

Unit: 1,000 ac-ft

	Development Year		
	1980	2000	2020
Annual Undepleted Water Supply	420	420	420
Total Depletion Requirements	160	179	207
Modified Water Supply	260	241	213

FUTURE SUFFICIENCY

Similar to present conditions, the water supply of the Little Colorado Subregion appears adequate to meet future demands. Increasing municipal and industrial demands will probably require distribution works to convey the available surface-water supplies to the points of use. Perhaps of greater importance will be the further development of ground water. In addition, watershed treatment and other measures to enhance runoff may provide increased water supplies sufficient to supplement present surface-water supplies.

GILA SUBREGION

CHAPTER E - GILA SUBREGION

HYDROLOGIC FRAMEWORK

The Gila Subregion, shown on maps 1 and 8, consists principally of the area drained by the Gila River above Painted Rock Dam. Also included are several small areas draining to Mexico, Willcox Playa, and a portion of Animas Valley. The latter areas are closed basins in southern Arizona and New Mexico. The total area in the Subregion is about 57,606 square miles, of which 8,045 square miles are in New Mexico.

	1,000 sq mi
Drainage area above Painted Rock Dam	49.6
Mexican drainage	4.0
Closed basins	4.0
	57.6

The Gila River, draining most of the Subregion, is the largest tributary to the Colorado River within the Lower Colorado Region. The Subregion extends from the Continental Divide in west-central New Mexico to Painted Rock Dam, about 20 miles west of Gila Bend, Arizona, and encompasses most of the southern half of Arizona. Climatic conditions and native vegetation vary from the low altitude Sonoran Zone to the Alpine Zone of the mountains nearing 12,000 feet in elevation. At the outflow point, Painted Rock Dam, the elevation is about 520 feet. Average annual precipitation exceeds 25 inches near Mount Baldy, but is only about 5 inches at the lowest elevations. In the upper portions of the Subregion summers are mild. Winter temperatures normally vary from below freezing at night to the upper fifties during the day. In the desert the climate is arid with abundant sunshine. Winter climate is extremely pleasant. In midsummer, maximum daytime temperatures frequently exceed 110 degrees and nights are moderately warm. The annual growing season in the lowlands approaches 300 days (see figure 1). Annual undepleted runoff varies from as much as 8 inches in the high elevations to 0.1 inch or less in the desert areas. Almost all of the available surface water has been utilized and outflow from the Subregion is small. However, recurrence of runoff similar to 1915-17 or 1941 would probably produce significant outflow from the Subregion.

Most of the water resource development is located in the lowlands where runoff emerges onto the desert. Annual runoff is extremely variable and occurs mostly as snowmelt between January and April. The Salt and Verde Rivers produce about 70 percent of the surface-water supply of the Subregion. Six major reservoirs on the Salt and Verde Rivers, having a capacity of 2.1 million acre-feet storage, control the runoff for utilization in the lower Salt and Gila valleys. Most of the remaining runoff in the Subregion originates from the Gila River above Ashurst-Hayden Diversion Dam. Principal Gila River tributaries above Ashurst-Hayden Dam are the San Francisco, San Carlos, and San Pedro Rivers. There are no large conservation storage reservoirs for surface water in the desert lowlands. Here, streamflow occurs mostly as flash flooding following thunderstorms, although a few tributaries rise to higher elevations and snowmelt furnishes a portion of the runoff. The Santa Cruz and Agua Fria Rivers are but a few of the tributaries deriving most of their flow from thunderstorm activites. Only infrequently does runoff of quantity reach the mouth of these tributaries or become outflow from the Subregion. Most of the desert runoff is consumed rapidly by evaporation and infiltration.

Ground-water overdraft has sustained the development of the Gila Subregion for many decades. Annual pumpage of about 1 million acre-feet in the late 1930's has increased to nearly 4.5 million acre-feet and has been accompanied by the increasing overdraft of the ground-water reserves. Total present water withdrawals are estimated as 5.7 million acre-feet. The spectacular growth of the Tucson and Phoenix metropolitan areas has increased municipal and industrial water uses sharply during the last 20 years.

WATER SUPPLY

Introduction

The undepleted water supply of the Gila Subregion has been developed and utilized for many decades. Except for infrequent large floods or an exceptional runoff sequence, outflow from the Subregion under present conditions of development is negligible. Further development of surface water within the basin is confined principally to the conservation of a portion of these waters which may become outflow, measures to increase runoff, and the reduction of noncrop consumption associated with irrigation and other uses. The expanding economy of the area has been supported by the overdraft of ground water and current ground-water pumpage exceeds surface-water diversion by several times. This overdraft is estimated to be 2.5 million acre-feet annually under 1965 conditions.

The Salt and Verde Rivers, draining the north-central portion of the Subregion, produce 70 percent of the available surface-water supply. Most of the remainder is produced from the upper Gila River drainage in New Mexico and southeastern Arizona. Streamflow emerging from the higher elevations onto the desert sustains great losses through evaporation and infiltration. Runoff is highly variable, both seasonally and annually, so that storage has long been utilized in the Subregion to make orderly water development possible.

Ground water is being depleted at an alarming rate, causing rapidly declining water levels, land subsidence, increasing pumping costs, and in many areas, degradation in water quality. Further discussion of the subregional ground-water resources is located in Chapter B.

The total area within Subregion 3 is about 57,606 square miles, of which 49,600 square miles contribute to the Gila River. The remaining area is either in closed basins or drains to Mexico. The estimated inflow from Mexico (1,090 square miles) approximates the runoff within the closed basins and the outflow to Mexico; therefore, Gila River runoff, per se, has been considered representative of the water supply within Subregion 3.

The undepleted runoff in the Gila Subregion varies from as little as 0.1 inch in the desert lowlands to as much as 8 inches in the high mountains. For purposes of these studies, the undepleted water supply for the Subregion is represented by the runoff at or near the points of major development, as shown below, rather than at the outflow boundary.

Table 26

Undepleted Water Supply--Gila Subregion
1914-1965

	1,000 acre-feet
Gila River at Kelvin	460
Salt River at Granite Reef Dam	1,220
Agua Fria River at Waddell Dam	92
Santa Cruz River at Cortaro	37
Average annual undepleted water supply (rounded)	1,800

At the Subregion boundary, about 38 river miles downstream from Gillespie Dam, the average annual runoff under the natural environment is estimated as about 1.3 million acre-feet--about 3.5 percent of the basin precipitation. Slightly over 1 million acre-feet annually reached the Colorado River. About 90 percent of the runoff from the Subregion originates in Arizona, the remainder occurs in New Mexico and Mexico. Table 27 shows the estimated annual runoff (1914-1965) at various points within the Subregion.

The undepleted annual water supply at or near the New Mexico-Arizona State line has been estimated by the New Mexico State Engineer as about 214,600 acre-feet [8-223] and will be used herein as representative of the 1914-65 period adopted for these studies.

Present Water Supply (1965)

The average water supply in the Gila Subregion including imports from the Little Colorado Subregion is estimated as 1.81 million acre-feet per year. Average outflow associated with this water supply is about 100,000 acre-feet annually, leaving about 1.71 million acre-feet of usable supply. Current depletion requirements are estimated at 4.42 million acre-feet and are satisfied largely through ground-water overdraft. Few river basins have attained the utilization efficiency of the Gila Subregion. This distinction, however, portends serious problems. Continued and increasing overdraft has resulted in land subsidence and increasing water costs. Problems of salinity and pollution, although perhaps somewhat imperceptible today, are foreseeable.

Where water users are primarily dependent on unregulated streamflow, as in the upper reaches of the Gila River and its tributaries, late season shortages frequently occur. Court decrees govern the use of water in many of these areas. In the lower areas, surface-water storage and ground-water pumpage alleviate short-term shortages. The area is, however, adversely affected by long drought periods. For the most part, storage reservoirs were built during a period of high runoff. Subsequent years have failed to produce the expected runoff which resulted, in some cases, in the abandonment of irrigated lands and a continuing water shortage on others.

Table 27

Estimated Average Annual Undepleted Runoff
Subregion 3 (Gila)
1914-1965

Gaging Station or Point	Drainage Areas (Approximate) 1/ (sq mi)	Average Annual Undepleted Runoff 2/ Mainstream (1,000 ac-ft)	Tributary Inflow to Mainstream (1,000 ac-ft)	Runoff Depth (Rounded) (inches)
Gila River below Blue Creek, near Virden, New Mexico	3,203	138		0.80
San Francisco River near Clifton, Arizona	2,766		145	1.00
San Simon Creek near Solomon, Arizona	2,192		16	0.15
Remaining Drainage Area, Gila River near Virden to Calva	3,309		100	0.60
Gila River at Calva, Arizona	11,470	330		0.55
San Carlos River near Peridot, Arizona	1,027		42	0.75
San Pedro River at Mouth, Arizona	4,485		80	0.35
Remaining Drainage Area, Gila River at Calva to Kelvin	1,029		34	0.60
Gila River at Kelvin, Arizona	18,011	460		0.50
Santa Cruz River at Cortaro, Arizona	3,503		37	0.20
Salt River at Granite Reef Dam, Arizona	12,907		1,220	1.75
Agua Fria River at Waddell Dam, Arizona	1,459		92	1.20
Remaining Drainage Area, Gila River at Kelvin to Gillespie Dam	13,770		80	0.10
Gila River at Gillespie Dam, Arizona	49,650	1,430		0.55
Drainage Area, Gila River, Gillespie Dam to Painted Rock Dam	1,250		6	0.10
Gila River at Painted Rock Dam, Arizona 3/	50,900	1,320		0.50

(See next page for footnotes)

Table 27

1/ Includes drainage areas in Mexico.

2/ Average annual undepleted runoff, 1914-58, is available from the Report on Water Supply of the Lower Colorado River Basin, Project Planning Report, November 1952; its two supplements of November 1953 and October 1963 and supporting data, Bureau of Reclamation. The available runoff was extended through 1965 by reconnaissance methods and is not intended as an updating of cited report.

3/ Estimated average annual undepleted runoff near the mouth of the Gila River near Dome, Arizona, is 1,050,000 acre-feet.

PRESENT UTILIZATION

The historic annual water withdrawals since 1915 for use in the Gila Subregion are shown on table 28. These withdrawals outline the trend of water resource development in the Subregion. Surface-water withdrawals dependent on runoff have decreased over the years while ground-water pumpage has continued to increase. Perhaps the greatest stimulus for the increase in pumpage was provided by the continuing drought since the 1940's and the demand for farm products following World War II. The present normal annual water withdrawal is estimated to be about 5.7 million acre-feet, of which 4.5 million acre-feet are from ground-water pumpage. The low Subregion pumpage in 1965 of 3.9 million acre-feet was a result of a wet year that reduced supplemental water demands significantly. By 1967, estimated pumpage had increased to 4.6 million acre-feet.

Decree restrictions [7] , [9] and other factors have limited water resource development in the upstream areas of the Gila River. In New Mexico, current total withdrawals are estimated as about 96,000 acre-feet annually. Nearly all of the withdrawal is for irrigation and represents a diversion of about 3 acre-feet per acre. In Arizona, present normal withdrawals are about 5.6 million acre-feet annually. Well over 90 percent is for irrigation, with a present estimated irrigation withdrawal of nearly 6 acre-feet per irrigated acre. The remaining withdrawals are used principally to meet the increasing demands of the cities of Phoenix and Tucson and the mineral resources industry.

Surface Water

The almost complete use of the available surface water in the Gila Subregion has been made possible by the impoundment of the variable runoff at the higher elevations and by making releases from storage at or near where the stream emerges onto the desert. The occasional streamflow in channels traversing the desert are primarily from flash flooding of small tributaries or infrequent flood releases from the major storage reservoirs. These flows are usually quickly consumed by evaporation and infiltration. For the most part, surface-water diversions in the Gila Subregion are based on measured records. Over 1,000,000 acre-feet of the total surface-water withdrawal in 1965 were diverted to the Arizona and South Canals of the Salt River Project, Florence-Casa Grande Canal serving the San Carlos Project, and the canals on the Gila River above San Carlos Lake, in the Duncan-Virden and Safford Valleys. The city of Phoenix and the surrounding communities are the principal recipients of surface water for municipal and industrial purposes.

Table 28

Estimated Annual Water Withdrawal
Gila Subregion

Units: 1,000 acre-feet

State, Area, and Source	Estimated Average Annual Withdrawal 1/											
	Historic											Normalized 1965 Level
	1915-1919	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965	
Arizona												
Upper Gila												
Ground-Water Pumpage												
Gila Basin above San Carlos	8	5	4	3	24	36	101	142	155	187	240	
Sulfur Springs (Cochise Co.)	2	1	1	3	3	9	37	102	196	255	340	
	10	6	5	6	27	45	138	244	351	442	580	580
Surface-Water Diversion	188	211	246	214	155	158	126	91	104	114	130	130
Subtotal	200	220	250	220	180	200	260	340	460	560	710	710
Middle Gila												
Ground-Water Pumpage												
Upper Santa Cruz	8	33	41	26	37	84	124	187	188	179	200	
Avra Valley (Pima Co.)	-	-	-	-	5	13	33	74	111	131	125	
Lower Santa Cruz	84	93	106	185	305	468	804	1,116	1,160	1,090	910	
Chino Valley (Yavapai Co.)	-	-	-	-	2	5	10	35	36	36	36	
Phoenix Area	29	259	520	567	709	903	1,446	2,094	2,312	2,108	1,545	
Centennial Wash (Maricopa-Yuma Co.)	-	-	-	-	-	2	3	19	82	237	290	
Gila Bend Area	-	-	-	-	-	19	44	113	190	176	115	
	121	385	667	778	1,060	1,494	2,464	3,638	4,079	3,957	3,221	3,820
Surface-Water Diversion	1,368	1,433	1,387	1,464	1,546	1,552	1,174	1,021	901	1,041	1,049	1,070
Subtotal	1,490	1,810	2,060	2,240	2,610	3,050	3,640	4,660	4,980	5,000	4,270	4,890
Total	1,690	2,030	2,310	2,460	2,790	3,250	3,900	5,000	5,440	5,560	4,980	5,600

Table 28

Estimated Annual Water Withdrawal
Gila Subregion

Units: 1,000 acre-feet

State, Area, and Source	Estimated Average Annual Withdrawal 1/											
	Historic											Normalized 1965 Level
	1915-1919	1920-1924	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965	
New Mexico												
Ground-Water Pumpage	-	-	-	-	-	-	2	20	24	52	65	65
Surface-Water Diversion	56	68	81	81	60	64	37	32	30	31	31	31
Total	56	68	81	81	60	64	39	52	54	83	96	96
Gila Subregion												
Ground-Water Pumpage	131	391	672	784	1,087	1,539	2,604	3,902	4,454	4,451	3,866	4,465
Surface-Water Diversion	1,612	1,712	1,714	1,759	1,761	1,774	1,339	1,144	1,035	1,186	1,210	1,231
Total	1,740	2,100	2,390	2,540	2,850	3,310	3,940	5,050	5,490	5,640	5,076	5,696

1/ Includes withdrawal in closed basins and drainage to Mexico. Arizona withdrawal shown for two areas, above (Upper Gila) and below (Middle Gila) Ashurst-Hayden Diversion Dam.

Mining at Morenci and the communities of Clifton and Morenci in Greenlee County, Arizona, receive surface waters from the Black and San Francisco Rivers in part from exports from the Little Colorado Subregion. Most of the remaining municipal and industrial developments in the Subregion, including the city of Tucson, must rely on ground-water pumping.

Ground Water

Large amounts of ground water are withdrawn from the aquifers in the alluvial basins by pumping from wells. Individual well discharges range from only a few gallons per minute for small domestic and stock wells equipped with windmills to several thousand gallons per minute for many of the large irrigation wells equipped with large pumps powered by electricity, diesel fuel, or natural gas. Some flowing wells provide small supplies of water, but in many instances, because of the decline of water levels, artesian wells are now equipped with pumps to obtain sufficient water. From 1915 through 1965, it is estimated that about 100 million acre-feet of water have been pumped from the ground-water reservoirs. In 1965 total ground-water pumpage was 3,900,000 acre-feet. With slight variations, the annual withdrawal of ground water in the Gila Subregion has been about 4.5 million acre-feet since 1955. These large withdrawals of ground water have resulted in declining water levels in the highly developed basins, indicating that a large part of the water is being withdrawn from ground-water storage in the basins--that is, the withdrawal is in excess of the replenishment. Table 28 shows ground-water pumpage by basins by 5-year intervals. At the current level of development, annual ground-water pumpage is estimated as 65,000 acre-feet in New Mexico and 4,400,000 acre-feet in Arizona. About 6 percent of the ground-water withdrawal is for purposes other than agriculture.

Recent agricultural development in the extreme western portion of the Subregion and the Sulfur Springs Valley has increased current pumpage significantly. Outside the Salt River Valley, ground-water pumpage is almost solely relied upon to meet the growing municipal and industrial water demands. In New Mexico and eastern Arizona ground-water withdrawal from the alluvial aquifers in the Gila and San Francisco River Valleys is replaced directly from the stream and long-term overdraft does not occur. Nearly all other ground-water pumpage in the Subregion constitutes an overdraft.

PRESENT WATER REQUIREMENTS

Present (1965) depletion and withdrawal water requirements in the Gila Subregion are shown on tables 6 and 7, respectively. As shown, an estimated total annual withdrawal of about 6.95 million acre-feet are needed to meet a depletion requirement of 4.42 million acre-feet. Over 90 percent of this requirement is for irrigated agriculture.

In-transit water is potential ground-water recharge which, due to declining water tables, interception by impervious beds (perched water), etc., is presently irrecoverable. This increases the effective rate of depletion of the available water supply, although these waters are not truly consumed. Within the central Arizona area, in-transit losses have been accounted for by including an additional 600,000 acre-feet in the irrigation consumptive-use requirement.

These losses occur mostly in south-central Arizona where historically deep ground-water levels have prevailed and requirements for water are presently met primarily from ground-water pumpage. Present information allows only an approximation to be made of the quantity of water associated with these transitory losses. Since about half of the central Arizona area is believed to be affected by this condition, 50 percent of the water applied in excess of the irrigation depletion requirement was assumed to be lost in transit. Other observers [10-67] refer to in-transit losses as being of the same magnitude as estimated above.

PRESENT MODIFIED WATER SUPPLY

Almost all of the surface-water supply is depleted in satisfaction of 1965 level water requirements. Subregion outflow does occur, however, principally from spills at upstream reservoirs. Recent spills from the Salt River System (1965-66) and long-range studies by the Bureau of Reclamation which show system spills, indicate a portion of the subregional water supply cannot be entirely controlled with the amount of storage presently available. Such spills are estimated to produce an average outflow at the subregional boundary of 100,000 acre-feet per year. This outflow is not considered usable in the Lower Main Stem Subregion, since its occurrence is erratic resulting from rare abnormal flood discharges.

Since the undepleted water supply is estimated as 1.8 million acre-feet and the annual depletion requirement, as shown on table 6, totals 4.4 million acre-feet, a large apparent deficiency in supply is indicated.

Table 29

1965 Modified Water Supply
Gila Subregion

Item	Million ac-ft
Average undepleted water supply	1.80
Imports from Subregion 2	0.01
Present depletion requirements	4.42
Present subregional outflow	0.10
1965 Modified water supply (deficiency)	-2.71

Except for local and seasonal shortages all of the deficiency occurs in the Arizona portion of the Subregion in the form of ground-water overdraft. To the extent that present theoretical requirements are not being fully satisfied, the apparent deficiency shown on table 29 is greater than may actually exist. It is estimated that total consumption in the Subregion, including reservoir evaporation, is about 4.2 million acre-feet (see table 5) with most of the shortage incurred by irrigated agriculture. This would result in an actual deficiency (overdraft of ground water) of about 2.5 million acre-feet. 1/

PRESENT SUFFICIENCY

The surface-water supplies of the Gila Subregion have been developed and utilized to such an extent that only the rare runoff event presently produces subregional outflow. Annual surface-water supplies are extremely variable and carryover storage is a necessity. In the Upper Gila River valleys of eastern Arizona and western New Mexico, water is diverted directly from the stream and late season shortages are common. The Subregion's major water demands are in the desert lowlands of southern Arizona where the combined use of the available surface water and ground water tends to eliminate water demand shortages.

1/ The effective rate of overdraft in Arizona is reported in [11-616] as about 2.5 million acre-feet annually; nearly all occurring in the Gila Subregion.

No water supply remains for further development in the Subregion except for a portion of the small subregional outflow and that portion presently depleted by consumptive losses associated with water conveyance and use. Current deficiencies in water supply of about 2.7 million acre-feet are being met almost entirely by the overdrafting of ground water. The principal objective of the recently authorized Central Arizona Project, which provides the facilities to divert Arizona's remaining Colorado River entitlement into the Subregion, is the reduction of ground-water pumpage. Colorado River water will also afford a base for water exchange to the upper areas of the Subregion now dependent on the whim of natural runoff.

FUTURE WATER REQUIREMENTS

Future water requirements in the Subregion for development years 1980, 2000, and 2020 are shown on tables 8 through 13. Projected total depletion requirements increase from 4.4 million acre-feet at the present time to about 5.5 million acre-feet by year 2020. Water requirements for electric power generation and municipal and industrial purposes exhibited the largest increases. Irrigation requirements are projected to remain relatively unchanged throughout the study period. In-transit losses, which are included in the irrigation depletion requirement through 1980, should be considerably diminished prior to the 2000 level of development if the Central Arizona Project is effective toward the stabilization or reduction of the presently rapid rate of decline of ground-water levels. Accordingly, in-transit losses were assumed to be excluded by that time.

FUTURE MODIFIED WATER SUPPLY

The authorized Central Arizona Project will provide additional storage capacity within the Subregion affording the control to practically eliminate Subregion outflow. For future conditions, outflow will be considered negligible.

Currently the Subregion is dependent on ground-water overdraft to satisfy the deficiency in water supply. The Lower Colorado Region framework studies assume the Central Arizona Project will provide, by 1980, the facilities to deliver Colorado River water into the Subregion. As presently planned, the project conveyance capacity from the Colorado River is 3,000 cfs or about 2.17 maf annually. From Bureau of Reclamation studies, future imports to the Gila Subregion from an unaugmented Colorado River are 1.76 maf, 1.12 maf, and 0.87 maf for the 1980, 2000, and 2020 levels of development, respectively [3-35].

Based on the above, the future modified water supply in the Gila Subregion is shown on table 30, below.

Table 30

Future Modified Water Supply
Gila Subregion

Units: Million ac-ft

Item	Development Year 1980	2000	2020
Average undepleted water supply	1.80	1.80	1.80
Subregion 2 imports	0.01	0.01	0.01
C.A.P. imports 1/	1.67	1.06	0.83
Future total water supply	3.48	2.87	2.64
Future depletion requirements	5.01	4.76	5.53
Modified water supply (deficiency)	-1.53	-1.89	-2.89

1/ Assumes 5 percent nonrecoverable losses in conveyance from the Colorado River to points of delivery.

FUTURE SUFFICIENCY

The apparent water-supply deficiencies derived in the previous section will probably be overcome by continuing ground-water overdraft or go unmet until sufficient additional supplies can be made available. Assuming augmentation of the Colorado River as this source, full use could be made of Central Arizona Project facilities to convey augmented water into the Subregion reducing the water supply deficiency to about 1.7 million acre-feet in 2020. Conveyance facilities additional to those provided by the Central Arizona Project would be needed to eliminate the remaining deficiency.

OBE-ERS ADDENDUM

CHAPTER F--OBE-ERS ADDENDUM

INTRODUCTION

The previous chapters of this appendix have dealt exclusively with Modified OBE-ERS projected levels of development. These projections were based upon regional review and modifications of the original projections (OBE-ERS) which were furnished to the Region by the Water Resources Council. This chapter will present the adequacy of the water supply available to the Lower Colorado Region to satisfy the demands of the OBE-ERS projected development for the target years of 1980, 2000, and 2020.

Similar to the Modified OBE-ERS data, the OBE-ERS projections were converted to land and water requirements by the responsible Work Groups. Supporting information is contained in the proper appendixes.

Table 31 is a brief comparison of the areas of major differences between the OBE-ERS and Modified OBE-ERS projections and the resulting difference in depletion water requirements. As shown, the increase in irrigated acreage is relatively small under both sets of projections. The population figures, on the other hand, show significant increases, especially in the Lower Main Stem Subregion. The increase from OBE-ERS to Modified OBE-ERS with respect to population, occurs principally in the Nevada portion of Subregion 1. In terms of net water requirements, the Modified OBE-ERS development would require in excess of 0.5 maf per year more than would the OBE-ERS development.

FUTURE WATER REQUIREMENTS

Tables 32 through 37 are summaries of depletion and withdrawal requirements for the various water-oriented activities at the OBE-ERS projected levels of development, 1980, 2000, and 2020.

FUTURE WATER SUPPLY

The future water supplies available for use in the Lower Colorado Region and its Subregions remain unchanged from that presented in earlier chapters of this appendix.

Table 31

Comparison of OBE-ERS and Modified OBE-ERS

Hydrologic Subregions

		1980		2000		2020	
	1965	OBE-ERS	Modified OBE-ERS	OBE-ERS	Modified OBE-ERS	OBE-ERS	Modified OBE-ERS
Irrigated Acres (1,000)							
Subregion 1	292.9	317.6	359.1	351.1	373.2	374.5	402.5
Subregion 2	28.6	21.5	34.4	21.9	35.6	21.9	35.6
Subregion 3	993.9	1,065.3	1,094.1	1,071.3	1,169.7	1,081.9	1,173.6
Total	1,315.4	1,404.4	1,487.6	1,444.3	1,578.5	1,478.3	1,611.7
Population (1,000)							
Subregion 1	312.7	504.8	762.3	935.0	1,429.3	1,612.8	1,874.7
Subregion 2	151.3	218.2	223.9	267.5	293.1	320.0	389.4
Subregion 3	1,383.2	1,879.1	1,880.6	2,993.2	3,000.0	4,601.2	4,612.7
Total	1,847.2	2,602.1	2,866.8	4,195.7	4,722.4	6,534.0	6,876.8
Depletion Requirements (1,000 acre-feet)							
Subregion 1	1,294.1	1,525.9	1,729.2	1,701.3	1,879.7	2,048.0	2,213.6
Subregion 2	113.0	117.7	144.8	133.3	164.3	150.1	191.8
Subregion 3	4,421.7	4,924.8	5,010.8	4,442.0	4,760.7	5,214.9	5,532.5
Total	5,828.8	6,568.4	6,884.8	6,277.2	6,804.7	7,413.0	7,937.9

Table 32

Lower Colorado Region
Estimated Depletion Water Requirements
1980 Level of Development
OBE-ERS
Hydrologic Subregion

Units in 1,000 acre-feet

		Annual Depletion Requirements							
State	Hydro-logic Subregion	Reservoir Evapo-ration (V) 1/	Mineral Resources (VII)	Irrigated Agricul-tural (X) 2/	Municipal and Industrial (XI)	Recre-ation (XII) 3/	Fish and Wildlife (XIII)	Elec-tric Power (XIV)	Total
Arizona	1	17.0	2.9	1,017.0	19.5	0.3	72.8	0.2	1,129.7
	2	33.0	2.6	44.0	12.1	0.7	8.1	0.1	100.6 4/
	3	187.0	70.7	4,344.0	214.2	3.6	18.9	4.4	4,842.8
	Total	237.0	76.2	5,405.0	245.8	4.6	99.8	4.7	6,073.1
Nevada	1	12.0	1.4	169.0	64.3	1.6	36.0	31.9	316.2
New Mexico	2	8.0	0.4	4.0	3.2	0.2	1.3	0.0	17.1
	3	9.0	5.9	63.0	2.8	0.0	1.3	0.0	82.0
	Total	17.0	6.3	67.0	6.0	0.2	2.6	0.0	99.1
Utah	1	20.0	0.0	57.0	2.9	0.1	0.0	0.0	80.0
Lower Colorado Region	1	49.0	4.3	1,243.0	86.7	2.0	108.8	32.1	1,525.9
	2	41.0	3.0	48.0	15.3	0.9	9.4	0.1	117.7 4/
	3	196.0	76.6	4,407.0	217.0	3.6	20.2	4.4	4,924.8
	Total	286.0	83.9	5,698.0	319.0	6.5	138.4	36.6	6,568.4

1/ Exclusive of Colorado River mainstream.

2/ Includes irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 15 percent of the computed irrigation requirement for noncrop consumption associated with irrigation. Also includes an estimated 600,000 acre-feet per year of water losses in transit in the central Arizona area of Subregion 3.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 33

Lower Colorado Region
Estimated Withdrawal Water Requirements
1980 Level of Development
OBE-ERS
Hydrologic Subregion

Units in 1,000 acre-feet

State	Hydrologic Subregion	Annual Withdrawal Requirements							
		Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X)	Municipal and Industrial (XI)	Recreation (XII) 2/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	17.0	7.1	2,010.0	42.7	1.1	108.5	0.2	2,186.6
	2	33.0	2.9	88.0	27.8	2.2	9.7	0.1	163.7 3/
	3	187.0	143.6	6,261.0	498.4	10.9	47.3	4.4	7,152.6
	Total	237.0	153.6	8,359.0	568.9	14.2	165.5	4.7	9,502.9
Nevada	1	12.0	2.8	333.0	162.8	4.8	39.2	31.9	586.5
New Mexico	2	8.0	0.8	7.0	7.2	0.5	1.6	0.0	25.1
	3	9.0	11.4	110.0	4.6	0.0	3.1	0.0	138.1
	Total	17.0	12.2	117.0	11.8	0.5	4.7	0.0	163.2
Utah	1	20.0	0.0	113.0	6.2	0.2	0.1	0.0	139.5
Lower Colorado Region	1	49.0	9.9	2,456.0	211.7	6.1	147.8	32.1	2,912.6
	2	41.0	3.7	95.0	35.0	2.7	11.3	0.1	188.8 3/
	3	196.0	155.0	6,371.0	503.0	10.9	50.4	4.4	7,290.7
	Total	286.0	168.6	8,922.0	749.7	19.7	209.5	36.6	10,392.1

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 34

Lower Colorado Region
Estimated Depletion Water Requirements
2000 Level of Development
OBE-ERS
Hydrologic Subregion

Units in 1,000 acre-feet

State	Hydrologic Subregion	Annual Depletion Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X) 2/	Municipal and Industrial (XI)	Recreation (XII) 3/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	18.0	4.3	1,064.0	24.9	0.4	86.7	8.0	1,206.3 4/
	2	37.0	3.1	44.0	18.9	1.2	9.9	0.0	114.1
	3	215.0	104.1	3,501.0	387.4	7.2	49.5	76.8	4,341.0
	Total	270.0	111.5	4,609.0	431.2	8.8	146.1	84.8	5,661.4
Nevada	1	12.0	2.1	164.0	147.5	3.6	61.0	19.0	409.2
New Mexico	2	8.0	0.5	3.0	4.8	0.4	2.5	0.0	19.2
	3	18.0	9.7	65.0	4.1	0.0	2.1	2.7	101.6
	Total	26.0	10.2	68.0	8.9	0.4	4.6	2.7	120.8
Utah	1	20.0	0.0	62.0	3.6	0.1	0.1	0.0	85.8
Lower Colorado Region	1	50.0	6.4	1,290.0	176.0	4.1	147.8	27.0	1,701.3 4/
	2	45.0	3.6	47.0	23.7	1.6	12.4	0.0	133.3
	3	233.0	113.8	3,566.0	391.5	7.2	51.6	79.5	4,442.6
	Total	328.0	123.8	4,903.0	591.2	12.9	211.8	106.5	6,277.2

1/ Exclusive of Colorado River mainstream.

2/ Includes irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 10 percent of the computed irrigation requirement for noncrop consumption associated with irrigation.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet per year to the Gila Subregion.

Table 35

Lower Colorado Region
Estimated Withdrawal Water Requirements
2000 Level of Development
OBE-ERS
Hydrologic Subregion

Units in 1,000 acre-feet

State	Hydrologic Subregion	Annual Withdrawal Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X)	Municipal and Industrial (XI)	Recreation (XII) 2/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	18.0	10.3	1,898.0	55.3	1.4	126.5	8.0	2,117.5
	2	37.0	3.3	79.0	45.7	3.7	11.9	0.0	180.6 3/
	3	215.0	211.4	5,350.0	942.5	21.6	84.7	76.8	6,902.0
	Total	270.0	225.0	7,327.0	1,043.5	26.7	223.1	84.8	9,263.5
Nevada	1	12.0	4.3	292.0	377.1	10.7	70.1	19.0	785.2
New Mexico	2	8.0	1.0	6.0	11.5	1.0	3.0	0.0	30.5
	3	18.0	19.3	109.0	7.2	0.0	4.2	2.7	160.4
	Total	26.0	20.3	115.0	18.7	1.0	7.2	2.7	190.9
Utah	1	20.0	0.0	109.0	7.8	0.2	0.2	0.0	137.2
Lower Colorado Region	1	50.0	14.6	2,299.0	440.2	12.3	196.8	27.0	3,039.9
	2	45.0	4.3	85.0	57.2	4.7	14.9	0.0	211.1 3/
	3	233.0	230.7	5,459.0	949.7	21.6	88.9	79.5	7,062.4
	Total	328.0	249.6	7,843.0	1,447.1	38.6	300.6	106.5	10,313.4

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 36

Lower Colorado Region
Estimated Depletion Water Requirements
2020 Level of Development
OBE-ERS

Hydrologic Subregion

Units in 1,000 acre-feet

State	Hydrologic Subregion	Annual Depletion Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X) 2/	Municipal and Industrial (XI)	Recreation (XII) 3/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	18.0	5.6	1,129.0	36.4	0.7	100.4	30.3	1,320.4
	2	37.0	0.8	44.0	27.2	1.9	16.0	0.0	126.9 4/
	3	245.0	138.2	3,488.0	705.4	12.8	164.7	345.6	5,099.7
	Total	300.0	144.6	4,661.0	769.0	15.4	281.1	375.9	6,547.0
Nevada	1	12.0	2.9	164.0	297.3	6.7	98.5	50.6	632.0
New Mexico	2	8.0	0.5	3.0	7.1	0.5	4.1	0.0	23.2
	3	19.0	12.4	70.0	6.0	0.0	3.4	4.4	115.2
	Total	27.0	12.9	73.0	13.1	0.5	7.5	4.4	138.4
Utah	1	20.0	0.0	67.0	4.5	0.1	0.2	3.8	95.6
Lower Colorado Region	1	50.0	8.5	1,360.0	338.2	7.5	199.1	84.7	2,048.0
	2	45.0	1.3	47.0	34.3	2.4	20.1	0.0	150.1 4/
	3	264.0	150.6	3,558.0	711.4	12.8	168.1	350.0	5,214.9
	Total	359.0	160.4	4,965.0	1,083.9	22.7	387.3	434.7	7,413.0

1/ Exclusive of Colorado River mainstream.

2/ Includes irrigation requirements as derived in Appendix X, Irrigation and Drainage, plus an estimated 10 percent of the computed irrigation requirement for noncrop consumption associated with irrigation.

3/ Prorated to States by the Water Resources Work Group based on population.

4/ Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.

Table 37

Lower Colorado Region
Estimated Withdrawal Water Requirements
2020 Level of Development
OBE-ERS
Hydrologic Subregion

Units in 1,000 acre-feet

State	Hydrologic Subregion	Annual Withdrawal Requirements: Reservoir Evaporation (V) 1/	Mineral Resources (VII)	Irrigated Agricultural (X)	Municipal and Industrial (XI)	Recreation (XII) 2/	Fish and Wildlife (XIII)	Electric Power (XIV)	Total
Arizona	1	18.0	13.5	1,858.0	77.0	2.0	161.7	30.3	2,160.5
	2	37.0	1.0	73.0	67.1	5.7	19.2	0.0	203.0 3/
	3	245.0	281.1	5,329.0	1,701.1	38.5	215.8	345.6	8,156.1
	Total	300.0	295.6	7,260.0	1,845.2	46.2	396.7	375.9	10,519.6
Nevada	1	12.0	5.8	269.0	705.3	20.2	115.2	50.6	1,178.1
New Mexico	2	8.0	1.2	6.0	17.3	1.5	5.8	0.0	39.8
	3	19.0	24.4	109.0	11.0	0.0	13.0	4.4	180.8
	Total	27.0	25.6	115.0	28.3	1.5	18.8	4.4	220.6
Utah	1	20.0	0.1	110.0	9.2	0.2	0.2	3.8	143.5
Lower Colorado Region	1	50.0	19.4	2,237.0	791.5	22.4	277.1	84.7	3,482.1
	2	45.0	2.2	79.0	84.4	7.2	25.0	0.0	242.8 3/
	3	264.0	305.5	5,438.0	1,712.1	38.5	228.8	350.0	8,336.9
	Total	359.0	327.1	7,754.0	2,588.0	68.1	530.9	434.7	12,061.8

1/ Exclusive of Colorado River mainstream.

2/ Prorated to States by the Water Resources Work Group based on population.

3/ **Excludes normal export of 15,000 acre-feet annually to the Gila Subregion.**

FUTURE MODIFIED WATER SUPPLY

The future modified water supplies reflecting OBE-ERS data are developed and presented on tables 38, 39, and 40, for the Gila, Little Colorado and Lower Main Stem Subregions, respectively. Table 40 also contains the regional evaluation of future water supply versus future water requirements. Results are similar though slightly less in magnitude, to those derived for the Modified OBE-ERS projections earlier in this appendix.

FUTURE SUFFICIENCY

Table 40 clearly shows the inadequacy of the available regional water supplies to meet future demands for water under the OBE-ERS projected levels of development. Further conclusions would be the same as those presented under the FUTURE SUFFICIENCY section of chapters B, C, D, and E.

Since the OBE-ERS projections indicate a lesser need for water than do the Modified OBE-ERS projection (see table 31), framework plans developed to provide adequate water supplies for the Modified OBE-ERS requirements would also fully satisfy the OBE-ERS requirements.

Table 38

Future Modified Water Supply
Subregion 3 - Gila
OBE-ERS

Units: Million acre-feet

Item	Development Year 1965	1980	2000	2020
Undepleted Water Supply	1.80	1.80	1.80	1.80
Imports from Subregion 1 1/	--	1.67	1.06	0.83
Imports from Subregion 2	0.01	0.01	0.01	0.01
Depletion Requirements	-4.42	-4.92	-4.44	-5.21
Unregulated Spills	-0.10	--	--	--
Modified Water Supply (Deficiency)	-2.71	-1.44	-1.57	-2.57

1/ Deliveries via a 3,000-cfs Central Arizona Project aqueduct from the Colorado River [3-35]. Assumes 5 percent consumptive losses from point of diversion to points of delivery (see table 30).

Table 39

Future Modified Water Supply
Subregion 2 - Little Colorado
OBE-ERS

Units: Million acre-feet

Item	Development Year 1965	1980	2000	2020
Undepleted Water Supply	0.42	0.42	0.42	0.42
Depletion Requirements (including exports to Subregion 3)	-0.13	-0.13	-0.15	-0.17
Modified Water Supply (Outflow to Subregion 1)	0.29	0.29	0.27	0.25

Table 40

Future Modified Water Supply
Subregion 1 - Lower Main Stem
OBE-ERS

Units: Million acre-feet

Item	Development Year 1965	1980	2000	2020
Modified Flow - Colorado River at Lee Ferry (1906-1965) (table 15)	11.64	10.26	8.97	8.54
Undepleted Tributary Runoff	0.90	0.90	0.90	0.90
Modified Inflow from Subregion 2 (table 39)	0.29	0.29	0.27	0.25
Total Modified Water Supply	12.83	11.45	10.14	9.69
Export and Depletion Requirements				
Subregion 1	1.29	1.53	1.70	2.05
Exports - California Region (page 81)	5.00	4.40	4.40	4.40
Exports - Gila Subregion (page 102)	--	1.76	1.12	0.87
Mexican Treaty	1.50	1.50	1.50	1.50
Main Stem Evaporation	1.20	1.20	1.20	1.20
Channel Losses (page 81)	0.66	0.39	0.39	0.39
System Spills [3-35]	0.65	0.52	0.15	0.15
Total	10.30	11.30	10.46	10.56
Subregional Surplus (+) or Deficiency (-)	+2.53	+0.15	-0.32	-0.87
Deficiency - Gila Subregion (table 38)	-2.71	-1.44	-1.57	-2.57
Regional Deficiency (-)	-0.18	-1.29	-1.89	-3.44

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