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Upper Colorado Region

Comprehensive Framework Study

Appendix V Water Resources

Upper Colorado Region State-Federal Inter-Agency Group / Pacific Southwest
Inter - Agency Committee / Water Resources Council June 1971

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This appendix was prepared by the
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of the
UPPER COLORADO REGION STATE-FEDERAL INTER-AGENCY GROUP
for the
PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE
WATER RESOURCES COUNCIL

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UPPER COLORADO REGION

COMPREHENSIVE FRAMEWORK STUDY

APPENDIX V

WATER RESOURCES

JUNE 1971

This report of the Upper Colorado Region 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 Upper 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.

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SUMMARY

This report presents the results of comprehensive investigations of water resources for formulation of framework plans to provide a broad guide to the best use, or combination of uses, of water resources to meet foreseeable short- and long-term needs. For flexibility in analysis and planning, the Upper Colorado River upstream from Lee Ferry, Arizona, has been divided into three subregions comprising the natural drainages of the Green River, Upper Main Stem, and San Juan-Colorado. Summaries of water resource data are also prepared for the states of Arizona, Colorado, New Mexico, Utah, and Wyoming.

Water supply from precipitation averages about 95 million acre-feet a year. Annual precipitation varies from less than 6 inches in desert areas of the southwestern portion of the region to over 50 inches in the high elevation headwater areas in Colorado. A broad range of climatic and resulting streamflow conditions exist. Large variations in annual discharge occur also, from year to year due to variations in precipitation, and over periods of years due to long-term climatic trends. Average annual discharge of the Colorado River at Lee Ferry was 12,426,000 acre-feet for the 52-year period 1914-65, with extremes of 21,894,000 acre-feet in 1917 and 4,396,000 acre-feet in 1934. Average annual virgin flow at Lee Ferry, as unaffected by the activities of man, is estimated at 14.87 million acre-feet over the 52-year period 1914-65.

Estimated average annual withdrawal and consumptive use of ground water is less than one percent of surface water use. A close relation exists in many areas between local ground and surface water resources.

Water is used for irrigation, domestic-municipal-industrial purposes, livestock watering, hydroelectric and thermal electric power generation, mineral activity, fish and wildlife facilities, and recreation. Large amounts of water are also exported to adjoining regions for multiple-purpose uses.

A total of 581 reservoirs with usable storage in excess of 29.7 million acre-feet had been constructed by 1965 to provide storage regulation for various water uses. Since 1965 over one million acre-feet of additional storage has been constructed or is under construction. The largest part of the storage capacity has been constructed as part of the Colorado River Storage Project primarily to provide long-term regulatory storage.

SUMMARY (Continued)

The following table compares water resources development for five levels of development. Virgin water supply is estimated at 14.87 million acre-feet. The five average annual levels of depletion are shown by type of use, state, and subregion. The levels of development first studied include the present (1965) and the framework plan "Regionally Interpreted OBERS," which was determined as the region's logical contribution to meet national needs. Three additional alternatives were developed to reflect capability of the region to supply goods and services not fully evaluated in the OBERS projections.

(1) States' alternative plan based on the availability of 6.545 million acre-feet of water. This plan utilized the same amount of water as the Framework Plan (regionally interpreted OBERS) development with primary shifts in power, export, minerals, and irrigation within states transfers in power between states and new uses for oil shale and coal by-products.

(2) States' alternative plan based on depletion of 8.16 million acre-feet of water plus delivery of an average 7.5 million acre-feet at Lee Ferry. The plan assumes the Colorado River water supply will be firmed to meet the division of water by both the Colorado River Compact and the Upper Colorado River Compact, and that the Mexican Treaty delivery plus associated losses would be a national obligation. Most of the increased depletion will occur in minerals, irrigation, and export.

(3) States' alternative plan depleting 9.44 million acre-feet based on use of water which is physically available at the project site without considering political or legal restrictions. Substantial augmentation would be required to meet Colorado River Compact requirements of the lower basin.

Outflow for the five levels of development varies from 11.4 million acre-feet at present to 5.4 million acre-feet, using the 1914-65 water supply and assuming no augmentation.

SUMMARY

Summary of water resources development, Upper Colorado Region

	Level of Development				
	1965	Regionally Interpreted OBERS Year 2020	State Alternatives		
			6.5 Million Acre-feet Year 2020	8.16 Million Acre-feet Year 2020	Water Available At Site Year 2020
			-----Acre-feet-----		
VIRGIN WATER SUPPLY (1914-65)	14,872,000	14,872,000	14,872,000	14,872,000	14,872,000
ON SITE WATER DEPLETIONS					
<u>By type of use</u>					
Municipal and industrial	27,400	110,100	147,600	191,800	201,800
Electric power (thermal)	23,200	626,600	604,400	713,800	754,800
Minerals	33,700	52,800	231,700	550,100	735,900
Fish and wildlife	11,700	87,800	88,400	121,700	121,700
Recreation	1,300	5,200	5,200	5,200	5,200
Stockpond evaporation and livestock use	34,900	59,000	59,000	59,000	59,000
Subtotal	132,200	941,500	1,136,300	1,641,600	1,878,400
Irrigation	2,127,800	3,294,000	3,296,800	3,657,700	4,088,500
Export	550,300	1,652,500	1,454,900	2,203,300	2,816,400
Less import	(-)2,600	(-)2,600	(-)2,600	(-)2,600	(-)2,600
Subtotal of all above	2,807,700	5,885,400	5,885,400	7,500,000	8,780,700
Main Stem Reservoir evaporation	643,000	660,000	660,000	660,000	660,000
Total	3,450,700	6,545,400	6,545,400	8,160,000	9,440,700
<u>By state</u>					
Arizona	10,100	50,000	50,000	50,000	50,000
Colorado	1,706,600	3,009,800	3,019,400	3,855,400	4,037,500
New Mexico	144,900	666,200	656,700	838,100	1,067,600
Utah	664,000	1,341,100	1,341,900	1,713,500	2,037,600
Wyoming	282,100	818,300	817,400	1,043,000	1,588,000
Total	2,807,700	5,885,400	5,885,400	7,500,000	8,780,700
<u>By subregion</u>					
Green River	1,059,500	2,385,100	2,328,300	3,040,300	3,788,400
Upper Main Stem	1,397,300	2,245,200	2,232,500	2,877,000	3,113,100
San Juan-Colorado	993,900	1,915,100	1,984,600	2,242,700	2,539,200
Total	3,450,700	6,545,400	6,545,400	8,160,000	9,440,700
OUTFLOW	11,421,300	8,326,600	8,326,600	6,712,000	5,431,300

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PART I

INTRODUCTION

The Upper Colorado Region is one of four Pacific Southwest regions assigned to the Pacific Southwest Interagency Committee by the United States Water Resources Council for comprehensive framework study. To coordinate the study in the Upper Colorado Region, the Upper Colorado River Commission was designated as the chairman agency of a State-Federal Interagency Group representing five states and many Federal agencies.

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 seasoned judgment of competent planners.

Supporting a "Main Report" are sixteen appendices. These are the results of work group assignments. This appendix "Water Resources," in addition to discussing water resources and presenting basic data, is a synopsis of present and estimated future water supply requirements including data drawn from other assigned appendices devoted to specific uses of water and related resources.

Purpose and Scope

The aim of this appendix is to present in narrative, graphic, and tabular form basic water resource data, analyses, and summaries thereof in preparing companion appendices leading to formulation of plans and programs of the "Main Report."

Because of the reconnaissance nature of the "Main Report," little effort was devoted to new study and research. Therefore, existing studies, inventories, and publications were heavily relied upon in assembling material for this appendix. Particular use was made of recent United States Geological Survey (USGS) Professional Papers -- "Water Resources of the Upper Colorado River," No. 441 and No. 442, with some updating to year 1965 to incorporate new material subsequent to 1957, the closing period of the two USGS reports. Likewise, other federal reports and studies by state organizations in connection with their state water plans were utilized. In identifying present water uses, a base year of 1965 has been used. All uses initiated after 1965, even though authorized prior to 1965, will be accounted for in subsequent check point years.

The initial studies conform to projections formulated by the Office of Business Economics, Department of Commerce, and the Economic Research Service, Department of Agriculture. The combined projection has been designated as "OBERS." There has, however, been applied a "Regional Interpretation" for agriculture, power, mining, and forestry projections. This appendix limits itself essentially to the "Regionally Interpreted OBERS" projections with check points at years 1980, 2000, and 2020.

In addition this appendix considers further projections based on alternate plans designated as follows:

- 1- States' Alternative at 6.5 m.a.f. Level of Development
- 2- States' Alternative at 8.16 m.a.f. Level of Development
- 3- States' Alternative -- Development of Water Supply Available at Site

Relation To The Other Parts of The "Main Report"

This appendix is one of sixteen supporting the "Main Report." All present and projected water uses are summarized on state, sub-region, and regional bases and analyzed as to their combined effect on flows and commitments at Lee Ferry, the point of outflow of the region as designated by the Colorado River Compact. The details of various categories of present and prospective water uses are found in companion appendices.

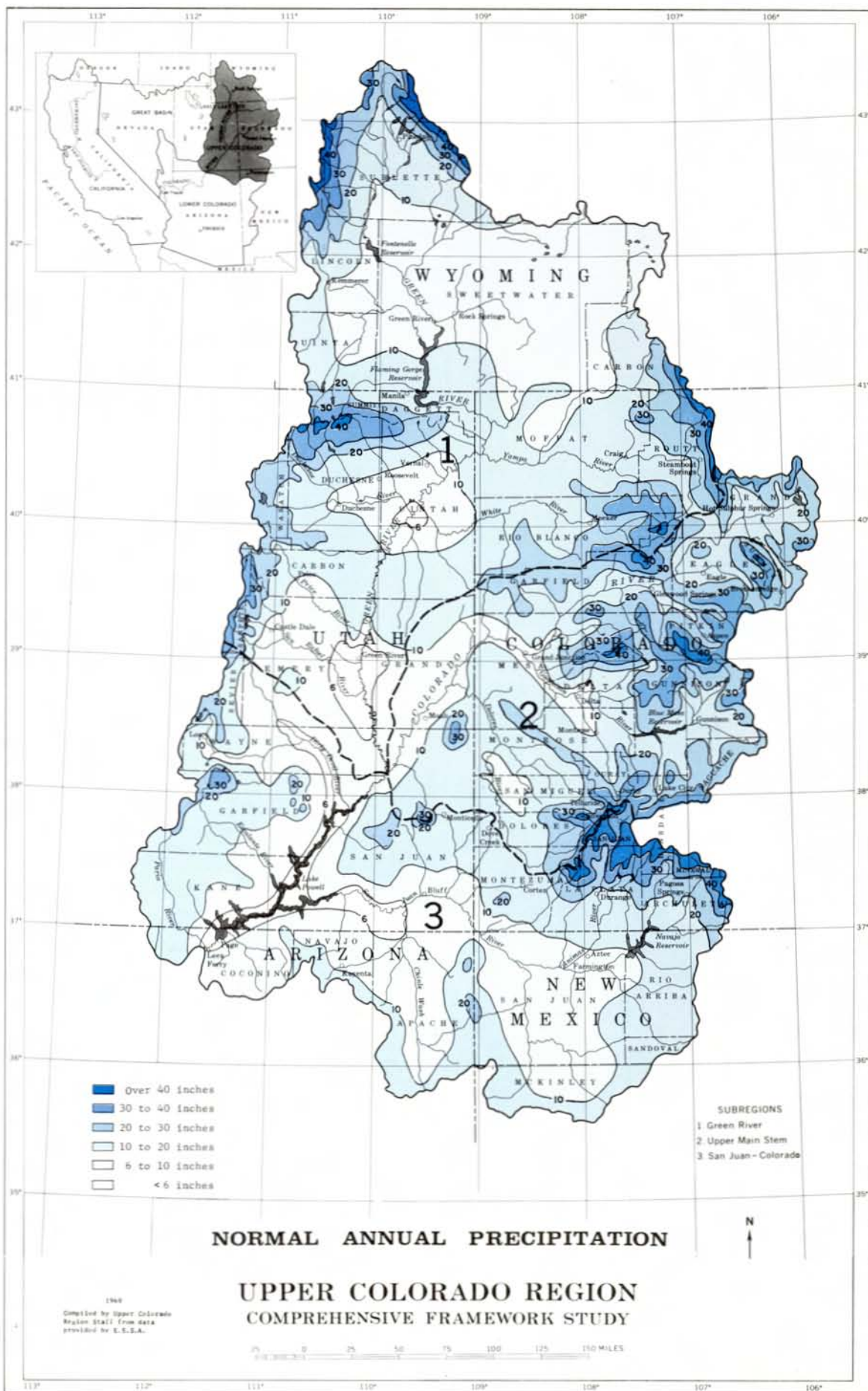
The Great Divide Closed Basin does not contribute to the water resources of the region except for a small amount of internal use.

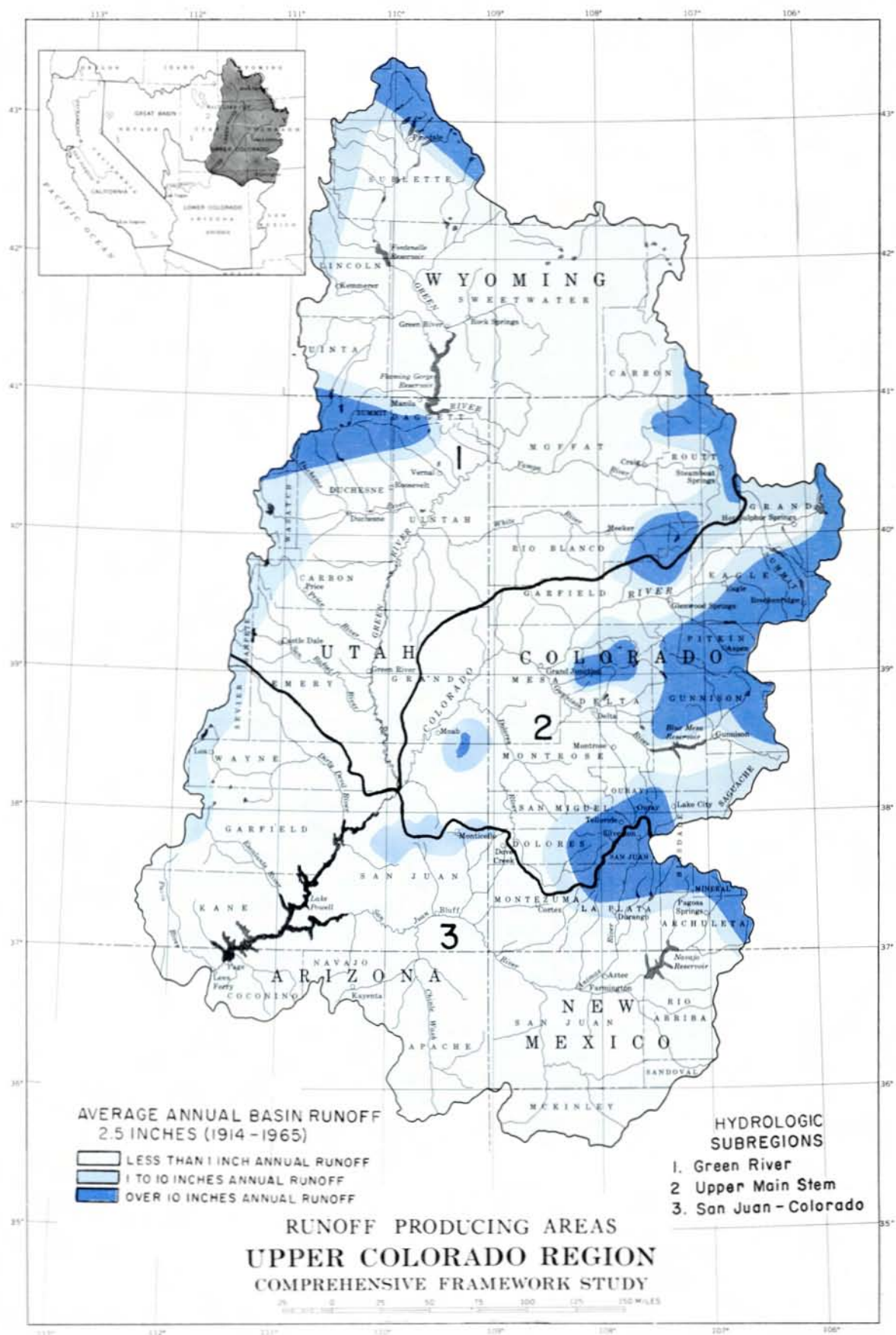
The Colorado River rises near the extreme eastern part of the Region at an altitude of 13,000 feet, and flows generally southwestward to Lee Ferry where the altitude is about 3,100 feet.

Main river channels are deeply entrenched in solid rock canyons in Utah and Arizona. The mostly barren and largely inaccessible areas provide very little opportunity or need for diversions from the rivers, and in this reach most of the depletion is through evaporation from the water surfaces. It is a region of intense interest to the people of the United States, being a land of spectacular beauty, breath-taking scenery, and majestic natural rock formations, attracting many tourists, adventurers, and naturalists. The wild canyons of the Colorado, Green, San Juan, and Yampa Rivers have presented a challenge to thrill-seeking boatsmen since the first expeditions of Major John Wesley Powell in 1869 and 1872.



Spring snowmelt





Historic unit discharge on the main stem, as shown in the following tabulation, decreases rapidly as the streams flow from headwaters at high altitude into the less humid areas and finally into desert areas.

Drainage area and historic unit discharge
Upper Colorado Region

Gaging Station	Drainage area <u>Square Miles</u>	Record prior to 1965 <u>Years</u>	Unit discharge <u>Cfs/Sq. Mi.</u>
Colorado River near Grand Lake, Colorado	103	46	0.922
Colorado River at Glenwood Springs, Colorado	4,560	66	.596
Colorado River near Cameo, Colorado	8,050	32	.484
Colorado River near Cisco, Utah	24,100	54	.327
Colorado River at Compact point, Lee Ferry, Arizona	109,580 <u>1/</u>	52	.155

1/ Drainage area as measured in connection with this study; other area figures are from USGS Water Supply Papers.

Part of the decrease in unit discharge as the river proceeds downstream can be attributed to exports from the region, depletions for irrigation and other consumptive uses, losses to ground water recharge, transpiration, and evaporation. However, most of the decrease is due simply to lower contribution from the downstream areas. Yet, as shown by the preceding map "Average Annual Basin Runoff," there is almost always an increase in discharge in the downstream direction, except immediately below large diversions.

Large variations in annual discharge occur also from year to year due to yearly variations in precipitation, and over periods of years due to long-term climatic trends. The average annual discharge of the Colorado River at Lee Ferry was 12,426,000 acre-feet for the 52-year period 1914-65, with extremes of 21,894,000 acre-feet in 1917 and 4,396,000 acre-feet in 1934. For the 17-year period 1914-30, the average discharge was 15,919,000 acre-feet per year, while for the 26-year dry cycle 1931-56 the average discharge was 11,183,000 acre-feet per year. These are residual flows reflecting upstream depletions approximating 1,800,000 acre-feet in 1914 increasing to about

2,800,000 acre-feet in 1962. Commencing in 1963 there began a withholding of large amounts of water in the upstream reservoirs of the Colorado River Storage Project. The average annual virgin flow at Lee Ferry, as unaffected by the activities of man, is estimated at 14.872 million acre-feet over the 52-year period 1914-65. As shown on the preceding map, the virgin contribution would average about 2.5 inches in depth over the basin.

Water is presently (1965) exported from the region through some 39 transmountain canals and tunnels, mostly located at the headwaters of small tributaries. Several of these diversions have operated for many years and in 1965 the diversion totaled 513,000 acre-feet. There is one small diversion into the region from the East Fork Sevier River in southern Utah averaging 2,600 acre-feet per year.

Prior to 1960 there were 92 storage reservoirs in the region having usable capacities of greater than 1,000 acre-feet and total usable capacity of 1,635,000 acre-feet. The large reservoirs built by the U. S. Bureau of Reclamation since 1960 are parts of the Upper Colorado River Storage Project and are mainly intended to store water for satisfying allocations to the Lower Colorado River basin while allowing additional local use of water from some of the headwater streams. Development of hydroelectric power is an added and most valuable benefit, which will in large measure repay the costs of the project. Recreation is another important benefit. However, loss to evaporation from increased exposed water surfaces is a deterrent to the construction of additional large reservoirs at the lower altitudes.

Summary records of streamflow at 13 selected gaging stations and 41 of the transmountain diversions in the Upper Colorado Region for the period 1914-65 are listed on tables 1 and 2.

Subregions

The Upper Colorado Region has been divided for purposes of this study into three major hydrologic subregions, namely, the Green River Subregion, the Upper Main Stem Subregion, and the San Juan-Colorado Subregion.

The Green River Subregion

The Green River subregion drains an area of about 48,660 square miles in southwestern Wyoming, northwestern Colorado, and northeastern and east-central Utah. In addition to 44,744 square miles in the natural drainage of the Green River Basin, the subregion includes 3,916 square miles in the Great Divide Closed Basin. The Green River, the largest tributary of the Colorado River, rises in the Wind River

Range in Wyoming at the north end of the Colorado River Basin, and flows southward to its junction with the Colorado River about 60 miles south of the town of Green River, Utah. The principal tributaries are the New Fork River, Big Sandy Creek, Blacks Fork, Henrys Fork, Yampa, White, Duchesne, Price, and San Rafael Rivers. The Great Divide Closed Basin has only one stream with perennial flow, a few perennial lakes, and numerous intermittent or dry lakes and streams. It does not contribute to the water resources of the region except for a small amount of internal use.

Prior to about 1960 there were 41 storage reservoirs in the subregion having usable capacities greater than 1,000 acre-feet and total usable capacity of 575,400 acre-feet. Recently constructed reservoirs in the Upper Colorado River Storage Project include Flaming Gorge Reservoir (1962, usable capacity 3,516,000 acre-feet) and Fontenelle Reservoir (1963, usable capacity 345,400 acre-feet) on the Green River, and the Steinaker off-channel storage reservoir near Vernal, Utah (1962, active capacity 33,300 acre-feet). Joes Valley Reservoir on Cottonwood Creek near Orangeville, Utah (capacity 54,600 acre-feet) was completed in October 1965.

A total of 17 transmountain diversions export about 109,500 acre-feet of water from the subregion annually. The principal transmountain diversions are the Duchesne and Strawberry tunnels.

The Green River portion of the subregion contributes about 38 percent of the total discharge at Lee Ferry from 41 percent of the total area, and produces an average annual unit discharge of about 0.15 cfs/sq mi. Measured yearly runoff from tributaries at the headwaters ranges up to 2.7 cfs/sq mi.

The Upper Main Stem Subregion

The Upper Main Stem subregion includes the Colorado River and all of its tributaries upstream from the junction of the Colorado and Green Rivers, an area of 26,192 square miles. Prior to 1918 this part of the Colorado River was known as the Grand River. The Colorado River rises upstream from Grand Lake in north-central Colorado, and drains the west-central portion of Colorado and a small area in east-central Utah. The principal tributaries are the Roaring Fork, Eagle, Gunnison, and Dolores Rivers. The larger of the transmountain diversions are the Hoosier Pass tunnel (1952), Roberts tunnel (1963), August P. Gumlick (formerly Jones Pass) tunnel (1940), Twin Lakes tunnel (1935), Grand River ditch (1892), Alva B. Adams tunnel (1947), and Moffat tunnel (1936). A total of 17 transmountain diversions export about 414,600 acre-feet of water annually from the region. In addition, about 102,600 acre-feet is exported from the Dolores River to the San Juan-Colorado subregion and does not represent a net loss to the Colorado River basin.

Prior to about 1960 there were 33 storage reservoirs in the subregion, having usable capacities greater than 1,000 acre-feet, and total usable capacity of 831,600 acre-feet. The Blue Mesa Reservoir (capacity 941,000 acre-feet) was completed in 1965 and storage in Morrow Point Reservoir (121,300 acre-feet) began in 1968.

In spite of the large exports of water from the subregion, the large areas of land under irrigation, and the fact that it contains the smaller area of the three subregions, the Upper Main Stem subregion is the largest contributor in total discharge, supplying about 46 percent of the total discharge at Lee Ferry from only 24 percent of the total area. See tabulation on page 5 for historic unit discharge.

The San Juan - Colorado Subregion

The San Juan-Colorado subregion includes all of the drainage area of the Colorado River downstream from the junction of the Colorado and Green Rivers, an area of about 38,644 square miles. The principal stream in this subregion is the San Juan River, which is the second largest tributary of the Colorado River, and drains parts of southwestern Colorado, northwestern New Mexico, southeastern Utah, and northeastern Arizona. It rises on the west slope of the Continental Divide in the southeastern part of the Upper Colorado River basin, and flows westward to its junction with the Colorado River about 75 miles west of Bluff, Utah. The principal tributaries of the San Juan River are the Navajo, Los Pinos, Animas, and La Plata Rivers. The other main tributaries in the subregion are the Dirty Devil, Escalante, and Paria Rivers.

Five transmountain diversions export an average of about 2,500 acre-feet per year from the San Juan-Colorado subregion. One diversion imports into the San Juan-Colorado subregion about 102,600 acre-feet per year from the Upper Main Stem subregion. Another diversion imports into the San Juan-Colorado subregion about 2,600 acre-feet per year from the Sevier River drainage of the Great Basin in Utah.

Prior to about 1960 there were 18 storage reservoirs in the subregion having usable capacities greater than 1,000 acre-feet, and total usable capacity of 228,200 acre-feet. Navajo Reservoir on the San Juan River near Archuleta, New Mexico, with a capacity of 1,696,000 acre-feet, was completed in June 1962. The Navajo Indian Irrigation Project, the main contractor from Navajo Reservoir, withdraws water by gravity canal at an elevation which makes the usable capacity of Navajo Reservoir 1,036,100 acre-feet. Lake Powell on the Colorado River was formed by Glen Canyon Dam at Page, Arizona. Storage began in March 1963, and the usable capacity is 25,002,000 acre-feet. These two reservoirs are part of the Upper Colorado River Storage Project.

The water yield of the subregion is about 0.12 cfs/sq mi annually, amounting to about 16 percent of the total flow at Lee Ferry from 35 percent of the total drainage area. Average annual unit runoff from tributaries near the headwaters of the San Juan River range up to 1.86 cfs/sq mi.

PART III

CLIMATE

The climate of most of the region is semiarid to arid and is predominately a four season climate. Wide variations in precipitation, temperature and wind movement occur primarily as a result of varied topography and to a lesser extent the rather wide range in latitude.

Predominately, the climate is associated with Pacific Ocean air masses which move inland from the west, carrying much of the region's precipitation. Seasonal influences include summer cyclonic thunderstorms that sweep into the southern portion from the Gulf of Mexico and occasional Canadian arctic air that extends into the northern portion during the winter months.

Precipitation

Precipitation is affected by two major factors, the moisture supply and the topography of the area. Since the region is several hundred miles from major sources of moisture and the air masses cross several mountain ranges before reaching the region, precipitation is limited for all except the high mountain areas. Average annual precipitation ranges from less than 6 inches in the lowest valleys to more than 50 inches in the higher mountains. Average precipitation in most valleys and agricultural areas ranges from about 8 to 16 inches per year. Precipitation in amounts over .10 inch per day occur on an average of about 10 to 50 days per year, depending primarily on elevation and altitude. Intensities vary widely but seldom exceed 4.0 inches in 24 hours.

Distribution of precipitation through the year shows a less distinct seasonal pattern than occurs in many other western regions. Precipitation is heaviest during the winter and spring months. An exception occurs in the southern portion where maximum monthly precipitation often occurs from the July, August, and September thunderstorms.

Precipitation during the late October through mid-April period is dominated by snow, particularly at higher elevations. Annual snowfall ranges from 200 to 300 inches in the higher mountains down to about 5 inches in the lower valley and plateau areas. Maximum snow accumulation occasionally exceeds 100 inches in the higher areas and does not completely melt until late summer.

Temperature

Temperatures over the area cover a wide range due to seasonal effects, differences in elevation and diurnal fluctuations. Temperature extremes in the region have varied from -60°F. at Taylor Park, Colorado, to 115°F. at Lees Ferry, Arizona. At most climatological stations mean monthly temperatures are lowest in January and highest in July and generally show about a 50°F. seasonal difference. Average annual temperatures vary from below freezing at elevations around 10,000 feet to about 50°F. for river valleys below 5,000 feet. Thus a decrease in temperature of about 3 or 4 degrees for each 1,000 foot increase in elevation occurs. Diurnal temperature fluctuations are a minimum in winter with variations of maximum and minimum daily temperatures of $20\text{-}25^{\circ}\text{F.}$ and reach a maximum during the summer with a daily variation of 40°F.

Variations in temperature and elevation produce large differences in the frost-free period. Freezing temperatures may occur at any time of the year in the higher mountain areas. The average number of days between the last 32°F. occurrence in the spring and the first occurrence in the spring and the first occurrence in the fall average 20 days or less at elevations about 8,500 feet to more than 180 days at elevations below 5,000 feet.

Wind and Evaporation

A wide range of surface wind conditions occurs in various portions of the region as the general west to east wind movement over the area is modified by topographical influences. Average wind velocities are rather high in mountains and ridges with westerly exposure, while the average wind speeds are relatively low in the more protected valley areas and assume direction according to local terrain. During much of the year high pressure systems and fair weather dominate the intermountain area, and these stagnant conditions result in light wind movement in the valley floor. Typically surface winds move up the valley slopes during the day and down the slopes at night. Cool nights are a characteristic of the valley floor. These conditions often prevail for a considerable period and create consistently high average wind movement at stations located in or near upland slopes or canyon areas.

Average annual wind velocity for the region varies from about 8 to 14 miles per hour. Over the northern portion wind movement is greater during the winter and spring months, averaging about 15 mph and ranging down to summertime velocities of about 7 to 10 mph with occasional gusts reaching up to about 40 mph. In the central and southern portion wind movement is highest during the summer months.

At Grand Junction, Colorado, maximum recorded wind velocity has reached 66 mph and has approached or exceeded 50 mph in every month of the year. The strongest winds are usually associated with local thunderstorms and have on occasion reached velocities of 80 to 90 mph in the San Juan subregion.

Estimates of annual evaporation rate from lakes and reservoirs range from less than 30 inches at higher elevations to about 60 inches in the lower valleys. Wind movement, temperature, solar radiation, and relative humidity are prime factors affecting these rates.

PART IV

SURFACE WATER

Stream Gaging Stations

Systematic collection of streamflow data began as early as 1894 with the establishment of gaging stations on the Colorado and Gunnison Rivers at Grand Junction, Colorado, the Green River at Green River, Utah, and the Price River at Wellington, Utah. Since that time the stream gaging program has been expanded to include a network of about 322 gaging stations on streams throughout the region. The daily records obtained at these stations are published annually in water supply papers of the United States Geological Survey.

The network of stations include 13 stations basic to this study located at or near points of outflow from each of nine major areas. These 13 base stations are listed in table 1 on the following page.

Estimated and recorded annual discharge at the 13 outflow stations are listed in table 2. Listed also in table 2 is the combined discharge of the Colorado River at Lees Ferry and the Paria River thereby deriving the discharge at Lee Ferry, the compact point. The daily discharge data are furnished in the United States Geological Survey Water Supply papers.

Records for 4 of these stations are detailed further in a graphical format that indicates the variability characteristics. Refer to the following three figures. These graphs demonstrate the erratic runoff experienced in the Upper Colorado Region. The flow duration graphs indicate the percent of time that any given discharge was equaled or exceeded during the period, without reference to chronological sequence. The monthly distribution graphs show the average, the maximum, and the minimum of the monthly mean flows. The histograms of annual discharge show the annual total flows in acre-feet, along with a graph indicating the 10-year moving averages.

In addition to the quantitative records of surface discharges, the U. S. Geological Survey publishes data on water quality. The quality aspect of surface water is contained in Appendix XV, "Water Quality, Pollution Control, and Health Factors."

Table 1 - Average annual discharge for key stream gaging stations,
Upper Colorado Region

Gaging station	Drainage area <u>Square Miles</u>	Records available	Average annual discharge for period of study <u>1/</u> 1914-1965 <u>Acre-Feet</u>
Green River near Greendale, Utah	15,100	Oct. 1950 - Sept. 1965	1,575,000
Little Snake River near Lilly, Colorado	3,730	Oct. 1921 - Sept. 1965	432,050
Yampa River near Maybell, Colorado	3,410	April 1916 - Sept. 1965	1,131,000
White River near Watson, Utah	4,020	May - November 1918 April 1923 - Sept. 1965	532,460
Green River at Green River, Utah	40,600	Oct. 1904 - Sept. 1965	4,427,300
San Rafael River near Green River, Utah	1,670	Sept. 1919 - July 1920 Oct. 1945 - Sept. 1965	112,330
Gunnison River near Grand Junction, Colorado	7,870	Oct. 1916 - Sept. 1965	1,898,200
Colorado River near Colorado- Utah State Line	17,900	May 1951 - Sept. 1965	5,066,400
Colorado River near Cisco, Utah	24,100	Oct. 1913 - Sept. 1965	5,662,000
San Juan River at Shiprock, New Mexico	12,900	Feb. 1927 - Sept. 1965	1,876,300
San Juan River near Bluff, Utah	23,000	Oct. 1913 - Sept. 1965	1,955,000
Colorado River at Lees Ferry, Arizona	108,170 <u>2/</u>	June 1921 - Sept. 1965	12,403,700
Paria River at Lees Ferry, Arizona	1,410	Oct. 1923 - Sept. 1965	22,670
Colorado River at Lee Ferry, Arizona	109,580 <u>2/</u>		12,426,370

1/ Average discharge during period of study is average of recorded flows plus flows estimated for periods of missing records.

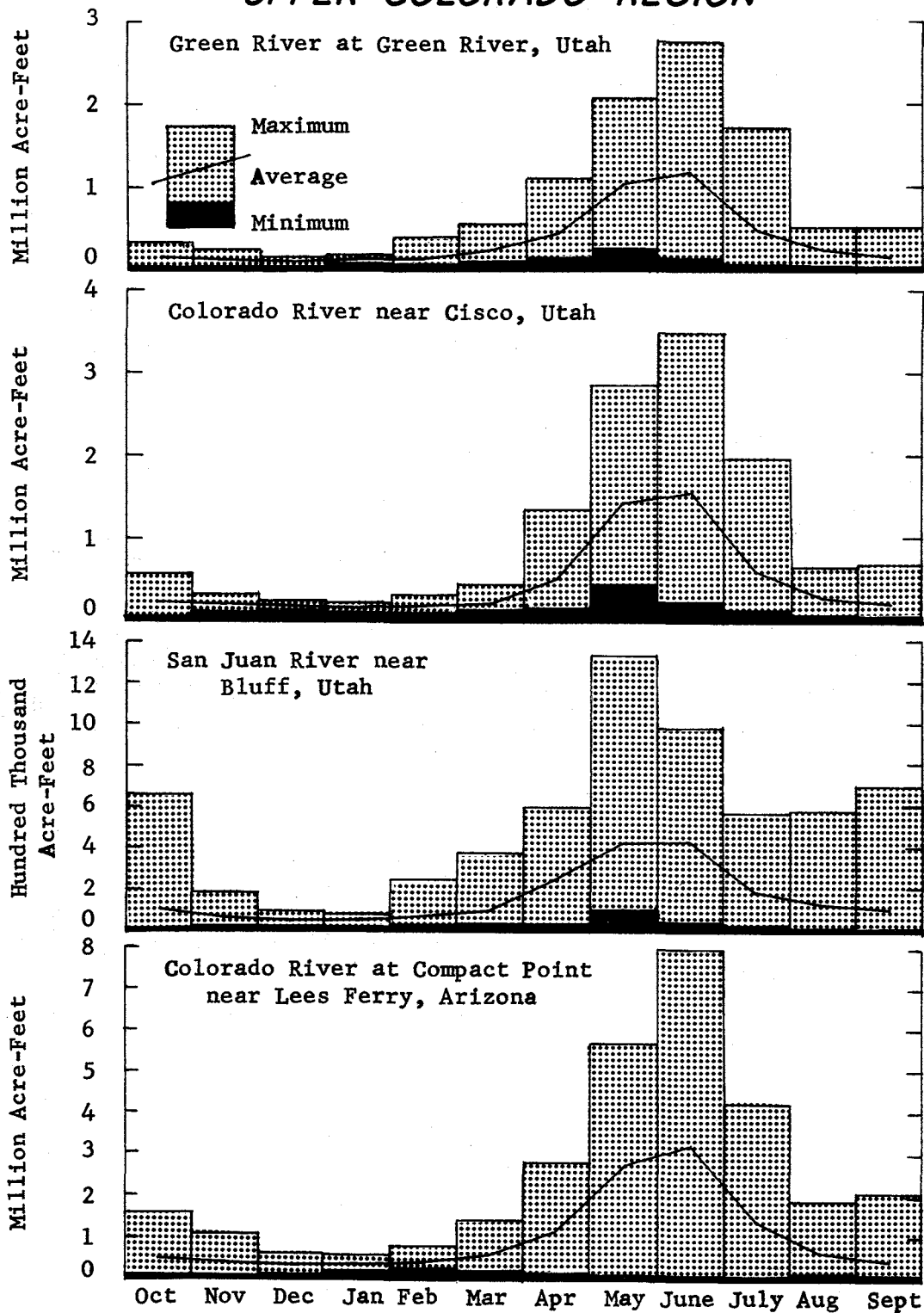
2/ Area as measured in connection with this study.

Table 2--Summary of 1914-65 annual flows at 13 key gaging stations, Upper Colorado Region
(Thousand acre-feet)

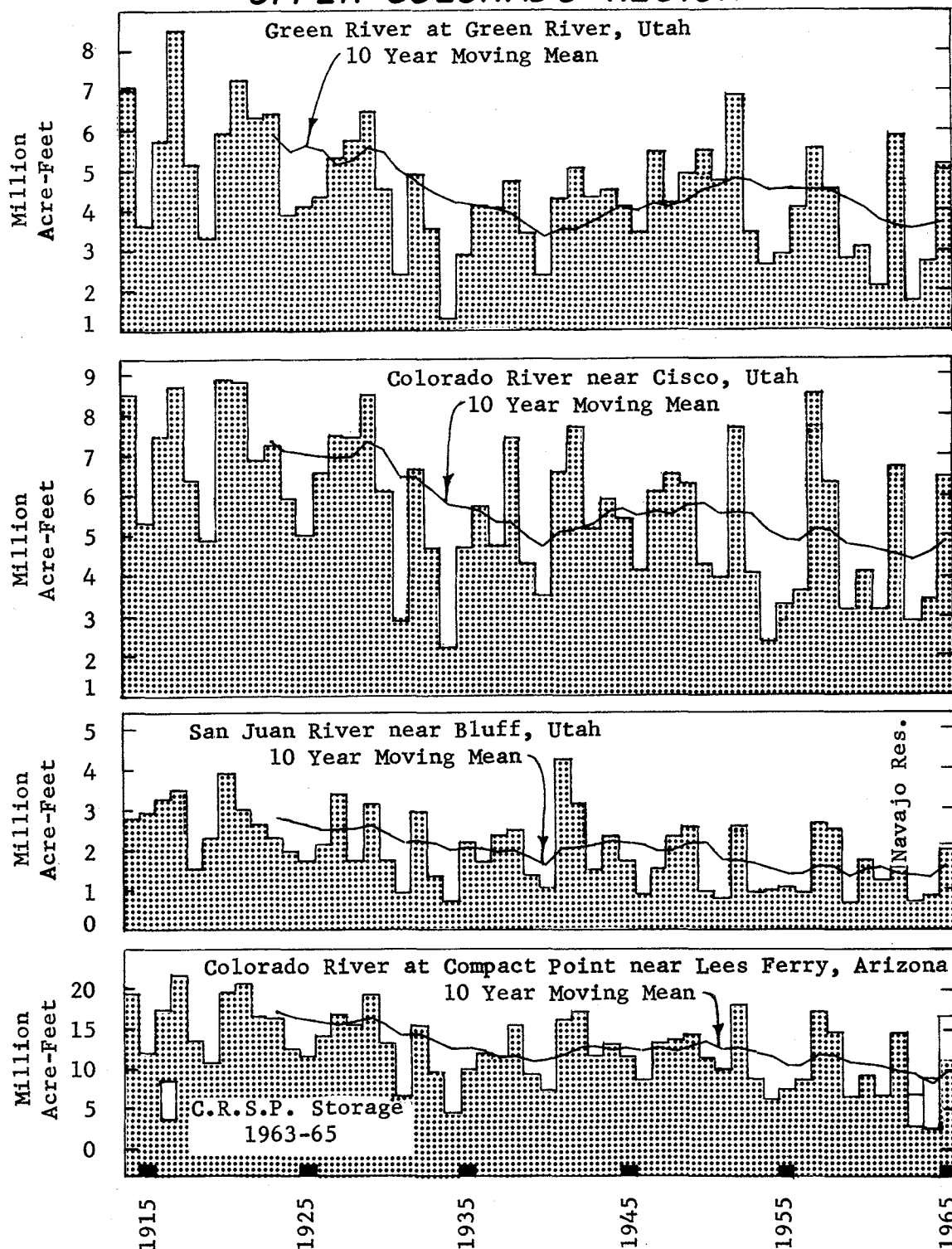
Water year	Green River near Greendale, Utah	Little Snake River near Lilly, Colo.	Yampa River near Maybell, Colo.	White River near Watson, Utah	Green River at Green River, Utah	San Rafael River near Green River, Utah	Gunnison River near Grand Junction, Colo.	Colorado River near Colorado-Utah State line	Colorado River near Cisco, Utah	San Juan River at Shiprock, N. Mex.	San Juan River near Bluff, Utah	Colorado River at Lees Ferry, Ariz.	Paria River at Lees Ferry, Ariz.	Colorado River at Lee Ferry, Ariz. (compact point)
1914	*2,580	*604	*1,480	*567	7,082	264	*2,963	*7,727	8,527	*2,690	2,795	*19,300	*31	*19,331
15	*1,259	*370	*921	*380	3,615	100	*1,701	*4,452	5,348	*2,722	2,919	*12,490	*15	*12,505
16	*2,226	*467	*1,232	*616	5,744	182	*2,563	*6,531	7,504	*3,116	3,238	*17,290	*39	*17,329
17	*2,532	*703	2,135	*726	8,433	317	2,850	*7,789	8,769	*3,364	3,435	*21,860	*34	*21,894
18	*2,154	*445	1,289	*597	5,104	126	2,024	*6,057	6,396	*1,450	1,512	*13,620	*30	*13,650
19	*947	*497	958	*474	3,226	*100	1,677	*4,366	4,874	*2,246	2,302	*10,840	*17	*10,857
1920	*1,876	*740	1,574	*664	5,947	*180	3,026	*7,986	8,900	*3,806	3,909	*19,720	*20	*19,740
21	*2,216	*691	1,802	*857	7,206	*300	2,758	*8,004	8,896	*2,863	2,971	*20,690	*24	*20,714
22	*2,279	459	1,126	*591	6,248	*270	2,308	*6,101	6,880	*2,581	2,612	16,280	*27	*16,307
23	*2,106	461	1,408	*610	6,345	*190	2,408	*6,509	7,273	*2,152	2,237	16,240	*25	*16,265
24	*1,452	391	952	474	3,826	*45	1,997	*5,334	5,932	*1,893	1,971	12,460	19	12,479
1925	*1,603	412	997	540	4,052	*52	1,724	*4,525	5,025	*1,675	1,756	11,311	30	11,341
26	*1,313	551	1,140	669	4,382	*62	1,994	*5,908	6,601	*2,068	2,168	13,980	32	14,012
27	*1,753	547	1,341	552	5,225	*100	2,433	*6,743	7,547	*3,128	3,337	16,540	46	16,586
28	*1,759	598	1,510	696	5,759	*120	2,473	*6,735	7,492	1,610	1,726	15,310	16	15,326
29	*1,688	878	2,025	1,257	6,464	*130	3,069	*7,586	8,511	2,749	3,102	19,190	35	19,225
1930	*1,825	295	1,064	605	4,554	*69	2,100	*5,437	6,097	1,545	1,724	13,050	19	13,069
31	*749	438	828	366	2,391	*29	787	*2,650	2,865	981	888	6,376	11	6,387
32	*1,486	758	1,388	595	4,822	*76	2,259	*5,989	6,687	3,006	2,948	15,250	38	15,288
33	*1,159	538	1,061	537	3,525	*84	1,467	*4,264	4,631	1,300	1,242	9,729	17	9,746
34	*468	80	375	281	1,306	*13	607	*2,045	2,220	676	662	4,377	19	4,396
1935	*1,006	242	878	402	2,850	*94	1,387	*4,295	4,681	2,389	2,183	9,895	17	9,912
36	*1,807	356	1,144	472	4,147	*140	1,753	*5,320	5,766	1,743	1,631	11,930	35	11,965
37	*1,496	487	940	392	4,134	*100	1,496	*3,912	4,664	2,270	2,336	11,870	27	11,897
38	*1,672	480	1,228	599	4,747	*94	2,454	*6,604	7,422	2,483	2,466	15,410	26	15,436
39	*1,241	303	930	448	3,420	*61	1,403	*4,019	4,252	1,199	1,239	9,360	34	9,394
1940	*621	260	847	388	2,376	*72	1,053	*2,914	3,463	910	998	7,055	26	7,081
41	*1,388	395	990	552	4,242	*140	2,295	*5,278	6,576	3,855	4,242	16,020	28	16,048
42	*1,579	461	1,189	688	4,990	*150	2,896	*6,697	7,706	2,791	3,078	17,010	20	17,030
43	*2,040	340	905	436	4,270	*68	1,761	*4,571	5,137	1,319	1,445	11,240	19	11,259
44	*1,661	391	851	446	4,476	*160	2,237	*4,939	5,903	2,111	2,289	13,200	19	13,219
1945	*1,427	479	1,243	499	4,159	*84	1,804	*4,751	5,407	1,462	1,620	11,530	16	11,546
46	*1,529	324	856	394	3,469	67	1,278	*3,750	4,062	812	865	8,722	23	8,745
47	*2,416	467	1,310	569	5,484	112	1,849	*5,632	6,051	1,382	1,488	13,490	23	13,513
48	*1,566	285	1,183	528	4,148	67	2,445	*5,806	6,554	2,211	2,319	13,670	19	13,689
49	*1,506	536	1,322	537	4,897	131	2,119	*5,445	6,287	2,321	2,523	14,340	20	14,360
1950	*2,579	442	952	447	5,511	55	1,387	*3,834	4,236	960	902	11,040	13	11,053
51	2,336	295	1,016	468	4,722	68	1,127	*3,951	3,921	668	668	9,817	14	9,831
52	2,226	728	1,447	694	6,838	315	2,625	6,847	7,707	2,482	2,542	17,960	19	17,979
53	1,288	269	829	476	3,395	81	1,331	3,773	4,037	873	935	8,787	18	8,805
54	1,251	178	522	341	2,618	41	664	2,086	2,329	943	985	6,101	16	6,117
1955	1,002	233	773	388	2,839	32	1,032	2,903	3,241	956	989	7,290	18	7,308
56	1,895	411	1,033	419	4,056	34	1,113	3,345	3,604	860	862	8,740	10	8,750
57	1,938	508	1,781	728	5,501	155	3,208	7,525	8,486	2,500	2,597	17,320	17	17,337
58	1,383	425	1,268	595	4,466	201	2,383	5,425	6,354	2,363	2,551	14,220	39	14,259
59	1,141	216	814	416	2,755	24	951	2,975	3,111	624	618	6,742	14	6,756
1960	998	300	1,010	401	3,019	38	1,390	3,749	4,132	1,697	1,690	9,182	11	9,193
61	747	163	629	346	2,026	51	1,015	2,760	3,084	1,183	1,188	6,643	31	6,674
62	2,113	569	1,492	668	5,829	113	2,194	6,196	6,696	1,442	1,511	14,770	15	14,785
63	167	204	630	337	1,663	50	914	2,585	2,819	508	625	2,500	20	2,520
64	838	318	865	396	2,784	60	1,347	3,112	3,357	694	792	2,414	13	2,427
1965	1,612	480	1,314	566	5,134	174	2,611	5,713	6,403	1,934	2,028	10,820	15	10,835
Average	1,575.0	432.0	1,131.0	532.5	4,427.3	112.3	1,898.2	5,066.4	5,662.0	1,876.3	1,955.0	12,403.7	22.7	12,426.4

* Estimated

SEASONAL DISTRIBUTION OF STREAMFLOW, UPPER COLORADO REGION

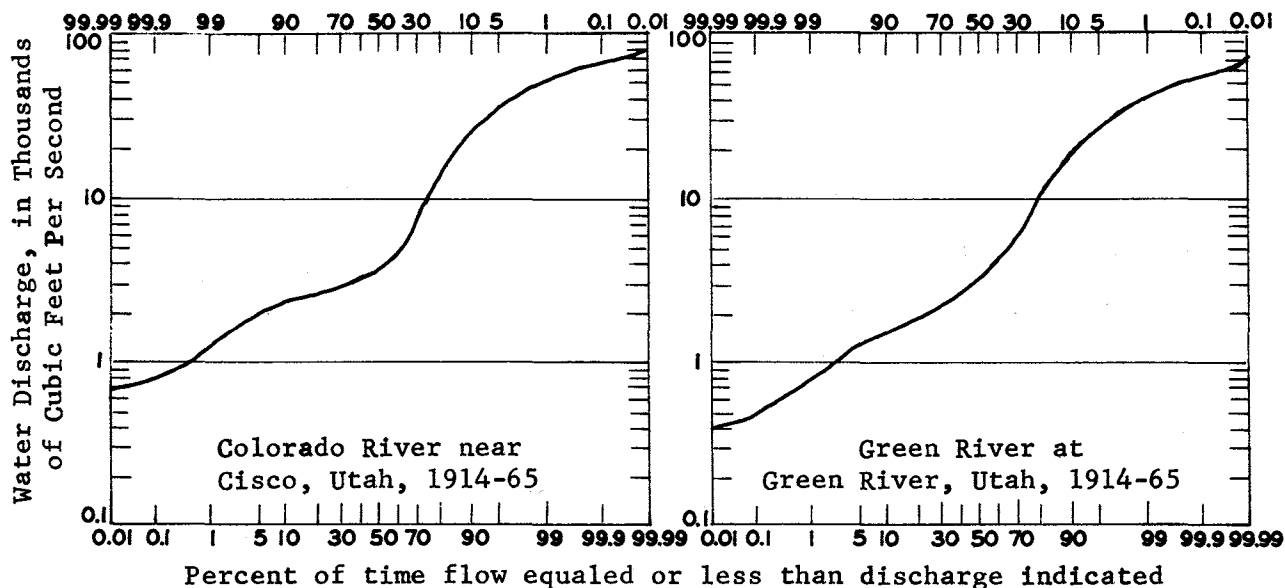


HISTOGRAMS OF ANNUAL STREAMFLOW, UPPER COLORADO REGION

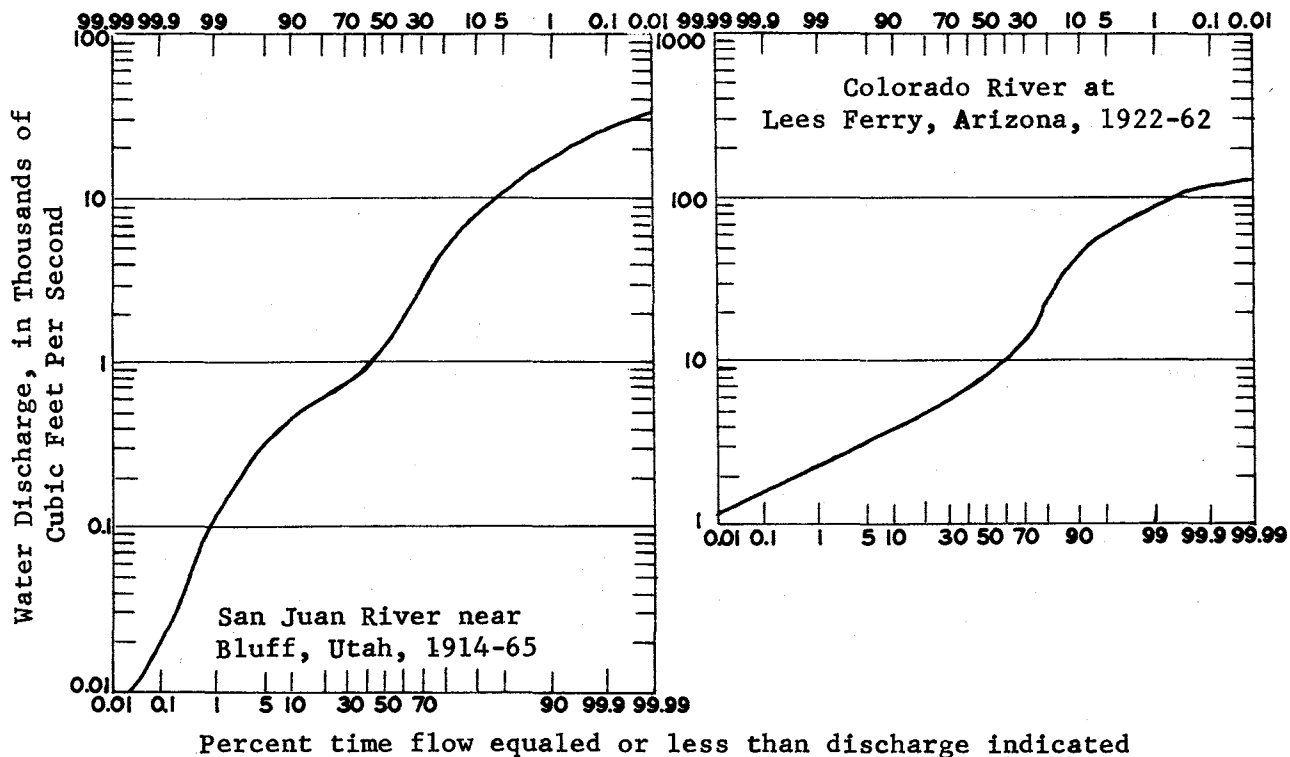


FLOW DURATION CURVES, UPPER COLORADO REGION

Percent of time indicated discharge was equaled or exceeded



Percent of time indicated discharge was equaled or exceeded



PART V

GROUND WATER

Geologic Setting

The rocks exposed range in age from Precambrian to Holocene (Recent). They consist mostly of consolidated and semiconsolidated continental and marine sedimentary rocks, but also include igneous and metamorphic rocks and unconsolidated alluvial and lacustrine deposits.

The rocks are grouped into eight major geologic groups based on age and general hydrologic properties. The geologic formations that are represented in these groups are listed and the extent and general description are shown in U. S. Geological Survey Professional Paper 441, plates 1-3. Groups 2 (mostly shale, siltstone, and fine-grained sandstone) and 4 (mostly sandstone with interbeds of mudstone and conglomerate) are the most widely exposed in the region. They crop out over about 62,000 square miles or about 56 percent of the region. Groups 1 (unconsolidated deposits) and 7 (volcanic rocks) are the least widely exposed, covering about 4,800 square miles or only about 4 percent of the region.

The rocks have been complexly folded and faulted in the mountainous areas and in some subregions, but they have been relatively undisturbed in a major portion of the Colorado Plateau. In the Colorado Plateau the rocks have been deeply eroded by the Colorado River and its tributaries.

Both the availability and chemical quality of ground water are greatly influenced by the geology. In general, the older consolidated rocks yield water slowly to wells and springs, whereas sand and gravel strata in the younger unconsolidated deposits and some igneous rocks yield water readily. However, even the oldest consolidated rocks, where they have been fractured by structural deformation or honey-combed by solution activity, yield water readily to wells and springs.

Rocks that have their origin in brackish water or marine environments and have low permeability, such as shales and some limestones, siltstone, and sandstones, generally yield water of the poorest chemical quality. Alluvium generally yields water of the best chemical quality, but the ground water in some alluvial aquifers may be highly saline owing to hydrologic interconnections with rocks that normally contain saline water.

General Availability of Ground Water

The general availability of ground water to individual wells is shown on the map on the following page. This map is based in part on records of wells and in part on the geology.

Yields to individual wells generally range from 5 to 50 g.p.m. (gallons per minute) over a major portion of the region. Yields of 50-500 g.p.m. can be expected from wells that tap alluvium along some of the major streams. Most wells along these streams for which records are available have yields nearer the lower limit. In a few local areas, such as the Fremont River Valley and Spanish Valley in southeastern Utah, yields as high as 500 g.p.m. are generally available, and yields of more than 1,000 g.p.m. are possible from properly constructed large-diameter wells. Wells in the upper Fremont River Valley tap aquifers in both the alluvium and igneous rocks. Numerous springs and seeps are scattered throughout the region. They most commonly discharge along faults, geologic contacts, or where stream channels intersect the water table. Most of the individual springs and seeps yield a few g.p.m., some yield more than 100 g.p.m., but only a very few widely scattered springs yield more than 450 g.p.m. The largest springs generally occur near the headwater areas of the larger streams.

Depths to Ground Water Levels

The depth to ground water is a factor affecting general availability and particularly the cost and feasibility of pumping. The following map shows the general depths to water levels. In general, depths to ground water levels are shallowest, generally less than 100 feet below land surface, in much of the Wyoming portion and along the alluvial plains of the main streams that are tributary to the Colorado River in other parts. Levels are deepest, generally more than 500 and locally more than 1,000 feet below land surface, in the Colorado Plateau adjacent to the deeply incised Colorado and San Juan Rivers.

Data in the mountainous areas and high plateaus are inadequate to determine depths to water. Depths to water levels in these areas probably range from only a few feet below land surface along most stream channels to more than 500 feet below land surface near the divides between streams.

Unconfined or artesian conditions in the water-bearing rocks in some subregions cause depths to ground water levels to vary from several hundred feet below land surface to several tens of feet above land surface at the same locality. For example, in parts of the San

Juan River basin in the Four Corners area and in the Uinta Basin, the depth to water in wells that tap unconfined aquifers exceeds 300 feet, whereas nearby wells that tap deeper confined aquifers flow at the surface.

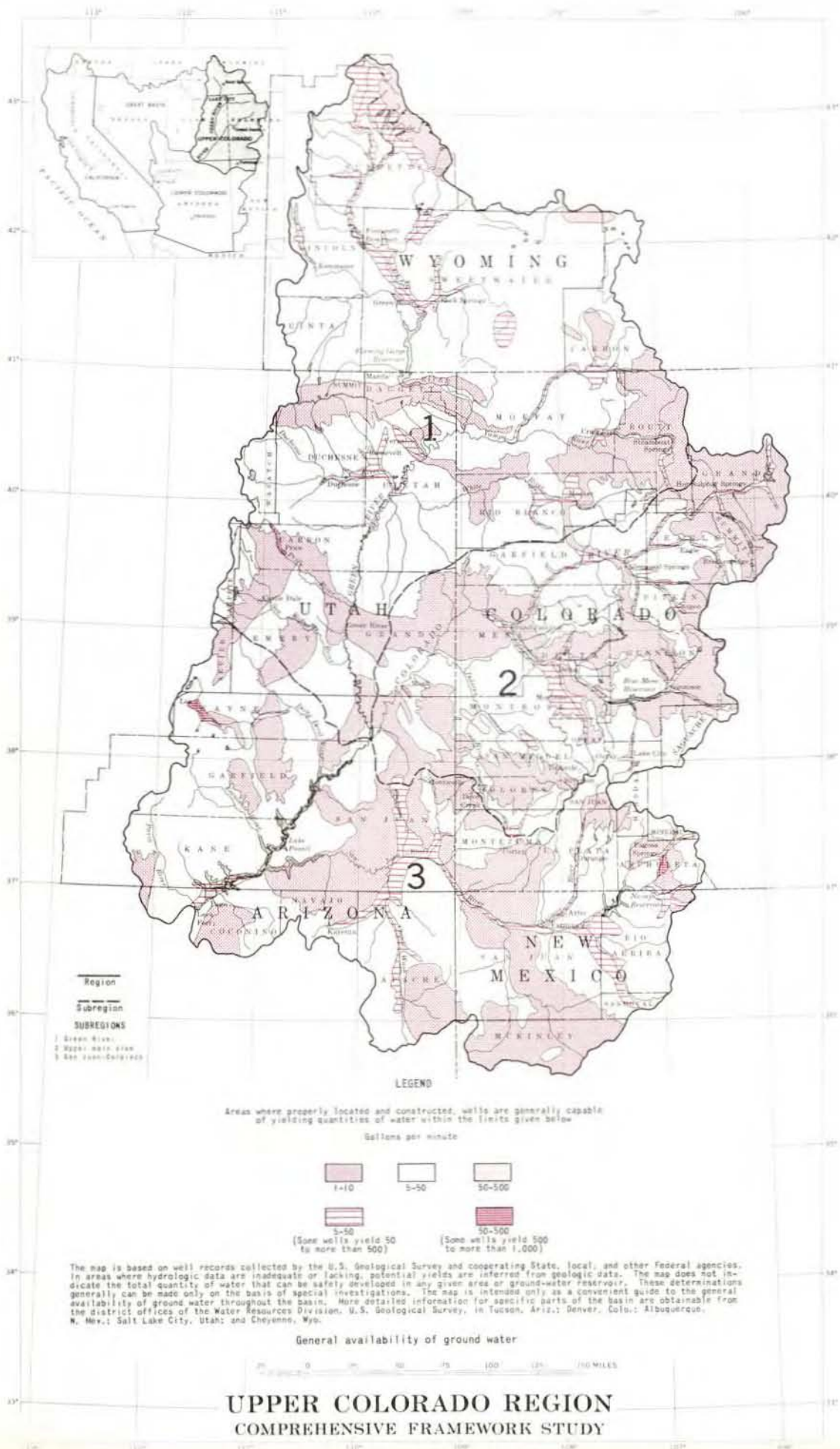
Water Level Fluctuations

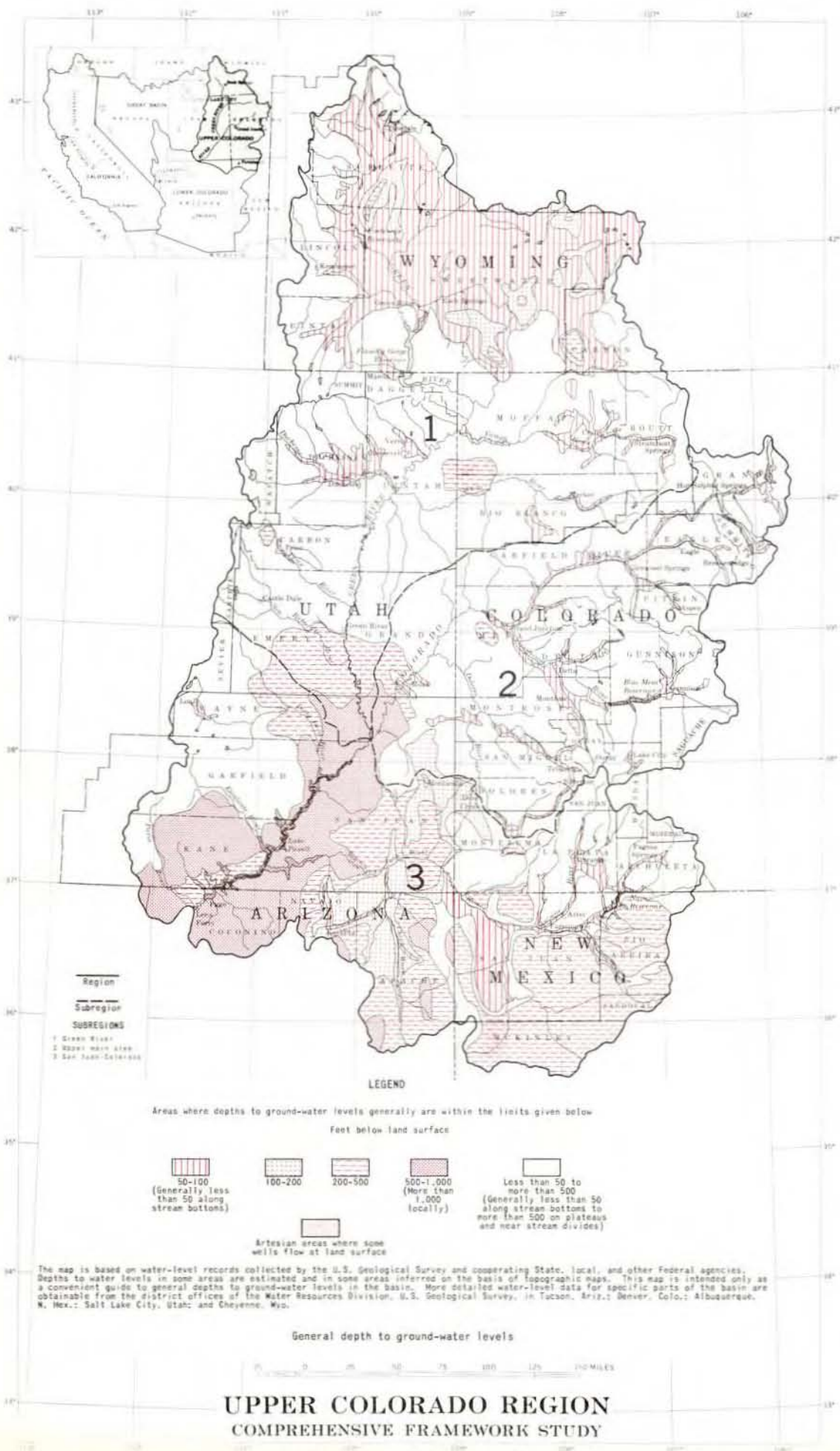
Changes in ground water storage owing to changes in natural recharge and discharge and to pumping cause fluctuations of water levels. Rising water levels usually indicate increases in ground water storage and declining water levels usually indicate decreases in storage. Water level records are not adequate to show in detail long term changes in water levels. The following map shows that changes have occurred locally during the period 1961-65. Net rises of more than 50 feet were recorded near Lake Powell, and similar rises are inferred in the vicinity of other new reservoirs, owing to increased bank storage around the reservoirs.

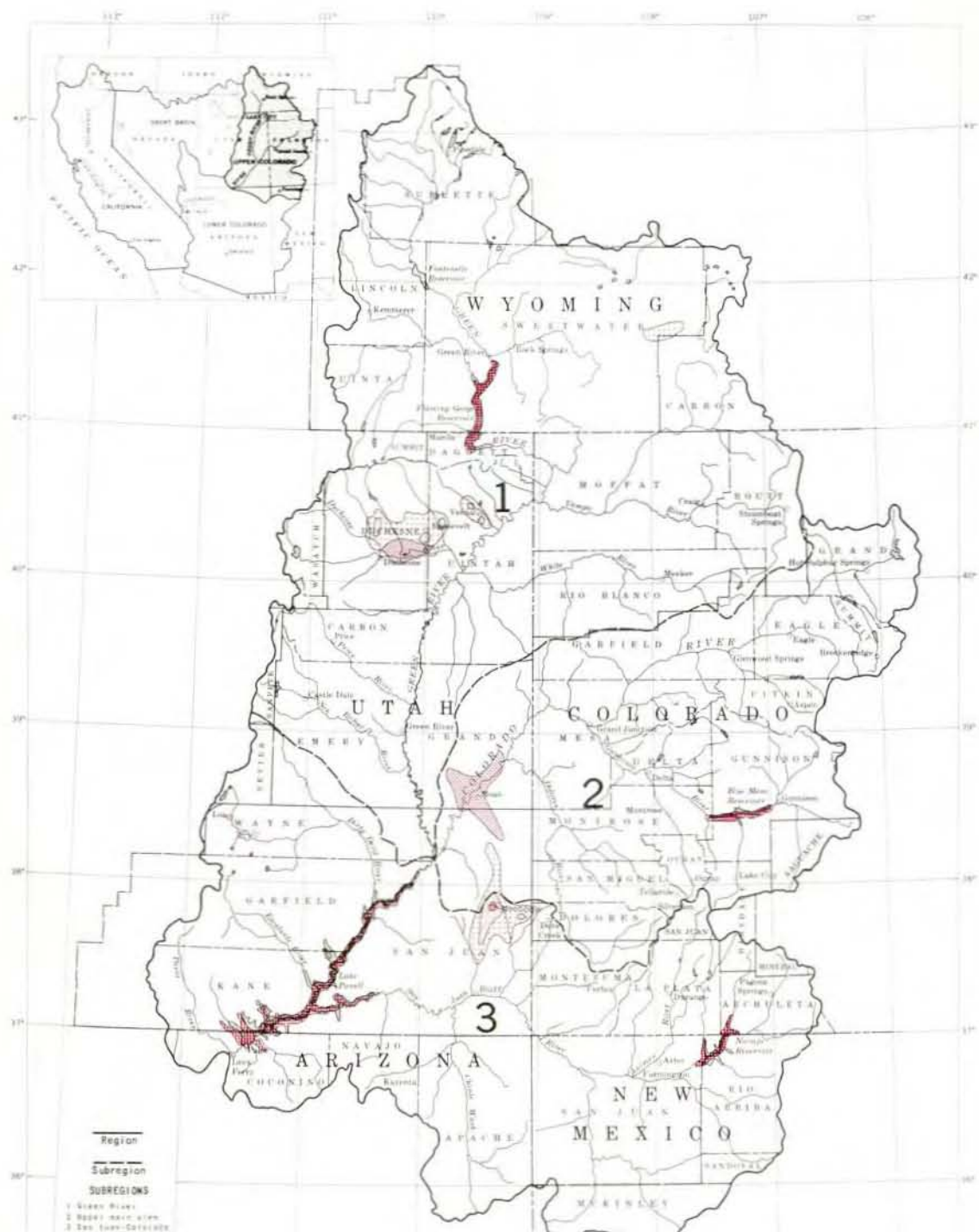
Ground Water Storage

The estimated storage capacity in the upper 100 feet of saturated thickness of aquifers is about 88 million acre-feet, with a range of estimates of 50 to 116 million.

The following map shows the estimated volume of recoverable ground water that is stored in the upper 100 feet of saturated rocks per square mile area; the following tabulation defines the area and total estimated volume of recoverable ground water in these same saturated rocks. Groups 2, 3, 4, 5, 6, and 8 contain the largest volume of recoverable ground water (maximum about 98 million acre-feet) owing to their great extent. However, the water generally is not readily available to individual wells, because the rocks as a whole are poorly permeable and yield the water very slowly. Conversely, groups 1 and 7 contain the smallest volume of recoverable water (maximum about 17 million acre-feet), and the water is generally readily available to individual wells because of the greater permeability of these rocks.





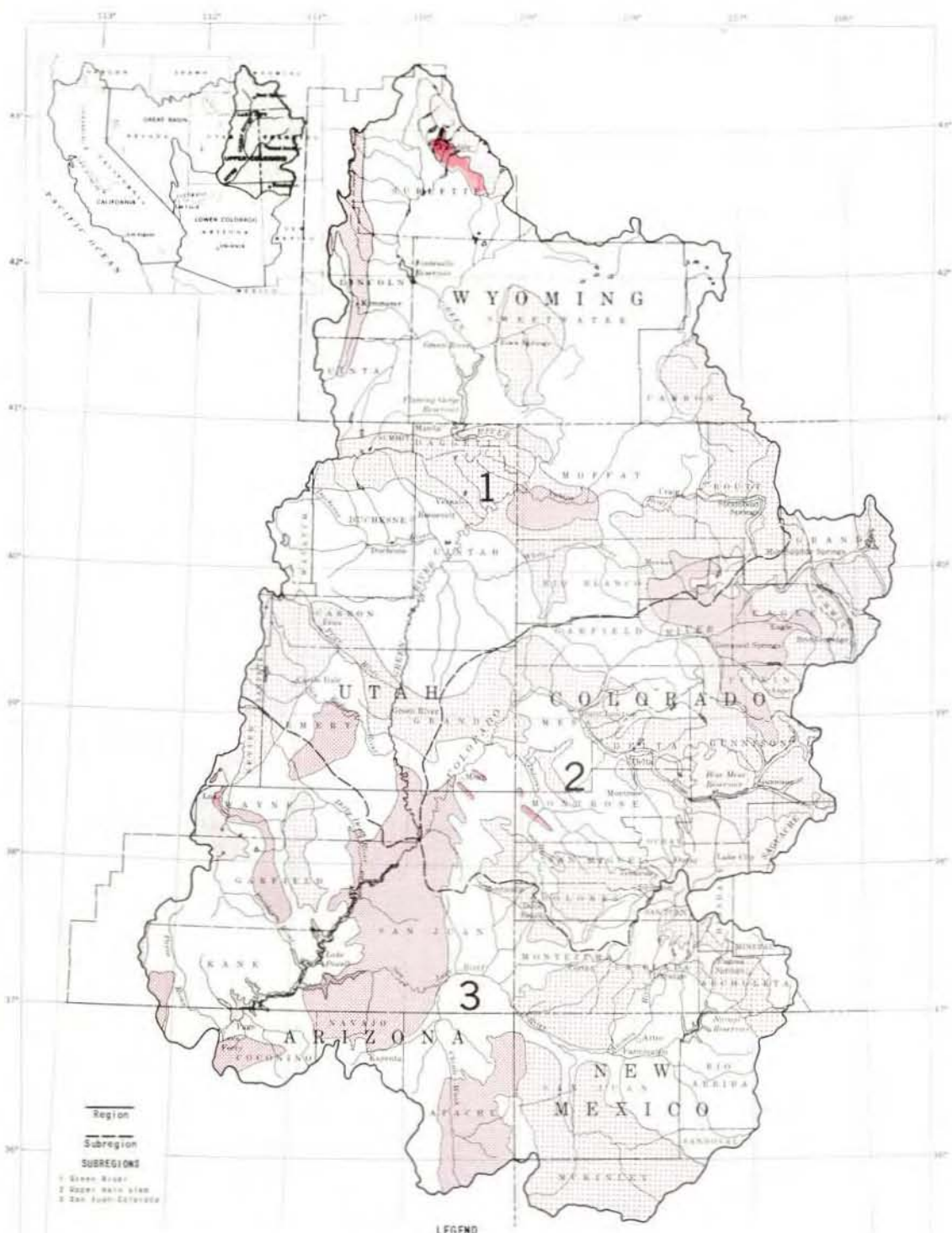


The map was compiled from water-level data collected by the U.S. Geological Survey and cooperating State, local, and other Federal agencies. The data shown are generalized in places, and more detailed data on water-level changes are obtainable from the district offices of the Water Resources Division, U.S. Geological Survey, in Tucson, Ariz.; Denver, Colo.; Albuquerque, N. Mex.; Salt Lake City, Utah; and Cheyenne, Wyo.

Net change in ground-water levels, 1961-65

0 25 50 75 100 125 150 MILES

UPPER COLORADO REGION COMPREHENSIVE FRAMEWORK STUDY



The map is based entirely on estimated specific yields of the various rock types in which water occurs. The figures are intended only as a convenient index to the relative volumes of ultimately recoverable ground water in storage. Where potential recharge is small, the quantity of recoverable water may be less than that shown; where potential recharge is large, the quantity recoverable may be larger than that shown. Also, the map was compiled without regard to chemical quality of ground water. Determinations of quantity and quality of water that can be developed in any given area can be made only on the basis of more detailed investigations. Additional data in some parts of the basin are obtainable from the district offices of the Water Resources Division, U.S. Geological Survey, in Tucson, Ariz.; Denver, Colo.; Albuquerque, N. Mex.; Salt Lake City, Utah; and Cheyenne, Wyo.

Estimated quantity of ground water stored in the upper 100 feet of saturated rocks

0 25 50 75 100 125 150 MILES

UPPER COLORADO REGION COMPREHENSIVE FRAMEWORK STUDY

Estimated storage of recoverable ground water
Upper Colorado Region

Hydro- logic group	Area		Specific yield (percent)	Storage		Water	
	Square miles	1,000 acres		Saturated thickness used (feet)		1,000 acre-feet Minimum	Maximum
1	1,300	830	5-15	50 <u>1/</u>		2,100	6,200
7	3,500	2,240	2-5	100		4,480	11,200
2, 4	62,400	39,930	1-2	100		39,900	79,800
5, 6	12,200	7,812	0.5-1	100		3,900	7,800
3, 8	<u>33,100</u>	<u>21,180</u>	0.0.5	100			<u>10,500</u>
Total	112,500	71,992				50,380	115,500

1/ Saturated thickness less than 100 feet in most parts of the basin.

Utilization of Ground Water

Table 3 shows the estimated average annual volumes of ground water withdrawn and consumed for various uses during the period 1961-65. These estimates are based in part on figures submitted for compilation of U. S. Geological Survey Circular 456, "Estimated Use of Water in the United States, 1960," and in part from preliminary figures submitted for a similar publication of estimated water use in 1965. According to table 3, total volumes of water withdrawn and consumed averaged about 133,000 and 40,000 acre-feet per year, respectively. Most of the water was withdrawn for industrial supply.

Table 3 - Estimated average annual use of ground water,
1961-65, Upper Colorado Region

Use	Units	Arizona	Colorado	New Mexico	Utah	Wyoming	Total (rounded)
Irrigation							
Full	Acres	0	3,000	0	4,000	1,300	8,300
Partial	Acres	0	4,700	0	6,900	1,200	12,800
Withdrawal	Ac-ft	0	18,000	0	22,000	4,600	44,600
Consumptive use	Ac-ft	0	8,600	0	10,700	2,300	21,600
Industrial							
Withdrawal	Ac-ft	12	56,000	340	600	4,400	61,400
Consumptive use	Ac-ft	.6	5,600	310	60	440	6,400
Public supplies							
Persons served	No.	0	29,900	0	41,000		70,900
Withdrawal	Ac-ft	0	11,200	0	13,800	335	25,300
Consumptive use	Ac-ft	0	2,500	0	3,400	85	6,000
Domestic and stock							
Persons served	No.	8,300	83,700	19,000	47,000	19,400	177,400
Withdrawal	Ac-ft	650	9,400	1,600	3,900	1,600	17,200
Consumptive use	Ac-ft	160	2,400	830	975	400	4,800

Effects of Ground Water Withdrawals

Under existing conditions of ground water development, effects of withdrawals are not widespread and are limited for the most part to local interference between discharging wells. However, any large scale development in the region might ultimately cause widespread effects on the water resources regimen. The most significant effects could be an ultimate decrease in streamflow, changes in chemical quality of the ground water, and decrease in natural discharge from shallow aquifers.

A close relation exists between ground and surface water resources. During periods of maximum overland runoff, water moves from stream channels into adjacent aquifers as ground water recharges. Conversely, during periods of minimum overland runoff, ground water moves into stream channels to augment streamflow. Any large scale development of ground water in the basin, therefore, would ultimately result in decreased streamflow. For example, more streamflow would be lost during high runoff periods to replenish depleted ground water supplies, and less ground water would be available to support streamflow during periods of low flow.

In some areas, aquifers containing fresh water are overlain or underlain by aquifers containing saline water. Large withdrawals from the fresh water aquifers would tend to decrease the pressure in those aquifers, thereby inducing recharge from the saline water aquifers and ultimately causing deterioration of the fresh water aquifer.

Large increases in ground water withdrawals may reduce consumptive use by nonbeneficial vegetation. Phreatophytes grow unchecked in many parts of the region, particularly in alluvial plains. If increased pumping resulted in a significant lowering or fluctuating of water levels in the root zones of phreatophytes, consumptive use by these nonbeneficial plants would be greatly reduced.

PART VI

STREAM MANAGEMENT

Impoundments

A total of 581 reservoirs, having capacities ranging upward from a minimum of about 50 acre-feet, have been constructed by Federal and non-Federal entities to provide storage regulation for the various water uses. This number includes Flaming Gorge Reservoir on the Upper Green River, Navajo Reservoir on the Upper San Juan River, and Lake Powell on the Colorado River that were constructed as features of the Colorado River Storage Project. The number does not include some 22,000 man-made stock ponds that have been constructed to provide drinking water for livestock. Exclusive of fish and wildlife and municipal and industrial reservoirs, the reservoirs have a total active capacity of 29,705,800 acre-feet.

Reservoirs constructed as of 1965,
Upper Colorado Region

Type of Reservoir	Number	Active Capacity
		<u>Acre-feet</u>
Irrigation		
Federal	18 2/3 <u>1/</u>	2,023,300
Non-Federal	<u>290</u>	<u>751,600</u>
Subtotal	308 2/3	2,774,900
Fish and Wildlife	232	-
Municipal and Industrial	30	-
Main Stem Regulation	2	25,748,900
Export Regulating and Exchange	<u>8 1/3 <u>1/</u></u>	<u>1,182,000</u>
Total	581	29,705,800

1/ 2/3 of storage in Green Mountain Reservoir for irrigation;
1/3 of storage for exchange.

Release Patterns

Operating criteria have been developed to fit the needs and functions of the individual reservoirs based on full recognition of water rights priorities and other legal restraints affecting the availability of water for storage. Water, stored during the nonirrigation season and during the snowmelt-runoff period when water is surplus to needs, is released to supply specific uses in accordance with established demand patterns. Irrigation demands are usually first met by direct diversion of available natural streamflows. As the streamflows diminish in the late summer, storage water is released as needed to supplement the natural flows in meeting the irrigation demand. Reservoir releases for irrigation usually begin in July and end in September or October. Reservoirs operated to supply municipal and industrial water are operated to supplement natural streamflows available under direct flow rights in much the same way as for irrigation. Reservoirs for fish and wildlife and recreation are maintained at full stage as nearly as possible. Operations for flood control are based on progressive runoff forecasts that predict the magnitude of the seasonal flood runoff. Using the forecasts as a guide, reservoirs being operated for flood control on a joint use basis are drawn down to provide the necessary storage space to control the predicted flood flows. The coordinated flood control and filling operation is designed with the objective of filling the reservoirs by the end of the high runoff season. Provisions for inviolate flood control capacity has not been found necessary in any of the region reservoirs.

Constraints

The water codes of the various states within the region, together with several legal documents of interstate and international significance, are commonly referred to as the "Law of the River."

Discussions on the state water codes, compacts, and treaties are contained in Appendix III, "Legal and Institutional Environments."

Main Stem River Regulation

A further modification is being effected by the main stem regulatory facilities of the Colorado River Storage Project. In the process of Main Stem regulation, evaporation from these reservoirs becomes an additional depletion, the magnitude of which is dependent upon the fluctuation of the regulatory facilities as they store and release water to meet the Colorado River Compact obligations.

Initial Filling Criteria

The Secretary of the Department of Interior has been operating the regulatory facilities under his initial filling criteria published in the Federal Register on July 19, 1962 (27 F.R. 6851). Inasmuch as long-range operating criteria have, for all practical purposes, now replaced the initial filling criteria, detail discussion will be reserved for the long-term operating criteria.

Long-Range Operating Criteria

Public Law 90-537, The Colorado River Basin Project Act, required the Secretary to adopt criteria for long-range operations under guidelines set forth in the Act not later than July 1, 1970. On June 9, 1970, there were published in the Federal Register "Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs."

In promulgating the long-range criteria the Secretary, over the objection of Upper Colorado Basin interests, retained from the original filling criteria charges against the Upper Basin for deficiencies in generation of firm power at the Hoover Powerplant incident to the initial filling of the Upper Basin storage reservoirs. At the option of the Secretary, the deficiency charges are to be met by either energy generated at the Upper Basin powerplants or energy purchased from funds out of the Upper Basin Account. The Secretary has indicated that, since all Upper Basin power is now covered by contract, future deficiencies will be supplied from power purchased with funds from the Upper Basin Account. P.L. 90-537 provides that such funds be replaced at the rate of \$500,000 per year from the Colorado River Development Fund supplied by Hoover powerplant revenues and any amounts unpaid after 1987 be taken from the Lower Basin Account. There are no provisions for reimbursement for energy generated at the Upper Basin powerplants for the deficiency purposes.

The long-range criteria provide the guidelines and regulations for coordinated operations for various purposes of the reservoirs of the Colorado River Storage Project in the Upper Basin and Lake Mead in the Lower Basin. Such operations are to be administered consistent with applicable Federal laws, the Mexican Water Treaty, interstate compacts and decrees relating to the use of the waters of the Colorado River. A formal review of the operating criteria will be made by the Secretary at least every five years with the states participating. Annual reports on past and contemplated annual operations are to be transmitted to the Congress and the Governors of the Colorado River Basin States.

Of particular importance to the Upper Basin interests is the provision that sufficient water is to be retained in storage in the Upper Basin reservoirs to assure delivery of water at Lee Ferry as required by the Colorado River Compact without impairment of Upper Basin consumptive uses. Such storage, in the amounts to be determined annually by the Secretary, constitutes the first call on the waters produced above Lee Ferry. Next, Lake Powell is to acquire the same amount of active storage as found concurrently at Lake Mead. During these two conditions the objective shall be to maintain a minimum release of water from Lake Powell of 8.23 million acre-feet per year. However, in order to meet the Compact Lee Ferry requirements of 75,000,000 acre-feet for the 10-year period ending September 30, 1972, there is recognized the need for releases greater than 8.23 million acre-feet in the years ending September 30, 1971 and 1972. This is due to the small releases at Glen Canyon Dam following closure in 1963.

When Lake Powell has retained the same amount of water as found concurrently in Lake Mead, releases greater than 8.23 million acre-feet annually are to be made from Lake Powell (a) to the extent they can be applied to downstream consumptive uses, (b) to maintain equal storage in Lake Powell and Lake Mead, and (c) to avoid spilling Lake Powell. All such releases shall be through the Glen Canyon powerplant and, when necessary, adjustments in requirements (a), (b), and (c) above are permissible to avoid a bypass of water around the Glen Canyon powerplant.

A disclaimer is included in the criteria as to the magnitude of the specified releases with respect to the actual requirements of the Compact.

The criteria also furnishes guidelines for the operation of Lake Mead, many of which have little or no effect upon the Upper Basin. However, the principle of equal opportunity for storage in Lake Powell and Lake Mead has the effect of sharing draw down at both reservoirs in meeting out storage water for downstream consumptive uses. Thus Upper Basin interests are particularly concerned with any buildup of excessive uses or wastes in the Lower Basin.

PART VII

NEED FOR ADDITIONAL HYDROLOGIC DATA

Stream Gaging

The hydrologic data collection networks generally are adequate to meet the needs associated with water resource development in the area. Systematic collection of streamflow data began in 1894 with the establishment of gaging stations on Colorado and Gunnison Rivers at Grand Junction, Colorado; Green River at Green River, Utah; and Price River at Wellington, Utah. Stream gaging expanded slowly, and by 1911 records were being obtained at 116 sites. The number of stations decreased between 1911 and 1929. In the latter year the Congress adopted a program of cooperation on a 50/50 basis with the states for stream gaging by the Geological Survey. This cooperative arrangement, coupled by the serious droughts of the 1930's and the needs of the Bureau of Reclamation for more streamflow data gave impetus to the stream gaging program. The number of stream gaging stations in the region currently being operated is about 322. In addition gages are maintained at 40 of the over 100 large reservoirs (over 1,000 acre-feet) to record stage fluctuations.

Water Quality Sampling

Systematic collection of chemical-quality data began in 1928-29 when chemical quality stations were established on Colorado River near Cisco, Utah, on Green River at Green River, Utah, and on San Juan River near Bluff, Utah. At the present time water quality is being monitored daily at about 139 stations. In addition to the daily records of chemical quality, chemical analyses are available for more than 850 miscellaneous sites, most of which are at, or near stream gaging stations.

Sediment Sampling

The collection of suspended sediment data was initiated in 1905 at five sites but discontinued after 1906. It was not resumed until 1929, when daily samples were taken on the Green River at Green River, Utah, San Juan River near Bluff, Utah, and Colorado River at Lees Ferry, Arizona. Between 1948 and 1951 the number of daily suspended sediment sampling stations was greatly increased and by 1957 daily suspended sediment data had been obtained at 21 sites. At the present time daily suspended sediment data is being obtained at 13 sites and suspended-sediment samples are being collected periodically at about 200 other sites.

Climatological Data

Climatological data are currently being collected at 235 stations. The types of data collected at these stations are as follows:

<u>Type of Data</u>	<u>No. of Stations</u>
Precipitation only - nonrecording	20
Precipitation only - recording	4
Precipitation only - storage	53
Precipitation and temperature - nonrecording	105
Precipitation and temperature - recording	0
Precipitation and temperature - both types	20
Precipitation, temperature, evaporation - nonrecording	16
Precipitation, temperature, evaporation - recording	0
Precipitation, temperature, evaporation - both types	6
More detailed meteorological data	11
Snow water content - snow courses	176
snow pillows - recording	11
aerials	21
Soil moisture units	26
Streamflow forecasts	56



Snow surveys for water supply forecasting

General Conclusion

In general it appears that the hydrologic and meteorologic data collection network in the Upper Colorado Region has been adequate for operation of large reservoirs and making broad studies. Current demands for additional data will require a large expansion. The number of stations may remain almost constant. Some new ones may be added, but some older stations may be dropped. The expansion will be in amount of data collected. There is a particular need for a hydrologic network applicable to small drainages.

Demands for additional real time reporting of all hydrometeorological data collection will be required for flood control, power generation, avalanche control, municipal water control and many other water oriented fields.

PART VIII

TECHNOLOGICAL ADVANCEMENTS

Introduction

The following are brief summaries of several potential advancements which may occur in the foreseeable future in the fields of water management techniques and water supply augmentation prepared from materials furnished by various experts in each field under the direction of the Pacific Southwest Inter-Agency Committee. Most of these potential advancements are of a relatively unproven nature, requiring more research and understanding before concluding their feasibility.

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 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 satellite 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 it is needed, coupled with the use of computers to rapidly evaluate and correlate this data, promises many improvements in the field of hydrometeorological forecasting.

Desalination

Desalination, whereby sea water or brackish inland water is converted to fresh water, shows promise of becoming a major source of fresh-water supply. The basic methods of desalination have long been

known; the problem is to produce large quantities of fresh water at a cost that is competitive with that for water obtained from conventional sources.

Recent investigations have indicated that in large plants (50 million gallons daily or more) the water cost would be around 30 cents per thousand gallons. That cost is competitive in some areas for domestic and industrial use but it is far beyond the economics of a supply for irrigation operations, where prices generally range from 5 to 10 cents per thousand gallons. Future cost reductions depend upon improving existing processes and design, finding better and cheaper materials for construction, obtaining further economies by building larger plants, and selling by-products in the form of heat, energy, and chemicals.

The Bureau of Reclamation recently completed a report exploring 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. The Upper Colorado Region could benefit from coastal desalination plants by water exchanges in the river system.

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 may reduce costs to a point where such operations would be justified for municipal and industrial uses.

Flow Measurement Techniques

Instrumentation in hydrology has developed greatly within the past few decades. Electronic circuitry is being adapted to replace mechanical equipment for measuring stages and velocities. Such devices as the optical current meter (for reading very high surface velocities without physical contact with the water) and the sonic velocity meter (for continuous recording of average velocity on a cross-channel line) help us gather streamflow data that has been difficult or impossible to collect. Equipment to measure tracer materials can help to determine the diffusing and mixing properties of waterways and to measure the rate of movement of delimited masses of water. Unmanned installations (quality of water monitoring stations) that can sample streamflow and record the concentration of sediment and of many solutes are being operated at sites of special interest. Such equipment must be improved and brought into more general use.

Laboratory studies of the use of dam crests, bridge constrictions and other waterway structures as measuring devices have been made, but more such studies are needed. There is also great need for sensors of water level, water depth, and streamflow that can operate without direct contact with the water itself, in order to reduce vulnerability to damage.

Techniques and equipment for determining the directions and rates of underground flow are as yet poorly developed, and the changes in chemical quality of water during its residence underground are as yet inadequately understood. There may be advances in the use of tracer substances to determine the nature of underground flow, and there is need for more complete metering of withdrawals from ground water.

Greatly refined measurements of all the surface components of the hydrologic budget are necessary to determine the recharge to ground water. There will undoubtedly be advances in the technology of interpretation of cores and well logs, in seismic exploration, and perhaps in completely new methods of determining the nature of aquifer characteristics. Advancements in these fields (study of the hydrologic budget and study of aquifers), and in the application of methods already known but as yet considered too costly for use in hydrology, together would greatly increase our knowledge of the underground regimen of water.

Development of the electronic digital computer together with automated methods of assembling and recalling data have made possible extensive manipulation of data and examination of postulated inter-relations. These advances have in turn aided in the development of synthetic hydrology, or the modeling of hydrologic systems, wherein simulated records of hydrologic variables can be produced that include known and assumed statistical characteristics of the parent population, thus providing a hypothetical scheme of future behavior that can aid in planning. It is likely that the relative magnitude of unexplained variability remaining in the simulated regimens will decrease, as length of record, refinement and verification (or rejection) of postulated relations, and improved techniques of analysis provide a wider base of knowledge for the processes of synthetic hydrology. The geometry and chemistry of the ground-water system, both as reservoir and as conduit, are extremely complex. The next several decades will undoubtedly see great efforts to define aquifer properties, and both measurements and models of these characteristics will be employed.

Almost certainly, improvements in instrumentation and communication, together with the increasing pressure for optimum water use and for protection from floods and from pollution, will bring about an increase in the demand for "real-time" data. Water management that makes efficient use of such data must rely upon programmed analyses of the hydrologic system to rapidly assess the time, place, and nature of input. It must compare the merits of competitive current needs and evaluate the effect upon the resource itself (including changes in chemical and physical quality as water passes through the various surface and underground components of the system, and changes in location determined by the varied needs of the system). Within the context of these variables, it must evaluate the probabilities of variations that may occur within the input-use-output system. Such management decisions will require an extensive net of sensing devices, registering at some remote central point almost instantaneously; knowledge of the probabilities associated with short-term variations in regional climate and in subregional water needs; knowledge of the effects of each potential use upon the water resource itself, and the capability for rapid comparison of these variables with a pre-selected set of operating rules. These requirements can be met within our present technological competence, but at great expense. The cost of managing a hydrologic system in such a manner may be much less in the future (at least, in proportion to the benefits that can be realized) as the use of the components becomes more general.

Automation will continue to reduce the time required for processing all data. Recently, such devices as digital recorders (in the field) and translators (to introduce the field data into computer storage) have come into wide use. The equipment itself and the methods of data processing are still in their infancy; as maturity approaches, probably in the near future, their promise of great speed and accuracy will be fulfilled.

Techniques that provide region-wide indexes of the rates of flow and the changes in quality of water are constantly being improved. The electronic computer has been prominent in the improvement, but the availability of broader-based and more accurate data has also been and will continue to be important to the development of such techniques. There will probably be need for fewer data collection points, but a broader scope of data from those points.

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 stream-flow 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. Advances are needed in sensors that penetrate below the land surface and in these reservoirs; also in the principles of sedimentation and 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.

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 methods. Potential applications in this capacity are numerous. Another possibility is 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 present disadvantages of the use of nuclear devices is the need for water contamination controls from radioactive materials.

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 relatively large increases in runoff that may be expected 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 improving existing techniques. Of great importance are the legal, environmental, and economic aspects that must be considered before large-scale modification of precipitation may be relied upon as an additional water source.

Watershed Treatment

Research conducted in the United States over the last 60 years has amply demonstrated that various land management activities and watershed treatment measures can affect rates of soil loss, debris-sediment content in streams, total water yields, timing of waterflows, and water quality. The type and degree of change following a specific activity or treatment on any given area is a function of climate, geology, soils, topography, vegetation, and other factors of the environment.

Manipulation of vegetative cover and other water yield improvement techniques can result in increased streamflow without damage to the watershed or to areas downstream if the activity is carefully planned and executed as a part of a coordinated land and resource management program. The danger lies in proceeding too fast with too little knowledge of the intricate plant-soil-water and other environmental relationships involved. Ill-conceived, poorly executed programs are likely to cause considerable damage to watershed soils and water quality and add to flood problems. Close coordination between weather modification programs and watershed treatment programs will be essential to minimize any adverse effects of anticipated increases in precipitation.

Harvesting of trees in the spruce-fir, lodgepole pine, white fir-Douglas fir, or aspen vegetation types can result in increased streamflow. Research in the snowpack zone of the commercial timber types has shown that specially designed timber harvest practices can increase water yields from the area treated by significant amounts. These practices, which modify snow accumulation patterns and snowmelt rates, reduce evaporation losses and prolong the snowmelt period. Thus, more of the precipitation is available for streamflow and at a time when it is most needed downstream. Specially designed timber harvest practices can be complementary to weather modification projects by causing more efficient use of the increased precipitation. Without any specially designed treatment, much of the precipitation in the snow zone returns to the atmosphere through evapotranspiration.

Similar opportunities for water yield improvement through vegetation management exist in many areas of noncommercial forest and in brush lands in the Upper Colorado Region. However, the potentials and limitations of each area must be carefully considered. For example, studies in the pinon-juniper vegetation type indicate that type conversion by removal of the pinon-juniper overstory and establishment of a range grass-type does not increase streamflow measurably. Due to a combination of factors including limited precipitation, soil characteristics and associated water-holding capacities, plant rooting depths, and high potential evapotranspiration, the replacement vegetation uses as much water as the pinon-juniper. The principal benefit of such treatment is to utilize available water to better meet the needs of man.

Under certain circumstances, mechanical treatment and revegetation of severely depleted watersheds may result in some decrease in total streamflow due to the reestablishment of riparian vegetation along stabilized stream channels and to the stabilization of revegetation of adjacent slopes. The primary benefits of this activity are the decrease in soil loss and attendant debris and sediment and the modification of extreme high and low water flows. Any reduction in streamflow has to be regarded as the cost, in water, of protection from floods and sedimentation, stabilization of age-old soil and of stream channels, increased range forage, improved wildlife habitat, and protection of fishery and recreation values along the stream.

Snow management in the alpine zone as an operational tool offers promise for improving timing of water yields. Research is actively being pursued in the Rocky Mountains to develop methods for controlling snow accumulation and snowmelt. Current techniques involve installation of snow fences, avalanche control, and application of materials to retard evaporation and control rate of snowmelt.

Efficient Use of Water

In arid areas many ingenious schemes exist and are being investigated for more efficient use of water. Many improvements in irrigation water management can increase production per unit of water used. Technological advancements in more efficient use of water are being made in mining, thermal power production, and industries.

PART IX

PRESENT WATER USE

Summary of Present Water Uses

On-site depletions for 1965 related to man's activities were 3.45 million acre-feet. These depletions represent the average annual uses at the 1965 level of development. Data have been adjusted where necessary to reflect average conditions that may not have occurred in some areas during the year 1965.

It should be specifically noted that these estimates of on-site depletions were made for the purposes of this framework study and are not to be construed as depletions charged to the various states under the provisions of the Colorado River and Upper Colorado compacts. In particular, they are site-located and do not necessarily reflect direct relationships to streamflow diminishment at Lee Ferry.

By far, the largest depletion was by the 1.62 million acres of irrigated crops, associated seeped and incidental phreatophyte areas, and irrigation reservoir evaporation, which is 62 percent of the total or 2.13 million acre-feet. Minor water uses for other purposes were municipal and industrial (0.8 percent), minerals and power (1.6 percent), stockpond and livestock use (1.0 percent), and recreation and augmented fish and wildlife (.4 percent). Over one-half million acre-feet of water was being exported from the region by Colorado and Utah. Evaporation losses from main stem regulating reservoirs for 1965 conditions of normal operation were 643,000 acre-feet.

For flexibility in analysis and planning, the region has been divided into three subregions comprising the natural drainage basins of the Green River, Upper Main Stem, and San Juan-Colorado. The Great Divide Closed Basin is included in the Green River Subregion. Summaries of stream depletions computed for the Upper Colorado Region by types of use for each subregion, and state follow. Respective companion appendices provide the sources and details of this data.

PART IX

PRESENT WATER USE

Table 4 - Water uses by states, 1965, Upper Colorado Region

Type of use	On-site depletions (acre-feet)					Total
	Arizona	Colorado	New Mexico	Utah	Wyoming	
Municipal and industrial	1,500	15,900	2,400	5,000	2,600	27,400
Electric power (thermal)		3,200	15,300	1,300	3,400	23,200
Minerals		16,900	1,600	9,400	5,800	33,700
Fish and wildlife	600	2,700	400	7,900	100	11,700
Recreation		700	100	300	200	1,300
Stockpond evaporation and livestock use	1,100	20,700	2,400	6,200	4,500	34,900
Subtotal	3,200	60,100	22,200	30,100	16,600	132,200
Irrigation						
Consumptive use	4,400	991,300	76,000	404,400	221,200	1,697,300
Incidental use	500	198,700	15,000	81,000	20,400	315,600
Reservoir evaporation	2,000	27,100	31,700	30,200	23,900	114,900
Total irrigation	6,900	1,217,100	122,700	515,600	265,500	2,127,800
Export						
Diversions		417,100		109,500		526,600
Reservoir evaporation		12,300		11,400		23,700
Less water import				(2,600)		(2,600)
Subtotal of all above	10,100	1,706,600	144,900	664,000	282,100	2,807,700
Main-stem reservoir evaporation						643,000 1/
Region total						3,450,700

1/ Flaming Gorge Reservoir (67,000 acre-feet) and Lake Powell (576,000 acre-feet).

Table 5 - Water uses by subregions, 1965, Upper Colorado Region

Type of use	On-site depletions (acre-feet)			Region total
	Green River	Upper Main Stem	San Juan-Colorado	
Municipal and industrial	7,900	12,300	7,200	27,400
Electric power (thermal)	6,300	1,600	15,300	23,200
Minerals	17,200	11,900	4,600	33,700
Fish and wildlife	8,000	1,300	2,400	11,700
Recreation	500	500	300	1,300
Stockpond evaporation and livestock use	13,300	11,200	10,400	34,900
Subtotal	53,200	38,800	40,200	132,200
Irrigation				
Consumptive use	662,400	747,400	287,500	1,697,300
Incidental use	113,600	167,300	34,700	315,600
Reservoir evaporation	42,400	16,900	55,600	114,900
Total irrigation	818,400	931,600	377,800	2,127,800
Export				
Diversions	109,500	414,600	2,500	526,600
Reservoir evaporation	11,400	12,300		23,700
Less water import			(2,600)	(2,600)
Subtotal of all above	992,500	1,397,300	417,900	2,807,700
Main-stem reservoir evaporation	67,000 1/		576,000 2/	643,000
Region total	1,059,500	1,397,300	993,900	3,450,700

1/ Flaming Gorge Reservoir

2/ Lake Powell

Present Uses (1965)

A brief description of present (1965) water uses follows. More detailed coverage on depletions is presented in appropriate appendices for each item.

Municipal and Industrial

Basic municipal, rural household, and industrial use by the 366,000 people in the hydrologic region was 25,100 acre-feet (64 gpcd). Evaporation from 30 municipal reservoirs was 2,300 acre-feet.

Electric Power

The 1965 water depletion by steam-electric generation plants was 23,200 acre-feet. This water was consumed primarily at 13 utility plants and several industrial plants which have a total capacity of about 1.3 million kilowatts. Principal use was for condenser cooling purposes. Water is consumed by once-through systems as well as by cooling-tower, and cooling-pond systems. The losses are due principally to induced evaporation as the temperatures of the heated effluent reaches equilibrium with ambient temperatures. Water is used for hydro-power but is not depleted by its use.

Minerals

Mineral industry water use in 1965 was 33,700 acre-feet. Estimates were computed primarily from the Bureau of Mines' 1962 water canvass and 1962-66 statistics. Depletions represent 39 percent of diversions for mineral industry activities.

Augmented Fish and Wildlife

The combined consumptive use total was 11,700 acre-feet, with 6,700 acre-feet for fish facilities, and 5,000 acre-feet for wildlife facilities. Evaporation from water areas was computed only on those facilities constructed and utilized primarily or specifically for fish and wildlife. Installations and facilities having water use numbered 104 for wildlife and 111 for fish.

Recreation

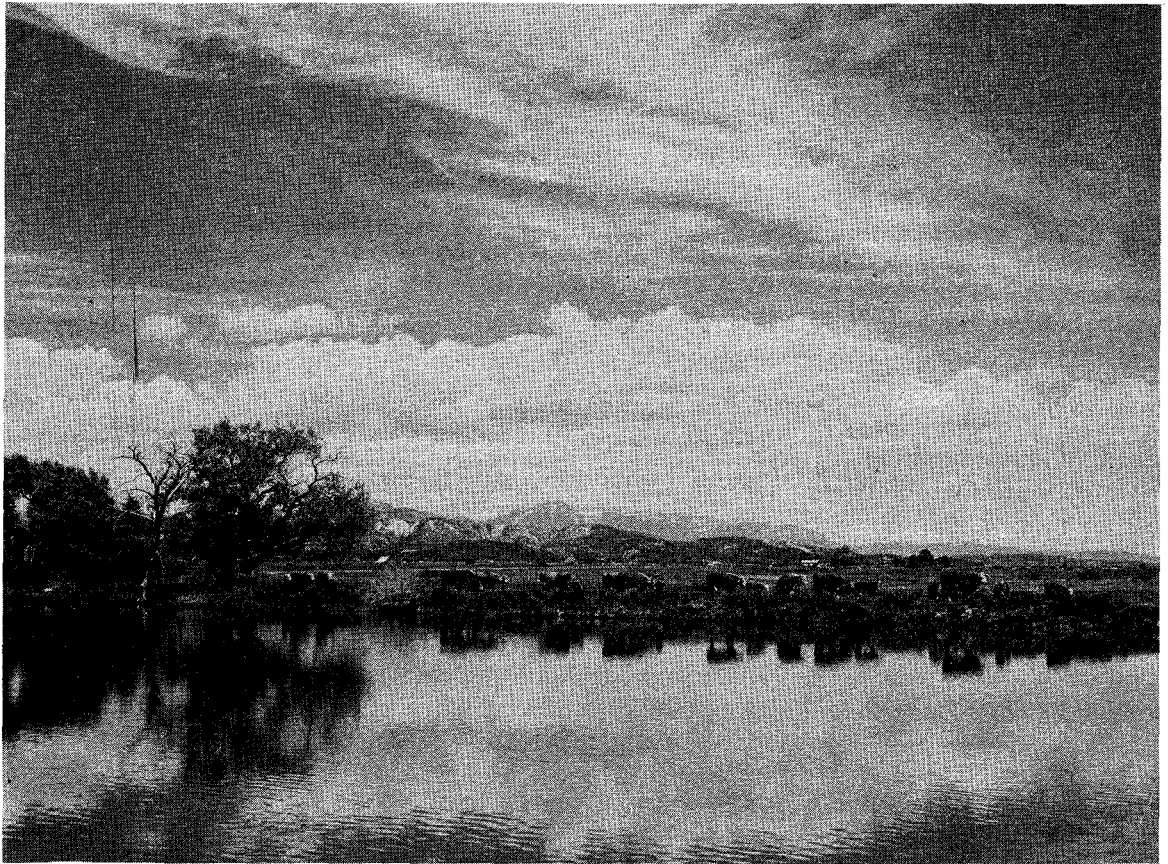
The amount of water consumed for recreation was not of major significance. Most was used at associated service facilities. The computed use is 7.70 gallons per recreation day for 56 million recreation days in the region, or 1,300 acre-feet. No reservoir has recreation as a dominant purpose, excluding fishing and wildlife facilities discussed in the preceding section.



State development for outdoor recreation

Stock Water Facilities and Livestock Use

Average annual evaporation from 22,035 manmade stockponds, used primarily for livestock water, was 23,900 acre-feet. An average annual 64 percent fullness factor (varying from 30 to 87 percent) is considered in computing evaporation on the total water surface area of 14,600 acres. Data on size and number of ponds are based on records of Bureau of Land Management, Forest Service, Bureau of Indian Affairs, and Soil Conservation Service. Livestock use by approximately one million animal units was 11,000 acre-feet.



Irrigation and livestock water pond

Irrigation

Consumptive use on 1,621,500 acres of irrigated crop land was 1.7 million acre-feet for 1965 average conditions. Consumptive use rates were computed utilizing the Blaney-Criddle Method and latest available data on local seasonal crop coefficients. The region was divided into 61 evaluation areas for determining local consumptive irrigation requirements. The studies are based on present average irrigated acreage and cropping pattern data. Consumptive use adjustments were made to reflect present average short water supply on 549,300 acres. Also there were 124,400 acres of idle land in the average year. The 1931-60 normal climatic conditions were defined by utilizing Weather Bureau records at 151 stations.

Incidental use on water-consuming, noncropped areas was charged on those areas which consume water incidental to the cropped lands as a result of the practice of irrigation. Incidental consumptive use was estimated at 315,600 acre-feet or 18.6 percent of the consumptive use by irrigated crops. Incidental water use values for New Mexico and Utah are the figures in the 1948 Upper Colorado River Compact Commission's Advisory Committee Report. Recent survey data from the Wyoming State Water Plan was used for Wyoming. Colorado data are from recent Type IV River Basin Cooperative Studies by the Colorado Water Conservation Board and the U. S. Department of Agriculture. Incidental water use in Arizona was estimated at 10 percent of consumptive irrigation requirement.

Reservoir Evaporation

Evaporation from 309 irrigation reservoirs for 1965 normalized conditions was 138,600 acre-feet. These reservoirs provide 2.77 million acre-feet of usable capacity for regulation of streamflow. The 1965 normalized evaporation on reservoirs is based on operation studies under normal operating conditions. Data have been adjusted where available to reflect average conditions that may not have existed during 1965. On many reservoirs operational data are not available and estimates were made using general relations of supply and demand.

Of the amounts shown above, evaporation from regulating and exchange reservoirs used in connection with export was 23,700 acre-feet. Storage in the 8 1/3 reservoirs used for this purpose was 1,182,200 acre-feet. The fraction shown allows for one-third of the storage of Green Mountain Reservoir for export purposes, the balance of storage is for irrigation.

Evaporation loss from main stem regulating reservoirs (Flaming Gorge, 67,000 acre-feet, and Lake Powell, 576,000 acre-feet) for 1965 normalized conditions was 643,000 acre-feet. It should be noted, however, that these evaporation losses will be charged against the separate States only if curtailment of use is required in the Upper Colorado River Basin to make delivery required by the compact at Lee Ferry. The 1965 normalized evaporation on the reservoirs is based on Bureau of Reclamation operation studies under normal operating conditions.

Imports

Inflow to the region through a transmountain diversion from Sevier River in the Great Basin to Paria River averages 2,600 acre-feet. This represents a credit against local use within this region.

Transmountain Diversions (Exports)

Transmountain diversion records for 39 of the current operative export facilities were analyzed to reflect present average export discharge from the region, recognizing that during any one year many factors in addition to supply and demand affect the diversion discharge. Normalized 1965 discharge by 22 diversions in Colorado is 417,100 acre-feet, and by 17 diversions in Utah is 109,500 acre-feet. Intraregional movement of water from one subregion to another is not included in these figures. Diversions in Utah of 109,500 acre-feet are to the Great Basin. Colorado diversions are: 353,400 acre-feet to the Platte River, 60,600 acre-feet to the Arkansas River, and 3,100 acre-feet to the Rio Grande as shown in tables 6 and 7.

Annual summaries of estimates and recorded diversions for 43 of the 47 facilities in the Upper Colorado Region are contained herein. 1/

-
- 1/ Fremont Pass Ditch - discontinued in 1943
West Hoosier Ditch - discontinued in 1939
East Hoosier Ditch - discontinued in 1940
Jones Pass Tunnel - included in Moffat Water Tunnel in 1959
Monte Cristo Tunnel - included in Hoosier Pass Tunnel
Bemrose Hoosier Diversion - included in Hoosier Pass Tunnel
McCullough Diversion - included in Hoosier Pass Tunnel

1965 to present update: Cheyenne-Laramie Diversion in Green River Subregion was added in 1967.

PART IX

PRESENT WATER USE

Table 6--Index to transmountain diversions gages, location, and records, Upper Colorado Region

Gaging station	Diversions		Records available (water years)	Average annual diversion (ac.-ft.)
	From river basin	To river basin		
Raber-Lohr Ditch at Weminuche Pass, Colo.	San Juan River	Rio Grande	1938-65	1,550
Piedra Pass Ditch at Piedra Pass, Colo.	San Juan River	Rio Grande	1940-65	79.3
Squaw Pass Ditch at Squaw Pass, Colo.	San Juan River	Rio Grande	1938-65	179
Fuchs Ditch at Weminuche Pass, Colo.	San Juan River	Rio Grande	1937-65	528
Treasure Pass Ditch at Wolf Creek Pass, Colo.	San Juan River	Rio Grande	1929-65	152
			*1923-28	(1923-65)
Strawberry Tunnel, West Portal, near Thistle, Utah	Green River	Jordan River	1915-65	62,280
Hobble Creek Ditch near Heber, Utah	Green River	Jordan River	1950-65	910
			*1914-49	(1914-65)
Cedar Creek Tunnel near Spring City, Utah	Green River	Sevier River	1950-58	347
			*1914-49	(1914-65)
			*1959-65	
Black Canyon Ditch near Spring City, Utah	Green River	Sevier River	1950-58	292
			*1914-49	(1914-65)
			*1959-65	
Candland Ditch near Mount Pleasant, Utah	Green River	Sevier River	1950-58	202
			*1914-49	(1914-65)
			*1959-65	
Larson Tunnel near Ephraim, Utah	Green River	Sevier River	1950-58	695
			*1925-49	(1925-65)
			*1959-65	
Twin Creek Tunnel near Mount Pleasant, Utah	Green River	Sevier River	1950-58	225
			*1914-49	(1914-65)
			*1959-65	
Strawberry River and Willow Creek Ditches near Heber, Utah	Green River	Jordan River	1950-65	2,410
			*1914-49	(1914-65)
Spring City Tunnel near Spring City, Utah	Green River	Sevier River	1950-65	2,070
			*1938-49	(1938-65)
Duchesne Tunnel near Kamas, Utah	Green River	Jordan River	1954-65	33,495
Reeder Ditch near Spring City, Utah	Green River	Sevier River	1950-58	245
			*1924-49	(1924-65)
			*1959-65	
Madsen Ditch near Ephraim, Utah	Green River	Sevier River	1940-65	35
			*1914-39	(1914-65)
John August Ditch near Ephraim, Utah	Green River	Sevier River	1940-43	199
			1945-58	(1914-65)
			*1914-39	
			*1944	
			*1959-65	
Fairview Ditch near Fairview, Utah	Green River	Sevier River	1950-65	1,340
			*1914-49	(1914-65)
Horseshoe Tunnel near Ephraim, Utah	Green River	Sevier River	1950-58	603
			*1914-49	(1914-65)
			*1959-65	
Coal Fork Ditch near Mount Pleasant, Utah	Green River	Sevier River	1950-58	264
			*1914-49	(1914-65)
			*1959-65	
Ephraim Tunnel near Ephraim, Utah	Green River	Sevier River	1950-65	3,530
			*1937-49	(1937-65)
Tropic and East Fork Canal near Tropic, Utah (IMPORT)	Sevier River	Paria River	1950-61	2,600
			*1914-49	(1914-65)
			*1962-65	
Larkspur Ditch at Marshall Pass, Colo.	Gunnison River	Arkansas River	1935-65	146
Tabor Ditch at Spring Creek Pass, Colo.	Gunnison River	Rio Grande	1928-65	220
			*1914-27	(1914-65)
Tarbell Ditch near Cochetopa Pass, Colo.	Gunnison River	Rio Grande	1949-65	338
			*1914-48	(1914-65)
Hoosier Pass Tunnel at Hoosier Pass, Colo.	Blue River	Arkansas River	1952-65	7,660
Fremont Pass Ditch at Fremont Pass, Colo. 1/	Blue River	Arkansas River	1928-65	1,320
Boreas Pass Ditch at Boreas Pass, Colo.	Blue River	Platte River	1933-65	155
			*1914-32	(1914-65)
West Hoosier Ditch at Hoosier Pass, Colo. 2/	Blue River	Platte River	1935-39	142
East Hoosier Ditch at Hoosier Pass, Colo. 3/	Blue River	Platte River	1935-40	297
Roberts Tunnel at Grant, Colo.	Blue River	Platte River	1964-66	28,540
Eureka Ditch near Plattop Mountain, Colo.	Tonahutu Creek	Platte River	1940-65	90
Alva B. Adams Tunnel at East Portal, near Estes Park, Colo.	Grand Lake Outlet	Platte River	1947-65	181,280
Berthoud Pass Ditch at Berthoud Pass, Colo.	Frazer River	Platte River	1909-65	611
				(1914-65)
Moffat Water Tunnel at East Portal, Colo.	Frazer River	Platte River	1936-65	37,260
August P. Gumlick Tunnel at East Portal, near Jones Pass, Colo. 4/	Williams Fork River	Platte River	1940-65	5,580
Columbine Ditch near Fremont Pass, Colo.	Eagle River	Arkansas River	1931-65	1,040
Ewing Ditch at Tennessee Pass, Colo.	Eagle River	Arkansas River	1908-65	1,130
				(1914-65)
Wurtz Ditch near Tennessee Pass, Colo.	Eagle River	Arkansas River	1932-65	2,120
Twin Lakes Tunnel at East Portal, near Twin Lakes, Colo.	Roaring Fork River	Arkansas River	1935-65	36,950
Busk-Ivanhoe Tunnel at East Portal, near Malta, Colo.	Roaring Fork River	Arkansas River	1925-65	4,500
Grand River Ditch at La Poudre Pass, Colo.	Colorado River	Platte River	1896-	15,930
			1965	(1914-65)

* Estimated.

1/ Zero discharge since 1943

2/ Discontinued in 1939

3/ Discontinued in 1940

4/ Flow included in Moffat tunnel in 1959

* Estimated.
1/ Import from Sevier River Basin into Colorado River Basin.

PART X

WATER RESOURCES FOR FUTURE DEVELOPMENT

Present Modified Flow

In order to ascertain the amount of water remaining over and above present (1965) uses, there have been reconstructed what are termed present modified flows. The reconstruction of present modified flows was accomplished in each of the three subregions for the study period 1914 to 1965, the premise being that the general hydrologic conditions of that period might reasonably be expected to reoccur in the future.

The 1914-65 study period was selected as the longest period for which reliable records were generally available in the region. The procedure is one of adding to the historic annual flows at the outflow points of each subregion past annual depletions, the result being virgin annual outflows. Then, assuming that all present uses were in effect throughout the 1914-65 period, the present (1965) normalized use in the subregion was deducted from the virgin flow, the result being the present (1965) modified flow. (See "Hydrology," Part II). In each subregion the studies reflect the use of waters produced locally within the subregion. In other words the flows of the Green River and the Colorado River at their confluence are not considered a local inflow to the San Juan-Colorado Subregion. The data from the three subregions can thus be summed up to ascertain the respective results at Lee Ferry, the outlet of the total region. In the study no attempt has been made to account for changes or differences in natural losses, sometimes referred to as "salvage." A considerable amount of such salvage water, however, is accounted for in the computation of reservoir losses in the Main Stem reservoirs.

Water supply available
Upper Colorado Region, in 1965

		Subregion		
	Green River	Upper Main Stem	San Juan-Colorado	Upper Colorado Region
	<u>(1,000 Acre-Feet)</u>			
Virgin Water Supply (1914-65)	5,460	6,806	2,606	14,872
Level of Depletions (1965)	993	1,397	418	2,808
Modified Flow (1914-1965) (excluding Main Stem Evap.)	4,467	5,409	2,188	12,064
Main Stem Reservoir Evapora- tion Normalized (1965)	67		576	643
Residual Flow	4,400	5,409	1,612	11,421

The present annual modified flow studies are summarized in the tables that follow, along with a diagram of the river and major tributaries.

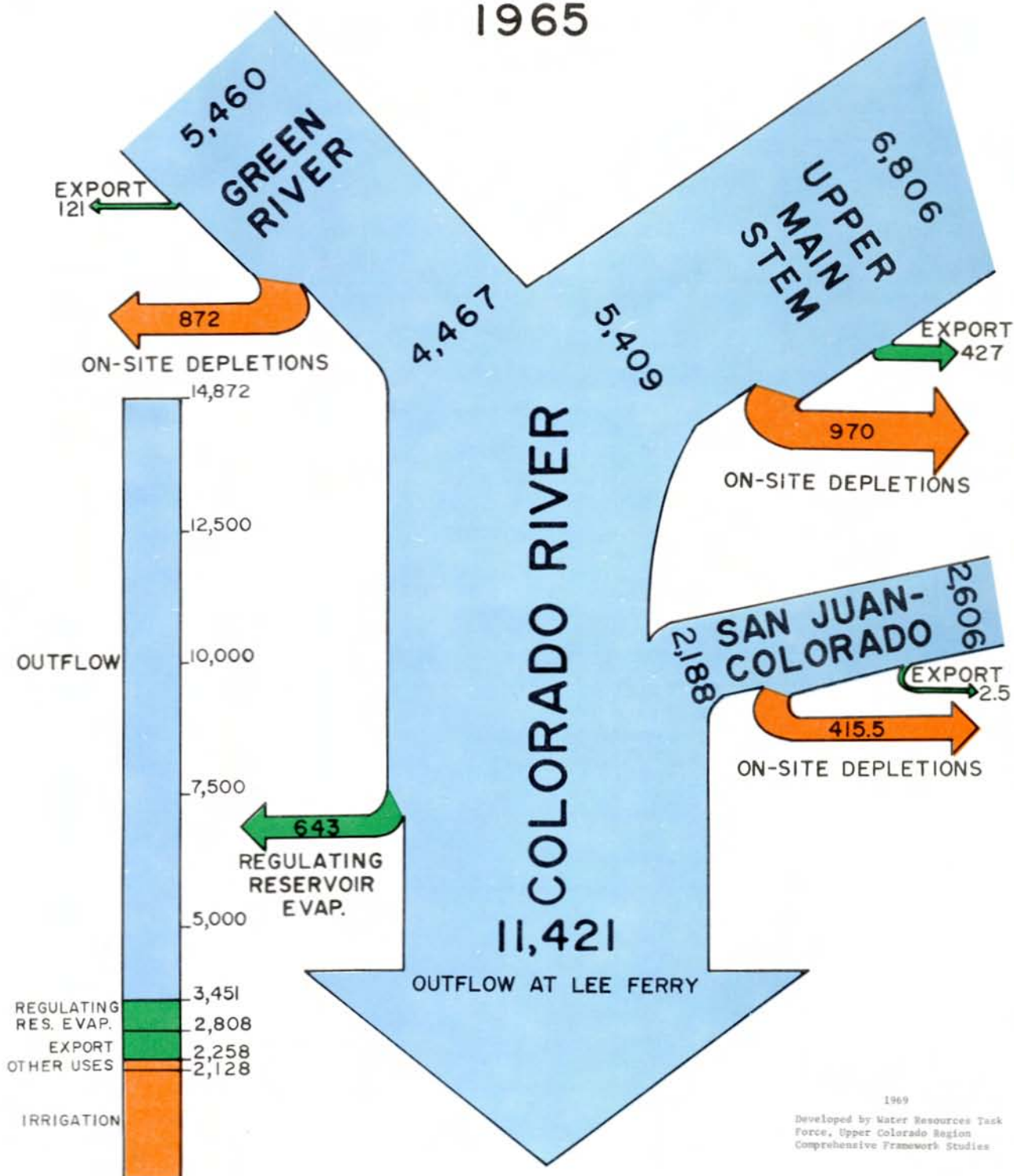
UPPER COLORADO REGION

WATER SUPPLY (1914-1965),

ON-SITE DEPLETIONS & OUTFLOW FOR 1965

(In Thousands of Acre Feet)

1965



1969

Developed by Water Resources Task Force, Upper Colorado Region Comprehensive Framework Studies

Table 8--Water resources summary, 1914-65, Green River Subregion.
(Unit--1,000 acre-feet)

Water year	Historic depletions						Total depletions	Virgin outflow	Present level of depletions (1965)	Present modified outflow from subregion
	Historic outflow from subregion	Trans-mountain diversions	Recent Reclamation projects	Net changes in storage (Federal Reservoirs)	Evaporation and bank storage (Federal Reservoirs)	All other depletions				
1914	7,346	7		77	11	731	826	8,172	992	7,180
15	3,715	17		27	13	732	789	4,504	↑	3,512
16	5,926	41		42	14	733	830	6,756		5,764
17	8,750	68		7	15	734	824	9,574		8,582
18	5,230	78		-32	14	735	795	6,025		5,033
19	3,326	80		-22	14	736	808	4,134		3,142
1920	6,127	70		32	14	737	853	6,980		5,988
21	7,506	73		22	15	738	848	8,354		7,362
22	6,518	77		-5	15	739	826	7,344		6,352
23	6,535	87		0	15	740	842	7,377		6,385
24	3,871	119		-83	13	741	790	4,661		3,669
25	4,104	90		-48	11	742	795	4,899		3,907
26	4,444	82		-24	13	743	814	5,258		4,266
27	5,325	72		17	13	744	846	6,171		5,179
28	5,879	80		4	16	745	845	6,724		5,732
29	6,594	65		20	16	746	847	7,441		6,449
1930	4,623	80		-27	13	747	813	5,436		4,444
31	2,420	81		-56	11	748	784	3,204		2,212
32	4,898	63		5	11	749	828	5,726		4,734
33	3,609	59		-2	12	750	819	4,428		3,436
34	1,319	35		-2	10	751	794	2,113		1,121
35	2,944	51		0	10	752	813	3,757		2,765
36	4,287	50		36	11	753	850	5,137		4,145
37	4,234	60		33	13	754	860	5,094		4,102
38	4,841	67	12	27	15	755	876	5,717		4,725
39	3,481	83	17	-42	14	756	828	4,309		3,317
1940	2,448	66	12	-19	12	757	828	3,276		2,284
41	4,382	61	9	21	13	758	862	5,244		4,252
42	5,140	68	12	-6	14	759	847	5,987		4,995
43	4,338	71	14	9	14	760	868	5,206		4,214
44	4,636	72	15	9	15	761	872	5,508		4,516
45	4,243	63	11	27	16	762	879	5,122		4,130
46	3,536	82	10	-15	16	764	857	4,393		3,401
47	5,596	74	16	22	17	765	894	6,490		5,498
48	4,215	85	10	-36	16	766	841	5,056		4,064
49	5,028	78	13	45	16	768	920	5,948		4,956
1950	5,566	81	13	28	17	769	908	6,474		5,482
51	4,790	82	12	10	17	770	891	5,681		4,689
52	7,153	63	12	145	21	771	1,012	8,165		7,173
53	3,476	94	16	-71	22	773	834	4,310		3,318
54	2,659	117	9	-63	22	774	859	3,518		2,526
55	2,871	116	12	-35	21	775	889	3,760		2,768
56	4,090	120	18	-6	24	777	933	5,023		4,031
57	5,656	102	13	88	23	779	1,005	6,661		5,669
58	4,667	105	22	-40	27	781	895	5,562		4,570
59	2,779	114	15	-75	18	784	856	3,635		2,643
1960	3,057	126	18	-58	17	786	889	3,946		2,954
61	2,077	82	10	-38	13	788	855	2,932	↓	1,940
62	5,942	121	24	74	21	791	1,031	6,973		5,981
63	1,713	93	25	860	118	793	1,889	3,602		2,610
64	2,844	111	40	674	131	795	1,751	4,595		3,603
65	5,308	99	24	1,170	177	798	2,268	7,576		6,584
Totals	236,062	4,081	434	2,726	1,180	39,455	47,876	283,938	51,584	232,354
52-year mean	4,539	78	8	53	22	759	921	5,460	992	4,468

PART X

WATER RESOURCES FOR FUTURE DEVELOPMENT

Table 9--Water resources summary, 1914-65, Upper Main Stem Subregion.
(Unit--1,000 acre-feet)

Water year	Historic outflow from subregion	Trans- mountain diversions	Recent Reclamation projects	Historic depletions		All other depletions	Total depletions	Virgin outflow from subregion	Present level of depletions (1965)	Present modified outflow from subregion
				Net changes in storage content (Federal Reservoirs)	Evaporation and bank storage (Federal Reservoirs)					
1914	8,760	12				734	746	9,506	1,397	8,109
15	5,510	16				736	752	6,262		4,865
16	7,692	19				738	757	8,449		7,052
17	9,004	12				741	753	9,757		8,360
18	6,504	19				743	762	7,266		5,869
19	5,020	14				745	759	5,779		4,382
1920	9,128	18				748	766	9,894		8,497
21	9,140	12				750	762	9,902		8,505
22	7,043	16				752	768	7,811		6,414
23	7,454	17				755	772	8,226		6,829
24	6,087	12				757	769	6,856		5,459
25	5,188	23				759	782	5,970		4,573
26	6,780	22				762	784	7,564		6,167
27	7,747	26				764	790	8,537		7,140
28	7,652	22				766	788	8,440		7,043
29	8,754	31				769	800	9,554		8,157
1930	6,273	23				771	794	7,067		5,670
31	2,987	17				773	790	3,777		2,380
32	6,882	27				776	803	7,685		6,288
33	4,780	25				778	803	5,583		4,186
34	2,319	18				780	798	3,117		1,720
35	4,848	42				783	825	5,673		4,276
36	5,928	73				785	858	6,786		5,389
37	4,837	78				787	876	5,713		4,316
38	7,623	130		11		790	955	8,578		7,181
39	4,384	99		35		792	885	5,269		3,872
1940	3,605	92		-6		794	857	4,462		3,065
41	6,794	110		-29		797	871	7,765		6,368
42	7,943	51		62	2	799	846	8,789		7,392
43	5,314	113		-6	2	801	1,045	6,359		4,962
44	6,086	80		127	4	804	869	6,955		5,558
45	5,582	127		-19	4	806	995	6,577		5,180
46	4,226	112		58	4	810	914	5,140		3,743
47	6,229	99		-12	4	815	976	7,205		5,808
48	6,752	83		58	4	819	830	7,582		6,185
49	6,484	109		-76	4	824	956	7,450		6,053
1950	4,397	125		29	4	829	952	5,349		3,952
51	4,073	184		-6	4	835	1,223	5,296		3,899
52	7,930	183		200	4	840	1,281	9,211		7,814
53	4,197	262	4	254	4	847	1,050	5,247		3,850
54	2,490	378	4	-67	4	853	973	3,463		2,066
55	3,396	372	4	-266	4	861	1,226	4,622		3,225
56	3,750	350	4	-15	4	868	1,224	4,974		3,577
57	8,719	317	4	-2	4	876	1,543	10,262		8,865
58	6,548	274	4	342	4	883	1,105	7,653		6,256
59	3,256	411	4	-60	4	893	1,270	4,526		3,129
1960	4,304	386	4	-42	4	902	1,360	5,664		4,267
61	3,266	324	9	64	5	912	1,308	4,574		3,177
62	6,898	374	16	58	5	921	1,384	8,282		6,885
63	2,982	395	16	68	4	931	1,112	4,094		2,697
64	3,527	488	16	-234	5	940	1,432	4,959		3,562
65	6,611	404	16	-17	6	949	1,812	8,423	1,397	7,026
Totals	303,684	7,026	105	437	101	42,043	50,221	353,905	72,644	281,261
52-year mean	5,840	135	2	946	2	808	966	6,806	1,397	5,409

Table 10--Water resources summary, 1914-65, San Juan-Colorado Subregion.
(Unit--1,000 acre-feet)

Water year	Historic depletions						Total depletions	Virgin outflow from subregion	Present level of depletions (1965)	Present modified outflow from subregion
	Historic outflow from subregion	Trans-mountain diversions	Recent Reclamation projects	Net changes in storage (Federal Reservoirs)	Evaporation and bank storage (Federal Reservoirs)	All other depletions				
1914	3,225	-3				267	264	3,489	418	3,071
15	3,280	-2				268	266	3,546	↑	3,128
16	3,711	-3				271	268	3,979		3,561
17	4,140	-2				272	270	4,410		3,992
18	1,915	-3				275	272	2,187		1,769
19	2,511	-2				276	274	2,785		2,367
1920	4,485	-3				279	276	4,761		4,343
21	4,068	-2				280	278	4,346		3,928
22	2,746	-3				283	280	3,026		2,608
23	2,276	-2				284	282	2,558		2,140
24	2,521	-3				287	284	2,805		2,387
25	2,048	-2				288	286	2,334		1,916
26	2,788	-3				291	288	3,076		2,658
27	3,514	-2				292	290	3,804		3,386
28	1,795	-3				295	292	2,087		1,669
29	3,877	-2				296	294	4,171		3,753
1930	2,173	-3				299	296	2,469		2,051
31	980	-2				300	298	1,278		860
32	3,508	-3				303	300	3,808		3,390
33	1,357	-2				304	302	1,659		1,241
34	758	-3				307	304	1,062		644
35	2,120	-2				308	306	2,426		2,008
36	1,750	-3				311	308	2,058		1,640
37	2,826	-1				312	311	3,137		2,719
38	2,972	-2				315	313	3,285		2,867
39	1,529	-1				316	315	1,844		1,426
1940	1,028	-2				319	317	1,345		927
41	4,872	1		56	2	320	379	5,251		4,833
42	3,947	-2		0	3	323	324	4,271		3,853
43	1,607	2		-4	3	324	325	1,932		1,514
44	2,497	-2		-35	3	327	293	2,790		2,372
45	1,721	1		32	3	328	364	2,085		1,667
46	983	-1		2	3	331	335	1,318		900
47	1,688	0		48	4	332	384	2,072		1,654
48	2,722	-1		-36	3	335	301	3,023		2,605
49	2,848	-1		-9	3	336	329	3,177		2,759
1950	1,090	-2		-26	3	339	314	1,404		986
51	968	-1		-2	2	340	339	1,307		889
52	2,896	-2		40	3	343	384	3,280		2,862
53	1,132	0		-27	3	344	320	1,452		1,034
54	968	3		18	3	347	371	1,339		921
55	1,041	2		7	4	349	362	1,403		985
56	910	3		-32	3	351	325	1,235		817
57	2,962	2		62	3	354	421	3,383		2,965
58	3,044	-2		-40	4	356	318	3,362		2,944
59	721	0		-33	3	357	327	1,048		630
1960	1,832	2		25	3	360	390	2,222		1,804
61	1,331	1		25	3	362	391	1,722		1,304
62	1,945	1	3	18	7	364	393	2,338		1,920
63	1/-2,175	1	4	2,873	638	367	3,883	1,708		1,290
64	1/-3,944	-1	5	3,738	1,302	369	5,413	1,469		1,051
65	1/-1,084	2	5	2,659	1,248	371	4,285	3,201	418	2,783
Totals	106,423	58	17	9,359	3,259	16,527	29,104	135,527	21,736	113,791
52-year mean	2,047	1	0	180	63	318	560	2,606	418	2,188

1/ Negative figures reflect storage in Lake Powell.

Table 11--Water resources summary, 1914-65, Upper Colorado Region.
(Unit--1,000 acre-feet)

Water year	Historic outflow at Lee Ferry	Trans-mountain diversions	Recent Reclamation projects	Historic depletions			Total depletions	Virgin outflow	Present level of depletions (1965)	Present modified outflow from region
				Net changes in storage content (Federal Reservoirs)	Evaporation and bank storage (Federal Reservoirs)	All other depletions				
1914	19,331	16		77	11	1,732	1,836	21,167	2,808	18,359
15	12,505	31		27	13	1,736	1,807	14,312		11,504
16	17,329	57		42	14	1,742	1,855	19,184		16,376
17	21,894	78		7	15	1,747	1,847	23,741		20,933
18	13,649	94		-32	14	1,753	1,829	15,478		12,670
19	10,857	92		-22	14	1,757	1,841	12,698		9,890
1920	19,740	85		32	14	1,764	1,895	21,635		18,827
21	20,714	83		22	15	1,768	1,888	22,602		19,794
22	16,307	90		-5	15	1,774	1,874	18,181		15,373
23	16,265	102		0	15	1,779	1,896	18,161		15,353
24	12,479	128		-83	13	1,785	1,843	14,322		11,514
25	11,340	111		-48	11	1,789	1,863	13,203		10,395
26	14,012	101		-24	13	1,796	1,886	15,898		13,090
27	16,586	96		17	13	1,800	1,926	18,512		15,704
28	15,326	99		4	16	1,806	1,925	17,251		14,443
29	19,225	94		20	16	1,811	1,941	21,166		18,358
1930	13,069	100		-27	13	1,817	1,903	14,972		12,164
31	6,387	96		-56	11	1,821	1,872	8,259		5,451
32	15,288	87		5	11	1,828	1,931	17,219		14,411
33	9,746	82		-2	12	1,832	1,924	11,670		8,862
34	4,396	50		-2	10	1,838	1,896	6,292		3,484
35	9,912	91		0	10	1,843	1,944	11,856		9,048
36	11,965	120		36	11	1,849	2,016	13,981		11,173
37	11,897	137		44	13	1,853	2,047	13,944		11,136
38	15,436	195	12	62	15	1,860	2,144	17,580		14,772
39	9,394	181	17	-48	14	1,864	2,028	11,422		8,614
1940	7,081	156	12	-48	12	1,870	2,002	9,083		6,275
41	16,048	172	9	139	17	1,875	2,212	18,260		15,452
42	17,030	117	12	-12	19	1,881	2,017	19,047		16,239
43	11,259	186	14	132	21	1,885	2,238	13,497		10,689
44	13,219	150	15	-45	22	1,892	2,034	15,253		12,445
45	11,546	191	11	117	23	1,896	2,238	13,784		10,976
46	8,745	193	10	-25	23	1,905	2,106	10,851		8,043
47	13,513	173	16	128	25	1,912	2,254	15,767		12,959
48	13,689	167	10	-148	23	1,920	1,972	15,661		12,853
49	14,360	186	13	65	23	1,928	2,215	16,575		13,767
1950	11,053	204	13	-4	24	1,937	2,174	13,227		10,419
51	9,831	265	12	208	23	1,945	2,453	12,284		9,476
52	17,979	244	12	439	28	1,954	2,677	20,656		17,848
53	8,805	356	20	-165	29	1,964	2,204	11,009		8,201
54	6,117	498	13	-311	29	1,974	2,203	8,320		5,512
55	7,308	490	16	-43	29	1,985	2,477	9,785		6,977
56	8,750	473	22	-40	31	1,996	2,482	11,232		8,424
57	17,337	421	17	492	30	2,009	2,969	20,306		17,498
58	14,259	377	26	-140	35	2,020	2,318	16,577		13,869
59	6,756	525	19	-150	25	2,034	2,453	9,209		6,401
1960	9,193	514	22	31	24	2,048	2,639	11,832		9,024
61	6,674	407	19	45	21	2,062	2,554	9,228		6,420
62	14,785	496	43	160	33	2,076	2,808	17,593		14,785
63	2,520	489	45	3,499	760	2,091	6,884	9,404		6,596
64	2,427	598	61	4,395	1,438	2,104	8,596	11,023		8,215
1965	10,835	505	45	4,266	1,431	2,118	8,365	19,200	2,808	16,392
Totals	646,168	11,049	556	13,031	4,540	98,025	127,201	773,369	146,016	627,353
52-year means	12,426	212	11	251	87	1,885	2,446	14,872	2,808	12,064

PART XI

PROJECTED WATER USE

Study of projections as published by the Office of Business Economics - Economic Research Service, "OBERS As Published," revealed a substantial departure from historical agricultural production in the region, especially that large feed crop imports were shown with an increasing surplus of pasture, range, and irrigated land. For these and other reasons, the basic level of development used for these studies in the Framework Plan, based on the Regionally Interpreted OBERS requirements which will be discussed in this chapter. Alternative levels of development are discussed in Part XII.

It should be noted that these studies were made to demonstrate certain levels of water development and are not to be construed as depletions charged to the various states under the provisions of the Colorado River Compact and Upper Colorado River Compact, nor to prejudice or jeopardize the positions of the several states therein. In particular, the depletions are site-located and do not necessarily reflect direct relationships to streamflow diminishment at Lee Ferry, Arizona. Water shortages at the site of use for projects which may be developed to make the programmed at-site depletions shown in these plans have not been taken into account in this preliminary study.

Framework Plan (Regionally Interpreted OBERS Level of Development)

The regional needs and corresponding water demands are based on an interpretation of the OBERS projections for the time frames of 1980, 2000, and 2020. Principal indices include population projections, production of assigned agricultural and industrial commodities within the region, and development of resources to meet demands generated in adjacent areas. Major items to respond to demands from outside the region include the production of meat animals, mining and processing of minerals, generation of hydro and thermoelectric power, and further development of the scenic and recreational resources to accommodate the large numbers of visitors who look to the Upper Colorado Region as a desirable vacation area.

A major demand also exists outside the region for water produced in the region. Large amounts of the water produced in the region are committed to downstream delivery and assigned to use in other basins of the Upper Colorado River Division States.

Included herein is a summary of estimated water uses in terms of on-site depletions, including the transmountain diversions from the stream system.

Water Needs in Terms of On-Site Depletions

By the year 2020 there will be on-site depletion needs of 6.5 million acre-feet. The largest consumptive use need, which is 50.5 percent of the total in 2020 or 3.29 million acre-feet, is for irrigated crops, associated seeped and incidental phreatophyte areas, and irrigation reservoir evaporation.

Minor water needs in 2020 are in municipal and industrial water supply (1.3 percent), minerals (0.8 percent), augmented fish and wild-life and recreation (1.4 percent), and stockpond evaporation and livestock use (.9 percent), thermal-electric power generation (9.7 percent). About 1.65 million acre-feet or 25.3 percent of the 2020 depletion would be exported from the region. Main Stem regulating reservoir evaporation would account for 10.1 percent, or 660,000 acre-feet of depletion. Summary tables for stream depletions for the five states and three subregions by types of needs for 1980, 2000, and 2020 follow.

The five States agreed that the year 2020 depletion distribution should reflect the States' percentages shown in the Upper Colorado River Basin Compact. This relationship, however, was not to be adhered to in the interim period. The water needs for 1980 and 2000 conform to the respective projections for each subregion.

Municipal and Industrial

Depletions by domestic, manufacturing, governmental, commercial and other related purposes in the basin for 2020 are 110,100 acre-feet.

Population and municipal, industrial, and related water users, Upper Colorado Region

Subregion	Population			Depletions		
	1980	2000	2020	1980	2000	2020
				Ac-ft	Ac-ft	Ac-ft
Green River	107,000	124,000	151,000	11,700	16,900	26,400
Upper Main Stem	143,000	171,000	204,000	16,200	24,900	40,400
San Juan-Colorado	176,000	241,900	324,800	15,100	25,900	43,300
Region Total	426,000	537,700	680,200	43,000	67,700	110,100

Total depletions of municipal and industrial water in gallons per capita per day (gpcd) average 147 in the Green River, 166 in the Main Stem, and 112 in the San Juan, with an average for the region of 136 gpcd. Projected depletion by the Navajo Indians by 2020 would average about 65 gpcd. This is in contrast to the present and projected depletion rate at Page, Arizona, of about 500 gpcd.

Thermal-Electric Power

The 2020 water depletion by steam-electric generation plants is estimated at 626,600 acre-feet. Nearly all consumptive use is for condenser cooling purposes. Power production by 2020 by states and for the region is estimated as follows: Arizona - 2,310 MW; Colorado - 16,976 MW; New Mexico - 7,123 MW; Utah - 5,759 MW; Wyoming - 9,913 MW; Region - 42,081 MW. This distribution among the States resulted from arbitrary assignments to conform with state compact allotments for the purpose of this study only.

Minerals

Projections of mineral production totaling \$2,014,000 would require a depletion of about 52,800 acre-feet in 2020. Projected depletions for water injection in oil fields in New Mexico are not included in this estimate.

Augmented Fish and Wildlife

The projected consumptive use comprises 127,400 acre-feet from the fish and wildlife facilities which will be required to satisfy future demand. This total represents 11,700 acre-feet of on-site depletions occurring in 1965 plus amounts of 88,000 acre-feet needed for waterfowl and 27,700 acre-feet needed for fish by the year 2020. The consumptive use is based on depletions from 51,200 surface acres of facilities intended primarily for fish and wildlife. It is reasonable to suppose, however, that multi-purpose facilities, not yet planned or authorized, may become available to meet part of this future demand.

Water-supply restrictions based on compact limitations for those parts of Arizona and New Mexico in the Upper Colorado Region will become a major problem in attaining the future development needed in this part of the region. For the purpose of this study fish and wildlife water usage at the year 2020 has been reduced from 12,200 acre-feet to 1,200 acre-feet for Arizona and from 35,300 acre-feet to 6,800 acre-feet for New Mexico. There may be a possibility of obtaining additional water in future years through the commitment of undeveloped water or the purchase and transfer of water developed for other purposes.

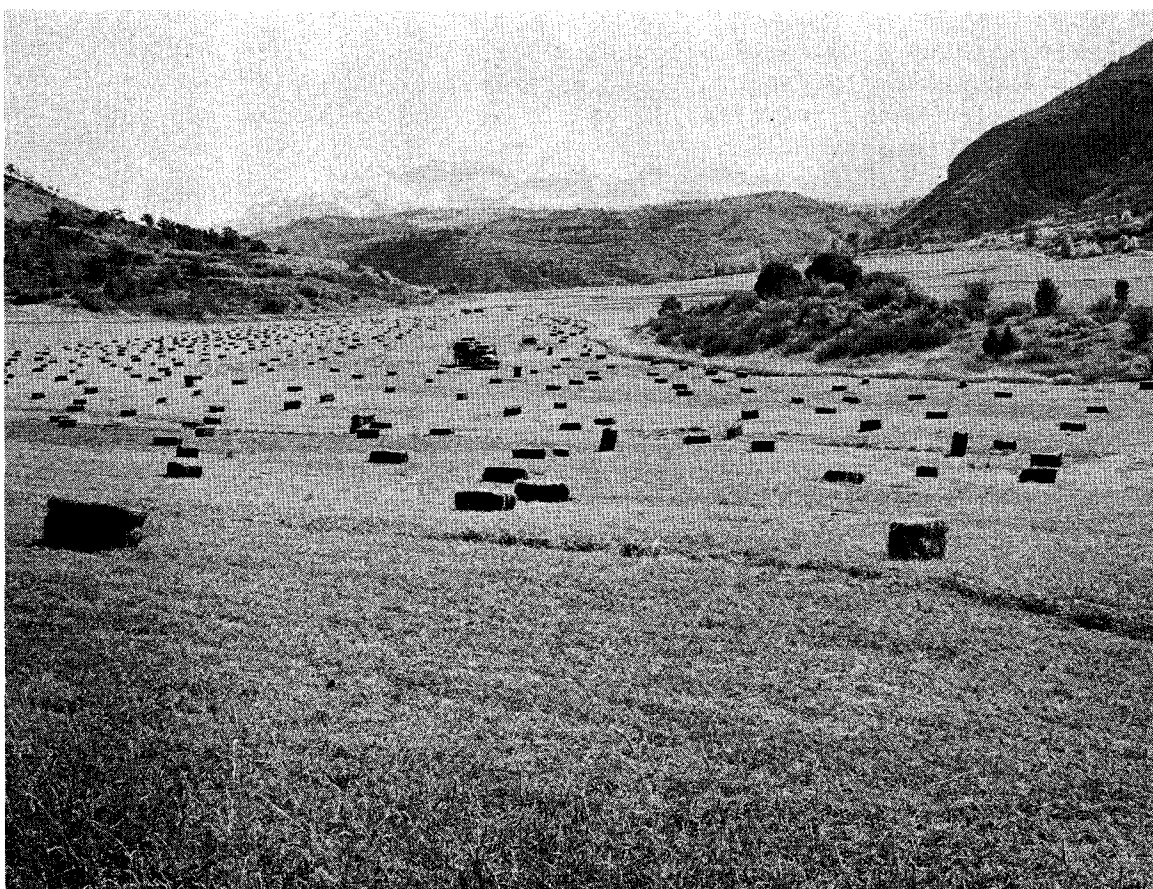
Recreation

The amount of water consumed in 2020 would be 5,200 acre-feet which is not of significance. Most will be used at associated service facilities. The computed use will be 7.7 gallons per recreation day for about 225 million projected recreation days by 2020 of which less than 3 percent would be by residents.

Stockpond Evaporation and Livestock Use

Stockpond evaporation from 38,000 stockponds in 2020 is estimated to be 41,000 acre-feet annually. In addition to livestock water these ponds provide sediment storage and erosion control. Some have a potential for fish and waterfowl habitat and recreation. Livestock water use by 2020 at 10 gallons per day per animal unit by 1.6 million cattle animal units is estimated to be 18,000 acre-feet.

Irrigation



Baled hay from irrigated meadow

On-site depletion by 2020 on 2.1 million acres of irrigated cropland, incidental use on water-consuming noncropped areas and irrigation reservoir evaporation would total 3.29 million acre-feet annually. An increase of about 500,000 acres of new full supply cropland would be developed between 1965 and 2020 to meet feed and food production projections. Of the 549,400 acres of presently short supply lands 421,100 acres would receive supplemental water to obtain full production.

Irrigation consumptive use by 2020, including supplemental water, would total 2,707,000 acre-feet. Irrigation reservoir evaporation would be about 187,000 acre-feet. Incidental use is estimated to increase from the present 315,600 acre-feet (18.6 percent of consumptive use) to about 400,000 acre-feet (14.8 percent of consumptive use) by 2020, which is an increase in irrigation efficiency of nearly four percent.

Import

Inflow to the region from the Great Basin to the Paria River would be the only import and will remain at the present level of 2,600 acre-feet annually.

Export by Transmountain Diversions

This plan envisions the export of 1.653 million acre-feet of water from the region by 2020. Wyoming's export of 185,000 acre-feet would be to the urban areas of Cheyenne-Laramie and to the North Platte and Bear Rivers systems. Colorado would export 883,000 acre-feet to the Fort Collins-Denver-Colorado Springs area for municipal, industrial and agricultural use, and to the Arkansas and Rio Grande systems. Utah would export 467,000 acre-feet to the Great Basin for municipal, industrial, and agricultural use. New Mexico would export 110,000 acre-feet to the Rio Grande by 1980 and an additional 7,500 acre-feet for municipal use at Gallup, located in the Lower Colorado Region.

Main Stem Reservoir Evaporation

Evaporation loss in 2020 from the five Main Stem regulating reservoirs (Lake Powell at 576,000 acre-feet, Flaming Gorge at 67,000 acre-feet, and three reservoirs in the Curecanti Unit at 17,000 acre-feet) for normal operating conditions would be 660,000 acre-feet. It should be noted, however, that these evaporation losses will be charged against the separate States only if curtailment of use is required in the Upper Colorado Region to make delivery at Lee Ferry under the Compact.

Summaries of Proposed Uses

The water demands for the Framework Plan based on the regionally interpreted OBERS level of development for the time frames by types of use are enumerated in the following five flow diagrams followed by tables 12 and 13.

UPPER COLORADO REGION

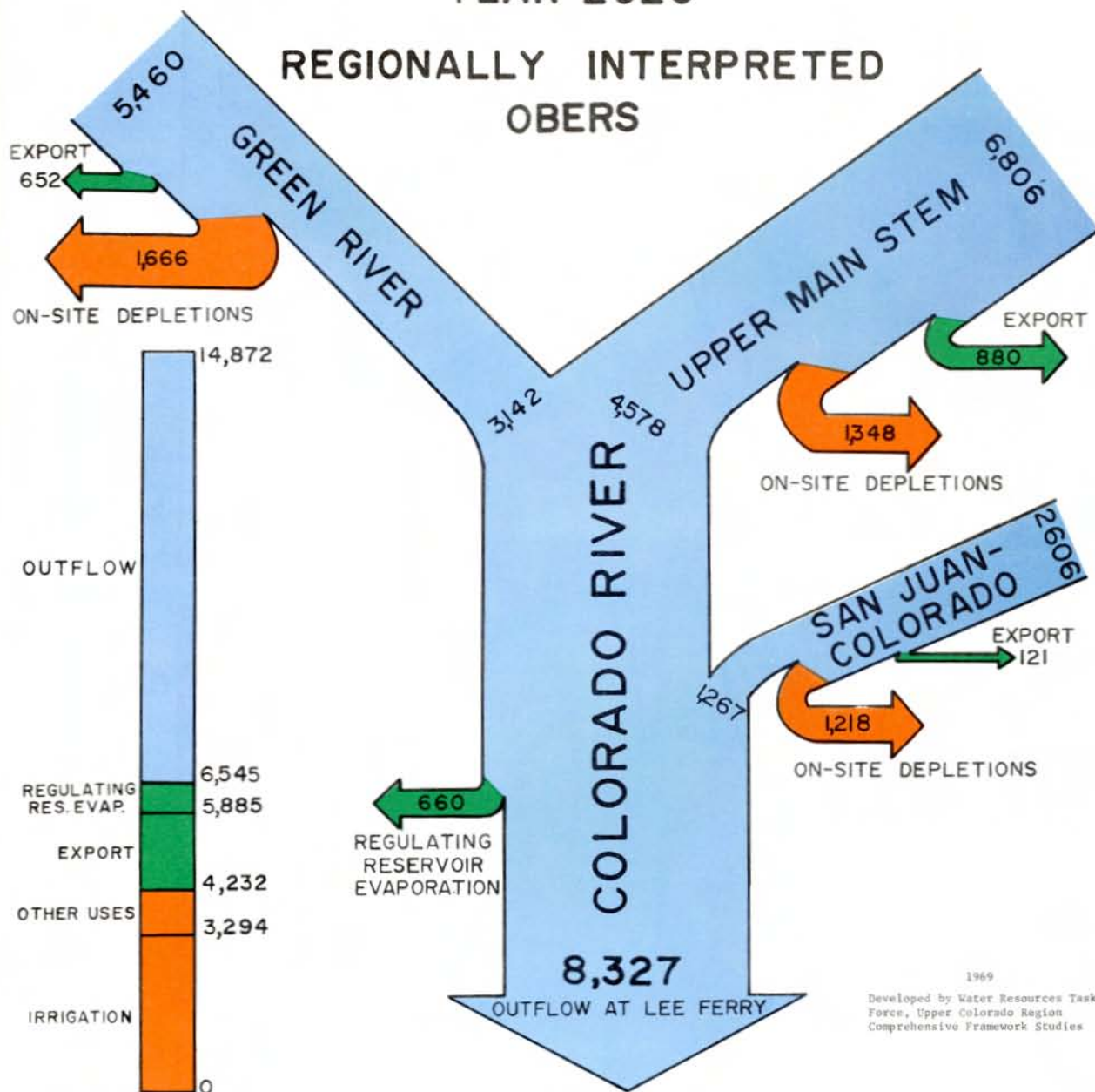
WATER SUPPLY (1914-1965),

ON-SITE DEPLETIONS & OUTFLOW FOR 2020

(In Thousands of Acre Feet)

YEAR 2020

REGIONALLY INTERPRETED OBSERS

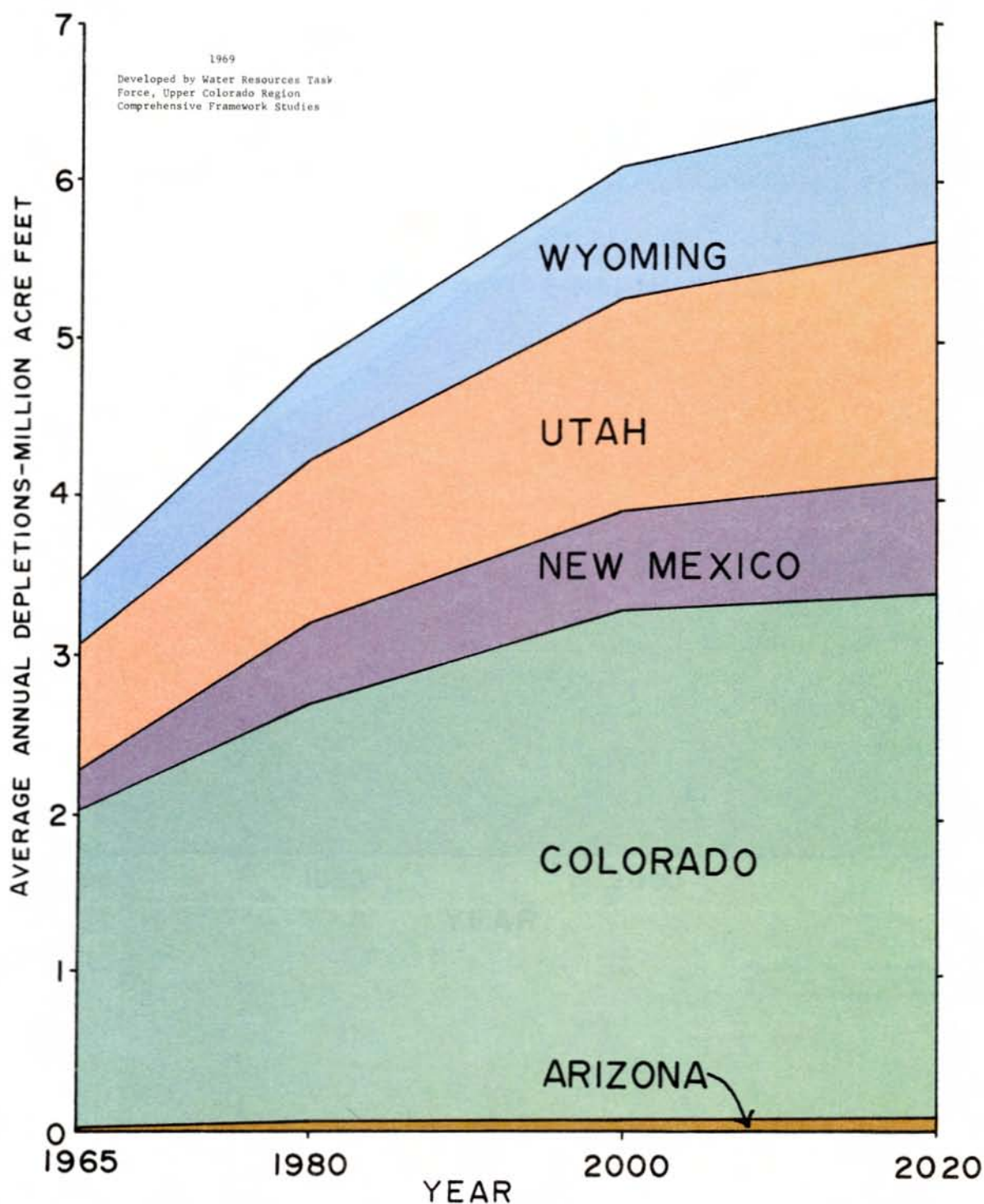


1969

Developed by Water Resources Task Force, Upper Colorado Region Comprehensive Framework Studies

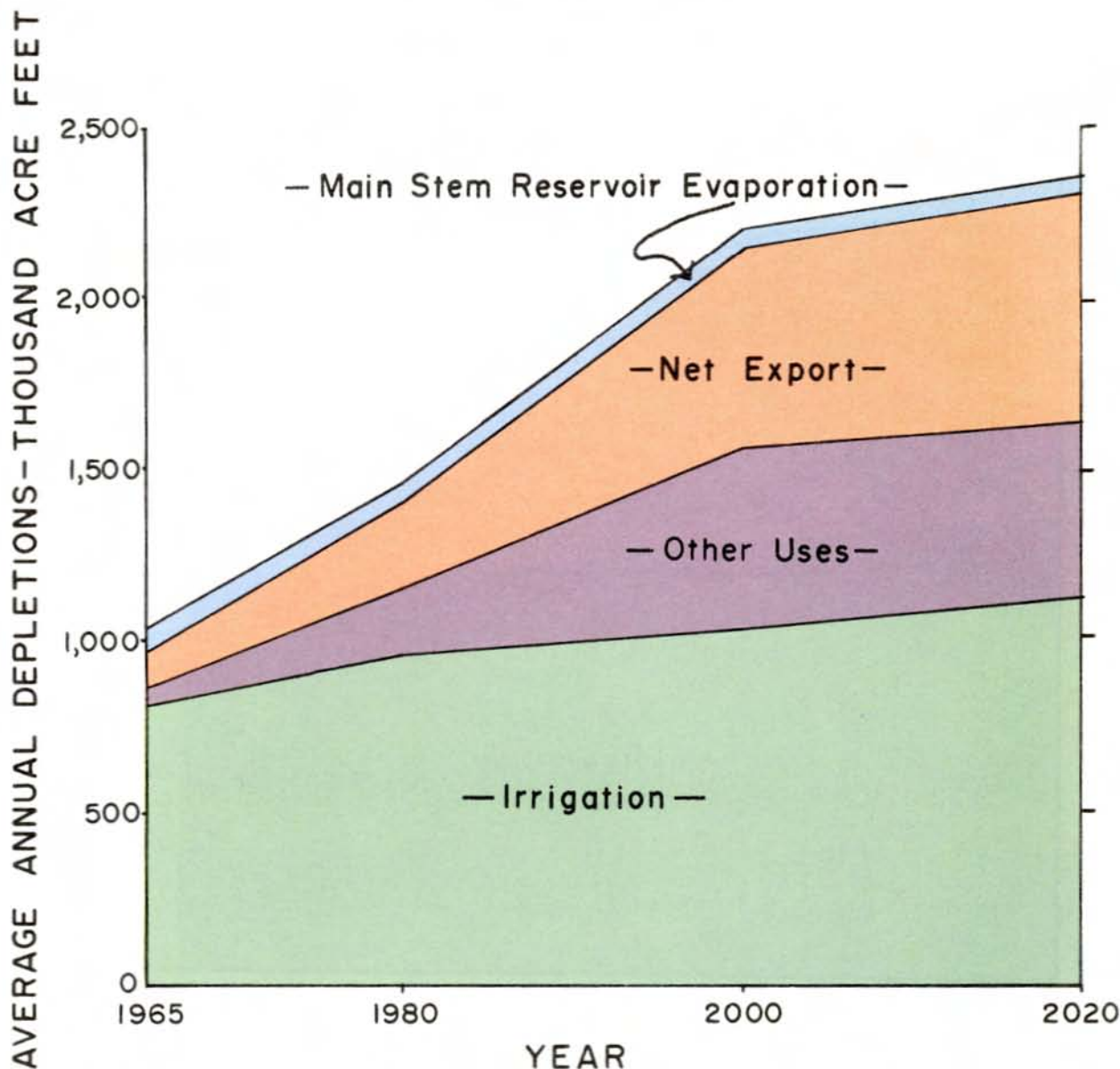
UPPER COLORADO REGION *WATER USE by STATES*

For the Regionally Interpreted OBERS
level of development



UPPER COLORADO REGION
GREEN RIVER SUBREGION
WATER USE

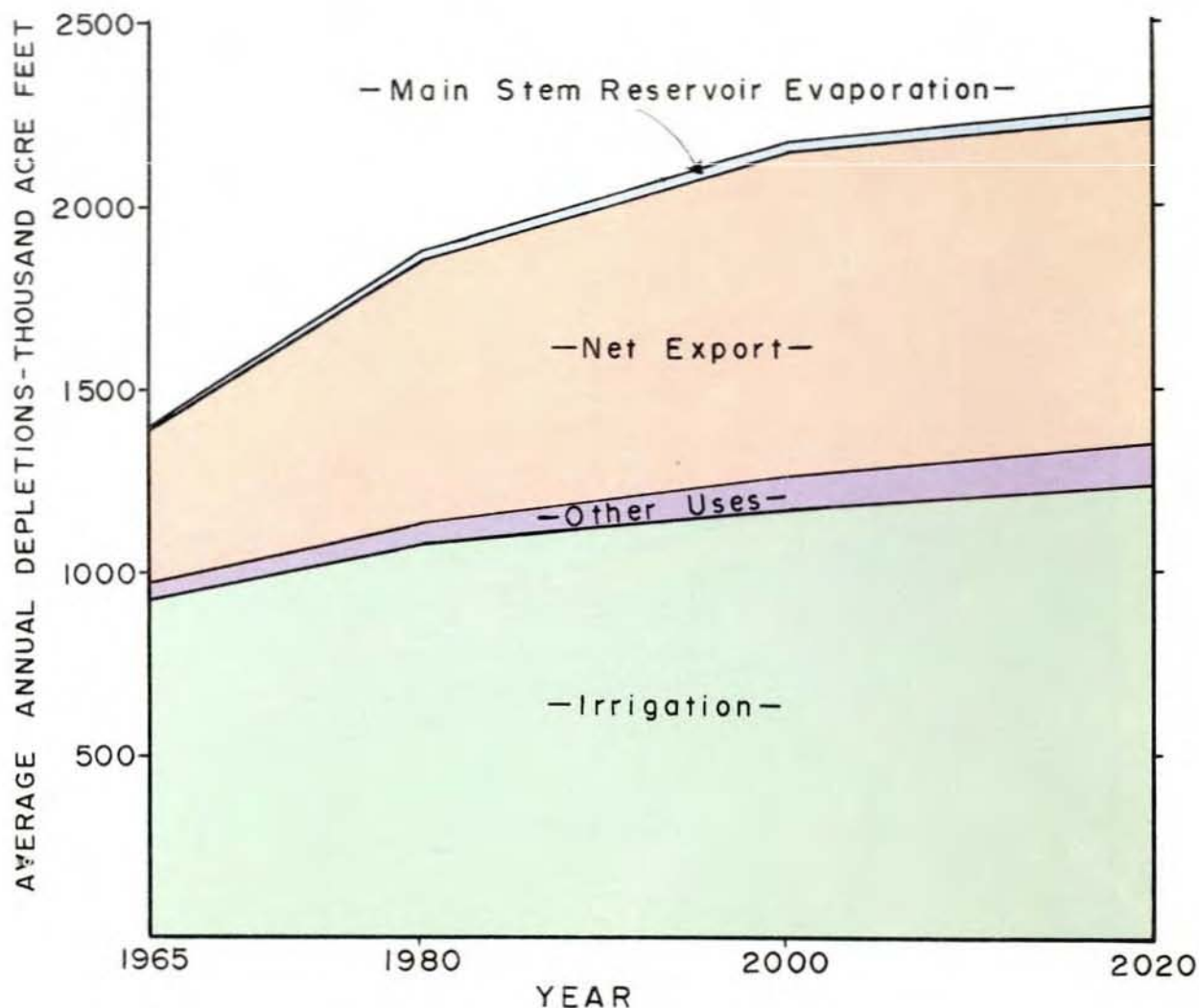
For the Regionally Interpreted OBERS
level of development



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Comprehensive Framework Studies

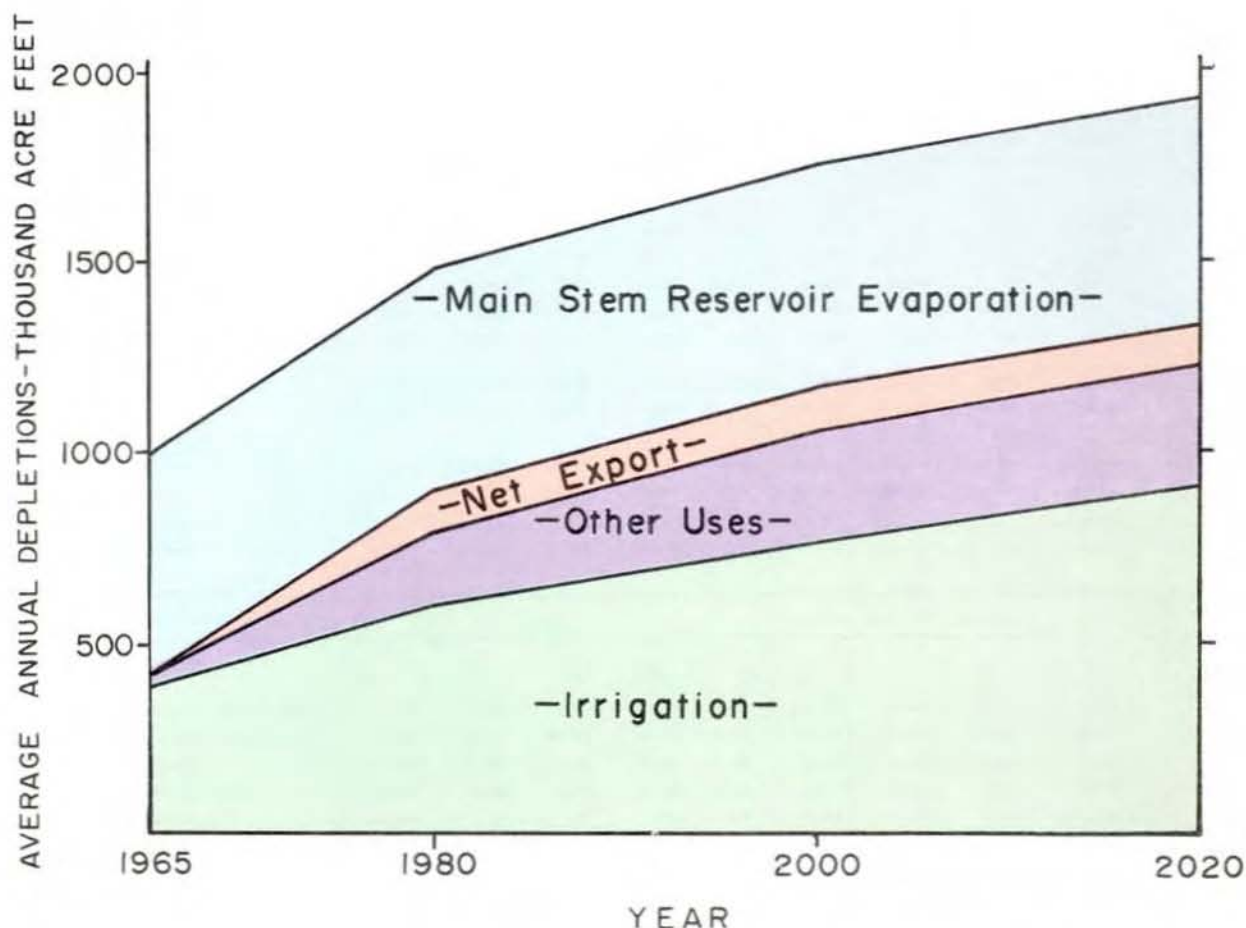
UPPER COLORADO REGION
UPPER MAIN STEM SUBREGION
WATER USE

For the Regionally Interpreted OBERS
level of development



UPPER COLORADO REGION
SAN JUAN-COLORADO SUBREGION
WATER USE

For the Regionally Interpreted OBERS
level of development



PART XI

PROJECTED WATER USE

Table 12 - Water use for framework plan
(Regionally interpreted OBERS level of development)
Upper Colorado Region

Type of use	On-site depletions (acre-feet per year)					Region	Green River		
	Arizona	Colorado	New Mexico	Utah	Wyoming		Upper Main Stem	San Juan-Colorado	
- - 1980 - -									
Municipal and industrial	2,900	22,100	5,900	7,800	4,300	43,000	11,700	16,200	15,100
Electric power (thermal)	34,100	26,700	55,700	50,400	33,200	200,100	72,500	1,800	125,800
Minerals	400	19,500	3,700	10,300	19,000	52,900	31,500	13,700	7,700
Fish and wildlife	1,200	38,800	6,800	22,200	18,800	87,800	49,400	7,900	30,500
Recreation	100	600	100	1,000	200	2,000	800	600	600
Stockpond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	132,700	75,100	99,000	80,300	427,200	181,200	53,900	192,100
Irrigation: consumptive use, incidental and reservoir evaporation	7,000	1,479,000	245,000	588,000	334,000	2,653,000	984,000	1,078,000	591,000
Export		719,000	117,500	190,000	65,000	1,091,500	255,000	716,000	120,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,330,700	437,600	874,400	479,300	4,169,100	1,420,200	1,847,900	901,000
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 1980						4,829,100	1,487,200	1,864,900	1,477,000
- - 2000 - -									
Municipal and industrial	4,800	34,300	10,600	12,100	5,900	67,700	16,900	24,900	25,900
Electric power (thermal)	34,100	254,600	106,800	86,400	148,700	630,600	393,500	24,200	212,900
Minerals	300	19,900	3,900	10,300	22,100	56,500	32,000	16,700	7,800
Fish and wildlife	1,200	38,800	6,800	22,200	18,800	87,800	49,400	7,900	30,500
Recreation	300	1,000	100	1,600	200	3,200	1,300	900	1,000
Stockpond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	379,100	131,500	141,600	201,500	896,100	511,300	91,700	293,100
Irrigation: consumptive use, incidental and reservoir evaporation	7,600	1,633,000	329,000	605,000	407,000	2,981,600	1,062,000	1,166,000	753,600
Export		883,000	117,500	437,000	150,000	1,587,500	587,000	880,000	120,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	2,895,100	578,000	1,181,000	758,500	5,462,600	2,160,300	2,137,700	1,164,600
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2000						6,122,600	2,227,300	2,154,700	1,740,600
- - 2020 - -									
Municipal and industrial	7,200	56,000	17,300	20,400	9,200	110,100	26,400	40,400	43,300
Electric power (thermal)	30,100	254,600	106,800	86,400	148,700	626,600	393,500	24,200	208,900
Minerals	300	17,000	2,600	11,400	21,500	52,800	26,400	20,800	5,600
Fish and wildlife	1,200	38,800	6,800	22,200	18,800	87,800	49,400	7,900	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stockpond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	403,800	137,700	153,700	205,300	941,500	519,100	115,200	307,200
Irrigation: consumptive use, incidental and reservoir evaporation	9,000	1,723,000	411,000	723,000	428,000	3,294,000	1,147,000	1,233,000	914,000
Export		883,000	117,500	467,000	185,000	1,652,500	652,000	880,000	120,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,009,800	666,200	1,341,100	818,300	5,885,400	2,318,100	2,228,200	1,339,100
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2020						6,545,400	2,385,100	2,245,200	1,915,100

1/ See explanation, page 52.

Table 13 - Available water supply for the Framework Plan,
Upper Colorado Region

	Green River	Upper Main Stem	San Juan- Colorado	Upper Colorado Region
	<u>(1,000 Acre-Feet)</u>			
Virgin Water Supply (1914-65)	5,460	6,806	2,606	14,872
<u>1980</u>				
Level of Depletions (1980)	1,420	1,848	901	4,169
Modified Flow (excluding Main Stem evap.)	4,040	4,958	1,705	10,703
Main Stem Evaporation	67	17	576	660
Residual Outflow	3,973	4,941	1,129	10,043
<u>2000</u>				
Level of Depletions (2000)	2,160	2,138	1,165	5,463
Modified Flow (excluding Main Stem evap.)	3,300	4,668	1,441	9,409
Main Stem Evaporation	67	17	576	660
Residual Outflow	3,233	4,651	865	8,749
<u>2020</u>				
Level of Depletions (2020)	2,318	2,228	1,339	5,885
Modified Flow (excluding Main Stem evap.)	3,142	4,578	1,267	8,987
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	3,075	4,561	691	8,327
<u>1/ Flaming Gorge Reservoir</u>				
<u>2/ Curecanti Unit Reservoirs</u>				
<u>3/ Lake Powell</u>				

PART XII

ALTERNATIVE LEVELS OF DEVELOPMENT

No. 1--State Alternative To The Framework Plan (6.5 Million Acre-Feet Level of Development)

For comparative purposes, the States have proposed an alternative development of the quantity required to satisfy the regionally interpreted OBERS level of development (6.5 m.a.f. per annum). The distribution of use by each State exactly equals the Upper Colorado River Compact percentage allotments. Adjustments in types of uses to accomplish the exact percentages were expressed by the respective States.

State Proposals

In the regionally interpreted OBERS plan, there is the need to service a large electric power market from potential fuel-burning electric powerplants in the Upper Colorado Region. Each of the States of Colorado, New Mexico, Utah, and Wyoming have programmed a part of their water resources for production of such energy. Previously, the States had agreed to maintain levels of water development very close to their respective percentage allotments in the Upper Colorado River Basin Compact. Without upsetting a multitude of water uses set forth in the regionally interpreted OBERS plan, the approximate State percentages could be maintained only by an arbitrary assignment to each State of portions of the needed power installations as necessary to bring each State's total water uses to amounts approximating the Compact percentages. Although the result depicted a reasonable satisfaction, on a region-wide basis, of the requirements for a regionally interpreted OBERS plan, there were certain objectionable features in the plan, particularly to Colorado and Utah.

To facilitate the comparison, departures from the basic data contained in the regionally interpreted OBERS are given herein.

In the revised year 2020 distribution, Arizona retained its exact allotment of 50,000 acre-feet per annum with no change in types of uses.

Wyoming also suggested no changes in its type of uses but revised its irrigation depletions downward 900 acre-feet per annum to stay exactly within its 14 percent allotment.

Utah indicated that a much greater portion of its potential thermal power production be included and added 11,700 megawatts with a support population of 26,000 people. Utah also added an oil shale development of 500,000 barrels per day with a support population of 39,000 people. In order to stay within its 23 percent allotment Utah revised downward its irrigation acreage (-10,500 acres) and likewise revised downward (-200,000 acre-feet annually) its export to the Bonneville Basin.

Colorado varied its irrigated land acreages and water depletions as follows: 18,000 less acres depleting 88,000 acre-feet less water in 1980, 80,000 more acres depleting 145,000 acre-feet more in 2000, and 6,500 more acres depleting 31,500 acre-feet more in 2020.

An oil shale development of one million barrels per day, with a support population of 78,000 depleting 97,000 acre-feet annually, was added. A coal by-products plant using 15,000 acre-feet and a potash plant, capacity 1.5 million tons annually, using 9,500 acre-feet annually are planned. Exports are increased by 2,400 acre-feet and fish and wildlife by 600 acre-feet annually.

It appears that Colorado will deplete its 51.75 percent allotment by the year 2000. Electrical power production is decreased by 9,690 MW from regionally interpreted OBERS, depleting 146,400 acre-feet less annually. In addition, 22,100 acre-feet of irrigation water will be transferred between 2001 and 2020 to meet municipal and industrial requirements.

New Mexico, in order to stay within its 11.25 percent of the 6.5 m.a.f. level of development in 2020, it was necessary to reduce the regionally interpreted OBERS use by a net of 9,500 a.f. annually. Major changes include a reduction of (1) 51,200 a.f. resulting from an arbitrary reduction in installed generating capacity in fuel burning powerplants, (2) an increase of 29,900 a.f. in mineral production, and (3) an additional municipal and industrial water use of 11,800 a.f. annually to supply a population increase of 64,500 persons.

Summaries of Proposed Uses

Table 14 enumerates water depletions by States, subregions, types of uses, and by time frames 1980, 2000, and 2020. Table 15 summarizes water supply depletions, modified flow, and residual outflow by subregions.

PART XII

ALTERNATIVE LEVELS OF DEVELOPMENT

Table 14 - Water use for the States' alternative
to the framework plan (6.5 MAF
level of development) 1980, 2000, and 2020
Upper Colorado Region

Type of use	On-site depletions (acre-feet per year)					Region	Green River	Upper Main Stem	San Juan-Colorado
	Arizona	Colorado	New Mexico	Utah	Wyoming				
-- 1980 --									
Municipal and industrial	2,900	22,100	7,200	10,100	4,300	46,600	12,200	16,200	18,200
Electric power (thermal)	34,100	10,700	90,000	125,400	33,200	293,400	56,700	1,600	235,100
Minerals	400	19,500	11,800	10,300	19,000	61,000	31,500	13,700	15,800
Fish and wildlife	1,200	38,800	6,800	22,200	18,800	87,800	49,400	7,900	30,500
Recreation	100	700	100	1,000	200	2,100	800	700	600
Stockpond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	116,800	118,800	176,300	80,300	532,300	165,900	53,800	312,600
Irrigation: consumptive use, incidental and reservoir evaporation	7,000	1,391,100	245,000	576,600	334,000	2,553,700	935,400	1,007,800	610,500
Export		663,400	117,500	190,000	65,000	1,035,900	255,000	660,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,171,300	481,300	940,300	479,300	4,119,300	1,356,300	1,722,500	1,040,500
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 1980						4,779,300	1,423,300	1,739,500	1,616,500
-- 2000 --									
Municipal and industrial	4,800	48,300	13,600	16,800	5,900	89,400	26,100	31,900	31,400
Electric power (thermal)	34,100	108,200	90,000	261,800	148,700	642,800	331,100	16,600	295,100
Minerals	300	128,300	17,400	10,300	22,100	178,400	74,400	67,700	36,300
Fish and wildlife	1,200	39,400	6,800	22,200	18,800	88,400	49,500	8,400	30,500
Recreation	300	1,100	100	1,600	200	3,300	1,400	900	1,000
Stockpond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	355,800	131,200	321,700	201,500	1,052,600	500,700	142,600	409,300
Irrigation: consumptive use, incidental and reservoir evaporation	7,600	1,778,200	411,000	660,600	407,000	3,264,400	1,197,500	1,184,500	882,400
Export		885,400	117,500	267,000	150,000	1,419,900	417,000	882,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,019,400	659,700	1,246,700	758,500	5,734,300	2,115,200	2,210,000	1,409,100
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2000						6,394,300	2,182,200	2,227,000	1,985,100
-- 2020 --									
Municipal and industrial	7,200	70,000	29,100	32,100	9,200	147,600	42,600	47,400	57,600
Electric power (thermal)	30,100	108,200	55,600	261,800	148,700	604,400	331,100	16,600	256,700
Minerals	300	124,500	32,500	52,900	21,500	231,700	109,400	71,800	50,500
Fish and wildlife	1,200	39,400	6,800	22,200	18,800	88,400	49,500	8,400	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stockpond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	379,500	128,200	382,300	205,300	1,136,300	556,000	166,100	414,200
Irrigation: consumptive use, incidental and reservoir evaporation	9,000	1,754,500	411,000	695,200	427,100	3,296,800	1,253,300	1,166,500	877,000
Export		885,400	117,500	267,000	185,000	1,454,900	452,000	882,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,019,400	656,700	1,341,900	817,400	5,885,400	2,261,300	2,215,500	1,408,600
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2020						6,545,400	2,328,300	2,232,500	1,984,600

1/ See explanation, page 52.

Table 15 - Available water supply for the States' alternative
to the Framework Plan (6.5 million acre-feet level of development)
Upper Colorado Region

	Green River	Upper Main Stem	San Juan- Colorado	Upper Colorado Region
	(1,000 Acre-Feet)			
Virgin Water Supply (1914-65)	5,460	6,806	2,606	14,872
<u>1980</u>				
Level of Depletions (1980)	1,356	1,723	1,040	4,119
Modified Flow (excluding Main Stem evap.)	4,104	5,083	1,566	10,753
Main Stem Evaporation	67	17	576	660
Residual Outflow	4,037	5,066	990	10,093
<u>2000</u>				
Level of Depletions (2000)	2,115	2,210	1,409	5,734
Modified Flow (excluding Main Stem evap.)	3,345	4,596	1,197	9,138
Main Stem Evaporation	67	17	576	660
Residual Outflow	3,278	4,579	621	8,478
<u>2020</u>				
Level of Depletions (2020)	2,261	2,215	1,409	5,885
Modified Flow (excluding Main Stem evap.)	3,199	4,591	1,197	8,987
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	3,132	4,574	621	8,327
<u>1/</u> Flaming Gorge Reservoir				
<u>2/</u> Curecanti Unit Reservoirs				
<u>3/</u> Lake Powell				

No. 2--State Alternative To The Framework Plan
(8.16 Million Acre-Feet Level of Development)

This is an alternate plan of development which reflects 8.16 million acre-feet of man-made depletions in the Upper Basin plus the delivery of an average $7\frac{1}{2}$ million acre-feet of water per annum at Lee Ferry. It includes the amounts of water evaporated from reservoirs related to deliveries at Lee Ferry. This plan assumes that the Colorado River water supply will be firmed to meet the Colorado River Compact division of water and that the Mexican Treaty delivery plus associated losses would be a national obligation. Depletion distribution among the states in 2020 equals their proportionate shares under the Upper Colorado River Basin Compact.

States have assumed that increased production associated with this level of development will be readily absorbed within national and increasing western markets. This is especially true since the added increment is a small part of the national market and will accordingly have a small impact.

State Proposals

Arizona retained its allotment of 50,000 acre-feet for 2020 with no changes in types of uses for regionally interpreted OBERS.

Colorado plans to irrigate 1,256,000 acres in 2020, which is 104,000 acres more than regionally interpreted OBERS, with a depletion of 1,941,500 acre-feet.

Oil shale developments, one on the Upper Main Stem by 2020 and one in the Green River by 2020, of one million barrels per day each, will deplete 194,000 acre-feet annually. A coal by-products plant using 15,000 acre-feet in the San Juan-Colorado, and a potash plant, capacity 1.5 million tons annually, using 9,500 acre-feet, are planned.

Fish and wildlife uses will total 71,400 acre-feet, a substantial increase over regionally interpreted OBERS. Thermo-electric power capacity of approximately 10,000 MW will deplete 153,200 acre-feet annually. Export will increase to 1.4 million acre-feet annually. This plan will meet regionally interpreted OBERS requirements for all sectors except power which will be met by Utah.

New Mexico plans no changes in agriculture, fish and wildlife, or recreation from regionally interpreted OBERS and will irrigate about 174,200 acres by the year 2020. Population by 2020 is estimated at 189,500 and the minerals industry is projected to available reserves and national need. Thermal-electric powerplant installed capacity

will be 5,623 MW. Export diverted to Rio Grande Basin via the San Juan-Chama Project and diverted to the Lower Colorado Region to the city of Gallup will be increased 125,000 acre-feet over OBERS for a total export of 243,000 acre-feet.

Utah will increase its use by irrigated crops 10,700 acre-feet over regionally interpreted OBERS and irrigate about 400,000 acres by 2020. There are no changes in fish and wildlife, recreation, or stock-pond evaporation and livestock use from OBERS. Export to the Great Basin by 2020 will increase to 447,000 acre-feet which is 20,000 acre-feet less than OBERS. Major changes are in increased thermal-electric power to 19,500 MW, increased mineral activity, including mining coal for powerplants, a million barrel per day oil shale development, and plants for processing oil impregnated sandstone and conversion of coal.

Wyoming's alternative plan of development includes a substantial increase in the mineral industry including a million barrels per day oil shale production, depleting 97,000 acre-feet of water, and conversion of coal. Trona plant capacity will continue to increase. Population will be increased over regionally interpreted OBERS by 63,000 to 148,000 by year 2020. The agricultural base of irrigated land will be higher than OBERS and increase to 518,500 acres by year 2020. Thermal-electric power installed capacity is estimated at almost 10,000 MW. Transbasin diversions to the North Platte are estimated at 153,000 acre-feet which is a 32,000 acre-foot reduction from regionally interpreted OBERS.

Summaries of Proposed Uses

Table 16 enumerates water depletions by States, subregions, types of uses, and by time frames 1980, 2000, and 2020. Table 17 summarizes water supply, depletions, and outflow by subregion for this alternative.

Table 16 - Water use for the States' alternative at the 8.16 MAF level of development, 1980, 2000, and 2020
Upper Colorado Region

Type of use	On-site depletions (acre-feet per year)						Green River	Upper Main Stem	San Juan-Colorado
	Arizona	Colorado	New Mexico	Utah	Wyoming	Region			
-- 1980 --									
Municipal and industrial	2,900	22,100	7,200	10,100	5,500	47,800	13,400	16,200	18,200
Electric power (thermal)	34,100	10,700	90,000	125,400	22,000	282,200	45,500	1,600	235,100
Minerals	400	19,500	19,800	10,300	23,900	73,900	36,400	13,700	23,800
Fish and wildlife	1,200	38,800	6,800	22,200	20,100	89,100	50,700	7,900	30,500
Recreation	100	700	100	1,000	200	2,100	800	700	600
Stockpond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	116,800	126,800	176,300	76,500	536,500	162,100	53,800	320,600
Irrigation: consumptive use, incidental and reservoir evaporation	7,000	1,391,100	245,000	576,600	431,500	2,651,200	1,032,900	1,007,800	610,500
Export		663,400	117,500	190,000	65,000	1,035,900	255,000	660,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,171,300	489,300	940,300	573,000	4,221,000	1,450,000	1,722,500	1,048,500
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 1980						4,881,000	1,517,000	1,739,500	1,624,500
-- 2000 --									
Municipal and industrial	4,800	50,000	13,600	20,200	7,300	95,900	29,500	31,900	34,500
Electric power (thermal)	34,100	153,200	90,000	291,800	37,000	606,100	234,400	61,600	310,100
Minerals	300	128,300	38,800	10,700	47,100	225,200	99,600	67,700	57,900
Fish and wildlife	1,200	39,400	6,800	22,200	20,100	89,700	50,800	8,400	30,500
Recreation	300	1,100	100	1,600	200	3,300	1,400	900	1,000
Stockpond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	402,500	152,600	355,500	117,500	1,070,500	433,900	187,600	449,000
Irrigation: consumptive use, incidental and reservoir evaporation	7,600	1,792,500	411,000	660,600	534,500	3,406,200	1,325,000	1,198,800	882,400
Export		925,400	243,000	437,000	125,000	1,730,400	602,000	882,900	245,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,120,400	806,600	1,450,500	777,000	6,204,500	2,360,900	2,269,300	1,574,300
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2000						6,864,500	2,427,900	2,286,300	2,150,300
-- 2020 --									
Municipal and industrial	7,200	84,100	29,100	42,500	28,900	191,800	78,300	54,400	59,100
Electric power (thermal)	30,100	153,200	90,000	291,800	148,700	713,800	346,100	61,600	306,100
Minerals	300	207,500	54,000	165,600	122,700	550,100	364,600	113,300	72,200
Fish and wildlife	1,200	71,400	6,800	22,200	20,100	121,700	50,800	40,400	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stockpond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	553,600	184,100	535,400	327,500	1,641,600	863,200	291,600	486,800
Irrigation: consumptive use, incidental and reservoir evaporation	9,000	1,941,500	411,000	733,700	562,500	3,657,700	1,470,100	1,262,600	925,000
Export		1,360,300	243,000	447,000	153,000	2,203,300	640,000	1,305,800	257,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,855,400	838,100	1,713,500	1,043,000	7,500,000	2,973,300	2,860,000	1,666,700
Main-stem reservoir evaporation						660,000 1/	67,000	17,000	576,000
Total for 2020						8,160,000	3,040,300	2,877,000	2,242,700

1/ See explanation, page 52.

Table 17 - Available water supply for the States' alternative
to the Framework Plan (8.16 million acre-feet level of development)
Upper Colorado Region

	Green River	Upper Main Stem	San Juan- Colorado	Upper Colorado Region
	<u>(1,000 Acre-Feet)</u>			
Virgin Water Supply (1914-65)	5,460	6,806	2,606	14,872
<u>1980</u>				
Level of Depletions (1980)	1,450	1,723	1,048	4,221
Modified Flow (excluding Main Stem evap.)	4,010	5,083	1,558	10,651
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	3,943	5,066	982	9,991
<u>2000</u>				
Level of Depletions (2000)	2,361	2,269	1,574	6,204
Modified Flow (excluding Main Stem evap.)	3,099	4,537	1,032	8,668
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	3,032	4,520	456	8,008
<u>2020</u>				
Level of Depletions (2020)	2,973	2,860	1,667	7,500
Modified Flow (excluding Main Stem evap.)	2,487	3,946	939	7,372
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	2,420	3,929	363	6,712
<u>1/</u> Flaming Gorge Reservoir				
<u>2/</u> Curecanti Unit Reservoir				
<u>3/</u> Lake Powell				

No. 3--State Alternative--Water Supply Available at Site

Development which would be possible if the states of the Upper Colorado Region could utilize water which would be physically available at site of project development is described briefly below. There has been no agreement between the states or within the states that this can be accomplished in the way indicated, but rather this discussion indicates utilization of water that is physically available for development. It is contemplated that there would be shifts between types of use as the needs develop. The plan would require substantial augmentation to meet Colorado River Compact requirements for delivery at Lee Ferry. If the Colorado River is augmented below Lake Powell, exchange arrangements would have to be made. Proper consideration of possible detriment to power revenues and of augmentation costs will be required.

Additional uses of 1.28 million acre-feet above the 8.16 m.a.f. level are described briefly by state, and summaries for total uses are shown in tables 18 and 19.

Arizona retained its allotment of 50,000 acre-feet for 2020 with no changes.

Colorado has identified additional uses by 2020, which would increase export to the eastern slope of the Rockies by 113,000 acre-feet annually and increase irrigation use by 69,000 acre-feet, primarily in the Upper Main Stem subregion.

New Mexico water depletions would increase 228,900 acre-feet, primarily for electric power, irrigation, and export to the Rio Grande Basin. Water depletions for mineral processing would be decreased about 40 percent.

Additional developments in Utah would all occur in the period 2001-2020. Irrigation projects not previously incorporated in plans would require over 200,000 acre-feet of water; coal conversion would double and require 22,300 acre-feet more water; and an additional 100,000 acre-feet would be exported to the Great Basin Region.

Projected depletions of the Colorado River system by Wyoming total 1,588,000 acre-feet, which is 545,000 acre-feet more than at the 8.16 million acre-feet level of development. Increases in depletions are limited to municipal and industrial water supply (primarily minerals) and export.

PART XII

ALTERNATIVE LEVELS OF DEVELOPMENT

Table 18 - Water use for the States'
alternative for water available at site,
Upper Colorado Region

Type of use	On-site depletions (acre-feet per year)						Green River	Upper Main Stem	San Juan- Colorado
	Arizona	Colorado	New Mexico	Utah	Wyoming	Region			
- - 1980 - -									
Municipal and industrial	2,900	22,100	7,200	10,100	10,500	52,800	18,400	16,200	18,200
Electric power (thermal)	34,100	10,700	112,000	125,400	22,000	304,200	45,500	1,600	257,100
Minerals	400	19,500	11,800	10,300	48,900	90,900	61,400	13,700	15,800
Fish and wildlife	1,200	38,800	6,800	22,200	20,100	89,100	50,700	7,900	30,500
Recreation	100	700	100	1,000	200	2,100	800	700	600
Stockpond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	116,800	140,800	176,300	106,500	580,500	192,100	53,800	334,600
Irrigation: consumptive use, incidental and reservoir evaporation	7,000	1,391,100	245,000	576,600	431,500	2,651,200	1,032,900	1,007,800	610,500
Export		663,400	118,000	190,000	115,000	1,086,400	305,000	660,900	120,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,171,300	503,800	940,300	653,000	4,315,500	1,530,000	1,722,500	1,063,000
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 1980						4,975,500	1,597,000	1,739,500	1,639,000
- - 2000 - -									
Municipal and industrial	4,800	50,000	13,600	20,200	19,300	107,900	41,500	31,900	34,500
Electric power (thermal)	34,100	153,200	131,000	291,800	37,000	647,100	234,400	61,600	351,100
Minerals	300	128,300	17,400	10,700	140,100	296,800	192,600	67,700	36,500
Fish and wildlife	1,200	39,400	6,800	22,200	20,100	89,700	50,800	8,400	30,500
Recreation	300	1,100	100	1,600	200	3,300	1,400	900	1,000
Stockpond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	402,500	172,200	355,500	222,500	1,195,100	538,900	187,600	468,600
Irrigation: consumptive use, incidental and reservoir evaporation	7,600	1,792,500	491,000	660,600	534,500	3,486,200	1,325,000	1,198,800	962,400
Export		925,400	243,000	437,000	300,000	1,905,400	777,000	882,900	245,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,120,400	906,200	1,450,500	1,057,000	6,584,100	2,640,900	2,269,300	1,673,900
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 2000						7,244,100	2,707,900	2,286,300	2,249,900
- - 2020 - -									
Municipal and industrial	7,200	84,100	29,100	42,500	38,900	201,800	88,300	54,400	59,100
Electric power (thermal)	30,100	153,200	131,000	291,800	148,700	754,800	346,100	61,600	347,100
Minerals	300	207,500	32,500	187,900	307,700	735,900	571,900	113,300	50,700
Fish and wildlife	1,200	71,400	6,800	22,200	20,100	121,700	50,800	40,400	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stockpond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	553,600	203,600	557,700	522,500	1,878,400	1,080,500	291,600	506,300
Irrigation: consumptive use, incidental and reservoir evaporation	9,000	2,010,500	571,000	935,500	562,500	4,088,500	1,550,900	1,385,600	1,152,000
Export		1,473,400	293,000	547,000	503,000	2,816,400	1,090,000	1,418,900	307,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	4,037,500	1,067,600	2,037,600	1,588,000	8,780,700	3,721,400	3,096,100	1,963,200
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 2020						9,440,700	3,788,400	3,113,100	2,539,200

1/ See explanation, page 52.

Table 19 - Available water supply for the States' alternative
for water available at site
Upper Colorado Region

	Green River	Upper Main Stem	San Juan- Colorado	Upper Colorado Region
	<u>(1,000 Acre-Feet)</u>			
Virgin Water Supply (1914-65)	5,460	6,806	2,606	14,872
<u>1980</u>				
Level of Depletion (1980)	1,597	1,740	1,639	4,976
Modified Flow (excluding Main Stem evap.)	3,863	5,066	967	9,896
Main Stem Evaporation	67	17	576	660
Residual Outflow	3,796	5,049	391	9,236
<u>2000</u>				
Level of Depletion (2000)	2,641	2,269	1,674	6,584
Modified Flow (excluding Main Stem evap.)	2,819	4,537	932	8,288
Main Stem Evaporation	67	17	576	660
Residual Outflow	2,752	4,520	356	7,628
<u>2020</u>				
Level of Depletion (2020)	3,721	3,096	1,963	8,780
Modified Flow (excluding Main Stem evap.)	1,739	3,710	643	6,092
Main Stem Evaporation	67 <u>1/</u>	17 <u>2/</u>	576 <u>3/</u>	660
Residual Outflow	1,672	3,693	67	5,432
<u>1/</u>	Flaming Gorge Reservoir			
<u>2/</u>	Curecanti Unit Reservoirs			
<u>3/</u>	Lake Powell			

End of Report