The Colorado River

"A NATURAL MENACE BECOMES A NATIONAL RESOURCE"

A Comprehensive Report on the Development of the Water Resources of the Colorado River Basin for Irrigation, Power Production, and Other Beneficial Uses in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming

By THE UNITED STATES DEPARTMENT OF THE INTERIOR

J. A. Krug, Secretary

SPONSORED BY AND PREPARED UNDER THE GENERAL SUPERVISION OF

U.S. THE BUREAU OF RECLAMATION.

Michael W. Straus, Commissioner

E. A. Moritz, Director, Region 3; E. O. Larson, Director, Region 4

MARCH 1946

THIS *edition of THE COLORADO RIVER is issued in advance of its publication as a Congressional Document in response to an urgent public demand for copies, many of them for official review. The document has not been transmitted to the Congress for consideration, nor will it be, until certain States and Federal officials who are now reviewing it have added their written comments to the text that appears here. When the report is published as a Congressional Document these comments will be included, or will appear in a supplementary volume.*

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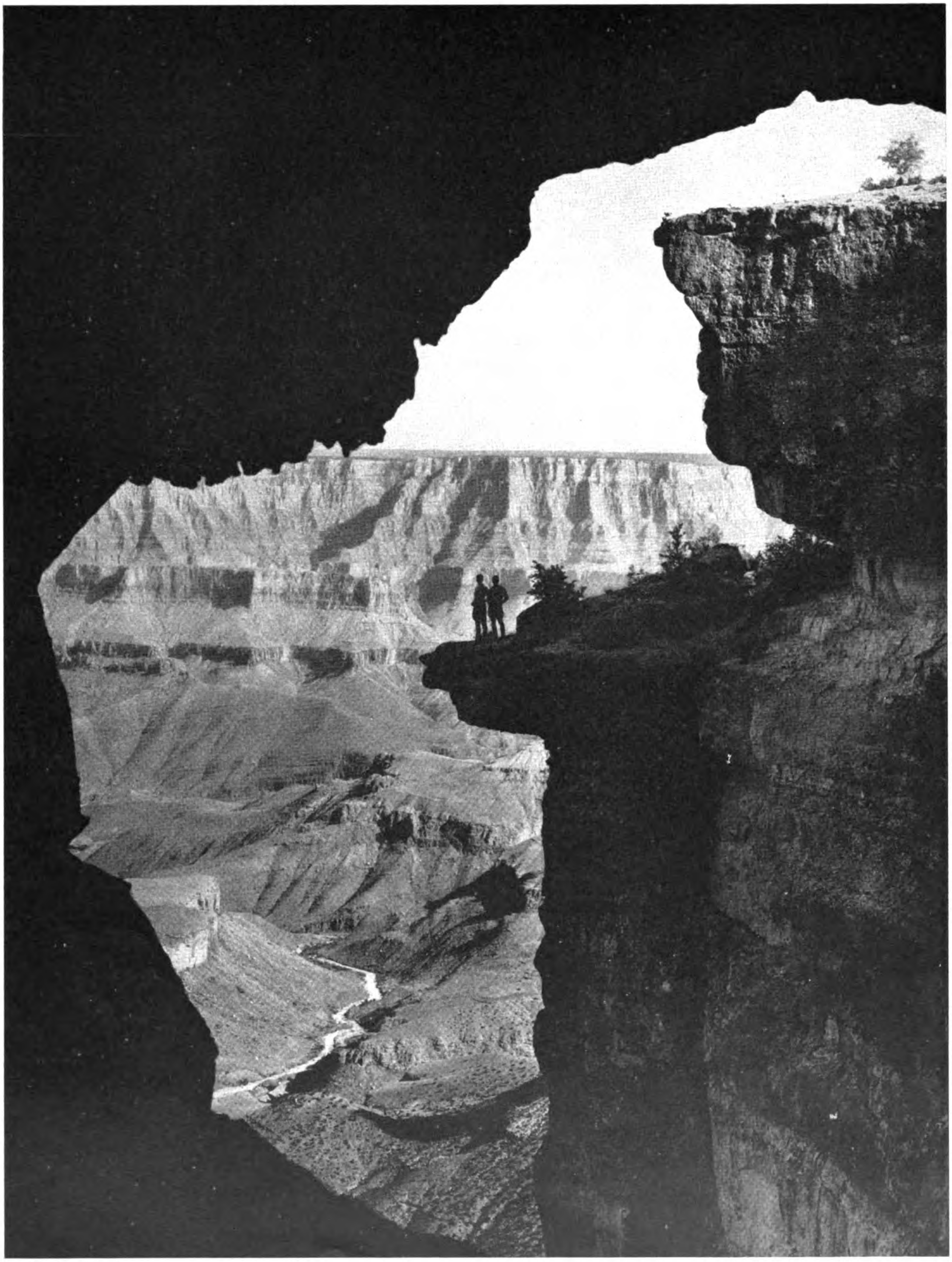
"[*This*] *report includes a description of the basin's resources, its needs and problems, and its present and potential development. . . .*

"*Upon clearance with the affected States and with the Secretary of War, copies of the report, together with comments, if any, of the affected States, and of the Secretary of War, will be submitted for your* [*the Secretary of the Interior's*] *transmittal to the President and, subsequently, to the Congress.*"



GRAND CANYON IN ARIZONA—*Carved by the Colorado River*

Proposed Report of the Secretary of the Interior

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WASHINGTON 25, D. C.

The SECRETARY OF THE INTERIOR.

JUNE 6, 1946.

SIR: I submit herewith a report dated March 22, 1946, on the Colorado River, which is a comprehensive report on the development of the water resources of the Colorado River Basin for irrigation, power production, flood and silt control, and other beneficial uses in the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

The report includes a description of the basin's resources, its needs and problems, and its present and potential development. Projects for future development of the water resources within the natural drainage basin are listed and their over-all results and benefits summarized. Projects for the exportation of water from the Colorado River Basin to adjacent basins are also discussed.

There is not enough water available in the Colorado River system for full expansion of existing and authorized projects and for development of all potential projects outlined in the report, including those possibilities for exporting water to adjacent watersheds. The formulation of an ultimate plan of river development, therefore, will require selection from among the possibilities for expanding existing or authorized projects as well as from among the potential new projects. Before such a selection for ultimate development can be made it will be necessary that, within the limits of the general allocation of water between upper basin and lower basin States set out in the Colorado River Compact, the Colorado River Basin States agree on suballocations of water to the individual States.

I concur generally in the recommendations of the regional directors as summarized in paragraph 70, page 22, of their report.[1] I hope that the Colorado River Basin States will recommend for construction, as the next stage of development, projects for which the stream flow depletions will assuredly fall within the ultimate allocation of Colorado River water which may be made to the individual States. I hope that the States of the Colorado River Basin will agree on suballocations of water within the limits of general allocations made by the Colorado River Compact. In addition, I suggest that arrangements be made for Federal participation in any conferences among States relating to suballocations of water. This will be important to insure that the Federal interest in over-all development is served fully.

The 134 potential projects or units of projects as described in the report are in addition to the existing and presently authorized projects or extensions of projects. Their estimated current construction costs are as follows:

[1] These recommendations appear on page 21, Regional Directors' Report, this volume.

Potential projects in the Colorado River Basin

Project and unit	Location of project	Source of water supply	Purpose to be served[1]	Estimated current construction costs
Upper basin				
Sublette	Wyoming	Green River	I, F, P	$58,400,000
West Side	do	do	I, F	
Daniel	do	do	I, F	
Elkhorn	do	do	I, P, F	
Paradise	do	New Fork River	I	
Eden	do	Big Sandy Creek	I	
Lower Big Sandy	do	do	I	
LaBarge	do	LaBarge Creek	I, F	
Fontenelle	do	Fontenelle Creek	I. F	
Seedskadee	do	Green River	I	
Opal	do	Hams Fork	I, F	5,760,000
Lyman	do	Blacks Fork, Smiths Fork	I, F	6,928,000
Henrys Fork	Wyoming, Utah	Henrys Fork	I, F	2,352,000
Flaming Gorge	do	Green River	P, F, H, S	16,000,000
Red Canyon	Utah	do	P, F	6,560,000
Little Snake River	Wyoming, Colorado	Little Snake River tributaries	I, P, F	34,400,000

See footnotes at end of table.

Potential projects in the Colorado River Basin—Continued

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated current construction costs
Upper basin—Continued				
Upper Yampa	Colorado	Yampa River	I, F	$3,680,000
Wessels	do	do	I, F	1,760,000
Mount Harris	do	Tributaries of Yampa River	I, F	5,280,000
Great Northern	do	Elkhead Creek and Elk River	I, F	4,320,000
Yellow Jacket	do	White River and Milk Creek	I, F	7,520,000
Deadman Bench	Colorado, Utah	Yampa River	I, P, F, H, S	38,080,000
Maybell	Colorado	do	I	1,120,000
Cross Mountain	do	do	P	8,000,000
Lily Park	do	do	P, F	3,040,000
Josephine Basin	do	White River	I	480,000
Piceance	do	Piceance Creek	I, F	1,280,000
Moon Lake extension	Utah	Duchesne River and tributaries	I, F	12,640,000
Fruitland	do	Red Creek	I, F	640,000
Castle Peak	do	Duchesne River	I, F	8,480,000
Mosby	do	Deep Creek, Whiterocks River	I, F	1,760,000
Vernal	do	Ashley Creek	I, F	2,400,000
Jensen	do	Brush Creek	I, F	480,000
Minnie Maud	do	Minnie Maud Creek	I, F	160,000
Green River Pumping	do	Green River	I	640,000
Echo Park	Colorado	do	P, F, H, S	68,800,000
Split Mountain	Utah	do	P, F, H, S	36,800,000
Emery County	do	Cottonwood Creek	I, F	4,000,000
Buckhorn	do	Huntington Creek	I, F	1,920,000
Gunnison Valley	do	Green River	I	1,760,000
Desolation Canyon	do	do	P, F, H	33,600,000
Rattlesnake Power	do	do	P, F, H	36,800,000
Troublesome	Colorado	Troublesome Creek	I, F	3,536,000
Muddy Creek	do	Muddy Creek	I, F	800,000
Gore Canyon	do	Colorado River	P	6,080,000
Fourmile	do	Fourmile Creek	I, F	960,000
Cattle Creek	do	Cattle Creek	I, F	688,000
Capitol Creek	do	Snowmass Creek	I	208,000
Woody Creek	do	Roaring Fork	I	272,000
Silt	do	Rifle Creek	I, F	2,112,000
West Divide	do	Middle Willow Creek	I, F	2,080,000
Hunter Mesa	do	Buzzard Creek	I, F	2,400,000
Roan Creek	do	Carr Creek	I, F	976,000
Collbran	do	Plateau Creek	I, F, M	3,104,000
Grand Valley Extension	do	Colorado River	I	664,000
Cisco-Thompson	Colorado, Utah	Colorado River [2]	P, I, F, H, S	54,784,000
Tomichi Creek	Colorado	Tomichi Creek	I, F	2,976,000
Cochetopa Creek	do	Cochetopa Creek	I, F	1,840,000
Ohio Creek	do	Anthracite and Castle Creeks	I, F	1,728,000
Lake Fork	do	Lake Fork	P. F	2,080,000
Sapinero	do	Gunnison River	P, F	12,480,000
Fruitland Mesa	do	Curecante and Sapinero Creeks	I. F	5,600,000
Smith Fork	do	Smith Fork	I, F	3,520,000
Paonia	do	East Muddy Creek and North Fork	I, F	2,240,000
Minnesota	do	Minnesota Creek	I, F	1,312,000
Leroux Creek	do	Leroux Creek	I, F	4,480,000
Grand Mesa	do	Currant, Surface, and Tongue Creeks.	I, F	3,072,000
Ouray	do	Uncompahgre River	P, I, F	6,560,000
Redlands	do	Gunnison River	I, F	587,000
Saucer Valley	do	Disappointment Creek	I, F	1,504,000
Nucla	do	Horsefly and Cottonwood Creeks	I, F	2,400,000
San Miguel	do	Anderson, Naturita and Dry Creeks, and San Miguel River.	I, F	10,544,000
West Paradox	do	West Paradox, Deep, and Geyser Creeks.	I, F	1,024,000
Dewey	Utah	Colorado River	P, F, H, S	60,800,000
Moab	do	do	P, F, H, S	15,840,000
Pack Creek	do	Mill Creek	I, F	1,240,000
Hatch Creek	do	Hatch Creek	I, F	640,000
Dulce-Chama-Navajo	Colorado	Navajo River	I, F	2,603,200
South San Juan	New Mexico	San Juan River	I, F	56,000,000
Carracas	Colorado	do	I	57,600
O'Neal Park	do	Piedra River	I	1,408,000
Hammond	New Mexico	San Juan River	I	1,160,000
Shiprock	do	San Juan River	I, F	33,825,600
Emerald Lake	Colorado	Pine River	P, F	9,920,000
Pine River Extension	Colorado, New Mexico	do	I	2,936,000
Florida	Colorado	Florida River	I, F	3,664,000
Animas-LaPlata	Colorado, New Mexico	Animas and LaPlata Rivers	I, P, F, S	101,654,400
McElmo	Colorado	McElmo Creek	I, F	624,000

See footnotes at end of table.

Potential projects in the Colorado River Basin—Continued

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated current construction costs
Upper basin—Continued				
Montezuma Valley Extension	Colorado	Dolores River	I, F	$2, 080, 000
Dolores	Colorado, Utah	do	I, F, S	19, 520, 000
Blanding	Utah	Recapture Creek	I, F	907, 200
Navajo Indian Project	Colorado	San Juan River	I, F, S	4, 656, 000
Bluff	Utah	do	P, F	30, 400, 000
Goosenecks	do	do	P, S, F, H	8, 320, 000
Slick Horn Canyon	do	do	P, S, F, H	10, 080, 000
Great Bend	do	do	P, S, F, H	16, 000, 000
Fremont	do	Fremont River	I, F	1, 280, 000
Torrey	do	do	I, F	320, 000
Escalante	do	Escalante River	I, F	1, 440, 000
Dark Canyon	do	Colorado River	P, F, S, H	168, 000, 000
Glen Canyon	Arizona	do	P, F, S, H	102, 400, 000
Transmission Grid				255, 000, 000
Subtotal, Upper Basin				1, 471, 227, 200
Lower basin				
Snowflake	do	Showlow and Silver Creeks	I, F, S	4, 160, 000
Black Creek	do	Black Creek	I, F, S	2, 880, 000
Holbrook	do	Little Colorado River	I, F, S, C	2, 080, 000
Winslow	do	Clear and Chevelon Creeks	I, F, S	30, 400, 000
Kanab Creek	do	Kanab Creek	I	320, 000
Hurricane	Utah, Arizona	Virgin River	I, P, S, F	14, 720, 000
Santa Clara	Utah	Santa Clara River	I, F, S	2, 720, 000
Panaca Valley	Nevada	Meadow Valley Wash	I, F	2, 080, 000
Moapa Valley	do	Muddy River	I, F, S	1, 120, 000
Moapa Valley Pumping	do	Lake Mead	I	4, 480, 000
Marble Canyon-Kanab Creek	Arizona	Colorado River	P, F, S, H	611, 200, 000
Coconino	do	Little Colorado River	F, S, H	6, 400, 000
Bridge Canyon	do	Colorado	P, I, F, S, H	234, 400, 000
Virgin Bay Pumping	Nevada	Lake Mead	I	2, 080, 000
Las Vegas Pumping	do	do	I, M	13, 440, 000
Davis Reservoir Pumping	do	Davis Reservoir	I	800, 000
Big Bend Pumping	do	Colorado River	I	1, 120, 000
Fort Mojave	do	do	I	1, 280, 000
Mojave Valley	Arizona	do	I	3, 040, 000
Alamo	do	Bill Williams River	F, P, H	5, 120, 000
Palo Verde Mesa	California	Colorado River	I	4, 960, 000
Wellton-Mohawk	Arizona	do	I	16, 960, 000
Sentinel	do	Gila River	F, H	24, 000, 000
River rectification and control	California, Arizona	Colorado River	F	8, 000, 000
Central Arizona	Arizona	do	I, F, P, M, U	692, 480, 000
Salt River				
Paradise Valley				
San Carlos				
Charleston				
Safford Valley				
San Francisco				
Duncan-Virden Valley				
New Mexico				
Chino Valley	do	Granite and Willow Creek	I	240, 000
Hassayampa	do	Hassayampa River	I, F	10, 640, 000
Transmission Grid				288, 150, 000
Subtotal, Lower Basin				1, 989, 270, 000
Total, Colorado River Basin.				3, 460, 497, 200

[1] Symbols used: I=Irrigation, F=flood control, P=power, H=hold-over storage for river regulation, S=silt retention, M=municipal, U=underground water recharge, C=channel improvement. In addition many potential reservoirs would have value for recreation and fish and wildlife conservation.
[2] Half the water required for this project would be diverted from the Gunnison River by exchange.

Estimates of the annual benefits from construction of the above potential projects have been made for illustrative purposes to show the probable economic justification of the ultimate comprehensive development. On the basis of average annual benefits and annual costs based on current prices the ratio of benefits to costs is approximately 1.00 to 1.00, which is a conservative estimate.

There are, in addition to the projects listed in the foregoing table, six existing Indian projects which now have an irrigated area of 2,470 acres. It is planned to enlarge these projects (Fort Mojave, Havasupai, Hualapai, Hopi, Moapa, and Uncompahgre) by an additional irrigable area of 30,200 acres which, when completed, could cause an estimated depletion of 73,000 acre-feet annually.

Sufficient data concerning these projects were not available to warrant their inclusion in the table, but their depletions, which represent less than one-half of one percent of the total depletions, should be considered in any allocation of water.

The Geological Survey has broad programs of geologic investigations and topographic mapping in the basin similar to those outlined to obtain basic hydrological facts which will contribute importantly to sound economic development. These surveys and investigations should be prosecuted actively so that data secured will be representative and adequate for the needs of planning and development.

The report is submitted to you pursuant to section 9 of the Reclamation Project Act of 1939 (53 Stat. 1187) and pursuant to section 15 of the Boulder Canyon Project Act (45 Stat. 1057). Upon clearance with the affected States and with the Secretary of War, copies of the report, together with comments, if any, of the affected States, and of the Secretary of War, will be submitted for your transmittal to the President and, subsequently, to the Congress.

I recommend that you adopt this report as your proposed report and that you authorize me, in your behalf, to transmit copies of this letter and of the attached proposed report to the affected States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, and to the Secretary of War in accordance with the requirements of section 1 of the act of December 22, 1944 (58 Stat. 887).

Respectfully,

William E. Warne,
Acting Commissioner.

Approved: June 7, 1946.

Oscar L. Chapman,
Acting Secretary of the Interior.

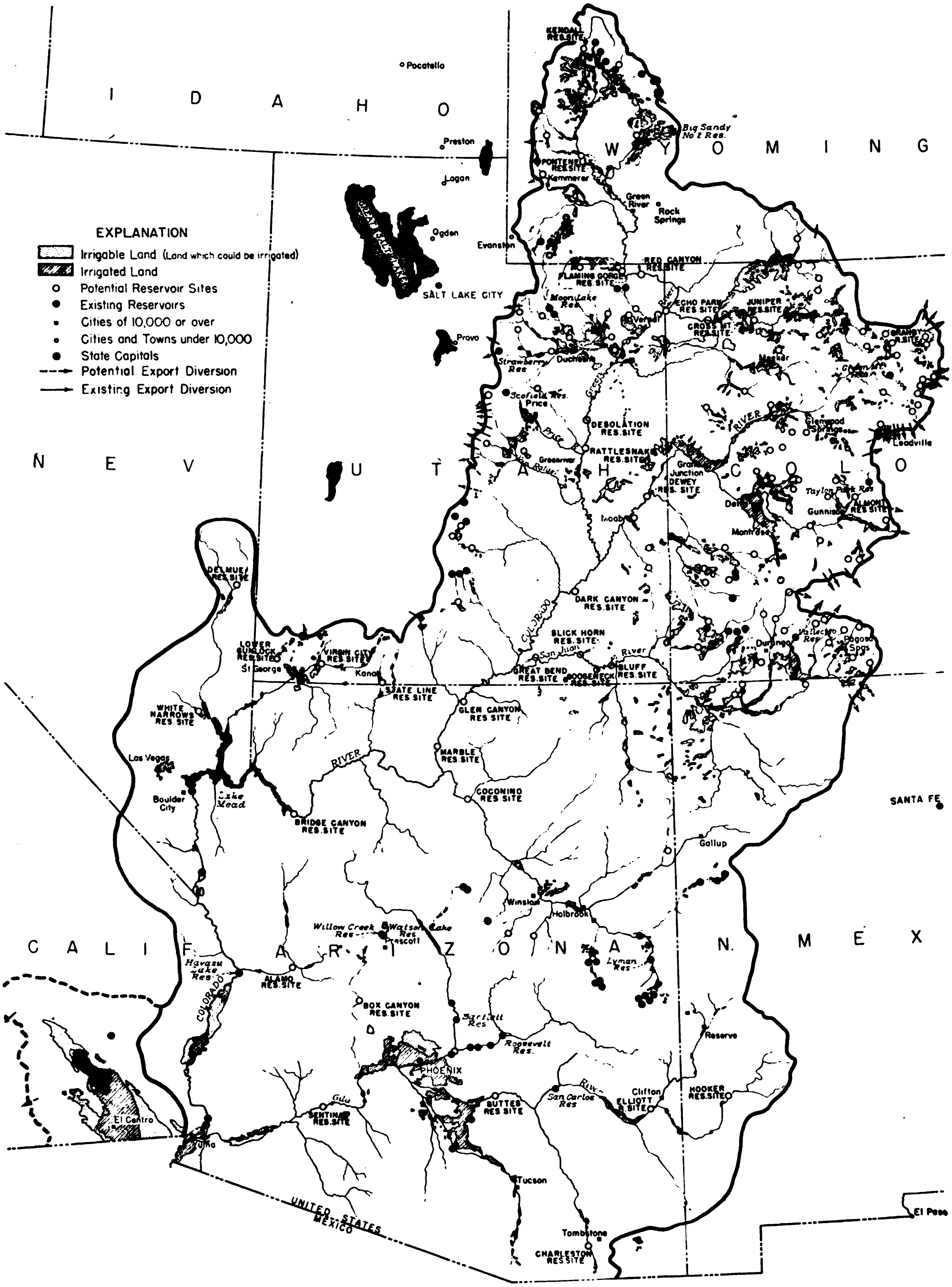
Regional Directors' Report

"There is not enough water available in the Colorado River system for full expansion of existing and authorized projects and for all the potential projects outlined in the report . . . [Therefore . . . it is recommended]

. . . "That the States of the Colorado River Basin, acting separately or jointly, recommend for construction, as the next stage of development, a group of projects, the stream flow depletions of which will assuredly fall within ultimate allocations of Colorado River water which may be made to the individual States.

. . . "That the States of the Colorado River Basin determine their respective rights to deplete the flow of the Colorado River consistent with the Colorado River Compact . . . .

"In the Colorado River Basin arable land without water is worth $1 to $5 an acre. Improved and irrigated it would be worth $75 to $300 an acre. The reclaiming of 1,500,000 acres would probably add more than one-quarter billion dollars to taxable values and supplemental water for 1,100,000 acres would further expand the tax base from 50 to 100 million dollars."



COLORADO RIVER BASIN

Regional Directors' Report

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MARCH 22, 1946.

From: Regional Director, Region III, Boulder City, Nevada.
Regional Director, Region IV, Salt Lake City, Utah.

To: The Commissioner, Bureau of Reclamation.

Subject: A comprehensive report on the development of the water resources of the Colorado River Basin in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

1. This letter is a report in brief form on the development of the water resources of the Colorado River Basin, which lies within the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. The substantiating material on which the report is based has been prepared as a presentation of the Department of the Interior, sponsored and coordinated by the Bureau of Reclamation. That material is attached.

Scope and Purpose

2. In order to show how the people in the basin and in the Nation can best be benefited by further development of the water resources of the basin, the report includes a description of the basin's resources, its needs and problems, and its present and potential development. Some 134 projects or units of projects are listed as possibilities for future development of the water resources within the natural drainage basin of the Colorado River. Estimates of costs, benefits, possible reimbursability and depletory effect on stream flow of these developments are presented. The report also discusses present and potential projects for the export of water from the Colorado River Basin to adjacent basins, but no estimates of construction costs, benefits, or reimbursability are presented. Because of the limited water supply all of the potential projects cannot be constructed and all of the existing and authorized projects expanded to the possible extent of their ultimate potentialities. The potential within-basin projects as a group are an index of the over-all results and benefits to be expected from the development of all the water resources of the basin. This report, with its substantiating material, provides a basin-wide perspective for planning development on a sound basis. It is intended to serve as a medium through which the Congress may be apprised of the potentialities for the development of the basin's water resources and as a guide in the selection of projects that ultimately will comprise the comprehensive plan for the utilization of the waters of the Colorado River system for irrigation, electrical power, and other purposes.

Authority for the Report

3. This report is authorized to be made by virtue of the Reclamation Act of June 17, 1902 (32 Stat. 388) and acts amendatory thereof or supplementary thereto, particularly the Boulder Canyon Project Act (45 Stat. 1057) and the Boulder Canyon Project Adjustment Act (54 Stat. 774).

Cooperation and Acknowledgments

4. The preparation of the report has been a joint effort of numerous Federal, State, and local governmental agencies, all looking toward the formulation of a comprehensive plan of ultimate development of the basin's water resources. The Geological Survey, National Park Service, Fish and Wildlife Service, Grazing Service, Bureau of Mines, Office of Indian Affairs, General Land Office, and Bureau of Reclamation, all within the Department of the Interior; the Federal Power Commission; and the Forest Service of the Department of Agriculture have prepared reports which are appended hereto as substantiating material. The experience and data files of the Corps of Engineers, War Department, and of the Soil Conserva-

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tion Service and Bureau of Plant Industry, Department of Agriculture, have been drawn on heavily through consultation with their personnel and free use of their publications.

5. The States of the basin have contributed materially to the report, formally through the Committees of Fourteen and Sixteen, which reviewed critically and constructively the initial draft of the substantiating material upon which this report is based, and less formally, but most usefully, through free access to their data and ready consultative services of their engineering and administrative personnel. The helpful services of many local governmental and private agencies, too numerous to be listed here, are gratefully acknowledged.

Description of Area

6. The Colorado River rises in the Rocky Mountains of Colorado and Wyoming, flows southwest about 1,400 miles and enters the Gulf of California. It drains an area of 242,000 square miles in this country—one-twelfth of the area of continental United States. The Salton Sea Basin in southeastern California, which includes the Coachella and Imperial Valleys, is discussed in this report because of its intimate relationship to the Colorado River.

7. In its course from the high peaks of the Rocky Mountains, the Colorado River traverses the mountain valleys of Colorado and Wyoming; flows through spectacular canyons, of which the Grand Canyon of the Colorado is the outstanding example, in southeastern Utah and northern Arizona; and finally, below Lake Mead, it courses through broad, alluvial valleys interspersed with mountain chains.

8. Climatologically, the basin has the extremes of year-round snow cover and heavy precipitation on the high peaks of the Rockies and truly desert conditions, in which precipitation is a rarity, in the Yuma area. Temperatures range from the temperate, affording only a 90-day growing season in the high mountain meadows of Colorado and Wyoming, to the semitropical with year-round cropping in the Yuma-Phoenix area. Developments by man within the basin are likewise startling in contrast, ranging from none in the remote plateaus of southeastern Utah and northern Arizona, inaccessible by highway or railroad and seen only by an occasional sheepherder, to the intensely developed suburban and agricultural areas surrounding Phoenix and Yuma and within the Imperial Valley.

9. The basin is important in the Nation's economy. Agricultural products include cattle and sheep from the vast range areas and the irrigated hay meadows of Wyoming, Colorado, New Mexico, Utah, and Arizona; temperate-climate fruits from Colorado; and citrus fruits, winter vegetables, livestock, and hay from the Phoenix-Yuma and Imperial Valley areas. There are now under irrigation 2,260,000 acres in the Colorado River watershed and an additional 416,000 acres are irrigated with Colorado River water in the Salton Sea Basin of southern California. In addition to the water used for this irrigation, 184,000 acre-feet annually are being exported to other adjacent stream basins in Colorado and Utah to supply requirements for irrigation, power, and domestic and municipal purposes, and 63,000 acre-feet were exported in 1945 to serve the Metropolitan Water District of Southern California.

10. Enormous beds of bituminous and subbituminous coal within the basin in eastern Utah, southern Wyoming, and western Colorado are estimated to contain nearly one-fourth of all the coal reserves in the United States. Mines in these areas now supply most of the coal requirements in the Rocky Mountain and Pacific Coast areas, including transcontinental railroads and the Utah and California steel industries. Vast deposits of oil shale and bituminous sandstone are undeveloped but, with coal, are becoming increasingly important as petroleum reserves approach exhaustion. Natural gas from basin fields in Wyoming, Colorado, and New Mexico supplies local needs and is piped to industrial areas outside the basin. Mines in Utah and Colorado are the leading domestic source of vanadium, uranium, radium, and molybdenum. Since 1910, Arizona has consistently led all States in copper production through mines and ore reduction mills within the basin. Gold and silver and several other metals, largely byproducts of copper mining, are mined in important quantities. Great beds of thinly-covered phosphate rock centering around the corner common to Utah, Wyoming, and Colorado provide a basis for a potential fertilizer industry.

11. Present development of hydroelectric power also presents a contrast as between areas in the basin. In the upper basin, that is, the basin above Lee Ferry, Arizona, only about 60,000 kilowatts of hydroelectric power have been developed. In the lower basin, on the other hand, the Boulder and Parker Dam power plants, those on the Salt River near Phoenix, and other lesser hydroelectric developments have an aggregate installed capacity of 1,258,000 kilowatts—roughly 50 percent of the dependable capacity available to the southern California-Arizona area. In 1945 Boulder and Parker Dam power plants alone produced 6.1 billion kilowatt-hours—about 60 percent of the energy consumed in that area. Further installation of 580,000 kilowatts of hydroelectric power is authorized or definitely planned.

12. The basin is important to the Nation from a recreational standpoint. Rocky Mountain, Mesa Verde, Bryce Canyon, Zion, and Grand Canyon National Parks, many National monuments, and the Boulder Dam National Recreational area lie wholly or partly within the

basin. These areas formally withdrawn for recreational purposes, together with the mountain streams and their unmatched trout fishing, the big game hunting, the Indian reservations, and the painted deserts of northern Arizona make the basin a National playground.

13. The construction of Boulder Dam by the Bureau of Reclamation was a great step in the control and development of the Colorado River. It has changed the character of a 565-mile section of the river from Grand Canyon to the Gulf of California. The dam controls destructive floods that formerly harassed farms and communities far downstream, and releases a controlled stream as needed for power development and municipal purposes and to irrigate lands in the lower Colorado River, Imperial, and Coachella Valleys. As a result of construction of Boulder Dam the domestic water supply of 14 cities 250 miles west of the Colorado River in the vicinity of Los Angeles is being augmented through the Colorado River Aqueduct of the Metropolitan Water District of Southern California. A new recreational area that attracts more than half a million people a year has been created by the dam and Lake Mead in an area formerly forbidding and unvisited. The lake is stocked with fish and has become one of the important features in the migration flyways for wild waterfowl. Power from Boulder Dam has made possible the vast industrial expansion of the Pacific Southwest, including the great shipyards, aircraft factories, and light metal refineries that helped so much to shorten the war.

Problems of the Basin

14. Substantial as is the contribution of the basin to the National economy, a much greater contribution can be made when its existing problems are eliminated and its potentialities developed. The basin's 900,000 people are less than one percent of the Nation's total but they occupy eight percent of the country's land area. Paradoxically, however, population pressure in parts of the basin forces young people to migrate elsewhere for opportunities. In this arid and semiarid area optimum use of the vast land resources is dependent on water being available for irrigation. Crop production without irrigation is possible in only a few areas and is of negligible importance. A stabilized and increased irrigation supply would permit a shift to more intensive types of farming in some sections thus providing agricultural opportunities for more people. The practical limit of water resources development by private enterprise has been reached. Development of the vast mineral resources is awaiting the low-cost power that can be generated at multipurpose dams which will serve also for irrigation and flood and silt control. The recreational resources—no inconsiderable asset—will be further realized as the basin's other resources and attendant community improvements are developed.

15. More specifically, inability to produce sufficient hay to winter-feed livestock has prevented optimum use of the fine range land of Wyoming, Colorado, and northern Utah; and lack of winter feed in southern Utah, New Mexico, and Arizona has forced use of the range the greater part of the year, possible because of the milder climate, and vast areas have been overgrazed with attendant erosion and destruction of national import.

16. Intensive irrigation farming is carried out in various parts of the upper basin, notably in the Grand Valley area in Colorado and the Uinta Basin in Utah. Several Federal Reclamation projects provide a fairly adequate irrigation supply in some areas but construction of additional projects is needed to supplement irrigation supplies for inadequately irrigated lands, permit more lands to be irrigated, and provide for substantial improvement in domestic water facilities.

17. Examples of lack of developed land and water resources to sustain existing communities are found in the Virgin River and Little Colorado River Basins. In the Virgin River Basin, somewhat isolated commercially and dependent almost exclusively upon an agricultural economy, the average area per irrigated farm is about 30 acres. To supplement his income the farmer has been forced to overstock the range, with the result that it has become denuded. Economic distress in the midst of undeveloped land and water resources prevails. The same conditions hold in the Little Colorado River Basin.

18. Population pressure, with its attendant demand for farm homes, has resulted in an overdevelopment of the water resources of the Phoenix area. Irrigators first relied on surface waters of the Gila and Salt Rivers, but expansion of irrigated areas led next to pumping of ground waters for purposes of drainage, and finally to overdraft of the ground water supply for irrigation. Ground water levels are being continually lowered, and pumping lifts already have become so great that substantial acreages in this very rich valley have been abandoned. Ultimate abandonment of as much as 200,000 acres is indicated unless a new supply of irrigation water is brought into the area.

19. Only by substantial drafts on Lake Mead storage has the southern California-southern Arizona power market area been able to meet its electric energy requirements during the war years immediately past. Normal load growth will require that this area, its oil and natural gas fuel supplies being seriously depleted, look to further hydroelectric power development on the lower Colorado River. Likewise expanding power loads in Utah, Colorado, and Wyoming focus attention on hydroelectric power possibilities in the upper basin. War emergency construction with the installation of 100,000 kilowatts of steam generating capacity in the Salt Lake City area

was necessary despite the importation to that area of a substantial amount of energy from Idaho and Montana.

20. The Colorado River carries a tremendous volume of silt, depositing annually approximately 137,000 acre-feet into Lake Mead. The silt discharge of the river does not portend immediate serious effect on the useful life of Lake Mead, a tremendous reservoir, but the service of this reservoir would be prolonged with upstream silt control. The small potential reservoirs at Bridge Canyon and Marble Canyon immediately upstream from Lake Mead would retain most of the silt now carried into Lake Mead but would soon be filled. Dams on heavy silt-carrying tributaries above these sites for the control of floods and silt, aided by proper watershed management, would do much to prevent impairment of the value of these main-stream reservoirs for river regulation and power development.

21. The Colorado River has always been an unstable stream through the alluvial plains and its delta area below the site of Boulder Dam. Recent rising of the river bed from silt deposition in the Needles-Topock area has required continuous raising of levees to prevent destructive flooding. In building its delta, the river has placed itself on a ridge, building it ever higher and continually threatening to break through protective works. In 1905 the river broke through and flooded the Imperial Valley, vastly enlarging the Salton Sea, and substantially damaging irrigation works, agricultural lands and improvements, and the roadbed of the Southern Pacific Railroad Co. before it was turned back into its channel in 1907. With desiltation of the river at Lake Mead, the channel downstream is undergoing a change in adjusting to the new regime. For the first 88 miles below Lake Mead the channel has been progressively lowered with most of the material being deposited in the 32-mile stretch next downstream. Control of the river channel below Boulder Dam is an important and difficult problem which will require attention for many years.

22. Although Boulder Dam provides full flood control of the Colorado River at Black Canyon, the area below is still subject to floods of lesser degree originating in the watershed areas of the Colorado, Gila, and Bill Williams Rivers below Boulder Dam. Above the dam there are no flood-control structures of significance to the river system as a whole. Local damage occurs frequently along tributary streams. For hundreds of miles above Boulder Dam the river and the lower stretches of its tributaries are confined in deep and barren canyons where floods can do no damage, but it is from these regions that most of the silt is carried into the river.

23. Flows of most tributary streams from which irrigation diversions are made recede in late summer to such an extent that crops suffer seriously from lack of water. Numerous reservoirs are needed to store flood flows for release as required for irrigation. The construction of Boulder Dam temporarily has solved the water-supply problem for main-stem diversion in the lower basin, but as expanding uses in all parts of the basin deplete available supplies, additional main-stream storage reservoirs will be necessary for the holding of water from wet to dry years and to permit it to be metered out to the manifold interests having rights in the stream. Dams built primarily for river regulation could serve also for power production, flood control, silt retention, fish and wildlife propagation, recreation, and other purposes.

24. The treaty between the United States and Mexico, which became effective on November 8, 1945, requires construction of Davis Dam (already authorized) by the United States within 5 years of that date, and necessitates certain facilities and arrangements for delivery of water to Mexico.

25. Numerous small projects now divert water from the Upper Colorado River Basin and convey it by tunnels or transmountain canals to adjoining watersheds for irrigation, domestic use, and power production. About 184,000 acre-feet are now being exported each year. The Colorado-Big Thompson project in Colorado and the Duchesne Tunnel of the Provo River project in Utah, both under construction by the Bureau of Reclamation, together with possible expansion under existing projects will provide for the exportation of an additional 474,000 acre-feet from the upper basin. There is a growing demand for more water from the Colorado River from water users in the adjacent North Platte, South Platte, Arkansas, Rio Grande, and Bonneville Basins. An ultimate diversion of 3,380,000 acre-feet annually from the upper basin is physically possible apparently at reasonable cost but the exportation of this amount would substantially limit potential within-basin uses.

26. The All-American Canal and the Colorado River Aqueduct are now exporting about 2,500,000 acre-feet of water from the Lower Colorado River for use in California. Potential expansion of these diversions to 5,300,000 acre-feet is possible but would likewise conflict with potential uses within the basin.

27. These major problems and others of smaller degree but nonetheless important to the economy of the basin and the Nation have prompted the preparation of this report.

Water Supply

28. In its virgin condition, before diversions were made by man, the Colorado River is estimated to have carried an average of 17,720,000 acre-feet of water annually across the International Boundary into Mexico. The annual flow varied from about 5,000,000 acre-feet to 25,000,000 acre-feet. Under the Mexican Treaty it is estimated that Mexico will receive 1,500,000 acre-feet

annually, leaving for consumption in the United States an average of 16,220,000 acre-feet plus such water as was consumed under virgin conditions by natural losses, preventable in part with full basin development.

29. Present water uses in the United States are estimated to deplete the virgin water supply at the boundary by about 7,120,000 acre-feet annually, leaving an average of about 9,100,000 acre-feet to meet expanding uses under existing or authorized projects and to supply new demands for potential projects within the Colorado River Basin States.

Division of Water

30. The Colorado River Compact, signed at Santa Fe, N. Mex., November 24, 1922, and made effective by subsequent ratification by the seven basin States, and by enactment of the Boulder Canyon Project Act (45 Stat. 1057), apportions the waters of the Colorado River system between the upper basin and the lower basin and provides that the States of the upper division (Colorado, New Mexico, Utah, and Wyoming) will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years. The compact also provides for a division of surplus waters after October 1, 1963. There is no final agreement among the States of the Colorado River Basin as to the amount of Colorado River water to be allocated to individual States nor have all of the States made final allocations of water among projects within their boundaries. There is not complete agreement among the States regarding the interpretation of the compact and its associated documents (the Boulder Canyon Project Act, the California Self-Limitation Act, and the several contracts between the Secretary of the Interior and individual States or agencies within the States for the delivery of water from Lake Mead). This report makes no attempt to interpret the Colorado River Compact or any other acts or contracts relating to the allocation of Colorado River water among the States and among projects within the States.

Future Development of Water Resources

31. Ultimate development of the water resources of the Colorado River will involve the investigation and construction of such projects as will fully utilize for irrigation, power production, flood control, and other beneficial purposes all the water in the Colorado River system available to the United States. Looking toward the formulation of a plan for comprehensive development, this report presents for consideration 134 potential projects or units of projects, mostly multiple purpose, for use of water within the natural drainage basin of the Colorado River. Potential projects for the export of water from the Colorado River Basin to adjacent basins are also discussed. The inventory of potential projects in this report and substantiating material is intended to be of use in the selection of projects which will comprise ultimately the final comprehensive plan. It is not intended that the listing of projects in this report will preclude the consideration of others that additional investigations may show to be desirable. In the formulation of the ultimate plan, however, consideration must also be given the possibilities for expanding projects now existing or authorized. Because of the limited water supply, it is not possible for all the potential projects to be constructed and for all the existing or authorized projects to be expanded to the possible extent of their ultimate potentialities. Each development can deplete the stream flow only insofar as permitted by the Colorado River Compact and other legal limitations. The formulation of an ultimate plan of river development, therefore, will require selection from among the possibilities for expanding existing or authorized projects as well as from among the potential new projects. Before such a selection of projects can be made it will be necessary that the seven Colorado River Basin States agree upon their respective rights to deplete the water supply of the Colorado River or that the courts apportion available water among them. Each State also will need to select from the potential projects within its boundaries those it desires to have constructed to consume its allocation of water. The many decisions and selections to be made require a vast background of factual information. To assist the States in the selection of projects the several agencies which have prepared this report stand ready to make available their consultative services and all information presently at hand. A great amount of engineering and economic investigational work has been required to assemble and evaluate the information from which has been prepared this inventory of potential projects. Detailed information is available for a substantial number of potential developments and only data of a reconnaissance nature for others, but from all the information available it should be possible, prior to a final settlement of water rights, to select a group of projects which are urgently needed, or which will be key units of the comprehensive plan for construction as the next stage of the development.

32. Although there would be enough water in the river system to serve all of the 134 within-basin projects or units of projects if no further exportation of water is made, it may be found more economical and the States may elect to forego construction of some irrigation projects within the natural drainage basin in order to make water available for exportation to adjacent watersheds within the basin States. When final allocations of water are made, moreover, some States may be unable to use their full amount unless part is exported. Power projects

do not consume water except by evaporation from power reservoirs, but most of these reservoirs serve multiple purposes and are required for full river regulation and control.

33. If all the 134 within-basin potential projects or units of projects were constructed, they would deplete the flow of the Colorado River by more than 6,000,000 acre-feet annually. New possibilities exist for the exportation of an additional 3,000,000 acre-feet annually to areas outside the natural drainage basin but within the boundaries of the Colorado River Basin States, as permitted by the Colorado River Compact. If all existing or authorized projects were constructed to the possible extent of their ultimate potentialities, they would increase present depletion by approximately 4,000,000 acre-feet. With present uses depleting the stream by about 7,000,000 acre-feet, the total depletions would aggregate more than 20,000,000 acre-feet, or about 25 percent more than the estimated amount of water available. Predominant among existing or authorized projects which could be further developed are those in the lower basin made possible by the construction of Boulder Dam. Possible future development of these enterprises would increase present river depletions by about 3,600,000 acre-feet annually, of which 2,800,000 acre-feet would be used in California outside the natural drainage basin of the Colorado River and the remainder would be consumed in Arizona or California or lost by reservoir evaporation. In the upper basin completion of existing or authorized transmountain diversion projects would further deplete the river by 474,000 acre-feet annually and expansion of within-basin projects would cause a depletion of 82,000 acre-feet.

34. The depletory effect on stream flow of all within-basin and export diversion projects, including existing or authorized projects and potential projects, is shown in table 1. The depletion shown under existing or authorized projects include present depletions resulting from projects in operation and possible depletions which would result from the extension of existing projects or the construction of authorized projects. Depletions are shown for the 134 potential within-basin projects and for the new export diversion possibilities.

TABLE I.—*Present and potential stream depletions in the Colorado River Basin*

Basin and State	Estimated average annual depletion (acre-feet) [1]			
	Existing or authorized projects		Potential projects	Total ultimate depletion
	Present depletion	Possible increase		
Upper Basin				
Arizona	10, 200		39, 000	49, 200
Colorado	1, 231, 300	507, 000	2, 522, 000	4, 260, 300
New Mexico	68, 400		450, 000	518, 400
Utah	515, 900	32, 000	1, 462, 700	2, 010, 600
Wyoming	374, 000	17, 000	576, 000	967, 000
Main stem reservoir losses			831, 000	831, 000
Pasture irrigation	(2)	(2)	500, 000	500, 000
Subtotal	2, 199, 800	556, 000	6, 380, 700	9, 136, 500
Lower Basin				
Arizona	1, 407, 200	571, 000	2, 015, 400	3, 993, 600
California	2, 680, 000	2, 946, 000	176, 000	5, 802, 000
Nevada	43, 800		213, 000	256, 800
New Mexico	29, 000		8, 000	37, 000
Utah	45, 000		56, 300	101, 300
Main stem reservoir losses	713, 000	66, 000	91, 000	870, 000
Subtotal	4, 918, 000	3, 583, 000	2, 559, 700	11, 060, 700
Total	7, 117, 800	4, 139, 000	8, 940, 400	20, 197, 200

Average flow available for depletion in the United States, 16,220,000 acre-feet.

[1] Includes both uses within the natural basin and export diversions to adjacent watersheds.
[2] Included in depletions shown by States.

Potential Projects

35. The 134 projects or units of projects included in the inventory of potential projects for development of the water resources of the Colorado River Basin are all located within the natural drainage basin of the Colorado River, 100 in the upper basin and 34 in the lower basin. (See par. 41, table II.) These within-basin potential projects considered as a group indicate in general the ultimate potentialities of future development. For that reason these projects are summarized in the following paragraphs. If similar basin reports for adjoining basins or individual project reports indicate the need and desirability for exporting water from the natural drainage basin for

use within the Colorado Basin States, as permitted by the Colorado River Compact, this would result in a corresponding reduction of within-basin uses. New possibilities for exportation of water to adjoining watersheds, such as the Blue River-South Platte and Gunnison-Arkansas projects in Colorado and the Central Utah project in Utah, are mentioned in the substantiating material but are not tabulated and summarized in the inventory of potential projects presented in this report.

36. If all of these 134 projects or units of projects should be constructed they would benefit 2,656,230 acres of land, 1,734,980 acres in the upper basin and 921,250 acres in the lower basin. Of this total 1,533,960 acres would be new land brought into cultivation, 1,230,810 acres in the upper basin and 303,150 acres in the lower basin, and 1,122,270 acres of inadequately irrigated land would be furnished a supplemental supply, 504,170 acres in the upper basin and 618,100 acres in the lower basin. (See par. 41, table III.) In addition to these lands vast areas of natural pasture lands in the upper basin would produce more abundantly under irrigation. These pasture lands, located mostly on gentle mountain slopes, have not been surveyed and consequently specific projects have not been planned to bring water to them, but in summarizing potentialities for new developments an ultimate river depletion of 500,000 acre-feet annually has been allowed for pasture irrigation.

37. These potential projects include 38 hydroelectric power plants with a total installed capacity of more than 3,500,000 kilowatts. (See par. 41, table IV.) Twenty-nine of the plants would be in the upper basin, mostly on tributary streams. The combined installed capacities of the upper basin plants would total 1,713,000 kilowatts and the annual energy output 9.2 billion kilowatt-hours. This is more than the anticipated requirement for power in the upper basin and would leave some for transmission to adjacent areas. The 9 new plants outlined for the lower basin would have installed capacities totaling 1,945,400 kilowatts and would produce 10.2 billion kilowatt-hours of additional energy a year. This would satisfy all expected demands in the lower basin and the adjacent West coast power market area until 1960, at which time additional power developments would be required to meet growing demands. The potential power output in both the upper and lower basins could be maintained substantially even with full development of the river system for irrigation and other purposes.

38. Potential power and irrigation reservoirs would make a substantial contribution to flood control in the basin, but the extent of that contribution cannot, of course, be determined until the projects to be constructed have been selected. Some of these reservoirs would permit use of a greater part of Lake Mead's capacity for irrigation storage and power production.

39. Reservoirs provided for irrigation, power production, or flood control would have incidental value for fishing, boating, and other recreational purposes. Reservoirs could be operated to maintain or improve the fishing in mountain streams. Specific projects are described which would furnish municipal supplies to Tucson, Ariz., and the Grand Valley area in Colorado. Future water requirements for growing municipalities and industries could be provided as needs arise. Many of the reservoirs would have storage capacity for retention of silt and mitigate that menace for a great many years to come.

40. Construction of all these potential projects for use of water in the natural drainage basin, including transmission grids, is estimated to cost $2,185,442,000 with expenditures divided $930,142,000 in the upper basin and $1,255,300,000 in the lower basin. These preliminary estimates are based on costs as of January 1940.

41. These 134 potential projects or units of projects, together with their locations, sources of water supply, purposes to be served, and estimated construction costs are listed in table II. Potential irrigation and power developments that would result from the construction of these projects are summarized in tables III and IV, respectively.

TABLE II.—*Potential projects in the Colorado River Basin*

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Upper basin				
Sublette	Wyoming	Green River	I, F, P	$36, 500, 000
West Side	do	do	I, F	
Daniel	do	do	I, F	
Elkhorn	do	do	I, F, P	
Paradise	do	New Fork River	I	
Eden	do	Big Sandy Creek	I	
Lower Big Sandy	do	do	I	
LaBarge	do	LaBarge Creek	I, F	
Fontenelle	do	Fontenelle Creek	I, F	
Seedskadee	do	Green River	I	
Opal	do	Hams Fork	I, F	3, 600, 000
Lyman	do	Blacks Fork, Smiths Fork	I, F	4, 330, 000
Henrys Fork	Wyoming, Utah	Henrys Fork	I, F	1, 470, 000
Flaming Gorge	do	Green River	P, F, H, S	10, 000, 000

See footnotes at end of table.

TABLE II.—*Potential projects in the Colorado River Basin*—Continued

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Upper basin—Continued				
Red Canyon	Utah	Green River	P, F	$4, 100, 000
Little Snake River	Wyoming, Colorado	Little Snake River tributaries	I, P, F	21, 500, 000
Upper Yampa	Colorado	Yampa River	I, F	2, 300, 000
Wessels	do	do	I, F	1, 100, 000
Mount Harris	do	Tributaries of Yampa River	I, F	3, 300, 000
Great Northern	do	Elkhead Creek and Elk River	I, F	2, 700, 000
Yellow Jacket	do	White River and Milk Creek	I, F	4, 700, 000
Deadman Bench	Colorado, Utah	Yampa River	I, P, F, H, S	23, 800, 000
Maybell	Colorado	do	I	700, 000
Cross Mountain	do	do	P	5, 000, 000
Lily Park	do	do	P, F	1, 900, 000
Josephine Basin	do	do	I	300, 000
Piceance	do	Piceance Creek	I, F	800, 000
Moon Lake Extension	Utah	Duchesne River and tributary	I, F	7, 900, 000
Fruitland	do	Red Creek	I, F	400, 000
Castle Peak	do	Duchesne River	I, F	5, 300, 000
Mosby	do	Deep Creek, Whiterocks River	I, F	1, 100, 000
Vernal	do	Ashley Creek	I, F	1, 500, 000
Jensen	do	Brush Creek	I, F	300, 000
Minnie Maud	do	Minnie Maud Creek	I, F	100, 000
Green River Pumping	do	Green River	I	400, 000
Echo Park	Colorado	do	P, F, H, S	43, 000, 000
Split Mountain	Utah	do	P, F, H, S	23, 000, 000
Emery County	do	Cottonwood Creek	I, F	2, 500, 000
Buckhorn	do	Huntington Creek	I, F	1, 200, 000
Gunnison Valley	do	Green River	I	1, 100, 000
Desolation Canyon	do	do	P, F, H	21, 000, 000
Rattlesnake Power	do	do	P, F, H	23, 000, 000
Troublesome	Colorado	Troublesome Creek	I, F	2, 210, 000
Muddy Creek	do	Muddy Creek	I, F	500, 000
Gore Canyon	do	Colorado River	P	3, 800, 000
Fourmile	do	Fourmile Creek	I, F	600, 000
Cattle Creek	do	Cattle Creek	I, F	430, 000
Capitol Creek	do	Snowmass Creek	I	130, 000
Woody Creek	do	Roaring Fork	I	170, 000
Silt	do	Rifle Creek	I, F	1, 320, 000
West Divide	do	Middle Willow Creek	I, F	1, 300, 000
Hunter Mesa	do	Buzzard Creek	I, F	1, 500, 000
Roan Creek	do	Carr Creek	I, F	610, 000
Collbran	do	Plateau Creek	I, F, M	1, 940, 000
Grand Valley Extension	do	Colorado River	I	415, 000
Cisco-Thompson	Colorado, Utah	do.[3]	P, I, F, H, S	34, 240, 000
Tomichi Creek	Colorado	Tomichi Creek	I, F	1, 860, 000
Cochetopa Creek	do	Cochetopa Creek	I, F	1, 150, 000
Ohio Creek	do	Anthracite and Castle Creeks	I, F	1, 080, 000
Lake Fork	do	Lake Fork	P, F	1, 300, 000
Sapinero	do	Gunnison River	P, F	7, 800, 000
Fruitland Mesa	do	Curecante and Sapinero Creeks	I, F	3, 500, 000
Smith Fork	do	Smith Fork	I, F	2, 200, 000
Paonia	do	East Muddy Creek and North Fork	I, F	1, 400, 000
Minnesota	do	Minnesota Creek	I, F	820, 000
Leroux Creek	do	Leroux Creek	I, F	2, 800, 000
Grand Mesa	do	Currant, Surface, and Tongue Creeks	I, F	1, 920, 000
Ouray	do	Uncompahgre River	P, I, F	4, 100, 000
Redlands	do	Gunnison River	I, F	367, 000
Saucer Valley	do	Disappointment Creek	I, F	940, 000
Nucla	do	Horsefly and Cottonwood Creeks	I, F	1, 500, 000
San Miguel	do	Anderson, Naturita, Dry Creeks, and San Miguel River.	I, F	6, 590, 000
West Paradox	do	West Paradox, Deep, and Geyser Creeks.	I, F	640, 000
Dewey	Utah	Colorado River	P, F, H, S	38, 000, 000
Moab	do	do	P, F, H, S	9, 900, 000
Pack Creek	do	Mill Creek	I, F	775, 000
Hatch Creek	do	Hatch Creek	I, F	400, 000
Dulce-Chama-Navajo	Colorado	Navajo River	I, F	1, 627, 000
South San Juan	New Mexico	San Juan River	I, F	35, 000, 000
Carracas	Colorado	do	I	36, 000
O'Neal Park	do	Piedra River	I	880, 000
Hammond	New Mexico	San Juan River	I	725, 000
Shiprock	do	do	I, F	21, 141, 000
Emerald Lake	Colorado	Pine River	P, F	6, 200, 000
Pine River Extension	Colorado, New Mexico	do	I	1, 835, 000
Florida	Colorado	Florida River	I, F	2, 290, 000

See footnotes at end of table.

TABLE II.—*Potential projects in the Colorado River Basin*—Continued

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Upper basin—Continued				
Animas-La Plata	Colorado, New Mexico	Animas and La Plata Rivers	I, P, F, S	$63, 534, 000
McElmo	Colorado	McElmo Creek	I, F	390, 000
Montezuma Valley Extension	do	Dolores River	I, F	1, 300, 000
Dolores	Colorado, Utah	do	I, F, S	12, 200, 000
Blanding	Utah	Recapture Creek	I, F	567, 000
Navajo Indian Project	Colorado	San Juan River	I, F, S	2, 910, 000
Bluff	Utah	do	P, F	19, 000, 000
Goosenecks	do	do	P, S, F, H	5, 200, 000
Slick Horn Canyon	do	do	P, S, F, H	6, 300, 000
Great Bend	do	do	P, S, F, H	10, 000, 000
Fremont	do	Fremont River	I, F	800, 000
Torrey	do	do	I, F	200, 000
Escalante	do	Escalante River	I, F	900, 000
Dark Canyon	do	Colorado River	P, F, S, H	105, 000, 000
Glen Canyon	Arizona	do	P, F, S, H	64, 000, 000
Transmission Grid				170, 000, 000
Subtotal, upper basin				930, 142, 000
Lower basin				
Snowflake	Arizona	Showlow and Silver Creeks	I, F, S	$2, 600, 000
Black Creek	do	Black Creek	I, F, S	1, 800, 000
Holbrook	do	Little Colorado River	I, F, S, C	1, 300, 000
Winslow	do	Clear and Chevelon Creeks	I, F, S	19, 000, 000
Kanab Creek	do	Kanab Creek	I	200, 000
Hurricane	Utah, Arizona	Virgin River	I, P, S, F	9, 200, 000
Santa Clara	Utah	Santa Clara River	I, F, S	1, 700, 000
Panaca Valley	Nevada	Meadow Valley Wash	I, F	1, 300, 000
Moapa Valley	do	Muddy River	I, F, S	700, 000
Moapa Valley Pumping	do	Lake Mead	I	2, 800, 000
Marble Canyon-Kanab Creek	Arizona	Colorado River	P, F, S, H	382, 000, 000
Coconino	do	Little Colorado River	F, S, H	4, 000, 000
Bridge Canyon	do	Colorado	P, I, F, S, H	146, 500, 000
Virgin Bay Pumping	Nevada	Lake Mead	I	1, 300, 000
Las Vegas Pumping	do	do	I, M	8, 400, 000
Davis Reservoir Pumping	do	Davis Reservoir	I	500, 000
Big Bend Pumping	do	Colorado River	I	700, 000
Fort Mojave	do	do	I	800, 000
Mojave Valley	Arizona	do	I	1, 900, 000
Alamo	do	Bill Williams River	F, P, H	3, 200, 000
Palo Verde Mesa	California	Colorado River	I	3, 100, 000
Wellton-Mohawk	Arizona	do	I	10, 600, 000
Sentinel	do	Gila River	F, H	15, 000, 000
River rectification and control	California-Arizona	Colorado River	F	5, 000, 000
Central Arizona: Salt River. Paradise Valley. San Carlos. Charleston. Safford Valley. San Francisco. Duncan-Virden Valley. New Mexico.	Arizona	do	I, F, P, M, U	432, 800, 000
Chino Valley	do	Granite and Willow Creeks	I	150, 000
Hassayampa	do	Hassayampa River	I, F	6, 650, 000
Transmission Grid				192, 100, 000
Subtotal, lower basin				1, 255, 300, 000
Total, Colorado River Basin				2, 185, 442, 000

[1] Symbols used: I=irrigation; F=flood control; P=power; H=hold-over storage for river regulation; S=silt retention; M=municipal; U=underground water recharge; C=channel improvement. In addition many potential reservoirs would have value for recreation and fish and wildlife conservation.
[2] Preliminary estimates based on construction costs Jan. 1, 1940.
[3] Half the water required for this project would be diverted from the Gunnison River by exchange.

TABLE III.—*Potential irrigation development in the Colorado River Basin*

Basin and State	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Upper basin			
Arizona	18, 680	6, 000	24, 680
Colorado	444, 060	226, 550	670, 610
New Mexico	224, 960	15, 100	240, 060
Utah	251, 780	161, 160	412, 940
Wyoming	291, 330	95, 360	386, 690
Subtotal, upper basin	1, 230, 810	504, 170	1, 734, 980
Lower basin			
Arizona	229, 050	594, 600	823, 650
California	16, 000	0	16, 000
Nevada	43, 100	4, 500	47, 600
New Mexico	2, 000	10, 800	12, 800
Utah	13, 000	8, 200	21, 200
Subtotal, lower basin	303, 150	618, 100	921, 250
Total, Colorado River Basin	1, 533, 960	1, 122, 270	2, 656, 230

TABLE IV.—*Potential power development in the Colorado River Basin*

Basin and State	Power plant installed capacity (kilowatts)	Annual firm generation (kilowatt-hours) [1]
Upper basin		
Arizona	400, 000	2, 188, 000, 000
Colorado	325, 500	1, 661, 000, 000
New Mexico		
Utah	986, 000	5, 383, 000, 000
Wyoming	1, 500	9, 000, 000
Subtotal, upper basin	1, 713, 000	9, 241, 000, 000
Lower basin		
Arizona	1, 937, 800	10, 182, 000, 000
California		
Nevada		
New Mexico	3, 000	8, 000, 000
Utah	4, 600	15, 000, 000
Subtotal, lower basin	1, 945, 400	10, 205, 000, 000
Total, Colorado River Basin	3, 658, 400	19, 446, 000, 000

[1] Net firm generation, exclusive of replacement power.

Summary of Annual Benefits and Costs of Potential Projects

42. A definite analysis of basin-wide development of water resources cannot be presented until a final selection of projects has been made. The following estimates and approximations are based on development of all potential within-basin projects summarized in the report. This analysis is presented to indicate the economic feasibility of a comprehensive plan for ultimate development of the water resources of the basin. All projects are considered integral units of a basin plan and as such their economic feasibility is comprehended by the finding of feasibility for the over-all basin plan. To accommodate ultimate development to the available water supply, those projects which further investigations show to be the less desirable will be eliminated from the ultimate plan. If some States elect to use part of the water to which they are entitled in out-basin or export diversion projects, a corresponding elimination of within-basin projects will be necessary. The ultimate effect of this selective process undoubtedly will be an even more favorable showing of economic justification for the over-all basin development.

43. It is expected that an allocation of costs as provided in section 9 of the Reclamation Project Act of 1939, and acts amendatory thereof or supplementary thereto, would result in an equitable and appropriate distribution of allocable costs among the purposes to be served.

44. Estimates of benefits from irrigation, power production, municipal water supplies, and flood control are summarized in the following table. The increase in gross crop income is taken as the measure of the benefits from irrigation. For the purpose of illustration, power benefits are determined as the gross income from the sale of electric energy at an assumed rate of four mills a kilowatt-hour, delivered at load centers. Returns from the sale of water for municipal purposes are not subject to a precise analysis but a gross annual return of $500,000 is assumed as a measure of the municipal benefits. Flood control benefits resulting from the construction of numerous dams and other structures are measured by the decrease in average annual flood damages along the Colorado River and its tributaries. These benefits indicate that a basin-wide plan for full development of the water resources could return to the Nation $1.30 for each dollar required to construct, maintain and operate the projects.

Annual benefits	
Irrigation benefits	$65, 000, 000
Power benefits	72, 000, 000
Flood control benefits	1, 000, 000
Municipal benefits	500, 000
Total measurable annual benefits	138, 500, 000
Annual costs	
Operation and maintenance	23, 000, 000
Amortization of construction cost ($2,185,442,000) in 50 years at 3 percent	85, 000, 000
Total annual costs	108, 000, 000
Ratio of benefits to costs	
Ratio of annual benefits to annual costs	1. 3 : 1

Extended Benefits to the West and to the Nation

45. The beneficial effect of complete control and utilization of waters of the Colorado River would be far-

reaching. Some benefits are tangible and are subject to measurement in monetary terms with a considerable degree of accuracy while others are less tangible and are not subject to accurate measurement. For example, a stable agriculture and abundant low-cost power together provide a sound basis for industrial and commercial expansion and thus are important to the region and the Nation but are not readily susceptible of dollar evaluation. Still other values would grow from better control of silt in the stream channels, from improved conditions for fish and wildlife, and from the enhancement of recreational facilities. A few of these less tangible benefits to the West and to the Nation are cited in the following paragraphs.

46. In the Colorado River Basin arable land without water is worth $1 to $5 an acre. Improved and irrigated it would be worth $75 to $300 an acre. The reclaiming of 1,500,000 acres would probably add more than one-quarter billion dollars to taxable values and supplemental water for 1,100,000 acres would further expand the tax base from 50 to 100 million dollars. This would provide increased return to State and local taxing institutions thus permitting improvements in the various services necessary to the welfare of the people. Increased earnings would also reflect favorably on income-tax receipts.

47. An increase in gross crop income estimated at $65,000,000 a year at prewar prices would in substantial measure represent feed for livestock. Conversion of these crops to beef, mutton, hides, wool, poultry, and dairy products would result in a much higher gross farm income. The increased revenue to the farmers would be spent in part for domestic and professional services, for common and skilled labor, for transportation and utilities, and for processing and packing. The thousands of farm families and an appreciably greater number who will provide services for the people will have increased purchasing power for services and commodities provided from nearly all parts of the Nation.

48. The availability of an abundance of low-cost electric power would stimulate industry in the entire power market area and, like expanded irrigation, would result in the creation of new taxable values, new opportunities, and increased purchasing and consuming power. Electricity could partially replace the West's diminishing oil reserves as a source of fuel and energy in homes, factories, and railroads. It would stimulate further the extraction and processing of the Colorado River Basin's vast mineral resources including metals, fertilizers, and the coal and shale which in the not-far-distant future may replace petroleum as the Nation's major source of oil and gasoline.

49. Increased production of food and fiber on basin farms would help to meet the increased demands of a growing Nation. The livestock and livestock products, citrus and other fruits, vegetables, seeds, sorghums and other agricultural produce from Colorado River Basin farms as a rule are not produced in this country in sufficient quantities to satisfy domestic needs. Foods produced in the basin are predominantly of a variety needed to improve the national diet and assure good health. The crops are supplemental to, rather than competitive with, crops produced on agricultural lands of other sections of the country. Full development of the water resources of the Colorado River will actually increase the demand for the products of farms in the great midwestern and southern farm belts.

50. Reservoirs will add scenic beauty and have recreational value. They will become the habitat of fish and wildlife. By affording control of stream flows they can be operated to improve fishing in the Colorado River and its numerous tributaries. Improved roads constructed to remote reservoirs, power plants, or tunnel portals will make accessible great scenic wonders, fishing spots, and hunting areas not now reached by modern travel.

51. Construction of the many projects would provide widespread employment. Less than half of the amount spent for labor would go to workers at project sites and the remainder to workers at producing centers, principally east of the irrigation States. As the projects are placed in operation many thousands of people will find employment opportunities in agriculture, industry, and the numerous associated and dependent enterprises that will be expanded or created as a result of these developments.

52. The Nation will more nearly approach economic self-sufficiency in the production of food and in the mining and processing of minerals. Vast facilities for increasing the national strength with food, power, industry, and mineral development, constructed in times when labor and materials are abundant, will stand ready to produce with a minimum expenditure of effort in time of war.

Reimbursement and Flood Control Allocation

53. The total estimated construction cost of all the potential within-basin projects outlined in this report is $2,185,442,000, based on January 1940 prices. Cost allocations to some benefits of a public character cannot appropriately be considered repayable by the water users under reclamation laws. Of the total cost, it is estimated that an allocation of $25,000,000 may reasonably be made to flood control. It is further estimated that gross revenues collectible from irrigators, power users, and municipalities will amount to $57,500,000 annually in excess of costs for operation and maintenance. The latter sum could be applied toward repayment of those reimbursable costs resulting from the allocations made to the various benefits.

Construction Program

54. There is need for proceeding at an early date with the construction of certain of the potential projects. In areas such as would be served by the Animas-LaPlata, Hurricane, and Snowflake projects, existing distress resulting from the lack of opportunities in irrigated agriculture should be relieved as promptly as practicable. The power markets of southern California and southern Arizona will shortly require the construction of a major hydroelectric development on the lower river; similarly, the load growth in Utah and western Colorado will require construction of power developments in the upper basin. An existing economy in the Salt and Gila River Valleys in central Arizona is threatened with serious losses through overdraft of its water supply from underground sources. Key developments necessary in many instances before lesser developments can proceed, should be constructed at an early date in order that those dependent projects may follow in logical order and basin-wide development be undertaken in stages.

55. To activate a construction program, it is suggested that the affected States decide from among the known potentialities which projects they desire to have the Bureau of Reclamation consider for construction and that such projects as are selected for construction comprise the next stage of development. The economic feasibility of the group of projects included in this next stage of development would be comprehended in the finding of feasibility for the over-all ultimate development of the basin. The group of projects should include those for which there is an immediate need and for which adequate water rights consistent with the Colorado River Compact and its associated and dependent documents are assured. As has been stated, the agencies which have prepared this report stand ready with their consultative services to assist the States in this selective process. When the next stage of development has been decided upon, it may be presented to the Congress as a program for authorization of construction.

Related Investigations

56. Various Federal agencies having an interest in development of resources in the basin have collaborated in the preparation of this report. These agencies have cooperated to the extent of funds and personnel available, and their specific comments are found in chapter VIII of the substantiating material attached.

57. The Geological Survey has furnished basic data on stream flow, ground-water supplies, quality of water, water utilization, minerals, and mapping. In order to obtain additional basic facts related to both surface water and ground water of the Colorado River Basin, the Geological Survey has outlined a 3-year investigational program estimated to cost about $650,000 a year. The basic water facts obtained by the Geological Survey are needed for use not only in the design, construction, and operation of potential projects but also in the planning, construction, operation, and administration of other structures, present and future, involving the use of water in the basin. Surveys and investigations should be prosecuted actively so that data secured will be continuous and representative.

58. The National Park Service has surveyed the recreational possibilities of the potential projects and has made a number of specific recommendations which will enhance their recreational value. The Bureau of Reclamation concurs in the objectives of these proposals. The National Park Service, however, questions the advisability of the Moab power project on the ground that it "would inundate the lower slopes and bottom of an unusually scenic canyon and eliminate the existing road which runs through the canyon between Moab and Dewey, Utah." A road could be constructed along the edge of the reservoir, and in all probability this would add to the scenic attractions of the canyon. Such differences do not represent conflicts between the purposes of these agencies both of which desire to secure maximum over-all benefits for the people of the basin.

59. The Fish and Wildlife Service has made preliminary studies of the potential projects reported herein and has made a number of specific recommendations which will assure the restoration and conservation of fish and wildlife resources. The Bureau of Reclamation concurs in principle with these recommendations. Owing to very limited stream flows which prevail during dry years, however, it would be impracticable to maintain the minimum releases of water which are desired. As detailed project plans are prepared, the interest of the Fish and Wildlife Service can be correlated into a unified program. In order to provide the increased fish stocking required for the new reservoirs the Fish and Wildlife Service should develop and expand its present facilities at Springville, Utah, construct a new combination trout-bass fisheries station near Page Springs in Oak Creek Canyon, about 40 miles south of Flagstaff, Ariz., and supplement the facilities of this new hatchery by further developing the Williams Station for necessary incubation of trout eggs, as recommended in its report.

60. The Grazing Service has outlined the objectives of its range improvement program and the benefits that will result from potential projects in stabilization of the livestock industry and conservation of natural resources. Results of the proposed Reclamation program in the Colorado River Basin will be favorable from a Grazing Service viewpoint.

61. The Bureau of Mines has probed the minerals of the basin to discover how they might best be mined, proc-

essed, and utilized to support the metallurgical and industrial economy that is envisioned. "The mineral industries in the Colorado River Basin constitute one of the most obvious outlets for power generated at multiple-purpose dams."

62. The Office of Indian Affairs has outlined projects that will benefit the Indians of the basin.

63. The General Land Office, which administers about 6 million acres of public land in the Colorado River Basin, has outlined a program to obtain optimum use of these public lands and to coordiate their utilization with the development of water resources.

64. The Forest Service has emphasized the need for careful management of water on the national forest lands to insure adequate safeguarding of the water yields.

65. The Federal Power Commission has furnished data upon which power utilization and market trends are based and has commented generally on the power resources of the basin.

66. The interest and cooperation of State and local groups, as well as other Federal agencies in the basin, are reflected throughout the report.

Conclusions

67. Future development of the water resources of the Colorado River Basin is needed to relieve economic distress in local areas, to stabilize highly developed agricultural areas, and to create opportunities for agricultural and industrial growth and expansion throughout the Colorado River Basin. Such development should be comprehended in a basin-wide plan for ultimate development of all water resources of the basin. The potential projects outlined in this report will form the basis for future detailed investigations and the selection and construction of sound projects. Considered as a group, these projects are an index of the over-all results and benefits to be expected from the development and utilization of all the available waters of the Colorado River system. They indicate also the engineering feasibility and economic justification of an over-all plan for basin development. Planning has progressed sufficiently to make possible a selection from among the potentialities of a group of projects to comprise a construction program for the next stage of basin development. These projects should be key features of or should fit into the final comprehensive plan to be developed through continued investigations and planning.

68. There is not enough water available in the Colorado River system for full expansion of existing and authorized projects and for all potential projects outlined in the report, including the new possibilities for exporting water to adjacent watersheds. The need for a determination of the rights of the respective States to deplete the flow of the Colorado River consistent with the Colorado River Compact and its associated documents therefore is most pressing.

69. It is concluded that future development of the water resources of the Colorado River Basin would benefit the National and local economies and a plan for development of all the water resources of the basin should therefore be effectuated, that the selection of a group of projects comprising the next stage of development would represent a logical step in effecting that plan, and that detailed investigations to develop the succeeding stages should be continued.

Recommendations

70. The following recommendations are made in view of the fact that there is not enough water available in the Colorado River system to permit construction of all the potential projects outlined in the report and for full expansion of existing and authorized projects, and that there has not been a final determination of the respective rights of the Colorado River Basin States to deplete the flow of the Colorado River:

(1) That the States of the Colorado River Basin, acting separately or jointly, recommend for construction, as the next stage of development, a group of projects, the stream-flow depletions of which will assuredly fall within ultimate allocations of Colorado River water which may be made to the individual States.

(2) That the States of the Colorado River Basin determine their respective rights to deplete the flow of the Colorado River consistent with the Colorado River Compact.

(3) That additional investigations, summarized below, and appropriations to the Department of the Interior for use by the various agencies within that Department for these investigations, be approved.

(*a*) The Bureau of Reclamation to continue and expand its detailed investigations of potential projects within the States of the Colorado River Basin to obtain adequate information by which the Department of the Interior in cooperation with the basin States can formulate a comprehensive plan for use of all the water resources of the basin and select and recommend projects for successive stages of development.

(*b*) The Geological Survey, National Park Service, Fish and Wildlife Service, Grazing Service, Bureau of Mines, Office of Indian Affairs, and General Land Office to initiate or continue to conduct such investigations and studies as required by the Secretary of the Interior to formulate and carry out the comprehensive plan.

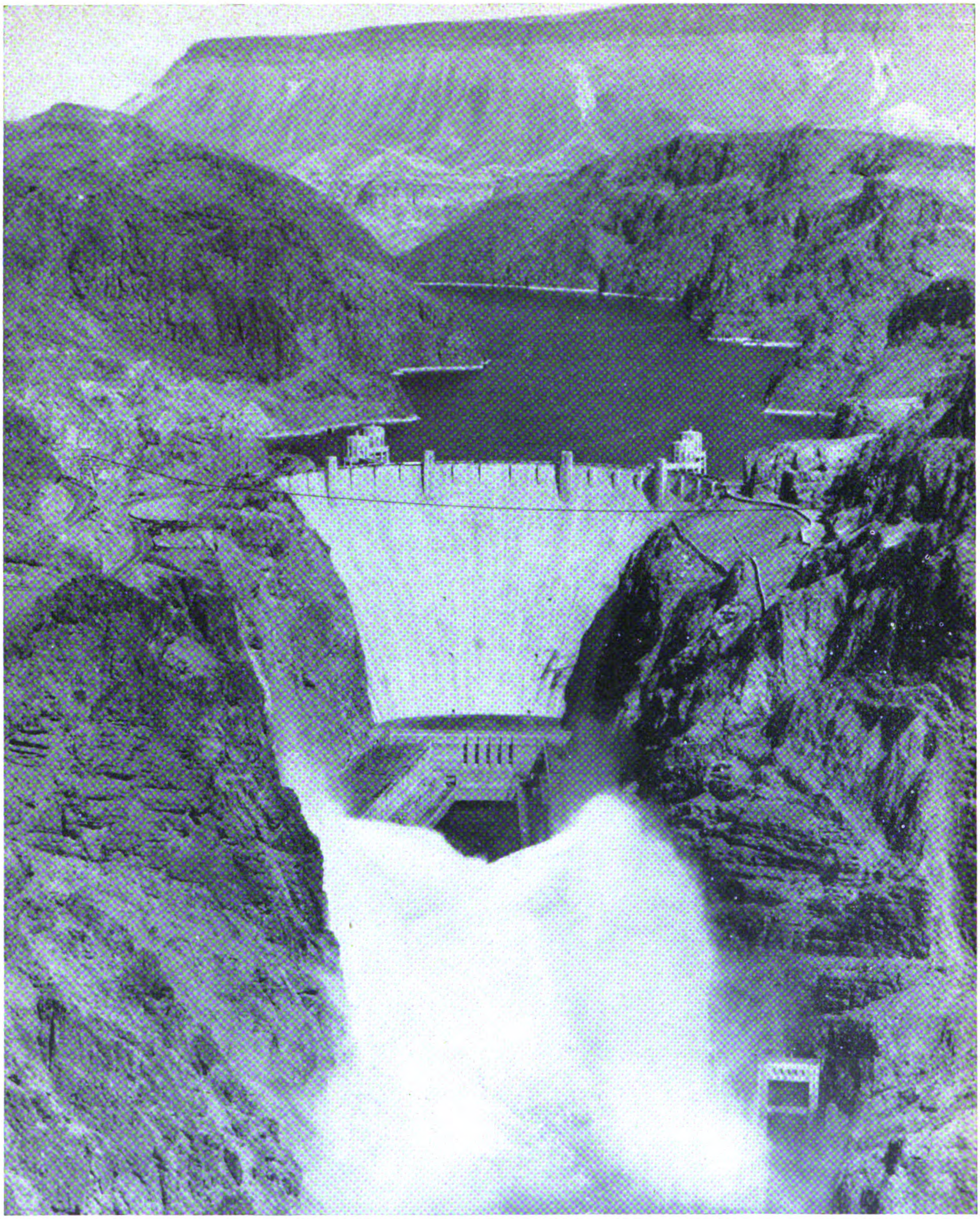
E. A. Moritz,
Regional Director, Region III.
E. O. Larson,
Regional Director, Region IV.

Substantiating Material

"Yesterday the Colorado River was a natural menace. . . .

"Today this mighty river is recognized as a national resource. . . .

"Tomorrow the Colorado River will be utilized to the very drop. Its water will convert thousands of additional acres of sagebrush desert to flourishing farms and beautiful homes for servicemen, industrial workers, and native farmers who seek to build permanently in the West."



BOULDER DAM

World's highest dam only partly harnesses the wild Colorado River

Foreword

Yesterday the Colorado River was a natural menace. Unharnessed it tore through deserts, flooded fields, and ravaged villages. It drained the water from the mountains and plains, rushed it through sun-baked thirsty lands, and dumped it into the Pacific Ocean—a treasure lost forever. Man was on the defensive. He sat helplessly by to watch the Colorado River waste itself, or attempted in vain to halt its destruction.

Today this mighty river is recognized as a national resource. It is a life giver, a power producer, a great constructive force. Although only partly harnessed by Boulder Dam and other ingenious structures, the Colorado River is doing a gigantic job. Its water is providing opportunities for many new homes and for the growing of crops that help to feed this nation and the world. Its power is lighting homes and cities and turning the wheels of industry. Its destructive floods are being reduced. Its muddy waters are being cleared for irrigation and other uses.

Tomorrow the Colorado River will be utilized to the very last drop. Its water will convert thousands of additional acres of sagebrush desert to flourishing farms and beautiful homes for servicemen, industrial workers, and native farmers who seek to build permanently in the West. Its terrifying energy will be harnessed completely to do an even bigger job in building bulwarks for peace. Here is a job so great in its possibilities that only a nation of free people have the vision to know that it can be done and that it must be done. The Colorado River is their heritage.

In 1902, Congress established a fund, "known as the Reclamation Fund, to be used in the examination and survey for and the construction and maintenance of irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semiarid lands in the" public-land States, and authorized and directed the Secretary of the Interior "to make examinations and surveys for, and to locate and construct * * * irrigation works for the storage, diversion, and development of waters, including artesian wells, and to report to Congress at the beginning of each regular session as to the results of such examinations and surveys, giving estimates of the cost of all contemplated works, the quantity and location of the lands which can be irrigated therefrom, and all facts relative to the practicability of each irrigation project; also the cost of works in process of construction as well as of those which have been completed." (Act of June 17, 1902, 32 Stat. 388.)

Responsibility for planning the control, improvement, and utilization of the Colorado River was assigned specifically to the Secretary of the Interior in the Boulder Canyon Project Act of December 21, 1928, which authorized and directed the Secretary "to make investigations and public reports of the feasibility of projects for irrigation, generation of electric power, and other purposes in the States of Arizona, Nevada, Colorado, New Mexico, Utah, and Wyoming for the purpose of making such information available to said States and to the Congress, and of formulating a comprehensive scheme of control and the improvement and utilization of the water of the Colorado River and its tributaries." (Sec. 15, 45 Stat. 1065.)

The Boulder Canyon Project Adjustment Act of July 19, 1940, further directs the continuation and extension, under the Secretary of the Interior, "of studies and investigations by the Bureau of Reclamation for the formulation of a comprehensive plan for the utilization of waters of the Colorado River system for irrigation, electrical power, and other purposes, in the States of the upper division and the States of the lower division, including studies of quantity and quality of water and all other relevant factors." (Sec. 2, 54 Stat. 774.)

In compliance with the law and in fulfillment of the public trust the Bureau of Reclamation sponsored the preparation of this report. With a view to determining how the people in the basin and in the Nation can be benefited by further development of water resources, the report surveys the resources and traces the economic development in the basin. It includes a discussion of present water resources development and descriptions of many potential projects. These projects indicate potentialities for ultimate development of all the water resources of the basin. Alternative projects are included in order that relative merits of all possibilties can be weighed, and those projects most likely to yield the greatest good to the greatest number of people can be selected for construction. All beneficial uses, including the irrigation of land, the production of hydroelectric power for the development of mineral resources and other industrial purposes, the furnishing of domestic and municipal water supplies, the preservation of fish and wildlife, and the enhancement of recreational areas, together with the control of floods and silt, and the restoration of ground-water levels were taken into account in formulating the potential projects.

This comprehensive report provides a basin-wide perspective for planning coordinated development on a sound basis. From time to time as additional detailed investigations of particular projects are completed and as various intrastate, interstate, and international problems are solved, modifications and changes will be indicated to assist in the selection of projects and the shaping of the ultimate development plan. Intrastate and interstate problems, to be solved by the citizens and States of the Colorado River Basin, and international problems, to be solved by the United States and Mexico, are interrelated, the solutions of some being dependent on the previous solutions of others and on additional investigations and construction in the basin. Such problems are being and will be solved in an orderly manner as needs arise. Further investigations and construction in the basin will be undertaken as authorization is given and appropriations made by the Congress.

Although the water supply available for potential projects for exportation of water outside the natural basin of the Colorado River is discussed in this report, no attempt is made to evaluate the costs or benefits of such projects. They will be evaluated separately or in connection with basin reports of importing watersheds.

In the preparation of this report various agencies of the Department of the Interior that are involved in the development of the Colorado River Basin cooperated with the Bureau of Reclamation to assure that cooperative planning for water development would be keyed to the welfare of the people of the basin. Their cooperation is reflected throughout the report and their specific contributions included in chapter VIII entitled "Cooperating Interests in the Basin." The Bureau of Reclamation is the agency of the Department of the Interior authorized to plan, construct, and operate projects for the reclamation of arid land, the production of hydroelectric power, and other beneficial purposes through the development of water resources. The Geological Survey has supplied valuable information on water supply, classification of mineral lands, mineral resources, and mapping. The National Park Service, concerned primarily with the preservation of parks and areas of historic and scenic interest for enjoyment of the American people, has indicated and evaluated possible benefits of the potential projects to recreation. The Fish and Wildlife Service has jurisdiction over Federal game refuges and is the Federal custodian of the fish and wildlife resources in the basin. The Grazing Service, administering the Federal grazing lands in the basin, is protecting watersheds from overgrazing, erosion, and other abuses, and is interested not only in securing adequate water supplies for stock but in the production of more irrigated crops to supplement range forage. The Bureau of Mines is engaged in the exploration and development of mineral resources and has a vital interest not only in flowing streams as a source of water necessary for mining, milling, and extracting metals or minerals from ores but in the availability of low-cost hydroelectric power for further development of mineral resources. Guarding the interests of the Indians in the basin is the Office of Indian Affairs which manages all Indian matters, including economic development, forestry and grazing, irrigation, education, and other activities. The General Land Office, which has jurisdiction over unappropriated and unreserved public domain, has outlined a program for the Colorado River Basin that consists largely of land classification, cadastral surveys, and investigation of mineral claims.

Other Federal agencies that have an interest in development of the basin also have made substantial contributions which are included as a part of chapter VIII. The Federal Power Commission has assisted in the study of power resources of the Colorado River Basin. Close cooperation with the Forest Service of the United States Department of Agriculture is important because increased irrigation development will require intensified watershed management on the National forest lands to insure adequate safeguarding of their water crop. The Corps of Engineers, United States Army, has submitted plans and suggestions for some flood-control projects, such information being included in the supporting data for the report.

Throughout the preparation of this report the Bureau of Reclamation cooperated with the various States and local agencies concerned with development in the basin. A tentative draft of the report was submitted to the Committees of 14 and 16, which committees represent the Colorado River Basin States and the Boulder Dam Power allottees, for their review and suggestions for revisions. Financial assistance has also been received from the States.

Eleven maps showing water resources development in each of the seven Colorado River Basin States, existing and potential power developments, conservation areas and facilities, and mineral resources are an appendix to this report.

Following is a list of terms that appear in the report, and their definitions:

Irrigable land.—Land suitable for irrigated farming included within an existing project or within a potential development that reasonably could be furnished a water supply.

New lands.—Irrigable lands which could be irrigated after project development.

Stream flow.—The flow in a stream channel. The volume of flow is measured in acre-feet. The rate of flow is measured in second-feet.

Acre-foot.—A unit of measure of volume. It is equivalent to the quantity of water that will cover 1 acre (43,560 square feet) 1 foot deep.

Second-foot.—A unit of measure of the rate of stream flow. It is the flow of 1 cubic foot (7.48 gallons) of water passing a given point per second of time.

Discharge.—The rate of flow; commonly expressed in second-feet, gallons per minute, acre-feet per day, etc.

Run-off.—The precipitation that appears as flow in streams. It is usually measured in volume per unit of time, such as acre-feet per day, month, or year.

Return flow.—That part of diverted stream flow returning to the stream.

Stream depletion.—The reduction in stream flow due to man-made improvements as they affect the virgin water supply of the Colorado River at Lee Ferry and at the International Boundary.

Silt.—The solid matter or sediment transported by a flowing stream.

Active storage capacity.—That space in the upper part of a reservoir normally utilized in regulating stream flow for purposes of irrigation, power, flood control, etc. Sometimes referred to as live storage.

Inactive storage capacity.—That space in the lower part of a reservoir not emptied in normal operation. It may be provided for a sedimentation pocket, to develop and maintain a power head, to establish a permanent lake for fish culture, recreation, etc. Sometimes referred to as dead storage.

Firm power.—Power that can be made available at any time to meet load demands. Production of firm power by hydroelectric plants is limited by water supply during years of low stream flow.

Kilowatt.—A unit of measure of rate of producing electrical energy.

Kilowatt-hour.—A unit of measure of quantity of electrical energy.

The Natural Setting

"The Colorado River rises high in the snow-capped Rocky Mountains of north central Colorado, flows nearly 1,400 miles southwest, and empties into the Gulf of California in Mexico far to the south. . . . This mighty river has gouged the rock of the mesas into gorges and chasms, most spectacular of which is the world-famous Grand Canyon in Arizona. . . .

"The Colorado River drains a vast area of 244,000 square miles, 242,000 square miles in this country—one-twelfth of the area of continental United States—and 2,000 square miles in northern Mexico. Tributaries extend into seven of the large Western States, including Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming."

CHAPTER I

The Natural Setting

The Colorado River rises high in the snow-capped Rocky Mountains of north central Colorado, flows nearly 1,400 miles southwest, and empties into the Gulf of California in Mexico far to the south. It is the second longest river in the United States outside the Mississippi River system. This mighty river has gouged the rock of the mesas into gorges and chasms, most spectacular of which is the world-famous Grand Canyon in Arizona, a titanic cleft over 200 miles long, as much as 12 miles wide, and a mile deep.

The Colorado River drains a vast area of 244,000 square miles, 242,000 square miles in this country—one-twelfth of the area of Continental United States—and 2,000 square miles in northern Mexico. The basin from Wyoming to below the Mexican border is some 900 miles long and varies in width from about 300 miles in the upper section to 500 miles in the lower section. It is bounded on the north and east by the Continental Divide in the Rocky Mountains, on the west by the Wasatch Range, and on the southwest by the San Jacinto Mountains, a range of the Sierra Nevada. Tributaries extend into seven of the large Western States including Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

The Salton Sea Basin, an additional area of 7,800 square miles which includes the Coachella and Imperial Valleys in southeastern California, is discussed as part of the Lower Colorado River Basin. It is, however, to be distinguished from other lower Colorado River areas because whatever Colorado River water reaches it cannot return by gravity flow to the parent stream.

Physical Characteristics

The upper or northern portion of the Colorado River Basin in Wyoming and Colorado is a mountainous plateau, 5,000 to 8,000 feet in altitude, marked by broad rolling valleys, deep canyons, and intersecting mountain ranges. Hundreds of peaks in these mountain chains rise to more than 13,000 feet above sea level and many exceed 14,000 feet. There are many picturesque mountain lakes in these headwater sections. The southern portion of the basin is studded with rugged mountain peaks interspersed with broad, level, alluvial valleys and rolling plateaus.

The main stream and its principal tributaries in Colorado flow, for the most part, in deep canyons. The Green River, primary tributary of the Colorado River, flows in similar canyons in Wyoming, Colorado, and Utah and its chief tributaries, Yampa and White Rivers from the east, and Duchesne, Price, and San Rafael Rivers from the west, flow through rolling hills and canyons to reach the Green.

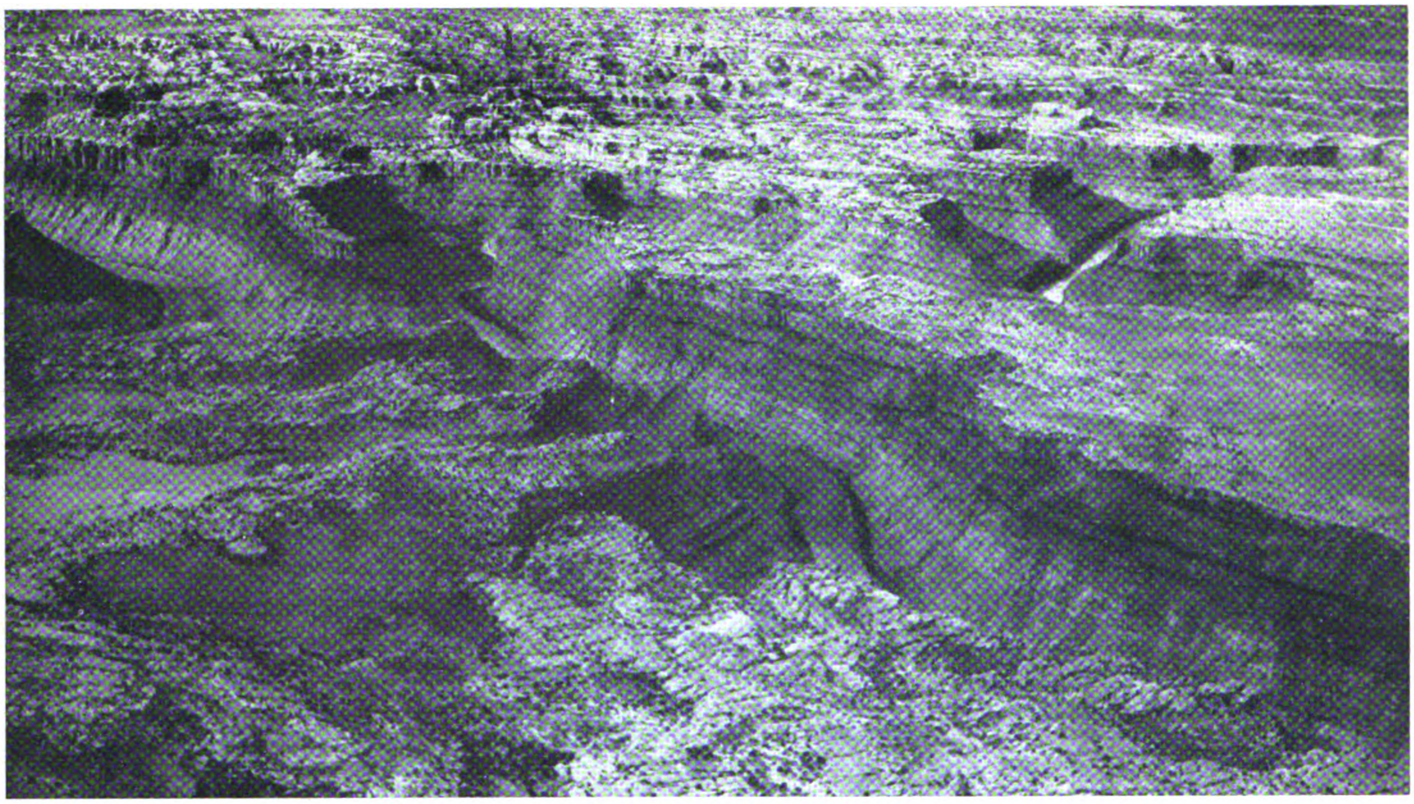
The San Juan River, a large tributary of the Colorado River from the east, drains mountain slopes and plateaus in southwestern Colorado, northwestern New Mexico, and northern Arizona and flows through a formidable canyon in southeastern Utah, joining the Colorado in Glen Canyon. The Glen Canyon section of the main stream and tributaries thereto are in deep canyons, draining a series of plateaus and mesas.

Below Glen Canyon is the awesome Grand Canyon where the Colorado has carved an unparalleled chasm. This canyon yawns above an inner gorge, rising in gigantic cliff-steps to the Colorado plateau, a mile above the stream bed. This great central plateau is a rolling expanse of brightly hued crags and cliffs, huge canyons, painted deserts, and extensive almost inaccessible barren areas. Elevations on the mesas of the plateau section generally range from 4,000 to 6,000 feet. The principal tributaries in this section are the Little Colorado River on the east and the Virgin River on the west.

Emerging from the canyon country at the southeast corner of Nevada, the Colorado River courses through broad valleys bordered by mesas. The Gila River, main tributary in this section, rises in the mountainous region of southwestern New Mexico and drains most of southern Arizona.

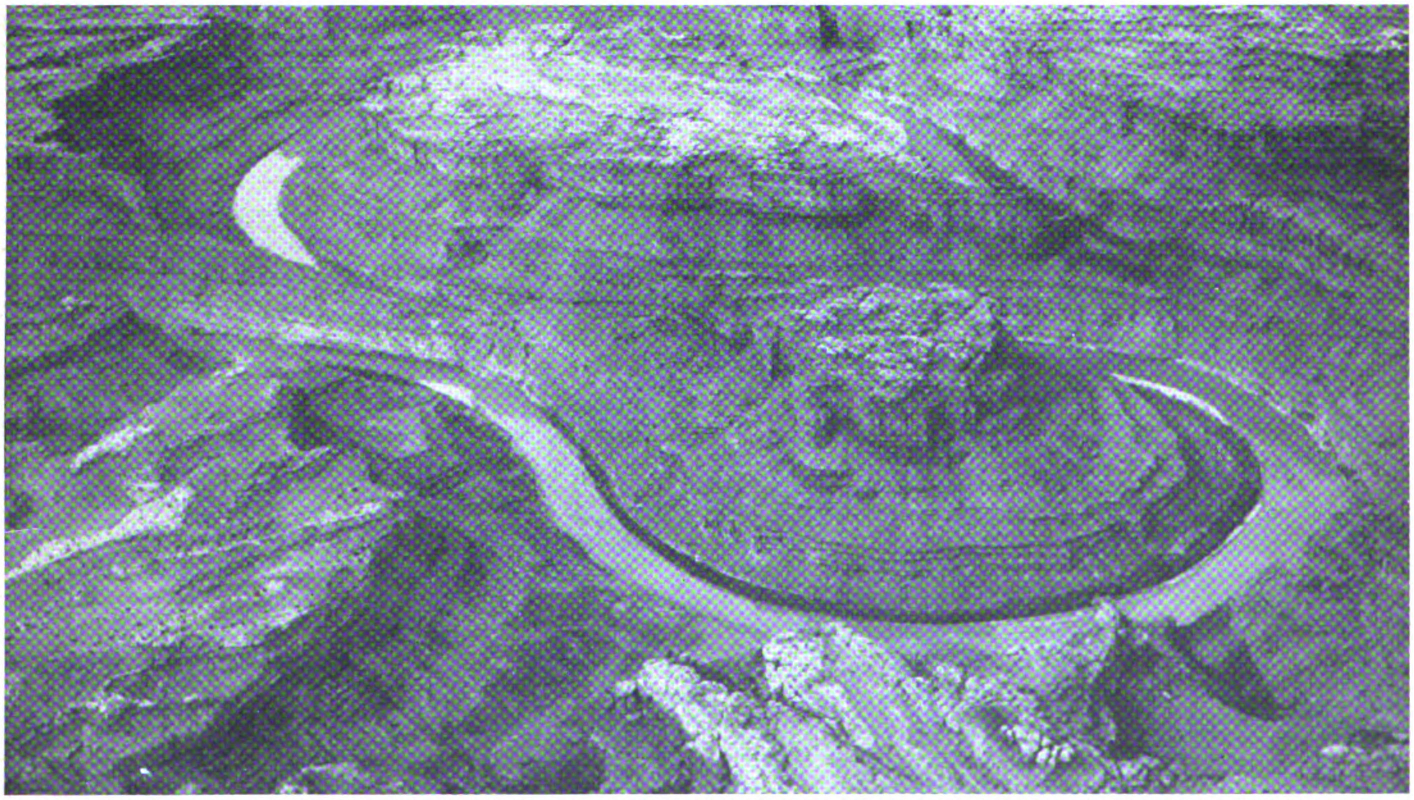
Southwest of the Gila Basin the Colorado River continues through its great delta area to the Gulf of California.

Physical characteristics suggest seven main divisions of the Colorado River Basin in the United States, three in the upper basin, or the drainage area above Lee Ferry, Arizona, and four in the lower basin, or the drainage



JUNCTION OF GREEN AND COLORADO RIVERS

The Colorado (left) is joined by the Green (right), its largest tributary



BOW-KNOT OF THE COLORADO RIVER

The Colorado meanders hundreds of miles through deep canyons in Utah and Arizona

COLORADO RIVER BASIN

Divisions of upper and lower basins

area downstream from Lee Ferry to the Mexican border. The *Green division* includes that part of Wyoming, Colorado, and Utah drained by the Green River. The *Grand division* is that part of Colorado and Utah drained by the Colorado River above the mouth of Green River. The *San Juan division* takes in that part of Utah, Colorado, New Mexico, and Arizona drained by that section of the Colorado River between the mouth of the Green River and Lee Ferry. The *Little Colorado division* includes that part of Arizona and New Mexico drained by the Little Colorado River, excluding that part below Moenkopi Wash. The *Virgin division* covers that part of Utah, Arizona, and Nevada drained by Kanab Creek and the Virgin and Muddy Rivers. The *Boulder division* includes the Imperial and Coachella Valleys in southeastern California and that part of Arizona, Nevada, and California tributary to the Colorado River below Lee Ferry, excluding that part of those States tributary to the Little Colorado River above Moenkopi Wash, Kanab Creek, Virgin River, Muddy River, and the Gila River above Sentinel. The *Gila division* comprises that part of Arizona and New Mexico drained by the Gila River above Sentinel and small independent drainage areas in Arizona and southwestern New Mexico.

For convenience in presenting some of the data and information in this report, reference is made to these seven divisions, detailed descriptions of which follow.

Green Division

From glacier-capped peaks on its Rocky Mountain rim to the barren wastes of its lower valleys and plateaus, the Green River Basin is one of great contrasts in topography. Wooded upland slopes are flanked with fertile grass-covered valleys, which in turn give way to dry and eroded badlands and deserts.

Rising in western Wyoming in the Wind River Mountains on the Continental Divide, the Green River also drains the northwest corner of Colorado and discharges into the Colorado River in southeastern Utah, 350 miles south of its origin, its meandering length totaling 730 miles. It drains 45,000 square miles, an area as large as the State of Pennsylvania, 39 percent of which is in Wyoming, 37 percent in Utah, and 24 percent in Colorado. Elevations in the Green River Basin range from 3,876 feet above sea level at the mouth of the Green River to 13,785 feet at Gannet Peak in the Wind River Mountains. Large areas of desert plateau contribute practically no water to the stream. Numerous small glacial lakes head the Green River and its higher tributaries.

The Yampa and White Rivers, tributaries from the east, both originating in Colorado on the western slope of the Rocky Mountains, flow westward and generally parallel. Much of the drainage area consists of rolling hills, but several prominent peaks rise within and between the basins of the two streams.

Duchesne, Price, and San Rafael Rivers, tributaries from the west, head on the eastern slope of the Wasatch Mountains and flow southeast to Green River.

Grand Division

The Colorado River above the mouth of the Green River was known to earlier generations as the Grand River. For that reason the area drained by the upper Colorado River is called the Grand division. A 200-mile strip of the Continental Divide through central Colorado forms the eastern boundary of the division, which includes the basin of the upper Colorado River and its tributaries down to the junction of the Colorado and Green Rivers in Utah.

The Colorado River rises among lofty peaks in the northwest portion of Rocky Mountain National Park, 70 miles northwest of Denver. Flowing southwest to Green River, it has an air-line length of 265 miles and a meandering length of 420 miles. It drains 26,500 square miles an area larger than West Virginia. Only 11 percent or 4,300 square miles of the area are in Utah while 22,200 square miles are in Colorado. Elevations range from 3,876 feet above sea level at Green River to more than 14,000 feet at mountain peaks. On this western slope of the Continental Divide are rugged mountains and high plateaus where the river and its numerous tributaries have become deeply entrenched in steep rugged canyons and relatively narrow valleys.

Main tributaries in the first 160-mile length of the Colorado River's southwest course, above Grand Junction, are Fraser, Williams, Blue, Eagle, and Roaring Fork Rivers from the south and Willow, Troublesome, and Muddy Creeks from the north. Gore Canyon, 80 miles above Glenwood Springs, is of special interest. Here the river tumbles through vertically walled canyons, dropping 360 feet in 5 miles in the steepest fall on the river.

Gunnison River, principal tributary of the upper Colorado River, has its headwaters draining the Continental Divide, and flows northwest to meet its parent stream at Grand Junction. North Fork and Uncompahgre River are the largest tributaries of the Gunnison.

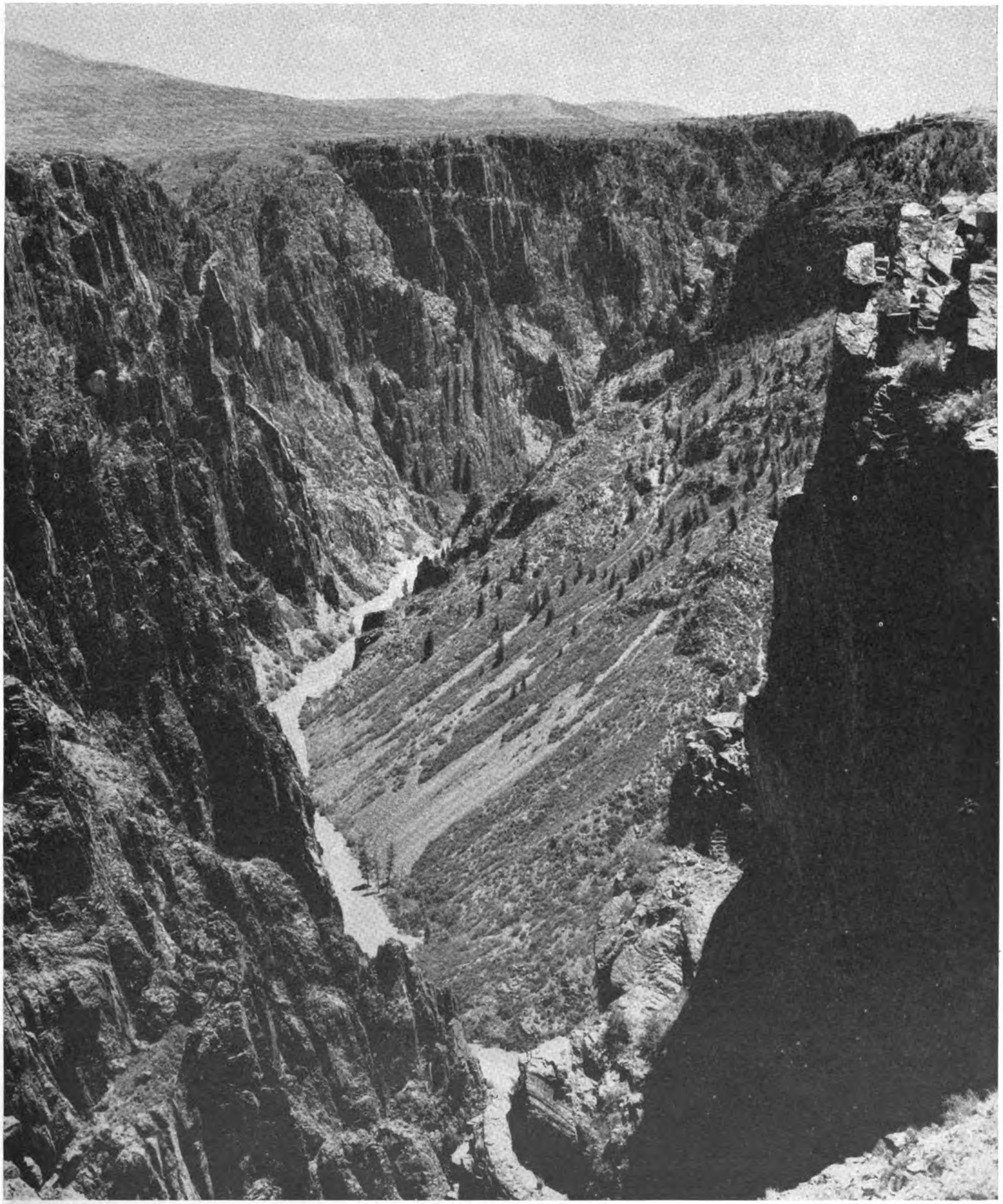
Dolores River, rising on the western slope of the San Juan Mountains, flows generally southwest and is joined by the San Miguel River and other lesser tributaries before flowing alternately through canyons and narrow valleys to the Colorado River in Utah.

San Juan Division

This area is rich in prehistoric Indian ruins, in natural wonders, and in spectacular scenic beauty. The area, with an elevation difference of more than 2 miles between the lowest and highest points, is one of extreme contrasts in topography. High tree-clad mountain areas with numerous clear, fish-stocked streams and small lakes rapidly give way to fertile foothill valleys, which merge into a vast, broken and barren, but picturesque and highly colored, plateau.

Deeply entrenched in this plateau the Colorado River meanders southwestward for 220 miles from the mouth of the Green River to Lee Ferry, an air-line distance of 130 miles. This section of the river, together with its tributaries, drains 39,000 square miles, an area almost as large as Ohio. Forty-three percent of this area is in Utah, 25 percent in New Mexico, 17 percent in Arizona, and 15 percent in Colorado.

The main tributary to this stretch of the Colorado River is the San Juan River. Second largest tributary of the Colorado, the San Juan River heads on the western slope



BLACK CANYON OF THE GUNNISON RIVER
The river has cut through crystalline rock to a depth of 3,000 feet

of the Continental Divide in southwestern Colorado and flows west, entering the main stream from the east 80 miles upstream from Lee Ferry.

Three small rivers, Fremont, Escalante, and Paria, rising on the Wasatch and Escalante mountainous plateaus, join the Colorado from the west. The streams in this division are erratic with violent fluctuations of flow in their lower reaches. In the deep canyons cut through the plateau areas these streams turn into raging silt-laden torrents during periods of heavy or continued downpours.

Little Colorado Division

A region of spectacular beauty with a wealth of scenic splendor, the Little Colorado division embraces an area of 25,000 square miles, 81 percent of which is in northeastern Arizona and the remainder in west-central New Mexico. Barren stretches of arid wasteland, petrified forests, painted deserts, rolling ranges, stately timber, and lofty mountains characterize the area.

The Little Colorado River rises among the evergreen forests of the White Mountains at elevations above 9,000 feet, flows through canyons that widen at intervals into valleys, enters a generally broad, sandy channel with low, steep, side walls, then cascades into a deep rock canyon and continues to the Colorado.

Northern tributaries of the river head in canyons in the Kaibab and Fort Defiance Plateaus and Black Mesa. As they approach the main valley floor, the channels widen to broad, flat sandy washes with low vertical side walls. Creeks draining the southern part of the basin rise as crystal mountain streams in the wooded highlands of the Mogollon Rim and flow through steep-walled canyons in their lower reaches.

South and west of the river the basin is dominated by the Mogollon Rim and the volcanic features of the peaks and cones near Flagstaff. Most of this area is a gently sloping plain with a few prominences and canyons to break the continuity.

North and east of the river at higher elevations lie forested plateaus, isolated mountains, mesas, and sloping plains broken by volcanic plugs. Painted deserts and badlands predominate in the lower altitudes.

Elevations in the basin range from 4,100 feet above sea level below Moenkopi Wash to 12,611 feet on the lofty San Francisco Peaks.

Virgin Division

Virgin—new, fresh, untouched—a significant name aptly applied by the early explorers. It is an area beautified by the forces of nature and only slightly touched by man. This typical mountain-desert country with its characteristic stretches of sand and sagebrush, its cloudless sky and scorching sun, is the center of volcanic eruptions and geologic displacements.

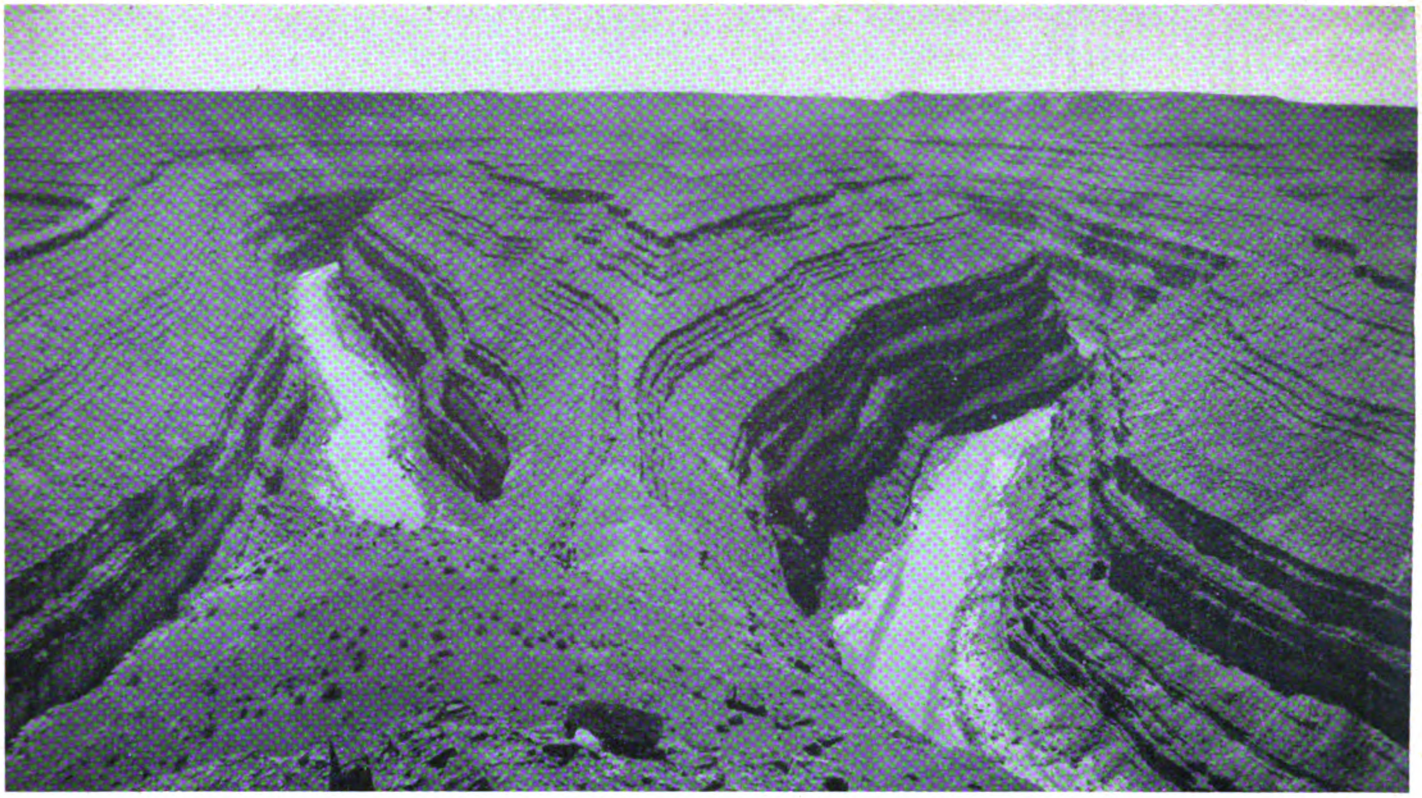
The Virgin division totals approximately 12,700 square miles, of which 3,600 square miles are in southwestern Utah, 3,600 square miles in northwestern Arizona, and 5,500 square miles in southeastern Nevada. Elevations range from 1,200 feet above sea level at Lake Mead to 10,000 feet at the headwaters of the Virgin River.

The terrain is extremely rough and broken. The dominating structural feature is the Hurricane Fault escarpment which marks the western boundary of the high plateau region. From a point near Beaver, Utah, it extends south for a distance of some 200 miles, crosses through the Virgin River Basin at Hurricane, Utah, and extends beyond the Colorado River. Deep gorges and rugged, massive erosional forms make up the striking and colorful attractions of Zion National Park and Monument located in the area. Comparatively recent lava flows and volcanic cones are salient features in parts of the division.

Kanab Creek heads in the Pink Cliffs along the southwestern rim of the Paunsaugunt Plateau in Utah at an elevation of 9,000 feet and flows 90 miles south to the lower end of Grand Canyon, where it joins the Colorado at elevation 1,880 feet. Johnson Creek, its principal tributary, heads in the same locality and roughly parallels Kanab Creek until it enters Arizona, where it turns southwest to join the main stream 5 miles southwest of Fredonia, Ariz. Above Kanab, Utah, the drainage area is rough and hilly and is covered with sagebrush and junipers. Streams are confined to narrow valleys and gorges. Below the confluence of the two creeks the stream plunges into the Colorado River through a deepening gorge cut into the north-sloping Kaibab and Uinkarat Plateaus.

Virgin River, heading along the southern rim of the Markagunt Plateau in Utah, flows across the southwest corner of Utah, crosses the northwest corner of Arizona, and discharges into Lake Mead in southeastern Nevada. The length of the river from its headwaters to its mouth is about 200 miles. Perennial tributaries, of which the Santa Clara River is the most important, head in the high plateaus and mountains to the north and flow south to the main stream. The river and main tributaries generally are confined in deep gorges or narrow valleys. Bench or mesa lands fringe the main stream and tributaries in some places.

Muddy River, originating in the Sheep Mountains, flows southeast for some 60 miles to enter Lake Mead near the settlement of Overton, Nev. Prior to the formation of Lake Mead by construction of Boulder Dam, Muddy River was tributary to Virgin River about 25 miles upstream from the confluence of Virgin and Colorado Rivers. Now, however, the two streams flow separately into Lake Mead. Meadow Valley Wash, the principal Muddy



GOOSENECKS OF THE SAN JUAN
A favorable site for a dam has been found on San Juan River below Bluff, Utah

LONG-RANGE VIEW OF GRAND CANYON
This panorama was photographed from Navajo Watch Tower

River tributary, flows from its headwaters south about 130 miles to its confluence with Muddy River near Moapa, Nev.

Boulder Division

The Colorado River enters the northeast corner of the Boulder division at Lee Ferry, weaves its way west and south for 350 river miles to empty into Lake Mead, then flows south 358 miles to the Mexican border. The division embraces an area of 48,600 square miles, including the Salton Sea drainage basin of 7,800 square miles. Of this area 32,900 square miles are in Arizona, 11,300 square miles in California, and 4,400 square miles in Nevada. Throughout the division great blocks of land have been lifted, forming plateaus and mountainous ridges. Other blocks have been depressed, forming valleys which later filled with material washed from the elevated areas. Elevations range from below sea level to more than 12,000 feet above sea level.

For the upper 280 miles, from Lee Ferry to Grand Wash Cliffs, the Colorado has cut through an elevated area. As the plateau rose slowly during geologic time, the river wore its course progressively deeper through the rock, forming Grand Canyon, a region of scenic grandeur. The most impressively beautiful part of this canyon is the 105-mile stretch set aside as Grand Canyon National Park.

Grand Wash Cliffs at the west end of Grand Canyon is one of the major escarpments in the United States. Here the plateau drops abruptly and is succeeded by alternating mountains and valley fills to the upstream end of Black Canyon. Through this stretch the Colorado dug its channel across the Virgin and Black Mountain ranges on a grade of 3.2 feet a mile, compared with 8 feet a mile in Grand Canyon. The narrowness and depth of Black Canyon afforded a favorable site for a high dam. Upstream from Black Canyon the river channel together with the Virgin River and Las Vegas Wash side valleys formed an ample basin for water storage and silt detention. The upstream end of Black Canyon was the site chosen for Boulder Dam.

Williams River, a flashy discharge tributary of the Colorado, comes in on a steep grade from the east just above Parker Dam, falling 500 feet in 32 miles. This stream is formed by two branches coming together some 36 miles above the mouth, the north branch, Big Sandy River, and the east branch, Santa Maria River.

From Headgate Rock to the Mexican border, the Colorado River falls an average of 1.4 feet a mile. The flood plain is several miles wide near Parker, Ariz., Blythe, Calif., and Yuma, Ariz. Bench lands, as those near Blythe and Yuma, are at moderate elevations (500 feet or less) above the Colorado River.

Across a range of sand hills west of Yuma is the Salton Sea Basin, a depression below sea level about 85 miles long and 20 miles wide. In the deepest part is the Salton Sea, 20 miles long and 10 miles wide. The surface of the sea is 241 feet below sea level. The Imperial Valley is considered as the delta sloping from the Colorado north to the Salton Sea. Coachella Valley lands slope south to the Salton Sea. The Imperial and Coachella Valleys are in large part alluvial deposits from the Colorado River. On the east, west, and north, however, the river deposits are overlaid on the edges of the valleys by coarser detrital material washed from surrounding mountains.

Gila River, the lower reaches of which are in this division, enters the Colorado River just east of Yuma.

Gila Division

Broad, smooth valleys, mountain chains, desert wastes, flowing water—this is the Gila division, a land of extremes and contrasts. It covers an area of 53,000 square miles, 47,380 of which are in south-central Arizona, and 5,620 square miles in western New Mexico. Run-off from the high mountains of eastern Arizona and western New Mexico forms the perennial flows of the Gila River and its tributaries. No lakes of any appreciable size are found in the basin. Elevations range from 530 feet at Sentinel to 12,600 feet at Humphrey's Peak in the San Francisco Mountains, near Flagstaff, Ariz.

Gila River flows for half of its course in steep, precipitous canyons alternating with relatively flat valleys. Both canyons and valleys are flanked by mountain ranges rising 7,000 to 10,000 feet above sea level.

San Francisco River, most important tributary of the Gila River before its confluence with Salt River, drains mountainous regions of southwestern New Mexico and southeastern Arizona.

San Pedro River rises in Sonora, Mexico, and flows north to join the Gila River some 20 miles below Coolidge Dam. Although most of its course is in open valleys, its tributaries drain several small but high mountain ranges.

Santa Cruz River, heading in the Patagonia and Huachuca Mountains of southern Arizona, flows into Sonora, Mexico, back into Arizona at a point near the border city of Nogales, and from there northward some 130 miles, spreading over the desert, with only occasional large flood flows reaching the Gila.

Salt River, largest tributary of the Gila River, is formed by the junction of Black River and White River, which rise in the high, timbered White Mountains of east-central Arizona. After being joined by Verde River, its principal tributary which rises in the northern Arizona plateau, the Salt River flows for 40 miles through fertile, open plains to the Gila.

Other tributaries of the Gila include the Agua Fria River, rising in the timbered Mingus Mountains of central Arizona, and the Hassayampa River, heading in Prescott National Forest near Prescott, Ariz.

Geologic History

Rocks of all ages from those of the Archean Age, the oldest known geological period, to the recent alluvial deposits, including igneous, sedimentary, and metamorphic types, are found in the Colorado River Basin. The high Rocky Mountains which dominate the topography of the region are composed of granite, schists, gneisses, lava, and sharply-folded sedimentary rocks. Many periods of deposition and erosion have played a part in the present structure of these mountains. Ancient seas settled in the basin countless times, depositing beds of limestone, sandstone, and shale. Each time crustal forces of the earth elevated the region above sea level, erosion again began cutting it down.

During a relatively late geological period, called the Pleistocene or Glacial Age, glaciers occupied the high watershed of all the mountains in Colorado, Wyoming, and Utah. The Rocky Mountains in Colorado, the Wind River Mountains in Wyoming, and the Uinta and Wasatch Mountains in Utah, all have been materially affected topographically by these ancient bodies of ice.

In contrast to the folded rocks of the mountains which fringe the basin, the plateau country of southwestern Wyoming, eastern Utah, and northern Arizona is composed principally of horizontal strata of sedimentary rocks. Many formations of hard sandstone and limestone separated by softer shale, often highly colored, have resulted in topographic and geological formations found in no other locality.

Slow but constant elevation of the land area has allowed the Colorado River and its tributaries to cut narrow deep canyons into the flat-topped mesas. This unique type of erosion reaches its culmination in the famous Grand Canyon. Here a broad area has been arched several thousand feet higher than the surrounding country, but the horizontal structure of the rock largely has been maintained. The river has cut through all the sedimentary rocks down to the oldest Archean granites.

The topography of the southern part of the basin is characterized by broad flat valleys separated by low ranges. The valleys are filled by large accumulations of alluvial gravels which all but bury the mountains. The ranges are mainly of igneous origin with granites and lava predominating. These rocks are part of the oldest known formation, the younger sedimentary rocks having been removed by erosion. Many mountain ranges are undoubtedly buried beneath the detrital material.

The present Gulf of California once extended much farther north than at present and filled what is now the Imperial Valley of California. The silt of the river was distributed far and wide in this sea which was partially cut off from the broad Pacific by a chain of islands. During and after the Glacial Period, when precipitation is believed to have reached its peak, the river had its greatest volume and transporting power. The stream then, as now, laden with the silts from the slopes of the Rocky Mountains and the Grand Canyon of Arizona, gradually built up a great delta which finally completely cut off a vast inland sea of brackish water. This ancient sea, known by geologists as Lake Cahuilla, covered an area of about 2,100 square miles.

After shifting channels countless times, sometimes discharging into the gulf and sometimes into the lake, the river finally became better stabilized in channels emptying into the gulf. With the loss of a water supply Lake Cahuilla gradually decreased by evaporation to remain as the present Salton Sea.

Native Plant and Animal Life

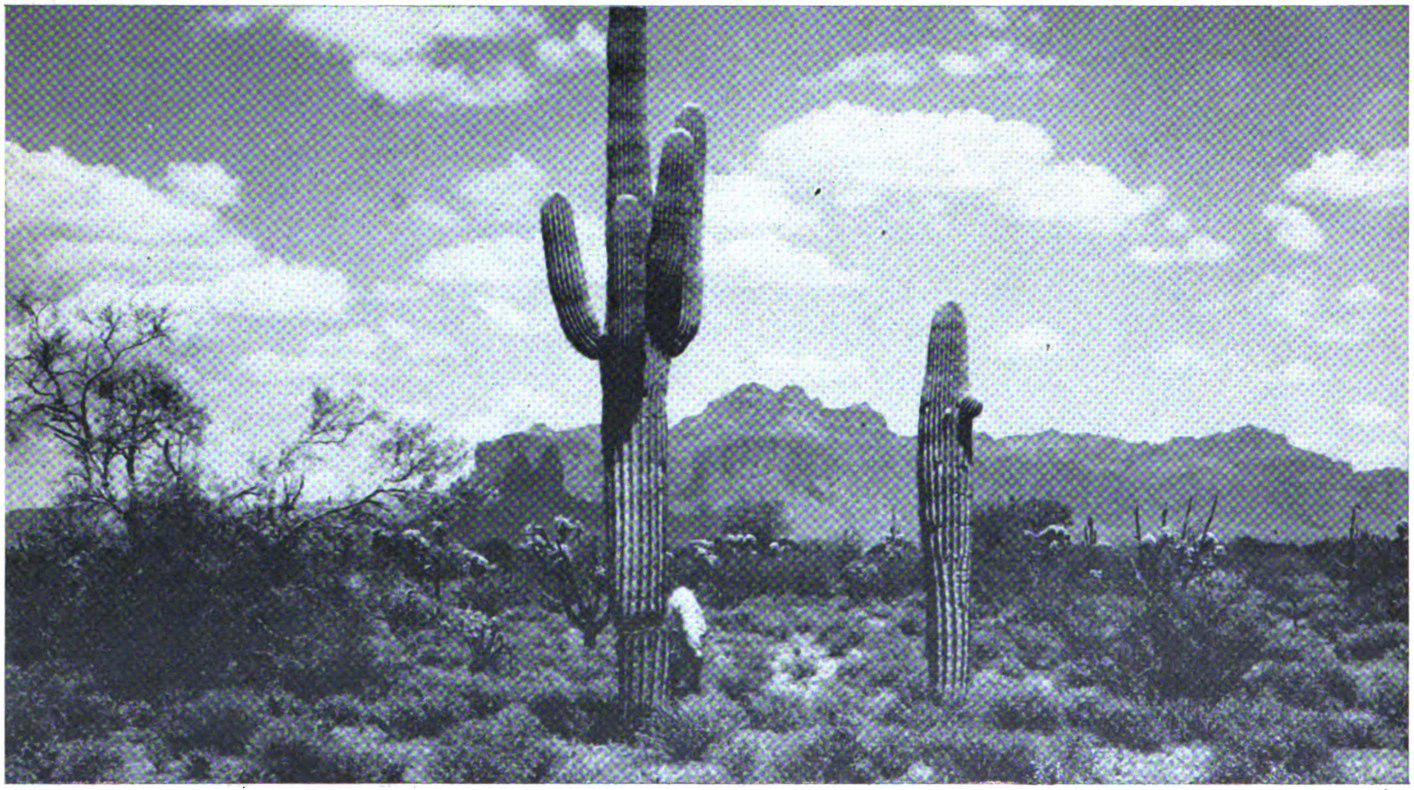
The flora and fauna of the Colorado River Basin are many and varied, including typical desert and alpine species.

The higher areas are covered with forests of pine, fir, spruce, and silver-stemmed aspens, broken by small glades and mountain meadows. Pinon and juniper trees, interspersed with scrub oak, mountain mahogany, rabbit brush, bunch grasses and similar plants grow in the intermediate elevations of the mesa and plateau regions. Scattered cottonwoods and chokecherries grow in the canyons with the cliff rose, the redbud, and blue columbine. A profusion of wild flowers carpet many mountain "parks." In the lower region large areas are almost completely devoid of plant life while other sections are sprinkled with desert shrubs, Joshua trees, other Yucca plants, and saguaro cacti, some of the latter giant plants reaching 40 feet in height. Occasionally cottonwoods or desert willows are found along desert streams with mesquite and creosote bush or catclaw and paloverde.

The Colorado River Basin is the natural habitat of the bighorn sheep, ptarmigan, and wild turkey. Deer, elk, and antelope are found in the forested and more primitive areas. Mountain lions, wild cats, lynx, and other predatory animals are fairly common in remote areas. Coyotes inhabit the plains country where they prey upon gophers, cottontails, jackrabbits, and other smaller mammals. Fur-bearing animals in the mountains include beaver, fox, badger, ermine, muskrat, skunk, and mink. Ducks, geese, snipe, white-wing pigeons, quail, dove, and other birds are numerous. Snakes and lizards with other reptiles and amphibians are frequently found in the desert areas.

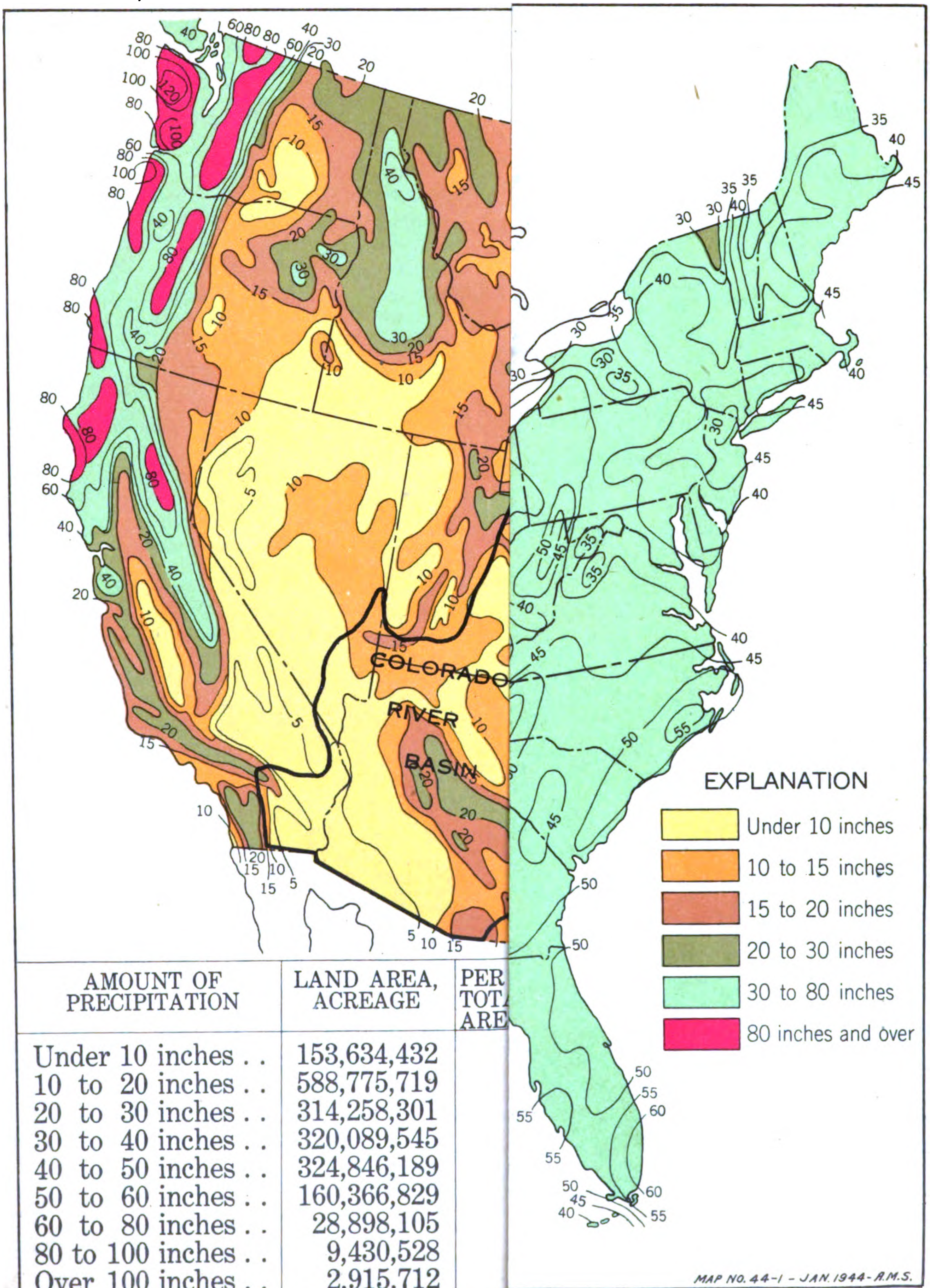
DESERT FLORA

Vast areas are sprinkled with Joshua trees, Yucca plants, and desert shrubs



DESERT SCENE

A view of Superstition Mountains with typical sage brush and cactus lands in the foreground



AMOUNT OF PRECIPITATION	LAND AREA, ACREAGE	PER TOTA ARE
Under 10 inches . .	153,634,432	
10 to 20 inches . .	588,775,719	
20 to 30 inches . .	314,258,301	
30 to 40 inches . .	320,089,545	
40 to 50 inches . .	324,846,189	
50 to 60 inches . .	160,366,829	
60 to 80 inches . .	28,898,105	
80 to 100 inches . .	9,430,528	
Over 100 inches . .	2,915,712	

The cold, clear mountain streams abound in trout, the most common varieties being rainbow, eastern brook, native, and Loch Leven. Bass, crappie, and bluegill prefer the lakes and reservoirs to the moving waters of the streams.

Climate

Climatologically, the Colorado River Basin has the extremes of year-round snow cover and heavy precipitation on the high peaks of the Rockies, snow-capped 8 to 10 months a year, and truly desert conditions with very little rain in the southern area around Yuma, Ariz. The wide range of climate in the basin is caused largely by differences in both altitude and latitude and to a lesser extent by topographic features.

Extremes of temperatures in the basin range from 50° below zero to 130° above zero. The northern portion of the basin is characterized by short, warm summers and long, cold winters, many mountain areas being blanketed by deep snow all winter. A peculiar climatic condition exists in the Grand division in Colorado where high mountains tend to divert east-bound storms either to the north or to the south over lower passes in the Continental Divide. The southern portion of the basin has long hot summers, practically continuous sunshine and almost complete absence of freezing temperatures. Summer heat is not so oppressive as temperatures would indicate because of the low humidity. Summer nights, typical of the desert, are seldom too warm for comfort. The little Colorado River Basin is noted for its high percentage of sunshine—about 80 percent of the total possible.

The entire basin is arid except in the extreme high altitudes of the headwater areas. Rainfall is insufficient for the profitable production of crops without irrigation. (See map "Average annual precipitation.") Along the Mexican border the annual precipitation averages only about 2.5 inches while in the higher mountains in Colorado, Wyoming, and Utah, the average is around 40 inches. In the northern part of the basin most precipitation falls in the form of winter snows and spring rains. Summer storms are infrequent but sometimes of cloudburst intensity in localized areas. Winds of high velocity are common in some sections. In the more arid southern portion the principal rainy season is in the winter months with occasional localized cloudbursts in the summer and fall.

Climatological data for representative stations in the basin are summarized in table I.

The length of the growing season varies from about 80 days in the higher elevations of the northern mountainous sections to year-round in the lower semitropical southern areas. In the northern sections hailstorms and late spring and early fall frosts occasionally damage crops. Although the growing season of the higher agricultural areas in the Grand division is short, air drainage in localized sections along the foothills of the lower valleys is favorable for the growing of such fruits as peaches, pears, cherries, apricots, and berries. Because of the long growing season in the lower regions of the southern portion of the basin double-cropping is commonly practiced in the principal farming districts. Crops in some southern areas are seldom damaged by frost, by hail and by warm, dry summer winds.

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TABLE 1.—*Weather records at representative stations, Colorado River Basin* [1]

Division and station	Elevation above sea (feet)	Years of record	Precipitation: Average annual (inches)	Precipitation: Average May–September (inches)	Temperature: Mean annual (degrees)	Temperature: Maximum (degrees)	Temperature: Minimum (degrees)	Average frost-free period (days)	Average growing season (days)
Green									
Kendall, Wyo	7, 600	20	17. 2	6. 94	33. 3	103	−52	53	91
Green, R., Wyo	6, 083	39	7. 7	3. 54	43. 5	103	−40	104	155
Vernal, Utah	5, 266	43	8. 93	3. 82	45	106	−38	118	179
Meeker, Colo	6, 500	42	15. 9	7. 23	43. 1	103	−43	117	143
Green R., Utah	4, 087	43	6. 1	3. 03	52. 5	112	−42	156	203
Grand									
Gunnison, Colo	7, 683	48	10. 1	5. 29	37	105	−47	95	114
Collbran, Colo	6, 200	46	15. 7	6. 74	46	100	−30	160	178
Norwood, Colo	7, 017	13	16. 6	----------	46	99	−29	119	----------
Grand Junction, Colo	4, 587	51	8. 7	3. 91	52	105	−21	190	185
Moab, Utah	4, 000	54	9. 4	3. 83	54. 7	113	−24	172	228
San Juan									
Pagosa Spgs., Colo	8, 150	16	26. 1	9. 63	41. 2	98	−39	84	115
Ignacio, Colo	6, 425	30	16. 1	8. 49	45. 7	101	−38	110	155
Northdale, Colo	6, 482	14	14. 8	----------	44. 8	103	−42	118	----------
Shiprock, N. Mex	4, 950	16	8. 1	5. 72	52. 5	109	−18	157	202
Escalante, Utah	5, 258	35	12. 2	5. 96	45. 7	102	−22	136	183
Little Colorado									
Winslow, Ariz	4, 880	36	18. 10	7. 38	54. 9	107	−19	172	216
Holbrook, Ariz	5, 069	52	9. 13	4. 88	54. 6	106	−21	169	209
St. Johns, Ariz	5, 650	36	11. 60	6. 67	52. 3	104	−22	159	194
Tuba City, Ariz	4, 593	40	6. 73	2. 98	55. 1	110	−15	181	232
Flagstaff, Ariz	6, 922	51	21, 12	8. 89	45. 7	102	−30	123	159
Gallup, N. Mex	6, 785	19	11. 94	----------	48. 5	98	−20	158	----------
Virgin									
St. George, Utah	2, 880	54	8. 66	3. 27	59. 7	116	−11	194	243
Springdale, Utah	4, 048	36	14. 91	5. 14	60. 0	112	−15	199	279
Kanab, Utah	4, 925	36	13. 03	4. 36	52. 6	106	−20	153	207
Alton, Utah	7, 000	29	16. 31	6. 62	44. 8	94	−20	114	170
Logandale, Nev	1, 400	36	5. 21	1. 59	65. 4	120	6	235	350
Caliente, Nev	4, 407	21	7. 16	0. 96	53. 0	110	−31	160	180
Boulder									
Yuma, Ariz	138	74	3. 37	1. 13	72. 2	120	22	331	365
Kingman, Ariz	3, 435	40	11. 14	3. 83	61. 5	117	6	213	320
Grand Canyon, Ariz	6, 930	37	16. 71	7. 58	48. 3	103	−22	141	181
Las Vegas, Nev	2, 033	37	4. 75	1. 81	23. 2	118	8	229	305
Needles, Calif	480	50	4. 72	1. 61	71	125	18	302	365
Brawley, Calif	−119	35	2. 62	0. 42	72	121	19	322	365
Gila									
Phoenix, Ariz	1, 107	47	7. 76	2. 84	70. 2	118	16	301	365
Prescott, Ariz	5, 022	73	18. 76	8. 22	52. 9	110	−21	144	202
Tucson, Ariz	2, 423	74	11. 51	6. 36	67. 2	118	0	240	365
Gila Bend, Ariz	737	49	5. 96	2. 30	72. 2	123	11	288	365
Globe, Ariz	3, 510	42	16. 60	7. 32	62. 6	110	10	231	365
Wickenburg, Ariz	2, 072	42	10. 89	4. 15	64. 9	115	11	231	317

[1] Data from records of U. S. Weather Bureau.

Claiming the Basin

"Man's claiming of the Colorado River Basin has provided a colorful chapter in American history—and one which is not closed. . . . It taxed the courage and resourcefulness of the people themselves. . . .

"This chapter deals with the people—who they are, why they came, where they settled, what towns and cities they established. . . . A study of the human resources is fundamental to an understanding of the problems, the needs, and the opportunities for future development of this great basin."

CHAPTER II

Claiming the Basin

Man's claiming of the Colorado River Basin has provided a colorful chapter in American history—and one which is not closed. Whether people came as missionaries to the Indians, seekers of gold, trappers and traders, explorers, immigrants crossing to more attractive areas, or as pioneers and settlers, the basin presented a challenge. It taxed the courage and resourcefulness of the people themselves. Those who survived to claim the basin as their home are vigorous Americans, who earned their "stake" in the land and its future. To them and to their children and to others who will elect to make this land their home, the challenge remains. What further use will be made of the basin, rich in resources of land, water, minerals, power, and recreational opportunities, is for them to determine. They are the empire builders.

Accumulating evidence shows the basin to have been widely populated thousands of years ago and here and there to have been intensely cultivated under irrigation systems. Spaniards came as early as the sixteenth century seeking gold or bringing the gospel to the Indians, but most of them failed to establish a lasting civilization. The immigrant waves which started rolling to the Pacific in the gold rush of 1849 hurried through the bleak plains of Wyoming to the north and avoided the hostile Indians and scorching deserts of the south. Permanent occupation of the basin by American settlers dates from the middle of the last century. Although settlement and development of the basin have slowly and steadily progressed, today it is still one of the most sparsely settled regions of the United States. It has a total population still below a million people, an average density of fewer than four persons to a square mile, and only two cities of more than 20,000 people.

This chapter deals with the people—who they are, why they came, where they settled, what towns and cities they established, and other related factors. A study of the human resources is fundamental to an understanding of the problems, the needs, and the opportunities for future development of this great basin.

Primitive Peoples

Archeological evidence indicates that the southern part of the Colorado River Basin was inhabited by ancient peoples—cave, cliff, and mud-house dwellers—eight to ten thousand years ago. Indian legends relate that these people were forced to leave the region because of volcanic eruptions in the vicinity of the San Francisco Peaks near Flagstaff, Ariz.

Ruins of dwellings and storehouses, and the remains of pottery, arrowheads, and other artifacts scattered throughout the Colorado River Basin bear mute evidence of the existence of scattered Indian tribes, many of whom had disappeared before the coming of the white man. Some of these, like the present-day Hopi, developed a simple agriculture and lived in permanent compact villages adjoining their cultivated fields. Some, like the Pima-speaking tribes of southern Arizona, harvested seeds and fruits, irrigated their lands and had small village settlements. Others, like the Utes and Paiutes of the plateaus to the north, lived an open, roving life, depending for a livelihood on hunting animals and collecting herbs. They built crude shelters of bark or skins, and seldom resided permanently in large settlements. Dwellings in the valleys were mostly of adobe but other pueblos near and on the cliffs were made of stone. Virtually four-storied apartment houses containing hundreds of rooms have been found.

The present Navajos and Apaches entered the basin as roving bands about 600 years ago and established a civilization which has persisted to the present day. The Pimas, Maricopas, and Papagos of the lower Gila Valley are among the most advanced Indian tribes found in the United States. The Chemehuevi ("Digger Indians") of west-central Arizona are among the least progressive. (See chapter VIII, Office of Indian Affairs.)

Farming by irrigation as now practiced in the Gila and Salt River Valleys may be a modern revival of an ancient agricultural development. Present canals are found to follow closely the route of an ancient canal system and the valleys contain numerous ruins of the villages and storehouses used by a people whose history is still in doubt. Extensive remains of the old agricultural development are found throughout almost the entire Gila River Valley. The ancient canals probably were capable of serving as much as 250,000 acres in all, though the area actually under cultivation at any one time may have been comparatively small. Primitive construction tools restricted the size of irrigation works. All irrigation was done by direct diversion. As the low-lying irrigated lands became waterlogged, the community moved to another location and developed new land. The numerous ruins are believed to be the evidence of those successive migrations. The cause of the final exodus of the original tribes from the region is not known, but is believed to have been severe drought. The present modern irrigation works are simply making more efficient use of the same streams which at one time made possible the agriculture which supported a primitive people.

Explorations

The deep canyons, obstructing cliffs, and desert wastes long hindered travelers in penetrating the Colorado River Basin. The Spanish conquistadors, exploring north from Mexico, were the first white men to enter the basin. In 1539 the Spanish explorer Francisco de Ulloa sailed to the head of the Gulf of California and because of the turbid water inferred that a stream entered the gulf in that vicinity. He did not see a river, but drew a rough map showing its supposed location.

The Colorado River actually was discovered in 1540 by Hernando de Alarcon, who explored the stream from its mouth to a point near the present site of Ehrenberg, Arizona, about 100 miles above the mouth of the Gila River. Two years later Lopez de Cardenas discovered the Grand Canyon but was unable to descend its sheer walls. To traverse the country and to obtain food and supplies seemed so hopeless to early explorers and missionary priests that 2 centuries elapsed before a crossing was made in the canyon section.

In the sixteenth century, Spanish explorers forded the Little Colorado River near the present site of Holbrook, Ariz. They named the river "Rio Alameda" or "River of the Groves," which would indicate that the stream flow characteristics at that time must have been materially different from the erratic flow of the present.

Father Escalante's expedition crossed the Virgin River in 1776 near St. George, Utah, after an unsuccessful search for an overland route from Santa Fe, N. Mex., to Monterey, Calif.

As time passed, stories of these early Spanish explorers combined with Indian legends grew into fabulous tales of this unknown land. It was said that the Colorado had great falls and whirlpools and that it ran underground for hundreds of miles. So formidable were the actual conditions that the Colorado River was long considered a dangerous obstacle to be circumtoured.

Spanish explorations continued to the beginning of the nineteenth century, the region being covered rather thoroughly. During this period two missions were built along the Colorado River, both of which were later destroyed by Indians. Some encouragement was given to Indian agriculture, but the Spaniards' main interest in the area lay in the exploitation of its mineral resources.

Venturesome traders, trappers, and explorers entered the area during the period 1820–1840. Beginning in 1824 General William Henry Ashley with a large band of expert trappers explored part of the Green River canyons. Other trappers and explorers who visited the basin during this period were James O. Pattie (1825), R. W. H. Hardy (1826), Jedediah Smith (1826), Kit Carson (1826), Ewing Young (1827), William Wolfskill (1830), Capt. Benjamin L. E. Bonneville (1832), and Thomas J. Farnham (1839). By the year 1840 this wilderness had been traversed throughout by white men except for the deep canyons of the Colorado.

The trapping of wild animals for their pelts was the first exploitation of the resources of the basin by Americans. From 1824 to 1840 General Ashley's fur company and its successors, eventually the Rocky Mountain Fur Co., met other trappers and Indians at annual rendezvous on the Green River. The trappers traded furs to Ashley's company for ammunition, whiskey, and various supplies and trinkets. The trapper's life was extremely arduous and hazardous, and few trappers survived for many years the attacks of hostile Indians. After 1840 the beaver was so depleted that trapping was no longer profitable.

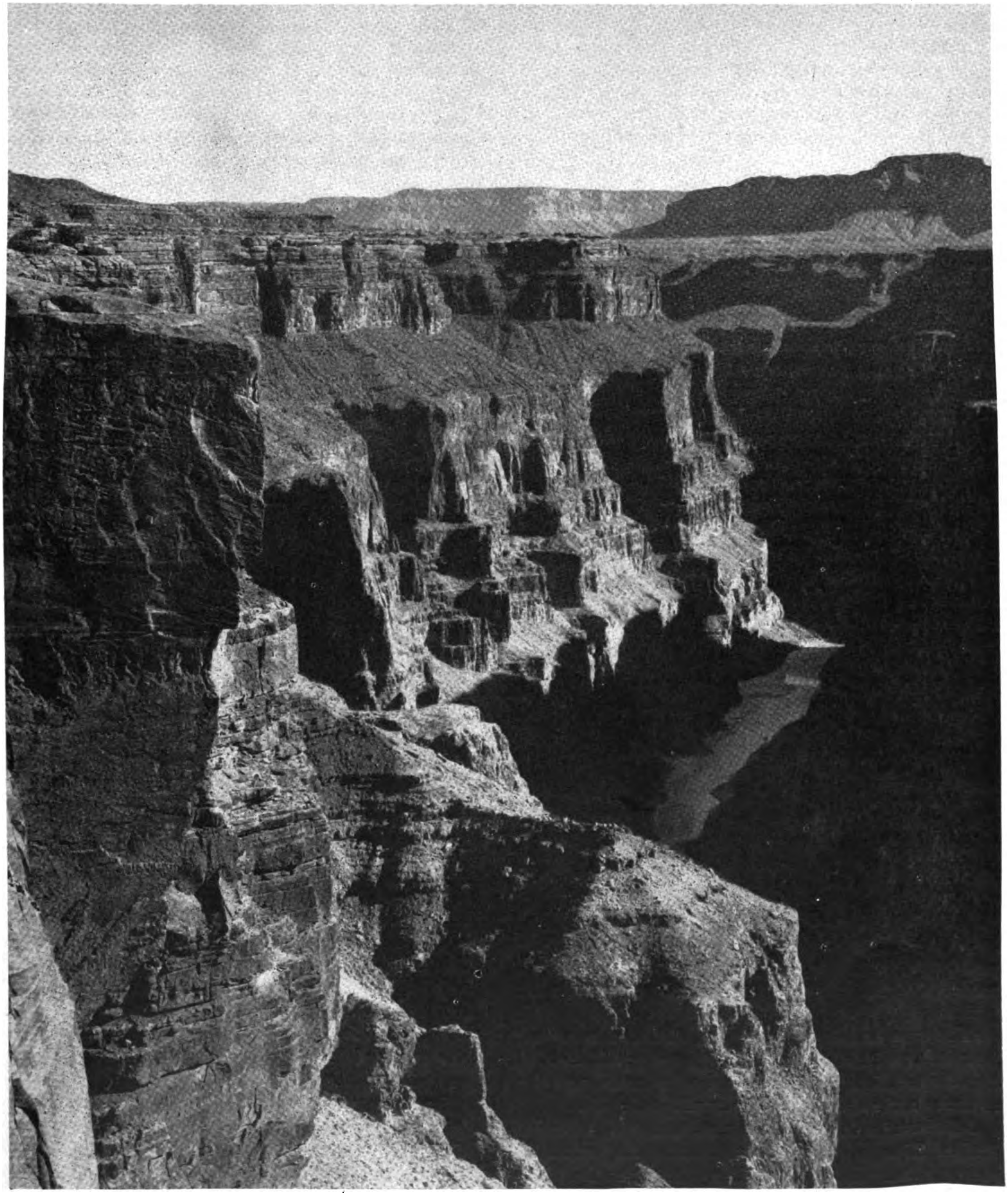
In 1843 Jim Bridger established a trading post on a branch of the Green River. John C. Fremont's explorations of the Colorado and the West covered the period 1842–46.

The historic march of the Mormon Battalion, a group of 500 officers and men mustered by the Mormon Church for service in the war with Mexico, crossed the southern part of the basin in 1846, marking a wagon road from Santa Fe to San Diego.

The treaty of Guadalupe-Hidalgo, signed in 1848 at the end of the war with Mexico, and the Gadsden Purchase in 1853 gave to the United States much of the territory now included in the seven Colorado River Basin States.

In 1849 after gold was discovered in California at Sutter's Mill, adventurers began to pour across the Colorado River at two main points, one near Yuma, Ariz., and the other at "The Needles" about 200 miles farther north. The gold seekers also used a northern route which crossed the Green River in Wyoming. At the same time the Mormons were crossing the upper part of the basin en route to the Salt Lake Valley in Utah, and many emigrants following the Oregon Trail traversed the Green River country.

With the establishment of Fort Yuma on the lower Colorado River in 1851 steamboating on the river began. Navigation was the first use made of the main Colorado River.



CANYON COUNTRY

Deep narrow canyons of the Colorado afford excellent power sites

Before the coming of the railroads, all freight for the interior of Arizona was carried by sea-going ships to the head of the Gulf of California; there it was transferred to the river boats of the Colorado Steam Navigation Co. and shipped to various points along the lower river whence it was carried overland by wagon train to its final destination.

In 1857 the War Department dispatched Lt. J. C. Ives to proceed up the Colorado River by boat as far as navigation was possible. He ascended in his steamboat only as far as Fort Callville near the head of Black Canyon, about 400 miles above the mouth of the river. It took him 5 days to navigate the last 20 miles.

In his report to the War Department, Lieutenant Ives said:

> The region last explored is, of course, altogether valueless. It can be approached only from the south, and after entering it, there is nothing to do but leave. Ours was the first, and doubtless will be the last, party of whites to visit this profitless locality. It seems intended by nature that the Colorado River along the greater portion of its lone and majestic way shall be forever unvisited and unmolested.

In 1869, Maj. J. W. Powell succeeded in leading a river expedition down through the canyons of the river. In traveling by boat from Green River, Wyoming, to the mouth of the Virgin River in Nevada, a few miles above where Lieutenant Ives had been stopped, he achieved the hitherto impossible feat of traversing a thousand miles of unknown rapids and formidable canyons. He became the first white man to gaze up the sheer walls of the Grand Canyon throughout its entire length and live to tell the tale.

Subsequently, Major Powell and others made additional voyages to explore the canyons. With the river explored, active investigation began to make it useful for man.

Settlement

Settlement of the Colorado River Basin has slowly but steadily progressed. Rural settlements have been scattered along streams. Towns and cities have grown up mainly near farms and mines and at important railroad points.

The early settlers endured many hardships in carving homes from the wilderness—the rigors of an arid climate, the depredations of Indians and wild beasts, and the arduous and wearisome existence of frontier life.

Missionaries influenced early settlement in the basin. Father Kino, a Spanish priest, founded the first settlements subsequent to his visit to the region in 1691. Spaniards established resident fathers in the Santa Cruz River Valley as early as 1700, and soon after several missions were constructed on the banks of the stream.

Among the early colonizers of the basin were Mormon pioneers, who settled in small agricultural communities along river valleys, cultivated the more favorable farming lands adjacent to streams where irrigation water was readily accessible, and grazed livestock on nearby range lands. Old Fort Supply in Wyoming and Santa Clara, Utah, were established by Mormons in 1854. Mormon settlements spread into other parts of Utah, and in Arizona and Nevada in the 1860's and '70's.

The lure of gold was a chief factor influencing early settlements. Many a pioneer settler came seeking his fortune in the gold rushes, but, finding that his dreams of easy riches would never materialize, stayed to raise livestock or to farm.

Several rich mines were discovered throughout the basin by transient prospectors and these discoveries were responsible for a temporary population influx. Miners and prospectors pushed over the mountains from older mining districts on the eastern slope of the Continental Divide. The placer ground at Breckenridge, Colorado, near the crest of the divide attracted the first settlers to this region in 1859. Within the next decade other mining camps were established near the mountain tops. Some miners turned to farming and found a lucrative business in supplying agricultural products to the mining communities. Settlement grew downward from the mountains into the valleys in this western slope section of Colorado, the advance being slowed somewhat by the hostility of the Indians who occupied the territory.

The greater part of the Uinta Basin in Utah was established as an Indian reservation in 1861.

Mining was active in southeastern Arizona from 1847 to 1860 under protection of the Federal Government, but during the Civil War hostile Indians caused nearly all of the early mining settlements to be abandoned. After the Civil War mining was resumed.

The establishment of amicable relations with the Indians and the construction of railroads through the basin finally made permanent settlement possible. The Union Pacific Railroad was completed to Green River, Wyo., in 1869. The Southern Pacific Railroad reached the Colorado River at Yuma, Ariz., in 1877, and the Atlantic and Pacific Railroad crossed the river at Needles, Calif., in 1883. With the coming of the railroads, navigation soon declined. Other than by railroad, early transportation was by horse and mule, pack train, or freight wagon traversing trails and primitive roads.

For many years mining was the leading industry in the Colorado River Basin but declined in relative importance with the development of irrigated agriculture. Many rich gold and silver lodes pinched out. Aspen, Telluride, and Silverton in Colorado, once prosperous cities pouring out gold and silver, became dozing towns. Production of copper, lead, and zinc became more important, and

Arizona displaced Colorado as the leading producer of minerals in the basin. Where valuable mines were discovered, towns sprang up in their immediate vicinity, and where possible, irrigated agriculture was practiced nearby to supply the demands of local markets.

Cattlemen were attracted to the expansive grazing areas of the basin and in many sections were the first settlers.

Colonization in the basin has been accompanied by a continual search for a satisfactory irrigation water supply. Settlers migrated to areas more readily irrigated and concentrated along river courses. A few small settlements were made in favored isolated areas.

The history of early settlement along the lower reaches of the Colorado River is a story of community struggles with destructive floods. Many towns were established only to be abandoned later when it became evident to the settlers that it was impossible for them to control the rivers. Dams were repeatedly washed out, crops withered and died in time of drought, and flash floods ravaged the fields and towns.

Private and community efforts were responsible for the establishment of early settlements. Some present-day settlements, however, followed in the wake of Federal Reclamation developments. These projects, making available new areas of fertile farm land and attracting many new settlers, have been the nuclei around which farming communities and trade centers have evolved.

Population

Referred to as an area of "wide open spaces", the Colorado River Basin is sparsely populated. On the basis of the 1940 census, which reported fewer than a million people in the basin, the average population density of the entire area, including urban centers, was 3.6 persons a square mile, as compared with a national average of 44.2 persons a square mile.

Population Growth

Except for short-lived surges resulting from mining, the population of the Colorado River Basin has steadily increased since its colonization. At the beginning of the Twentieth Century the basin supported only 261,197 persons, or little more than an average of one person a square mile. The population has more than tripled in the first 40 years of this century.

The first settlements which grew into permanent communities were largely the result of farming. But farming was slow to develop into a stable industry, and in the early stages it was not adapted to the support of sizable centers of population. Urban communities began to rise with the development of federally financed irrigation projects. The city of Phoenix, Ariz., grew rapidly in the decade 1910–20 when great strides were taken in the development of irrigation in the immediate vicinity.

The relatively high rate of natural increase, the improvement in transportation facilities, the opening of scenic features of the country to tourists, the accessibility of outside markets, and migrations from the Middle West have been largely responsible for the increase in population during the 1930–40 period.

Population growth has not been uniform throughout the basin. Between 1900 and 1940 the Lower Basin increased its population five times while during the same period the upper basin little more than doubled. A phenomenal growth was experienced by the southern California area where the population increased more than 12 times in the same 40-year period.

The people of the Colorado River Basin are predom-

Table II.—*Population growth in the Colorado River Basin*

Division	1900	1910	1920	1930	1940
Upper basin					
Green	42, 110	59, 450	85, 320	93, 330	99, 710
Grand	57, 050	84, 590	84, 380	84, 050	105, 450
San Juan	32, 340	47, 890	53, 450	66, 920	81, 290
Total	131, 500	191, 930	223, 150	244, 300	286, 450
Lower basin					
Little Colorado River	19, 057	34, 631	44, 146	60, 986	75, 341
Virgin	9, 569	10, 305	11, 706	13, 879	17, 213
Boulder	10, 414	33, 871	79, 899	111, 558	127, 568
Gila	90, 657	161, 969	275, 433	363, 466	411, 497
Total	129, 697	240, 776	411, 184	549, 889	631, 619
Colorado River Basin	261, 197	432, 706	634, 334	794, 189	918, 069
Southern California	282, 090	703, 675	1, 253, 800	2, 791, 927	3, 524, 860
United States	75, 994, 575	91, 972, 266	105, 710, 620	122, 775, 046	131, 669, 275

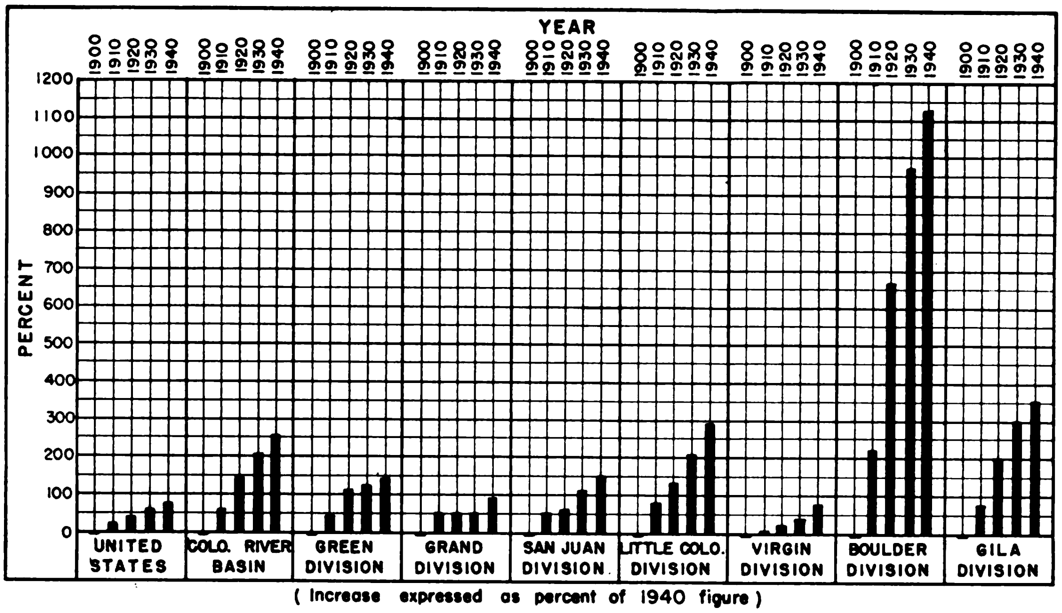


FIGURE 1.—*Population Growth, 1900–1940.*

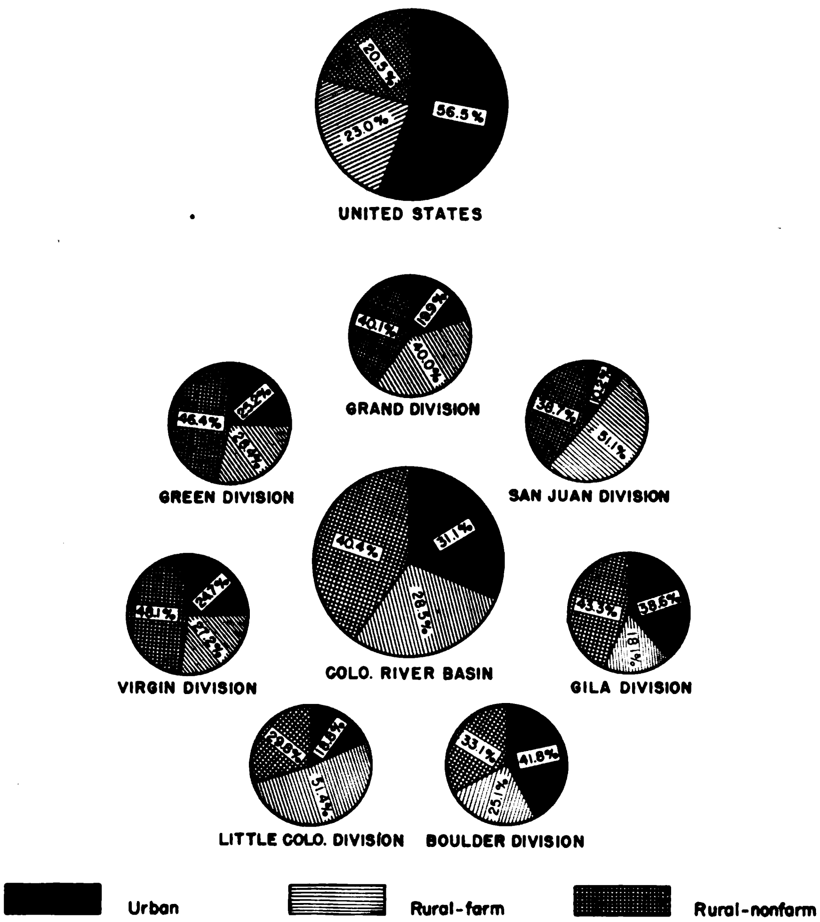


FIGURE 2.—*Distribution of Population, 1940 Census.*

inantly white, almost 90 percent of the population being so classified in 1940. Of the nonwhite races, Indians are in greatest number, both in the upper and lower basins, and are concentrated in vast Indian reservations scattered throughout this area. Indian and Negro populations are increasing.

Distribution of Population

Approximately 69 percent of the 1940 population of the Colorado River Basin was classified as rural. This means that approximately 630,000 people lived either in the open country or in towns and villages of fewer than 2,500 population. Only 28 percent of the total population lived on farms and approximately that proportion was directly dependent upon agriculture for a livelihood.

Urban centers are scattered throughout the basin. Largest settlements in the upper basin are mining, agricultural, and railroa dcenters. In the lower basin concentration of population is mainly where irrigation is extensive, although recreational and scenic attractions have been responsible for the location and growth of many cities. Conforming to a National trend, there is an increasing concentration of population in urban centers. Principal towns and cities in the basin are:

Division	Population (1940)	Division	Population (1940)
Green		**Little Colorado—Con.**	
Rock Springs, Wyo	9, 827	Winslow, Ariz	4, 577
Price, Utah	5, 214	Holbrook, Ariz	1, 184
Helper, Utah	2, 843	**Virgin**	
Green River, Wyo	2, 640	St. George, Utah	3, 591
Craig, Colo	2, 123	Hurricane, Utah	1, 524
Vernal, Utah	2, 119	Caliente, Nev	1, 500
Kemmerer, Wyo	2, 026	Kanab, Utah	1, 365
Grand		Pioche, Nev	1, 182
Grand Junction, Colo	12, 479	**Boulder**	
Montrose, Colo	4, 764	Brawley, Calif	11, 718
Delta, Colo	3, 717	El Centro, Calif	10, 017
Glenwood Springs, Colo	2, 253	Las Vegas, Nev	8, 422
Gunnison, Colo	2, 177	Yuma, Ariz	5, 325
Fruita, Colo	1, 466	Williams, Ariz	2, 622
Rifle, Colo	1, 373	**Gila**	
San Juan		Phoenix, Ariz	65, 414
Durango, Colo	5, 887	Tucson, Ariz	36, 818
Farmington, N. Mex	2, 151	Douglas, Ariz	8, 625
Shiprock, N. Mex	2, 131	Prescott, Ariz	6, 018
Escalante, Utah	1, 106	Bisbee, Ariz	5, 853
Little Colorado		Nogales, Ariz	5, 135
Gallup, N. Mex	7, 041	Silver City, N. Mex	5, 044
Flagstaff, Ariz	5, 080	Safford, Ariz	2, 266

Population Movement

The towns first established in the basin were little more than temporary camps, and a look at a map of 40 or 50 years ago will reveal names of communities which are today but memories of a romantic past.

From the beginning the population possessed a high degree of mobility, particularly in the lower basin. Although the number and size of permanent communities have increased since the turn of the century the population has not lost its trait of mobility. The University of Arizona found from a recent study of population trends in Arizona that while the decade 1930–40 brought 134,000 people into the State, the net population gain was only 63,000 persons, of which 32,000 could be attributed to the natural increase in the resident population. Some 103,000 people had claimed Arizona as a place of residence during that decade but had failed to become permanently established.

Economic depressions and disasters in other States have dislodged many people from permanent moorings, and those thus affected have moved aimlessly about the country. The droughts and dust storms which occurred in the Middle West in the 1930's resulted in such migrations. Hearings before the House of Representatives Committee of the Seventy-Seventh Congress investigating migratory labor problems revealed that 63 percent of all migrants into Arizona and southern California during this period came from the Middle West. The committee found that while 66 percent of the group investigated had been farm operators or owners prior to migration, less than 15 percent became owners or operators of farms in their new locations. The majority of the migrants from the Middle West became farm laborers or joined the ranks of the semiskilled or unskilled workers, depending on seasonal or other temporary employment.

The population of the upper basin has been less affected by immigration than that of the lower bsin. Instead of growing from migration, Utah lost by outward movement of its residents from 1920 to 1940. Many young people left the State to seek work and opportunities in larger industrial centers and metropolitan areas. Despite its outward migration, Utah has had a net population gain each decade because of its high birth rate. In 1930 Utah had the highest rate of natural increase in the Nation.

The rise of war industries during World War II brought to the area its most rapid influx of people. The most significant movements were to southern Nevada and central Arizona. Las Vegas, Nevada, tripled in population during the war period, and the city of Phoenix, Arizona, increased approximately 130 percent. At the same time, thousands of young men left the area to join the Nation's armed forces. Thus, the war induced movements into and out of the basin.

The relatively undeveloped state of the basin and its store of natural resources indicate that by no means has the population reached its peak growth.

Dividing the Water

"In this chapter the history of irrigation development is traced to this critical period and problems are presented that pressed for solution in the development and use of the Colorado River for irrigation, flood control, power production, and other beneficial uses.

"The Colorado River Compact which divided the water between the upper and lower basins, other legislative acts pertaining to the development of the Colorado River, and the Mexican treaty allocating certain of the waters of the Colorado River to the sister republic are briefly outlined with no attempt at legal interpretation."

CHAPTER III

Dividing the Water

As more people claimed the Colorado River Basin for their home, they came to realize that the extent of the ultimate habitable area was determined by the limitations of the dependable water supply and that the Colorado River was increasingly important as a national resource.

How to divide the waters of the Colorado River for beneficial use presented complications. Because the watershed reached into seven States in this country interstate problems required solution before any comprehensive development could be undertaken. Since the river's lower delta and its mouth extend into Mexico international problems also were presented.

In the history of the development of the Colorado River the early 1920's was a significant period. By that time the use of water in the lower river area had reached the maximum possible without extensive storage regulation, and demands for additional water had created a critical situation which finally resulted in the Colorado River Compact, the Boulder Canyon Project Act, and subsequent acts pertaining thereto.

In this chapter the history of irrigation development is traced to this critical period and problems are presented that pressed for solution in the development and use of the Colorado River for irrigation, flood control, power production, and other beneficial uses. The Colorado River Compact which divided the water between the upper and lower Basins, other legislative acts pertaining to the development of the Colorado River, and the Mexican treaty allocating certain of the waters of the Colorado River to the sister republic are briefly outlined with no attempt at legal interpretation.

Fundamental to a division of the water is a knowledge of the quantity, quality, and flow characteristics of the water available. Virgin conditions of the Colorado River are considered for this purpose.

Virgin Conditions

The Colorado River, draining 242,000 square miles in this country, has the largest watershed of any stream in the United States outside of the Mississippi River Basin. Beginning high on the Continental Divide it empties into the Gulf of California at sea level.

Rain and snow fall in abundance on the Rocky Mountains rimming the upper part of the Colorado River Basin, but great expanses in the lower areas are comparatively dry. The average annual precipitation for the entire drainage area of less than 15 inches is near the lowest for the major river basins of America. Nearly 90 percent of the moisture that falls returns again to the atmosphere through evaporation, and only about 10 percent flows in the river channel. Yet about 10 percent of the scanty precipitation on so vast an area makes up the flow of the mighty Colorado River. The river grows almost to its full size from contributions of tributaries in the upper half of its drainage area, above Lee Ferry in Arizona. Below that only minor contributions are made by the Little Colorado and Virgin Rivers, and between Black Canyon (site of Boulder Dam) and the entry of the Gila River near the Mexican border inflow is insufficient to offset evaporation losses in the desert region. From an analysis of all available data, average virgin flows at various points are estimated as follows:

TABLE III.—*Estimated Virgin flows in the Colorado River Basin*

Stream	Location	Average annual flow (acre-feet)
Green River	At mouth	5, 903, 000
Colorado River	Above mouth of Green River.	7, 289, 000
Do	Lee Ferry in Arizona	[1] 16, 270, 000
Little Colorado River	Near the mouth	338, 000
Virgin River	Littlefield	310, 000
Colorado River	Boulder Dam	[1] 17, 330, 000
Do	Laguna Dam	[1] 16, 450, 000
Gila River	Dome	[1] 1, 270, 000
Colorado River	International boundary	[1] 17, 720, 000

[1] See appendix I, "Water supply, Colorado River."

Before man built the existing structures providing partial river control, seasonal flows of all streams fluctuated greatly. In the spring the Colorado River fed by melting snow was a mighty, raging torrent, reaching flood peaks of 250,000 second-feet or more. Below the canyon section it overflowed its banks and inundated the country for miles around. In summer in years of low run-off its flow became a mere trickle by comparison, sometimes dropping to 2,500 second-feet. The only sustained summer flow of most tributaries was the outflow from numerous mountain lakes fed by the melting of perpetual snow banks. The northern tributaries had greater sustained flows than those in the southern region, but they too were subject to great fluctuations.

The flow of the river also fluctuated greatly from year to year. At Lee Ferry, under virgin conditions, annual flows probably ranged from as little as 5,500,000 acre-feet to as much as 25,000,000 acre-feet. Flows of tributary streams were characterized by even greater variations, especially those of the lower region. Under virgin conditions the average annual flow of the Gila near Phoenix is estimated to have been 2,282,000 acre-feet, of which probably only about 1,270,000 acre-feet reached the Colorado because of losses in the lower river area.

The creeks and streams at higher elevations generally bring clear, pure water into the main Colorado River, although they become roily during the spring run-off. Soluble salts in quantities damaging to plant growth occur in isolated tributaries but the injurious effects are local and generally unimportant. Diluted by larger streams of the system, these soluble salts of tributary streams cease to be harmful. Water of the main river becomes progressively more saline as it moves downstream and receives return flows from irrigation and drainage from basin lands but is considered suitable for irrigation at the lowest diversion. (See Ch. VIII, Geological Survey "Quantity and Quality of Water.")

Tributaries entering the middle and lower sections of the Colorado River, notably the San Juan, Little Colorado, and Virgin Rivers, have highly erosive watersheds and hence contribute great quantities of silt to the main stream. At normal flow stages little silt is carried, but more is picked up in spring and early summer when flows become high and turbulent. Occasional summer cloudbursts cut into unstable earth sections, flushing large amounts of mud and silt into the streams.

Early Development of the River

Irrigation

The first white irrigators in the Colorado River Basin were the Jesuits who established themselves at the old missions of Cuevavi and San Xavier in Arizona in 1732. In the period 1768 to 1822, considerable irrigation was practiced along the Santa Cruz River near the missions and the Spanish presidios of Tubac and Tucson.

After the Gadsden Purchase in 1854, a number of Americans—military followers, stragglers from the immigrant stream to California, and others, pioneers by instinct—began to settle and develop irrigation in Arizona. Thomas H. Blythe moved to the Palo Verde Valley in 1856 and commenced the first recorded use of the Colorado River in California. In 1877 he made the first filing on Colorado River water in California. About the same time the first modern irrigation works were being constructed in Wyoming, Utah, and Colorado. In 1854 Mormon pioneers began to irrigate from Blacks Fork, a tributary of Green River, in Wyoming. Irrigation in the basin in Colorado began in the 1860's and 1870's when prospectors and miners came over the Continental Divide from the older mining districts on the eastern slope of the Rockies. The Federal Government first attempted to reclaim arid lands on the Colorado River Indian Reservation in 1867. In 1883 the Grand Valley Canal, a private development, was started to irrigate a relatively large area in Grand Valley on the western slope of the Rockies in west-central Colorado.

The possibility of exporting water from the Colorado River to the Imperial Valley of California by a simple diversion canal passing in part through Mexico was recognized even before the Civil War. In 1876 Lt. Eric Bergland made surveys on the lower river for the War Department for the purpose of investigating flood conditions and to determine the feasibility of diverting water from the Colorado River to the Imperial Valley through a canal wholly within the United States. He reported unfavorably on such a canal but efforts continued for a water supply to the Imperial Valley. Despite the difficulties and undesirability of a canal through Mexico for the irrigation of Imperial Valley from the Colorado River, construction of an international canal was finally begun in 1902 by the California Development Co. By September 1904 nearly 8,000 people had settled in the valley; 700 miles of canal were in operation; and 75,000 acres of land were cropped.

After passage of the Reclamation Act by Congress in 1902, the Reclamation Service (Bureau of Reclamation since 1923) of the United States Department of the Interior began investigations to determine the feasibility of constructing large irrigation works in the West. Some of the early projects constructed in the Colorado River Basin by the Reclamation Service were the Uncompahgre and Grand Valley projects in Colorado, the Strawberry Valley project in Utah, and the Yuma and Salt River projects in Arizona.

Irrigation continued to expand in both the Upper and Lower Basins. In 1922 the approximate irrigation development in the entire Colorado River Basin, according to a report by F. E. Weymouth, then Chief Engineer of the Reclamation Service, was as follows:

TABLE IV.—*Irrigation Development in the Colorado River Basin (1922)*

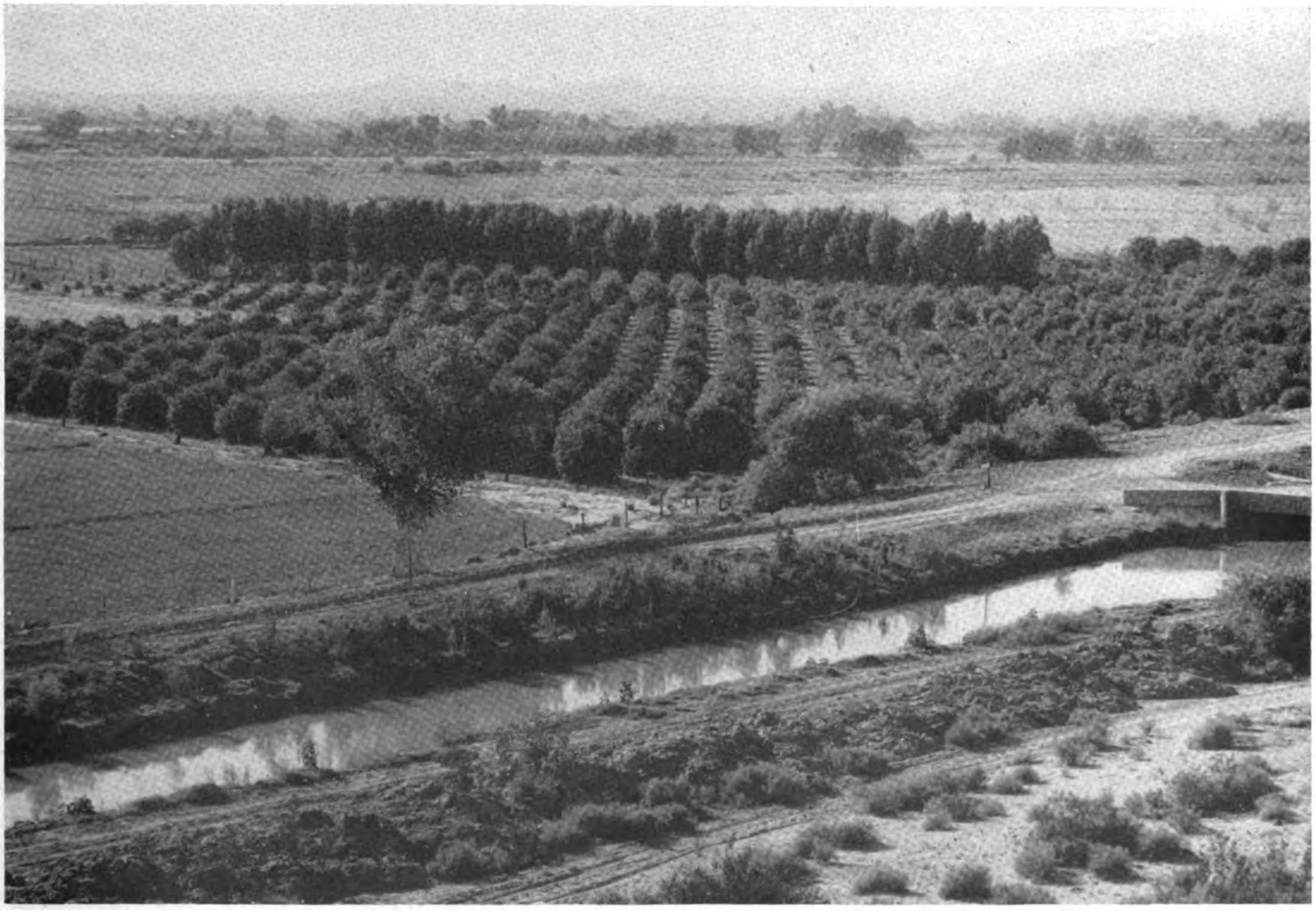
	Area irrigated (acres)	Area irrigable (acres)	Total (acres)
Upper Basin	1, 450, 000	2, 750, 000	4, 200, 000
Lower Basin	950, 000	1, 350, 000	[1] 2, 300, 000
Total in United States	2, 400, 000	4, 100, 000	6, 500, 000
Mexico	200, 000	800, 000	1, 000, 000
Total	2, 600, 000	4, 900, 000	[1] 7, 500, 000

[1] Includes 430,000 acres irrigated and 400,000 irrigable in the Gila River Basin.

Irrigation in the upper basin was mainly in scattered small developments on the main stream and many tributaries. General farm crops predominated, and in a large portion of the irrigated area, particularly in much of the Green River country, wild hay for livestock feed was the principal crop. At that time a total of 115,000 acre-feet of water annually was being exported from the Upper Basin for irrigation in adjoining basins. The Strawberry Valley project was diverting water from Strawberry River, a tributary of Duchesne River, to Spanish Fork in the Bonneville Basin in Utah. Several other small diversions were being made into the South Platte and Arkansas watersheds in Colorado. Additional large diversions, amounting to over 400,000 acre-feet, were being considered for development in these States, including transmountain diversions for the municipal water supply of Denver.

Topography and the high cost of projects, as well as climate and lower crop values, were limiting the rate of irrigation expansion in the upper basin.

Development in the lower basin, with its climatic conditions favorable to intensive cultivation of semitropical fruits, cotton, lettuce, and melons, was being hampered by limited low-season stream flows. Irrigation on the Gila was well advanced by 1922. The Imperial Valley, which then had over 400,000 acres under irrigation by direct diversion from the Colorado River without storage regulation, suffered a water shortage in each low-water



YUMA PROJECT

This early reclamation development on the Colorado illustrates how irrigation water conveyed in canals like that shown in the picture transforms desert (foreground) into citrus grove (background) year. The canal serving Imperial Valley lands also supplied water for the irrigation of 200,000 acres or more in Mexico, thus exporting some 3,000,000 acre-feet annually out of the basin for use in both countries.

Flood Control

Uncontrolled the Colorado River was a natural menace. Before the construction of Boulder Dam, the lower stretches of the river were annually subject to long sustained floods from the melting snows of the high mountains in Colorado, Wyoming, and Utah. Floods originating in the lower tributaries were of shorter duration but extremely erratic and perhaps not less damaging. The tragic menace from floods, however, was not fully realized until 1905. Then the Colorado, swollen by flood waters from the Gila, broke through a cut which was made 4 miles below the international boundary by the California Development Co., operators of the Alamo Canal. For 16 months the Colorado poured its entire flow into Imperial Valley's sunny fields and flourishing communities. It enlarged the Salton Sea to a lake 76 feet deep and 488 square miles in area, and threatened permanently to engulf the entire valley. The break was finally closed with great difficulty and expense, but about 30,000 acres of arable land had been inundated, farms ruined, homes destroyed, highways washed away, and railroad tracks wrecked. Miles of mainline track of the Southern Pacific Railroad had to be moved to higher ground, and tangible damage into the millions of dollars was sustained. Here, in the need for flood control, was the prime motivating reason for the construction of Boulder Dam.

Protection of the delta lands lying principally below the level of the Colorado had required the building of levees in both United States and Mexico. Each year these were lashed by silt-laden floods. The levees were built higher and stronger. Maintenance of the levees was an expensive burden and was complicated by international problems.

Levees constructed to protect the Yuma project on the Colorado just north of the international boundary line had broken several times with disastrous local results. Another similar flood occurred in 1922 when the levees along the Palo Verde Valley in California were broken. To protect the lands on the lower river, 150 miles of levees were maintained. Although many additional breaks occurred, the major levees were intact in the early 1920's. Defensive measures, however, became more and more burdensome. From 1906 to 1924, 10¼ million dollars were spent by various agencies on levee construction and maintenance on the lower Colorado River, including protection for Imperial Valley. Even this large expenditure did not eliminate the menace. The continued threat of a major break from some unexpected river change still remained and 100,000 people lived in fear that the river might overwhelm them.

Silt Problems

The difficulty of maintaining an adequate levee system was aggravated by siltation. Each year the Colorado River was depositing over 100,000 acre-feet of silt in the delta region, lifting itself higher and higher and making a larger and continuous expenditure necessary to maintain levees protecting the Imperial Valley. In 1923 and 1924 the Imperian irrigation district was spending over $500,000 annually to remove silt from its canal systems. In addition, it was estimated that Imperial Valley farmers expended about $1,000,000 to repair damages from silt deposits on their farms.

Hydroelectric Power

In the early 1920's the existing hydroelectric power developments in the Colorado River Basin were largely confined to the tributaries of the Colorado River. Thirty-six plants with a combined capacity of about 37,000 kilowatts were in operation, the largest being the Shoshone plant of the Colorado Power Co. on the main stream above Glenwood Springs, Colo., and the plant built by the Bureau of Reclamation at Roosevelt Dam on the Salt River in Arizona. Each of these plants had an installed capacity of approximately 10,000 kilowatts.

In 1922 the Salt River Valley Water Users' Association started the construction of a series of three dams below Roosevelt Dam on the Salt River for irrigation storage and power production to help supply the needs of the Phoenix area.

In the early 1920's the southern California coastal plains centering around the Los Angeles metropolitan area were experiencing a phenomenal growth, the population more than doubling from 1920 to 1930. A great potential power market thus was being created. Serious consideration was also being given to the electrification of railroads in the Colorado River Basin. Although the power uses within the basin at that time were small in the aggregate and the sparse population needed little power development for ordinary local uses, the rapidly growing market in the southern California area combined with advancement in electric power transmission had created a demand for a large amount of additional power. The growth of the power load was rapidly exhausting the available hydroelectric resources of southern California and an additional source of power was much needed for its growing industrial development.

Municipal Water Supply

With no large cities in the basin, the needs and developments for municipal water supply within the area had been small, but in the early 1920's it was becoming increasingly evident that the rapidly growing southern California metropolitan area would soon demand a new source of water. Los Angeles was utilizing fully its Owens Valley water and had studied other sources from which water could be obtained. The only adequate practical source appeared to be the Colorado River, whose floodwaters, if properly conserved, could be made available for such use.

The need for a source of domestic water supply became an additional and potent reason for urging the development of the Colorado River. In 1923 the first reconnaissance for an adequate route from the Colorado River to the southern California area was undertaken by the city of Los Angeles. The general feasibility of such an aqueduct was soon established, and on June 28, 1924, the city of Los Angeles made a filing with California State authorities on a flow of 1,500 second-feet of water from the Colorado River, or 675,000 gallons per minute.

Summary of Conditions in the Early 1920's

By 1920 the population of the Colorado River Basin was 634,334 persons, with the lower basin growing more rapidly than the upper basin. In the early 1920's mining was being replaced by irrigated agriculture as the leading industry in the basin. Livestock grazing was important, lumbering was a lesser industry, and the tourist trade was just starting to develop.

Several important national parks had been found in the basin, the most important being the Rocky Mountain National Park, established in 1914, and the Grand Canyon National Park established in 1919. The Fall River Road over the Continental Divide in Rocky Mountain National Park was completed in 1920. By that time health resorts and scenic attractions in the basin along the transcontinental railroads long had been enjoyed by the traveling public, but automobiles and the rapid development of a network of good highways were just beginning to make accessible generally the basin's more remote areas.

Large sections of land in the basin had been set aside as Indian reservations. Over 17,000,000 acres in Arizona alone were under the jurisdiction of the Office of Indian Affairs. The Indian population, which was about 80,000 in 1920, had remained practically constant for years, but began to increase materially during the 1920's.

Livestock grazing continued to be an important industry in the basin. By 1920 control of large grazing areas by the Forest Service was stabilizing and making more profitable the livestock industry.

Irrigation development in the upper basin was considered to be lagging behind that in the lower basin, where rapid progress was being made in the Gila River Basin. Main stream developments on the lower river, however, were being impeded by lack of storage facilities; existing developments were suffering frequent shortages and, moreover, were being threatened by continued flood hazards aggravated by silt problems.

Thus by 1920 the situation with respect to the Colorado River had become very tense. Increasing upstream depletions were accompanied by increased requirements for irrigation development in California and Mexico. The constant threat of an unmanageable break of the river into Imperial Valley during flood stages was also becoming more serious with the rising level of the river and its flood plains within the levees protecting the Imperial Valley. Meanwhile the rapid growth of the metropolitan district of the southern California coastal region was creating a great demand for a large block of power and for additional municipal water supplies. Similar demands for municipal water for the growing city of Denver in the adjacent Platte River Basin were anticipated.

About the same time a keen interest in the Colorado River was displayed by various public and private agencies, seeking the right to develop hydroelectric power but proposing to provide storage and flood control incidentally.

An extensive investigation by the Bureau of Reclamation to develop ways and means of meeting all of the various needs resulted in the recommendation for the construction of a dam either in Boulder Canyon or Black Canyon for flood control, navigation improvement, irrigation storage, silt control, and power development. The long standing need for a canal wholly within the United States also was recognized and it was recommended that such a canal connecting the river at Laguna Dam with the Imperial Valley be constructed and thus eliminate all international complications.

Between the Upper and Lower Basins

Forces Activating Interstate Agreement

For a number of years prior to 1922 the lower basin area, growing more rapidly in population than the upper basin, had pressed for development of the lower river and the upper basin and objected. In 1919 and again in 1920 bills were introduced in Congress for Federal assistance in building an all-American canal. In April 1922 a third bill had proposed not only the building of an all-American canal, but also the building of a storage dam on the main river below the mouth of the Green River.

It was rapidly becoming apparent that the normal flow of the Colorado River would not be adequate to supply all of the uses envisioned by the Colorado River Basin States. The proposals for storage in the lower basin without guaranties to the upper basin States were regarded by the latter as threatening to establish priorities which would preclude later use of the water in the upper basin.

The law respecting rights to the use of waters of interstate streams was not well settled. Each of the various

States claimed exclusively the right to regulate the appropriation of water within its boundaries. At the same time claims were made that the Federal Government had jurisdiction over the waters of interstate streams. It was argued that no reasonable regulation of the flow of the Colorado River by storage appeared to be feasible except with the approval and the control of some authority higher than the States and that the Federal Government logically should effect the regulation of Colorado River development. The lower part of the stream was or had been navigable and, therefore, was subject to jurisdiction by the United States. At the same time the desire prevailed to obtain Federal aid in the financing of the huge multiple-purpose development considered necessary for the utilization of the stream flow of the lower Colorado River.

Some form of an agreement between the various factions was essential before comprehensive development of the Colorado River could proceed. Each State approached the problem individually. The conception of a division of water as between the upper and lower basins, which was finally adopted, instead of an apportionment among the individual States, crystallized slowly. The common desire for a solution gained momentum and finally resulted in an interstate compact.

The lower basin States favored a compact because they wished to enlist the support of the upper basin States in securing legislation by the Congress for main stream developments which were urgently needed for further expansion in the lower basin. States in the upper basin favored a compact because they desired to feel secure in their rights to further development of water uses, believing that they would be deprived of such rights by prior appropriations and uses downstream if they did not enter into a special agreement.

The States of both areas desired to retain control of water rights within their respective boundaries and thus were willing to enter into an interstate agreement to avoid the complete Federal control of the Colorado River that otherwise possibly would result.

Another significant motivating factor leading up to the Colorado River Compact was the desire of the people in the Colorado River Basin to give agriculture priority over power in the use of water.

Negotiations Leading to the Compact

In 1920 at a meeting of representatives of governors of Western States, a novel proposal by Delph E. Carpenter of Colorado that the States exercise their treaty-making powers was endorsed as a means of extricating the Colorado River Basin States from their perplexing predicament. After this proposal was approved by the governors, the respective legislatures of the seven Colorado River Basin States adopted appropriate legislation authorizing the appointment of compact commissioners, and on August 19, 1921, the Congress approved this proposal. The Colorado River Commission was organized in Washington, D. C., on January 26, 1922, with Herbert Hoover, then Secretary of Commerce, representing the United States and serving as chairman, and commissioners representing each of the seven basin States, as follows:

Commissioner	*State*
W. S. Norviel	Arizona.
W. F. McClure	California.
Delph E. Carpenter	Colorado.
J. G. Scrugham	Nevada.
Stephen B. Davis, Jr	New Mexico.
R. E. Caldwell	Utah.
Frank C. Emerson	Wyoming.

Following its organization meeting and numerous executive sessions held in Washington, the Commission met for public hearings in Phoenix, Los Angeles, Salt Lake City, Grand Junction, Denver, and Cheyenne in 1922. Final sessions, held at Santa Fe during November of the same year, culminated on November 24 in the signing of the Colorado River Compact by the commissioners of each of the seven basin States and the representative of the United States. The compact, however, was subject to ratification by the legislative bodies of the States involved and by the United States.

The compact was approved during the following year (1923) by six of the seven basin States, Arizona declining. As the compact provided that it would become binding only upon approval by the legislatures of each of the signatory States and by the Congress of the United States, it became necessary for the six approving States and the United States to enact laws waiving the provision of the compact requiring approval by all seven States and providing that the compact would become effective as to approving States if six States, including California, concurred. Such legislation was enacted and in 1929 the compact became binding upon all of the basin States except Arizona by a provision of the Boulder Canyon Project Act. Arizona did not ratify the compact until February 24, 1944.

The Colorado River Compact

The Colorado River Compact provides principally for a division of the available water of the Colorado River system between the "Upper Basin" and the "Lower Basin" at Lee Ferry, which is defined as a point on the Colorado River 1 mile below the mouth of Paria River. The nearest stream gage to this point on the Colorado River is at Lees Ferry, which is above the mouth of the Paria River. Lee Ferry, a few miles below the Arizona-Utah boundary, is a natural point of demarcation. Here all the waters of the entire upper system, including the Paria River and return flow from irrigation diversions, converge to form a single stream. The total stream flow

NEAR LEE FERRY—*The dividing point*

at Lee Ferry is computed by adding the flow of the Paria River to the flow of the Colorado at Lees Ferry.

The compact (art. IIIa) apportions to each of the upper and lower basins in perpetuity a total of 7,500,000 acre-feet for beneficial consumptive use annually and (art. IIIb) grants the further right to the lower basin to increase its beneficial consumptive use by 1,000,000 acre-feet annually. This division does not apportion the total annual water yield of the system, but (art. IIIc) establishes the basis for supplying any right later recognized in Mexico and (art. IIIf) leaves the apportionment of any excess among the States after October 1, 1963.

The compact also divides the basin States into two divisions: the "States of the Upper Division," including Colorado, New Mexico, Utah, and Wyoming; and the "States of the Lower Division," including Arizona, California, and Nevada. By the terms of the compact (art. IIId), the States of the Upper Division cannot cause the flow of the Colorado River at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years. Since the State boundaries do not conform to the actual drainage basin boundaries of the upper and lower basins, two of the States of the Upper Division, New Mexico and Utah, have a part of their territory in the lower basin. Arizona, one of the States of the Lower Division, also had a part of its territory in the upper basin.

By a provision in the compact, the Colorado River Basin includes "All the drainage area of the Colorado River system and all other territory within the United States of America to which the waters of the Colorado River system shall be benficially applied." Other provisions limit the use of Colorado River water to the seven basin States. Thus the exportation of waters from the actual drainage basin to adjoining areas is authorized "if such diverted water is to be used within the boundaries of the States

THE COLORADO RIVER BASIN STATES

. . . within the boundaries of which the waters of the Colorado River System shall be beneficially applied

through which the Colorado River system extends and if such use is not in excess of that allowed by the compact."

The compact recognizes the Colorado River as a navigable stream, but (art. IVb) holds that its use for navigation shall be subservient to its use for domestic and agricultural water supply and for power purposes.

* * * water of the Colorado River system may be impounded and used for the generation of electrical power, but such impounding and use shall be subservient to the use and consumption of such water for agricultural and domestic purposes and shall not interfere with or prevent use for such dominant purposes.

In addition, the compact (art. VII) provides that:

Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian tribes.

With respect to Mexico the compact (art. III) reads:

(c) If, as a matter of international comity, the United States of America shall hereafter recognize in the United States of Mexico any right to the use of any waters of the Colorado River system, such waters shall be supplied first from the waters which are surplus over and above the aggregate of the quantities specified in paragraphs (a) and (b); and if such surplus shall prove insufficient for this purpose, then the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin, and whenever necessary the States of the Upper Division shall deliver at Lee Ferry water to supply one-half of the deficiency so recognized in addition to that provided in paragraph (d).

The Colorado River Compact cleared the way for legislation authorizing the construction of major projects. It removed the cause for rivalry in the development of the upper and lower basins. Prior development in the lower basin would create no prior right to the use of water in that basin as against the use in the upper basin. This left the upper basin free to develop in the manner and time required.

Events Leading to the Boulder Canyon Project Act

Long strenuous efforts were involved in obtaining congressional approval and authority to undertake major developments on the Colorado River. In 1914 Congress made a special appropriation for more intensive study of Colorado River problems by the Reclamation Service and followed this with additional allotments. Reconnaissance studies were made of reservoir sites, irrigation projects, and water rights within the basin. Engineer John T. Whistler in Reclamation Service reports, made in 1918 and 1919, concluded that there was sufficient water in the river to supply all future irrigation requirements within the drainage basin if storage capacity of 10,000,000 to 12,000,000 acre-feet were provided, and that proposed storage for irrigation also would provide a large degree of flood protection and would be of material benefit to water power development. The principal reservoir sites considered were on the Colorado River in the upper basin.

In 1918 two agreements were made between the Imperial Irrigation District, successor to the California Development Co., and the United States, providing for surveys and the appointment of a joint board (All-American Canal Board) to plan the construction of an All-American canal from Laguna Dam. The first Kettner bill, to authorize construction of such a canal, was introduced in Congress in June 1919. Neither this bill nor its successor, introduced in the second session of the same Congress, was enacted.

The Kinkaid Act in May 1920 authorized and directed the Secretary of the Interior to make an examination and report on the condition and possible irrigation development of Imperial Valley. One-half of the cost of this examination and investigation was to be paid by the United States and the other half by local interests.

The principal reservoir sites discussed in the Whistler reports, being located above Grand Canyon, would not provide the flood protection which was the essential and most urgent need of Imperial Valley. Accordingly, investigations by the Reclamation Service were transferred to the lower basin. Topographic surveys were made of the Colorado River upstream from Bulls Head by the Geological Survey. The Reclamation Service made a detailed survey of dam sites in Black and Boulder Canyons, and because of their interrelation with the problems of the Imperial Valley, a general review of the conditions and water resources of the entire Colorado River Basin was also undertaken.

A report by A. P. Davis, director of the Reclamation Service, to the Secretary of the Interior in July 1921 gave the results of investigations demonstrating the feasibility of Boulder Dam from the construction standpoint and presented studies on flood control, water supply, and hydroelectric power showing conclusively that the development of a reservoir of such capacity as would be possible by the construction of a dam at one of these sites was the key to the problem of proper and orderly development of the water resources of the Colorado River Basin. This report was the first to propose a dam of such unprecedented height as 600 feet.

The Secretary of the Interior in transmitting his report, popularly known as the Fall-Davis report, to the Senate on February 28, 1922, included among his proposals the following two recommendations:

It is recommended that through suitable legislation the United States undertake the construction with Government funds of a highline canal from Laguna Dam to the Imperial Valley, to be reimbursed by the lands benefited.

It is recommended that through suitable legislation the United States undertake the construction with Government funds of a reservoir at or near Boulder Canyon on the lower Colorado River to be reimbursed from leasing the power privileges incident thereto.

Two months after the Fall-Davis report was transmitted to the Senate, Congressman Phil D. Swing and Senator Hiram Johnson, both of California, introduced bills seeking to authorize the construction of a project for Colorado River development which would embody the recommendations of that report. These were the first of four Swing-Johnson bills introduced successively in the Sixty-seventh, Sixty-eighth, Sixty-ninth, and Seventieth Congresses, the last of which became the Boulder Canyon Project Act.

Meanwhile, influential groups of lower basin citizens urged construction by the United States of Boulder Dam and the All-American Canal. There was also considerable opposition to these proposals, especially from those who were against public power development.

In February, 1924, the results of 2 years' additional work under the Kinkaid Act were embodied in a report made by Chief Engineer F. E. Weymouth of the Bureau of Reclamation, which stressed the immediate need of flood protection and for storage to prevent shortage of water and crop losses in the Imperial Valley. He concluded that the urgent problems of river control and utilization in the Colorado River Basin could be solved by (a) construction of a dam in Black Canyon to raise the water

605 feet and form Boulder Canyon Reservoir with a capacity of 34,000,000 acre-feet; (b) reservation of 8,000,000 acre-feet of capacity at the top of the reservoir for flood control with the provision for a decrease of 4,000,000 acre-feet, dependent on adequate upstream development; (c) provision for irrigation to receive priority over power in the use of remaining storage; (d) construction of a powerhouse with 1,200,000 horsepower installed capacity; and (e) construction of an All-American canal from Laguna Dam to Imperial Valley. The report submitted preliminary designs for a dam in Black Canyon and fully demonstrated advantages of this site.

In 1924 late summer flow in the Colorado River was so low that the Imperial Valley in California for a few weeks received barely enough water for domestic and stock-watering purposes and suffered severe crop losses. The immediate construction of Boulder Dam was then demanded.

Preliminary surveys indicated the practicability of an aqueduct from the Colorado River to supply municipal water to the Los Angeles metropolitan area. In 1925 the electorate of the city of Los Angeles authorized the issuance of $2,000,000 in bonds to provide funds for a more intensive and detailed study of the possible use of Colorado River water for a municipal supply, having in mind a plan that would benefit metropolitan southern California.

In the committee hearing on the third Swing-Johnson bill in 1926, congressional consideration for the first time was given to this proposal to use the Colorado River for a domestic water supply for southern California. As additional engineering work for a Colorado River aqueduct was performed, it became evident that any practicable diversion from the river would involve pumping, which would would require a large amount of low-cost power. This created at once a potential market for a substantial part of the power from a major river development. When these facts were laid before the Congress, support for the Swing-Johnson measure became more general.

After long debate the Boulder Canyon Project Act (Swing-Johnson bill, H. R. 5773) was passed by the House on May 25, 1928. Four days later the Congress, by joint resolution, authorized the appointment of a Colorado River Board and directed it to report on several vital questions concerning the proposed Boulder Canyon project. Thereupon the Secretary of the Interior appointed to this board Charles P. Berkey, Daniel W. Mead, Warren J. Mead, Robert Ridgeway, with Major General William T. Sibert, as chairman, all eminent engineers and geologists.

On November 24, 1928, the board submitted its report which declared that a proposed dam across the Colorado River at Black or Boulder Canyon was feasible, that the Black Canyon site was preferable to the Boulder Canyon site, and "that a growing demand for power in southern California when considered on a conservative basis will be sufficient to absorb the probable power output of the proposed hydroelectric plant."

In its report the board prescribed changes in plans which increased the estimated cost of the dam, but it had satisfied the Congress of the feasibility of the project. Many of the recommendations were incorporated in amendments to the bill, finally becoming a part of the Boulder Canyon Project Act.

The bill as finally amended was passed by the Senate and the House and signed by President Coolidge on December 21, 1928, thus ending the long campaign for legislation providing for the first major Colorado River development.

Boulder Canyon Project Act

The Boulder Canyon Project Act (sec. 1) provides:

> That for the purpose of controlling the floods, improving navigation and regulating the flow of the Colorado River, providing for storage and for the delivery of the stored waters thereof for reclamation of public lands and other beneficial uses exclusively within the United States, and for the generation of electrical energy as a means of making the project herein authorized a self-supporting and financially solvent undertaking, the Secretary of the Interior, subject to the terms of the Colorado River Compact hereinafter mentioned, is hereby authorized to construct, operate, and maintain a dam and incidental works in the main stream of the Colorado River at Black Canyon or Boulder Canyon adequate to create a storage reservoir of a capacity of not less than 20 million acre-feet of water and a main canal and appurtenant structures located entirely within the United States connecting the Laguna Dam, or other suitable diversion dam, which the Secretary of the Interior is hereby authorized to construct if deemed necessary or advisable by him upon engineering or economic considerations, with the Imperial and Coachella Valleys in California, the expenditures for said main canal and appurtenant structures to be reimbursable, as provided in the reclamation law, and shall not be paid out of revenues derived from the sale or disposal of water power or electric energy at the dam authorized to be constructed at said Black Canyon or Boulder Canyon, or for water for potable purposes outside of the Imperial and Coachella Valley: *Provided, however,* That no charge shall be made for water or for the use, storage, or delivery of water for irrigation or water for potable puposes in the Imperial or Coachella Valleys; also to construct and equip, operate, and maintain at or near said dam, or cause to be constructed, a complete plant and incidental structures suitable for the fullest economic development of electrical energy from the water discharged from said reservoir; and to acquire by proceedings in eminent domain, or otherwise, all lands, rights-of-way, and other property necessary for said purposes. (45 Stat. 1057.)

The Boulder Canyon Project Act (sec. 2a) also set up the Colorado River Dam fund as a special fund to carry out provisions of the act. An appropriation not to exceed $165,000,000 was authorized to be repaid with 4 percent interest except $38,500,000 to be used for the construction of the All-American canal. Before any money could be appropriated or any construction work done the Secretary of the Interior (sec. 4b) was required to make provision for revenues, by contract or otherwise, which in his judgment would be adequate to pay all expenses of operation and maintenance and repay with interest at 4 percent within 50 years of the completion of the project all money advanced by the Federal Government for the construction of the dam and incidental works.

The contract between the United States and the Imperial Irrigation District, entered into on October 23, 1918, for the construction of the All-American canal entirely at the expense of the district, was recognized in the act (sec. 10) but the Secretary was given authority to modify such agreement with the consent of the district.

The Secretary (sec. 15) is authorized and directed to make investigations and public reports on the feasibility of projects for irrigation, power, and other multiple uses, for the purpose of formulating a comprehensive scheme of control and the improvement and utilization of the water of the Colorado River and its tributaries. A sum of $250,000 was authorized to be appropriated from the Colorado River Dam fund for such purposes.

The Boulder Canyon Project Act also (sec. 4a) provides that the act shall not take effect, and that no work shall be begun and no moneys expended nor water rights claimed thereunder, unless and until, within 6 months all seven of the basin States had ratified the Colorado River Compact or, as an alternative, unless and until six of the seven States, including the State of California, had ratified the compact, and the State of California, "as an express covenant and in consideration of the passage of" the Boulder Canyon Project Act, had agreed to limit its annual consumptive use of Colorado River water to not to exceed "4,400,000 acre-feet of the waters apportioned to the lower basin States by paragraph (a) of article III of the Colorado River Compact, plus not more than one-half of any excess or surplus waters unapportioned by said compact, such uses always to be subject to the terms of said compact." Wyoming, Colorado, New Mexico, and Nevada had ratified the compact on a 6-State basis in February and March of 1925. In March of 1929 California unconditionally ratified the compact as a 6-State compact, and Utah's ratification followed immediately. On June 25, 1929, President Hoover issued a proclamation pursuant to the provisions of the act, stating that all prescribed conditions under the second alternative mentioned had been fulfilled and that the Boulder Canyon Project Act was effective as of that date.

Contracts for Power and Water

Negotiations for power contracts were started by the Secretary of the Interior in 1929, and the next year two contracts, carrying an obligation to take and pay for all of the firm energy to be generated at Boulder Dam, were signed at Los Angeles. The first was a lease of power privileges to which the United States, the city of Los Angeles (through its department of water and power), and the Southern California Edison Co. were parties. The second was a contract for the purchase of electric energy to which the United States and the Metropolitan Water District of Southern California were parties.

On July 3, 1930, President Hoover signed an act, carrying an appropriation of $10,660,000 for starting construction of the Boulder Canyon project which automatically placed the power contracts in effect. Preparations for construction of Boulder Dam were started immediately as the first step in the actual carrying out of the primary intent of the Boulder Canyon Project Act—"To convert a natural menace into a national resource" by harnessing the mighty Colorado River. The dam was completed and the first water stored in Lake Mead in 1935.

Under the terms of a contract between the United States and the Metropolitan Water District of Southern California made in 1930 and amended on September 28, 1931, the United States undertakes to deliver to the district 1,100,000 acre-feet of water annually from storage in Lake Mead. Delivery is made in accordance with the priorities fixed in a schedule agreed to in August 1931 by the Metropolitan Water District of Southern California, Palo Verde Irrigation District, Imperial Irrigation District, Coachella Valley County Water District, the city of Los Angeles, and the city and county of San Diego. The agreement defined the rights of the parties named and also those of the portion of the Yuma project in California. A charge of $0.25 per acre-foot is made for water delivered to the Metropolitan Water District of Southern California and to the city and county of San Diego.

The Metropolitan Water District of Southern California is a public corporation organized in December 1928. The original organization included Los Angeles and 10 other cities. The district now includes 14 cities.

Under the terms of another contract between the United States and the Metropolitan Water District of Southern California, signed February 10, 1933, the United States built Parker Dam on the Colorado River below Boulder Dam with funds provided by the district. The dam is owned and operated by the United States and provides regulation for diversion of water into the Colorado River Aqueduct which was constructed by the district to carry Colorado River water to the southern California coastal plain.

Beginning with 1930, numerous contracts were made by the United States with California, Arizona, and Nevada interests for the use of water stored by Boulder Dam and the power produced at Boulder and Parker Dams. Each such contract, including the one with the Metropolitan Water District, makes the delivery of water and power subject to availability under the terms of the Colorado River Compact and the Boulder Canyon Project Act.

BOULDER CANYON PROJECT ADJUSTMENT ACT

The Boulder Canyon Project Adjustment Act, signed by President Franklin D. Roosevelt on July 19, 1940, removed competition as the basis for rates and charges for power from the Boulder Canyon project and specified that power income must be sufficient to operate and maintain the project; to provide certain specified annual sums for payment to the States of Arizona and Nevada and into the Colorado River Development fund; and to repay to the United States with interest at 3 percent during a 50-year period the advance made to the Colorado River Dam fund, less $25,000,000 allocated to flood control and deferred beyond 50 years.

This act set up the Colorado River Development fund and provided for the transfer from the Colorado River Dam fund

the sum of $500,000 for the year of operation ending May 31, 1938, and the like sum of $500,000 for each year of operation thereafter, until and including the year of operation ending May 31, 1987. * * * Receipts of the Colorado River Development fund for the years of operation ending in 1938, 1939, and 1940 * * * are authorized to be appropriated only for the continuation and extension, under the Secretary of studies and investigations by the Bureau of Reclamation for the formulation of a comprehensive plan for the utilization of waters of the Colorado River system for irrigation, electrical power, and other purposes, in the States of the upper division and the States of the lower division, including studies of the quantity and quality of water and all other relevant factors. The next such receipts up to and including the receipts for the year of operation ending in 1955 are authorized to be appropriated only for the investigation and construction of projects for such utilization in and equitably distributed among the four States of the upper division. Such receipts for the years of operation ending in 1956 to 1987, inclusive, are authorized to be appropriated only for the investigation and construction of projects for such utilization in and equitably distributed among the States of the upper division and States of the lower division. * * * Such projects shall be only such as are found by the Secretary to be physically feasible, economically justified, and consistent with such formulation of a comprehensive plan. Nothing in this act shall be construed so as to prevent the authorization and construction of any such projects prior to the completion of said plan of comprehensive development; nor shall this act be construed as affecting the right of any State to proceed independently of this act or its provisions with the investigation or construction of any project or projects. (54 Stat. 774.)

Between United States and Mexico

At the time of the Gadsden Purchase, the Colorado River was considered to be valuable for navigation only. But as time passed and the West was settled, thriving communities were established in the United States and in Mexico, wholly dependent upon diversion of Colorado River water for irrigation. Their continued existence and future growth were limited strictly to the extent water might be diverted and consumed for irrigation purposes. This irrigation development had been made without any international agreement or treaty providing for irrigation use of the water of this important international river and without either country insisting upon the maintenance of navigability in the border regions of the Colorado River envisioned in early treaties between the two countries. Both Mexico and the United States now recognize that the best interests of the peoples concerned were promoted by diversion of water for irrigation rather than by maintenance of the river as a navigable stream.

The All-American Canal system has replaced the Alamo Canal diversions to California lands and also for the most part Laguna Dam diversions to the Yuma project. Mexico, however, continues to use the Alamo Canal, which diverts from the Colorado River at a point 1½ miles within the United States, and also makes a number of diversions from the Colorado River farther downstream.

The Colorado River compact, as previously quoted, provides that if the United States recognizes that Mexico has any right to the use of any waters of the Colorado River system that such an amount shall be supplied from water which is surplus over 16,000,000 acre-feet per annum and in case such surplus water should be insufficient that each basin from its apportioned share shall supply one-half of the deficiency.

THE TREATY WITH MEXICO

A treaty between the United States of America and the United Mexican States relating to the division of the waters of the Colorado and Tijuana Rivers and of the Rio Grande, was signed by representatives of the respective Governments at Washington on February 3, 1944. The treaty (Executive A, 78th Cong., 2d sess.) the protocol (Executive H, 78th Cong., 2d sess.) signed November 14, 1944, and clarifying reservations to the treaty were ratified by the United States Senate on April 18, 1945. The treaty was ratified by the Mexican Senate on September 27, 1945.

By its provisions (art. 2) the general administration of the treaty is entrusted to the International Boundary and Water Commission, designated to be the successor of the International Boundary Commission created by the convention of the two countries on March 1, 1889.

The Commission shall in all respects have the status of an international body, and shall consist of a United States section and a Mexican section. The head of each section shall be an engineer commissioner. Wherever there are provisions in this treaty for joint action or joint agreement by the two governments, or for the furnishing of reports, studies, or plans to the two governments, or similar provisions, it shall be understood that the particular matter in question shall be handled by or through the Department of State of the United States and the Ministry of Foreign Relations of Mexico.

Each government is to accord diplomatic status to the commissioner and certain other officers of the section of the other government.

The treaty (art. 10) allots to Mexico from the waters of the Colorado River:

(a) A guaranteed annual quantity of 1,500,000 acre-feet to be delivered in accordance with certain conditions and specifications as to point and rate.

(b) Any other quantities arriving at the Mexican points of diversion, with the understanding that in any year in which, as determined by the United States section, there exists a surplus of waters of the Colorado River in excess of the amount necessary to supply users in the United States and the guaranteed quantity of 1,500,000 acre-feet annually to Mexico, the United States undertakes to deliver to Mexico * * * additional waters of the Colorado River system to provide a total quantity not to exceed 1,700,000 acre-feet a year. Mexico shall acquire no right * * * by use of the waters of the Colorado River system for any purpose whatsoever, in excess of 1,500,000 acre-feet annually.

In the event of extraordinary drought or serious accident to the irrigation system in the United States, thereby making it difficult for the United States to deliver the guaranteed quantity of 1,500,000 acre-feet a year, the water allotted to Mexico under subparagraph (a) of this article will be reduced in the same proportion as consumptive uses in the United States are reduced.

The water of the Colorado River to be furnished Mexico by the United States under the treaty (art. 11) "shall be made up of the waters of the said river, whatever their origin," and shall be delivered by the United States in the boundary portion of the Colorado River, except that until 1980 Mexico may receive 500,000 acre-feet annually, and after that year 375,000 acre-feet annually through the All-American canal as part of the guaranteed quantity.

Other provisions (art. 12) of the treaty provide that the two governments agree to construct the following works:

Mexico shall construct at its expense, within a period of 5 years from the date of the entry into force of this treaty, a main diversion structure below the point where the northernmost part of the international land boundary line intersects the Colorado River. The Commission shall thereafter maintain and operate the structure at the expense of Mexico. Regardless of where such diversion structure is located, there shall simultaneously be constructed such levees, interior drainage facilities, and other works, or improvements to existing works, as in the opinion of the commission shall be necessary to protect lands within the United States against damage from such floods and seepage as might result from the construction, operation, and maintenance of this diversion structure. These protective works shall be constructed, operated, and maintained at the expense of Mexico by the respective sections of the commission, or under their supervision, each within the territory of its own country.

The United States, within a period of 5 years from the date of the entry into force of this treaty, shall construct in its own territory and at its expense, and hereafter operate and maintain at its expense, the Davis storage dam and reservoir, a part of the capacity of which shall be used to make possible the regulation at the boundary of the waters to be delivered to Mexico in accordance with the provisions of article 15 of this treaty * * *

and

shall construct or acquire in its own territory the works that may be necessary to convey a part of the waters of the Colorado River allotted to Mexico to the Mexican diversion points on the international land boundary line referred to in this treaty. Among these works shall be included: the canal and other works necessary to convey water from the lower end of the Pilot Knob Wasteway to the international boundary, and, should Mexico request it, a canal to connect the main diversion structure * * * with the Mexican system of canals * * * Such works shall be constructed or acquired and operated and maintained by the United States section at the expense of Mexico. Mexico shall also pay the costs of any sites or rights-of-way required for such works.

The Commission shall construct, operate, and maintain in the limitrophe section of the Colorado River, and each section shall construct, operate, and maintain in the territory of its own country on the Colorado River below Imperial Dam and on all other carrying facilities used for the delivery of water to Mexico, all necessary gaging stations and other measuring devices for the purpose of keeping a complete record of the waters delivered to Mexico and of the flows of the river. All data obtained as to such deliveries and flows shall be periodically compiled and exchanged between the two sections.

Another provision (art. 13) of the treaty directs that:

The commission shall study, investigate, and prepare plans for flood control on the lower Colorado River between Imperial Dam and the Gulf of California, in both the United States and Mexico * * * The two Governments agree to construct through their respective sections of the commission, such works as may be recommended by the commission and approved by the two governments, each government to pay the costs of the works constructed by it. The commission shall likewise recommend the parts of the works to be operated and maintained jointly by the commission and the parts to be operated and maintained by each section. The two governments agree to pay in equal shares the cost of joint operation and maintenance and each government agrees to pay the cost of operation and maintenance of the works assigned to it for such purpose.

The protocol, which is an integral part of the treaty as ratified, provides that:

Wherever * * * specific functions are imposed on, or exclusive jurisdiction is vested in, either of the sections of the International Boundary and Water Commission, which involve the construction or use of works for storage or conveyance of water, flood control, stream gauging, or for any other purpose, which are situated wholly within the territory of the country of that section, and which are to be used only partly for the performance of treaty provisions, such jurisdiction shall be exercised, and such functions, including the construction, operation, and maintenance of the said works, shall be performed and carried out by the federal agencies of that country which now or hereafter may be authorized by domestic law to construct, or to operate and maintain, such works. Such functions or jurisdictions shall be exercised in conformity with the provisions of the treaty and in cooperation with the respective section of the commission, to the end that all international obligations and functions may be coordinated and fulfilled.

Ratification of the treaty is a step forward in international cooperation. A 98-year point of dispute over allocation of the waters of the Colorado River and other rivers rising in the United States and flowing into Mexico should be settled.

Developing the Basin

"Present developments are indicative of future possibilities. A growing Nation . . . is demanding full development and use of all its resources . . . .

"Millions of acres of dry fertile lands yet are idle and most irrigated areas are not producing maximum yields because of water shortages, . . . flood waters still uncontrolled flow destructively to the Pacific Ocean and are lost for beneficial use. Control of these waters will require cooperative planning and systematic development involving construction of huge structures, mostly beyond the financial range of private enterprise. . . .

"Prosperity in the Colorado River Basin brought by full development of water and land resources will have a stimulating beneficial effect on the economy of the entire country."

CHAPTER IV

Developing the Basin

Water holds a key position in developing the resources of the Colorado River Basin. It is the "critical material" because of its limited supply and great demand. Development and utilization of other resources in this arid land depend upon the availability of water. Crops must be irrigated; cattle on the vast ranges must be partially fed from hay produced on irrigated land; towns and cities must be located within distance of dependable domestic and municipal water supplies; and mining and many other industries depend to an extent on the availability of hydroelectric power.

The use that has been made of the basin's resources by those people who have claimed this land as their home and the needs and problems confronting them must be understood before any solution or plan can be suggested to improve present conditions and create additional opportunities. For that purpose this chapter includes a survey and appraisal of the basin's resources and economic activities.

The Colorado River Basin is a part of America's frontier. It is, perhaps, as little developed as any comparable area in the United States. Yet it is known that here lie buried one-sixth of the entire world's coal reserves, billions of barrels of oil in shale and sand (equivalent to many times the known petroleum reserves in all the oil fields of the United States) and vast treasures of other minerals including petroleum, natural gas, copper, lead, zinc, gold, silver, rare hydrocarbons, vanadium, molybdenum, phosphates, and many others. For only a few of these can it be said that development has had even a good beginning.

Crop production in the basin is dependent almost wholly on irrigation. More than 2½ million acres—much with an inadequate late season supply—are now irrigated. Development of the basin's land and water resources is little beyond the half-way mark toward ultimate potentialities. Livestock raising is the basin's principal agricultural pursuit, but the numerous herds of cattle and sheep that graze the vast ranges and forests are dependent on supplemental feed from irrigated farms.

Only in the last two decades has a good start been made in exploiting the possibilities of the Colorado River for generating hydroelectric power. Construction of Boulder Dam to control the flow of the lower river was the first big development. Even with completion of all present and authorized construction which will give to the river system installed generating capacity of 2 million kilowatts, only a little more than a third of the basin's water power will be harnessed.

Extending more than two-thirds the distance across the Nation, from Mexico to Canada, the Colorado River Basin is crossed in an east-west direction by several transcontinental railroads and highways. North-south transportation is dependent very largely on a few highways. The improvement of highways and transportation facilities characterizing this generation has bettered living conditions in the basin and has increased the basin's economic contributions to the Nation. Some important agricultural and mineral areas, however, are today a hundred miles or more from railroads. Further improvement and expansion of transportation facilities within the basin would be a national asset.

Practically the only manufacturing in the basin is the processing of farm and forest products on a limited scale. Most of the food, fiber, and minerals produced or mined in the area is shipped away in raw state. In recent years the Los Angeles metropolitan area has become one of the Nation's principal manufacturing areas due in large measure to low-cost power produced at Boulder Dam.

The spectacular natural beauty, shrouded in the romantic aura of frontier adventure, delights the tourist and health seeker. The basin is fast becoming a national playground. Rocky Mountain, Mesa Verde, Bryce Canyon, Zion, and Grand Canyon National Parks, the Painted Desert, Petrified Forest and Boulder Dam National Recreational Area as well as many national monuments lie wholly or partly within the basin. Unmatched trout fishing in mountain streams and lakes, big-game hunting, and Indian reservations add to the basin's outstanding attractions.

The people on the basin's irrigated farms and those in the cities and towns that rise on the commerce created by irrigated agriculture and by mining exercise purchasing power that establishes markets for automobiles, farm machinery, and other products manufactured and grown in all parts of the country.

Permanent settlement of this frontier region is approaching the end of a century, but only in small measure have the basin's bounties been applied to man's use. Present developments are indicative of future possibilities. A growing Nation and a world power is demanding full development and use of all its resources.

UPPER BASIN

Agriculture, particularly livestock raising, and mining are the principal industries of the upper basin. Oil refining, lumbering, transportation, trade, recreation, and construction are of lesser but growing importance.

Growth and distribution of population were discussed in chapter II. With its 1940 population of 286,450 distributed over 110,500 square miles, the upper basin's average of 2.6 persons per square mile is only one-seventeenth of the national population density. Sparse settlement and great distances between communities create special economic and social problems. Goods and services are more difficult to obtain and more costly than in thickly populated areas. A few ranch homes are 100 miles from medical, dental, and hospital facilities. Many families are located long distances from schools, churches, and trading centers. Opportunities for many forms of recreation and social and educational activity are restricted.

In such a large, sparsely settled area difficult problems arise in providing and maintaining roads and other public services. Many local roads are poor and during parts of the year impassable by motor vehicles. Some rural homes are without electric service, but power lines are being extended to small communities, farms, and ranches, thereby adding to the convenience and comfort of the people.

Labor Force

The economy of a region is affected more by the labor force, employed workers and those actively seeking work, than by any other segments of the population. It is this group that is the highest in both production and consumption of goods.

The labor force expands or contracts with changing economic conditions. In good times its ranks are swelled by young people leaving school before completing their courses and by housewives, retired persons, and others who normally are not employed. The size of the labor force also is influenced by the composition of the population. Where the percentage of children or old people is above average the labor force is likely to be small. Employable persons who make up the labor force are most likely to migrate to areas where economic opportunities are greater. The percentage of the total population in the labor force generally is an index to the economic prosperity of a region.

The United States census for 1940 shows a male labor force, over 14 years of age, of 72,317 in the upper basin, equivalent to 25 percent of the total population, compared with 40 percent for the Nation as a whole. Thirty-four percent of the upper basin's workers were employed in agriculture, 13 percent in mining, and 35 percent in other regular occupations. The other 18 percent were either employed on Government "relief" projects or were seeking work, the proportion of the labor force in this group being larger than for the average of the Nation.

TABLE V.—*Labor force in selected employment groups in upper basin (1939)*[1]

State area	Percent of labor force: Gainfully employed: Agriculture	Gainfully employed: Mining	Gainfully employed: All other jobs	Employed on emergency work	Seeking work	Number in labor force
Wyoming	18	28	41	4	9	9, 890
Colorado	35	10	38	6	11	43, 329
Utah	36	15	27	10	12	14, 720
New Mexico	61	2	22	6	9	4, 378
Upper basin	34	13	35	7	11	72, 317
United States	20	2	63	5	10	39, 944, 240

[1]Male persons over 14 years of age.

The income from many farms was insufficient to support the farm operator, making it necessary for him to find supplemental employment. In 1939, a year of average farming conditions, about one-third of the farmers worked away from their farms for pay an average of about a third of their time. Mining and public work provided most of the outside employment, which required many farmers to leave their families. Most of the farmers who worked away were no doubt the operators of small part-time farms.

TABLE VI.—*Supplemental employment of farmers in upper basin (1939)*

State area	Farmers working away from their farms: Number	Farmers working away from their farms: Percent of all farmers in labor force	Average days per year each farmer worked away from his farm
Wyoming	369	38	123
Colorado	3, 683	29	138
Utah	2, 084	45	129
New Mexico	392	16	151
Upper basin	6, 528	32	131

Additional irrigation water would expand and stabilize farming and create greater agricultural opportunities for upper basin people. Fewer farmers would be required to find other employment, and in periods of economic distress fewer workers would be seeking "emergency work."

Land Ownership and Use

Of the land in the upper basin only about 22 percent is privately owned, 78 percent is owned by either county, State, or Federal Governments or by Indians and yields no tax revenues. The pattern of land use in the upper basin is approximately as follows:

	Acres	Percent of total area
Irrigated land	1, 325, 000	1. 9
Cultivated without irrigation	272, 000	. 4
Grazing land:		
Publicly owned	29, 221, 000	41. 4
Privately owned	8, 775, 000	12. 4
State and county owned	2, 860, 000	4. 0
Indian reservations	8, 775, 000	12. 4
National forests	13, 378, 000	18. 9
National parks and monuments	586, 300	. 8
Miscellaneous areas	5, 503, 700	7. 8
Total	70, 696, 000	100. 0

About 70 percent of the total land area is classed as grazing land in the tabulation. Grazing is also extensive on national forest lands and on other areas so that much more than 70 percent of the total area is actually grazed. The 1940 United States Census reported 285,000 acres of irrigated land used as pasture.

The better grazing lands are in the higher stream valleys and on the mountains and foothills. These lands are used for summer grazing of cattle and sheep, and the scanty vegetation in the lower desert areas provides winter range for sheep.

Crop land, both irrigated and dry-farmed, comprised only 2.3 percent of the total acreage in 1939 and only 1.9 percent was actually cropped.

Farming without irrigation is generally unsuccessful in the Upper Basin because of the uncertain rainfall. It is practiced, however, to some extent in the Yampa and White River Basins, and favorable climatic conditions in the past few years together with high prices have encouraged expansion of dry farming in the Dry Side area of the La Plata River Basin and on the upland mesa between Cortez, Colo., and Monticello, Utah. In general, at altitudes where rainfall is sufficient during the summer to grow crops without irrigation, the season is too short for crops to mature.

Soils

The entire upper basin is underlain with sandstones, limestones, and shales composing the parent rock from which the soil forming material has been derived. Four types of soil are found: (1) alluvial soils made up from stream-deposited materials; (2) glacial soils in the form of glacial deposits or out-wash plains derived partly from granites and other igneous material of the higher mountains; (3) residual soils formed in place by the weathering of surface rocks but altered in places through deposition from higher residual lands; and (4) aeolian, or wind deposited soils, appearing in a few places as sand dunes and other formations.

In the upper valleys lands suitable to agricultural development are largely composed of alluvial soils and are confined to the bottom lands, terraces, and valley fills. These soils are high in organic matter and are inherently fertile. They are generally of sandy loam to loam in texture. Most of these soils have good natural drainage provided by light textured soil over gravelly subsoil and a moderate slope. With the exception of small localized areas the soils in the upper valleys are free from harmful accumulations of alkali. The depth of the soil and the amount of rock on the surface usually determine the suitability of the lands for agriculture.

Mesas, plateaus, basin-like depressions caused through erosion, and narrow valleys along the various streams characterize the lower sections of the upper basin. The broader valleys and depressions that have been covered with alluvial soils are more suitable for cultivation where soil is of sufficient depth. Vast areas of residual soils are too shallow or too alkaline for agricultural development. Extensive drainage is often necessary in the lower valleys where irrigation is practiced.

Wind formed soils are not extensive. Some are found in small areas south of the San Juan River along the northeastern sides of ridges or other topographic uplifts which break the winds and harbor the deposited materials. The largest area of arable aeolian soil is east of Chaco River on the high benches south of Farmington, New Mexico.

Agriculture

Types of farming.—All farms are classified by the Bureau of Census into types according to the major source of income. In the upper basin livestock farms predominate.

Table VII.—*Types of farms in upper basin (1939)*

State area	Types of farms according to major source of income (percent of total number of farms)				
	Livestock and livestock products	Field crops	Other crops	Products used in household	Total
Wyoming	77. 8	7. 8	0. 3	14. 1	100
Colorado	35. 7	32. 3	9. 8	22. 2	100
Utah	39. 8	19. 2	1. 1	39. 9	100
New Mexico	27. 9	21. 0	5. 5	45. 6	100
Upper basin	37. 6	26. 9	6. 9	28. 6	100

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In 1939, livestock and livestock products accounted for 75 percent of the total value of the products sold and traded in the upper basin. Livestock alone amounted to 55 percent and wool to 10 percent of the total. Compared with the Nation as a whole the upper basin farm income from animals and wool was greater, while income from dairy products, poultry, poultry products, and crops was less. A considerable part of the crop income was from the sale of feed to local livestock men for winter feed of breeding stock.

TABLE VIII.—*Value of farm products sold or traded in upper basin (1939)*

State area	Percent of total value of farm products					
	Livestock	Dairy products	Poultry and poultry products	Wool and other livestock products	Crops	Total
Wyoming	66	5	1	25	3	100
Colorado	53	6	2	8	31	100
Utah	53	9	5	17	16	100
New Mexico	40	3	2	15	40	100
Upper basin	55	6	3	11	25	100
United States	26. 6	16. 8	8. 4	1. 6	46. 6	100

In the Wyoming portion of the basin only 3 percent of the income was from crops while in the New Mexico area 40 percent was from crops.

The farms of the upper basin produce primarily meat, hides, and wool, supplies of which are inadequate to meet the Nation's needs.

The livestock industry in the upper basin is based upon vast areas of grazing land unsuited to more intensive agriculture. Much of this land belongs to the Federal Government and is in either forest reserves or grazing districts. The rest is privately owned or belongs to the States. By reason of differences in elevation and climate some of these lands can be grazed only during summer months and others only during the winter, spring, and fall. By moving livestock with the changing seasons of the year, sometimes long distances, some animals are grazed the year around. This is particularly true of sheep. The carrying capacity of range lands varies. The summer grazing lands normally carry more stock per acre than do the spring, fall, and winter lands. Because of this and the necessity of providing supplemental feed from crop lands to carry stock over extremely severe winter periods and abnormally dry summer periods, the use of crop and range lands is interrelated. Maximum use of grazing lands is not possible without forage from crop lands, and much of the crop lands would have little value except in conjunction with the use of grazing lands.

Range lands of the basin have been stocked at the maximum for a long time and in local areas damage has resulted from over grazing. Much of the damage resulted from a lack of sufficient forage from irrigated crop lands to balance natural range production. Although corn and other concentrated feeds are shipped into the basin each winter to carry sheep through severe storms and other critical periods, these imports do not eliminate the need for local forage from irrigated crop lands for cattle.

An increase in the production of farm produced forage would avoid damage to range lands by over grazing and by keeping livestock off grazing land until vegetation has a good start in the spring; enable livestock men to feed breeding stock through drought periods without losses, and thus avoid liquidation of breeding stock because of inadequate local feed supplies; and permit, in many cases, more liberal feeding of breeding stock and calves to increase the calf and lamb crops and reduce losses from death.

Livestock.—With such a large proportion of the upper basin lands usable only for grazing livestock, range livestock production has become the dominant industry. Although the number of farms has continued to increase in the area, the grazing resources were fully utilized prior to 1910. Since that time the total number of cattle and sheep has remained about the same, increasing and decreasing slightly as a result of livestock cycles and climatic conditions. The number of dairy cows, however, has increased proportionately with the number of farms. Many of the cows classified as dairy cows are of beef breeding and hence the average milk production per cow is low. Trends in the number of cattle and sheep in the upper basin for the period 1890–1940 are shown on an accompanying chart (fig. 3).

Compared with the average farm in the United States in 1940 the average farm in the upper basin had about 12 times as many sheep, and 2.5 times as many cattle, but fewer dairy cows, swine, and chickens. While livestock production is the dominant enterprise not all livestock farms are operated on a large scale. In the Utah area most of the cattle operations are small, but in Wyoming cattle ranches are generally large.

TABLE IX.—*Livestock in upper basin (1939)*

State area	Average number of livestock per farm					
	Horses	Dairy cows	Other cattle	Sheep	Swine	Chickens
Wyoming	13. 1	5. 8	83. 0	440. 6	1. 5	35. 5
Colorado	4. 7	3. 2	22. 0	53. 1	3. 2	35. 7
Utah	4. 0	3. 6	15. 0	86. 7	3. 4	32. 9
New Mexico	3. 5	. 8	3. 6	55. 2	1. 0	12. 4
Upper Basin	4. 8	3. 1	21. 2	79. 0	2. 9	32. 4
United States	3. 2	3. 9	6. 0	6. 6	5. 6	55. 4

The livestock enterprise in the basin is largely restricted to the production of feeder cattle, feeder lambs, and sheep

HEREFORDS ON THE RANGE NEAR MOAB, UTAH
Range lands have been stocked at the maximum and overgrazed

HAY HARVEST ON EDEN PROJECT, WYOMING
Production of more hay on irrigated land will permit optimum use of the range

and wool. Most of the animals are sent to the Corn Belt, where they are finished for market. Livestock operations in the basin thus complement those of the Middle West. A few grass-fattened cattle, lambs, and sheep are shipped directly to slaughter markets. Except in favorable years, however, forage is inadequate to fatten more than a small proportion of the animals.

Crops and yields.—Of the total cropped acreage harvested in the upper basin in 1939 about 83 percent was irrigated and 17 percent was dry-farmed. Most of the dry-farmed crops were produced in Colorado and consisted mainly of wheat and dry beans.

The land harvested totaled only 1,073,130 acres. Alfalfa hay, the most important crop, amounted to 28 percent and all hay 64 percent of the total. Other crops, including corn, oats, barley, and some wheat, raised the total amount of the harvested land used for feed crops to more than 80 percent. Row crops grown for cash income included potatoes, sugar beets, and dry beans. The beans are grown largely on dry land in the San Juan River area and make up a considerable part of the cash crop acreage. The Grand Junction area and other smaller areas of Colorado are important fruit producing areas.

Compared with most irrigated areas and with many nonirrigated regions, the average yields per acre of many crops in this basin are low. This is due partly to the fact that much of the land has an inadequate irrigation supply and precipitation is insufficient for satisfactory yields without irrigation. The growing season is short for most crops. Often two cuttings of hay per season and sometimes only one are obtained. Some lands with soils too poor to produce high yields are now being cultivated.

TABLE X.—*Yields of major crops in upper basin (1939)*

State area	Average yield per acre				
	Tons		Bushels		
	Alfalfa	Wild hay	Dry-land wheat	Irrigated wheat	Barley
Wyoming	1. 2	0. 9	11. 6	20. 0	28. 5
Colorado	1. 8	1. 1	12. 7	22. 2	26. 0
Utah	1. 6	1. 2	17. 1	25. 6	32. 6
New Mexico	2. 8	. 7	10. 6	30. 0	13. 9
Upper basin	1. 7	1. 0	13. 1	25. 1	28. 0

Number of farms.—By 1910 range lands of the upper basin were being fully utilized and irrigation had been developed so far as possible by private enterprise, yet since then the number of farms has continued to increase (fig. 4). The rate of increase, however, has slowed down materially. New farm units have provided only for the natural increase of local populations and not for new settlers moving into the area. Recently many new farms have been established in areas where the acreage and other resources per farm are smallest, forcing in some instances a change to a more intensive type of farming. With grazing privileges on public lands fully utilized, new farmers in most cases have had to follow a type of farming for which the area is not well adapted. Especially is this true in areas of high elevation and where the irrigation water supply is uncertain and inadequate. This has also resulted in a large number of part-time farms in localities with little opportunity for supplemental work away from the farm.

TABLE XI.—*Number of farms in the upper basin (1939)*

State area	Year			
	1880	1900	1920	1940
Wyoming	90	556	885	966
Colorado	230	5, 699	13, 024	12, 668
Utah	122	1, 759	3, 969	4, 660
New Mexico	------	492	874	2, 383
Upper Basin	442	8, 506	18, 752	20, 677

Size of farms.—Although the number of farms has been increasing without a corresponding increase in available farm land, census reports paradoxically show the size of the average farm in the upper basin to be increasing also (fig. 5). The apparent but largely unreal expansion of the farm area has resulted in part from the transfer of public grazing land into private ownership. The average size of farms in the basin is relatively large as would be expected from the type of farming practiced, but there are also some small farms. According to the 1940 census, 27 percent of all farms consisted of less than 50 acres. With some types of farming, 50 acres would constitute a large farm but in this basin 50 acres are entirely inadequate except in a few localities such as those where fruits and vegetables are grown successfully. There were 1,304 farms of less than 10 acres, nearly all operated, no doubt, on a part-time basis. Farms are largest in the Wyoming portion of the basin where stock raising is dominant and smallest in Utah, where a high population pressure results from a birth rate near the highest in the Nation.

TABLE XII.—*Sizes of farms in upper basin (1939)*

State area	Percent of total number of farms in various size groups						
	Less than 50 acres	50 99 acres	100 170 acres	180 379 acres	380 799 acres	700 or more acres	Total
Wyoming	8. 3	6. 1	15. 9	17. 0	17. 9	34. 8	100. 0
Colorado	28. 1	15. 4	18. 3	16. 2	9. 8	12. 2	100. 0
Utah	28. 3	19. 2	21. 4	14. 6	6. 6	9. 9	100. 0
New Mexico	26. 9	9. 4	9. 9	14. 2	12. 9	26. 7	100. 0
Upper basin	27. 1	15. 2	17. 9	15. 6	9. 8	14. 4	100. 0

PEACH ORCHARD NEAR GRAND JUNCTION, COLO.
Grand Valley is an important fruit-producing area

TOMATOES FROM GRAND VALLEY PROJECT
Additional irrigation will make possible more intensive agriculture

UPPER COLORADO RIVER BASIN

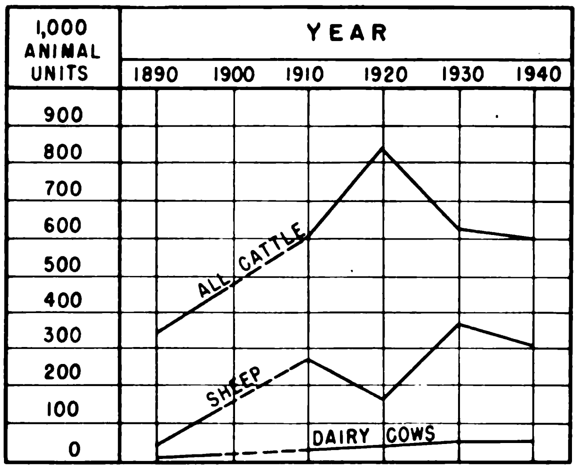


FIGURE 3.—*Trends in animal units, 1890–1940.*

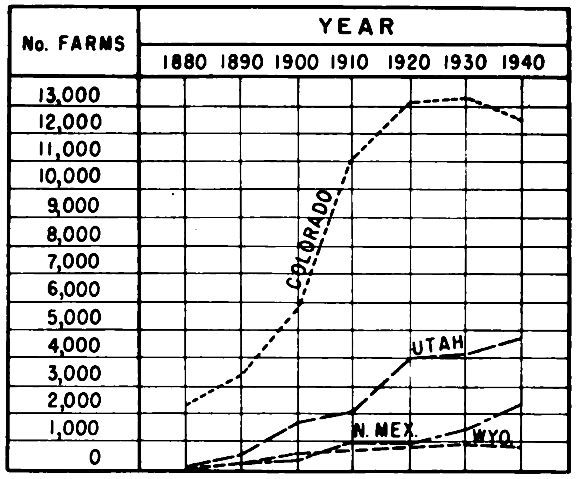


FIGURE 4.—*Number of farms, 1880–1940.*

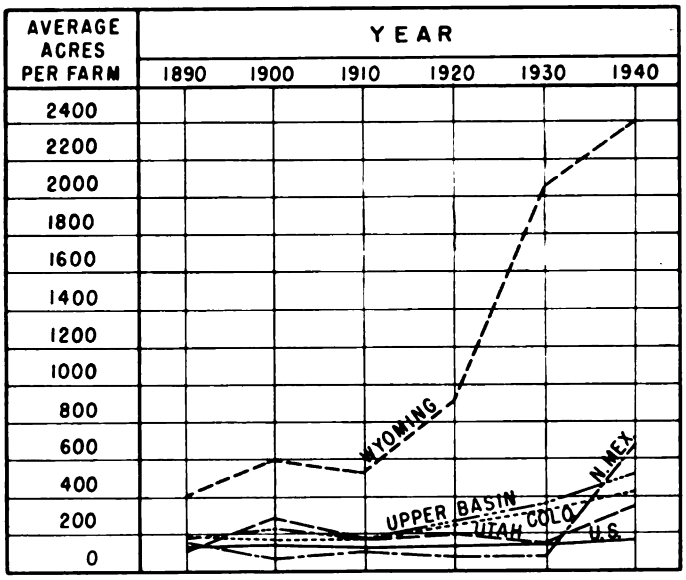


FIGURE 5.—*Size of farms, 1890–1940.*

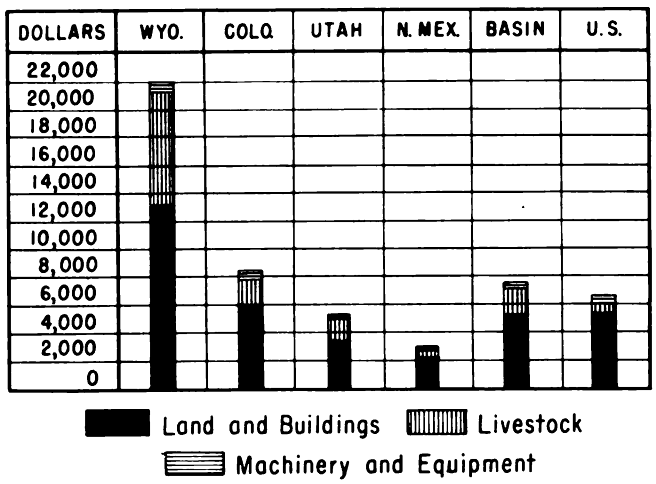


FIGURE 6.—*Value of farm property, 1939.*

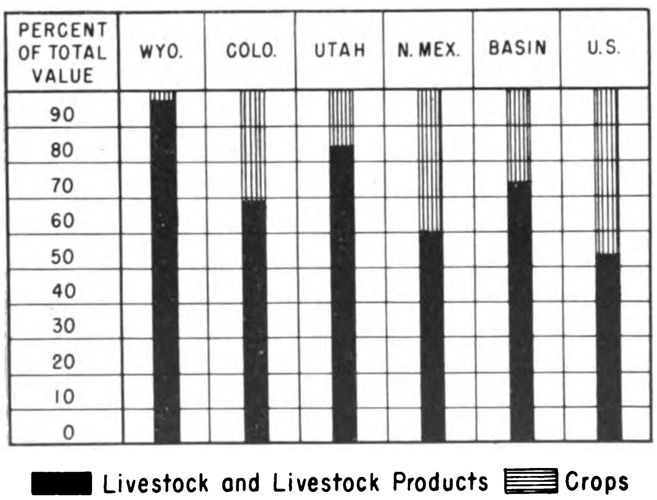


FIGURE 7.—*Value of agricultural products, 1939.*

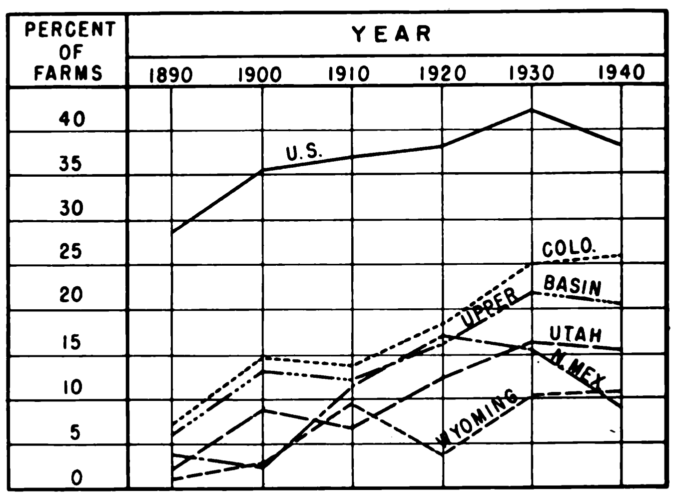


FIGURE 8.—*Farm tenancy, 1890–1940.*

The 27 percent of farms with less than 50 acres per farm contained but 1.1 percent of the total land area and harvested but 5.9 percent of the cropped acres in the upper basin. At the other extreme 14 percent of the farms had 75 percent of the total land and 36 percent of the harvested acres. Farmers of small tracts do not have enough land to make a living from livestock and in most instances water is insufficient to enlarge and intensify their farming operations. The small farmers in the area would benefit greatly from irrigation development. More intense farming through irrigation would develop small economic farm units.

TABLE XIII.—*Farm land available in upper basin (1939)*

State area	Type of farm land available (average number of acres per farm)				
	Irrigated crop land harvested	Total crop land	Irrigated land	Grazing land [1]	All agricultural land [1]
Wyoming	181	194	276	10, 204	10, 398
Colorado	43	65	53	1, 551	1, 616
Utah	30	45	44	3, 469	3, 514
New Mexico	11	19	11	1, 315	1, 334
Upper basin	43	52	57	2, 360	2, 412

[1] Includes public land used for grazing.

Value of farm property.—The average value per farm in the upper basin as reported in the 1940 United States census was $7,805. This was about $1,000 more than the average for all farms in the United States. As compared with the average of all farms in the Nation the average basin farm has a little more invested in land, has less in buildings, and more than twice as much in livestock. Many of the livestock operators in the upper basin use land belonging to the Federal or State Governments in which they have little or no investment (fig. 4).

TABLE XIV.—*Value of farm property in upper basin (1939)*

State area	Average value per farm				
	Land	Buildings	Livestock	Implements and machinery	Total
Wyoming	$11, 142	$2, 013	$7, 778	$898	$21, 832
Colorado	4, 777	1, 366	1, 712	626	8, 481
Utah	2, 759	720	1, 618	360	5, 457
New Mexico	1, 809	509	593	208	3, 120
Upper basin	4, 278	1, 152	1, 846	530	7, 805
United States	3, 811	1, 707	747	502	6, 767

The average farm valuation in Wyoming is much higher than in other States because practically all of the farms in the Wyoming area of the Colorado River Basin are specialized livestock ranches involving large acreages. In the other States there are more crop farms and many livestock farms that are too small for efficient operation.

Farm income.—The total value of agricultural products sold or traded in the upper basin in 1939 amounted to $40,000,000 according to the 1940 United States census. Livestock and livestock products accounted for three-fourths of this amount (fig. 8).

TABLE XV.—*Average income from farms in upper basin (1939)*

State area	Income per farm	Income per capita of farm population	Income per acre of harvested land	
			Total farm income	Crop income
Wyoming	$4, 392	$954	$23. 80	$0. 72
Colorado	1, 699	360	30. 71	9. 60
Utah	1, 127	264	34. 56	5. 43
New Mexico	555	107	37. 64	15. 17
Upper basin	1, 564	335	30. 13	7. 65
United States	1, 089	217	20. 68	9. 63

These statistics of farm income strikingly show the importance of the livestock industry in this region. The income per farm and per capita population is about 50 percent higher than the average for the entire United States. This is because livestock operations are conducted in large-scale units for greater efficiency, and the farm labor requirement is low. The total farm income per acre of crop land harvested was also higher than the average of the Nation, but the crop land income per acre was lower because of the relatively large acreage of livestock and grazing lands. Wyoming, where livestock raising is of greatest relative importance in the upper basin, is in marked contrast with New Mexico where farmers are dependent to a larger extent upon crops.

Farm tenancy.—The upper basin in common with all of the Mountain States has relatively few tenant-operated farms (fig. 8). In 1940 there was slightly more than half as many tenant-operated farms in the upper basin as in the United States as a whole, mainly because livestock farming is not well adapted to a tenancy. The economic age of the upper basin also may be a contributing factor. The risks to the livestock farm owner are too great with tenancy. Most of the tenancy that does exist is in the nonlivestock types of farming.

Part-owner-operated farms are more common in this area than in the country as a whole. This has resulted from the frequent ownership by inheritance, homesteading, or unwise purchase of tracts too small for an economic unit. Because these cannot be economically operated independently they are often leased to livestock men to supplement their own holdings.

Minerals and Mining [1]

The most extensive and commercially most important mineral resources of the upper basin are coal, oil, and natural gas. The upper basin is the leading domestic source of vanadium, uranium, and radium ore, and also molybdenum. Zinc, lead, silver, and gold are commercially important. Metals of minor interest include copper, manganese, bismuth, and antimony. Among the nonmetallic or industrial minerals and rocks, gypsum, salt, and limestone are abundant and accessible but have not been developed extensively. Potash and magnesium deposits are possible future sources of supply. (See appendix, maps entitled "Mineral Resources, Colorado River Basin.")

The remoteness of large portions of the upper basin from established industrial and transportation centers has been responsible for the restricted character of industrial developments based on minerals and has also retarded intensive exploration for new mineral deposits. The important discoveries of carnotite ores and carnallite made during the war period are indicative of new developments that can be expected with continued intensive exploration. Recent success in an expanded oil drilling program is highly encouraging. Some of these mineral resources may not be developed to a large extent immediately, but with improved technological processes together with increased demands and the depletion of more economical sources of supply, the time may not be far away when large scale developments will take place in the upper basin.

Mineral fuels and other hydrocarbons

Coal.—The upper basin contains enormous reserves of coal, mostly of bituminous and subbituminous grade. Reserves here are much larger than those in any other section of comparable size in the world and amount to approximately one-third of all of the coal deposits in the United States and one-sixth of those in the entire world. Some of this coal is below present mineable depths, but mineable reserves alone are nearly one-fourth of the Nation's total deposits. Coal reserves within the upper basin are roughly estimated at 400 billion tons.

The importance of these vast reserves is enhanced by the almost complete absence of any coal deposits in the States west of this region. The only exception of any consequence is the coal deposits of the State of Washington, but this coal is inferior in quality and more difficult to mine than the coals of the upper basin. Large quantities of coal from the upper basin are now shipped west, north, and sometimes east. These coals can be mined more cheaply than those in most other regions and may provide the basis for much of the future industrial development of the western part of the United States.

Mine entries above ground level are possible for a large portion of the deposits. Thick beds, ranging from 8 feet to a maximum of 90 feet and virtually horizontal, can be mined with comparative ease.

Bituminous coals from the upper basin are considered the highest quality bituminous coals on the western market. They are low in ash and moisture, extremely low in sulphur and highly volatile with a high heat value. Largest coal mines in the upper basin are in the Rock Springs and Kemmerer districts in Wyoming, served by the Union Pacific Railroad, and near Price, Utah, on the Denver & Rio Grande Western Railroad. Most of the coal mined in the Colorado area is bituminous but some good grade anthracite is mined in Gunnison County.

Coal production in the upper basin increased more than 50 percent in the period 1940–43. Part of the increase was in coking coals mined near Sunnyside, Utah, for new steel plants at Geneva, Utah, and Fontana, Calif. The new completely mechanized mine located near Sunnyside has a capacity to produce 8,000 tons of coking coal per day. Other important deposits of coking coal are located near Crested Butte, Durango, and Norwood, Colo. Coal in the Willow Creek area, Wyo., was found recently to be suitable for blending with other coal in the manufacture of metallurgical coke.

The increased coal production to meet war demands is indicative of future expansion in the industry, which no doubt will be accompanied by additional heavy investments in modern mining equipment. As coal is used more economically, especially through effective utilization

[1] Based in part on information supplied by Geological Survey.

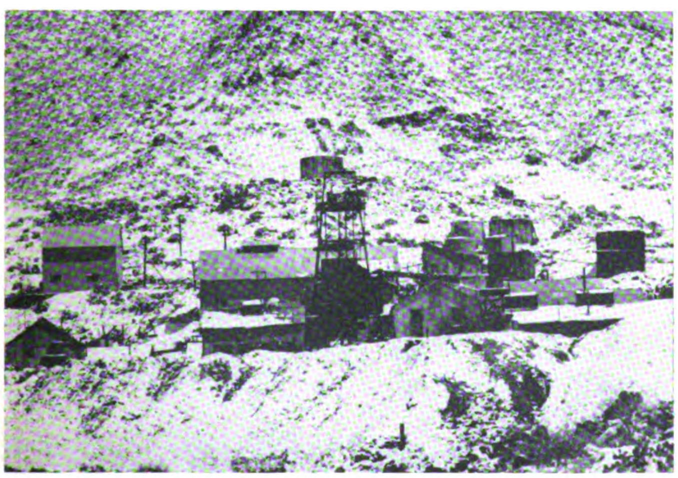
Table XVI.—*Coal production in upper basin*

State area	Tons mined				
	1920	1930	1935	1940	1943 [1]
Wyoming	6, 212, 000	4, 577, 000	3, 800, 000	4, 660, 000	2, 446, 125
Colorado	2, 037, 000	1, 641, 000	1, 491, 000	1, 827, 000	5, 699, 837
Utah	5, 881, 000	4, 168, 000	2, 919, 000	3, 504, 000	6, 896, 817
New Mexico	3, 000	7, 000	7, 000	34, 000	73, 717
Upper basin	14, 133, 000	10, 393, 000	8, 217, 000	10, 025, 000	15, 116, 496

[1] Estimated.

COAL MINE NEAR SUNNYSIDE, UTAH

Coking coals are mined here for western industries



LEAD-SILVER MINE

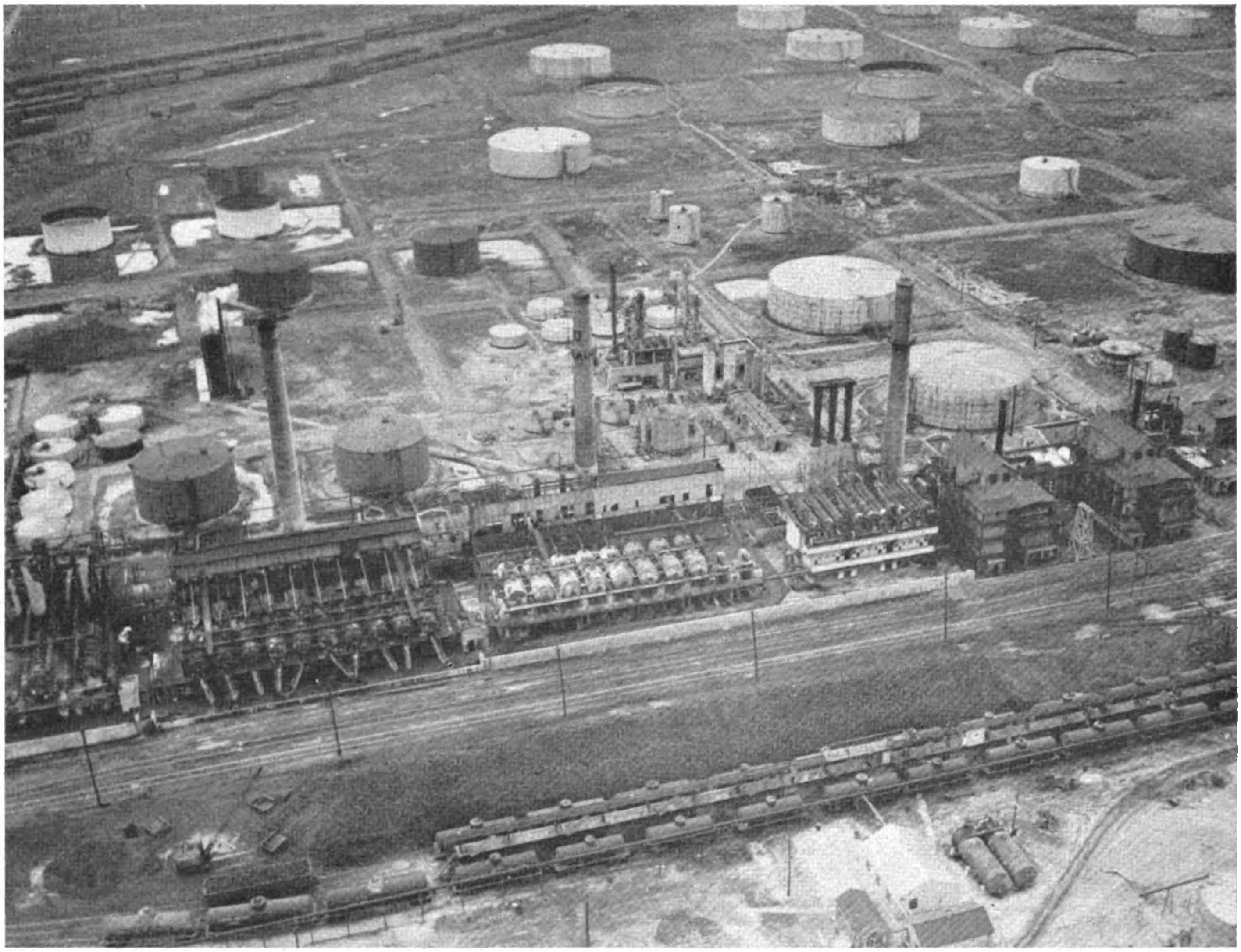
Power is supplied from Boulder and Parker Dam power plants on Colorado River

GOLD MINE

Additional low-cost power is needed to develop vast mineral resources of the volatile substances, satellite industries are expected to increase.

Petroleum and natural gas.—Oil and gas have been discovered in 40 widely distributed fields in the upper basin. Most of the fields, however, are located in northwestern Colorado and in an area in southwestern Colorado and northwestern New Mexico. Wells now being drilled near Vernal, Utah, may prove to be the beginning of the first major oil field in Utah. Proved reserves of petroleum in the upper basin were estimated at 43,200,000 barrels as of October 1, 1943. Production in 1943 exceeded 3,250,000 barrels of oil and 21 billion cubic feet of gas, 60 and 70 percent respectively coming from northwestern Colorado.

Oil from Wyoming wells and from wells in the Rangely field in Colorado is piped to refineries at Salt Lake City. Other Colorado crude oil is refined at Craig and Denver. Gas from both the Baxter Basin field in Wyoming, one of the largest in the world, and from the Hiawatha field in Wyoming and Colorado is piped to Salt Lake City, Ogden, and other places in Utah as well as to several towns in Colorado and southwestern Wyoming. Oil from wells in the San Juan River Basin is refined at Farmington and Bloomfield, N. Mex. Natural gas from this area is piped to Durango, Colo., and Shiprock, Farmington, Bloomfield, Albuquerque, Santa Fe, Belen, and Bernalillo, N. Mex.



UTAH OIL REFINING COMPANY

Oil from Colorado and Wyoming is piped to refineries in Salt Lake City

Oil shale.—The upper basin also contains the largest deposits of oil shale in the United States. The reserves of this potentially important mineral fuel account for approximately 82 percent of the 75 billion barrels of recoverable oil in shale in the United States, which is equal to four or five times the known reserves of petroleum in all the oil fields of the Nation. The extraction of the oil from shale will require the establishment of plants near the deposits. Whether oil shale or coal or both are utilized to meet future needs for oil and gasoline, these mineral fuels are of great potential importance.

Bituminous sandstone and rare hydrocarbons.—Another oil-bearing material of great potential importance is bituminous sandstone. At the present time it is being used as a road surfacing material. Large deposits are worked near Vernal and Sunnyside, Utah. The Vernal deposit contains about 2 billion tons averaging between 8 and 15 percent bitumen by weight, but most of it can be recovered only by underground mining. The deposit near Sunnyside is also very large; a sample of it averaged 11 percent bitumen by weight.

The only known deposits of gilsinite, elaterite, wurtzilite, and ozocerite are in the upper basin. In normal times these materials are mined from veins and shipped to all parts of the world for use in the manufacture of roofing, insulating materials, and such articles as ink and switch handles.

The gilsonite deposits occur mainly in the Uinta Basin in Utah. Annual output during the 10-year period 1934–43 averaged 35,996 tons valued at $852,636. Reserves have been estimated at 25 million tons. The annual output of ozocerite and wurtzilite in Utah amounts to only a few hundred tons.

This array of mineral fuels and carbonaceous materials is not approached by any region in any other part of the world. The extent to which these materials may provide the basis for future mining and mineral processing within the basin and in contiguous areas cannot be foretold definitely, but it is certain that their effect on future industrial development will be important.

Nonferrous metals

The upper basin has contributed more than 8,000,000 ounces of gold, 300,000,000 ounces of silver, 1,000,000 tons of lead, 500,000 tons of zinc, and 160,000 tons of copper to the total mineral production of the Nation.

The production of these nonferrous metals for typical years since 1920 has been as follows:

TABLE XVII.—*Mineral production in upper basin*

	1920	1925	1930	1935	1940	1942
Gold (oz.)	102, 350	91, 950	55, 370	61, 920	93, 620	53, 000
Silver (oz.)	3, 374, 000	2, 501, 000	2, 951, 000	3, 762, 000	8, 361, 000	1, 706, 000
Copper (tons)	1, 469	1, 052	4, 475	7, 165	11, 724	865
Lead (tons)	16, 275	22, 393	13, 742	2, 734	8, 410	9, 941
Zinc (tons)	14, 690	26, 157	24, 726	272	4, 520	27, 838

The limited production and reserves of gold, silver, copper, lead, and zinc are confined to several small areas, mainly in southwestern Colorado. The production of these metals will increase in the future, no doubt, with advancement in operational techniques. At present nearly all of the metal ores mined in the basin must be shipped to outside mills and smelters.

Gold and silver.—A number of districts in the San Juan Mountains, Colo., have been important sources of gold and silver derived from ores relatively near the surface, but deeper ores in the same districts are now contributing lead, zinc, and copper as well as gold and silver. Large quantities of gold and silver have also come as byproducts of base-metal ores in the zinc-lead districts.

Copper.—Copper has been mined in substantial quantity along with zinc and lead at Gilman, Colo., and has been a byproduct of zinc, lead, and precious metal ores elsewhere. Substantial reserves of ore, mostly of low grade, are present in sandstone in the Colorado Plateau, but only small quantities of high-grade ore have been shipped.

Zinc and lead.—Deposits of zinc and lead in the upper basin are practically confined to western Colorado. The leading district is at Red Cliff and Gilman in Eagle County, from which 170,000 tons of zinc and 66,000 tons of lead, together with some silver and gold, have been mined. Its reserves of zinc are estimated to be about 525,000 tons and those of lead 105,000 tons.

Other districts that have contributed substantial quantities of zinc and lead are the Breckenridge and Kokomo districts in Summit County, Aspen district in Pitkin County, Rico district in Dolores County, Telluride district in San Miguel County, closely spaced districts in Ouray County, and the Eureka district in San Juan County.

Ferro-alloy metals.

Molybdenum.—The Climax molybdenum district, the largest single metal-mining operation in Colorado and the largest molybdenum district in the world, is situated close to the Continental Divide in northeastern Lake County, Colo. Mining there began in 1918, and from then until 1943 the total output has amounted to 268,618,190 pounds of metallic molybdenum contained in concentrates. The quantity of ore mined daily during 1942 and 1943 ranged from 15,000 to 20,000 tons.

Molybdenum-tungsten deposits in the Gold Hill district, Gunnison County, Colo., first became productive during World War I, when a few hundred tons of ore containing 4.5 percent of molybdenum sulphide and 100 tons of ore containing 11 percent tungstic oxide were mined. They have been worked for tungsten during World War II. Reserves include 60,000 tons of relatively high-grade molybdenum ore and from 100,000 to 200,000 tons of ore containing not more than 0.5 percent molybdenum sulphide. No estimate of tungsten reserves has been made.

Vanadium, uranium, and radium.—Deposits of vanadium-bearing sandstone are widely distributed in western Colorado and eastern Utah, and are also present in northern Arizona and New Mexico, but output thus far has come principally from those in Colorado and Utah, which constitute the leading domestic source of vanadium, uranium, and radium. Vanadium from Paradox Valley in Colorado and Utah was a source of bombastic uranium, used in the manufacture of the atomic bomb. Deposits near Placerville, Colo., were discovered in 1899. From 1911 to 1923 the ores of the region were intensively mined for their radium and uranium, but from 1915 to 1923 some vanadium was produced as a byproduct. Mining practically ceased in 1923 when pitchblende from the Belgian Congo began to supply radium. Since 1937 the ores have been mined for vanadium. From 1909 to 1943 the output amounted to 23,000,000 pounds of elemental vanadium contained in mill products. From 1907 to 1920 about 202 grains of radium were recovered, equivalent to about 1,000 tons of uranium oxide.

Reserves of inferred ore total many million tons, but because of spotty distribution and high cost of development only a small fraction of these reserves could be considered commercially available under conditions prevailing in 1943. The indicated and measurable reserves do not exceed 500,000 tons of ore. The region, however, should continue to be an important source of vanadium, and contains the largest domestic reserves of uranium and vanadium.

Manganese.—Although small bodies of manganese ore are widely distributed throughout much of the upper basin, particularly in Utah, they do not constitute an important resource. A manganese ore body, estimated at over a million tons and containing 16.8 percent manganese and 11.3 percent iron is located on the northern slope of the Uinta Mountains in Utah. Estimated reserves include about 15,000 tons of 30-percent ore, only a part of which can be profitably mined even at wartime prices; about 100,000 tons of 10- to 30-percent ore, and about 350,000 tons of 4- to 10-percent ore. Since 1901, when the first shipment was made, about 12,000 tons of ore containing 40 to 45 percent manganese have been shipped.

Tungsten.—Tungsten deposits in the upper basin occur only in western Colorado and are of very little commercial interest. Output has been extremely small, even when wartime prices prevailed. Estimated reserves are as follows:

County, Colorado	Indicated ore		Inferred ore	
	Tons	Units [1]	Tons	Units [1]
Gunnison	1, 000	2, 400	1, 900	3, 850
Ouray			500	750
San Juan	100	400	800	1, 650
San Miguel			250	500
Summit	150	950	175	900
	1, 250	3, 750	3, 625	7, 550

[1] A unit amounts to 20 pounds of tungstic oxide (WO_3).

Minor metals

Antimony.—Antimony is present in small deposits in Dolores, Gunnison, Ouray, Pitkin, San Juan, and San Miguel Counties, Colorado, but not in commercial quantities as an ore of antimony. Lead-antimony deposits have been mined but owing to the penalty for high antimony content in lead ore, these ores are generally avoided. Many of the complex base- and precious-metal ores in the San Juan region contain some antimony, part of which is recovered as a smelter or refinery byproduct.

Bismuth.—Bismuth is also found in many districts in western Colorado, but not in commercial deposits of bismuth ore. Part of it is recovered in the smelting and refining of base- and precious-metal ores.

Nonmetallic (industrial) minerals

Though there is almost no industrial utilization of industrial minerals in the basin, there are potential resources that are either known to be large or, if adequately explored, may prove to be large. These include phosphate, potash, and sodium carbonate deposits in Wyoming, salt and associated potash deposits in southeastern Utah, and salt and associated gypsum in southwestern Colorado. Limestone and dolomite are present at several places in Colorado, Wyoming, and northwestern New Mexico. Deposits of helium and carbon dioxide gases also occur in the upper basin.

Phosphate rock.—Only a relatively small portion of the great western field of phosphate rock is in the upper basin. It occurs in the Salt River and Wyoming ranges and around the flanks of the Uinta Mountains in Utah. The beds in Wyoming are mainly thin and comparatively inaccessible but of moderately high grade. Those in Utah are generally of low grade and vary greatly in thickness. The nearness of large hydroelectric power sites, however, and the possibility of mining the rock by open pit methods may lead to extensive development of this rock as a fertilizer. Estimated reserves of phosphate rock amount to 1,616,000,000 long tons averaging 40 to 50 percent calcium phosphate.

Potash.—Large deposits of leucite, a mineral containing potash and alumina, in the Green River Basin in Wyoming may eventually prove to be a feasible source of potash. The possibility of its development would be greatly enhanced by the production of fertilizer materials, especially phosphates, in nearby areas. Reserves of potash rock in this area amount to 1,900,000,000 tons which contain an estimated 190,000,000 tons of potash. Reserves of potash and magnesium salts in southeastern Utah occur at a depth of 3,000 feet and cannot be estimated from available data, but the known deposits are sufficiently widespread and of sufficiently high grade to be regarded as an important potential resource.

Recent exploration near Thompson, Utah, has proved the presence of extensive deposits of carnallite, a chemical combination of potassium chloride and magnesium chloride, and of other potash-bearing minerals. Further development may lead to the utilization of these minerals for the production of potash separately or as a joint or byproduct with magnesium. Had these explorations for carnallite been made at an earlier date, they probably would have led to the construction of a processing plant to supply in part the war needs for metallic magnesium. These western resources present one of the most favorable raw material basis for a concentrated mixed fertilizer industry in the world.

The availability of large supplies of cheap electricity would be an important factor in promoting the utilization of these abundant fertilizer minerals.

Salt.—The exploration for carnallite also revealed the presence of much larger beds of sodium chloride. Wells drilled in widely sparated areas in southeastern Utah have cut through beds of common salt 2,000 feet or more in thickness. Possibilities of future production of iodine and other important substances are also indicated. Salt deposits in Paradox Basin, Colorado, amount to billions of tons, but they are nearly all at depths of more than 1,000 feet. Salt is being mined only at Bedrock, Montrose County, Colorado, for use in the production of vanadium. Estimates of possible reserves of sodium carbonate (trona) in Sweetwater County, Wyoming, range from 158,000,000 to 7,000,000,000 tons. Brine containing sodium carbonate has served intermittently as the raw material for production of a small amount of sal soda.

Gypsum—Gypsum ores outcrop along the west flank of the San Rafael Swell in east-central Utah. Reserves in this section are estimated at 9,701,600,000 tons. The tonnage of large reserves in western Colorado has not been estimated. Gypsum reserves constitute a large source of supply for future use when market conditions are favorable for their development.

Helium.—Helium is produced from natural gas in the Rattlesnake field, New Mexico, and is known to occur with natural gas in the Woodside and Harley Dome fields, Utah. Figures of output and reserves are not available.

Carbon Dioxide.—Carbon dioxide gas, obtained from the Farnham anticline, is manufactured into liquid and solid carbon dioxide at Wellington, Utah. The output in 1943 amounted to 160,972,000 cubic feet.

Building Stones.—The only building or monumental stone worthy of note in the upper basin is Colorado Yule marble, a product of high quality quarried intermittently at Marble, Gunnison County, Colo. The high cost of quarrying and the long distance from the large markets have been obstacles in the development of this industry. Crushed stone is produced for local use at several places, and limestone has been burned into lime at scattered places. Only one lime plant, at Glenwood Springs, Colo., was operated in 1943.

Other industrial minerals.—Other industrial minerals in the basin include sulphur in Emery County, Utah; pyrite in large quantities in several mining districts; analcite (a zeolite), of possible usefulness in water-softening, in eastern Uintah County, Utah, and adjacent parts of Colorado; pumice, used locally at Durango, Colo.; amorphous graphite, derived through the intense alteration of coal, near Pitkin, Gunnison County, Colo.; vermiculite, which has been exploited in a small way in Gunnison County, Colo.; and fluorspar, which occurs as a gangue mineral in certain metalliferous veins, and has been shipped from the Barstow mine in Ouray County, Colo. Past shipments of fluorspar slightly exceed 10,000 tons; known reserves are negligible, but a total of 10,000 tons is inferred for the two or three deposits that have any commercial promise.

Lumbering

The high mountain areas of the upper basin support extensive stands of timber, much of which is suitable for various building and industrial uses. Timber stands are quite widely distributed over the basin but are most heavily concentrated in western Colorado. In 1939 saw and planing mills gave employment to 560 workers. With two exceptions these mills are small and supply only a limited local trade. Much lumber is shipped in from mills outside the basin that are better equipped to process the lumber in the forms required for a variety of uses. Because of the inaccessibility and the scattered nature of timber stands, lumber from this area cannot compete at present on National markets, but as other timber reserves are depleted and local needs increase the timber resources of this region no doubt will be utilized more fully and will support important lumbering industries.

Manufacturing

The processing of agricultural products on a small scale is practically the only manufacturing in the upper basin. At present there are three factories that process fruits and vegetables and two beet sugar factories. In several main farming areas small grain mills produce flour and other grain products, largely for local use. A few small creameries and cheese plants also operate in the area. Only a small portion of the ore mined receives preliminary milling before it is shipped outside the basin. The remoteness of the area, the newness of its economy, and the widely scattered production of the small quantity of raw materials suitable for processing have all tended to restrict manufacturing in the basin.

Table XVIII.—*Manufacturing census data—upper basin*

	Number of employees engaged	Value of raw materials	Value of processed products	Value added by processing
1919	3, 319	$9, 977, 000	$17, 369, 000	$7, 392, 000
1929	2, 940	19, 523, 000	28, 230, 000	8, 707, 000
1939	2, 025	9, 584, 000	14, 311, 000	4, 727, 000

The limited amount of manufacturing in the upper basin is indicative of undeveloped nature of the economy of the region. Practically all of the fabricating industries that are established process products produced in the basin. The reason may be partly that Denver and Salt Lake City are both close and provide large portions of the manufactured commodities consumed in the region.

Transportation and Markets

Low-cost transportation is vital to the economy of the upper basin because of its scattered population, expansive area, and long distance from eastern centers of production and consumption. Residents of the region pay freight on manufactured articles which are shipped in. They also indirectly absorb freight charges on shipments of their raw materials to outside markets because they must sell their products at delivered prices in competition with producers closer to market centers.

The main east-west lines of the Union Pacific and the Denver and Rio Grande Western Railroads cross the central part of the upper basin. The few important trading and shipping centers in the Green River Basin limit convenient outlets for crops and livestock. The Union Pacific Railroad extends through the southern part of Wyoming. The Denver and Rio Grande Western Railroad has shipping points at Price and Green River, Utah, and at various places along the Colorado, Gunnison, and Uncompahgre Rivers in Colorado. A narrow-gauge branch of The Denver and Rio Grande Western connects with the standard-gage line at Alamosa, Colo., and extends west to Durango, Colo., and thence south to Farmington, N. Mex. Another narrow-gage line of the Rio Grande Southern Railroad connects Durango and Mancos with Montrose, Colo., to the north. The Denver and Salt Lake Railroad enters the upper basin from the east but terminates at Craig, Colo.

Pinedale, Wyo., in the extreme north of the upper basin must transport its livestock and crops 102 miles to the nearest railroad point at Rock Springs. Closest rail centers to Vernal, Utah, are Helper, Utah (105 miles), and Craig, Colo. (123 miles). Other important areas in southern and eastern Utah and in the Dolores River Basin in Colorado are many miles from rail connections.

United States highways 6, 30, 40, 50, and 160 also extend east and west across the basin. North-south highways are fewer but U. S. Nos. 187 and 189 serve the Wyoming portion of the basin and Nos. 160 and 550 extend from Crescent Junction, Utah, and Grand Junction, Colo., respectively into the San Juan River Basin. Many Federal, State, and local highways are interconnected. Good roads have fostered the trucking system that serves the area. All but the remote and mountainous areas can be reached by all-weather roads. A few unimproved roads traverse parts of the area, but much of the barren and badland regions is inaccessible by the road.

High transportation costs have restricted development in the upper basin. The Bank of Vernal, Utah, is constructed of brick sent from Salt Lake City by parcel post. It was erected in 1919 when freight was $2.50 a hundred pounds and parcel post only $1.05.

The urban population within the upper basin provides a local market for whole milk, fruits, and vegetables, but considerable quantities of potatoes, vegetables, fruits, and processed foods are imported. Large quantities of grain and other livestock feeds also are imported normally. Only high-value-per-pound products can be exported profitably. These include livestock, wool, butter, cheese, eggs, poultry, seeds, vegetables, fruit, and honey. Livestock are sent to Denver, Kansas City, Omaha, Salt Lake City, and Ogden, and wool is shipped to Boston.

Most minerals are shipped in raw ore form out of the basin for refining, although in recent years some milling and reducing of ores have been done near the mines before shipment. Main ore markets are Leadville, Colo., Midvale and Tooele, Utah, Amarillo, Tex., and Coffeyville, Kan. Coal is shipped to eastern Colorado, central Utah, and southern Idaho for domestic and industrial purposes and to Denver and Pueblo, Colo., Provo, Utah, and Fontana, Calif., for use in iron ore reduction.

In general the Wyoming and Utah portion of the upper basin is a part of the Salt Lake City-Ogden trade area and the Colorado and New Mexico portion is connected with the Denver trade area.

TABLE XIX.—*Value of trade in upper basin (1939)*

Division	Wholesale	Retail
Green	$9, 303, 000	$29, 668, 000
Grand	14, 453, 000	31, 040, 000
San Juan	6, 000, 000	15, 000, 000
Upper basin	29, 756, 000	75, 708, 000

RECREATION

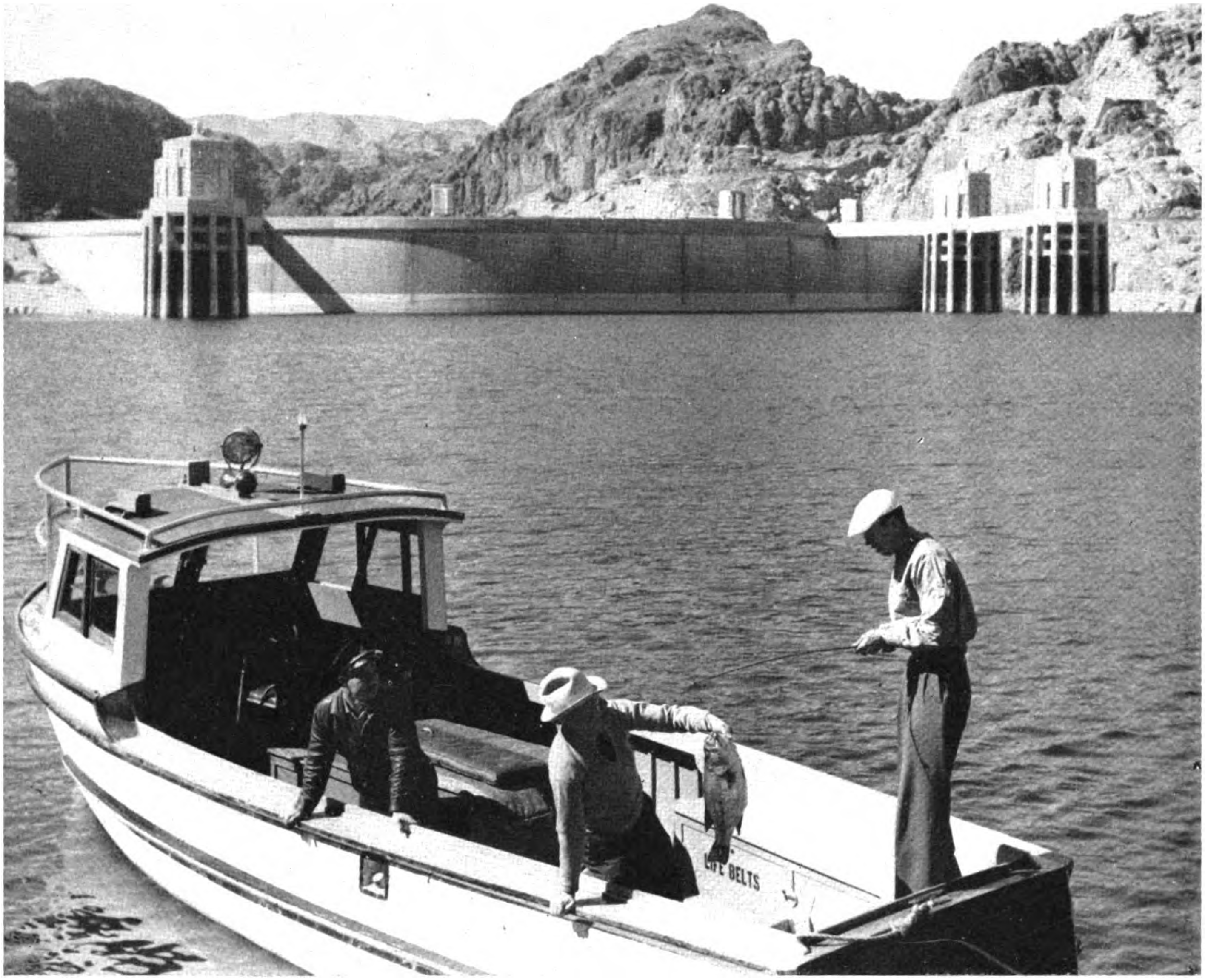
The upper basin with its lofty snow-capped mountains, clear trout-stocked streams and lakes, beautiful forests and cool but sunny weather in the mountain country attracts vacationists from all pars of the Nation. In the San Juan Basin is the world's largest natural bridge, brilliantly colored rock formations, some of the best preserved Indian ruins and cliff dwellings, and "Four Corners," the only point in the United States where four States join. The largest and most complete deposits of dinosaur fossils yet discovered have been unearthed near Vernal, Utah.

Bryce Canyon and Mesa Verde National Parks and part of Rocky Mountain National Park are within the upper basin. There are also 13 national monuments, including Yucca House, Navajo, Capital Reef, Arches, Natural Bridges, Hovenweep, Canyon de Chelly, Chaco Canyon, Aztec Ruins, Rainbow Bridge, Dinosaur, Colorado, and Black Canyon. The San Juan wilderness area of a quarter million acres has been set aside as a primitive preserve in the San Juan National Forest along the Continental Divide. Other primitive preserves have been established in different parts of the basin. National Parks, monuments, and forests are shown on a map entitled, "Conservation Areas and Facilities" included in an appendix of this report. (See Chapter VIII, National Park Service.)

Game is in abundance in most all parts of the upper basin. Sportsmen find excellent fishing in mountain streams and lakes. Trout are plentiful in the clear, cold water of upper Green River and its tributaries. In the upper Colorado River Basin 318 streams totaling 2,327 miles and 273 lakes furnish plentiful fishing. The Colorado State Department of Game and Fish and the Forest Service cooperate in keeping the streams and lakes well stocked with fish. The varieties of trout most common are eastern brook, native, rainbow, and Loch Leven. Val-

OUTDOOR LIFE

Visitors enjoy the cool breezes on Lake Mead aboard the Grand Canyon Boulder Dam tours cruiser "Hualapai." This trip to the Grand Canyon and return is offered daily



ROD AND REEL

Fishermen displaying their catch, a 9-pound, 1-ounce bass taken from Lake Mead

lecito Reservoir and Fish Lake offer good fishing in the San Juan Basin.

Hunters are attracted particularly by deer, elk, and antelope herds, now increasing under protective measures. Mountain sheep, black and brown bear, beaver, fox, badger, ermine, muskrat, skunk, mink, wildcat, lynx, coyote, martin, weasel, rabbit, porcupine, grouse, sage chickens, and ducks also are found. Chinese pheasants, introduced into the Green River Basin in the early 1920's are now numerous near irrigated lands.

Private summer homes and commercial camps and resorts which offer accommodations to sportsmen are ideally situated near more accessible streams and lakes. Grand Lake in Rocky Mountain National Park is noted for its beauty.

Steamboat Springs, Colo., with its warm mineral baths is a popular resort area. Berthoud Pass and West Portal (Moffat Tunnel), Colo., favored because of their high altitudes and nearness to Denver, are noted winter sports areas. They offer good accomodations and ideal ski runs. The Hot Sulphur Springs ski tournament has been an annual event since 1911.

The many recreational advantages of the upper basin will be more fully enjoyed as they become more accessible through improved transportation. Their value will be enhanced through development of other resources.

LOWER BASIN

Agriculture and mining compete for first place in economic importance in the lower basin. Since agriculture employs a much larger percentage of the population, it is ranked generally as the most important industry in the area. The gross annual income from mining, however, is greater than that from agriculture. Livestock raising is an important agricultural enterprise, although not dominant as in the upper basin. Crops bring slightly higher returns than livestock. The warm climate permits both summer and winter cropping where irrigation water is available and high-value crops, such as citrus fruits and winter vegetables, are produced.

In 1940, 631,620 people were living within the 140,000 square miles of the lower basin. This average density of 4.5 persons per square mile is almost double that of the upper basin but is barely more than one-tenth of the national average.

The building of Boulder Dam and its appurtenant works to control and utilize the waters of the Colorado River has done much to increase the lower basin's economic contribution to the Nation. Agricultural lands near the river have been spared the ravages of destructive floods, and nearly a million acres have now been provided a dependable water supply, with further expansion in prospect. Low-cost electric energy from the project has stimulated industrial growth in the lower basin and the surrounding territory. War industries of practically every type and on substantial scale sprang up suddenly.

Within the basin lie some of the scenic masterpieces of Nature's handiwork. These, together with man-made attractions, draw millions of tourists to the area annually. Catering to these visitors has become a well-defined industry. Establishments such as auto courts, hotels, guest ranches, tourist bureaus, and curio stores are almost wholly dependent upon this trade. Countless other businesses are affected by tourist travel. The value of this industry is increasing.

Land Use

The lower basin, including the Salton Sea drainage area, comprises an area two and one-half times the size of New York State. Land in the area is grouped, according to use, as follows:

	Acres	Percent of total area
Farm land:		
Irrigated land	1, 351, 000	1. 5
Other farm land	29, 291, 000	32. 4
Indian reservations	16, 193, 000	17. 9
National forests	14, 934, 000	16. 5
National parks, monuments and recreational areas	3, 607, 000	4. 0
Other land	41, 073, 000	45. 6

Some of the areas as presented are overlapping and consequently the total exceeds the basin area. For instance part of the farm land is included also in the area in Indian reservations. A very large portion of the basin area is used for grazing. Included in the area grazed are part of the irrigated land and most of the "other farm land," also substantial parts of Indian reservations, National forests, and "other land." Limited grazing is permitted on National parks and monuments. Only 1.5 percent of the entire area is irrigated, yet this small portion is the base for the total crop production. Dry farming is practiced to a limited degree in a few of the higher agricultural areas, particularly in the Virgin and Little Colorado divisions, but is almost negligible in the economy of the lower basin.

Soils

Soils of the lower basin have developed in a climate where low rainfall and high temperatures prevail, with the result that they are very low in organic material and have lost little of their soluble plant nutrients through leaching. Soil colors vary from gray to red, with pinks and reds prominent. Practically all agricultural soils are of alluvial formation but vary rather widely in composition, texture, and fertility.

Valley bottom soils are generally derived from the more recent alluvial materials, and range in texture from sands to clays. They are best suited to agriculture because of high fertility, smooth topography, and proximity to irrigation supplies.

Bench and terrace soils make up the largest acreage of irrigable soils in the lower basin. Surface soils of this type vary from rather coarse and sandy to fine textured, and contain abundant quantities of the mineral elements of fertility. The subsoil is usually finer textured and in places is composed of heavy clay. Quite frequently a zone of lime accumulation occurs in the subsoil and in some areas a definite lime hardpan has been formed at various depths below the surface.

Extensive areas of desert soils in the lower basin usually grade from coarse sands and gravels near the base of mountains to fairly heavy clay loams and clays near the center of the valleys. Many areas are high in soluble salt content, but where good drainage can be provided, salts can be leached easily from the soils and the land made highly productive. These desert soils are stratified and the various horizons grade from coarse, raw sand to heavy, plastic clay. Where medium-textured soil occurs in sufficient depth at the surface or near enough to the surface to insure adequate water-holding capacity, the land merits agricultural development if the total salt content is low, or if leaching and drainage can be provided.

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MILCH COWS IN IRRIGATED PASTURE

All-year pasturing produces higher grade milk and assures plentiful winter supply

IRRIGATED SUGAR BEETS GROWN FOR SEED

Seed production is an important contribution to the Nation

Agriculture

Crops were grown in the lower basin hundreds of years before any other part of what is now the United States was settled. Agriculture has been and always will continue to be dependent on a satisfactory supply of irrigation water. The area is favored with an all-year growing season. Many crops, such as small grains and vegetables, grown in most parts of the Nation only in summer are produced here in winter. These combined with perennial crops such as alfalfa and pasture and semitropical crops in warmer parts of the basin result in a high degree of cropland occupancy. Crop failures are rare, but when they occur it is possible for another planting to be growing on the land within a short time, provided an adequate water supply is available.

Double-cropping of the same land with both winter and summer crops is a common practice where irrigation water supplies are adequate. This practice brings a high annual income per acre. Double-cropping, however, causes a heavy drain on soil fertility and necessitates either the rotation of soil-building crops or the use of commercial fertilizers, or both.

Because of the wide variety of crops that can be grown successfully in the lower basin the pattern of crop production is continually changing. New crops are being introduced and varieties of other crops developed. In recent years a number of crops new to the region have been tested and are now in commercial production. Among these are guar, a drought-resistant forage bean; psyllium, a seed used for medicinal purposes; mung beans, valued for food and forage; and many varieties of sorghum.

Alfalfa, grown on approximately 30 percent of the irrigated land, covers a larger acreage than any other crop. It is an important cash crop both for local sale and for shipment to southern California, the world's largest hay market. The production of alfalfa seed is also important. The extensive range lands of the lower basin together with adjacent areas in Mexico and New Mexico furnish a great number of feeder stock. These animals can be pastured on alfalfa fields and finished on hay, silage, and grain before being processed locally or shipped to markets. Alfalfa is of fundamental importance as a soil-building crop, and its use in the rotation system is partly responsible for high yields of other crops.

All-year pasturing is possible in the area. Cows so pastured produce more and higher grade milk, richer in fool value and vitamin content, than do cows fed otherwise.

Seed production is one of the lower basin's most important agricultural contributions to the Nation. With excellent growing conditions, water for irrigation, and virtual freedom from rain during the harvest season, seeds are plump, of strong germination, and excellent color. Twenty to 25 percent of the sorghum seed used in the United States and more than 40 percent of the sugar beet seed are produced here. Bermuda grass seed, grown largely in the Lower Colorado and Gila River Valleys, is used extensively in the development of pastures, erosion-control plantings, and lawns throughout most of the Southern States. Flaxseed yields are high in the Yuma and Imperial Valleys and bring good prices because of the high iodine content of the seed which gives a drying quality to the oil extracted.

The Coachella Valley has become the principal source of the Nation's domestic date crop. The dates grown in this region are of exceptionally high quality.

Range livestock are dependent on irrigated areas for winter feed. Sheep are brought from mountain ranges to irrigated valleys during the late fall and lambed during November. The lambs are fed on alfalfa and grain pastures and marketed in the early spring.

Agriculture in the region can expand only to the extent more water can be made available. Much more land is suitable for crop production than is in cultivation. Water is the limiting factor.

Types of farms

Types of farms in the lower basin classified according to the major source of income are shown in the accompanying chart (fig. 9). The percentage is of the total number of farms.

Livestock and dairy farms.—Approximately 36.6 percent of the farms are livestock and dairy farms. The vast areas of grazing land have led to extensive ranching operations. The percentage of livestock farms will probably remain high, but with more feed produced on irrigated land in the future the percentage of finished cattle and dairy products is likely to increase. An increase of population in rural areas and the continued growth of urban centers will be accompanied by an increase in the demand for the products of the dairy and the feeder livestock farm.

Field-crop farms.—In an area where ranch livestock is so important, the production of feed crops on irrigated lands is likewise important. Such crops as alfalfa, small grains, and sorghums are grown principally as an adjunct of the livestock industry. Cotton has been the most important field crop, but its relative importance is decreasing.

Fruit and truck farms.—Fruit and vegetable or truck farms are much more important in the irrigated areas of the lower basin than either the percentage of such farms or their acreage would indicate because gross returns per acre are very high and a large amount of labor is required.

Subsistence farms.—The highest percentage of farms is classified as subsistence farms, so called because most of the farm products are consumed by the farm household. In certain localities within the basin inheritance has resulted in farms being divided into very small individual holdings which are operated as subsistence farms. Many

WINTER VEGETABLES FOR EASTERN MARKETS

Irrigated lands produce tons of carrots and provide a livelihood for many growers and handlers

Indian farms are subsistence units. Subsistence farms produce very few products for sale, unless they are handled in conjunction with range land. The development of new lands and the provision of supplemental water supplies for lands now inadequately irrigated will improve present farming conditions.

Number and Size of Farms

Arizona is representative of the lower basin with reference to the size of farms. In 1940 Arizona with an average of 1,389 acres per farm, had larger farms than any upper basin State except Wyoming. Livestock raising was the major farming activity on large farms. Between 1930 and 1940 the number of large farms (those over 100 acres) in the lower basin increased 2.1 times, while the percent of the total area of such farms increased only 1.6 times. The most significant increase in large farms took place between 1935 and 1940. During that period the number of farms of fewer than 10 acres was cut almost in half.

Table XX.—*Number and size of farms in lower basin*

Size group	1910	1920	1925	1930	1935	1940
	Percent of total number of farms					
Under 10 acres	27. 2	7. 0	11. 1	24. 1	26. 3	15. 0
10–49 acres	25. 0	31. 1	28. 4	30. 9	33. 2	24. 5
50–99 acres	8. 9	17. 1	17. 6	12. 9	11. 1	8. 4
Subtotal	61. 1	55. 2	57. 1	67. 9	70. 6	47. 9
100–499 acres	36. 3	36. 0	32. 2	22. 2	19. 2	21. 5
500–999 acres	1. 8	4. 8	4. 8	4. 8	4. 9	10. 5
Over 1,000 acres	. 8	4. 0	5. 9	5. 1	5. 3	20. 1
Subtotal	38. 9	44. 8	42. 9	32. 1	29. 4	52. 1
Total	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
	Number of farms					
Under 100 acres	5, 643	5, 506	6, 154	9, 624	13, 291	8, 854
Over 100 acres	3, 584	4, 469	4, 648	4, 549	5, 533	9, 614
Total	9, 227	9, 975	10, 802	14, 173	18, 824	18, 468

The general trend is toward larger farms. The increase in the size of ranches is due partly to the decrease in the number of livestock the public range can support. Crop farms are increasing in size and number in certain areas because improved machinery makes possible higher efficiency in farm operation.

Irrigated farm acreage.—The average number of irrigated acres per farm in the lower basin decreased slightly during the period 1910 to 1940. The decrease was due largely to the increase in number of irrigated farms, with a lesser corresponding increase in irrigated acreage. The Little Colorado division had the smallest irrigated farm units as well as the greatest decrease in irrigated acreage per farm. The number of irrigated farms in that division increased from 554 in 1910 to 1,942 in 1940, but the total irrigated acreage increased only 35 percent. The small size of these units results from the high percentage of Indian farms and the large number of subsistence white farms.

Farm operation.—Full renters or tenants made up 14 percent of all farm operators and farmed about 19 percent of the cultivated land in 1940. Owner-renters or

LOWER COLORADO RIVER BASIN

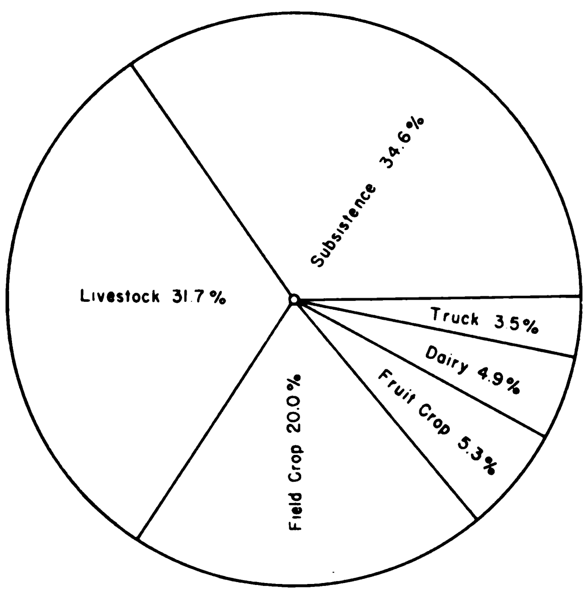


Figure 9.—*Types of farms.*

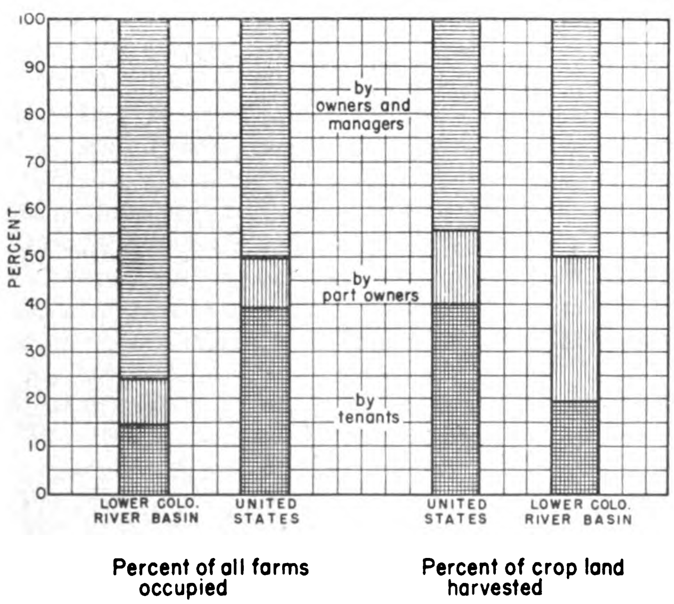


Figure 10.—*Farm operation, 1940.*

TABLE XXI.—*Irrigated farm acreage in lower basin*

Division	Average irrigated acreage per irrigated farm (acres)			
	1910	1920	1930	1940
Little Colorado	32.6	37.6	18.2	12.6
Virgin		31.7	31.9	28.6
Boulder	108.6	126.6	115.0	132.4
Gila	79.1	69.8	71.7	69.3
Lower basin	82.2	84.0	78.8	75.2

part owners (those renting a portion of the farm lands they harvest), operated only one-tenth of all farms, but farmed more than one-third of all the crop land harvested in 1940. Owner-operators made up the rest of the farmers and represent the largest group, harvesting nearly 50 percent of the crop land in 1940 (fig. 10).

While the extent of farm leasing in the lower basin is below the national average, it presents a problem in certain irrigated sections of the basin, mainly because the terms of the individual leases fail to make provision for preserving the productivity of the soil and for the upkeep of improvements on the farms. Land that has been in alfalfa for a number of years, however, is often leased to vegetable growers for a period of 1 to 3 years, the plan being to replant to a soil-building crop after the lease has expired.

Value of farm lands and buildings.—Land values vary widely depending upon location, soil quality, topography, water supply and other factors. Raw land, without prospective irrigation possibilities usually sells for $1 to $10 an acre. Irrigated land sells for $100 to $250 an acre with the higher prices more common in the Boulder and Gila divisions.

The decrease in the total value of all farm land and farm buildings from 1930 to 1940 was 24.2 percent, as compared with 29.7 percent for the entire country. The average value per farm of all land and buildings in the basin is 50 percent above the average for the United States, while in the Gila and Boulder divisions, the average farm value is twice that of the entire country.

TABLE XXII.—*Value of farm lands and buildings in lower basin*

Division	Average value of lands and buildings					
	1930		1935		1940	
	Per farm	Per acre	Per farm	Per acre	Per farm	Per acre
Little Colorado	$2,446.00	$3.00	$1,831.00	$2.97	$2,090.00	$1.39
Virgin	6,036.00	20.57	4,169.00	12.63	4,770.00	7.97
Boulder	18,457.00	70.29	10,346.00	41.98	11,057.00	12.43
Gila	15,593.00	16.92	8,478.00	9.12	11,644.00	9.91
Lower basin	13,474.00	19.33	7,246.00	10.56	8,389.00	7.07
United States	7,614.00	48.52	4,823.00	31.16	5,518.00	31.71

The decrease in the per-acre land values during the 1930 to 1940 period is attributed to a number of factors. Agricultural prices declined during this period which was one of the major economic depressions. Considerable land of much lower value than that previously farmed was purchased. The acreage of farm land doubled during this period, whereas the total number of farms increased from 21,193 to 25,795, an increase of only 17 percent; consequently the value per acre of farm improvements was not in proportion to the increase in acreage.

Land values have risen since the 1940 census was taken, and in many sections of the lower basin a land boom is under way. Lands in financial distress 10 years ago now are selling generally at double and treble the prices of 1933 to 1935.

Farm products and value.—The basin is favored by a climate ideal for producing winter crops. Citrus fruits and winter vegetables returned $3,800,000 and $7,300,000 respectively to the farmers of the basin in 1939. During the months of December and January the country is largely dependent for its supply of lettuce on Arizona and the Imperial Valley of southern California. In 1943 the Salt River and Yuma Valleys in Arizona shipped 6,600 carloads of winter lettuce, shipments being consigned to 45 of the 48 States. In 1939 the per capita value of farm products of the basin was $97, as compared with $75 in the Nation.

Livestock and livestock products sold in 1939 made up 36.7 percent of all agricultural production in the basin, as compared with 35.5 percent for the entire Nation. Feeder cattle, sheep, and goats are the predominating livestock. Only a few hogs are raised in the area. An increase in production of feed crops may result in a considerable increase in the proportionate value of livestock and livestock products.

The sale of dairy products is important in some irrigated areas. Dairying probably will increase, but it is doubtful that it will ever assume the importance in the agriculture of the basin that it does in agriculture of the Nation as a whole.

Farmers and stockmen of the lower basin consume in their homes only half as much of their farm products as do the average farmers of the Nation. Agriculture is less diversified here and a smaller variety of products is suitable for home consumption.

TABLE XXIII.—*Value of agricultural products in lower basin (1939)*

Items	Lower basin		United States	
	Value	Percent of total	Value	Percent of total
Sold:				
Livestock and livestock products	$22, 835, 000	36. 7	$2, 429, 289, 000	31. 3
Dairy products	4, 295, 000	6. 9	1, 118, 193, 000	14. 4
Crops	31, 506, 000	50. 7	3, 094, 947, 000	39. 8
Farm products used by farm household	3, 534, 000	5. 7	1, 132, 063, 000	14. 5

MINERALS AND MINING

The first white settlers in the lower basin were adventurers, many of whom originally had set out to seek gold in California. It was natural that they should prospect the region through which they traveled. Significant gold and silver strikes were made in the 1880's. These strikes led to booms with their attendant influx of people. But the mining industry, as developed in the last century, was a precarious business. There was no orderly development, no scientific method of locating ore deposits, or any attempt at establishing this major resource as the basis of a stable industry. Numerous ghost towns throughout the entire area give mute testimony to the feverish and impetuous exploitation of the ore resources.

Today, mining and mineral resources are of vital importance to the region, but attitudes and methods have changed. Emphasis is now upon sound planning and development with full utilization of modern scientific knowledge and methods.

Valuable minerals are well distributed, and important mining operations are found in many parts of the lower basin. (See appendix, maps entitled "Mineral Resources, Colorado River Basin.") Mining camps are markets for farm crops, and mines consume large quantities of the lumber produced by local lumber mills. The transportation of ore, metals, and mining supplies is one of the main sources of revenue for railroads and trucking companies. Mining properties furnish one of the principal tax sources for State and local governments. Mining enterprises provide employment for many of the residents and have made possible the development and improvement of many isolated and remote areas.

Of all minerals mined in the lower basin, copper is most important. Each year, since 1910, Arizona has ranked first among the States in copper production, and probably will continue to hold such rank for many years. Large mines are operated at Bisbee, Morenci, Superior, Globe, Miami, Ray, Ajo, and Jerome, Ariz. The remaining copper deposits have been estimated to contain about 23 billion pounds which could be recovered at costs ranging from 6 to 18 cents per pound. The largest reserve of ore in the basin is found at Morenci, Ariz., where proven future supplies total 300 million tons of ore containing from 20 to 25 pounds of copper per ton. (See figs. 11 and 12.)

Gold ranks second in annual gross income from mining in the lower basin. About 50 percent of the gold produced is recovered as a byproduct of copper ores. The largest known reserves of gold are found in ores primarily valuable for their base metals. Mines in high-grade ore districts have been sporadic in production, their output fluctuating with prevailing market conditions. The Delmar, Nev., district, the largest of the straight gold-and-silver-producing areas, produced in 1940 minerals valued at $130,700. Little commercial grade ore remains in any of the known gold-ore deposits.

Silver is third in importance as a source of income from mining. About 75 percent of the silver produced comes from copper ores, and a large part of the remainder is produced as a byproduct of the lead and zinc mining industry.

Zinc production is handicapped by the distance to zinc smelters. High shipping costs make the development of low-grade ore deposits difficult and sometimes impossible. Zinc deposits are generally associated with lead or copper. The largest zinc ore reserves are in copper deposits but these are low-grade, and mining and milling costs are high. From the standpoint of production costs, the most important zinc reserves are those associated with lead. One of the largest of these is found in Mojave County near Boulder Dam. The construction of an electrolytic treatment plant in this district, using low-cost power developed at Boulder Dam, would greatly stimulate zinc production. Considerable amounts of zinc ore are produced in the Superior, Patagonia, Nogales, Bisbee, Iron King, Mammoth, Hillside, and San Xavier districts of Arizona, and the San Simon and Lordsburg districts of New Mexico.

LOWER COLORADO RIVER BASIN

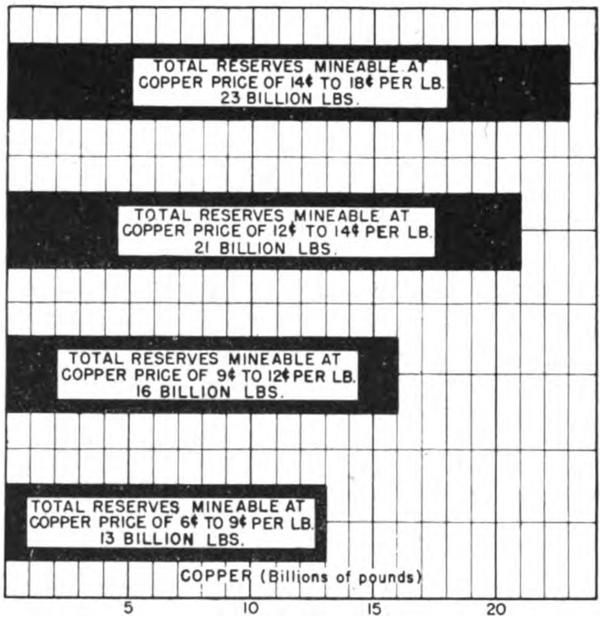


FIGURE 11.—*Estimated reserves of copper in the major mining districts.*

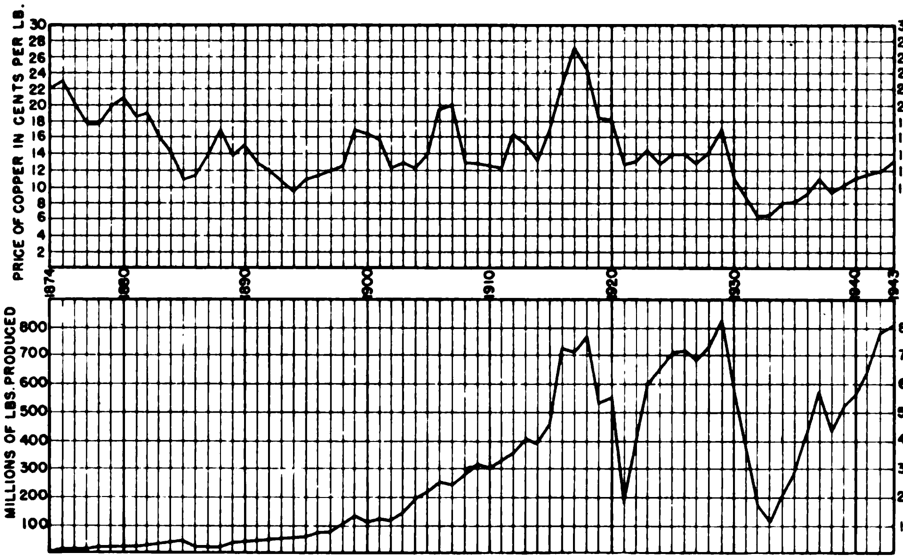


FIGURE 12.—*Copper production from principal mining districts.*

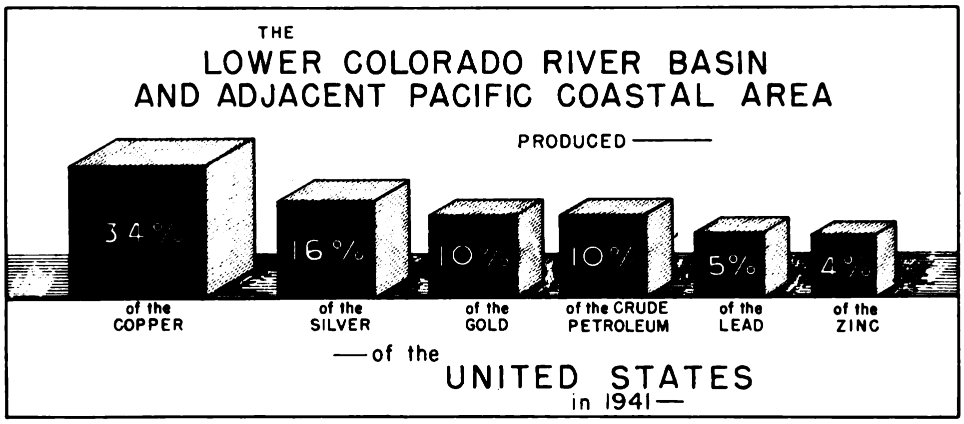


FIGURE 13.—*Mineral production in lower basin and southern California.*

Lead is produced in moderate quantities at various districts, notably Patagonia, Mammoth, Iron King, Bisbee, Cerbat Mountain, Hayden, and San Xavier in Arizona; Pinos Altos, Steeple Rock, Lordsburg, and San Simon in New Mexico; and the Goodsprings district in Nevada. (See fig. 13.)

TABLE XXIV.—*Gross value of principal metals mined in lower basin*

Metal	1941 production	Total production
Copper	$77, 910, 000	$2, 840, 000, 000
Gold	11, 652, 000	247, 550, 000
Silver	5, 904, 000	198, 450, 000
Zinc	2, 562, 000	19, 140, 000
Lead	1, 804, 000	32, 500, 000
Total	99, 832, 000	3, 337, 640, 000

Production of cobalt, mercury, manganese, vanadium, molybdenum, and asbestos was greatly stimulated by war conditions. Cobalt is mined in the Tombstone, Ariz., area; mercury in the Ord district of the Mazatzal Mountains, Ariz.; manganese in the Bisbee, Ariz., region; vanadium in the Mammoth district of Arizona; molybdenum in the Mammoth and Globe-Miami districts of Arizona; and asbestos in Gila County, Ariz.

Several manganese ore bodies are found in the area, the most extensive being located in the Artillery Peak district of Arizona and in the Three Kids mine near Las Vegas, Nev. Both of these areas were large producers during World War II. This country's largest manganese mine is located near Las Vegas.

Coal is known to occur at several locations. Small amounts are mined for local consumption, but deposits have proved too poor in grade to compete with the higher grade coals mined in New Mexico and Colorado. Subbituminous grade coal is found in the Kolob-Kanab district of Iron and Kane Counties, Utah. To date, coal mining has been on a very small scale, and development work has not been extensive enough to determine the reserves available.

Limestone and gypsum are mined in the lower basin. Important deposits of various salts are found in many of the dry lake beds of Nevada and California. Deposits of silica sand near Overton, Nev., are mined and shipped to the west coast for use in glass manufacturing. Numerous other minerals, including alunite, magnesite, clay diatomite, bentonite, borates, calcium chloride, and petroleum, are mined commercially on a comparatively small scale in the basin.

Adjacent to the lower basin are southern California's petroleum and natural gas fields, among the largest in the country. The gross value of production from these fields during 1942 is shown in the following table:

TABLE XXV.—*Natural gas and petroleum produced in southern California (1942)*

County	Value of total production		
	Natural gas	Gasoline	Crude oil
Los Angeles	$6, 186, 796	$11, 598, 193	$90, 620, 837
Orange	1, 293, 338	2, 048, 105	25, 457, 382
Ventura	2, 180, 252	2, 602, 076	20, 148, 305
Total	9, 660, 386	16, 248, 374	136, 228, 524

Recently developed electrometallurgical processes should greatly stimulate the mining industry of the region if sufficient low-cost power becomes available. Large and important ore deposits of various grades are yet to be mined. Development of the lower grade deposits, hitherto economically impracticable, will become feasible with low-cost power. Several large zinc deposits of medium or better grade, which are not at present being worked because of high transportation costs to distant ore treatment plants, could be developed with low-cost power.

The possibility of discovering new ore deposits should not be overlooked. Technical advances in prospecting methods are continually being made. Vast areas underlying the numerous alluvium-filled basins and valleys of the region are impossible to prospect by present methods and offer a promising field for the discovery of new deposits of valuable ores.

Industrial research organizations are discovering and developing new uses for mineral products and other petroleum products and derivatives.

MANUFACTURING AND OTHER INDUSTRIES

The lower basin has been almost totally dependent upon outside areas for manufactured goods. In the last thirty years a rapid growth in population and an increase in transportation facilities and supplies of low-cost electric energy have been conducive to industrial development.

In 1940 one-half of the manufacturing establishments were engaged in processing food products. These included meat packing, poultry packing, flour milling, icecream making, fruit packing, fruit and vegetable canning, and dairy processing plants. Cotton gins, cottonseed-oil mills, and breweries also operated in the region.

Twenty-two plants were dependent upon the forest for raw materials. In this group were 12 sawmills, 5 planing mills, and 5 veneer mills. Twenty-four establishments manufactured household furniture and furnishings. Twenty-five plants manufactured brick, hollow tile, cement, and concrete products. Three plants processed cotton products and three plants manufactured machine tools. Various other smaller manufacturing plants were operating.

World War II was responsible for the development of large industries in the lower basin. Las Vegas, Nev., was the center of much such activity. The world's largest magnesium plant was located within the trading area of that city. The manufacture of industrial tools and implements for war increased greatly during the war period. Several manufacturing industries were established near Phoenix, Ariz., including an aluminum fabricating plant and an airplane factory. An airplane assembly plant was located at Tucson. Construction of an arsenal near Flagstaff created a temporary boom. Small military establishments, such as the naval training air base at Holbrook, caused local temporary prosperity. The wartime demand for wood increased the tempo of lumbering operations. War prices for food increased the farm income.

Very little industrial utilization of the metallic minerals produced in the lower basin is made within the area. Practically all metals mined locally are shipped for refinement and fabrication to plants located in other States. Some of the nonmetallic minerals producer, however, are treated and utilized by local industries. Plaster is manufactured at Douglas, Ariz., from gypsum mined in the Sulphur Springs Valley. Limestone is roasted at several plants, and the lime produced is marketed throughout the region. Much of the common brick used by the construction industry is manufactured at various local brickyards.

Lumbering operations are important in the vicinity of Flagstaff, where 1,500 persons are thus employed. A lumber mill with an annual capacity of one hundred million board feet is located at McNary, Ariz. Forests in this region are practically all under the jurisdiction of the United States Forest Service, and therefore, the available resources can be expected to remain fairly constant.

Indian arts, such as weaving and silversmithing, furnish an important source of income to the native craftsmen and to curio shops.

Another industry of considerable importance, which depends on and assists with the marketing of the fruit and vegetable crop, is the manufacture of ice. Within the lower basin several ice plants, including one specializing in dry ice, furnish refrigeration for produce en route to market.

The few factories normally located in the region produce chiefly either materials used in agriculture or mining or commodities for local markets. These manufactured products include dynamite, boxes and crates, saddles and harnesses, concrete pipe, fabricated steel, auto radiators, storage batteries, paint and varnish, and air-conditioning equipment.

Probably one reason for the lack of extensive industrial development in the lower basin is its proximity to numerous factories in the southern California coastal region where natural advantages such as seaports and low-cost fuel supplies have aided the development of extensive industries.

In the last two decades the nearby Los Angeles metropolitan area has become one of the Nation's principal manufacturing centers. The six counties which comprise the southern California area are engaged in virtually every line of manufacturing. In 1940 this region had 6,254 manufacturing establishments and employed 139,287 wage earners. In number of establishments the processing of food ranks first, there being more than 1,200 such plants. Nearly 500 factories manufactured household furnishings and appliances.

The Nation's largest airplane factories were located in southern California during the war.

The refining of petroleum is by far the most important of the industries related to or dependent on mining. The many crude oil derivatives obtainable by refining have made the petroleum business an activity of considerable scope. Petroleum products produced in southern California include gasoline, synthetic rubber, tar, asphalt, toluene, phenol, paint bases, solvents, fertilizers, alcohols, acetic acid, formaldehyde, ammonia, and many others.

Another important mineral industry in the southern California region is the manufacture of Portland cement. During 1942 the 5 cement mills operating in the area shipped a total of 11,582,051 barrels to markets scattered throughout southwestern United States.

Large quantities of hollow tile and brick are produced in southern California plants. Varieties of brick are manufactured and sold throughout the State and in contiguous areas of the lower basin. Other construction materials produced include lime, sand, gravel, and crushed rock.

Many industries found in the coastal region of southern California are based on raw materials from the lower basin.

Markets and Transportation

Trading and shipping centers are well distributed throughout the agricultural areas of the lower basin and provide convenient outlets for crops and livestock.

Forage crops such as alfalfa generally cannot be shipped out of the basin economically because of the transportation charges. The extensive local livestock-raising industry creates a great demand for these crops and prices are generally based on the prevailing price at Phoenix plus trucking costs. Alfalfa hay not fed locally to livestock is sold in Los Angeles and in San Diego.

Livestock is marketed mostly on the hoof and shipped to feeding pens located either in the southern part of Arizona or in States outside the basin. Finished feeders are shipped to Los Angeles and San Diego.

Larger towns such as Flagstaff, Holbrook, and Winslow, Ariz., provide a limited market for vegetables and prod-

TABLE XXVI.—*Manufacturing census data—Lower basin and Southern California (1939)*

Division	Number of employees engaged	Value of raw materials	Value of processed products	Value added by processing
Little Colorado	976	$587, 000	$1, 665, 000	$1, 078, 000
Virgin	16	37, 000	92, 000	55, 000
Boulder	1, 151	4, 864, 000	9, 869, 000	5, 005, 000
Gila	4, 630	16, 448, 000	27, 031, 000	10, 583, 000
Lower basin	6, 773	21, 936, 000	38, 657, 000	16, 721, 000
Southern California	139, 287	758, 716, 000	1, 325, 803, 000	567, 087, 000
Total	146, 060	780, 652, 000	1, 364, 460, 000	583, 808, 000
United States		32, 160, 107, 000	56, 823, 025, 000	24, 662, 918, 000
Percent lower basin is of United States total		0. 07	0. 07	0. 07
Percent lower basin and Southern California is of United States total		2. 43	2. 40	2. 37

uce. Additional markets for summer vegetables can be found in the southern portions of the State where the climate is too warm to permit successful truck gardening during the hotter months. Local mining districts provide valuable markets for dairy and poultry products and vegetables. Winter and summer vegetables are shipped mostly to the east and west coasts, with Los Angeles and San Francisco as the chief outlets. Bermuda and alfalfa seeds are shipped to the Southern States. Flaxseed is sent to Los Angeles to be processed for oil. Citrus fruits are marketed throughout the country. Small fruits, of which the date is the most important, are sold mainly in the Los Angeles area, but part of the crop has a ready market in the midwestern and eastern cities. Dairy products not consumed locally are shipped to the Los Angeles area. Before World War II, much of the short-staple cotton produced in the region was shipped to Japan.

East and west railroad transportation throughout the basin is handled well considering the vast, sparsely settled area involved. The basin is crossed by the Atchison, Topeka & Santa Fe Railway and in the extreme southern part by the main line of the Southern Pacific Railroad. Branch lines of each of these railroads serve the major mining and irrigated areas. The main line of the Union Pacific Railroad connecting Salt Lake City and Los Angeles crosses the basin in a north and south direction, with branch lines extending from Caliente to Pioche and from Moapa to Overton.

A system of United States highways and State roads connects the more important population centers. Highways for east and west travel in general follow the railroads: U. S. 66 crosses the northern part; U. S. 60 and 70 cross the central part; and U. S. 80 serves the southern part. These are paved, well maintained, and open to travel the year round. North-south highways include U. S. 91 extending from Salt Lake City through the basin to Los Angeles and U. S. 89 from Salt Lake City to southern Arizona. U. S. 666 south of Springerville, Ariz., is one of the most scenic roads in the world and is known as the Coronado Trail. A network of unimproved roads leads to ranches and smaller population centers, but many are impassable during wet weather, and sandy stretches make automotive travel difficult during droughts. A great part of the basin is accessible only by foot travel or by horseback. Transcontinental truck and bus lines, American Air Lines, and Transcontinental Western Air Lines pass through or over various farming districts and towns in the lower basin.

WHOLESALE AND RETAIL TRADE

In 1939 the lower basin and southern California together had 4.29 percent of the Nation's retail and 3.47 percent of the Nation's wholesale trade. In all of the divisions retail trade exceeded wholesale trade, but in the southern California area wholesale trade exceeded retail trade.

TABLE XXVII.—*Wholesale and retail trade—Lower basin and Southern California (1939)*

Division	Wholesale trade		Retail trade	
	Value	Percent of United States	Value	Percent of United States
Little Colorado	$6, 079, 220	0. 011	$16, 396, 298	0. 039
Virgin	1, 657, 969	. 003	6, 306, 269	. 015
Boulder	41, 449, 230	. 075	39, 519, 283	. 094
Gila	88, 425, 024	. 160	137, 056, 235	. 326
Lower basin	137, 611, 443	. 249	199, 278, 085	. 474
Southern California	1, 780, 106, 264	3. 221	1, 603, 053, 452	3. 813
United States	55, 265, 640, 000		42, 041, 790, 000	

The lower basin and each division show a higher per capita expenditure in retail than in wholesale trade. In the southern California area the per capita wholesale expenditures exceed retail trade expenditures. The Little Colorado was the only division in the lower basin which did not exceed the national average per capita expenditure in retail trade.

TABLE XXVIII.—*Expenditures in trade—Lower basin and Southern California (1939)*

Division	Per capita expenditure	
	Wholesale trade	Retail trade
Little Colorado	$81. 68	$218. 80
Virgin	104. 80	363. 68
Boulder	246. 85	409. 47
Gila	214. 38	333. 02
Lower basin	202. 10	331. 93
Southern California	505. 30	454. 84
United States	419. 57	319. 29

RECREATION

The scenic beauty of the lower basin had been recognized long before its other resources were developed or stabilized. This region of high mountains, deep canyons, colorful deserts, and thousands of square miles of scenic wilderness has drawn millions of tourists to view its natural majesty and to enjoy its delightful climate in winter. Twenty-one national parks and monuments and 13 national forests are located in the area. The Grand Canyon, Petrified Forest, and Zion Canyon, to mention only a few, enjoy world renown.

Within the last decade the area has acquired a man-made attraction—Boulder Dam with its recreational area—which rivals all of its natural wonders and which symbolizes man's conquest of nature's fickleness. This dam impounds the world's largest man-made lake. Lake Mead extends 115 miles upstream from the dam, through canyons, cliffs, and scorching deserts into the lower reaches of Grand Canyon and opens to the tourist scenic beauty hitherto inaccessible. The Boulder Dam National Recreational Area, located hundreds of miles from any large metropolitan center, has become a tourist mecca and before World War II ranked sixth among the national parks and monuments in the United States in the number of visitors.

Zion National Park attracts tourists from all parts of the country. The unique colorful scenery in this area is used by the moving-picture industries as a setting for "Western" and other pictures. Through technicolor films, the matchless desert beauty near Kanab, Utah, has become familiar wherever motion pictures are shown.

The Little Colorado River Basin is almost entirely within a spectacular scenic area locally known as "The Enchanted Circle." The fantastically-colored Painted Desert and Petrified Forest are within this basin, and tourist travel is heavy to these wonderlands. Other popular attractions in this vicinity are the Sunset Crater, an extinct volcano which becomes a riot of color at sunset; the San Francisco Peaks, frequently snow-capped, which tower over the surrounding countryside; and the Meteor Crater, formed by the impact of a meteorite during some past age. At Grand Falls, when the Little Colorado River is in flood stage, one may see a chocolate-colored river plunge 185 feet into the canyon below.

In the Gila River Basin popular attractions include Casa Grande, Montezuma Castle, Tonto, Tuzigoot, and Gila National Monuments; saguaro and organ pipe cacti; spectacular rock formations at Chiricahua, New Mexico; and the early Spanish mission church at Tumacacori, Ariz. Prescott, Tonto, Apache, Crook, Gila and Coronado National forests are located in this area.

Trips to the Indian reservations yield a glimpse into the lives of a people who have carried many of the ways of their prehistoric ancestors down to the present day. The various ceremonial dances of these natives are especially interesting to the eastern visitor. Wupatki National Monument and Walnut Canyon, Ariz., are sites of numerous, fascinating, prehistoric Indian ruins. El Morro National Monument, the great rock where early Spanish explorers carved their names is located near Gallup, New Mexico. Prehistoric dinosaurs have left their tracks in stone 60 miles north of Flagstaff.

The waters of the Colorado River, detained at intervals in man-made lakes, teem with fish of many types. Bass, crappie, and bluegills abound in the reservoirs while trout and catfish prefer the moving waters of the main channel. Lake Mead is a fisherman's paradise. Reservoirs on the Gila River and its tributaries are kept well stocked with fish from numerous fish hatcheries in the region and most of the clear, cold streams in the mountain areas contain rainbow, Loch Leven, and other trout. Upper reaches of certain small tributaries of the Virgin River provide suitable environment for trout and offer limited fishing for recreation, but the main stem of the Virgin River, Kanab Creek, and Muddy River do not contain fish because of intermittent flows, silt-laden freshets, or the mineral content of the waters.

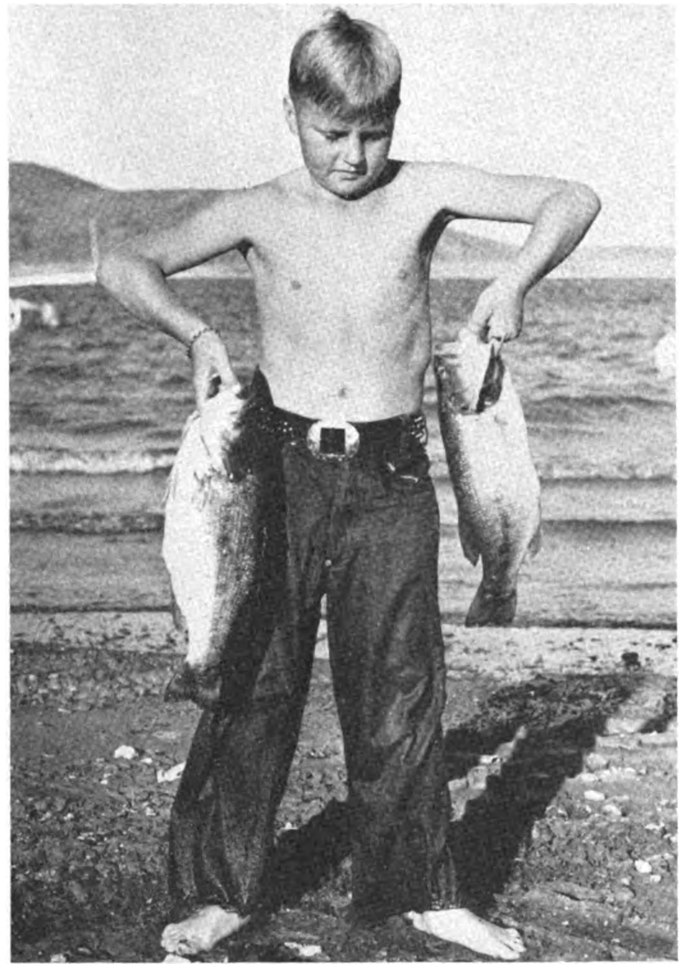
Game abound in both the valley and mountain regions. The sportsman finds a plentiful supply of such big game as deer, elk, and bear in the forested and more primitive areas, and all of these animals may be hunted legally during certain seasons. Mountain lions, coyotes, and other predatory animals are fairly common in remote areas and may be hunted the year round. Numerous species of small game attract many local hunters. Game birds found in the basin include the wild turkey, duck, goose, snipe, white-wing pigeon, quail, and dove. Five national game refuges are located partly or wholly within the lower basin for the protection and propagation of wild-life.

The National Park Service has done a great deal toward preservation of the natural and artificial wonderlands for the education and enjoyment of future generations. The Forest Service is improving lakes in the vicinity of Flagstaff to enhance their value for boating, fishing, and swimming.

Recreation is a major industry of growing importance in the lower basin. Numerous hotels, auto courts, restaurants, dude ranches, and curio shops depend almost wholly on tourist trade. Gasoline and service stations, automotive accessory stores, and similar establishments are partially dependent upon the touring public. Airlines, railroads, bus lines, and highways derive much of their annual traffic from tourist travel. In 1938, an average year, the Governor of Arizona placed a value of $80,000,000 on the State's tourist industry. The same year tourist trade in southern California was valued at $194,684,000.

SUMMARY—COLORADO RIVER BASIN

This review of present economic developments in the Colorado River Basin points to the serious need for additional development of water and land resources. In some regions nature provides water in such abundance that it is taken for granted, but here in the Colorado River Basin people look to the fluctuating annual supply as the most accurate index to their prosperity.



ANGLER'S PRIDE

Lake Mead is called the "Eden of all bass fishermen"

SKIING ON SURVEYOR PEAK

High snow-capped mountains provide excellent winter sports areas

HIVES OF BEES IN DATE GROVE
An irrigated date grove is a sweet setting for honey bees

ATTRACTIVE HOME ON IRRIGATED FARM
Opportunities will be provided for many new farm homes for veterans and others

Agriculturally the basin has advanced to the limit of its controlled water supply with only about 1.7 percent of its total area, or 2,676,000 acres, under irrigation. Of this irrigated area 1,325,000 acres are in the upper basin and slightly more, 1,351,000 acres, are in the lower basin. Millions of acres of dry fertile lands yet are idle and most irrigated areas are not producing maximum yields because of water shortages, while at the same time flood waters still uncontrolled flow destructively to the Pacific Ocean and are lost for beneficial use. Control of these waters will require cooperative planning and systematic development involving construction of huge structures, mostly beyond the financial range of private enterprise.

Much of the vast range can never be irrigated but its sparse vegetation will always be a major base of the basin's economy. Over-grazing and unseasonal use of the range are preventing optimum utilization of range land and are causing destructive floods and wasteful erosion of top soil. The production of more hay and other forage on irrigated land for pen and winter feeding will permit maximum utilization of the range, protect livestock against severe winters, permit expansion of dairying and livestock operations, and, in general, increase and stabilize the livestock industry. More people thus could obtain a prosperous livelihood from the industry, and the Nation would be rewarded with more beef and mutton, hides, wool, and dairy products.

Lack of sufficient water is responsible for crop failures and low yields. In areas where cash crops are grown, increased and dependable water supplies will make possible higher yields on lands now irrigated, prevent crop failures, make possible an increase in the cropped acreage and permit farmers to diversify and intensify farming operations. The products of these farms—peaches, apples, citrus fruits, summer and winter vegetables, seeds, sorghums, and other crops—will be readily absorbed in the American market. As a result farm income will be increased and farmers will enjoy security, stability, greater prosperity, and a higher standard of living.

Many farms in the basin are too small for efficient operation. This condition has resulted mainly from subdividing holdings through inheritance, and from the purchase of tracts too small for economic units. An increase in the irrigated acreage will make possible larger farm units and thus reduce the number of part-time farmers in the upper basin forced to seek supplemental employment away from the farms and the number of subsistence farms in the lower basin.

At present there is not enough irrigated land to provide agricultural opportunities to those in the basin who would like to farm. Of the 39,145 farms in the basin, 20,677 are in the upper basin and 18,468 are in the lower basin. The irrigation of desert lands will provide many new farms for servicemen, industrial workers, and others who wish to establish themselves in the basin. Consequently fewer young people will be forced to migrate elsewhere, and to some degree the temporary population influx into the lower basin and southern California areas during the war period will be absorbed permanently into the economic structure of the basin.

Development of vast mineral resources of the Colorado River Basin is awaiting low-cost power. In mineral wealth—coal, oil, oil shale, natural gas, copper, gold, silver, phosphate, magnesium and numerous others—the basin is unsurpassed. The need for these buried treasures is growing. Power necessary for additional mineral development can be supplied by the construction of multiple-purpose dams that will serve irrigation and other beneficial uses.

Need for improvement in domestic water facilities is becoming pressing in some areas and additional water supplies are needed also for expansion of many existing industries and the development of new industries.

Lack of transportation facilities, particularly in the upper basin, is hampering the livestock industry. With the expansion of agriculture and other industries in the basin, transportation facilities will be extended to serve areas now remote and isolated.

It is apparent that full control and utilization of the water of the Colorado River system is necessary for additional and continual growth in the basin. It will bring greater prosperity to people living within the basin and provide opportunities for others who are yet to come. Living conditions will be bettered, a broader tax base will be established, and at the same time, the need for public expenditures for relief of unemployment will diminish. A greater population in the basin will bring a solution of many of the economic and social problems now resulting from extremely sparse settlement.

It is well established in this day when goods and services are freely interchanged among the many parts of the Nation and the world, that prosperity cannot be isolated. Prosperity in the Colorado River Basin brought by full development of water and land resources will have a stimulating beneficial effect on the economy of the entire country.

Using the Water

"This chapter describes the nature and extent of present water uses in the Colorado River Basin and outlines potential projects for beneficial use of all of the water of the entire river system.

"All beneficial uses, including the irrigation of land, the production of hydroelectric power, the preservation of fish and wildlife, and the enhancement of recreational areas, together with the control of floods and silt, and the restoration of ground-water levels were taken into account in formulating the potential projects."

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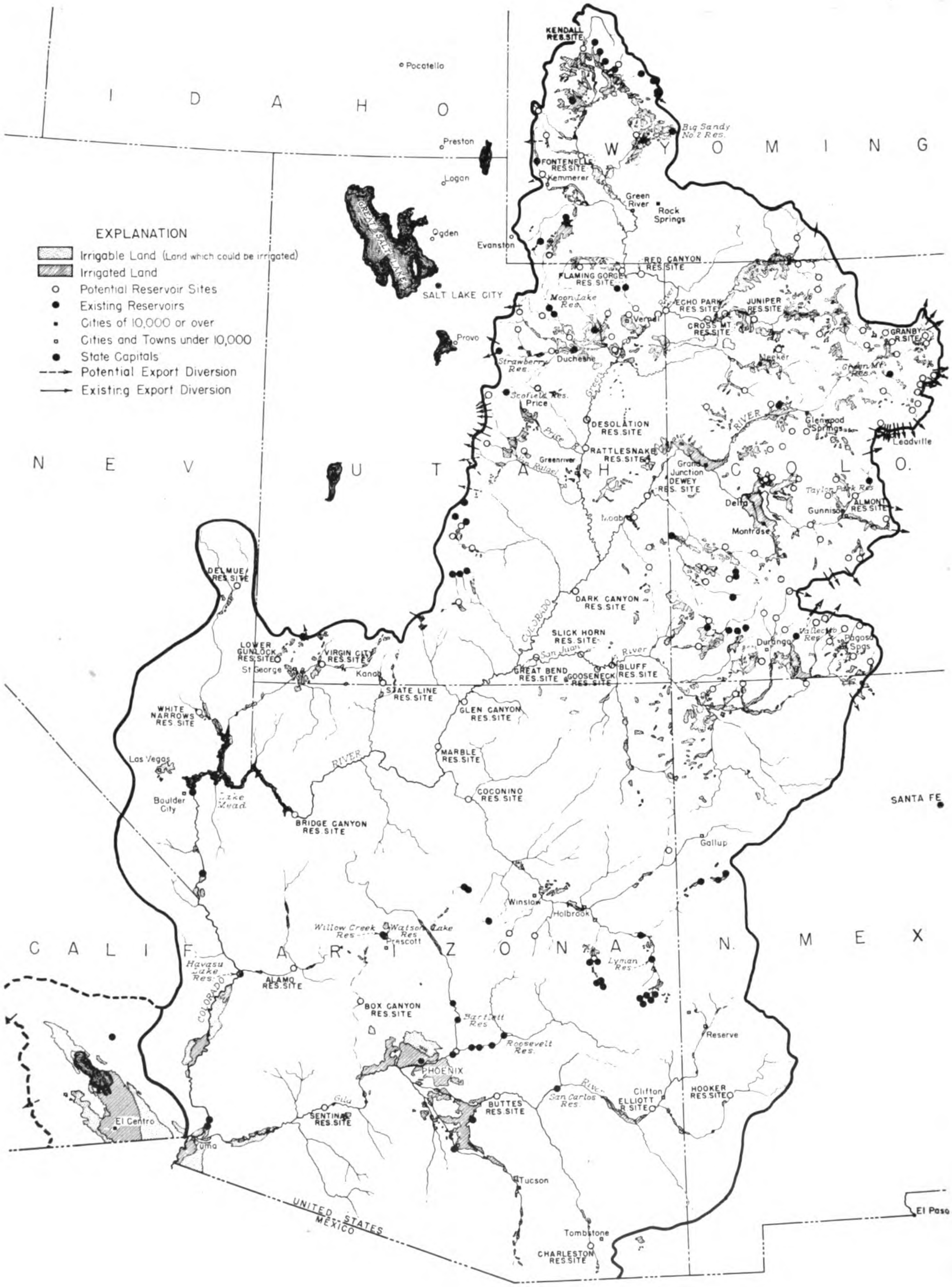


Irrigation development, Colorado River Basin

CHAPTER V

Using the Water

More water—water from the Colorado River—is the hope of the future. Man cannot govern the amount of water that falls as rain and snow, but he can prevent its needless waste by careful planning and building of dams, canals, power plants, and other works that will so control and conserve it that more water will be available for his use.

A survey of the basin's resources and economic activities not only establishes water as the critical material—the most important natural resource—but focuses attention on what present use is being made of that precious material and how it can best be used in the future to serve man's various needs.

This chapter describes the nature and extent of present water uses in the Colorado River Basin and outlines potential projects for beneficial use of all the water of the entire river system. Such a basin-wide perspective of ultimate potentialities will provide for planning coordinated development on a sound basis. All beneficial uses, including the irrigation of land, the production of hydroelectric power, the preservation of fish and wildlife, and the enhancement of recreational areas, together with the control of floods and silt, and the restoration of ground-water levels were taken into account in formulating the potential projects. Domestic, municipal, and industrial water supplies are planned for a few areas where demands are now established, and adaptations for other such uses may be made as needs arise.

The construction of all potential projects described and their operation, added to present water uses, would create a demand for more water than normally is available in the river system. Certain of the projects are key units or for other reasons hold initial preference in the plan of ultimate development. Those could be constructed at once as the next phase of river control and utilization. Later selection of projects will be influenced by more complete surveys, cost estimates, stream flow records, and by agreement among the respective States as to the allocation of the water which has already been apportioned between the upper and lower basins.

Estimates of present depletions of the water supply of the Colorado River and of future depletions from construction of potential projects are based on average flows during the long-time period of record, 1897 to 1943 inclusive. Depletions are considered to be the reductions in virgin stream flow of the Colorado River at Lee Ferry and at the international boundary resulting from man-made improvements.

The upper and lower basins are discussed separately and each is further divided, to permit more detailed treatment of specific areas, into the divisions suggested by physical characteristics: the Green, Grand, and San Juan divisions in the upper basin, and the Little Colorado, Virgin, Boulder, and Gila divisions in the lower basin. (See chapter I.)

State maps, one for each of the seven Colorado River Basin States, entitled "Water Resources Development, Colorado River Basin," showing the location of irrigated and irrigable lands, existing and potential reservoir sites, main canals, and other features of existing and potential projects for the development of water resources, are included as an appendix of this report.

UPPER BASIN

An area larger than New York, Pennsylvania, and New Jersey combined, is tributary to the Colorado River above Lee Ferry. This is the Upper Colorado Basin. It includes parts of five Rocky Mountain States. Rimmed by some of the highest mountains in America, snowcapped throughout the year, it is the source of the greater part of the water reaching the Colorado River.

Within the basin 1,325,000 acres are now irrigated. Much of this irrigated acreage produces pasture grasses and hay and serves as a home base for livestock grazing on the vastly larger areas of range and forest land. Some irrigated lands, however, are devoted to more intensive farming with vegetables and fruits as chief crops. The construction of potential projects outlined in this chapter would practically double the upper basin's irrigated area and bring supplemental water to half a million acres now lacking a full supply. These potential projects would bring water to lands determined by land classification to be arable. Vast areas of native pasture lands, mostly at high elevations, were not so classified, but would become more productive under irrigation. These lands have not

Green division of the Colorado River Basin

been surveyed, nor have works been designed by which they might be irrigated, which accounts for their exclusion from specific project plans. To provide for the eventual irrigation of these lands and miscellaneous areas of arable lands not otherwise covered in the basin plan an ultimate depletion in the flow of Colorado River at Lee Ferry of 500,000 acre-feet each year is reserved. It is not possible to divide this potential depletion among the divisions or States of the upper basin.

Scarcely a start has been made in developing the hydroelectric power resources of the upper basin. Present generation of 330 million kilowatt-hours annually could be increased 28 times with full development of water resources in the basin.

The exportation of water for use in adjoining basins, now averaging only about 184,000 acre-feet annually, is only 6 percent of ultimate potentialities, if it were not for limitations of the Colorado River Compact. In presenting possible exportations of water from the upper basin to the adjoining North Platte, South Platte, Arkansas, Rio Grande, and Bonneville Basins it is contemplated that appropriate understandings will be reached between representatives of both the exporting and importing basins concerning the manner in which such projects shall be constructed and operated to safeguard within the upper basin the vested and future rights in irrigation; to preserve fishing and recreational facilities and scenic attractions; to maintain conditions of river flow for the benefit of local domestic uses and sanitary purposes; and to utilize the waters for irrigation, power, industrial development and other purposes, in such a manner that the greatest benefits are realized.

Green Division

The Green River drains 45,000 square miles in Wyoming, Utah, and Colorado. Its drainage area is 70 percent larger than that of the Colorado River above their junction, but its average annual contribution to the Colorado River is only 44 percent of the combined flows of the two streams at their confluence.

Average annual flows of the Green River and its principal tributaries for the longest period of record and for the 1931-40 decade, the driest period of record, are shown in the following table:

TABLE XXIX.—*Average annual stream flows in the Green division*

Station	Period of record	Average annual flow (acre-ft.)	
		For period of record	For 1931-40 period
Green River at Daniel, Wyo. (Warren Bridge)	1934–43	339, 000	[1] 320, 000
New Fork at Boulder, Wyo.	[2] 1915–43	281, 000	225, 000
Henrys Fork at Linwood, Utah	1929–43	54, 000	44, 000
Green River at Linwood, Utah	1929–43	1, 234, 000	1, 066, 000
Yampa River at Maybell, Colo	1917–43	1, 065, 000	952, 000
Brush Creek at Jensen, Utah	1940–43	16, 000	[1] 15, 000
Ashley Creek at Vernal, Utah	[2] 1915–43	75, 000	58, 000
White River at Watson, Utah	1924–43	549, 000	452, 000
Green River at Green River, Utah	1906–43	4, 902, 000	3, 370, 000
San Rafael River at Tidwell, Utah	1911–18	190, 000	[1] 132, 000

[1] Estimated.
[2] Records not complete.

Flows of the Green River and its tributaries are greatest in the spring when mountain snows are melting. About 60 percent of the annual run-off occurs during April, May, and June. Late summer flows are extremely low. Storage is necessary for regulation of the flood run-off to furnish supplemental water to lands lacking a dependable supply, to provide irrigation water to lands still undeveloped, to permit diversion of surplus water to adjoining basins, and for the production of firm power.

The streams emerge from canyons relatively clear and pure but pick up some alkali in the valleys, especially in late summer when return flows from irrigation are high. Run-off from raw shale beds along LaBarge, Fontenelle, Big Sandy, and Bitter Creeks and Strawberry River carries a fairly high salt concentration, a danger that must be recognized and studied further in planning future development. Heavier concentration may result from expanded irrigation, from increased exportation of pure water from the stream heads, and from reservoir evaporation. Silt is not prevalent enough in streams of the Green River Basin to constitute a serious problem.

Development of ground water resources in the Green River Basin has been limited to a few small wells for stockwatering and domestic uses. Some water obtained from wells is heavily charged with minerals. Neither the quality nor the quantity of ground water now developed is indicative of any substantial use of water from wells for irrigation in the future. Hot springs at Steamboat Springs, Colorado, are the largest of three spring areas in the Yampa River Basin.

PRESENT DEVELOPMENT OF WATER RESOURCES

Irrigation accounts for the greatest use of Green River water at present. Homes, cities, livestock, and industries consume necessary but comparatively small quantities. Five small hydroelectric power installations on tributary streams serve rural areas. Streams and lakes are natural spawning waters for fish, and the mountains and valleys are habitat for wildlife; but little has been done to improve natural conditions.

Irrigation within the Green River Basin commenced in 1854 when Mormon pioneers established old Fort Supply in Wyoming on their immigrant trail and diverted water from Blacks Fork onto adjacent land. From this humble beginning progress has been slow. The short growing season, particularly in the upper Green River Basin in Wyoming, limits the kinds of crops that can be grown successfully. The greater part of the Uinta Basin was established as an Indian reservation in 1861 and lands unoccupied by Indians were not opened to settlement until 1905. The remoteness of much of the basin from railroads has also slowed agricultural progress, but with the growth of highway transportation this disadvantage may largely be overcome.

Approximately 571,000 acres in the Green River Basin are now irrigated and 11,470 acres more will be provided water through works now being constructed. Most of the present use is by simple diversions and easily constructed canals. A large part of these lands suffer late-season water shortages. Some water from tributaries of the Duchesne, Price, and San Rafael Rivers in the Green River Basin is exported westward to the Bonneville Basin in Utah.

Present development of water resources in the Green River division is discussed in more detail under four subdivisions: (1) Upper Green River Basin, (2) Yampa and White River Basins, (3) Uinta Basin, and (4) Price and San Rafael River Basins.

Upper Green River Basin.—This area extends from the headwaters of the Green River down to the Yampa River which enters the main stream from the east in Colorado. It is about 90 percent in Wyoming, with the remainder in Utah and Colorado.

Irrigation development in this area includes numerous community or privately owned ditches and small reservoirs. Ditches divert at frequent intervals along the streams. Most of them have been constructed and are maintained at minimum expense. It is common for farmers to have individual ditches, and in some cases single farms are served by several ditches diverting from a stream at different points. In addition to many small irrigation reservoirs and stock-watering ponds, 17 reservoirs with capacities of 1,000 acre-feet or more, all constructed by private interests, are distributed throughout the basin. Private holdings of irrigated land are large. Most are hay-producing ranches, varying from a few acres to several thousand acres.

The Eden project, being rehabilitated and extended by the Bureau of Reclamation, is the only Federal irrigation project in the upper Green River Basin. As authorized in 1940, the project will furnish a full or supplemental irrigation supply for 20,000 acres. Surplus flows of Big Sandy Creek will be stored in Big Sandy Reservoir No. 2, to have a capacity of 35,000 acre-feet, for use on project lands. With completion of the Eden project, 245,660 acres in the upper Green River Basin will be irrigated.

The seven existing power plants in this subdivision include only one small hydroelectric development with a capacity of 150 kilowatts. Most of the energy is generated at four steamplants and is used largely for coal mining. There are no interconnections with outside systems.

Yampa and White River Basins.—The Yampa and White Rivers, flowing westward and generally parallel, drain the eastern arm of the Green River Basin. The greater part of their drainage basins is in northwestern Colorado and the remainder is in southern Wyoming and eastern Utah.

Within the two basins 117,230 acres are now irrigated. Most of the irrigated lands are along river or creek bottoms, with only a few small areas on benches from 20 to 40 feet above stream beds. Diversions are made through numerous community or privately owned ditches. Water is stored in several small reservoirs, capacities of which total 14,500 acre-feet. These reservoirs have been built at minimum expense to serve lands belonging to only a few operators. Some of the reservoirs have not been used in recent years because their dams were considered unsafe.

A 200-kilowatt power plant at Meeker, Colo., is the only hydroelectric development in these basins. A 4,250-kilowatt plant at McGregor and a 375-kilowatt plant at Meeker, both steam-electric, furnish most of the power used in the area.

Uinta Basin.—The Uinta Basin, as considered in this report, includes areas drained by the Duchesne River, and Ashley, Brush, Willow and Minnie Maud Creeks. The drainage area is entirely in northeastern Utah, and except for the Willow Creek drainage is west of Green River. The Green River channel from the Yampa River to Minnie Maud Creek is considered to be within the Uinta Basin.

Irrigated lands within the Uinta Basin amount to 165,600 acres, most of which is short of late-season water. Indians once owned 77,000 acres of irrigated land in this basin but have sold 25,300 acres. Present regulations prevent sales and limit leases. In 1942 Indians leased 26,200 acres, cultivating only 11,800 acres themselves.

Sixteen Government-built main canals and six small ditches make up the Indian irrigation system, totaling 162 miles of canal and 633 miles of laterals and sublaterals. Indian water rights were established before unoccupied lands in the reservation area were opened to outside settlers. Consequently their primary rights consume all late-season water of the Duchesne River and its tributaries, leaving white-owned lands critically short. In normal years Indian lands receive enough water, but they would profit by storage regulation to provide better seasonal distribution. No storage reservoirs have been constructed for Indian lands.

Throughout the basin white settlers have organized mutual irrigation companies for the purpose of building irrigation works and distributing water. Private diversions are largely limited to tributary streams and springs.

Serving Uinta Basin lands are 28 reservoirs, some very small, with a total storage capacity of 74,000 acre-feet. More than half of this was provided by the Bureau of Reclamation with the construction of the Moon Lake project (1935–38), which includes Moon Lake and Midview Reservoirs. Water from Strawberry Valley Reservoir, constructed in 1913 on Strawberry River as one of the earlier Bureau of Reclamation developments, is exported westward by tunnel to lands in the Bonneville

Basin. The Duchesne Tunnel, to divert water from the Duchesne River to the Bonneville Basin, is now under construction as a unit of the Provo River project. When completed it will export annually an average of 32,000 acre-feet of flood water from the Colorado River Basin.

The four existing power developments include one Diesel and three small hydroelectric plants, with combined capacities of 2,050 kilowatts. There are no connections with plants outside the Uinta Basin.

Price and San Rafael River Basins.—Adjacent to each other, these two basins are in east central Utah. Both the Price and San Rafael Rivers originate on the eastern slope of the Wasatch Mountains and flow southeast in parallel courses to Green River. The Green River channel from Minnie Maud Creek to the Colorado River, for convenience, is considered as a part of the Price and San Rafael Basin area.

Within this area 15,970 acres are irrigated from Price River, 35,250 from San Rafael River and 2,820 acres from Green River, thus aggregating 54,040 acres. At one time 25,000 acres were irrigated from Price River, but poor soil, erosion, and alkali have caused the irrigated area to be reduced to its present size. Any future expansion of irrigation to new areas is expected to be accompanied by abandonment of a less productive area now irrigated.

Natural flows of Price River are supplemented for irrigation by releases from the Scofield Reservoir on Price River. Scofield Dam, constructed by private interests in 1926 to impound 61,000 acre-feet of water, partially failed 2 years later. For safety, storage has since been restricted to 30,000 acre-feet. The Bureau of Reclamation was authorized to replace this dam and in 1943 began construction of a new dam 800 feet downstream. The reservoir formed by this new dam will have a capacity of 73,000 acre-feet of water, 30,000 acre-feet of which will replace the usable capacity behind the old dam, and 8,000 acre-feet will be reserved for fish propagation. The remaining 35,000 acre-feet will be held for a time by the United States and ultimately used to store water for irrigating Price River lands in exchange for other water exported from high tributaries of the Price River to the Bonneville Basin.

Huntington, Cottonwood, and Ferron Creeks are the sources of irrigation supply in the San Rafael Basin, each serving independent areas with irrigation companies distributing the flow of each stream. Storage capacity aggregates 5,875 acre-feet on Huntington Creek and 1,310 acre-feet on Ferron Creek. Late-season water shortages are most acute in the Huntington Creek area where the acreage irrigated is greatest in proportion to the available water. Eleven small projects, including the Sanpete project (Ephräim and Spring City tunnels) constructed by the Bureau of Reclamation, divert flood water westward to the Bonneville Basin.

The lands irrigated directly from Green River are in the vicinity of Green River, Utah, and are served mostly by pumping.

Water piped from tributary streams and springs supplies larger municipalities in the Price and San Rafael River Basins. No electric power is produced. Transmission lines carry power into the area from the Bonneville Basin to the west.

Summary.—The following tables summarize present irrigation developments in the Green division showing the more important reservoirs, areas irrigated, estimated stream depletion by water consumed within the basin, and amounts exported to adjacent basins.

TABLE XXX.—*Irrigation reservoirs in the Green division* [1]

Subdivision and reservoir	Source of water	Location	Capacity (acre-feet)
Upper Green River Basin:			
New Fork Lake	New Fork River	Wyoming	22, 700
Willow Lake	Lake Creek	do	15, 120
Boulder Lake	Boulder Creek	do	12, 820
Eden No. 1	Big and Little Sandy Creeks	do	12, 300
Big Sandy No. 2 [2]	Big Sandy Creek	do	35, 000
Fremont Lake	Pine Creek	do	10, 760
Sixty-seven	North Piney Creek	do	4, 330
Middle Piney Lake	Middle Piney Creek	do	4, 200
Hoop Lake	Beaver Creek	Utah [3]	3, 930
Uinta No. 3	Blacks Fork	Wyoming	2, 000
Patterson Lake	do	do	1, 870
Beaver Meadows	Lost Creek	Utah [3]	1, 790
Elkhorn	Little Sandy Creek	Wyoming	1, 450
Pacific No. 2	Pacific Creek	do	1, 400
Silver Lake	Silver Creek	do	1, 220
Black Joe Lake	Big Sandy Creek	do	1, 100
Piedmont	Big Muddy Creek	do	1, 090
Kemmerer	Hams Fork	do	1, 060
Yampa and White River Basins:			
Upper Yampa No. 1	Yampa River	Colorado	5, 500

See footnotes at end of table.

TABLE XXX.—*Irrigation reservoirs in the Green division* [1]—Continued

Subdivision and reservoir	Source of water	Location	Capacity (acre-feet)
Uinta Basin:			
Strawberry	Strawberry River	Utah	283, 000
Moon Lake	Lake Fork River	do	35, 800
Oaks Park	Brush Creek	do	6, 730
Midview	Duchesne River	do	5, 790
Twin Potts	Lake Fork River	do	3, 950
Kidney Lake	do	do	3, 920
Paradise Park	Whiterocks River	do	3, 140
Lake Atwood	Uinta River	do	2, 700
John Starr	do	do	2, 370
East Park	Brush Creek	do	1, 300
Montez Creek	Uinta River	do	1, 260
Fox Lake	do	do	1, 200
Price and San Rafael River Basins:			
Scofield [2]	Price River	do	73, 000
E. K. Olson	do	do	3, 500
Erickson Flat	Huntington Creek	do	2, 460
Cleveland	do	do	2, 315
Ferron	Ferron Creek	do	1, 200

[1] Includes only reservoirs with capacities of more than 1,000 acre-feet.
[2] Project under construction.
[3] Water used in Wyoming.

TABLE XXXI.—*Present irrigated areas in the Green division by States*

Subdivision	Acres irrigated			
	Colorado	Utah	Wyoming	Total
Upper Green River Basin	1, 840	9, 430	[1] 234, 390	[1] 245, 660
Yampa and White River Basins	104, 030	50	13, 150	117, 230
Uinta Basin	0	165, 600	0	165, 600
Price and San Rafael River Basins	0	54, 040	0	54, 040
Total	105, 870	229, 120	[1] 247, 540	[1] 582, 530

[1] Includes 11,470 acres of new land in Eden project, under construction.

TABLE XXXII.—*Estimated present average annual water consumption in Green division*

Subdivision	Water consumed (acre-feet)			
	Colorado	Utah	Wyoming	Total
Upper Green River Basin	2, 000	18, 000	[1] 372, 000	[1] 392, 000
Yampa and White River Basins	113, 000	0	19, 000	132, 000
Uinta Basin	0	243, 000	0	243, 000
Price and San Rafael River Basins	0	97, 000	0	97, 000
Total	115, 000	358, 000	[1] 391, 000	[1] 864, 000

[1] Includes 17,000 acre-feet for Eden project, under construction.

TABLE XXXIII.—*Estimated present average annual water exports from Green division*

Subdivision and project [1]	Exporting stream, Green River Basin	Importing stream, Bonneville Basin	Acre-feet
Uinta Basin:			
Daniel Creek	Strawberry River	Daniels Creek	3, 500
Strawberry Valley [2]	do	Spanish Fork River	66, 000
Provo River [3]	Duchesne River	Provo River	32, 000
Price and San Rafael River Basins:			
Sampete [3]	Cottonwood Creek	Oak Creek	4, 000
Do	do	Ephraim Creek	4, 000
Miscellaneous projects, No.:			
1	Huntington Creek	Tributaries of Sanpitch River	4, 000
1	Price River		
6	Cottonwood Creek		
2	Ferron Creek		
Total			113, 500

[1] All projects are in Utah.
[2] Constructed by Bureau of Reclamation.
[3] Under construction by Bureau of Reclamation.

Potential Development of Water Resources

Thirty-three potential projects are outlined for use of water in the Green division. These projects would be primarily for irrigation and power production, but would have incidental value for flood control, silt retention, river regulation, recreation, and fish and wildlife conservation.

In addition eleven projects, including two alternative schemes, are mentioned which would export an average of 1,137,700 acre-feet of water annually from the Green River Basin to adjoining basins for irrigation and incidental power production.

Potential irrigation development in the division could provide a full supply of water for 639,650 acres of new land and a supplemental supply for 270,730 acres now inadequately irrigated. The present irrigated area thus would be more than doubled and about 50 percent of the lands now irrigated would receive supplemental water.

Eleven power plants could be constructed in the division having a total installed generating capacity of 460,000 kilowatts. Large reservoirs on the main stream would regulate the flow for power production and would help stabilize the flow of the Colorado River at Lee Ferry.

Upper Green River Basin

Six potential projects, one having nine separate units, are outlined for use of water in the upper Green River Basin; four of these would provide an increased water supply for irrigation and would be primarily for power production. Two additional projects which would export surplus water to adjoining basins are also described.

Sublette project.—This project includes all of the potential developments for irrigation and power production within the Green River Basin upstream from Green River, Wyo. The nine units comprising the project are interrelated. Return flows from irrigation of the units at higher elevations would augment the water supplies for the lower units. In all 251,080 acres of dry land, and 46,260 acres now inadequately irrigated would receive water. Only one small power plant is included in this project (Elkhorn unit).

West Side unit would provide irrigation water for the northern part of the basin adjacent to Beaver, Horse, Cottonwood, and Piney Creeks, all tributaries of the Green River. A canal heading at a reservoir (capacity 340,000 acre-feet) at the Kendall site and extending south and west 105 miles could serve 66,050 acres, of which 37,000 acres are now inadequately irrigated and 29,050 acres are new land in need of a full water supply.

Daniel unit would irrigate small patches of river bottom land, amounting to 5,160 acres of new land between Kendall reservoir site and the mouth of New Fork River. Enlargement and extension of existing ditches would be required. A reservoir at the Kendall site would provide necessary storage.

Elkhorn unit would irrigate 134,030 acres of new land on the east side of Green River between Kendall reservoir site and Pacific Creek near Eden, Wyo., by a 160-mile main canal heading at Kendall Reservoir and collecting surplus flows from Green River, New Fork River, and Big Sand Creek. Storage would be provided by Kendall, Burnt Lake (capacity 25,000 acre-feet), and Boulder Lake (180,000 acre-feet) reservoirs. A tunnel 1,800 feet long would tap Burnt Lake Reservoir and deliver the water to a penstock where a head of 530 feet would be utilized at a 1,500-kilowatt plant, capable of producing 9,000,000 kilowatt-hours of energy annually. Water used for energy generation would be reregulated at Boulder Lake Reservoir for irrigation purposes.

Paradise unit would involve pumping water from New Fork River to irrigate 4,490 acres of new land along the river below the mouth of Boulder Creek. Seasonal power from the Burnt Lake power plant (Elkhorn unit) would be sufficient for a 32-foot pumping lift. Natural and return flows would be ample without providing reservoir storage.

Eden project extension unit would bring into cultivation 20,250 acres in addition to the 11,470 acres of new land and 8,530 acres of insufficiently irrigated land near Eden, Wyo., that will be served when the Bureau of Reclamation completes the construction of the Eden project. This additional acreage of new land could be irrigated by constructing 12 miles of new canal and extending laterals planned in the present construction program. Return flows to Big Sandy Creek from upstream irrigation would provide a full water supply.

Lower Big Sandy unit would furnish a full water supply to irrigable lands totaling 11,850 acres on both sides of Big Sandy Creek near its confluence with Green River by gravity diversion of irrigation return flows reaching the creek.

LaBarge unit could bring water to 3,370 acres of new land and 5,540 acres of land now insufficiently irrigated near LaBarge, Wyo. A reservoir of 10,000 acre-feet capacity at the LaBarge Meadows site on LaBarge Creek, together with some new canals and laterals would be required.

Fontenelle unit would require a 5,000 acre-foot reservoir at the Minnie Holden site on Fontenelle Creek with enlargements and extensions of the present distribution system in order to provide water for 2,050 acres of new land and 3,720 acres now lacking an adequate supply along both sides of Fontenelle Creek.

Seedskadee unit would serve 40,830 acres of rich irrigable lands located along both sides of Green River below its confluence with Fontenelle Creek. With the exception of 4,500 acres which would have to be reached by a 33-foot pump lift, the lands could be irrigated by gravity diversions from the Green River. No reservoir storage would be required. If Fontenelle Dam, a feature of the potential Green River-Bear River Diversion project, is constructed, diversion of water for this unit could be greatly simplified by canals heading in Fontenelle Reservoir at high elevations.

Opal project.—To serve 16,020 acres of new land and 5,400 acres now insufficiently irrigated in the Hams Fork area, two new canals diverting southward from Hams Fork and a reservoir with 60,000 acre-feet capacity at the Middle Hams Fork site would have to be provided.

Lyman project.—Storage in an off-stream reservoir of 30,000 acre-feet capacity at the Bridger site would furnish supplemental water to 20,910 acres along Blacks Fork River. The reservoir could be fed by canals from Blacks Fork and the West Fork of Smiths Fork. Downstream from these lands are 3,100 acres which could be irrigated from return flow if an additional new canal were constructed. Also in the vicinity of the Lyman project lands are 7,950 acres under present canals but not now irrigated. Water for these lands could be obtained by the construction of a canal to bring water from the Henrys Fork project.

Henrys Fork project.—This project would serve 21,090 acres of irrigated land and 9,190 acres of new land in the Henrys Fork and Sheep Creek areas and in addition the 7,950 acres of new land in the Lyman area. Full development would require utilization of the Big Basin natural reservoir site for the storing of 107,000 acre-feet of water. This reservoir could be formed by the construction of only a small dike, water being supplied from the tributaries of Henrys Fork through a feeder canal. An outlet canal from the reservoir to Henrys Fork lands and the enlargement and extension of the present interstate canal would be required. To serve the new lands in the Lyman area a 30-mile canal extending west from the reservoir would be needed.

Flaming Gorge project.—Flaming Gorge and Horseshoe Canyon on the Green River, 3 to 4 miles south of the Wyoming-Utah boundary, present several alternative sites for a dam to provide for power production and stream regulation. A dam at a point on the river where the water surface elevation is about 5,840 feet above sea level could raise the water surface to elevation 5,995 feet, forming a reservoir with a total capacity of 1,500,000 acre-feet and an active capacity of 1,050,000 acre-feet. The reservoir would be 55 miles long and would reach to within 10 miles of Green River, Wyo., and transcontinental highway U S 30. From the reservoir a tunnel could be driven 4 miles to the point where Skull Creek joins the Green River 17 miles downstream from the dam by river route. A short penstock from the tunnel portal would carry water to a power plant at the mouth of Skull Creek, where the tailwater elevation would be 5,700 feet and the maximum static power head 295 feet. With an installed capacity of 30,000 kilowatts this power plant could produce 158 million kilowatt-hours of firm energy annually.

Red Canyon project.—The Red Canyon dam site on Green River is 8 miles east of the mouth of Skull Creek where the Flaming Gorge power plant would be located. In meandering between the two locations the river flows 13 miles and drops 131 feet. This full drop could be utilized for power production by means of a dam at the Red Canyon site and a power plant with an installed capacity of 12,000 kilowatts. The annual firm power production would amount to 68 million kilowatt-hours. The reservoir, confined within near-vertical canyon walls, would have a capacity of 50,000 acre-feet. Stream regulation would have to be provided from the Flaming Gorge development.

South Pass diversion project.—With a 31-mile collecting canal, 8 miles of which would be in rock, to divert flows of East Fork River (tributary to New Fork), Big Sandy Creek, and Little Sandy Creek to Landor Creek an annual average of 50,000 acre-feet of water could be exported from the Green River Basin for use in the Missouri River Basin. The water would supplement flows of North Platte River for irrigating lands in Wyoming.

Green River-Bear River diversion project.—This project would consist of two separate units which would export approximately 337,000 acre-feet of water annually from the Green River Basin to Bear River in the Bonneville Basin for irrigation of lands in Wyoming and Utah and for the production of power. Allowing 20,000 acre-feet for reservoir evaporation the total depletion to the Green River by construction of both units would amount to 357,000 acre-feet.

Hams Fork-Twin Creek unit would export 37,000 acre-feet annually from Hams Fork and LaBarge and Fontenelle Creeks to Twin Creek, tributary of Bear River. The construction of 41 miles of canal, including three tunnels with combined lengths of 5.1 miles, would be required. Collected flows from all three streams would be regulated by Middle Hams Fork Reservoir, also a feature of the Opal project. To regulate the additional flows for export the reservoir capacity would have to be enlarged from 60,000 to 170,000 acre-feet.

Green River-Smiths Fork unit would export 300,000 acre-feet of water annually from the Green River to Smiths Fork, a tributary of Bear River, by means of a 37-mile tunnel heading near LaBarge, Wyo., at the potential Fontenelle Reservoir (capacity 400,000 acre-feet). Because of reservoir evaporation the actual depletion to the Green River by construction of this unit would be 320,000 acre-feet annually.

Yampa and White River Basins

Twelve projects for ultimate development of water resources within these basins are outlined. Ten are primarily for expansion of irrigation and two are mainly for power production. In addition two plans, one of which is an alternative, to export surplus water to the adjoining North Platte Basin are described as possibilities.

Little Snake River project.—With the development of this project 92,110 acres of new land and 15,710 acres now partially irrigated would be furnished irrigation water and 43,000,000 kilowatt-hours of firm power would be produced annually. A reservoir of 15,000 acre-feet capacity at the Savery site on Savery Creek could supplement natural flows in irrigating lands both along the Little Snake River below the point where Savery Creek enters from the north. The enlargement and extension of present canals and the construction of a new canal diverting from Savery Creek would be needed to serve lands on Dolan Mesa, north of Little Snake River.

Two reservoirs would be provided on Slater Creek, which flows northward into the Little Snake River. The higher reservoir at Columbus Mountain site, with a capacity of 125,000 acre-feet, would receive most of its water by feeder canals from the Middle Fork of the Little Snake River and from Elk River, a tributary of the Yampa River. Water released from this reservoir would be diverted just above Slater Falls and carried by a canal 3½ miles long to a 7,500-kilowatt power plant where a power head of 454 feet could be utilized. Tailwater in summer would be diverted into the potential Great Divide canal and carried to 31,000 acres of new land. Twelve miles downstream from the power plant is the Pot Hook reservoir site. A reservoir at this site with a capacity of 85,000 acre-feet would store winter power releases and spring inflow to Slater Creek below the Columbus Mountain Reservoir. Water from the Pot Hook Reservoir would be conveyed by the potential Pot Hook canal, heading at the junction of Slater Creek and Little Snake River, to 44,000 acres of new land south of the Little Snake River and below lands served from the Great Divide canal.

Upper Yampa project.—The irrigation of 11,140 acres of cultivated land and 3,460 acres of new land along the upper Yampa River both above and below the town of Yampa, Colo., would be possible with storage in the Yampa River Reservoir No. 4, with a capacity of 14,000 acre-feet, to supplement natural flows and existing storage.

Wessels project.—This project would serve 6,010 acres of new land on benches above present canals and 380 acres now irrigated but in need of a supplemental supply near Steamboat Springs, Colo. The natural flow of the Yampa River augmented by releases from a 15,000 acre-foot reservoir at the Upper Bear site on the Yampa River would provide sufficient water for irrigation.

Mount Harris project.—Supplemental water would be furnished to 1,450 acres of cultivated land and a new supply to 16,600 acres of dry land with the development of this project. These lands, covering rolling benches south of the Yampa River between Steamboat Springs and Craig, Colo., are mostly on the Hayden Mesa with only a small part in the Twenty Mile Park area. Dunkley Reservoir on Fish Creek with a capacity of 30,000 acre-feet could store water delivered by feeder canals from Williams Fork River and Trout, Middle, and Foidel Creeks. Canals would have to be built to carry the water released for irrigation to the project area.

Great Northern project.—Full irrigation service for 16,010 acres of dry land and 3,260 acres of irrigated land in need of more water along and between Elkhead and Fortification Creeks, northern tributaries to the Yampa River, is possible. A reservoir of 30,000 acre-feet capacity at the California Park site on Elkhead Creek could be fed in part by a feeder canal from Elk River. Water stored in the reservoir would supplement natural flows of the two creeks. A new canal system would be required to carry the water to the lands.

Yellow Jacket project.—Water for irrigating 31,820 acres of new land and 5,950 acres of land requiring supplemental water would be furnished with the development of this project. Most of the land lies on benches south of the Yampa River between the mouth of Williams Fork and Maybell, Colo., but 11,790 acres are along northern tributaries of the White River, north and east of Meeker, Colo. The irrigation supply would come from White River and Milk Creek, a tributary of the Yampa River. A reservoir of 30,000 acre-feet capacity at the Thornburgh site on Milk Creek could serve project lands in the Yampa River drainage area. A canal to carry the unregulated flow of the White River could partly supply the reservoir and could serve adequately project lands along White River tributaries.

Deadman Bench project.—This multiple-purpose project would bring irrigation water to 89,720 acres of new land, 28,540 acres of which are in Colorado and 61,180 acres in Utah. It would also produce 87 million kilowatt-hours of firm energy annually and provide stream regulation, flood control, silt control, and recreational opportunities. A dam across the Yampa River at the Juniper site, 24 miles west of Craig, Colo., raising the water level 185 feet, from the present river elevation of 5,945 feet up to 6,130 feet, would create a reservoir 20 miles long with a capacity of 1,250,000 acre-feet. Of the total reservoir capacity 60,000 acre-feet would be used for irrigation, 740,000 acre-feet for power production and flood control, and 450,000 acre-feet reserved as inactive, but useful for silt control, fish propagation, and recreational purposes. The power plant at the base of the dam would have an installed capacity of 15,000 kilowatts. The irrigation canal would divert from the reservoir 120 feet above stream bed and would carry water to new lands on Deadman Bench between the Yampa and White Rivers.

Maybell project.—Water released from Juniper Reservoir through the power plant into the Yampa River could be conveyed by a canal to 8,540 acres of dry land along the Yampa River below the reservoir and near the mouth of Little Snake River.

Cross Mountain project.—The Yampa River below the Juniper reservoir site flows into Maybell Valley. Cross Mountain blocks the lower end of the valley except for a narrow chasm through which the river escapes. By driving a tunnel 2.3 miles through the mountain and constructing a low diversion dam at the canyon head to divert the river into the tunnel, a fall of 175 feet could be utilized. The dam at river elevation 5,810 feet would be only 15 feet high and the backwater would flood only a few acres. The power plant would have an installed capacity of 18,000 kilowatts, and with stream regulation provided by the upstream Juniper Reservoir, would have an annual firm production of 99 million kilowatt-hours.

Lily Park project.—The Little Snake River unites with the Yampa River in Lily Park. A few miles below the confluence of the rivers the valley narrows. Here where the river enters a canyon is the Lily Park power site. The present river surface at the site is at elevation 5,580 feet above sea level. A dam could be constructed to raise the surface 70 feet thus backing the water about 6 miles up the Little Snake River and 12 miles up the Yampa River to Cross Mountain. With the water surface at a maximum elevation of 5,650 feet the reservoir capacity would only be 75,000 acre-feet. Some hay land would be flooded. A larger reservoir is not needed for regulation of the stream below the Juniper Reservoir. Little Snake River would be partially regulated by upstream irrigation developments. A power plant installed at the dam would have a capacity of 10,000 kilowatts and be capable of producing 47 million kilowatt-hours of firm energy annually.

Josephine Basin project.—By the extension of the present Miller Ditch to carry the unregulated flow of the White River, 2,400 acres of new land located 4 miles southwest of Meeker, Colo., could be irrigated.

Piceance project.—Piceance Creek flows northwest to join the White River 20 miles west of Meeker. A 5,000 acre-foot reservoir on the creek 30 miles above its mouth could store water for the irrigation of lands along the creek channel, including 610 acres of new land and 2,380 acres of cultivated land in need of a supplemental supply.

Little Snake-North Platte diversion project.—The exportation of about 51,000 acre-feet of water annually from the North Fork of Little Snake River, Battle Greek, and Sandstone Creek to the North Platte Basin for irrigation of lands in Wyoming and by exchange in Colorado would be possible with the construction of a 60-mile canal.

Elk River-North Platte diversion project.—Under the tentative plan for development of the Little Snake River a canal would carry water out of the Little Snake River Basin (Little Snake-North Platte diversion project) and another canal would bring water into the basin from Elk River, a tributary of the Yampa River (Little Snake River project). An alternative plan would eliminate both of these transmountain canals and also the potential Columbus Mountain Reservoir and Slater Falls power development (Little Snake River project), which would be dependent largely upon water imported from Elk River. Additional main stream storage on the Little Snake River at either the Sheep Mountain or the Three Forks sites could furnish part of the water supply that would have been brought from Elk River to lands in the Little Snake River Basin. Approximately 75,000 acre-feet of the flow of Elk River thus would be available annually for diversion by tunnel to the North Platte River for use on lands in Colorado and Wyoming. Further field investigations and an allocation of water between Wyoming and Colorado are prerequisites to final adoption of a plan of development.

Uinta Basin

For the development of the water resources of Uinta Basin 10 projects are outlined for use of water within the basin; 8 of these would be primarily for irrigation and 2 for power production. Two projects, one an alternative, to export surplus water to the Bonneville Basin are also described. The irrigation developments would serve white- and Indian-owned lands. The Office of Indian Affairs is considering a few small projects to provide supplemental water for lands administered by that agency. Most of those are provided for in the plans for basin-wide development.

Moon Lake project extension.—North of the Duchesne River, extending from Rock Creek eastward through the Whiterocks River service area, are 86,200 acres of irrigated land including some owned by Indians that could be furnished supplemental water and 26,300 acres of new land that could be made productive with irrigation water if storage were provided in the following reservoirs: (1) Pelican Lake, 5,200 acre-feet capacity, supplied from Uinta and Whiterocks Rivers; (2) Halfway Hollow, 32,200 acre-feet capacity, also supplied from Uinta and Whiterocks Rivers; (3) Upalco, 12,300 acre-feet capacity, storing flows from Yellowstone Creek; and (4) one or more reservoirs at undetermined sites on Rock Creek or other streams capable of releasing an average of 23,000 acre-feet annually to arable lands on the Blue Bench and, if additional yields are provided to replace natural summer flows, exports of water to the Bonneville Basin through the potential Rock Creek tunnel could be increased accordingly. The first three reservoirs listed would be at off-stream sites, but could be fed from existing canals with slight extensions. New construction required would include a service canal from Halfway Hollow Reservoir to Ouray Valley, which would also be usable as a feeder canal for Pelican Lake Reservoir; a 6-mile extension of the present Yellowstone Canal, now serving the Moon Lake project, to Uinta River; a 3-mile canal from Lakefork River to Yellowstone Creek above the head of the Yellowstone Canal; and a canal from Rock Creek to the Blue Bench and Lakefork River.

Fruitland project.—A storage reservoir of 4,000 acre-feet capacity on Red Creek, a tributary of Strawberry River, with extensions of present service canals would provide water for the irrigation of 1,600 acres of new land and 400 acres lacking an adequate supply near Fruitland, Utah.

Castle Peak project.—A canal 34 miles long, heading at Duchesne River near Duchesne, Utah, could carry water to 21,700 acres of new land and 2,100 acres of land now insufficiently irrigated on south Myton Bench. Water could be stored for late season use in reservoirs at the Hades site (25,000 acre-feet capacity) on the North Fork of Duchesne River and at the Starvation site (65,000 acre-feet capacity) on Strawberry River, or at alternative sites on tributaries of the Duchesne River above the canal heading.

Mosby project.—Water from Whiterocks River imported by a canal into Deep Creek could be stored in a reservoir of 13,000 acre-feet capacity at the Crow Creek site on Deep Creek to irrigate 3,800 acres of new land and provide supplemental water for 400 acres located about 12 miles west of Vernal, Utah.

Vernal project.—Storage of Ashley Creek water in Stanaker Reservoir, a potential offstream reservoir of 34,000 acre-feet capacity, would be used to irrigate 1,900 acres of new land and furnish a supplemental supply to 22,300 acres of cultivated land near Vernal. In addition to a dam to impound water in Stanaker Reservoir short feeder and service canals would be needed.

Jensen project.—A reservoir of 6,000 acre-feet capacity at the Tyzack site on Brush Creek would provide sufficient storage to supply 3,600 acres of irrigated land with additional water and 800 acres with a full amount near Jensen, Utah. Existing canals could distribute the water.

Minnie Maud project.—A supplemental water supply could be furnished 800 acres of irrigated land bordering Minnie Maud Creek along the Duchesne-Carbon County boundary by storage in a small reservoir (550 acre-feet capacity) at the Minnie Maud site on Minnie Maud Creek.

Green River pumping project.—By pumping water from Green River with lifts of about 40 feet, 11,000 acres of dry land and 1,000 acres of irrigated land between Jensen and Ouray, Utah, could be adequately irrigated. With the present wide fluctuations in river flow, diversion dams cannot be maintained and occasionally part of the area is inundated. Future upstream power reservoirs would smooth out the flow and make pumping for irrigation practicable.

Echo Park project.—Three and one-half miles downstream from the confluence of the Green and Yampa Rivers is Echo Park dam site. It is in Colorado only 2 miles east of the Utah State line. The river elevation at the site is 5,048 feet above sea level. A dam to raise the water surface 500 feet would impound 5,560,000 acre-feet of water (4,710,000 acre-feet active capacity) and would control the flow at that point. The reservoir would extend up Green River 64 miles to Red Canyon and up Yampa River 44 miles to Lily Park. A number of suspected archeological sites along the Yampa River should be thoroughly explored prior to filling the reservoir. A power plant installed at the dam would have a capacity of 120,000 kilowatts and would be capable of producing annually 668 million kilowatt-hours of energy. In addition to power, this multiple-purpose project would provide hold-over storage, flood control, silt retention, and recreational opportunities. During a succession of dry years releases would help meet the stream flow requirements at Lee Ferry specified by the Colorado River Compact. Transcontinental highway US 40 is only 20 miles south of the site and would afford easy access to the area for vacationists.

Split Mountain project.—Below Echo Park, the Green River leisurely divides and unites several times to form large islands, giving rise to the name "Island Park." It then flows through Rainbow Park and Little Park to Split Mountain, so named because the river has split the mountain in half. A dam at the head of Split Mountain Canyon at river elevation 4,930 feet could raise the water surface 118 feet, backing water up to the Echo Park Dam and forming a reservoir with a capacity of 320,000 acre-feet (295,000 acre-feet active capacity). Stream flow would be regulated by the upstream Echo Park Reservoir. A power head of 200 feet could be utilized by means of a pressure tunnel in three sections extending from the dam 8.3 miles downstream to a power plant, 5 miles up the river from Jensen, Utah. With an installed capacity of 90,000 kilowatts, this plant could produce 846 million kilowatt-hours of firm energy annually.

Central Utah project.—An exportation of 625,000 acre-feet annually could be made from streams in the Uinta Basin to the Bonneville Basin in Utah. A collecting conduit would intercept flows of Brush Creek, Ashley Creek, and the Duchesne River and their tributaries, delivering the water by gravity flow to the Strawberry Reservoir which would be enlarged to a capacity of 1,300,000 acre-feet. Releases from the reservoir would be made through a tunnel into Diamond Fork of Spanish Fork River where a 2,900-foot drop could be utilized to generate electricity before the water is reregulated and used for irrigation in the Bonneville Basin.

Water could be pumped from the potential Echo Park Reservoir on Green River to replace irrigation supplies now used on lands in the Uinta Basin which would be diverted to the Bonneville Basin under this project and to permit expansion of irrigation in the Uinta Basin.

The construction of this project would eliminate the Rock Creek Tunnel project and also would make unnecessary most of the structures otherwise required for the Moon Lake extension, Fruitland, Castle Peak, and Mosby projects.

Rock Creek Tunnel project.—Construction of this project would bring additional water from the Colorado River Basin watershed into the Bonneville Basin. By means of a 9-mile tunnel from Rock Creek, a tributary of Duchesne River, to upper Duchesne River, 45,000 acre-feet of water annually could be brought into the Duchesne River and thence carried by the Duchesne tunnel to Provo River. The Duchesne tunnel, a feature of the Provo River project, is a 6-mile tunnel under construction to bring 32,000 acre-feet annually from the Duchesne River to Provo River. It would be lined with concrete to reduce friction losses and accommodate the larger flow brought from Rock Creek. If replacement storage were provided for Uinta Basin lands, additional summer flows of approximately 8,000 acre-feet from Duchesne River and Rock Creek could be diverted into the tunnels.

Price and San Rafael River Basins

Five projects are outlined as possibilities for development of water resources in these basins. Four small transmountain diversions are also discussed.

Emery County project.—A reservoir of 57,000 acre-feet capacity of the Joes Valley site on Cottonwood Creek, a tributary of the San Rafael River, and a highline canal from Cottonwood Creek to Huntington Creek would provide ample irrigation service to all lands under present canals from the two streams, including 20,000 acres now insufficiently irrigated and 3,300 acres of dry land in the vicinity of Huntington and Castle Dale, Utah. By impounding spring run-off and thus providing compensating storage in late season for the irrigation of lands with appropriated water rights, this reservoir would make possible increased transmountain diversions from Huntington and Cottonwood Creeks through existing works.

Buckhorn project.—By the enlargement and extension of the Cleveland canal to carry surplus waters of Huntington Creek to a potential reservoir of 15,000 acre-feet capacity at the Buckhorn site, 3,800 acres of new land about 12 miles east of Castle Dale, Utah, could be made productive with irrigation.

Gunnison Valley project.—West of Green River, Utah, are 3,800 acres of irrigable land that could receive water from Green River with a 280-foot pump lift. East across the river are 430 acres requiring only a 50-foot pump lift, and 6,600 acres that could be reached by pumping a maximum of 370 feet. Inexpensive power for pumping could be obtained from the development of nearby power sites on the Green and Colorado Rivers.

Desolation Canyon project.—Of several dam sites in Desolation Canyon of the Green River suitable for power production the Upper Three Canyan Creek site appears to be the best. It is 50 miles by river upstream from Green River, Utah. A dam to raise the water surface from a present elevation of 4,400 feet up to 4,650 feet would back water upstream to a point just above the White and Duchesne Rivers, creating a reservoir with a total capacity of 900,000 acre-feet and an active capacity of 700,000 acre-feet. The reservoir would regulate the inflow to Green River below the Echo Park Dam with only occasional spills. A power plant in the dam with an installed capacity of 78,000 kilowatts could produce 433 million kilowatt-hours of firm energy annually.

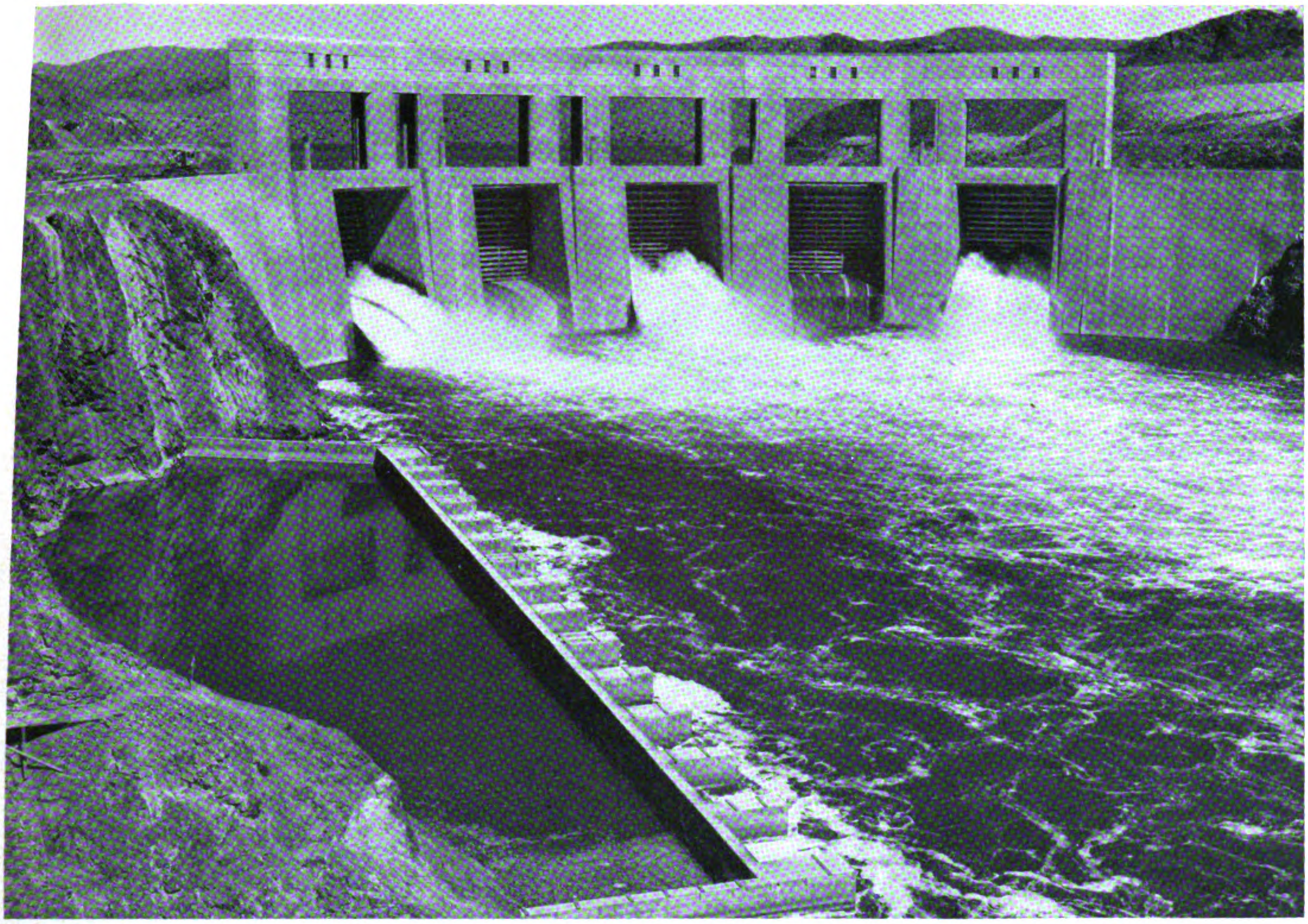
Rattlesnake Power project.—The Rattlesnake Dam site, lowest power site on Green River, is 22 miles upstream from Green River, Utah. A dam to raise the water surface 250 feet above its present elevation of 4,150 feet would create a reservoir with a capacity of 500,000 acre-feet, 370,000 acre-feet of which would be active capacity. The power plant would have an installed capacity of 78,000 kilowatts and an anual firm production of 434 million kilowatt-hours.

Gooseberry project.—From a 17,000 acre-foot reservoir at the Mammoth site on Gooseberry Creek, a tributary of Price River, about 11,500 acre-feet of water could be diverted anually westward through a tunnel 2.3 miles long to irrigate fertile lands in the Sanpete Valley of the Bonneville Basin.

White River diversion project.—The exportation of 2,700 acre-feet of water annually from the White River, a tributary of the Price River, to Spanish Fork River for irrigation of lands under the Strawberry Valley project in the Bonneville Basin would be possible by the reconstruction of an abandoned canal. Three small reservoirs on tributaries of the Price River could provide replacement storage for the Price River lands and thus increase the possible diversion to 4,200 acre-feet.

Ferron-Manti Creek diversion project.—This is one of the two tunnel diversion possibilities that exist to take water from the head of Ferron Creek, a tributary of the San Rafael River, to lands in southern Sanpete Valley in the Bonneville Basin. No stream flow records are available but it is estimated that an average of 15,000 acre-feet of surplus water may be exported through the two tunnels. One tunnel 2.2 miles long would bring water to Manti Creek. En route to irrigate lands this water could be used in two existing municipal power plants having combined heads of 2,974 feet.

Ferron-Twelve Mile Creek diversion project.—A tunnel extending 1.8 miles to Twelve Mile Creek would make possible the other diversion from Ferron Creek, thus help-



PARKER DAM

General view looking upstream and showing Parker Dam discharging about 10,000 second feet of water

MAIN CANAL

A section of the main canal of the Salt River project ing to export the 15,000 acre-feet of water a year from the Colorado River Basin for use in the adjoining Sanpete Valley.

Summary

The following tables summarize the possibilities for ultimate development of water resources in the Green River Basin, showing the multiple purposes to be served by the various projects, estimated construction costs, potential reservoirs and their capacities, areas to be furnished full and supplemental supplies of irrigation water, and power plants with their potential capacities and annual production of firm energy. Most of the reservoirs would have incidental value for recreation and fish and wildlife conservation. Potential export diversions and stream depletions are also summarized.

TABLE XXXIV.—*Potential projects in the Green division*

Subdivision and project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Upper Green River Basin				
Sublette	Wyoming	Green River	I, F, P	$36, 500, 000
West Side unit	do	do	I, F	
Daniel unit	do	do	I, F	
Elkhorn unit	do	do	I, P, F	
Paradise unit	do	New Fork River	I	
Eden unit	do	Big Sandy Creek	I	
Lower Big Sandy	do	do	I	
LaBarge	do	LaBarge Creek	I, F	
Fontenelle unit	do	Fontenelle Creek	I, F	
Seedskadee unit	do	Green River	I	
Opal	do	Hams Fork	I, F	3, 600, 000
Lyman	do	Blacks Fork, Smiths Fork	I, F	4, 330, 000
Henrys Fork	Wyoming, Utah	Henrys Fork	I, F	1, 470, 000
Flaming Gorge	do	Green River	P, F, H, S	10, 000, 000
Red Canyon	Utah	do	P, F	4, 100, 000
Yampa and White River Basins				
Little Snake River	Wyoming, Colorado	Little Snake River tributaries	I, P, F	21, 500, 000
Upper Yampa	Colorado	Yampa River	I, F	2, 300, 000
Wessels	do	do	I, F	1, 100, 000
Mount Harris	do	Tributaries of Yampa River	I, F	3, 300, 000
Great Northern	do	Elkhead Creek and Elk River	I, F	2, 700, 000
Yellow Jacket	do	White River and Milk Creek	I, F	4, 700, 000
Deadman Bench	Colorado, Utah	Yampa River	I, P, F, H, S	23, 800, 000
Maybell	Colorado	do	I	700, 000
Cross Mountain	do	do	P	5, 000, 000
Lily Park	do	do	P, F	1, 900, 000
Josephine Basin	do	White River	I	300, 000
Piceance	do	Piceance Creek	I, F	800, 000
Uinta Basin				
Moon Lake Extension	Utah	Duchesne River and tributaries	I, F	7, 900, 000
Fruitland	do	Red Creek	I, F	400, 000
Castle Peak	do	Duchesne River	I, F	5, 300, 000
Mosby	do	Deep Creek, Whiterocks River	I, F	1, 100, 000
Vernal	do	Ashley Creek	I, F	1, 500, 000
Jensen	do	Brush Creek	I, F	300, 000
Minnie Maud	do	Minnie Maud Creek	I, F	100, 000
Green River Pumping	do	Green River	I	400, 000
Echo Park	Colorado	do	P, F, H, S	43, 000, 000
Split Mountain	Utah	do	P, F, H, S	23, 000, 000
Price and San Rafael River Basins				
Emery County	do	Cottonwood Creek	I, F	2, 500, 000
Buckhorn	do	Huntington Creek	I, F	1, 200, 000
Gunnison Valley	do	Green River	I	1, 100, 000
Desolation Canyon	do	do	P, F, H	21, 000, 000
Rattlesnake Power	do	do	P, F, H	23, 000, 000
Total				259, 900, 000

[1] Symbols used: I=irrigation, P=power, F=flood control, S=silt retention, H=hold-over storage for river regulation.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE XXXV.—*Potential reservoirs in Green division*

Subdivision and name of site	Source of water supply	Project served	Total capacity (acre-feet)
Upper Green River Basin			
Kendall	Green River	Sublette	340,000
Burnt Lake	Fall Creek	do	25,000
Boulder Lake	Boulder Creek	do	180,000
LaBarge Meadows	LaBarge Creek	do	10,000
Minnie Holden	Fontenelle	do	5,000
Fontenelle	Green River	Green-Bear diversion	400,000
Middle Hams Fork	Ham's Fork	Opal and Green-Bear diversion	170,000
Bridger [1]	Blacks Fork, West Fork	Lyman	30,000
Big Basin [1]	Tributary of Henrys Fork	Henrys Fork	107,000
Flaming Gorge	Green River	Flaming Gorge	1,500,000
Red Canyon	do	Red Canyon	50,000
Yampa and White River Basins			
Savery	Savery Creek	Little Snake River	15,000
Columbus Mountain	Slater Fork	do	125,000
Pot Hook	do	do	85,000
Reservoir No. 4	Yampa River	Upper Yampa	14,000
Upper Bear	do	Wessels	15,000
Dunkley	Fish Creek	Mount Harris	30,000
California Park	Elkhead Creek	Great Northern	30,000
Thornburgh	Milk Creek	Yellow Jacket	30,000
Juniper	Yampa River	Deadman Bench and Maybell	1,250,000
Lily Park	do	Lily Park	75,000
Piceance	Piceance Creek	Piceance	5,000
Uinta Basin			
Pelican Lake [1]	Whiterocks and Uinta Rivers	Moon Lake Extension	5,200
Halfway Hollow [1]	do	do	32,200
Upalco [1]	Lakefork River	do	12,300
Hades	Duchesne River	Castle Peak and Rock Creek tunnel	25,000
Starvation	Strawberry	do	65,000
Crow Creek	Deep Creek and Whiterocks River	Mosby	13,000
Stanaker [1]	Ashley Creek	Vernal	34,000
Tyzack	Brush Creek	Jensen	6,000
Red Creek	Red Creek	Fruitland	4,000
Minnie Maud	Minnie Maud Creek	Minnie Maud	550
Strawberry Enlargement	Brush and Ashley Creeks	Central Utah	1,300,000
Echo Park	Green River	Echo Park	5,560,000
Split Mountain	do	Split Mountain	320,000
Price and San Rafael River Basins			
Mammoth	Gooseberry Creek	Gooseberry	17,000
East Fork	White River	White River diversion	1,000
North Fork	do	do	1,000
Willow Creek	Willow River	do	1,000
Joes Valley	Cottonwood Creek	Emery County	57,000
Buckhorn [1]	Huntington Creek	Buckhorn	15,000
Desolation	Green River	Desolation	900,000
Rattlesnake	do	Rattlesnake	500,000
Total			13,360,250

[1] Offstream.

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TABLE XXXVI.—*Potential irrigation development in Green division*

Subdivision and project	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
Upper Green River Basin				
Sublette:				
West side unit	Wyoming	29, 050	37, 000	66, 050
Daniel unit	do	5, 160		5, 160
Elkhorn unit	do	134, 030		134, 030
Paradise unit	do	4, 490		4, 490
Eden project extension unit	do	20, 250		20, 250
Lower Big Sandy unit	do	11, 850		11, 850
LaBarge unit	do	3, 370	5, 540	8, 910
Fonetnelle unit	do	2, 050	3, 720	5, 770
Seedskadee unit	do	40, 830		40, 830
Opal	do	16, 020	5, 400	21, 420
Lyman	do	3, 100	20, 910	24, 010
Henrys Fork	Wyoming, Utah	17, 140	21, 090	38, 230
Subtotal		287, 340	93, 660	381, 000
Yampa and White River Basins				
Little Snake River	Wyoming, Colorado	92, 110	15, 710	107, 820
Upper Yampa	Colorado	3, 460	11, 140	14, 600
Wessels	do	6, 010	380	6, 390
Mount Harris	do	16, 600	1, 450	18, 050
Great Northern	do	16, 010	3, 260	19, 270
Yellow Jacket	do	31, 820	5, 950	37, 770
Deadman Bench	Colorado, Utah	89, 720		89, 720
Maybell	Colorado	8, 540		8, 540
Josephine Basin	do	2, 400		2, 400
Piceance	do	610	2, 380	2, 990
Subtotal		267, 280	40, 270	307, 550
Uinta Basin				
Moon Lake project extension	Utah	26, 300	86, 200	112, 500
Fruitland	do	1, 600	400	2, 000
Castle Peak	do	21, 700	2, 100	23, 800
Mosby	do	3, 800	400	4, 200
Vernal	do	1, 900	22, 300	24, 200
Jensen	do	800	3, 600	4, 400
Minnie Maud	do		800	800
Green River pumping	do	11, 000	1, 000	12, 000
Subtotal		67, 100	116, 800	183, 900
Price and San Rafael River Basins				
Emery County	do	3, 300	20, 000	23, 300
Buckhorn	do	3, 800		3, 800
Gunnison Valley	do	10, 830		10, 830
Subtotal		17, 930	20, 000	37, 930
Total		639, 650	270, 730	910, 380

TABLE XXXVII.—*Potential irrigation development in Green division by States*

State and subdivision	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Wyoming			
Upper Green River Basin	283, 030	85, 450	368, 480
Yampa and White River Basins	8, 300	9, 910	18, 210
Subtotal	291, 330	95, 360	386, 690
Colorado			
Yampa and White River Basins	197, 800	30, 360	228, 160
Utah			
Upper Green River Basin	4, 310	8, 210	12, 520
Yampa and White River Basins	61, 180		61, 180
Uinta Basin	67, 100	116, 800	183, 900
Price & San Rafael River Basins	17, 930	20, 000	37, 930
Subtotal	150, 520	145, 010	295, 530
Total	639, 650	270, 730	910, 380

TABLE XXXVIII.—*Potential power development in Green division*

River basin and project	State	Stream	Power plant installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)
Green River				
Sublette (Elkhorn unit)	Wyoming	Fall Creek	1, 500	9, 000, 000
Flaming Gorge	Utah	Green River	30, 000	158, 000, 000
Red Canyon	do	do	12, 000	68, 000, 000
Echo Park	Colorado	do	120, 000	668, 000, 000
Split Mountain	Utah	do	90, 000	486, 000, 000
Desolation	do	do	78, 000	433, 000, 000
Rattlesnake	do	do	78, 000	434, 000, 000
Yampa River				
Little Snake River	Colorado	Slater Creek	7, 500	43, 000, 000
Deadman Bench (Juniper)	do	Yampa River	15, 000	87, 000, 000
Cross Mountain	do	do	18, 000	99, 000, 000
Lily Park	do	do	10, 000	47, 000, 000
Total			460, 000	2, 532, 000, 000

TABLE XXXIX.—*Potential export diversions from Green division*

Subdivision and project	State served	Estimated average annual diversion (acre-feet)
Upper Green River Basin		
South Pass diversion	Wyoming	50, 000
Green River-Bear River diversion:		
Hams Fork-Twin Creek unit	do	37, 000
Green River-Smiths Fork unit	Utah and Wyoming	320, 000
Yampa and White River Basins		
Little Snake-North Platte	Wyoming and Colorado.	[1] 51, 000
Elk River-North Platte	do	75, 000

TABLE XXXIX.—*Potential export diversions from Green division*—Continued

Subdivision and project	State served	Estimated average annual diversion (acre-feet)
Uinta Basin		
Central Utah	Utah	625, 000
Rock Creek Tunnel	do	[1] 53, 000
Price and San Rafael River Basins		
Gooseberry	do	11, 500
White River diversion	do	4, 200
Ferron-Manti Creek	do	15, 000
Ferron-Twelve Mile Creek	do	
Total		1, 137, 700

[1] Smaller of alternative projects not included in total.

TABLE XL.—*Present and potential stream depletions in Green division*

State and subdivision	Estimated average annual depletion (acre-feet)				
	Present depletion		Potential increase		Total ultimate depletion
	Consumed in basin	Exported	Consumed in basin	Exported	
Colorado					
Upper Green River	2,000				2,000
Yampa and White River	113,000		324,000	[1] 75,000	512,000
Subtotal	115,000		324,000	[1] 75,000	514,000
Utah					
Upper Green River	18,000		9,000	320,000	347,000
Yampa and White River			95,000		95,000
Uinta Basin	243,000	[2] 101,500	135,000	625,000	[2] 1,104,500
Price and San Rafael River	97,000	12,000	25,000	30,700	164,700
Subtotal	358,000	[2] 113,500	264,000	975,700	1,711,200
Wyoming					
Upper Green River	[3] 372,000		474,000	87,000	[3] 933,000
Yampa and White River	19,000		15,000		34,000
Subtotal	[3] 391,000		489,000	87,000	[2] 967,000
Total	[3] 864,000	[3] 113,500	1,077,000	1,137,700	[4] 3,192,200

[1] Return flow usable in Wyoming.
[2] Includes 32,000 acre-feet expected to be diverted by the Duchesne tunnel of the Provo River project.
[3] Includes 17,000 acre-feet expected to be consumed by the Eden project, authorized for construction.
[4] The Green division will share also in the depletion of 500,000 acre-feet annually allowed for pasture irrigation in the upper basin

Grand Division

The drainage area of the Colorado River above the mouth of the Green River for convenience in this report is called the Grand division. Extending westward from the crest of the Continental Divide in central Colorado the division encompasses an area of 26,500 square miles, 89 percent of which is in Colorado and 11 percent in Utah. The division is larger than West Virginia and one-fourth the size of Colorado. Most of the run-off originates in the high mountainous eastern part of the region where rain and snowfall is heavy. The Grand division has a drainage area only three-fifths as large as that of the Green River, but its average annual run-off is 25 percent more than that of the Green division.

Average annual flows of the upper Colorado River and its principal tributaries for the long-time period of record and the critically dry decade (1931–40) are shown in table XLI.

TABLE XLI.—*Average annual stream flows in the Grand division*

Station	Period of record	Average annual flow (acre-feet)	
		For period of record	For 1931–40 period
Colorado River at Glenwood Springs, Colo	1900–43	2,140,000	1,704,000
Roaring Fork River at Glenwood Springs, Colo	1906–43	1,076,000	824,000
Colorado River at Cameo, Colo	1934–43	2,911,000	[1] 2,835,000
Gunnison River above Grand Junction, Colo	[2] 1897–1943	2,075,000	1,446,000
Dolores River at Dolores, Colo	[2] 1900–43	338,000	270,000
Dolores River at Gateway, Colo	1938–43	871,000	[1] 568,000
Colorado River near Cisco, Utah	[2] 1914–43	6,024,000	4,669,000

[1] Estimated.
[2] Records not complete.

The upper Colorado River and its tributaries are fed largely by melting snow. Even with the present depletions from irrigation 55 percent of the annual run-off occurs in May and June and 72 percent in the 4-month period, April through July. The river system produces more water than would be required to irrigate fully all arable land within its basin, but future expansion of irrigation is dependent on reservoir storage for proper seasonal distribution.

The upper tributaries of the Colorado River contribute clear water to the system. The Gunnison River below North Fork and the Colorado below Glenwood Springs carry some silt but not generally in sufficient amounts to be harmful although greatly concentrated in summer cloudburst storms of short duration. Dissolved mineral salts increase with return flow from irrigation below an elevation of 7,000 feet but do not reach harmful proportions.

Little use is made of ground water in the Grand division. A few shallow wells supply some water for domestic and stock use. In the lower valleys, where shale bedrock predominates, most ground water is heavily charged with

Grand division of the Colorado River basin

dissolved mineral salts. Subsurface structural conditions needed for a large artesian water development are not known to exist anywhere in the division.

Present Development of Water Resources

Scanty rainfall makes irrigation necessary for crop production in this division. The first irrigation ditches were constructed to divert from headwater streams, but as agriculture expanded new ditch diversions followed downstream and the usual order of developing irrigation from lower valleys upstream was reversed. Many water rights of first priority are still appurtenant to lands high on streams. Early ditches were small and simply constructed to serve only one or two farms. Later when construction of diversion dams on the lower, wider streams and larger canals to serve expansive areas required cooperative effort, numerous mutual enterprises were organized.

Federal irrigation projects were started in the area shortly after the Bureau of Reclamation was established by an act of Congress in 1902. The Uncompahgre project was the first Federal development authorized in this division. In 1912 the Grand Valley project was begun. Together, facilities of these projects served more than 100,000 acres or over 20 percent of the land irrigated in the Grand division. In 1938 the Bureau of Reclamation reconstructed the Fruitgrowers dam for storage of 4,600 acre-feet of water. It replaces an old dam, built by the irrigators in 1898, which was breached and failed during a flood in June 1937.

The neighboring San Juan River area in the Colorado River Basin receives water from the Dolores River. The exportation of surplus water eastward across the Continental Divide was commenced in 1880 when the small Ewing ditch for placer mining was constructed from the head of Eagle River to the Arkansas River watershed. Additional diversions either across mountain passes in canals or under them in tunnels followed. Construction has been started on other developments to take water out of the basin, including the Colorado-Big Thompson project of the Bureau of Reclamation.

Sixteen hydroelectric plants with combined capacities of 49,717 kilowatts are operating in the Grand diversion at present. Largest is the 21,600-kilowatt Green Mountain plant, recently completed as a unit of the Colorado-Big Thompson project. The Shoshone plant of the Publice Service Co. of Colorado, the second largest, has a capacity of 14,400 kilowatts. Thirteen small stream and internal combustion power plants have combined capacities of only 8,497 kilowatts. More power is generated than consumed in this area. Transmission lines carry large blocks of power over the mountains for use in eastern Colorado.

The amount of water used for domestic, municipal, industrial, and stock-watering purposes is small in comparison with the available supply. The mountain streams and lakes are kept well stocked with fish, making the Grand division one of the most popular fishing and summer recreational areas in the Nation.

Present development of water resources is discussed in more detail under three subdivisions.

Colorado River above Gunnison River.—The Colorado and its headwater tributaries above the Gunnison River irrigate 256,000 acres, and expansion of existing irrigation facilities will bring water to 15,670 acres more, bringing to 271,670 acres the total area that will be irrigated by diversions from the Colorado River above the Gunnison.

Upstream from Palisade, 186,000 acres are irrigated, nearly 60 percent of which is in the mountain valleys above Glenwood Springs, where ditches are small, averaging 3 miles in length and 8 second-feet in capacity. Water is plentiful during most of the growing season, being heavily applied in amounts varying from 5 to 8 acre-feet an acre annually. From this irrigation there is a large return flow to the river. About one-fourth of the irrigated land, however, suffers from the lack of water in late season. Supplemental water can be supplied in part by the construction of simple canals to divert water from larger streams, but storage in reservoirs will also be necessary. Expensive construction is prohibited by the low value of crops that are produced. Most land produces native grasses valued annually from $7 to $15 an acre.

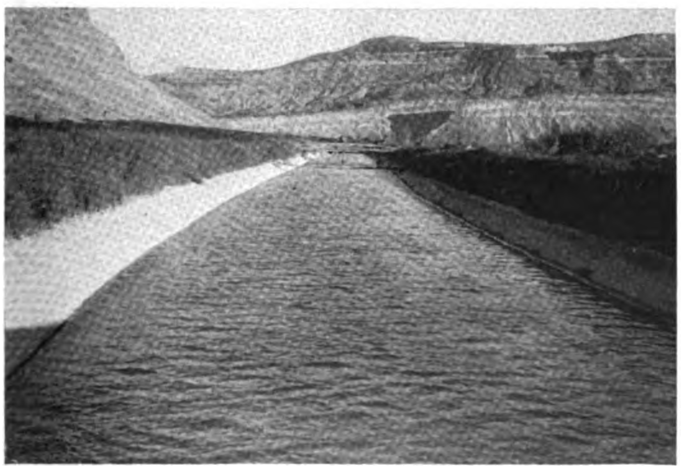
Between Glenwood Springs and Palisade the climate is suitable for growing crops of higher value, such as fruits, vegetables, alfalfa, and sugar beets; consequently larger and more costly irrigation developments have been possible. The irrigated lands, being on mesas higher than the river, are served almost entirely from tributary streams. Some storage reservoirs have been provided, but about half of the area irrigated is in need of an additional late-season water supply. From 3.5 to 5 acre-feet of water is applied annually to each acre. Return flow from irrigation finds its way into the river channel and is usable for irrigation in Grand Valley and lower areas.

In the Grand Valley, which begins at Palisade and extends west almost to Utah, 70,000 acres are irrigated by diversions from Colorado River above its confluence with the Gunnison River, and 15,670 acres more will be reached with full expansion of existing irrigation systems. The Grand Valley Irrigation Co. built a 110-mile canal in 1883 which serves 30,000 acres. Other smaller developments followed. In 1912 the Bureau of Reclamation commenced construction of its Grand Valley project. With a diversion dam on the Colorado River 8 miles above Palisade, and a canal to serve lands above the existing Grand Valley Canal, this project now irrigates 40,000 acres, including some lands irrigated before 1912 but now supplied from the project canal. Additional small acreages are being reclaimed each year. All irrigated lands in Grand Valley receive an adequate supply of water.

Projects now in operation export about 96,000 acre-feet of water annually from the headwaters of the Colorado River across the Continental Divide to the South Platte and Arkansas Basins. Several of these projects, notably the Denver municipal system (Moffat tunnel) for diversion from Frazier River and its tributaries, have not yet been completed. Upon their completion average annual diversions will aggregate 197,000 acre-feet. A further exportation of 320,000 acre-feet to the Big Thompson River, a tributary of the South Platte, will be possible when the Bureau of Reclamation completes construction of the Colorado-Big Thompson project. This project will provide supplemental water for 615,000 acres of fertile farm land in northeastern Colorado, now insufficiently irrigated. Power will be generated at the newly constructed Green Mountain plant on Blue River, a tributary of the Colorado, and at five plants having combined heads of 2,800 feet to be constructed in the South Platte Basin. The Green Mountain Reservoir with a capacity of 154,600 acre-feet will provide replacement storage for use in the Colorado River Basin when export diversions would otherwise reduce Colorado River flows below irrigation requirements and will also provide water for power generation. The Granby Reservoir of 546,400 acre-feet will impound water on the upper Colorado River. From it the water will be lifted an average of 130 feet to a canal leading to Shadow Mountain and Grand Lakes from

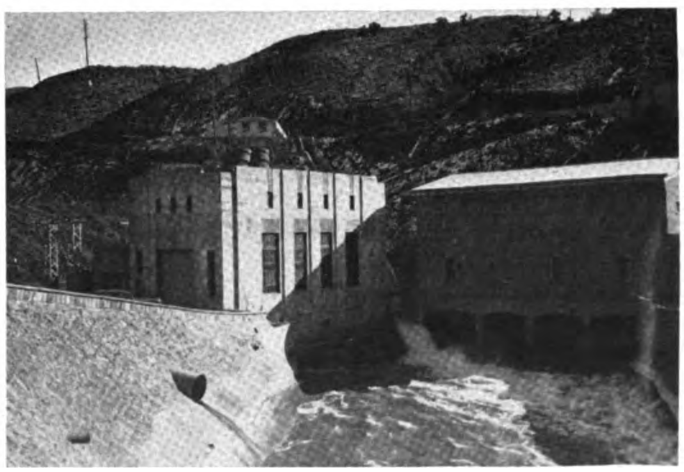
COLORADO RIVER DIVERSION DAM

Bureau of Reclamation completed this dam in 1915 for Grand Valley Project



GRAND VALLEY CANAL

This 55-mile canal carries water to irrigate lands in Grand Valley



GRAND VALLEY POWER PLANT

This plant will furnish necessary energy for pumping irrigation water which the water will flow in the 13-mile newly driven Alva B. Adams tunnel through the Continental Divide, thence through five power plants eventually to be constructed. Carter Lake, Horsetooth, and other reservoirs will regulate the water for irrigation.

Gunnison River.—The Gunnison River and its tributaries, including North Fork and Uncompahgre River, irrigate 238,000 acres of fertile lands in west central Colorado. About 17,000 additional acres will be served when present enterprises are fully developed.

Upstream from Sapinero, 61,600 acres are irrigated along the upper Gunnison River, where lands are high, the growing season is short, water is abundant, and crop values per acre are low.

Fertile soils, good air drainage, careful husbandry, and extensive irrigation developments combine to make the lands along the North Fork River among the most productive in the basin. To irrigate adequately the 56,200 acres now under cultivation an annual diversion of from 3.5 to 5 acre-feet of water for each acre would be required. Only about half of the land now irrigated has a full water supply. Reservoirs and canals have been provided at relatively high cost. Some alterations in the present systems and exchanges of water rights together with new construction will be required for maximum use of the available water resources.

In the valley of the Uncompahgre River 70,400 acres are irrigated by the Uncompahgre project of the Bureau of Reclamation, and an estimated 17,000 acres more will be added when lands that have been drained in recent years are placed in production. A 6-mile tunnel carries water diverted from the Gunnison River west to project lands. The natural flow of the river, supplemented when necessary by storage releases from the upstream Taylor Park Reservoir, provides a full water supply.

Lesser tributaries of the Gunnison, including Cimarron Creek, Crystal Creek, Smith Fork, and Forked Tongue Creek irrigate substantial areas. These areas do not receive an adequate supply, particularly in the late-growing season. Water is pumped from the lower Gunnison to about 3,100 acres of land in Grand Valley, southeast of Grand Junction.

Three small ditches export water from the Gunnison River Basin across the Continental Divide to the Arkansas River and Rio Grande Basins.

Colorado River between Gunnison and Green Rivers.—Little land is irrigated directly from the Colorado River between the Gunnison and Green Rivers, but tributary streams serve about 45,600 acres. More than 80 percent of these lands are within the Dolores River Basin and receive water from that stream and its tributaries. About 100,000 acre-feet of water also are diverted westward from the Dolores River to irrigate 30,000 acres of land in Montezuma Valley of the San Juan Basin, and 7,400 acre-feet are diverted from Lost Canyon, a tributary of the Dolores, to 4,600 acres in the Summit project, also in the San Juan Basin.

Summary.—Present irrigation development in the Grand division is summarized in the following tables:

TABLE XLII.—*Irrigation reservoirs in the Grand division* [1]

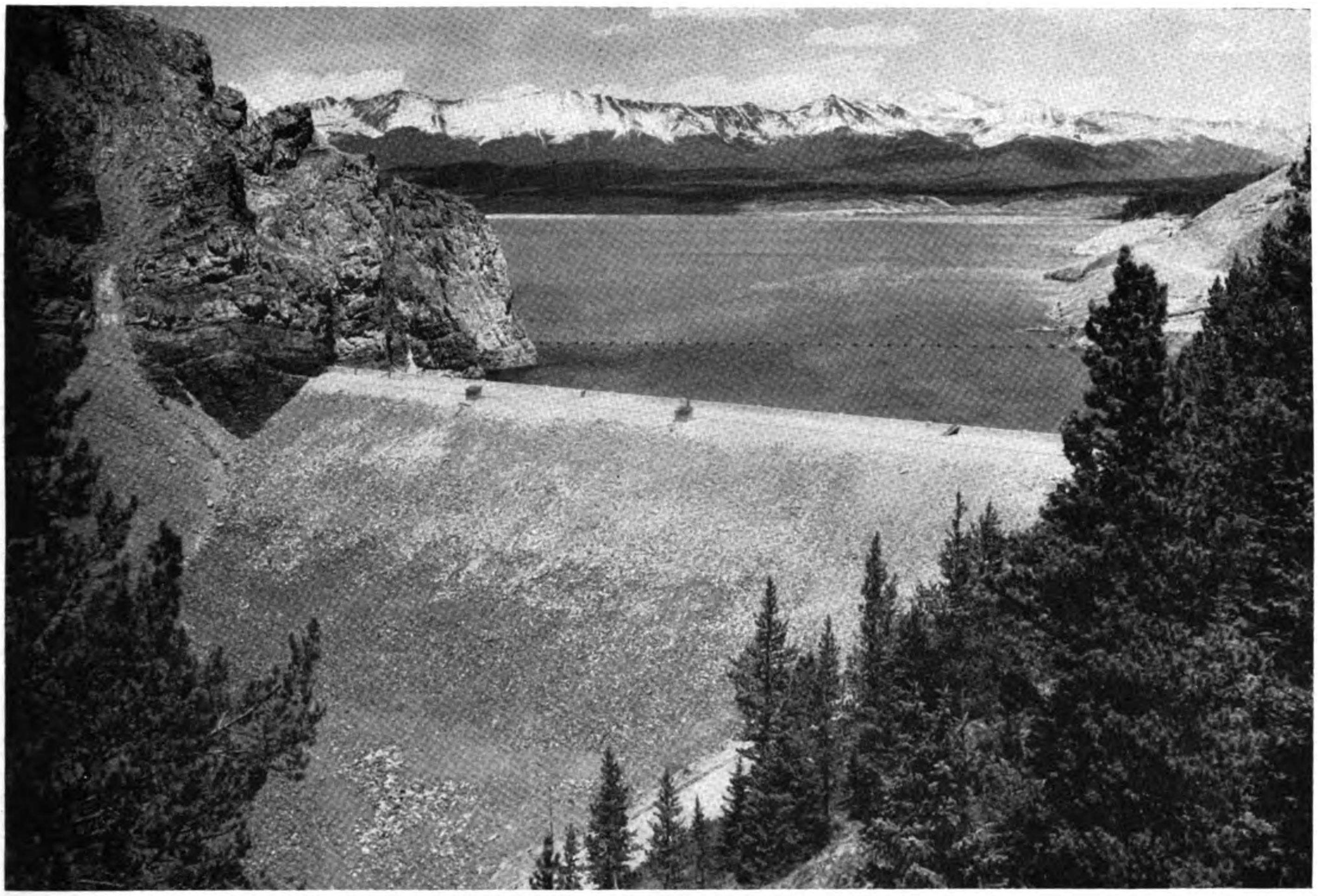
Reservoir	Source of water	Capacity (acre-feet)
Colorado River above Gunnison River		
Granby [2]	Colorado River	546, 400
Williams Fork	Williams Fork River	[3] 6, 300
Green Mountain	Blue River	154, 600
Ivanhoe	Ivanhoe Creek	1, 400
Missouri Heights	Cattle Creek	2, 800
Harvey Gap	East Fork Rifle	4, 800
Big Creek No. 1	Big Creek	2, 700
Big Creek No. 3	do	1, 800
Big Creek No. 7	do	1, 500
Leon Lake	Leon Creek	3, 000
Cottonwood Lake No. 1	Cottonwood Creek	2, 800
Gunnison River Basin		
Taylor Park	Taylor River	106, 000
Fruitland	Crystal Creek	4, 800
Overland	Cow Creek	2, 600
Fruitgrowers	Surface and Currant Creeks	4, 600
Park	Surface Creek	3, 200
Eggleston Lake	Kiser Creek	2, 700
Barron	do	1, 000
Deep Ward	Ward Creek	1, 400
Island Lake	do	1, 100
Cedar Mesa	Surface Creek	1, 000
Colorado River between Gunnison and Green Rivers		
Lake Hope	Lake Fork of San Miguel	2, 300
Trout Lake	do	2, 740
Lone Cone	Naturita and Brewster Creeks.	1, 830
Gurley	Beaver Creek	3, 200
Buckeye	Deep and Geyser Creeks	2, 000
Ground Hog	Beaver, Little Fish, and Ground Hog Creeks.	22, 000

[1] Includes only reservoirs with capacities of more than 1,000 acre-feet; all reservoirs are in Colorado.
[2] Authorized, dam not yet constructed.
[3] Enlargement planned by city of Denver.

TABLE XLIII.—*Present irrigated areas in the Grand division by States*

Subdivision	Acres irrigated		
	Colorado	Utah	Total
Colorado River above Gunnison River	[1] 271, 670	0	[1] 271, 670
Gunnison River	[2] 255, 000	0	[2] 255, 000
Colorado River between Gunnison and Green River	38, 000	8, 000	46, 000
Total	564, 670	8, 000	572, 670

[1] Includes 15,670 acres to be irrigated from existing projects in Grand Valley.
[2] Includes 17,000 acres of new land to be irrigated under the Uncompahgre project.



TAYLOR PARK DAM IN COLORADO

Reservoir releases supplement irrigation supplies for Uncompahgre project

FISHING AT GREEN LAKES RESORT

Sportsmen find excellent fishing in mountain streams and lakes

TABLE XLIV.—*Estimated present average annual water consumption in Grand division*

Subdivision	Water consumed (acre-feet)		
	Colorado	Utah	Total
Colorado River above Gunnison River	409, 000	0	409, 000
Gunnison River	367, 000	0	367, 000
Colorado River between Gunnison and Green Rivers	65, 000	13, 000	78, 000
Total	841, 000	13, 000	[1] 854, 000

[1] Includes allowance for undeveloped lands under existing projects estimated at 65,000 acre-feet. (See note following table XLIII.)

TABLE XLV.—*Estimated present average annual water exports from Grand division*

Exporting stream [1]	Importing stream	Acre-feet		
		Present	Future increase [2]	Total
Colorado River	South Platte	54, 000	395, 000	449, 000
Do	Arkansas	42, 000	26, 000	68, 000
Gunnison River	do	300	0	300
Do	Rio Grande	2, 000	0	2, 000
Total		98, 300	421, 000	[3] 519, 300

[1] All exportations to Colorado.
[2] Future increase with full development of present and authorized projects.
[3] Does not include 108,000 acre-feet diverted from Dolores River for use in San Juan area of Colorado River Basin.

Potential Development of Water Resources

Thirty-five potential projects for development of water resources in the Grand division are outlined. The irrigation of 224,000 acres of dry arable land and 160,220 acres of cultivated land lacking a full irrigation supply would be possible.

Nine hydroelectric power plants with an aggregate installed capacity of 288,000 kilowatts would be capable of producing nearly 1.6 billion kilowatt-hours of firm energy annually. Several other favorable power sites probably will be located when detailed surveys are made.

Some of the projects would provide municipal and industrial water supplies and recreational opportunities and in addition would benefit fish and wildlife.

Three additional projects would increase by 160,400 acre-feet present diversions to the San Juan area in the Colorado River Basin.

Possibilities exist for exporting annually an average of 1,492,000 acre-feet across the Continental Divide to the Rio Grande, South Platte, and Arkansas Rivers.

Potential projects are discussed under the three subdivisions of the Grand division.

Colorado River Basin above Gunnison River

Of the 14 projects which would expand irrigation by diversion from the Colorado River above Grand Junction, 3 are upstream from Glenwood Springs, 4 are in the Roaring Fork River area, and 7 divert from the main Colorado River or its tributaries between Glenwood Springs and the mouth of the Gunnison River. Two of these projects would increase power production. The water available for export from this subdivision would probably amount to 639,000 acre-feet.

Troublesome project.—This project would serve lands located in Troublesome Creek Valley upstream from Glenwood Springs and northeast of Kremmling, Colorado. Two dams, one to impound 7,500 acre-feet of water at the Rabbit Ear site on Troublesome Creek and another to store 9,000 acre-feet on East Troublesome Creek, together with enlargement and extension of two service canals, would be required to provide water for irrigating 3,600 acres now inadequately supplied and 6,800 acres of new land. With the farm lands all above an elevation of 7,000 feet, a short growing season would limit crops to native grasses.

Muddy Creek project.—Muddy Creek flows south to join the Colorado River at Kremmling. Along its course are 2,520 acres of irrigated native grass land requiring supplemental water and 3,620 acres of irrigable land. A water supply could be provided by constructing a dam to store 7,000 acre-feet at the Barbers Basin site on Muddy Creek and a 17-mile canal to carry water from the reservoir to project lands.

Gore Canyon project.—Below Kremmling, Colo., the Colorado River flows through Gore Canyon where it falls 360 feet in 5 miles. This drop could be used to generate power by the construction of a low diversion dam at the head of the canyon and a tunnel to convey the water to a power plant at the lower end. Upstream regulation at the existing Green Mountain Reservoir on the Blue River and at other reservoirs that might be provided to furnish replacement water for transmountain diversions would help smooth out natural flows for greater firm-power production. With an installed capacity of 30,000 kilowatts, the plant would generate 177 million kilowatt-hours of firm energy annually.

Fourmile project.—Located 8 miles southwest of Glenwood Springs, this project would irrigate 500 acres of new land and 1,400 acres in need of supplemental water. Existing ditches along Fourmile Creek, a tributary of Roaring Fork, could distribute the water, but a dam to store 2,000 acre-feet of water at Fourmile No. 4 reservoir site on Fourmile Creek would be required.

Cattle Creek project.—Only storage would need to be provided to irrigate 900 acres of new land and to furnish 5,500 acres with supplemental water. The lands are located along Cattle Creek, which flows westward to join Roaring Fork, 9 miles above Glenwood Springs. The off-stream Missouri Heights Reservoir of 2,800 acre-feet capacity could be enlarged to a capacity of 9,000 acre-feet and filled by an enlargment of its 2-mile feeder canal from Cattle Creek.

Capitol Creek project.—A new service canal 10 miles long would be required to bring water from Snowmass Creek to 2,000 acres of grass lands now insufficiently irrigated from Capitol Creek. Both Snowmass and Capitol Creeks flow northeast and converge before joining Roaring Fork at Snowmass, 12 miles downstream from Aspen.

Woody Creek project.—Two thousand acres of irrigated land located near the junction of Woody Creek with Roaring Fork, 6 miles south of Aspen, could be furnished ample supplemental water by a new canal 13 miles long diverting from Roaring Fork at Aspen. Native grass is also the principal crop on these lands.

Silt project.—First of five potential developments downstream from Glenwood Spring, the Silt project would require construction of a dam at the Rifle Gap site on Rifle Creek to provide storage for 10,000 acre-feet of water. Reservoir water would be released to present users from Rifle Creek and in exchange an equivalent amount from East Rifle Creek, a tributary, would be diverted southeastward through an improved Grass Valley Canal to supply 1,100 acres of new land and 5,200 acres now partially irrigated near Silt, Colorado.

West Divide project.—This project, located south across the Colorado River from the Silt project, would supply water to 400 acres of new land and 7,700 acres now inadequately irrigated. A 7,000 acre-foot reservoir at the Haystack site on Middle Willow Creek would be provided but no new ditches would be required.

Hunter Mesa project.—On Hunter Mesa, located southwest of Rifle, Colo., and immediately west of lands of the West Divide project are 4,700 acres of dry land and 2,300 acres in need of supplemental water. An adequate water supply could be obtained from Buzzard Creek, a tributary of Plateau Creek, by means of a 10,000 acre-foot storage reservoir at the Owens Creek site on Buzzard Creek and a 27-mile canal to carry water to the lands.

Roan Creek project.—Along Roan Creek, which enters the Colorado River at Debeque, Colo., are 3,100 acres of irrigated land which could be furnished supplemental water by construction of a dam to impound 3,000 acre-feet of water at the Carr Creek site on Carr Creek, a tributary.

Collbran project.—In Plateau Valley in the vicinity of the towns of Collbran, Plateau City, and Mesa are 7,100 acres of new land and 18,900 acres irrigated with only a partial water supply. A 24,000 acre-foot reservoir at the Vega site on Plateau Creek, supplied by a 3-mile canal from Leon and Park Creeks, and two new distribution canals totaling 42 miles in length would provide water for these lands. An alternative plan would utilize part of the water for municipal purposes in the vicinity of Palisade, Grand Junction, and Fruita in Grand Valley.

Grand Valley project extension.—Five thousand acres of arable land above the highline canal of the Grand Valley project near Grand Junction could be supplied irrigation water by pumping from the canal with lifts ranging from 32 to 125 feet.

Cisco-Thompson project.—Scattered tracts of undeveloped arable land extend from Thompson, Utah, eastward across Grand County into Colorado. About 87,000 acres, of which all but 3,500 acres are in Utah, are situated below elevation 4,975 feet. Wedged between the Green and Colorado Rivers but high above both streams, these lands present a difficult problem to irrigation planers. From a reconnaissance investigation a gravity diversion from the Colorado River appears most practicable. The canal would head about three miles upstream from the town of Grand Valley, Colo., and continue on the south side of the river for 34 miles; thence crossing the river by siphon it would continue through a 13-mile tunnel and 140 miles of canal to the land, making its total length nearly 190 miles. High lands in Grand Valley could also be irrigated from this canal making unnecessary the pumping outlined in the Grand Valley project extension. Summer flow of the river would be insufficient to supply both this project and irrigation demands in Grand Valley. To make up deficiencies in Grand Valley, replacement storage could be provided at the Whitewater site 6 miles above the mouth of the Gunnison River, where, without detailed surveys, it is estimated that a dam 200 feet high would impound 1½ million acre-feet. The upper 50 feet of storage would provide full stream regulation. With reservoir outlets 150 feet above the stream, a canal could run to the northeast, delivering water by gravity flow to the existing Grand Valley canal near Paliside, but a 45-foot pump lift would be required to serve the Highline canal. Water released through an outlet in the west abutment of the Whitewater Dam would irrigate 4,700 acres of land in the Redlands area south of Grand Junction. Power could be generated under a minimum head of 150 feet by release of surplus storage water from the reservoir. The power plant would have an installed capacity of 18,000 kilowatts and the annual output would amount to 100 million kilowatt-hours.

Colorado River-Yampa River diversion project.—By diverting surplus waters of the Colorado River at Kremmling, Colo., through a tunnel to the headwaters of the Yampa River, this project would substantially increase the power potentialities of the Yampa and Green Rivers (Green division) and reduce in a lesser amount the potential power output of the Colorado River in the Grand division. It presents an alternative possibility and merits further study.

Potential export diversions.—Surplus water of the Colorado River above the entry of the Gunnison River could be exported eastward across the Continental Divide for use in the South Platte and Arkansas River Basins. With adequate diversion works and replacement storage reservoirs for supplying irrigation requirements in the Colorado River Basin, and either replacement water for power generation or replacement power for the Shoshone plant of the Public Service Co. of Colorado at Glenwood Springs, it is estimated that water would be available for export as follows:

TABLE XLVI.—*Potential export diversions from Colorado River above Gunnison River*

Exporting stream	Importing basin	Estimated average annual amount available for export (acre-feet)
Eagle River and Piney Creek	South Platte	160,000
Blue River	do	290,000
Williams River	do	50,000
Frying Pan River	Arkansas	64,000
Crystal River	do	75,000
Total		639,000

Gunnison River

Future developments outlined for Gunnison River Basin include thirteen projects to irrigate 91,530 acres, produce 176 million kilowatt-hours annually, and serve other purposes. Transmountain diversion projects would export 853,000 acre-feet of water annually to the Rio Grande and Arkansas Rivers.

Tomichi Creek project.—This project would bring into production 3,100 acres of arable dry land and provide supplemental water for 8,300 acres of partially irrigated grass lands along Tomichi Creek, extending upstream from Parlin, Colo., which is 10 miles southeast of Gunnison. A 10,000 acre-foot reservoir at the Upper Tomichi Creek site and a 22-mile canal to reach part of the area would be required. In the event an export diversion project is constructed which would divert water from other tributaries of the Gunnison River into the Tomichi Creek Basin en route to the Arkansas Basin, a larger acreage in the Tomichi Creek Basin could be irrigated.

Cochetopa Creek project.—Twenty-five miles south of Gunnison along Cochetopa Creek, a principal tributary of Tomichi Creek, are 3,900 acres of irrigable land and 4,700 acres of irrigated land requiring supplemental water. A full irrigation supply could be obtained for these lands with a 5,500 acre-foot reservoir at the Banana Ranch site on Cochetopa Creek and a 2,500 acre-foot reservoir at the McDonough site on Los Pinos Creek, a tributary. A new canal would also be required to reach part of the area.

Ohio Creek project.—High lands along Ohio and Antelope Creeks north of Gunnison, Colo., suitable for growing native grasses would be irrigated by this project. About 3,470 acres of new land would be furnished a full supply of water, and 11,300 acres in need of more water, a supplemental supply. Two reservoirs would be required: Lake Brennan (capacity to be enlarged from 376 acre-feet to 3,000 acre-feet) on Anthracite Creek, a tributary of North Fork River, and Castle Creek (6,000 acre-feet capacity) on a tributary of Ohio Creek. A 2.5-mile canal to carry storage releases from Lake Brennan to Ohio Creek and canals to reach the new land would be needed.

Lake Fork project.—On Lake Fork of the Gunnison River 2 miles south of Lake City, Colo., is a potential power site. The development would include a dam near the outlet of Lake San Cristobal creating a reservoir of 29,800 acre-feet capacity and a conduit 2.85 miles long, connecting the reservoir with a power plant in Wade Gulch. Nearby on Henson Creek a low diversion dam at Hidden Treasure Mill would divert the flow into another conduit 2.45 miles long. The flow of both Lake Fork and Henson Creek would be available for power production under a static head of 308 feet. The power plant installed capacity would be 6,000 kilowatts and the annual firm production 12 million kilowatt-hours.

Sapinero project.—Potential transmountain diversions from the headwaters of the Gunnison River would require a reservoir for re-regulation of the flow before it enters the Black Canyon of the Gunnison. A dam at a site near the mouth of Sapinero Creek could also be utilized for power production. A power plant could be constructed at the dam with an installed capacity of 18,000 kilowatts capable of producing 100 million kilowatt-hours each year.

Fruitland Mesa project.—Crystal Creek, flowing southwest joins the Gunnison River about 4 miles upstream from the intake portal of the Gunnison Tunnel of the Uncompahgre Reclamation project. Its waters are diverted northward to lands on the Fruitland Mesa south and west of Crawford, Colo. An additional supply of about 35,000 acre-feet yearly could be brought to Crystal Creek from Curecanti and Sapinero Creeks to the east by means of 30 miles of canal and 3 miles of tunnel. Stream regulation would be provided either in the basins of origin, on Crystal Creek, or by the enlargement of the existing Gould or Fruitland Reservoirs, supplied by a canal from Crystal Creek. A full water supply would be furnished 7,650 acres of new land and 9,590 acres now irrigated would receive supplemental water.

Smith Fork project.—Construction of a 4-mile feeder canal from Smith Fork to supply a 15,000 acre-foot reservoir at the Grand View site south across the creek from Crawford, Colo., and the enlargement and extension of existing distribution canals would make possible the irrigation of 4,230 acres of new land and provide supplemental water to 9,220 acres now insufficiently irrigated, all in the vicinity of Crawford.

Paonia project.—Construction of a dam to store 14,000 acre-feet of water at the Spring Creek site on East Muddy Creek, a tributary of the North Fork of Gunnison River, and the enlargement of a 35-mile distribution canal would bring water to 2,000 acres of new land and supplement present inadequate supplies for 12,700 acres located north of North Fork near Hotchkiss, Colo. This plan is a modification of the Paonia project as previously authorized for construction.

Minnesota project.—This project would require only a 3,000 acre-foot reservoir at the Beaver site on Minnesota Creek to supply water to 2,600 acres of partially irrigated land and 200 acres of undeveloped land located south of North Fork River near Paonia.

Leroux Creek project.—A reservoir with a capacity of 10,000 acre-feet at the Castle site on Deaver Gulch supplied by a 1-mile canal from Leroux Creek would provide water for 3,900 acres of dry land located on Redlands Mesa north of North Fork River near its confluence with Gunnison River. A service canal 8 miles long would be required.

Grand Mesa project.—Currant, Surface, and Tongue Creeks join the Gunnison River a few miles downstream from its confluence with the North Fork. Surplus flows of these streams could provide supplemental water for 18,200 acres of fertile land now irrigated and a full supply for 5,200 acres of good arable land. Construction required would include a dam to store 12,000 acre-feet of water at the Gorsuch Reservoir site on Currant Creek, a 19-mile feeder canal, and a 20-mile distribution canal. In addition, Eggleston Lake on the headwaters of Forked Tongue Creek, which now stores 2,700 acre-feet, would be enlarged to store 3,700 acre-feet.

Ouray project.—The Uncompahgre River, a tributary of the Gunnison River, heads in the San Juan Mountains of southwestern Colorado and in the first 27 miles of its course falls 3,200 feet.

The best power sites are in a canyon near Ouray, Colo. A few miles south of the town an earth dam could be constructed on Red Mountain Creek at Ironton Park creating a reservoir of 21,900 acre-feet to regulate the flow of the creek and to receive the flow of the Uncompahgre River diverted around the mountain side in a conduit.

A power plant down the canyon would receive water from the reservoir under a head of 1,130 feet. Below this plant the Uncompahgre River would be diverted to a second power plant at Ouray where a power head of 750 feet could be utilized. The third and final stage of the power development would be a power plant below Ouray at Bachelor Switch with a head of 475 feet. The total installed capacity of the entire development would be 16,000 kilowatts and the annual firm production 64 million kilowatt-hours.

Regulated power water releases below the Bachelor Switch power plant could be diverted in summer for the irrigation of 9,330 acres of new land and 2,340 acres in need of supplemental water on Log Hill Mesa, northwest of Ridgeway, Colo. A diversion dam and a canal 37 miles long would be required. The Ironton Park Reservoir would also provide some flood control downstream in Uncompahgre Valley.

Redlands project.—Lands on the Redlands Mesa west of Grand Junction, Colo., are irrigated by pumping from the Gunnison River with lifts ranging from 100 to 300 feet. An extension of present facilities within reasonable pump lifts would make possible the irrigation of 1,600 acres of new land.

Potential export diversions.—The Arkansas River Basin and to a small extent the Rio Grande Basin could receive water conveyed across the Continental Divide from headwaters of the Gunnison River. With works to collect and divert the water, including pumps with lifts up to 1,000 feet, and reservoirs from which to replace water required for irrigation and power generation in the Colorado River Basin, the following exportations could be made:

TABLE XLVII.—*Potential Export Diversions from the Gunnison River*

Exporting stream	Importing basin	Estimated average quantity available for export annually (acre-feet)
Gunnison River and tributaries above Gunnison, Colo.	Arkansas	460, 000
Gunnison River and tributaries below Gunnison, Colo.	do	340, 000
Anthracite Creek	do	40, 000
Cebolla Creek	Rio Grande	13, 000
Total		853, 000

Colorado River between Gunnison and Green Rivers

Possibilities for irrigation development in this part of the basin include four projects along the Dolores River, principal tributary of the Colorado River in this area, and two along lesser tributaries. Two main stream power potentialities are also described. Power development possibilities are believed to exist on the Dolores River and its tributaries but have not been investigated. In addition, three diversion projects would benefit lands in the adjoining San Juan division of the Colorado River Basin.

Saucer Valley project.—Disappointment Creek is the first stream to join Dolores River after it flows into San Miguel County. Along the creek are 1,300 acres of irrigated land requiring supplemental water and 5,000 acres of undeveloped land in need of a full supply. This area could be served by a 14,000 acre-foot reservoir at the Custer site on Spring Creek with a feeder canal from Disappointment Creek. Two new service canals would also be required.

Nucla project.—Supplemental water is needed for 5,800 acres of irrigated land located north of San Miguel River near Nucla, Colo. A full supply of water could bring into production 5,700 acres of dry land situated northwest of the town. Water necessary for all of these lands could be provided by construction of dams to store 20,000 acre-feet at the Finch site on Horsefly Creek and 5,000 acre-feet at the Cottonwood site on Cottonwood Creek, and by enlargement and extension of the Colorado Cooperative canal. Both reservoirs would be on tributaries of the San Miguel River. Future water supply studies may show that water from these reservoirs could replace water from other tributaries now used on lands within the project area, thus releasing water from those tributaries for use on lands south of the river in the San Miguel project.

San Miguel project.—A new aqueduct, heading on the south bank of the San Miguel River, 4 miles downstream from Vance Junction could continue west past Fall, Saltado, and Beaver Creeks to the Miramonte and Stone Cabin Reservoirs. The aqueduct could divert natural flows of intercepted streams, including some water now used near Nucla, providing replacement storage can be had at the future Finch and Cottonwood Reservoirs of the Nucla project. Miramonte Reservoir on Naturita Creek would have a capacity of 63,000 acre-feet. Water released from Miramonte Reservoir would supplement present supplies for 14,100 acres and irrigate 33,900 acres of new land in the Dry Creek and Gypsum Creek Valleys and near Norwood and Redvale. Stone Cabin Reservoir to provide 12,000 acre-feet of storage capacity on Dry Creek could store natural and return flows of Dry Creek in addition to that supplied from the feeder canal for use on 7,000 acres of new land along East Paradox Creek. The Gurley Reservoir on Anderson Creek would be enlarged by 7,800 acre-feet to a total capacity of 11,000 acre-feet and its existing feeder canal would be enlarged and extended to Fall Creek. The enlarged reservoir could serve the same area as Miramonte Reservoir.

West Paradox project.—West Paradox Creek originates in Utah and flows southeast to join the Dolores River in Colorado. In its valley are 3,900 acres of irrigated land in need of supplemental water and 5,500 acres of arable dry land. At the present time high ditches bring water from nearby streams to West Paradox Basin where storage is provided at the 2,000 acre-foot Buckeye Reservoir. Full development would require present collecting ditches to be enlarged and extended to bring Taylor Creek into the system. The capacity of Buckeye Reservoir would need to be increased from 2,000 to 9,500 acre-feet and a new service canal constructed.

Dewey project.—The Dewey Dam site is in Utah on the Colorado River 3 miles below the mouth of Dolores River and 16 miles southeast of Cisco, Utah. A dam to raise the present river water surface from an elevation of 4,085 feet up to a maximum surface of 4,405 feet would create a reservoir with a total capacity of 8,200,000 acre-feet and an active capacity of 6,300,000 acre-feet. The reservoir would extend 55 miles up the Colorado River and 20 miles up the Dolores River with 110 square miles of lake surface and a maximum width at the lower end of 12 miles. The Denver and Rio Grande Western Railroad and highways U S 50 and Utah 128 would be relocated out of the flooded area. The town of Cisco, population 53, lies entirely within the reservoir site but if relocated on the reservoir shore line and on both a railroad and a transcontinental highway, it should have ample opportunity to become a resort center. The development would be multiple purpose for silt retention, flood control, recreation, hold-over storage for river regulation, and power production. A power plant at the dam would have an installed capacity of 140,000 kilowatts and could produce 797 million kilowatt-hours of firm energy annually.

Moab project.—A dam on the Colorado River, just above the highway bridge on U S 160 at Moab, Utah, would back the river up to the Dewey Dam site. The present stream elevation at the site is 3,947 feet and the reservoir would have a surface elevation of 4,085 feet and a capacity of 183,000 acre-feet. The town of Moab would not be inundated. The power plant installed at the dam would have a capacity of 60,000 kilowatts and an annual firm production of 344 million kilowatt-hours. The development would be multiple purpose for silt retention, flood control, recreation, hold-over storage, and power development.

Pack Creek project.—Along the lower channel of Mill Creek and continuing up Pack Creek, its tributary, is a 10-mile strip of land which includes 3,150 acres of good soil. Only 1,950 acres, mostly in the downstream portion near Moab, Utah, are irrigated, and these require supplemental water some years. A reservoir of 3,000 acre-feet capacity at a site on Mill Creek located just upstream from the land could store water to supplement existing supplies for the lower portion of the strip and to replace Pack Creek flows which could then be used entirely on the upper part. Also by driving a tunnel 640 feet through a ridge, Mill Creek flows above the reservoir could be diverted to augment the water of Pack Creek in irrigating the upper lands.

Hatch Creek project.—Hatch Creek, known also as Cain Spring Creek and Lockhard Creek, flows northwest and enters the Colorado River 12 air-line miles southwest of Moab. On two of its tributaries, Coyote and East Canyon Creeks, are two promising reservoir sites which have been surveyed by the State engineer of Utah. Below each site are strips of undeveloped and unclassified land which are considered arable by local interests. Water supplies have not been determined but it is probable that 8,500 acre-feet of water could be stored on Coyote Creek and 2,500 acre-feet on East Canyon Creek to supplement natural flows for irrigating about 4,000 acres of land.

Potential diversions to San Juan division.—Present diversions of water from the Dolores River to lands in the

San Juan River Basin, averaging 108,000 acre-feet annually could be increased 38,000 acre-feet by expansion of the existing Montezuma Valley project, and 120,600 acre-feet by construction of the Dolores project, including a dam to impound 185,000 acre-feet at the McPhee site on the Dolores River. Reservoir losses would consume approximately 6,000 acre-feet, reducing actual delivery under the Dolores project to 114,600 acre-feet.

The potential Blanding project would divert water from the head of Indian Creek, the lowest tributary of the Colorado River in the Grand division, to lands in the San Juan division. A 1-year record of stream flow (1928) indicates that an annual diversion of 1,800 acre-feet might be made.

These three projects are more fully described as potential developments in the San Juan division.

Summary

The following tables summarize the plan for ultimate development of the Grand division, showing potential projects and their multiple purposes, estimated costs, potential reservoirs and their capacities, new lands to be irrigated, areas to be furnished a supplemental supply of irrigation water, potential diversions to the San Juan Basin in the Colorado River Basin, potential export diversions, and estimated amounts of water to be consumed and exported by States.

TABLE XLVIII.—*Potential projects in the Grand Division*

Subdivision and project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Colorado River above Gunnison River				
Troublesome	Colorado	Troublesome Creek	I, F	$2,210,000
Muddy Creek	do	Muddy Creek	I, F	500,000
Gore Canyon	do	Colorado River	P	3,800,000
Fourmile	do	Fourmile Creek	I, F	600,000
Cattle Creek	do	Cattle Creek	I, F	430,000
Capitol Creek	do	Snowmass Creek	I	130,000
Woody Creek	do	Roaring Fork	I	170,000
Silt	do	Rifle Creek	I, F	1,320,000
West Divide	do	Middle Willow Creek	I, F	1,300,000
Hunter Mesa	do	Buzzard Creek	I, F	1,500,000
Roan Creek	do	Carr Creek	I, F	610,000
Collbran	do	Plateau Creek	I, F, M	1,940,000
Grand Valley Extension	do	Colorado River	I	415,000
Cisco-Thompson	Utah and Colorado	do.[3]	P, I, F, H, S	34,240,000
Gunnison River				
Tomichi Creek	Colorado	Tomichi Creek	I, F	1,860,000
Cochetopa Creek	do	Cochetopa Creek	I, F	1,150,000
Ohio Creek	do	Anthracite, Castle Creek	I, F	1,080,000
Lake Fork	do	Lake Fork	P, F	1,300,000
Sapinero	do	Gunnison River	P, F	7,800,000
Fruitland Mesa	do	Curecante, Sapinero Creeks	I, F	3,500,000
Smith Fork	do	Smith Fork	I, F	2,200,000
Paonia	do	East Muddy Creek and North Fork	I, F	1,400,000
Minnesota	do	Minnesota Creek	I, F	820,000
Leroux Creek	do	Leroux Creek	I, F	2,800,000
Grand Mesa	do	Currant, Surface, and Tongue Creeks	I, F	1,920,000
Ouray	do	Uncompahgre River	P, I, F	4,100,000
Redlands	do	Gunnison River	I, F	367,000
Colorado River between Gunnison and Green Rivers				
Saucer Valley	do	Disappointment Creek	I, F	940,000
Nucla	do	Horsefly and Cottonwood Creeks	I, F	1,500,000
San Miguel	do	Anderson, Naturita, Dry Creek and San Miguel River.	I, F	6,590,000
West Paradox	do	West Paradox, Deep, and Geyser Creeks.	I, F	640,000
Dewey	Utah	Colorado River	P, F, H, S	38,000,000
Moab	do	do	P, F, H, S	9,900,000
Pack Creek	do	Mill Creek	I, F	775,000
Hatch Creek	do	Hatch Creek	I, F	400,000
Total				138,207,000

[1] Symbols used: I=irrigation, P=power, F=flood control, S=silt retention, H=hold-over storage for river regulation, M=municipal supply.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940.
[3] Half the water required for this project would be diverted from the Gunnison River by exchange.

TABLE XLIX.—*Potential reservoirs in the Grand division* [1]

Subdivision and name of site	Source of water supply	Project served	Total capacity (acre-feet)
Colorado River above Gunnison River			
Rabbit Ear	Troublesome Creek	Troublesome	7, 500
East Troublesome	East Troublesome	do	9, 000
Barbers Basin	Muddy Creek	Muddy Creek	7, 000
Fourmile No. 4	Fourmile Creek	Fourmile	2, 000
Missouri Heights enlargement	Cattle Creek	Cattle Creek	9, 000
Rifle Gap	Rifle Creek	Silt	10, 000
Haystack	Middle Willow Creek	West Divide	7, 000
Owens Creek	Buzzard Creek	Hunter Mesa	10, 000
Carr Creek	Carr Creek	Roan Creek	3, 000
Vega	Plateau Creek	Collbran	24, 000
Gunnison River			
Tomichi	Tomichi Creek	Tomichi	10, 000
Banana Ranch	Cochetopa Creek	Cochetopa	5, 500
McDonough	Los Pinos Creek	do	2, 500
Lake Brennan enlargement	Anthracite Creek	Ohio Creek	3, 000
Castle Creek	Castle Creek	do	6, 000
Lake San Cristobal	Lake Fork River	Lake Fork	29, 800
Sapinero	Gunnison River	Sapinero	200, 000
Grand View	Smith Fork Creek	Smith Fork	15, 000
Spring Creek	East Muddy Creek	Paonia	14, 000
Beaver	Minnesota Creek	Minnesota	3, 000
Castle	Leroux Creek	Leroux	10, 000
Gorsuch	Surface, Tongue and Currant Creeks	Grand Mesa	12, 000
Eggleston enlargement	Surface Creek	do	3, 700
Ironton Park	Uncompahgre River	Ouray	21, 900
Whitewater	Gunnison River	Cisco-Thompson	1, 500, 000
Colorado River between Gunnison and Green River			
Custer	Disappointment Creek	Saucer Valley	14, 000
Finch	Horsefly Creek	Nucla	20, 000
Cottonwood	Cottonwood Creek	do	5, 000
Gurley enlargement	Anderson Creek	San Miguel	11, 000
Miramonte	Naturita Creek	do	63, 000
Stone Cabin	Dry Creek	do	12, 000
Buckeye enlargement	Deep and Geyser Creeks	West Paradox	9, 500
Dewey	Colorado River	Dewey	8, 200, 000
Moab	Colorado	Moab	183, 000
Mill Creek	Mill Creek	Pack Creek	3, 000
Coyote	Coyote	Hatch Creek	8, 500
East Canyon	East Canyon Creek	do	2, 500
McPhee [2]	Dolores River	Dolores	185, 000
Total			10, 641, 400

[1] Does not include reservoirs for potential export diversions.

[2] Water diverted to San Juan Basin within Colorado River Basin.

TABLE L.—*Potential irrigation development in the Grand division*

Subdivision and project	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
Colorado River above Gunnison River				
Troublesome	Colorado	6, 800	3, 600	10, 400
Muddy Creek	do	3, 620	2, 520	6, 140
Fourmile	do	500	1, 400	1, 900
Cattle Creek	do	900	5, 500	6, 400
Capitol Creek	do	0	2, 000	2, 000
Woody Creek	do	0	2, 000	2, 000
Silt	do	1, 100	5, 200	6, 300
West Divide	do	400	7, 700	8, 100
Hunter Mesa	do	4, 700	2, 300	7, 000
Roan Creek	do	0	3, 100	3, 100
Collbran	do	7, 100	18, 900	26, 000
Grand Valley extension	do	5, 000	0	5, 000
Cisco-Thompson	Colorado and Utah	87, 000	0	87, 000
Subtotal		117, 120	54, 220	171, 340
Gunnison River				
Tomichi Creek	Colorado	3, 100	8, 300	11, 400
Cochetopa Creek	do	3, 900	4, 700	8, 600
Ohio Creek	do	3, 470	11, 300	14, 770
Fruitland Mesa	do	7, 650	9, 590	17, 240
Smith Fork	do	4, 230	9, 220	13, 450
Paonia	do	2, 000	12, 700	14, 700
Minnesota	do	200	2, 600	2, 800
Leroux Creek	do	3, 900	0	3, 900
Grand Mesa	do	5, 200	18, 200	23, 400
Ouray	do	9, 330	2, 340	11, 670
Redlands	do	1, 600	0	1, 600
Subtotal		44, 580	78, 950	123, 530
Colorado River between Gunnison and Green River				
Saucer Valley	Colorado	5, 000	1, 300	6, 300
Nucla	do	5, 700	5, 800	11, 500
San Miguel	do	40, 900	14, 100	55, 000
West Paradox	do	5, 500	3, 900	9, 400
Pack Creek	Utah	1, 200	1, 950	3, 150
Hatch Creek	do	4, 000	0	4, 000
Subtotal		62, 300	27, 050	89, 350
Total		224, 000	160, 220	384, 220

TABLE LI.—*Potential irrigation development in the Grand division by States*

State and subdivision	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Colorado			
Colorado River above Gunnison River	33, 620	54, 220	87, 840
Gunnison River	44, 580	78, 950	123, 530
Colorado River between Gunnison and Green Rivers	57, 100	25, 100	82, 200
Subtotal	135, 300	158, 270	293, 570
Utah			
Colorado River above Gunnison River	83, 500	0	83, 500
Colorado River between Gunnison and Green Rivers	5, 200	1, 950	7, 150
Subtotal	88, 700	1, 950	90, 650
Total	224, 000	160, 220	384, 220

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TABLE LII.—*Potential power development in the Grand division*

River basin and project	State	Stream	Power plant installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)
Colorado River				
Gore Canyon	Colorado	Colorado River	30,000	177,000,000
Dewey	Utah	do	140,000	797,000,000
Moab	do	do	60,000	344,000,000
Gunnison River				
Lake Fork	Colorado	Lake Fork	6,000	12,000,000
Sapinero	do	Gunnison River	18,000	100,000,000
Ouray (3 plants)	do	Uncompahgre	16,000	64,000,000
Cisco-Thompson	do	Gunnison	18,000	100,000,000
Total			288,000	1,594,000,000

TABLE LIII.—*Potential diversions to the San Juan division*

Project	State served	Estimated average annual amount available for export (acre-feet)
Montezuma Valley extension	Colorado	38,000
Dolores	Colorado and Utah.	[1] 120,600
Blanding	Utah	1,800
Total		160,400

[1] Includes 6,000 acre-feet evaporation from McPhee Reservoir.

TABLE LIV.—*Potential export diversions from the Grand division* [1]

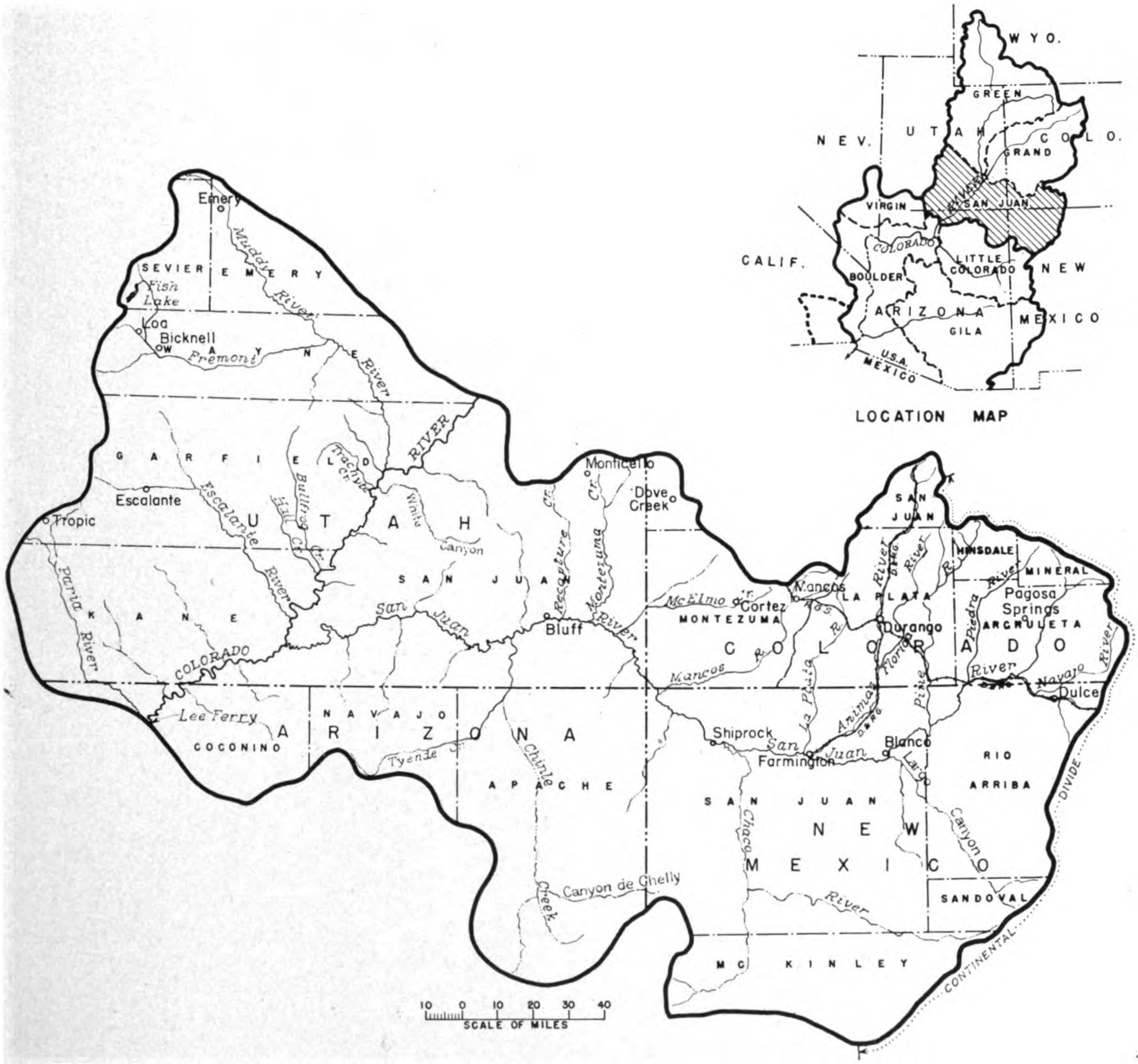
Exporting stream	Importing basin	Estimated average annual amount available for export (acre-feet)
Colorado River above Gunnison River.	South Platte	500,000
Do	Arkansas	139,000
Gunnison River	do	840,000
Do	Rio Grande	13,000
Total		1,492,000

[1] For use in Colorado outside Colorado River Basin.

TABLE LV.—*Present and potential stream depletions in the Grand division*

State and subdivision	Estimated average annual depletion (acre-feet)				
	Present depletion		Potential increase		Total ultimate depletion
	Consumed in basin	Exported	Consumed in basin	Exported	
Colorado					
Colorado River above Gunnison River	[1] 409,000	[2] 517,000	72,000	639,000	1,637,000
Gunnison	[3] 367,000	2,300	104,000	853,000	1,326,300
Colorado River between Gunnison and Green Rivers	65,000	[4] 108,000	119,000	[4] 136,000	428,000
Subtotal	841,000	627,300	295,000	1,628,000	3,391,300
Utah					
Colorado River above Gunnison River	0	0	88,000	0	88,000
Gunnison River	0	0	88,000	0	88,000
Colorado River between Gunnison and Green Rivers	13,000	0	10,000	[4] 24,400	47,400
Subtotal	13,000	0	186,000	24,400	223,400
Total	854,000	627,300	481,000	1,652,400	[5] 3,614,700

[1] Includes 33,000 acre-feet expected to be consumed through expansion of existing projects in Grand Valley
[2] Includes 421,000 acre-feet expected to be exported through completion and expansion of existing projects.
[3] Includes 32,000 acre-feet expected to be consumed through expansion of the Uncompahgre project.
[4] Diverted to San Juan division within the Colorado River Basin.
[5] The Grand division will share also in the depletion of 500,000 acre-feet annually allowed for pasture irrigation in the Upper Basin.



San Juan Division of the Colorado River Basin

San Juan Division

Deeply entrenched in a plateau area the Colorado River meanders southwestward for 220 miles from the mouth of the Green River to Lee Ferry, an air-line distance of 130 miles. The main tributary to this section of the stream is the San Juan River, entering from the east about 80 miles upstream from Lee Ferry. Three small rivers, Fremont, Escalante, and Paria, designated as Western Tributaries, join the Colorado River from the west. The division is roughly rectangular in shape, averaging 300 miles long east and west, and 130 miles wide north and south. Its 39,000 square miles, an area almost as large as Ohio, are 43 percent in Utah, 25 percent in New Mexico, 17 percent in Arizona, and 15 percent in Colorado.

The division includes some mountainous areas where precipitation is heavy and vast stretches of desert plateau. Although it contains 35 percent of the land in the Upper Basin it contributes only 20 percent of the Colorado River flow at Lee Ferry.

Recorded flows of streams within the division for the long-time period of record and the critically dry decade (1931–40) appear in the following table:

TABLE LVI.—*Average annual stream flows in the San Juan division*

Station	Period of record	Average annual flow (acre-feet)	
		For period of record	For 1931–1940 period
San Juan River at Rosa, N. Mex	1921–43	897,000	783,000
Pine River at Ignacio, Colo	1911–43 [1]	271,000	184,000
San Juan River near Blanco, N. Mex	1929–43	1,137,000	998,000
Animas River at Farmington, N. Mex	1905–43 [1]	763,000	532,000
San Juan River at Farmington, N. Mex	1905–43 [1]	2,000,000	1,623,000
San Juan River at Shiprock, N. Mex	1917–43 [1]	2,100,000	1,745,000
San Juan River near Bluff, Utah	1916–43 [1]	2,140,000	1,659,000
Paria River at Lees Ferry, Ariz	1924–43	26,000	25,000

[1] Records incomplete.

Streams originating in the mountains are almost the only source of water for present and potential developments within the division. They are fed mostly by melting snow and consequently the greater portion of the run-off is in the spring, usually during the months of May, June, and July. Stream flows decrease rapidly after the spring floods and usually are lowest during the latter part of July and in August. With few exceptions these low summer flows are now fully utilized and future irrigation expansion is largely dependent on storage of winter and flood season run-off.

Water in the mountain streams is of good quality and has been used for irrigation from 40 to 60 years. Little silt is carried by streams above the irrigated areas except after heavy rains. Below Blanco, N. Mex., the silt load of the San Juan River becomes heavy and is contributed mainly by intermittent tributaries draining the desert area to the south. Floods from summer cloudbursts discharge silt laden torrents into the San Juan River, which in turn delivers to the Colorado River a large portion of the silt that plagues downstream developments. In like manner, Fremont, Escalante, and Paria Rivers pick up silt from desert and badland areas during torrential rains.

Present Development of Water Resources

The present development of water resources in the San Juan division has made possible the irrigation of 214,000 acres of land. Domestic, municipal, and stock-watering uses, although important, consume small quantities of water. Some water is used to generate power at five small hydroelectric plants, having combined installed capacities of 5,100 kilowatts, but is later reused downstream for irrigation.

San Juan River Basin.—Most sections of agricultural importance were once included in Indian reservations, and substantial areas are still under Indian control. United States, however, purchased 3 million acres from the Indians in 1873 and in 1899 opened to white settlers reservation lands unoccupied by Indians. Some Indian allotted lands have been purchased by individual whites.

Between 20,000 and 30,000 acres of Indian lands are now irrigated, the area varying with the seasonal water supply. These lands are widely scattered among numerous projects and are served by Government-built canals. Water storage capacity of 36,000 acre-feet is provided by seven of the larger Indian reservoirs built for use on Indian lands. Some Indian lands also receive water from the Vallecito Reservoir of the Pine River project, constructed by the Bureau of Reclamation.

Most white-owned irrigated lands in the San Juan Basin are reached by the hundreds of canals and ditches built by individual enterprise or group cooperation. The Montezuma Valley projects is the largest development. It brings natural flow from the Dolores River in the Grand division and storage from the 22,000 acre-foot Ground Hog Reservoir on that stream to 32,300 acres in the McElmo Creek drainage area of the San Juan Basin. The Narraguinnep Reservoir stores 9,300 acre-feet of water thus diverted near the irrigated land. Lost Canyon Creek, a tributary of the Dolores River, also provides water for 4,600 acres at the head of McElmo Creek, with storage provided in three small reservoirs.

In 1941 the Bureau of Reclamation substantially completed construction of Vallecito Dam to store 126,300 acre-feet of water on Pine River. The stored water is now being used in part to supplement natural flows on lands under existing canals. Full use will require the extension and rehabilitation of these canals to irrigate new lands. The Bureau is now building a dam on Jackson Gulch, supplied by a feeder-canal from West Mancos River, to provide reservoir capacity for storing 10,000 acre-feet of water to supplement the supply for 10,000 acres now irrigated from the Mancos River and tributaries, and for domestic use at Mesa Verde National Park.

Water resources have been developed to irrigate 184,000 acres in the San Juan River Basin as follows:

	Acres
San Juan River	18,250
Piedra River	4,000
Rio Blanco	1,150
Navajo River	2,000
Pine River	33,100
Florida River	13,800
Animas River	21,700
La Plata River	24,700
Mancos River	10,000
McElmo Creek	38,000
Montezuma, Recapture, and Cottonwood Creeks	7,300
Chinle Creek and Chaco River	10,000
Total	184,000

Except for the Pine River and McElmo Creek areas these lands usually suffer serious late-season water short-

VALLECITO DAM

Vallecito Dam on Pine River was completed by Bureau of Reclamation in 1941

VALLECITO RESERVOIR

Colorado's high San Juan Mountains provide a picturesque setting for Vallecito Reservoir

ages. The Mancos River area will be fully supplied upon completion of construction now under way.

Several small ditches divert annually an average of about 4,000 acre-feet of water from the San Juan River Basin to the Rio Grande Basin. Authorized for construction by the Bureau of Reclamation as a part of the San Luis Valley project is the Weminuche Pass diversion, whereby an open canal from the headwaters of Pine River will divert an average of 21,000 acre-feet annually into the Rio Grande Basin. Replacement storage will be required to protect future developments in the San Juan Basin.

The Western Colorado Power Co's. 4,500-kilowatt Tacoma plant located on the Animas River 20 miles above Durango generates most of the electric energy produced in the San Juan River Basin. Stream flow through the plant is regulated by the off-stream Electra Lake Reservoir of 21,000 acre-feet capacity, supplied from Cascade and Elbert Creeks. Three other hydroelectric plants in the basin have capacities totaling only 450 kilowatts.

Western Tributaries.—In this area about 30,000 acres are irrigated, of which 14,600 acres are served from Fremont River; 8,000 acres from Muddy River, a tributary of the Fremont; 4,400 acres from Escalante River; and 3,000 acres from Paria River. A minor diversion from the Sevier River in the Bonneville Basin to Paria River lands is the only importation of water into the Colorado River Basin. Nearly all canals, ditches, and reservoirs have been constructed by individual or community enterprise. The four largest reservoirs are on the Fremont River and have combined capacities of 14,400 acre-feet. Several smaller reservoirs are distributed throughout the area, but there is insufficient stored water to supply the late-season demands of most lands.

Hydroelectric power is generated at only one small plant in this area having an installed capacity of 150 kilowatts. This plant, supplemented by a small diesel installation, provides energy for the upper Fremont River area. Most other populated areas are served with electricity transmitted from adjoining regions.

Summary.—Present irrigation developments in the San Juan division are summarized in the following tables which show the larger reservoirs, irrigated areas, estimated consumption of water in the division, water imported into the division, and water exported from the division to adjacent basins.

Potential Development of Water Resources

Control and use of present surplus flows of the San Juan division and diversion of an average of 154,400 acre-feet annually from the Grand division could bring a full irrigation supply to 367,160 acres of arable dry land and supplemental water to 73,220 acres now inadequately irrigated. With an installed capacity of 965,000 kilowatts potential power plants in the division could produce 5,115,000,000 kilowatt-hours of firm energy annually. Most all developments would provide, in some degree, other benefits for flood and silt control, recreation, and propagation of fish and wildlife.

Potential transmountain diversions to the Sevier River and Rio Grande Basins would export annually an average

Table LVII.—*Reservoirs in the San Juan division* [1]

Subdivision and reservoir	Source of water supply	State	Capacity (acre-feet)
San Juan River Basin			
Vallecito	Pine River	Colorado	126, 300
Electra Lake	Cascade and Elbert Creeks	do	21, 000
Jackson Gulch [2]	West Fork Mancos River	do	10, 000
Bauer Lake	Chicken Creek	do	1, 070
Summit	Lost Canyon	do	4, 800
Narraguinnep	Dolores River	do	9, 300
Captain Tom [3]	Toadlena Wash	New Mexico	1, 730
Choiska [3]	Choiska Wash	do	1, 000
Juans Lake [3]	Kimenola Wash	do	5, 000
Many Farms [3]	Chinle Wash	Arizona	25, 000
Lower Rock Point [3]	do	do	1, 000
Marsh Pass [3]	Laguna Creek	do	1, 160
Wheatfields [3]	Wheatfields Creek	do	1, 000
Western Tributaries			
Fish Lake	Fremont River	Utah	4, 000
Johnson Valley	do	do	4, 000
Forsythe	do	do	3, 400
Spectacle Lake	Escalante River	do	1, 250
Torgeson	Fremont River	do	3, 000

[1] Includes only reservoirs with capacities of more than 1,000 acre-feet. All are irrigation reservoirs except Electra Lake which is used only for power.

[2] Under construction, Mancos project.

[3] Serves Indian lands.

TABLE LVIII.—*Present irrigated areas in the San Juan division by States*

Subdivision	Area irrigated (acres)				
	Arizona	Colorado	New Mexico	Utah	Total
San Juan Basin	6, 000	132, 300	38, 000	7, 700	184, 000
Western Tributaries	0	0	0	30, 000	30, 000
Total	6, 000	132, 300	38, 000	37, 700	214, 000

TABLE LIX.—*Estimated present average annual water consumption in the San Juan division*

Subdivision	Water consumption (acre-feet)				
	Arizona	Colorado	New Mexico	Utah	Total
San Juan Basin	10, 200	238, 000	68, 400	13, 400	330, 000
Western Tributaries	0	0	0	54, 000	54, 000
Total	10, 200	238, 000	68, 400	67, 400	[1] 384, 000

[1] Deduction of water imported from adjoining basins (See Table) reduces depletion of water originating in the San Juan division, exclusive of exports, to 272,000 acre-feet.

TABLE LX.—*Estimated present average annual water imports into the San Juan division*

State	Importing stream	Exporting stream	Acre-feet
Colorado	McElmo Creek	Dolores River	100, 000
Do	do	Los Canyon Creek	8, 000
Utah	Paria River	Sevier River	[1] 4, 000
Total			112, 000

[1] Only importation of water into Colorado River Basin.

TABLE LXI.—*Estimated present average annual water exports from the San Juan division*

State	Exporting stream	Importing stream	Acre-feet
Colorado	San Juan River Piedra River Pine River	Rio Grande	4, 000
Colorado [1]	Pine River	do	21, 000
Total			25, 000

[1] Weminuche Pass diversion, authorized for construction as a part of the San Luis Valley project.

of 92,000 acre-feet for use in these adjoining areas. Additional exportations are alternatives to irrigation developments in the San Juan division.

San Juan River Basin

Twenty projects, 19 for basin development, and 1 for exportation of water to an adjacent basin are described in the San Juan River Basin. Three alternative export diversion developments are also outlined.

Dulce - Chama - Navajo Project. — A reservoir at the Navajo site on the Navajo River, two low diversion dams, two main canals, and a distribution system would be required to irrigate 15,900 acres of new land, including 3,700 acres along the Navajo and Little Navajo Rivers and in the Coyote Park area of Colorado and 12,200 acres in New Mexico extending from Dulce to and slightly across the low ridge which forms the Continental Divide west of Chama, N. Mex. Supplemental water also would be provided for 1,950 acres now irrigated with only a partial water supply. A reservoir with a capacity of 20,000 acre-feet at the Navajo site would be sufficient for this project but a greater capacity, probably 50,000 acre-feet, would be desirable for joint use with the South San Juan project or the alternative San Juan-Chama diversion project.

South San Juan Project.—South of San Juan River in New Mexico, extending southeast from Bloomfield to the Continental Divide near Cuba and westward from Largo Canyon to Chaco River, is a vast area of undeveloped and unclassified land, part of which is considered arable by local people. The land is high, ranging in elevation from 5,600 feet near the San Juan River to 8,000 feet at the Continental Divide. A reconnaissance indicates that irrigation water could best be supplied by a gravity diversion from headwaters of the San Juan River. The aqueduct would head on the West Fork of the San Juan River in Colorado, run southward to a point near the Continental Divide 15 miles west of Chama, N. Mex., continue southwest along the west slope of the Divide to a point near Cuba, and thence turn northwest onto project lands. The main aqueduct would be nearly 300 miles long. Storage reservoirs would be required on the West and East Forks of the San Juan River and on Rio Blanco and Navajo River. The development probably would be limited by the available water supply to 75,000 acres.

Carracas project.—This project would provide water for 840 acres of new land and 190 acres inadequately irrigated along the San Juan River between Gato (Pagoso Junction) and Arboles, Colo. Construction of a low diversion dam on the river and a canal to carry water to the land would be required.

O'Neal Park project.—The 5,820 acres of new land and 1,780 acres now partially irrigated, possible of development through construction of this project, are located in O'Neal Park and near the head of Stollsteimer Creek west of Pagosa Springs, Colo. A 32,200-acre-foot reservoir (13,600 acre-feet active capacity) at the offstream O'Neal Park site, supplied by a new canal from the Piedra River, and a distribution canal system would be required.

Hammond project.—Natural flow of the San Juan River could be diverted into a future canal at a low diversion dam to be constructed near Blanco, New Mexico, and used to irrigate a 3,700-acre strip of arable dry land on the south side of the river near Bloomfield, New Mexico.

Shiprock project.—A compact area of arable land, comprising 70,000 acres, is located within the Navajo Indian Reservation south of Shiprock, N. Mex., and west of Chaco River. Irrigation of these lands would require a 125,000 acre-foot reservoir (100,000 acre-feet active capacity) at the Arboles site on the San Juan River near the Colorado-New Mexico State line, a diversion dam near Blanco, and a gravity conduit extending 75 miles to the land. A pump lift of 100 feet would be needed to irrigate part of the land above the conduit.

Emerald Lake project.—On the Pine River, a tributary of the San Juan River, is a power site in the San Juan mountains 25 miles northeast of Durango, Colo. Two natural lakes, Emerald and Divide, could be used as reservoirs by the construction of a dam at the outlet of each. With a combination of collection conduits, three short tunnels, a siphon, and penstock the flow would be available for power production under a static head of 1,973 feet. A power plant with an installed capacity of 15,000 kilowatts could produce 72 million kilowatt-hours of firm energy annually. The development would be multiple purpose for power production and flood control.

Pine River project extension.—Surplus flows of Pine River and its tributaries, supplemented by storage from the existing Vallecito Reservoir, could be used to irrigate 15,100 acres of new land owned by both Indians and whites and would provide supplemental water to 1,200 acres now irrigated. Ten thousand acres of this land are located west and southwest of Ignacio, Colo. To serve this area construction of a diversion dam at the head of the existing King Consolidated Canal, north of Bayfield, Colo., and enlargement and extension of that canal would be required. The remaining 5,100 acres are in small tracts scattered throughout irrigated lands in the vicinity of Bayfield, Ignacio, and Arboles, Colo. Rehabilitation and extension of 10 existing canals would be necessary to irrigate these lands.

Florida project.—Along the Florida River and on adjoining mesas in the vicinity of Durango, Colo., are 6,300 acres of new land and 13,800 acres of irrigated land with only a partial water supply. Additional water for full irrigation of these lands could be provided by construction of a dam to store 23,300 acre-feet at the Lemon site on the Florida River and enlargement and extension of existing distribution canals.

Animas-La Plata project.—Supplemental water for 24,700 acres of insufficiently irrigated land in the La Plata River Basin and a full supply for 86,300 acres of new land in that basin and adjacent areas, including 25,500 acres under the Monument Rock project on the Navajo Indian Reservation, could be furnished by this project. In addition power could be produced and flood damage would be mitigated. Nine reservoirs would be needed, three of which would be primarily for power production.

A collection aqueduct could bring the flows of Mineral Creek and Cement Creek to the Howardsville Reservoir (54,000 acre-feet capacity) on Animas River which would be connected by a pressure conduit to a 12,000-kilowatt power plant downstream at Silverton, Colo., operating under a static head of 542 feet. Farther downstream on the Animas River between Sultan Creek and Whitehead Gulch is the Silverton Reservoir site (28,000 acre-feet capacity). From this reservoir, water could be released through a tunnel to Lime Creek, where a reservoir (30,000 acre-feet capacity) could be provided to receive this regulated flow plus unregulated inflows from Cascade Creek through a collection conduit and tunnel. From Lime Creek a short tunnel through West Needle Mountain would lead to a power plant on the Animas River where the static head would be 1,155 feet and the installed capacity 40,000 kilowatts.

The two power plants in this development would have installed generating capacities aggregating 52,000 kilowatts and annual firm production of 192 million kilowatt hours. A reconnaissance survey of other tributaries of the San Juan River would probably reveal additional power sites.

The Teft Reservoir (140,000 acre-feet capacity) on the Animas River, 20 miles north of Durango, would collect water released in the winter from the three power reservoirs. Heading at the Teft Reservoir, the main project canal would continue on the west side of the Animas River intercepting flows of Hermosa, Junction, and Lightner Creeks and storage releases from the Hermosa Park Reservoir (25,000 acre-feet capacity) on Hermosa Creek. The canal would cross the Animas-La Plata Divide northeast of Fort Lewis College and extend across the La Plata River Valley to the Dry Side area, serving lands along its course. It would continue thence southwest along the Mancos-La Plata Divide to the head of Salt Creek, which creek in turn would supply the Monument Rocks Reservoir (19,800 acre-feet capacity) and project lands below it, located north of Shiprock. Long Hollow Reservoir (14,000 acre-feet capacity), 12 miles southwest of Durango, would be connected with the La Plata River by inlet and outlet canals. Another canal diverting from Long Hollow Creek would irrigate the McDermott-Farmington Glade area near the Colorado-New Mexico State line. State Line Reservoir (32,000 acre-feet capacity), astride the State line on La Plata River, would serve valley lands and regulate flows into an outlet canal extending southwest to the Meadows Reservoir (11,400 acre-feet capacity) and to lands in the Meadows area.

McElmo project.—A reservoir of 3,000 acre-feet capacity on Mud Creek would provide adequate water to supplement the supply and improve the quality of water for 1,000 acres of irrigated land in McElmo Canyon, Colo.

Montezuma Valley project extension.—Water from Dolores River in the Grand division now irrigates 30,000 acres of land in Montezuma Valley in the San Juan River Basin. Storage to supplement natural flow is provided at the Ground Hog Reservoir on the headwaters of Dolores River and at the offstream Narraguinnep Reservoir in the San Juan Basin. Expansion of the project to include another 10,000 acres would be possible by enlargement of the Narraguinnep Reservoir to store 5,700 acre-feet in addition to its present 9,300 acre-feet, creation of 8,000 acre-feet of storage at Totten Lake, also in the San Juan Basin, and extension of distribution canals.

Dolores project.—A storage reservoir of 185,000 acre-feet capacity (100,000 acre-feet active capacity) at the McPhee site on the Dolores River in the Grand division about 10 miles below Dolores, Colo., and a canal, leading from that reservoir and crossing the divide into the San Juan Basin by means of a 4,400-foot tunnel, could provide water for 40,000 acres of arable land located in the Dove Creek area. About 32,500 acres are in Colorado and 7,500 acres are in Utah.

Blanding project.—Thirty-eight hundred acres of land on the mesa between Recapture and Cottonwood Creeks in the vicinity of Blanding, Utah, are partially irrigated from direct flows of Recapture Creek. The diversion of water from Indian Creek, a tributary to the Colorado River in the Grand division, and a storage reservoir on Recapture Creek would provide supplemental water to these lands. A collection ditch on the headwaters of Indian Creek, a mile-long tunnel to Recapture Creek, and a 1,000-acre-foot reservoir on Recapture Creek about 6 miles north of Blanding would be required. Construction of the tunnel has been started by local interests.

Navajo Indian projects.—The Office of Indian Affairs has outlined 57 small potential projects in the San Juan Basin to benefit lands in the Navajo Indian Reservation. Five are located in the Red Wash drainage area, 21 in Chaco River Basin, 21 in the Chinle Creek area, 4 along the San Juan River, and 6 in miscellaneous drainage areas. The developments involve the construction of additional canals and offstream reservoirs to store flash flows. By means of these projects supplemental water would be provided for 14,600 acres now irrigated and a full irrigation supply would be furnished to 34,200 acres of new land.

Bluff project.—In the canyon of the lower San Juan River is the Bluff dam site near Comb Wash, 13 miles below Bluff, Utah, at a river elevation of 4,135 feet above sea level. A reservoir capacity of 3,000,000 acre-feet would require construction of a dam to raise the water surface to an elevation of 4,475 feet. A power plant with an installed capacity of 52,000 kilowatts could produce 289 million kilowatt-hours of firm energy annually. The reservoir also would have value for flood control and silt retention.

Goosenecks project.—At a point on the San Juan River 43 miles below Bluff, Utah, at a river elevation of 3,958 feet is the Goosenecks site. A dam to raise the water surface to an elevation of 4,135 feet would provide a reservoir with storage capacity of 500,000 acre-feet. The power plant installed capacity would be 30,000 kilowatts and the annual firm production 152 million kilowatt-hours.

Slick Horn Canyon project.—Named Slick Horn because of the seepage from oil sands that coats the water and canyon walls, this reservoir site is on the San Juan River 70 miles below Bluff, Utah, at river elevation of 3,750 feet. Here a dam could be constructed to raise the water to a maximum elevation of 3,958 feet and form a reservoir with storage capacity of 300,000 acre-feet. The capacity of the power plant would be 30,000 kilowatts and the annual firm production 176 million kilowatt-hours.

Great Bend project.—Thirty miles above the mouth of the San Juan River is the Great Bend reservoir site at elevation 3,498 feet. Backwater from the potential Glen Canyon Dam would flood the site to a maximum reservoir elevation of 3,528 feet. However, much of the time this site would not be flooded as the average Glen Canyon Reservoir elevation would be only 3,461 feet. The Great Bend Dam would raise the reservoir water surface to an elevation of 3,750 feet forming a reservoir with a capacity of 1,000,000 acre-feet. A power plant with an installed capacity of 36,000 kilowatts could produce 203 million kilowatt-hours of firm energy annually. Below this site the San Juan River empties into the colorado River 78 miles above Lee Ferry, Ariz.

Piedra-Rio Grande diversion project.—Two reservoirs in the Piedra River Basin and a tunnel through the Continental Divide would be required to export an average of 85,000 acre-feet of water annually from the Piedra River to the Rio Grande Basin. Replacement storage reservoirs would be necessary to provide water for future developments in the San Juan Basin.

Alternative plans.—Three projects for exportation of waters of the San Juan Basin are possible but allocation of water to them would restrict supplies for some of the other developments outlined for use of water within the basin. For this reason these projects are presented as alternative possibilities but are excluded from the tables summarizing potential basin developments. However, detailed investigations may show construction of some of these to be desirable.

The Animas-Rio Grande diversion project could export annually an average of 130,000 acre-feet of water from the Animas River watershed above Silverton, Colo., to the Rio Grande Basin. Fourteen miles of collecting canal leading to a reservoir of 54,000 acre-feet capacity on the Animas River at Howardsville, Colo., and a 13-mile tunnel through the Continental Divide would be required. There is insufficient water for both this project and the Animas-La Plata project as outlined.

San Juan-Chama diversion project could export 300,000 acre-feet of water annually from headwaters of the San Juan River to the Rio Grande Basin. Reservoirs would be provided on the east and west forks of the San Juan River, and on the Rio Blanco and Navajo River. An aqueduct would collect the water and convey it through the Continental Divide to the head of the Rio Chama, a tributary of the Rio Grande. Benefits from use of this water need not be limited to downstream water users in the Rio Grande Basin in New Mexico, but users in the San Luis Valley of Colorado could also benefit by exchange. As in other potential trans-mountain diversions, replacement storage would be required to compensate San Juan Basin interests. This project would utilize the same water supply as would the South San Juan project, consequently both could not be constructed.

San Juan-South Fork diversion project could export annually an average of 53,000 acre-feet of water from the headwaters of the San Juan River above Pagosa Springs, Colo., ot the south fork of the Rio Grande. The diversion system would consist of a feeder canal 2.6 miles long from the west fork of the San Juan River to Beaver Creek, and a tunnel 10 miles long from Beaver Creek to the south fork of the Rio Grande, with a 1-mile branch tunnel intercepting the flow of Wolf Creek. Water available to the South San Juan project or the San Juan-Chama diversion project would be depleted by the amount diverted to the south fork of the Rio Grande.

Western Tributaries

Three projects for further irrigation development in these stream basins and one for export of water to the adjoining Bonneville Basin are outlined.

Fremont project.—A supplemental water supply for 9,000 acres of irrigated land and a full supply for 1,000 acres of new land located in the vicinity of the towns of Fremont, Loa, Lyman, and Bicknell would be provided by a 4,000-acre-foot reservoir on Fremont River at the Mill Meadows site, 4 miles northeast of Fremont, and a 2,000-acre-foot reservoir on Road Creek, a tributary of Fremont River near Loa.

Torrey project.—A 2,000-acre-foot reservoir at the Torrey site on Fremont River would by exchange furnish supplemental water to 1,200 acres in the vicinity of Torrey, Utah. The reservoir water would be released to downstream lands in exchange for increased upstream diversions to the existing Torrey Canal.

Escalante project. An impounding dam on Escalante River near Escalante, Utah, could provide 25,000 acre-feet of storage capacity (18,000 acre-feet active capacity). With a feeder canal to the reservoir from Pine Creek and an outlet canal cut through a natural embankment on the south side of the reservoir, a full irrigation supply could be furnished 3,000 acres southeast of the town.

Muddy Creek Diversion project.—Lack of storage sites on Muddy Creek to regulate water for downstream use suggests the possibility of exporting surplus flows of that stream west to the Bonneville Basin. By construction of 11 miles of feeder canal and a 2.2-mile tunnel through the mountain divide, an average of 7,000 acre-feet annually could be exported to Twelvemile Creek, a tributary of the Sevier River.

Main stream of Colorado River

Two prospective sites for power developments are located on the main stream of the Colorado River below Green River and above Lee Ferry and therefore are in the San Juan division.

Dark Canyon project.—This dam site on the Colorado River in Utah is 186 miles by river above Lee Ferry, Ariz., and 74 miles by road and trail southeast of Hanksville, Utah. Much of this region is unexplored. The Dark Canyon site has been photographed from the air by the National Park Service and surveyed and photographed by the Geological Survey.

A dam raising the water surface 432 feet from the present river elevation of 3,528 feet up to 3,960 feet would provide a reservoir storage capacity of 1,400,000 acre-feet of which 1,100,000 acre-feet would be active. The reservoir, confined between canyon walls would extend up the Colorado River to the Moab Dam site and up the Green River almost to Green River, Utah. A power plant at the dam with an installed capacity of 350,000 kilowatts could generate 1.8 billion kilowatt-hours of firm energy annually. The project would also have value for silt retention, flood control, recreation and, hold-over storage to satisfy flow requirements of the Colorado River Compact at Lee Ferry.

Glen Canyon project.—A few miles south of the Utah-Arizona State line and 4 miles up the Colorado River from Lee Ferry, Ariz., is the Glen Canyon site at river elevation 3,127 feet. A dam to raise the water surface 401 feet would provide a reservoir of 8,600,000 acre-feet capacity with active storage of 6,300,000 acre-feet. The power plant installed capacity would be 400,000 kilowatts and the annual firm production 2.2 billion kilowatt-hours. The lake would extend 182 miles up the Colorado River to the Dark Canyon dam site and up the San Juan River 30 miles to the Great Bend site. Only 10 miles from highway U. S. 89, this lake would have unusual recreational possibilities. The reservoir would also be useful for silt retention, hold-over storage, and flood control.

An alternative plan would place a higher dam at the Glen Canyon site to raise the water 605 feet above the present streambed. This would create a reservoir of 34,000,000 acre-feet capacity (larger than Lake Mead, 32,360,000 acre-feet capacity) of which 29,000,000 acre-feet would be active capacity. In addition to having value for flood control and silt retention, the reservoir would have tremendous hold-over capacity to assist the upper basin in delivering water at Lee Ferry as required by the Colorado River Compact. A 580,000-kilowatt power plant installed at the dam could generate an average of 3.3 billion kilowatt-hours annually. When full, the reservoir would inundate the Great Bend dam site on the San Juan River, precluding construction at that location, and extend to within 18 feet of the elevation of the Slick Horn Canyon site farther upstream. The Dark Canyon dam site on the Colorado River would be submerged under 204 feet of water. With the potential Dark Canyon development thus eliminated it would be necessary to find other means of developing the 215 feet of head between Moab, Utah, and the Glen Canyon Reservoir.

Summary

Potentialities for the development of water resources of the San Juan division are summarized in the following tables:

TABLE LXII.—*Potential projects in the San Juan division*

Subdivision and project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
San Juan Basin				
Dulce-Chama-Navajo	Colorado	Navajo River	I, F	$1, 627, 000
South San Juan	New Mexico	San Juan River	I, F	35, 000, 000
Carracas	Colorado	do	I	36, 000
O'Neal Park	do	Piedra River	I	880, 000
Hammond	New Mexico	San Juan River	I	725, 000
Shiprock	do	do	I, F	21, 141, 00
Emerald Lake	Colorado	Pine River	P, F	6, 200, 000
Pine River extension	Colorado, New Mexico.	do	I	1, 835, 000
Florida	Colorado	Florida River	I, F	2, 290, 000
Animas-La Plata	Colorado, New Mexico.	Animas and La Plata River	I, P, F, S	63, 534 000
McElmo	Colorado	McElmo Creek	I, F	390, 000
Montezuma Valley extension	do	Dolores River	I, F	1, 300, 000
Dolores	Colorado, Utah	do	I, F, S	12, 200, 000
Blanding	Utah	Recapture Creek	I, F	567, 000
Navajo Indian projects	Colorado	San Juan River	I, F, S	2, 910, 000
Bluff	Utah	do	P, F, S, H	19, 000, 000
Goosenecks	do	do	P, S, F, H	5, 200, 000
Slick Horn Canyon	do	do	P, S, F, H	6, 300, 000
Great Bend	do	do	P, S, F, H	10, 000, 000
Western tributaries				
Fremont	do	Fremont River	I, F	800, 000
Torrey	do	do	I, F	200, 000
Escalante	do	Escalante River	I, F	900, 000
Main stream Colorado River				
Dark Canyon	do	Colorado River	P, F, S, H	105, 000, 000
Glen Canyon	Arizona	do	P, F, S, H	64, 000, 000
Total				362, 035, 000

[1] Symbols used: I=irregation; P=power; F=flood control; S=silt retention; H=holdover storage for river regulation.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE LXIII.—*Potential reservoirs in the San Juan division*

Subdivision and name of site	Source of water supply	Project served	Total capacity (acre-feet)
San Juan Basin			
Navajo	Navajo River	Dulce-Chama-Navajo and South San Juan.	50, 000
West Fork	West Fork San Juan River	South San Juan	70, 000
East Fork	East Fork San Juan River	do	35, 000
Blanco	Rio Blanco	do	15, 000
O'Neal Park [1]	Piedra River	O'Neal Park	32, 200
Arboles	San Juan River	Shiprock	125, 000
Emerald Lake	Pine River	Emerald Lake	6, 000
Divide Lake	do	do	21, 000
Lemon	Florida River	Florida	23, 300
Howardsville	Animas River	Animas-La Plata	54, 000
Silverton	do	do	28, 000
Lime Creek	do	do	30, 000
Teft	do	do	140, 000
Hermosa Park	Hermosa Creek	do	25, 000
Long Hollow [1]	La Plata River	do	14, 000
State Line	do	do	32, 000
Meadows [1]	La Plata and Animas Rivers	do	11, 400
Monument Rocks [1]	do	do	19, 800
Totten Lake [1]	Dolores River	Montezuma Valley extension	8, 000
Narraguinnep Enlargement[1]	do	do	15, 000
McElmo	McElmo Creek	McElmo	3, 000
McPhee	Dolores River	Dolores	185, 000
Recapture	Recapture Creek	Blanding	1, 000
Bluff	San Juan River	Bluff	3, 000, 000
Goosenecks	do	Goosenecks	500, 000
Slick Horn Canyon	do	Slick Horn Canyon	300, 000
Great Bend	do	Great Bend	1, 000, 000
Western tributaries			
Mill Meadows	Fremont River	Fremont	4, 000
Road Creek	Road Creek	do	2, 000
Torrey	Fremont River	Torrey	2, 000
Escalante	Escalante River	Escalante	25, 000
Main stream Colorado River			
Dark Canyon	Colorado River	Dark Canyon	1, 400, 000
Glen Canyon	do	Glen Canyon	8, 600, 000
Total			15, 776, 700

[1] Offstream.

TABLE LXIV.—*Potential irrigation development in the San Juan division*

Subdivision and project	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
San Juan Basin				
Dulce-Chama-Navajo	Colorado, New Mexico	15, 900	1, 950	17, 850
South San Juan	New Mexico	75, 000		75, 000
Carracas	Colorado	840	190	1, 030
O'Neal Park	do	5, 820	1, 780	7, 600
Hammond	New Mexico	3, 700		3, 700
Shiprock	do	70, 000		70, 000
Pine River extension	Colorado, New Mexico	15, 100	1, 200	16, 300
Florida	do	6, 300	13, 800	20, 100
Animas-La Plata	Colorado, New Mexico	86, 300	24, 700	111, 000
McElmo	Colorado		1, 000	1, 000
Montezuma Valley extension	do	10, 000		10, 000
Dolores	Colorado, Utah	40, 000		40, 000
Blanding	Utah		3, 800	3, 800
Navajo Indian projects	Colorado	34, 200	14, 600	48, 800
Subtotal		363, 160	63, 020	426, 180
Western tributaries				
Fremont	Utah	1, 000	9, 000	10, 000
Torrey	do		1, 200	1, 200
Escalante	do	3, 000		3, 000
Subtotal		4, 000	10, 200	14, 200
Total		367, 160	73, 220	440, 380

TABLE LXV.—*Potential irrigation development in the San Juan division by States*

State	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Arizona: San Juan River Basin	18, 680	6, 000	24, 680
Colorado: San Juan River Basin	110, 960	37, 920	148, 880
New Mexico: San Juan River Basin	224, 960	15, 100	240, 060
Utah:			
San Juan River Basin	8, 560	4, 000	12, 560
Western tributaries	4, 000	10, 200	14, 200
Subtotal	12, 560	14, 200	26, 760
Total	367, 160	73, 220	440, 380

TABLE LXVI.—*Potential power development in the San Juan division*

Subdivision and project	State	River	Installed capacity (kilowatts)	Annual firm generation (kilowatt hours)
San Juan River				
Emerald Lake	Colorado	Pine	15, 000	72, 000, 000
Animas-La Plata (2 plants)	do	Animas	52, 000	192, 000, 000
Bluff	Utah	San Juan	52, 000	289, 000, 000
Goosenecks	do	do	30, 000	152, 000, 000
Slick Horn Canyon	do	do	30, 000	176, 000, 000
Great Bend	do	do	36, 000	203, 000, 000
Colorado River				
Dark Canyon	do	Colorado	350, 000	1, 843, 000, 000
Glen Canyon	Arizona	do	400, 000	2, 188, 000, 000
Total			965, 000	5, 115, 000, 000

TABLE LXVII.—*Potential import diversions to the San Juan division* [1]

Subdivision and project	State served	Estimated average annual diversion (acre-feet)	Estimated construction cost [2]
San Juan River Basin			
Montezuma Valley extension	Colorado	38, 000	$1, 300, 000
Dolores	Colorado, Utah	[3] 114, 600	12, 200, 000
Blanding	Utah	1, 800	567, 000
Total		[3] 154, 400	14, 067, 000

[1] All potential diversions are from the Grand division in the Colorado River Basin.
[2] Includes cost of works in exporting basin. Preliminary estimates based on construction costs of Jan. 1, 1940.
[3] Exclusive of 6,000 acre-feet evaporation from McPhee Reservoir.

TABLE LXVIII.—*Potential export diversions from the San Juan division*

Subdivision and project	State served	Estimated average annual diversion (acre feet)
San Juan Basin		
Piedra-Rio Grande	Colorado	85, 000
San Juan-Chama	North Mexico, Colorado	[1] 300, 000
San Juan-South Fork	Colorado	[1] 53, 000
Animas-Rio Grande	do	[1] 130, 000
Western tributaries		
Muddy Creek	Utah	7, 000
Total		92, 000

[1] Alternative projects excluded from estimates of potential stream depletions in San Juan division.

TABLE LXIX.—*Present and potential str eam depletions in the San Juan division* [1]

State and subdivision	Estimated average annual depletion (acre-feet)				
	Present depletion		Potential increase		Total ultimate depletion
	Water consumed	Water exported	Water consumed	Water exported	
Arizona					
San Juan Basin	10, 200	----------	39, 000	----------	49, 200
Colorado					
San Juan Basin	238, 000	[2] 25, 000	251, 000	85, 000	599, 000
New Mexico					
San Juan Basin	68, 400	----------	450, 000	----------	518, 400
Utah					
San Juan Basin	13, 400	----------	19, 000	----------	32, 400
Western tributaries	[3] 50, 000	----------	11, 000	7, 000	[3] 68, 000
Subtotal (Utah)	63, 400	----------	30, 000	7, 000	[4] 100, 400
Total	380, 000	25, 000	770, 000	92. 000	[4] 1, 267, 000

[1] Includes depletions of water originating in the San Juan division, also water imported from the Grand division in the following quantities: Colorado, 108,000 acre-feet, present, and 136,000 acre-feet, potential; Utah, 24,400 acre-feet, potential (San Juan). Excluding imported water San Juan division depletions are, present, 297,000 acre-feet, potential, 701,600 acre-feet; total ultimate, 998,000 acre-feet.

[2] Includes 21,000 acre-feet expected to be exported via Weminuche Pass as a part of the San Luis Valley project.

[3] Does not include depletion of 4,000 acre-feet of water imported from Bonneville Basin.

[4] The San Juan division will share also in the depleting of 500,000 acre-feet annually allowed for pasture irrigation in the upper basin.

Summary—Upper Basin

Present irrigation developments and stream depletions in the upper basin are summarized by States in the tables which follow. Summaries of potential developments with estimated costs based on 1940 prices and potential stream depletions also are shown.

Table LXXIII shows that with full development of existing and potential projects the ultimate average reduction from virgin stream flow at Lee Ferry would exceed 9 million acre-feet. In estimating this probable depletion alternative projects which would compete directly for a water supply with other projects were excluded. However, in a sense, all of the projects are competitive to the extent that the total demand for water exceeds the Colorado River Compact allocation to the upper basin.

Since water-supply studies are based on average flows during the period 1897–1943, wide annual fluctuations from the averages in both natural flows and depletions may be expected. In years of short water supply both basin use and exportations will be limited of necessity to available natural flows except as hold-over storage has been provided. In years when natural flows are abundant, greater quantities will be used and exported and hold-over reservoirs will be filled. The larger main-stem reservoirs provided chiefly for power will be operated on a long-time hold-over basis, being filled during a succession of wet years and emptied to provide firm power and to satisfy compact requirements for water at Lee Ferry during dry periods, such as the 1931–40 decade.

Upstream depletions either from basin use or exportation will affect the amount of water available for the generation of power. The total permissible depletion in the upper basin, however, is subject to limitations of the Colorado River Compact. Estimates of potential power output were made on the basis that enough water would be allowed to flow through the power plants and on to the lower basin to satisfy requirements of the Colorado River Compact and the pending treaty with Mexico. On any particular tributary, power potentialities may be greater or less than estimated, depending on the extent to which upstream water-consuming projects are developed.

TABLE LXX.—*Present irrigated areas in the upper basin*

Division	Acres irrigated					
	Arizona	Colorado	New Mexico	Utah	Wyoming	Total
Green	------------	105, 870	------------	229, 120	[1] 247, 540	[1] 582, 530
Grand	------------	[2] 564, 670	------------	8, 000	------------	[2] 572, 670
San Juan	6, 000	132, 300	38, 000	37, 700	------------	214, 000
Total	6, 000	[2] 802, 840	38, 000	274, 820	[1] 247, 540	1, 369, 200

Includes 11,470 acres of new land in Eden project, authorized for construction.

[2] Includes 32.670 acres irrigable under existing projects.

TABLE LXXI.—*Present hydroelectric generating capacity in the upper basin*

Division	Present installed capacity (kilowatts)					
	Arizona	Colorado	New Mexico	Utah	Wyoming	Total
Green		200		2, 050	150	2, 400
Grand		49, 667		50		49, 717
San Juan		4, 650	280	170		5, 100
Total		54, 517	280	2, 270	150	57, 217

TABLE LXXII.—*Potential development of water resources in the upper basin* [1]

State and division	Acres to be irrigated		Power plants		Estimated construction cost [2]
	New land	Furnished supplemental water	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)	
Arizona: San Juan	18, 680	6, 000	400, 000	2, 188, 000, 000	$65, 628, 000
Colorado:					
Green	197, 800	30, 360	170, 500	944, 000, 000	96, 300, 000
Grand	135, 300	158, 270	88, 000	453, 000, 000	57, 232, 000
San Juan	110, 960	37, 920	67, 000	264, 000, 000	69, 227, 000
Subtotal	444, 060	226, 550	325, 500	1, 661, 000, 000	222, 759, 000
New Mexico: San Juan	224, 960	15, 100	0	0	76, 882, 000
Utah:					
Green	150, 520	145, 010	288, 000	1, 579, 000, 000	116, 500, 000
Grand	88, 700	1, 950	200, 000	1, 141, 000, 000	80, 975, 000
San Juan	12, 560	14, 200	498, 000	2, 663, 000, 000	150, 298, 000
Subtotal	251, 780	161, 160	986, 000	5, 383, 000, 000	347, 773, 000
Wyoming: Green	291, 330	95, 360	1, 500	9, 000, 000	47, 100, 000
Transmission grid					170, 000, 000
Total	1, 230, 810	504, 170	1, 713, 000	9, 241, 000, 000	930, 142, 000

[1] In addition to irrigation and power production, many potential reservoirs would have value for flood control, silt retention, recreation, fish and wildlife conservation, and provide hold-over storage for river regulation.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940. For interstate projects irrigation costs are prorated to States on basis of area irrigated; power costs are allocated to States in which power plants will be located. Does not include costs for potential export diversions.

TABLE LXXIII.—*Present and potential stream depletion in upper basin*

State and division	Estimated average annual depletion (acre-feet)						
	Existing or authorized projects				Potential projects		Total ultimate depletion
	Present depletion		Future increase				
	Consumed in basin	Exported	Consumed in basin	Exported	Consumed in basin	Exported	
Arizona: San Juan	10, 200	0	0	0	39, 000	0	49, 200
Colorado:							
Green	115, 000	0	0	0	324, 000	[1] 75, 000	514, 000
Grand	776, 000	98, 300	65, 000	421, 000	295, 000	1, 492, 000	3, 147, 300
San Juan	238, 000	4, 000	0	21, 000	251, 000	85, 000	599, 000
Subtotal	1, 129, 000	102, 300	65, 000	442, 000	870, 000	1, 652. 000	4, 260, 300
New Mexico: San Juan	68, 400	0	0	0	450, 000	0	518, 400
Utah:							
Green	358, 000	81, 500	0	32, 000	264, 000	975, 700	1, 711, 200
Grand	13, 000	0	0	0	186, 000	0	199, 000
San Juan	63, 400	0	0	0	30, 000	7, 000	100, 400
Subtotal	434, 400	81, 500	0	32, 000	480, 000	982, 700	2, 010, 600
Wyoming: Green	374, 000	0	17, 000	0	489, 000	87, 000	967, 000
Evaporation from power reservoirs					831, 000		831, 000
Reserved for pasture irrigation					500, 000		500, 000
Total	2, 016, 000	183, 800	82, 000	474, 000	3, 659, 000	2, 721, 700	9, 136, 500

[1] Return flow usable in Wyoming.

LOWER BASIN

The Lower Colorado Basin, embracing an area of 121,500 square miles, is twice as large as the six New England States combined. It is slightly larger tha nthe upper basin, on which it is dependent for most of its water supply. With its vast areas of fertile lands and excellent growing climate, the lower basin's demands for water greatly exceed available water resources.

The term "lower basin" is here used to refer not only to areas downstream from Lee Ferry which drain into the Colorado, but also to the drainage basin of the Salton Sea, including Imperial and Coachella Valleys. Diversions to this area are treated as exportations, since from them no water can return to the parent stream.

Present export diversions from the lower basin are made only in California and amount to approximately 2,500,000 acre-feet or more than half of the present depletion of the entire river system below Lee Ferry. Full development under existing or authorized exportation projects, all in California, would more than double present exports. Aside from this possible expansion, only one potential project is described which would take water out of the Colorado River Basin. It involves a diversion of 112,000 acre-feet for municipal use by the city of San Diego.

Water of the Colorado River system is now irrigating 1,351,100 acres in the lower basin which is comparable to the present irrigated area in the upper basin. Full expansion under recently constructed works will increase the irrigated area by 509,000 acres. Potential projects are described in this chapter which, if constructed, would bring water to an additional 303,150 acres and supplement present supplies for 618,100 acres inadequately irrigated.

The construction of Boulder Dam and other appurtenant structures is largely responsible for the vast irrigation expansion still under way. Even more spectacular is the recent increase in hydroelectric power generation. Upon completion of present authorized construction in the lower basin hydroelectric generating capacities will exceed 1,800,000 kilowatts. This capacity would be more than doubled with construction of the potential projects outlined.

Little Colorado Division

Flowing northwest to join the Colorado River midway in its long course to the sea, the Little Colorado River drains 25,000 square miles in northeastern Arizona and west-central New Mexico. Crystal-clear tributary streams rising in the mountains are rapidly absorbed by the thirsty sands of the lower channels. Rain is infrequent but sometimes falls with great intensity. At such times the streams become raging, chocolate-colored torrents, carrying to the main Colorado in 1 year the equivalent of 9 inches of top soil from an entire township.

Vegetation over the basin as a whole is scant. Luxuriant growths, however, are found along river courses where water is available throughout the year, and they consume large quantities of water. It is estimated that over 98 percent of the rain falling in this division is consumed by plants, is lost by evaporation, or percolates underground and does not reappear within the basin.

Water Resources

Surface water.—The following table summarizes the average annual flows past those points where sufficient information is available to permit their computation.

Table LXXIV.—*Average annual stream flows in the Little Colorado division*

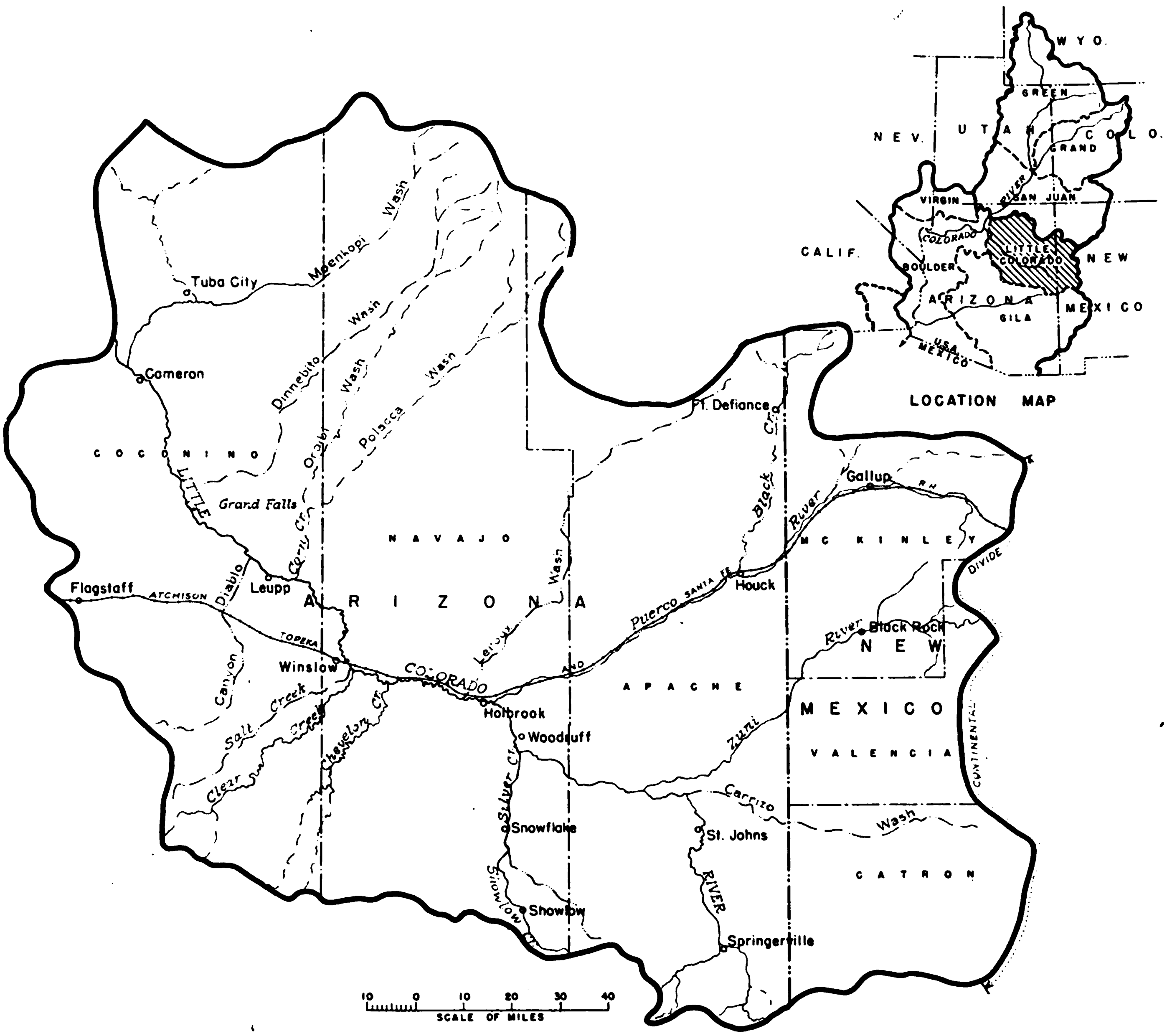
Station	Period of record	Average annual flows (acre-feet)	
		For period of record	For 1931–40 period
Little Colorado River at Grand Falls, Ariz	1926–43	236,700	199,000
Chevelon Creek near Winslow, Ariz	[1] 1930–43	38,800	37,300
Clear Creek near Winslow, Ariz	[1] 1930–43	69,300	61,600
Moenkopi Wash near Tuba, Ariz	1927–43	16,600	13,700

[1] Records incomplete.

The foregoing stations, except that on Chevelon Creek, are downstream from all diversions and represent the surplus flows of the streams in question. During the period of record the irrigated acreage within the basin has been virtually constant.

Stream-flow characteristics over the basin as a whole are similar. The channels contain water the year-round in the higher elevations but receive only intermittent flows in the lower altitudes. Flows over the entire area are erratic and subject to flash floods of great magnitude. The larger part of the annual run-off from the northern tributaries usually occurs during the summer months, while that from the south is somewhat retarded by the heavily vegetated highlands of the Mogollon Rim.

Approximately 55 percent of the average annual flow of Little Colorado River at Grand Falls, Ariz., downstream from all major tributaries except Moenkopi Wash, occurs during the months of February, March, and April, while only 35 percent comes during July, August, and September. Extremes in fluctuation occurred in 1938 when there was no flow in the stream for 213 days, while in March of that year a flood of 38,000 second-feet was recorded. Undependable stream flows make hold-over storage a prerequisite for maximum irrigation development.



Little Colorado Division of the Colorado River Basin

Ground water.—Little is known about the ground water resources of the basin. The scarcity of existing wells and the absence of accurate data on wells preclude definite conclusions as to the location and extent of ground waters. The very fact that no exploitation has been made of this resource in a country where water is such a valuable commodity would indicate the lack of possibilities.

Small artesian areas are known to exist in some portions of the basin. Two such areas are found south of the Little Colorado River, one southwest of Holbrook, Ariz., and the other northwest of Hunt, Ariz. In the absence of more complete geological and water level information, it is impossible to determine accurately the extent of these areas or the existence of other artesian belts, or to predict potenial yields. It appears, however, that the artesian water resources are small and cannot be expected to furnish any large quantities of irrigation water.

Nonartesian water is often found in sandstones, in lava flows, and in sands and gravels along major streams. Frequently water is at great depths, particularly when found in the sandstones. All known pumped wells are used for domestic, public, stock watering, or railroad purposes. Irrigation with pumped water is not practiced to any appreciable extent in the division. There is no evidence which indicates that the ground-water resources of this basin are of sufficient importance to be considered as a potential source of water for irrigation development.

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Quality of water.—Surface flows of water in this division are of good quality near their points of origin. As the water progresses downstream, however, it flows through formations that are high in soluble salts, thus becoming unsuited for irrigation use near the mouths of the streams. Mineral springs, in places, contribute large quantities of dissolved salts to the waters of the streams. Near Winslow, Ariz., several springs discharge an average of 20 tons of salts daily into the flows of both Chevelon and Clear Creeks. Salt concentrations in the waters range from virtually zero near the headwaters to as high as 3,000 and 4,000 parts per million in the lower Little Colorado River. Waters of the Little Colorado are of questionable quality between St. Johns and Holbrook, Ariz., and are entirely unsuited for irrigation use below the latter town.

The quality of the ground water in the basin varies widely with location. Chemical analyses show water from different wells varying from 100 to 6,000 parts per million total dissolved solids. The more saline water is not suitable for irrigation use. In general, wells containing the poorest quality water are located in shale-sandstone formation or in the sands and gravels of Cottonwood Wash, Leroux Wash, or the Little Colorado River bottoms.

Present Development of Water Resources

General.—Early settlers in the division learned through bitter experience that it was impossible for them to control the rivers except in a few selected localities. Settlers gradually migrated to the more readily irrigated areas, and development progressed without a coordinated plan and without knowledge of the wide variations in annual stream flow to which the rivers are subject. During wet periods far more land was brought under irrigation than could possibly be supplied during periods of drought. Subsequent years of deficient stream flow brought economic and even physical suffering. This was especially true in the upper Little Colorado River area, where over-development progressed to the point where a court decree was necessary to establish relative priorities. As a result, virtually all of the waters of this area have been apportioned. Only during extreme floods does any water escape the region.

Development of the surface water resources on the Indian reservations has followed a somewhat different pattern. Irrigation projects have been planned, constructed, and operated under the supervision of the Office of Indian Affairs. Agricultural development has been adapted, insofar as possible, to the needs and temperament of the Indians. Individual holdings are small, and dry farming is practiced to some extent with little success. Flood-irrigated lands, or areas which receive water only during times of flood, are extensively cultivated. Despite the planning, supervision, and assistance of the Office of Indian Affairs, serious problems have arisen because the Indian population is continually increasing.

Irrigation.—The climate of the basin is such that irrigation is essential for successful agriculture.

The principal areas irrigated in the division are:

	Acres irrigated
Little Colorado River above St. Johns	15, 180
Silver Creek Basin	4, 360
Woodruff area	520
Holbrook-Joseph City area	1, 520
Winslow area	610
Upper Zuni River	6, 770
Scattered areas	19, 040
Total	[1] 48, 000

[1] Includes Indian lands: 5,560 acres in the upper Zuni River Basin, 2,540 acres in scattered areas, and 16,500 acres under flood irrigation.

Irrigation is accomplished chiefly by gravity diversions from the main stream. About three-fourths of the white irrigated land is served through the facilities of 13 irrigation companies. The remaining one-fourth is irrigated by individuals.

There is no import or export of water by transmountain diversions.

Power development.—The character of the stream flow in the area does not lend itself to the development of power. In addition, there is little market for power owing to the scattered population and the lack of industrial development. There are only two hydroelectric generating plants in the Little Colorado division capable of producing firm power. The combined installed capacity of these plants is 125 kilowatts. Steam and Diesel plants scattered through the area have a total installed capacity of approximately 3,000 kilowatts.

Drainage.—Some areas of the division have become waterlogged and have been taken out of production. As these areas should never have been in production, no effort has been made to drain them. On a whole the topography has reduced drainage problems to a minimum on most of the irrigated areas.

Flood control.—Most of the lands lying in the flood plains of this division are undeveloped and unimproved. Hence, the rampant floods to which the area is subject cause relatively little damage except for occasional removal of diversion dams. In only a few independent areas do floods endanger developments. The swollen streams, however, transport large quantities of silt into the Colorado River. Existing rservoirs in the Little Colorado division were neither constructed nor are operated for flood control; however, they afford a certain amount of protection.

Summary.—The following tables summarize present development of water resources in the Little Colorado division:

TABLE LXXV.—*Existing reservoirs in the Little Colorado division* [1]

Reservoir	Source of water	Location	Purpose served	Capacity (acre-feet)
Lyman	Little Colorado River	Arizona	Irrigation	21, 900
Lake Mary	Walnut Creek	do	Municipal	18, 900
Lone Pine	Showlow Creek	do	Irrigation	14, 000
Udall	Carrizo Wash	do	Irrigation, stock	9, 530
Daggs	Silver Creek	do	Irrigation	5, 170
Upper Lake Mary	Walnut Creek	do	Municipal	5, 080
Soldiers Annex Lake	Canyon Diablo	do	Irrigation, stock	5, 000
Chevelon	Chevelon Creek	do	Irrigation	4, 300
White Mountain No. 1	Hall Creek	do	do	2, 390
River No. 3	Little Colorado River	do	do	1, 670
New Scott	Porter Creek	do	do	1, 200
Lakeside	Showlow Creek	do	Irrigation, power	1, 200
Concho Lake	Concho Creek	do	Irrigation, stock	1, 200
Hog Wallow No. 4	South Fork	do	Irrigation	1, 000
Pine Lake	Showlow Creek	do	do	1, 000
Zuni	Zuni River	New Mexico	do	13, 000
Rescad	do	do	Domestic, irrigation	8, 720
Ramah	do	do	Domestic, stock	1, 170

[1] Includes only reservoirs with capacities of more than 1,000 acre-feet.

TABLE LXXVI.—*Present irrigated areas in the Little Colorado division*

Area	Acres irrigated		
	Arizona	New Mexico	Total
Silver Creek Basin	4, 360	0	4, 360
Holbrook-Joseph City area	1, 520	0	1, 520
Winslow area	610	0	610
Other	32, 740	8, 770	41, 510
Total	39, 230	8, 770	48, 000

TABLE LXXVII.—*Estimated percent average annual depletions in the Little Colorado division*

Area	Depletions (acre-feet)		
	Arizona	New Mexico	Total
Silver Creek Basin	6, 500	0	6, 500
Holbrook-Joseph City area	2, 300	0	2, 300
Winslow area	900	0	900
Other	49, 000	13, 000	62, 000
Total	58, 700	13, 000	71, 700

POTENTIAL DEVELOPMENT OF WATER RESOURCES

Opportunities for development in the Little Colorado division are largely confined to four areas. One potential project is outlined for each of these areas. The potential Bridge Canyon project on the Colorado River, discussed in this chapter under the Boulder division, would bring power into the Little Colorado division.

Although the Coconino dam site is located on the Little Colorado River downstream from the Little Colorado division, construction of a dam at this site would form a reservoir extending into the division. The Coconino Dam is discussed in this chapter under the Boulder division.

Snowflake project.—This development in Silver Creek Basin would include the diversion of water from Showlow Creek through a 2-mile tunnel into a storage reservoir of 25,000 acre-feet capacity at the Shumway site. At the reservoir the waters of Showlow Creek would be commingled with those of Silver Creek and distributed to about 6,700 acres of new lands lying on both sides of Silver Creek in the vicinity of Snowflake, Ariz. A portion of the 2,000 acres now irrigated would be supplied water through the facilities of the new system. The irrigation structures planned would have some incidental flood-control benefit.

Black Creek project.—Construction of a reservoir at the Black Creek site near Houck, Ariz., would provide 48,600 acre-feet of irrigation storage capacity. Releases to the natural channel of Black Creek would be diverted into a canal north of the Puerco River. A siphon crossing of the Puerco River would convey the water to a distribution system serving 4,000 acres along the south bank of that stream. This project is an alternative to an upstream irrigation development within the Navajo Indian Reservation in Arizona and New Mexico, for which the Office of Indian Affairs holds prior water rights. Either plan would have about the same depletory effect upon stream flows.

Holbrook project.—Along the Little Colorado River near Joseph City, Ariz., are 1,800 acres of new land and 600 acres now inadequately irrigated which would receive water from this project. Storage would be provided in a reservoir at the Fork site on Little Colorado River just below the mouth of Silver Creek. Of its total capacity of 117,000 acre-feet, 75,000 would be for silt retention. A canal diverting from this reservoir would parallel the river on the south side to a point 4 miles west of Holbrook, where a siphon would carry the water across the river into a canal leading to the project lands. Incidental channel improvements resulting from construction of this project, together with the regulatory effect of silt and irrigation storage, would provide some flood protection for downstream property.

Winslow project.—This development would utilize the waters of Clear and Chevelon Creeks for the irrigation of 19,750 acres of new lands, including 5,000 acres of Indian lands and 14,750 acres of white-owned lands, all on the north side of the Little Colorado River in Arizona. Construction of the Willow Creek Dam on Clear Creek would provide for storage of 45,000 acre-feet of water, and construction of Wildcat Dam on Chevelon Creek would impound another 49,000 acre-feet for irrigation use. Because of the steep-walled canyons in which the streams are entrenched, tunnels heading at diversion weirs would be necessary to convey water to the canals leading to the project lands. In addition, a siphon crossing under the Little Colorado River would be required.

Summary

The following tables summarize potential development in the Little Colorado division, showing various purposes to be served by potential projects, estimated construction costs, potential reservoirs, and present and potential stream depletions.

TABLE LXXVIII.—*Potential projects in the Little Colorado division*

Project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Snowflake	Arizona	Showlow and Silver Creek	I, F, S	$2, 600, 000
Black Creek	do	Black Creek	I, F, S	1, 800, 000
Holbrook	do	Little Colorado River	I, F, S, C	1, 300, 000
Winslow	do	Clear and Chevelon Creek	I, F, S	19, 000, 000
Total				24, 700, 000

[1] Symbols used: I=irrigation, P=power, F=flood control, S=silt retention, C=channel improvement.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE LXXIX.—*Potential reservoirs in the Little Colorado division*

Name of site [1]	Source of water supply	Project served directly	Total capacity (acre-feet)
Shumway	Showlow and Silver Creeks	Snowflake	25, 000
Black Creek	Black Creek	Black Creek	48, 600
Forks	Little Colorado	Holbrook	117, 000
Willow Creek	Clear Creek	Winslow	45, 000
Wildcat	Chevelon Creek	Winslow	49, 000
Total			284, 600

[1] All in Arizona.

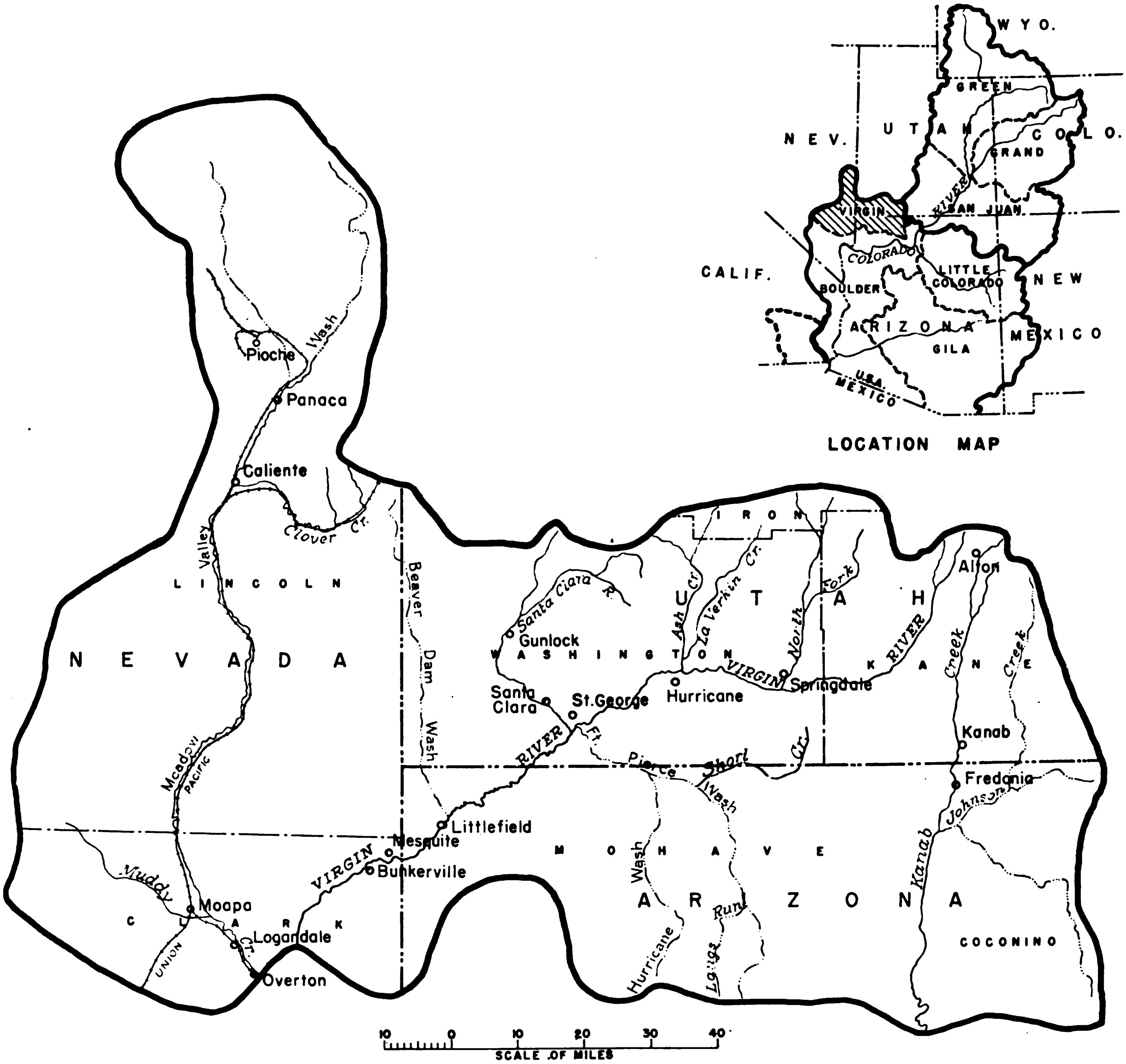
TABLE LXXX.—*Potential irrigation development in the Little Colorado division*

Project [1]	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Snowflake	6, 700	0	6, 700
Black Creek	4, 000	0	4, 000
Holbrook	1, 800	600	2, 400
Winslow	19, 750	0	19, 750
Total	32, 250	600	32, 850

[1] All projects in Arizona.

TABLE LXXXI.—*Present and potential stream depletions in the Little Colorado division*

State subdivision	Estimated average annual depletion (acre-feet)		
	Present depletion	Potential increase	Total ultimate depletion
Arizona:			
Silver Creek Basin	6, 500	10, 000	16, 500
Black Creek Project	0	6, 000	6, 000
Holbrook-Joseph City area	2, 300	2, 700	5, 000
Winslow area	900	30, 000	30, 900
Other areas	49, 000	0	49, 000
Subtotal	58, 700	48, 700	107, 400
New Mexico (all areas)	13, 000	0	13, 000
Total	71, 700	48, 700	120, 400



Virgin Division of the Colorado River Basin

Virgin Division

The Virgin River is flanked on the east by Kanab Creek and on the west by Muddy River. All three streams flow south or southwest to the Colorado River. The Virgin and Muddy Rivers once joined before reaching the Colorado, but both now discharge separately into Lake Mead, the reservoir formed by Boulder Dam. Kanab Creek enters the Colorado River in Grand Canyon National Park. The combined drainage areas of these tributaries in Arizona, Nevada, and Utah constitute the 12,700 square miles of the Virgin division.

Water Resources

Surface water.—The principal streams, fed chiefly from springs and melting snow, head in the high plateaus and mountains bounding the area on the north. Except for several springs and occasional freshets from summer rains, the proportionately large areas at lower and intermediate elevations contribute little run-off.

The discharge rate of several major springs in the division is nearly uniform throughout the year. All other stream flows are erratic and fluctuate widely from season to season and from year to year. Storage regulation, therefore, is necessary for maximum utilization of water. High spring run-off from melting snow usually ends in May or June. Low flows then continue well into the fall. Occasional freshets or floods occur in all seasons of the year; in winter and spring from heavy rain or rapidly melting snow or both, and in summer and fall from localized torrential rains.

The average annual virgin flow of the Virgin River at Littlefield, Ariz., near its mouth is estimated at 310,000 acre-feet. Recorded flows of streams at various points are shown in the following table. Unfortunately there are no discharge records of Kanab Creek and Meadow Valley Wash, the principal tributary of Muddy River.

TABLE LXXXII.—*Average annual stream flows in the Virgin division*

Station	Period of record	Average annual flow (acre-feet)	
		For period of record	For 1931–1940 period
North Fork of Virgin River near Springdale, Utah	1926–1943	78,000	78,000
Virgin River at Virgin, Utah	1910–1943	162,000	142,000
Virgin River at Littlefield, Ariz	1930–1943	204,000	189,000
Santa Clara River below Gunlock, Utah	1939–1943	22,000	[1] 19,000
Muddy River at head of Moapa Indian Reservation, Nevada	[2] 1917–1943	--------	[1] 31,000

[1] Estimated.
[2] Records incomplete.

Ground water.—Many small springs and seeps scattered through the area have been developed for stock watering and domestic purposes, and all the larger springs are utilized for irrigation. Other than the discharge of springs, ground water is of limited importance. A few small wells in alluvial-filled valleys are operated for irrigation and domestic purposes. There are no known ground-water basins having large contributing drainage areas, and the possibilities of further ground-water development for irrigation are believed to be insignificant.

Quality of water.—Waters of the upper portion of the Virgin River and of all its northern tributaries are of suitable chemical quality for irrigation use. These waters have been used for many years for irrigation, and no detrimental effects to crops have been apparent.

Below La Verkin, Utah, mineral springs contribute to the Virgin River large quantities of water which are highly charged with mineral salts, chiefly carbonates, sulphates, and chlorides of calcium, magnesium, and sodium. At Littlefield, Ariz., near the mouth of the river, mineral springs contribute an average of 60 second-feet of water, which constitutes most of the low flow of the stream. This water is unsatisfactory for domestic use. Only because a high percentage of the mineral content is gypsum is the water at all usable for irrigation, and then only for the more salt-tolerant crops.

Waters of Kanab Creek and Meadow Valley Wash are of good chemical quality and have long been used for irrigation. Muddy River waters, derived principally from springs, are of fairly good quality for irrigation.

Silt content of streams in the Virgin division is fairly low in the headwaters at nearly all times and also in the lower reaches during ordinary low flows. Freshet and flood flows, however, are high in silt content.

PRESENT DEVELOPMENT OF WATER RESOURCES

General.—Although the total run-off during the low-flow season is now fully utilized for irrigation and some shortages are experienced, the major part of the stream flow during the nonirrigation and high spring run-off seasons escapes from the area unused. Plans for development of portions of this surplus water for irrigation have been proposed from time to time and there has been some effort toward promotion of projects, but no successful developments therefrom have as yet materialized.

Domestic water for communities is obtained for the most part from springs, and nearly all communities have municipal distribution systems. Some community domestic supplies are pumped from wells. Outlying farmsteads obtain domestic supplies from privately owned springs, irrigation ditches, small wells, or by hauling from distant sources. Many seeps and springs have been developed for stock watering, and many watering ponds have been constructed on the ranges for capture of occasional surface run-off.

Irrigation.—Irrigation was early expanded to the limits of natural stream flow, and by 1905 some streams were overappropriated, with shortages resulting in low run-off seasons. The high cost of potential projects has precluded any material development of new systems by local interests for irrigation of additional lands in the area since about 1905. Present storage development is practically negligible.

Approximately 36,100 acres are irrigated in the Virgin division, of which 23,500 acres are in Utah, 2,800 acres are in Arizona, and 9,800 acres are in Nevada. These areas include 400 acres of Indian lands; the Office of Indian Affairs estimates that 700 additional acres of Indian lands in existing developments will be irrigated ultimately. Irrigated acreage varies somewhat from year to year depending upon fluctuations in stream flow as well as economic conditions. All irrigation development has been accomplished by individuals and mutual irrigation companies.

Nearly all irrigation developments are simple gravity diversions without storage regulation. Some small areas are served by pumping. About 15,000 acres of the total irrigated area have a fairly adequate water supply. The remaining area suffers frequent water shortages of varying degree. No water is imported into the division and only one small diversion is made out of the area. This diversion is from the headwaters of Santa Clara River to Pinto Creek in the Bonneville Basin.

Power development.—Stream flow is used for power production at five hydroelectric plants in the area. One plant of 1,000-kilowatt capacity is located on the Virgin River at La Verkin, Utah, and three plants with combined capacities of 1,890 kilowatts are located on Santa Clara River near Veyo and Gunlock, Utah. These four plants are owned and operated by the Southern Utah Power Co., which supplies electric energy to most of the communities in the Utah portion of the division. The fifth plant is the recently installed St. George municipal plant located on the pipe line diverting municipal water from springs at the head of Cottonwood Creek, 15 miles northwest of St. George. This plant has a capacity of 550 kilowatts, and its output is augmented by two diesel installations at St. George, having a combined capacity of 800 kilowatts. Communities in the Nevada portion are served with power from the Boulder Dam power plant.

Summary.—Irrigated areas and estimated amounts of water consumed in the Virgin division are summarized in the following tables:

TABLE LXXXIII.—*Present irrigated areas in the Virgin division*

Stream	Acres irrigated			
	Arizona	Nevada	Utah	Total
Virgin River	1, 800	2, 800	19, 600	24, 200
Muddy River	0	7, 000	0	7, 000
Kanab Creek	1, 000	0	3, 900	4, 900
Total	2, 800	9, 800	23, 500	36, 100

TABLE LXXXIV.—*Estimated present average annual depletions in Virgin division*

Stream	Depletions (acre-feet)			
	Arizona	Nevada	Utah	Total
Virgin River	3, 600	9, 800	38, 000	51, 400
Muddy River	0	14, 000	0	14, 000
Kanab Creek	1, 500	0	7, 000	8, 500
Total	5, 100	23, 800	45, 000	73, 900

POTENTIAL DEVELOPMENT OF WATER RESOURCES

The major water-use problem in this division is that of providing storage regulation of the available stream flow to secure a full supply for lands now inadequately irrigated and for as large an additional irrigable area as is practicable. Such development would help to stabilize irrigated agriculture, relieve the local population pressure, and enlarge the livestock feed base so as to attain more nearly a balance in industry of the area.

Kanab Creek project.—Storage on the main streams of either Kanab Creek or its tributary, Johnson Creek, is impracticable because of the high silt discharge of these streams. New development is limited to offstream storage of the comparatively silt-free, nonirrigation season flows of Kanab Creek, which are derived essentially from springs emerging in the stream bed several miles above the town of Kanab. To provide such storage a reservoir of 1,400 acre-feet capacity at the offstream State Line site would be fed a water supply from Kanab Creek through a short extension of the existing Kanab canal. The stream flow thus diverted and stored would furnish a supplemental supply for 1,000 acres of land near Fredonia, Ariz.

Hurricane project.—A reservoir of 165,000 acre-feet total capacity (65,000 acre-feet active and 100,000 acre-feet reserved for silt) on Virgin River at the Virgin City site 3 miles northeast of Hurricane, Utah, together with a 27-mile canal extending southwest from the reservoir, would furnish a supplemental supply for 6,500 acres of land now insufficiently irrigated and a full supply for 14,000 acres of new land, all in the Hurricane-St. George Valley in Utah and Arizona. The existing 1,000-kilowatt power plant at La Verkin, Utah, dependent on erratic river flow, would be abandoned, and power would be developed at three new plants having a combined capacity of 4,600 kilowatts and a combined head of 800 feet. In addition to meeting power replacement and project pumping needs, these plants would produce about 15,000,000 kilowatt-hours of firm power annually. The reservoir would also have incidental value for flood control, silt retention , fishing, and recreation.

Santa Clara project.—Full regulation and utilization of the flow of Santa Clara River, the principal Virgin River tributary, could be obtained by means of an 18,000-acre-foot (14,000 acre-feet active capacity) reservoir at the Lower Gunlock site on that stream. A supplemental water supply for irrigating 1,700 acres of land in need of more water and a full supply for 2,000 acres of new land in Utah under existing canals would be provided. The reservoir would have incidental value for flood and silt control and for fishing and recreation.

Panaca Valley project.—Irrigation development in the Muddy River Basin is limited by available water. A 48,000-acre-foot reservoir at the Delmue site on Spring Creek near its mouth (the head of Meadow Valley Wash) 7 miles northeast of Panaca, Nev., would provide storage for irrigation water and flood control. A new 10-mile canal would carry this water to 2,000 acres of land in need of a supplemental supply and 2,000 acres of new land. The reservoir would have incidental value for fishing and recreation.

Moapa Valley project.—A reservoir of 9,500 acre-feet capacity at the White Narrows site on Muddy River would provide water storage regulation to furnish a supplemental water supply for 2,500 acres and a full supply for 1,500 acres of new land in Moapa Valley, Ariz. This reservoir would also provide 2,500 acre-feet of storage for flood control and silt retention. Rehabilitation of the present distribution system and drainage of project lands would be included in the project development.

Moapa Valley Pumping project.—This development would provide an irrigation supply for 6,000 acres of new land in the Muddy River drainage area by pumping from Lake Mead. The first pump would lift the water 130 feet to a canal 22 miles long. A second pump would lift the water an additional 105 feet where half the flow would be diverted in a 5-mile canal. A third pump would lift the remaining flow another 80 feet to a canal 10 miles long.

Summary

The following tables summarize potential development of water resources in the Virgin divisions, including the various purposes to be served by potential projects, estimated construction costs, areas to be irrigated, and stream depletions.

TABLE LXXXV.—*Potential projects in the Virgin division*

Project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Kanab Creek	Arizona	Kanab Creek	I	$200,000
Hurricane	Utah, Arizona	Virgin River	I, P, S, F	9,200,000
Santa Clara	Utah	Santa Clara River	I, F, S	1,700,000
Panaca Valley	Nevada	Meadow Valley Wash	I, F	1,300,000
Moapa Valley	do	Muddy River	I, F, S	700,000
Moapa Valley pumping	do	Lake Mead	I	2,800,000
Total				15,900,000

[1] Symbols used: I-irrigation, P-power, S-silt retention, and F-flood control.
[2] Preliminary estimates based on construction cost of Jan. 1, 1940.

TABLE LXXXVI.—*Potential reservoirs in the Virgin division*

Name of site	Source of water supply	Project served	Total capacity (acre-feet)
State Line	Kanab Creek	Kanab Creek	1,400
Virgin City	Virgin	Hurricane	165,000
Lower Gunlock	Santa Clara	Santa Clara	18,000
Delume	Meadow Valley Wash	Panaca Valley	48,000
White Narrows	Muddy Creek	Moapa Valley	9,500
Total			241,900

TABLE LXXXVII.—*Potential irrigation development in Virgin division*

Project	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
Kanab Creek	Arizona	0	1,000	1,000
Hurricane	Utah, Arizona	14,000	6,500	20,500
Santa Clara	Utah	2,000	1,700	3,700
Panaca Valley	Nevada	2,000	2,000	4,000
Moapa Valley	do	1,500	2,500	4,000
Moapa Valley pumping	do	6,000	0	6,000
Total		25,500	13,700	39,200

TABLE LXXXVIII.—*Potential irrigation development in the Virgin division by States*

State	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Arizona	3, 000	1, 000	4, 000
Nevada	9, 500	4, 500	14, 000
Utah	13, 000	8, 200	21, 200
Total	25, 500	13, 700	39, 200

TABLE LXXXIX.—*Potential power development in the Virgin division*

Project	Name of power plant	River	Installed capacity (kilowatts)	Annual generation (kilowatt-hours)
Hurricane	Virgin	Virgin	2, 000	12, 900, 000
Do	Bench Lake	do	800	5, 200, 000
Do	Warner Valley	do	1, 800	14, 700, 000
Total			4, 600	[1] 32, 800, 000

[1] Net firm generation would be 15,000,000 kilowatt-hours in addition to replacement of power from the 1,000-kilowatt La Verkin, Utah, plant, project pumping needs, and secondary energy.

TABLE XC.—*Present and potential stream depletions in the Virgin division*

State and subbasin	Estimated average annual depletion (acre-feet)		
	Present depletion	Potential increase	Total ultimate depletion
Arizona			
Virgin River	3, 600	12, 000	15, 600
Kanab Creek	1, 500	700	2, 200
Subtotal	5, 100	12, 700	17, 800
Nevada			
Virgin River	9, 800	0	9, 800
Muddy River	14, 000	15, 000	29, 000
Colorado River	0	21, 000	21, 000
Subtotal	23, 800	36, 000	59, 800
Utah			
Virgin River	38, 000	56, 300	94, 300
Kanab Creek	7, 000	0	7, 000
Subtotal	45, 000	56, 300	101, 300
Total	73, 900	105, 000	178, 900

Boulder Division

The Boulder division, roughly 450 miles long and 150 miles wide, embraces 48,600 square miles in Arizona, California, and Nevada. It includes not only the area which drains into the Colorado River below Lee Ferry, excluding areas tributary to the Little Colorado River above Moenkopi Wash, Kanab Creek, Virgin River, Muddy River, and the Gila River above Sentinel, but the valley containing the Salton Sea, whose drainage is not tributary to the Colorado River and whose diversions therefore constitute exports from the basin.

The Colorado River enters the division from the northeast at Lee Ferry, weaves its way west and south for 350 river miles, then flows south 358 miles emerging from the Boulder division at the Mexican border. The Williams River, formed by the confluence of Big Sandy and Santa Maria Rivers in west central Arizona and entering the Colorado just above Parker Dam, is the only major stream rising in the Boulder division.

WATER RESOURCES

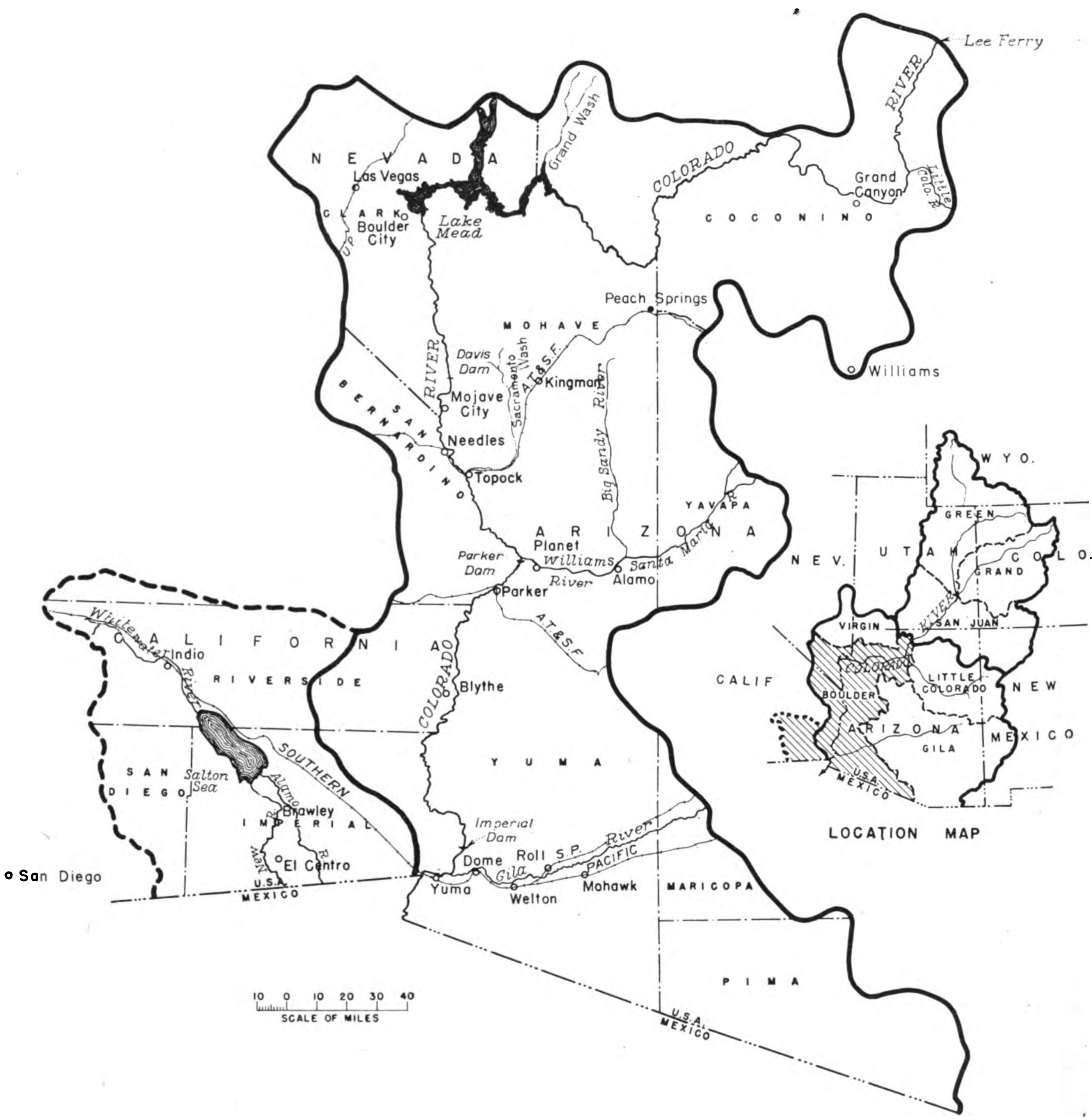
Surface water.—Gage height records of the Colorado River at Yuma, Ariz., have been maintained continuously since 1878, although discharge measurements date only from 1902. During later years other measuring stations have been established on the main stream and tributaries. The average annual virgin flow of the Colorado River at Lee Ferry, based on the period 1897–1943, is estimated at 16,270,000 acre-feet. The virgin flow for the Gila River near Dome, Ariz., is estimated to be 1,270,000 acre-feet. The average annual flows of the Colorado River and two of its tributaries as recorded at various points in the Boulder division are as follows:

TABLE XCI.—*Average annual stream flows in the Boulder division*

Station [1]	Period of record	Average annual flows (acre-feet)	
		For period of record	For 1931–40 period
Colorado River at Lees Ferry	1921–43	12, 727, 900	10, 142, 000
Colorado River at Bright Angel	1922–43	12, 977, 000	10, 520, 000
Colorado River near Topock	1917–43	13, 740, 000	[2] 7, 729, 000
Colorado River at Yuma	1903–43	13, 316, 000	[2] 5, 709, 000
Williams River at Planet	1928–43	116, 000	125, 400
Gila River near Dome	1930–43	84, 600	57, 900

[1] All in Arizona.
[2] Filling of Lake Mead was started in 1935, which accounts for the low average flow at these gaging stations.

About 67 percent of the annual run-off of the Colorado River occurs during the period April to July inclusive. Regulation by reservoirs is necessary to permit full utilization of the water. Large storage reservoirs also provide protection from floods, which normally occur during the spring period from melting snow, but occasionally come in late summer or early fall with torrential downpours.



Boulder Division of the Colorado River Basin

At present the flow of the Colorado River exceeds the requirements of the irrigated lands, but future developments should be limited to the available water supply.

Flows from the Williams River are erratic and subject to flash floods of great magnitude. During the 10-year period, 1931 to 1940, the annual flows varied from 11,800 to 307,000 acre-feet.

The Gila River channel is dry at Dome, Ariz., for long periods. No flow is recorded at this station some years. Occasionally torrential rains cause large floods.

Ground water.—Ground water occurs in this division in the valleys of the Colorado River and the lower Gila River. The Las Vegas Valley in southern Nevada and the Coachella Valley in the Salton Sea Basin in southern California have benefited from use of ground water.

Of the 250 producing wells in the Las Vegas area in

1938, about 75 percent were artesian. The depth of the wells drilled varied from 150 to over 1,150 feet. Lack of conservation of the artesian water has depleted the available supply, especially in the upper artesian sands.

The development of the Coachella Valley, also an artesian-well basin, has been almost continuous since the first well was drilled in 1898. However, the placing of new lands under irrigation recently has caused a serious drawdown of the ground-water level in the basin.

Other developments of irrigated lands by wells exist in the Colorado and lower Gila River Valleys, the most important of which is the Wellton-Mohawak area in southwestern Arizona. Supplies of ground water in this area are replenished by the flood waters of the Gila River. Developments on the upper Gila watershed have greatly reduced the amount of flood water reaching these downstream areas. In recent years the ground water supply has decreased and its salt content has increased. As a consequence, an unsatisfactory economic condition exists in this area.

Quality of water.—Water of the lower Colorado River is suitable for irrigation use. Before the completion of Boulder Dam and the subsequent storage of water in Lake Mead, the content of dissolved material in the water tended to fluctuate with the various flows. Generally, high flows were relatively low in total dissolved solids and low flows were high. Since the lake has filled, the outflow water is fairly constant in dissolved solid content, averaging annually about 680 parts per million. As it progresses downstream, however, the content of dissolved solids in the river water increases somewhat until at Yuma, the total dissolved solids average about 700 parts per million. Water of this quality is suitable for irrigation and domestic use. Although the calcium carbonate content makes the water hard, thus requiring more soap for cleansing purposes, it is of benefit to the sandy soils of the southwestern desert lands. When water of this quality is used for irrigation, the calcium ions present in the water replace to some extent the sodium ions in the soil. This tends to improve soil structure by making it more granular or flocculent, as well as more friable.

The silt content of the waters of the Colorado River has been greatly reduced by the construction of Boulder, Parker, and Imperial Dams. During the years 1911 through 1934, before the construction of these dams, the river carried an average annual silt load of 179,920,000 tons at the Yuma sampling station. For the years 1936 through 1942, the average annual silt load of the river at the same point was 13,100,000 tons.

Silt problem.—Water entering the Boulder division at Lee Ferry carries immense quantities of silt. The San Juan River, largest of the southern tributaries of the upper basin, contributes about one-quarter of the silt passing Grand Canyon, and the northernmost tributary of the lower basin, the Little Colorado, accounts for about one-sixth more. From Lee Ferry to the upstream end of Lake Mead, the Colorado River, falling approximately eight feet per mile, is continuously cutting its course, even through the hard rocks of the canyon. Silt originates not only from stream cutting in the channels of the river and its important tributaries, but also from general erosion. The rate of land reduction through erosion in the Colorado River Basin is the highest of any stream basin in the United States.

Lake Mead receives the silty load of both the Colorado and the Virgin Rivers. Storage capacity in Lake Mead is being reduced an estimated 137,000 acre-feet a year by the deposition of this silt.

The clear water discharged from Lake Mead picks up and transports downstream a considerable amount of river bed material, progressively lowering the bed for the first 88 miles. An estimated 100 million cubic yards had been removed by the end of 1943. From 1941 through 1943 about 35 million cubic yards were deposited in the next 32-mile stretch downstream. A large but unknown amount of material has been carried beyond this stretch and deposited in Havasu Lake, the reservoir formed by Parker Dam. For a long period prior to Boulder Dam the river deposited some of its silt load in these same sections, causing a rise in the water surface elevation averaging annually about 0.35 feet in the vicinity of Needles and about 0.55 feet at the Topock gaging station.

A similar condition of cutting out and redepositing has taken place below Parker Dam. Clear water leaving Parker Dam has scoured out bottom material and lowered the river bed elevation for 93 miles downstream, and beyond that point the river bed has been raised.

By early 1944 the water surface at the diversion of the Palo Verde irrigation district had been lowered by river retrogression to such an extent that a full diversion into the district's canal became impractical.

Between Imperial Dam and Laguna Dam little change in river conditions has taken place, but below Laguna Dam some 30 million cubic yards of material have been removed from the river banks and bed since January 1940. All material passing the Imperial Dam sluiceway, as well as that from the Gila River, has been transported downstream.

Controlling the silt load of the Colorado River and its tributaries to prevent damage is an important phase of water conservation for beneficial use. Silt control is especially desirable upstream from Lake Mead, where the Colorado River alone carries each year about 180 million tons of silt, which, when deposited, occupies a volume estimated at 110,000 acre-feet. Obviously, therefore, any plan of development must provide adequately for sediment storage. The possibility of removing sediment deposits by sluicing holds little prospect for success.

Present Development of Water Resources

General.—Boulder Dam and Lake Mead, with over 32 million acre-feet of storage capacity, provide the key to present and future development of water resources in the division. Water stored here is released as required for irrigation, for power development, and for domestic uses. The lake acts as a desilting basin, clarifying the muddy Colorado and making it fit for human consumption; it catches and, to a great extent, subdues the floods which pour down the river channel; and in addition it furnishes an unexcelled water playground in the desert. For complete development and regulation of the river, however, other dams should be built above Boulder.

Davis Dam, on the Colorado River 67 miles below Boulder with its reservoir of 1,600,000 acre-feet capacity, will serve many purposes by reregulating the releases from Boulder Dam. Construction of this dam, temporarily halted by an order of the War Production Board, is scheduled to be resumed in 1946.

Below Davis Dam are four diversion dams: Parker, for the Metropolitan Water District of Southern California; Headgate Rock, for the Colorado River Indian Reservation; Imperial, for the All-American Canal System and the Gila project; and Laguna, for the Yuma project. Although the latter three are primarily for diversion purposes, small amounts of power are generated at plants either at the dams or in the canals below. The Parker power plant is an important unit in the power network of the area.

Prior to the construction of Boulder Dam, all irrigation from the river was dependent on natural stream flow; now, however, storage water is used to supplement natural flow for most of the irrigated areas.

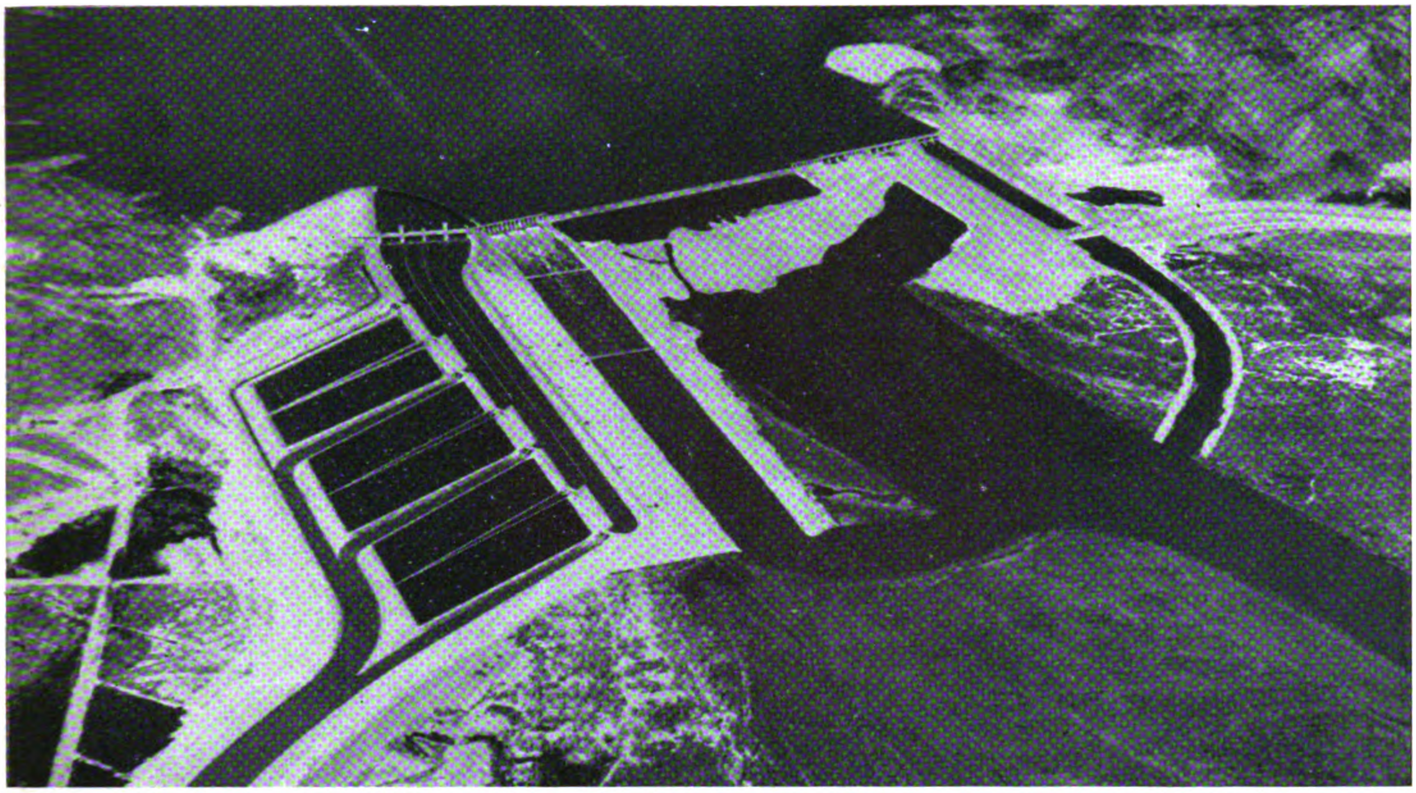
Irrigation.—The Colorado River Indian irrigation project is the first major irrigation development downstream from Boulder Dam. Irrigation has been practiced on this reservation since the seventies, first by gravity ditch diversions which later failed, then by pumping, and since June 1942 by diversion at the newly completed Headgate Rock Diversion Dam and Main Canal. Works are now completed to irrigate 9,400 acres. The system is designed ultimately to irrigate 100,000 acres.

Palo Verde irrigation district lands are located along the Colorado River in California mainly in southeastern Riverside County but with a small area extending into Imperial County. Distribution works have now been constructed by the district to deliver water to 75,000 acres. This district in recent years has experienced difficulty in diverting its required water because of silt deposits in the intake canal and the lowering of the river channel at the headgate by scouring. By 1943 the channel had lowered to such an extent that it was evident the district would not be able to maintain its gravity diversion, and an appeal was made to the Bureau of Reclamation for assistance. The Bureau subsequently constructed a temporary rock weir to raise the water surface to a sufficient height for diversion into the district's canal, pending a permanent solution of the problem.

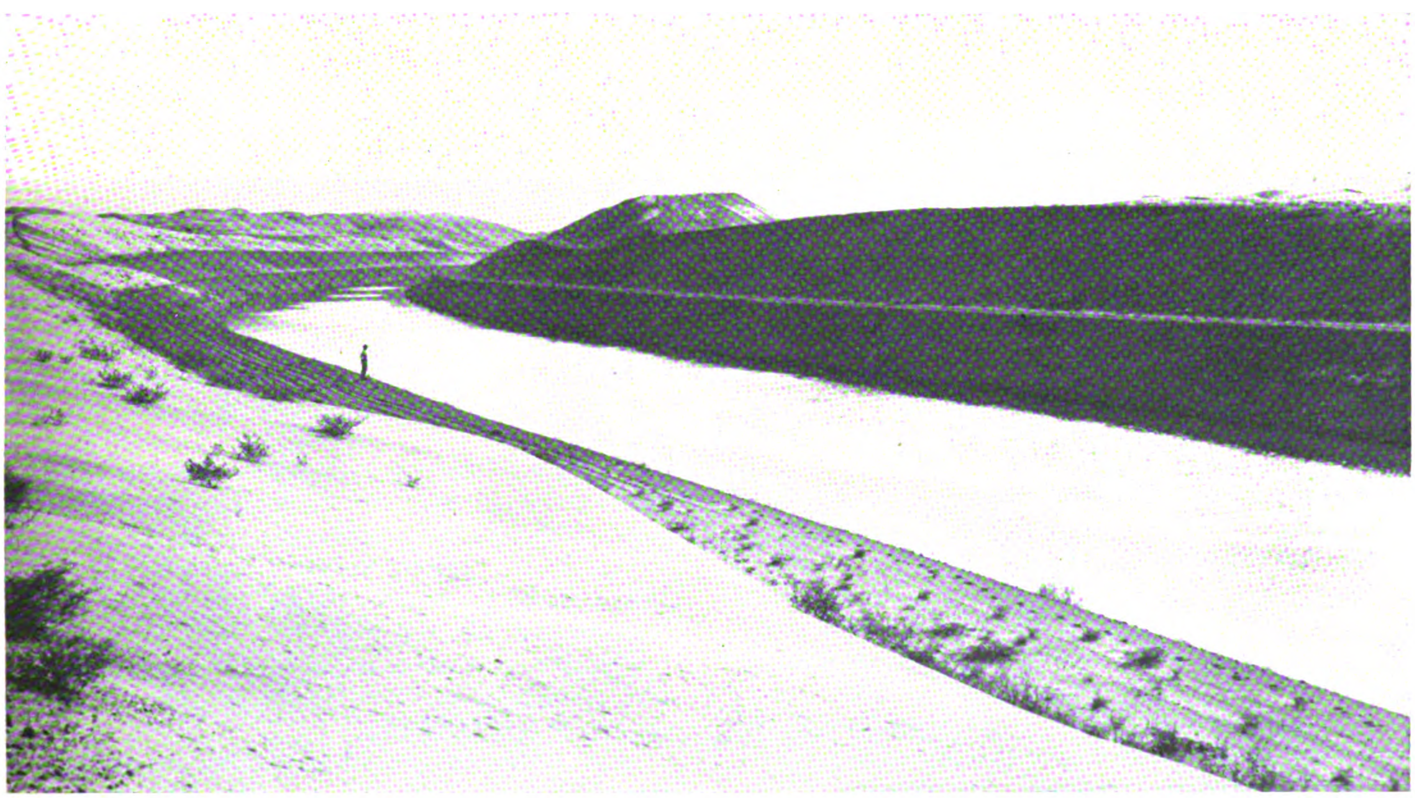
Prior to 1940, lands in the Imperial irrigation district were served by the Imperial Canal, which diverted water from the Colorado River below Yuma. A part of this canal looped into Mexico, which led to complications and made it highly desirable to have a canal located entirely within the United States. The All-American Canal system of the Bureau of Reclamation's Boulder Canyon project answers this purpose. In 1943, there were 400,400 acres irrigated in the Imperial irrigation district from the All-American Canal. The project is still under construction and will irrigate ultimately lands in Imperial Valley, Coachella Valley, East and West Mesas, and Pilot Knob Mesa. The area now irrigated in Coachella Valley by ground water will be served supplemental water from the Colorado River.

The Yuma project, located in Yuma County, Ariz., and Imperial County, Calif., was one of the first irrigation developments of the Bureau of Reclamation and its earliest on the Colorado River. Construction was authorized in 1904, and the first water was delivered during the 1907 season. Water is diverted at Laguna Dam for a portion of the California lands and from the All-American Canal at the Siphon Drop power plant for the remainder of the project. In 1943, 58,800 acres were irrigated including 7,800 acres of Indian land, reported by the Office of Indian Affairs as the maximum development possible.

The Gila project is located in the southwest corner of Arizona and borders on the east side of the Yuma project. As originally conceived, this project contemplated irrigation of 585,000 acres of land. Although considered as one development, the location of the lands suggests certain groupings within the project itself. These are designated as the Yuma Mesa, South Gila Valley, North Gila Valley, and Wellton-Mohawk divisions. Construction of facilities for the irrigation of 150,000 acres in the Yuma Mesa, South Gila Valley, and North Gila Valley divisions has been started. Imperial Dam, already completed, is the diversion dam for both the All-American Canal and the Gila Gravity Main Canal. Water is now being delivered to North Gila Valley and to a small acreage of the Yuma Mesa. Originally it was planned to develop 139,000 acres in the Yuma Mesa. It now appears more desirable to limit the irrigated area to 70,000 acres thus permitting greater development in the other three divisions where it is believed the water could be used to better advantage. A new authorization will be required, however, for any development in the Wellton-Mohawk division. The extent of ultimate development in the Gila project will depend upon the final allocation of water between this project and the potential central Arizona project,



IMPERIAL DAM AND DESILTING BASINS ON COLORADO RIVER
Diversion structure for both All-American and Gila Main Canals



ALL-AMERICAN CANAL
Carries Colorado River water 90 miles to irrigate California's Imperial Valley

discussed under the Gila division, or other possible developments within the State of Arizona.

About 1,200 and 500 acres are irrigated by gravity diversion from Big Sandy River and Kirkland Creek, respectively. Both streams are tributaries of the Williams River.

Some 1,200 acres near Las Vegas, Nev., are now irrigated from ground water sources. About 16,000 acres in Coachella Valley, 6,600 acres in the South Gila Valley, and 7,800 acres in the Mohawk Municipal Water Conservation District near Roll, Ariz., are also irrigated from ground water. The two areas last named may be furnished a water supply under the Gila project.

Municipal and industrial use.—The Colorado River aqueduct in southern California is the only large municipal diversion out of the Boulder division. The aqueduct was constructed by the Metropolitan Water District of Southern California, composed at present of the cities of Anaheim, Beverly Hills, Burbank, Compton, Fullerton, Glendale, Long Beach, Los Angeles, Pasadena, San Marino, Santa Ana, Santa Monica, and Torrance and of the Coastal Municipal Water District. The Metropolitan District's first objective in constructing the Colorado River aqueduct was to supply Colorado River water for domestic, industrial, and other beneficial uses to the area within its boundaries, and to such additional surrounding areas as may later desire to join the district. Water is pumped from Havasu Lake and conveyed by the aqueduct to the southern California area.

Because of the critical nature of the water situation at San Diego, President Roosevelt on November 29, 1944, directed that the Bureau of Reclamation complete plans and specifications for an aqueduct to take 50 million gallons of water per day from the Colorado River aqueduct of the Metropolitan Water District of Southern California and deliver it to San Vicente Reservoir of the San Diego water system. The President directed that the Bureau of Yards and Docks perform the necessary construction. Contracts for construction of some parts of the aqueduct were awarded during the summer of 1945.

Water is pumped from Lake Mead and conveyed by pipe line to Henderson, Nev., for municipal and industrial use, mainly by Basic Magnesium, Inc.,

Drainage and overflow protection.—The cultivated areas included in the Colorado River Indian Reservation, Palo Verde Irrigation District, Yuma project, and Imperial Irrigation District are protected by levees from river overflow. In these districts the lands next to the river are higher than those farther removed and bordered by table lands. Seepage from canals and storm run-off from these higher lands cause drainage problems on the lower lands. As yet the canal seepage from higher lands has not been serious, but some protective measures have been taken. All four areas are dependent on artificial drains to remove excess water.

In recent years it has been difficult to maintain a satisfactory discharge from the drain-ditch system in the lower part of the Palo Verde Valley.

Drainage conditions on the upper Colorado River Indian Reservation and the Yuma project have been benefited by retrogression of the river channel opposite the lands.

Water drained from California lands of the Yuma project is pumped over the levee to the river when the river is high; water drained from Arizona lands of the project is pumped over the levee into Mexico.

Some of the levees and drains protecting lands in the division are:

TABLE XCII.—*Levees and drains in the Boulder division*

	Open drains (miles)	Underground tile drains (miles)	Levees (miles)
Colorado River Indian Reservation	35		2
Imperial irrigation district	[1] 1,238	546	(2)
Palo Verde irrigation district	80		35
Yuma project	87		45

[1] Maintained by the district Length of open drains in private ownership not available.
[2] Levees are in Mexico.

Power.—Power production in the Boulder division is of utmost importance to the lower basin and to southern California. It is here that the waters of the Colorado River are utilized to generate the tremendous electric energy output of the Boulder and Parker Dam power plants.

Thirteen transmission lines extend from Boulder Dam power plant to power market areas in Arizona, Nevada, and southern California. The two largest electric utilities in southern California, the Southern California Edison Co., Ltd., and the City of Los Angeles Department of Water and Power, obtained 25 and 78 percent, respectively, of their total energy from this one source in 1943. Average firm power production at the Boulder power plant is about 4.5 billion kilowatt-hours annually, but during 1944 about 6 billion kilowatt-hours were generated.

The Parker Dam power plant is connected to the Boulder Dam power plant by transmission facilities which permit an interchange of electric energy, thereby conserving water. During the fiscal year 1944 the Parker Dam plant generated 781,642,000 kilowatt-hours. Transmission lines run from the Parker Dam plant to load centers in Arizona, to the Metropolitan Water District pumping plants, and to the All-American Canal power plants in California.

Other hydroelectric plants in the area include those on the All-American Canal, which, although comparatively small, are very important because of their location near the power market. Some plants on the canal are not yet installed but are authorized and considered as present developments.

Power facilities in the area have been taxed to capacity, and the demand shows a definite need for additional generating and transmission facilities. The Davis Dam power plant, when constructed, will help to alleviate power shortages in the area.

Summary.—Important dams, irrigated acreages, and net effective stream depletion are summarized in the following tables:

TABLE XCIII.—*Important dams in the Boulder division*

Name of dam	River	Purpose	Capacity of reservoir (acre-feet)
Boulder	Colorado	River regulation, irrigation, power	32, 359, 000
Davis [1]	do	do	1, 940, 000
Parker	do	River regulation, irrigation, municipal diversion, power	716, 600
Headgate Rock	do	Irrigation diversion	
Imperial	do	Irrigation diversion, desilting	85, 000
Laguna	do	Irrigation diversion	

[1] Authorized.

TABLE XCIV.—*Irrigated and irrigable area under present developments (1943)*

Area	Irrigated (acres)	Additional irrigable (acres)	Total (acres)
Colorado River Indian Reservation	5, 000	95, 000	100, 000
Palo Verde irrigation district	38, 000	37, 000	75, 000
All-American Canal:			
Imperial irrigation district	400, 400	122, 600	523, 000
East Mesa		[1] 40, 000	40, 000
West Mesa		[1] 50, 000	50, 000
Pilot Knob Mesa		[1] 15, 000	15, 000
Coachella Valley	[2] 16, 000	69, 000	85, 000
Yuma project	58, 800	8, 500	67, 300
Gila project:			
Yuma Mesa	100	69, 900	70, 000
North Gila Valley	4, 400	1, 000	5, 400
South Gila Valley	[2] 6, 600	1, 000	7, 600
Wellton-Mohawk	[2] 7, 800		7, 800
Las Vegas area	[2] 1, 200		1, 200
Williams River	1, 700		1, 700
Total	[3] 540, 000	[3] 509, 000	[3] 1, 049, 000

[1] Based on incomplete land classification.
[2] Now irrigated from ground water.
[3] The 416,400 acres of irrigated and 296,600 acres of irrigable land under the All-American Canal are outside the natural Colorado River Basin. Excluding these lands Boulder division totals would be: irrigated 123,600 acres; irrigable 212,400 acres; total 336,000 acres.

TABLE XCV.—*Areas irrigated in the Boulder division by States (1943)*

Area	Arizona (acres)	California (acres)	Nevada (acres)	Total (acres)
Colorado River Indian Reservation	5, 000	0	0	5, 000
Palo Verde irrigation district	0	38, 000	0	38, 000
All-American Canal	0	[1] 400, 400	0	[1] 400, 400
Coachella Valley (ground water)	0	16, 000	0	[1] 16, 000
Yuma project	52, 300	6, 500	0	58, 800
Gila project	4, 500	0	0	4, 500
South Gila Valley (ground water)	6, 600	0	0	6, 600
Wellton-Mohawk (ground water)	7, 800	0	0	7, 800
Williams River	1, 700	0	0	1, 700
Las Vegas (ground water)	0	0	1, 200	1, 200
Total	77, 900	460, 900	1, 200	540, 000

[1] Outside the natural Colorado River Basin.

TABLE XCVI.—*Estimated present average annual stream depletions in the Boulder Division*

Stream	Irrigation, industrial, municipal uses			Reservoir losses (acre-feet)	Total depletions (acre-feet)
	Arizona (acre-feet)	California (acre-feet)	Nevada (acre-feet)		
Colorado River	205,000	[1] 2,680,000	[2] 20,000	713,000	3,618,000
Williams River	3,400	0	0	0	3,400
Total	208,400	[1] 2,680,000	[2] 20,000	713,000	3,621,400

[1] Includes exportation of 2,500,000 acre-feet to the Salton Sea drainage area by the All-American Canal and 35,000 acre-feet to Metropolitan Water District of Southern California by the Colorado River aqueduct for municipal purposes, exports thus totaling 2,535,000 acre-feet.
[2] Diversion for industrial use by Basic Magnesium, Inc.

POTENTIAL DEVELOPMENT OF WATER RESOURCES

The Boulder division is naturally divided by physical characteristics into two general regions. Above Boulder Dam the deep canyons and rapid fall of the Colorado River are ideal for power developments, while below Boulder the region is more susceptible of irrigation and it is there where most of the additional irrigation projects probably will be located.

Marble Canyon-Kanab Creek project.—The Colorado River drops approximately 1,260 feet in the 150 miles between Glen Canyon Dam site in the upper basin and the estimated normal water surface of the potential Bridge Canyon Reservoir. Approximately 100 miles of the river and 950 feet of the drop are within the boundary of the Grand Canyon National Park. To develop fully the power possibilities of the Colorado River and yet avoid the construction of dams or other works in the Grand Canyon National Park, Colorado River waters not needed to maintain a steady stream for scenic purposes in the park could be diverted through a tunnel 44.8 miles long to a power plant near the mouth of Kanab Creek. With an installed capacity of 1,250,000 kilowatts this Kanab Creek power plant operating under an average head of about 1,100 feet could produce 6.5 billion kilowatt-hours of firm energy annually. A 300-foot dam constructed at the Marble Canyon site would divert water to the tunnel and form a reservoir of 500,000 acre-feet capacity extending upstream to the potential Glen Canyon Dam. Water released from the dam in Marble Canyon for scenic purposes in the park would pass through a 22,000-kilowatt power plant at the dam under an average head of 275 feet. This plant would be capable of producing 164,000,000 kilowatt-hours of firm energy annually.

Coconino project.—Construction of a dam at the Coconino site on the Little Colorado River would provide silt and flood control. This construction would reduce the amount of silt entering the potential Bridge Canyon Reservoir by an estimated 18,000 acre-feet annually. Reduction of flood peaks on the Colorado River main stem would also result. The height of the dam would be 260 feet above bedrock and the reservoir capacity would be 1,600,000 acre-feet.

Bridge Canyon project.—A dam at the Bridge Canyon site on the Colorado River at the head of Lake Mead would serve both power and irrigation purposes. This dam would have a height above bedrock of 740 feet and would form a reservoir with a capacity of 3,720,000 acre-feet. The Colorado River falls about 670 feet between the western portion of the Grand Canyon National Park and this dam site. Practically all of this fall could be utilized to produce power in a power plant at the dam with a total installed capacity of 650,000 kilowatts. The power plant would be operated in coordination with all other Government-owned plants on the Colorado River to make possible greater production of firm energy. The Bridge Canyon Dam could also serve as an irrigation diversion structure for the Central Arizona project, discussed in this report under potential development in the Gila division.

With construction of this dam it would be possible to reduce storage space reserved in Lake Mead for flood control, thus increasing the average available power head for the Boulder Dam power plant.

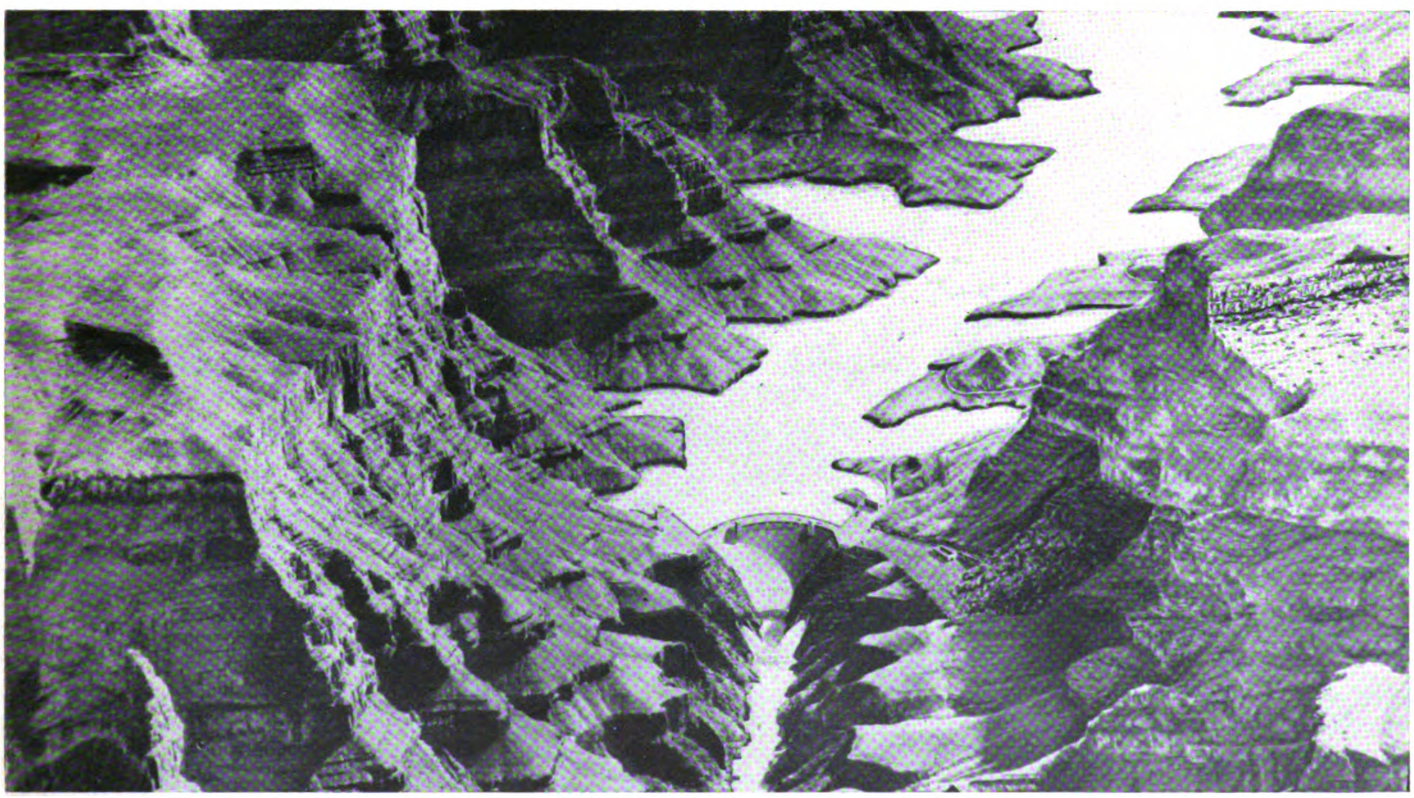
Other benefits accruing as a result of the construction of this project would include improved regulation of stream flow and development of a scenic region between Grand Canyon National Park and the Boulder Dam National Recreation area.

Virgin Bay pumping project.—This project would make possible the irrigation of 2,800 acres of new land along a 6-mile stretch at the eastern edge of the Virgin River arm of Lake Mead by pumping from the lake. An average lift of 200 feet would irrigate 1,600 acres of the area, and an average lift of 360 feet would serve the remaining 1,200 acres. Two main lateral canals totaling some 20 miles in length, including 1.5 miles of tunnel, and 1.5 miles of pump penstock would be required.

Las Vegas pumping project.—Water for this project, which embraces an area of 20,000 acres of new land surrounding the city of Las Vegas, would be pumped from Lake Mead with a maximum total lift of some 900 feet to irrigate 15,000 acres, and through another lift of about 275 feet to serve an additional 5,000 acres. Some 24 miles of lined, open main canal, 6.5 miles of tunnel, 1

A SITE IS FOUND

Reclamation engineers and geologists locate suitable dam sites



A DAM IS PLANNED

Potential Bridge Canyon Dam as envisaged by Reclamation project planners

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mile of siphon, and 3 pumping plants would be required. Practically all project lands would require drainage.

The present draft on the ground water supply in the Las Vegas Valley is believed to about equal the natural recharge of the underground reservoir. Population expansion and increased needs for future industries will require supplemental water from Lake Mead. This Las Vegas pumping project could be enlarged to serve additional needs, or an independent development for an industrial and domestic water supply may prove desirable. Domestic and industrial needs together with steadily growing recreational uses ultimately may require 100,000 acre-feet of water annually.

Davis Reservoir pumping project.—An area of 2,000 acres of new land 20 miles above Davis Dam site on the Nevada side of Davis Reservoir would be irrigated by pumping from the reservoir. One pump would lift the water an average of 180 feet to irrigate 400 acres, and a second pump lift of 200 feet would serve the other 1,600 acres in the project. A total of some 8,000 feet of pressure pipe and several miles of main laterals would be required.

Big Bend pumping project.—An area of 3,700 acres of new land extending from one mile below Davis Dam 6 miles downstream on the Nevada side of the Colorado River would be irrigated by pumping from the river into two main laterals, each about 6 miles long. Two pumping lifts would be required, one of 250 feet to serve 2,000 acres and another of 500 feet to reach the remaining 1,700 acres.

Fort Mojave project.—About 5,100 acres of new land located in the southern tip of Nevada would be served under this project by pumping from the Colorado River. An area of 2,600 acres of bottom lands, including 1,630 acres of Indian lands in the Fort Mojave Reservation, could be reached with a 30-foot lift, and a total of 2,500 acres of slope lands could be served by five successive 100-foot lifts serving 500 acres each.

Mojave Valley project.—Lands situated on the Arizona side of the Colorado River about 8 miles upstream from Needles, Calif., would be included in this project. By pumping from the river, 10,000 acres of mesa and bench lands could be irrigated. A pumping plant located near near Fort Mojave, Ariz., would lift the water 215 feet to a main canal extending east and south for a distance of 7 miles.

Alamo project.—Floods on Williams River menace principally lands along the Colorado River below Parker Dam. Havasu Lake, formed by Parker Dam, can control floods originating in the watershed area of the Colorado River between Davis Dam site and Parker Dam, but only at the expense of serious loss of potential energy production.

To remedy this situation would require construction of a flood-control dam at the Alamo site on Williams River. The dam would have a height above bed rock of 270 feet, and the nominal reservoir capacity at the spillway crest would be 946,000 acre-feet. The dam would be so constructed that it could be modified eventually for use in conserving water and generating power. Erratic stream flows, however, would make considerable hold-over storage imperative, and resultant high evaporation losses preclude the irrigation of any considerable areas of land.

Palo Verde Mesa project.—Near Blythe, Calif., 16,000 acres of mesa lands would be served by enlarging 13 miles of the Blythe Canal and pumping with a lift of 165 feet to a new 20-mile main canal on the mesa.

Chuckawalla project.—The Chuckawalla project in California is in a large inland basin with no surface drainage outlet. To provide surface drainage would require a channel about 16 miles long with a maximum cut of 115 feet. Water to irrigate lands in this basin could be pumped about 210 feet from the Palo Verde irrigation district canal to a main canal about 40 miles long. Soils of the valley are largely coarse, granitic alluvial outwash from the surrounding mountains, and large sections of the land are covered with surface rock or cut by drainage courses. Some land near the lower elevations of the valley is suitable for agriculture if drained properly. Under priorities to Colorado River water presently assigned by the State of California, a water supply for the Chuckawalla Valley appears to be remote. The potentialities of the valley must be recognized in future planning; but because of the uncertainty of water supply, these potentialities are not shown in the summary tables.

Wellton-Mohawk division of Gila project.—As previously stated, it now appears desirable to limit development of the Yuma Mesa division of the Gila project and utilize the same water for more advantageous developments elsewhere. One such possibility is the Wellton-Mohawk division of the Gila project. Seventy thousand acres of new land could be served. In addition 7,800 acres now irrigated by pumping ground water could be furnished a supplemental supply. Water would be diverted from the existing Gila gravity main canal on the south side of Gila River and conveyed by canal to a pump where it would be raised to project lands, all of which are below the 342-foot contour. A siphon would be constructed to convey the pumped water to project lands on the north side of the Gila River.

San Diego project.—The exportation of 112,000 acre-feet of water annually from the Colorado River to the San Diego area is contemplated for this project. Under one plan water would be diverted at Imperial Dam and carried in the All-American Canal to the west side of the Imperial Valley, thence by pumping, canals, siphons, and tunnels through and across the Peninsula Range of California into the San Diego River where it would be captured in San Diego City's El Capitan Reservoir. Existing main and lateral pipe lines would transport the water to points of municipal use.

Choice of the aqueduct route which was surveyed by the Bureau of Reclamation from the Colorado River aqueduct of the Metropolitan Water District of Southern California to the San Vicente Reservoir of the San Diego water system was based on its adaptability to emergency construction. An aqueduct could be built here to relieve the critical water situation at San Diego in much shorter time than could one from the All-American Canal. This emergency construction, however, does not eliminate the possibility of a future connection with the All-American Canal. Whether such a connection ultimately will be made will depend on economic and other considerations which take into account the delivery of water over a long period of time.

Sentinel or Painted Rock project.—A dam constructed at or near the Sentinel site on the Gila River below the Gillespie Diversion Dam to form a reservoir with a capacity of about 3,000,000 acre-feet would provide control of devastating floods in the lower Gila River and protect downstream developments on that river and on the Colorado River below the entry of the Gila. Because the dependable water supply at this potential reservoir is uncertain, its use for irrigation is, for the present, discounted. Irrigation possibilities should be appraised later, following future upstream developments and after the regimen of the stream has become stabilized.

The United States Engineer Office of the War Department has made a field survey and examination for a dam at Painted Rock, about 15 miles above the Sentinel Dam site, and is of the opinion that the site at Painted Rock is more suitable than the one at Sentinel. Full consideration should be given, therefore, to the Painted Rock site in connection with a project in this general locality.

River rectification and control.—In the preceding text under the heading "Silt Problem," reference was made to changing conditions in the Colorado River channel both before and after the building of Boulder Dam. Three existing examples of river control construction intended to cope with the vagaries of the river can be cited: First, levee construction near Yuma, undertaken several years ago for general flood protection; second, present dyking and other construction at Needles where aggradation of the river channel has caused flooding and bank cutting; and third, construction of a temporary diversion weir at the headworks of the Palo Verde irrigation district canal where degradation of the river channel, although improving land drainage, has impaired the functioning of the existing headworks.

These three examples are typical of construction to meet the conditions of the present. Conditions along the river are continually undergoing change at this instant but there are no problems in a critical state other than those mentioned. Notwithstanding, steps for river regulation and prevention of damage are immediately necessary. The Bureau of Reclamation is now preparing plans for river control involving strengthening of the Yuma levees, continuing construction of emergency measures at Needles and at the Palo Verde canal intake, and maintaining all constructed works. Dredging of the channel near Needles should be started. The Bureau should plan to forestall future damage where that is possible, and be prepared to take remedial measures where the need arises.

Summary

Potential development in the Boulder division is summarized in the following tables:

TABLE XCVII.—*Potential projects in the Boulder division*

Project	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Marble Canyon-Kanab Creek	Arizona	Colorado River	P, F, S, H	$382, 000, 000
Coconino	do	Little Colorado River	F, S, H	4, 000, 000
Bridge Canyon	do	Colorado River	P, I, F, S, H	146, 500, 000
Virgin Bay pumping	Nevada	Lake Mead	I	1, 300, 000
Las Vegas pumping	do	do	I, M	8, 400, 000
Davis Reservoir pumping	do	Davis Reservoir	I	500, 000
Big Bend pumping	do	Colorado River	I	700, 000
Fort Mojave	do	do	I	800, 000
Mojave Valley	Arizona	do	I	1, 900, 000
Alamo	do	Williams River	F, P, H	3, 200, 000
Palo Verde Mesa	California	Colorado River	I	3, 100, 000
Wellton-Mohawk	Arizona	do	I	10, 600, 000
Sentinel	do	Gila River	F, H	15, 000, 000
River rectification and control	California, Arizona	Colorado River	F	5, 000, 000
Total				583, 000, 000

[1] Symbols used: I=irrigation, P=power; F=flood control; S=silt retention; H=hold-over storage for river regulation.

[2] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE XCVIII.—*Potential reservoirs in the Boulder division*

Name of site [1]	Source of water supply	Project served directly	Total capacity (acre-feet)
Marble Canyon	Colorado River	Marble Canyon-Kanab Creek	500,000
Coconino	Little Colorado River	Bridge Canyon	1,600,000
Bridge Canyon	Colorado River	do	3,720,000
Alamo	Williams River	Alamo	946,000
Sentinel	Gila River	Sentinel	3,000,000
Total			9,766,000

[1] All in Arizona.

TABLE XCIX.—*Potential irrigation development in the Boulder division*

Project [1]	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
Virgin Bay pumping	Nevada	2,800	0	2,800
Las Vegas pumping	do	20,000	0	20,000
Davis Reservoir pumping	do	2,000	0	2,000
Big Bend pumping	do	3,700	0	3,700
Fort Mojave	do	5,100	0	5,100
Mojave Valley	Arizona	10,000	0	10,000
Palo Verde Mesa	California	16,000	0	16,000
Wellton-Mohawk division of Gila project	Arizona	70,000	7,800	77,800
Total		129,600	7,800	137,400

[1] All projects are in natural drainage basin of the Colorado River.

TABLE C.—*Potential irrigation developments in the Boulder division by States*

State	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total area
Arizona	80,000	7,800	87,800
California	16,000	0	16,000
Nevada	33,600	0	33,600
Total	129,600	7,800	137,400

TABLE CI.—*Potential power development in the Boulder division*

Project [1]	Name of power plant	River	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)
Marble Canyon-Kanab Creek	Marble Canyon	Colorado	22,000	164,000,000
	Kanab Creek	do	1,250,000	6,570,000,000
Bridge Canyon	Bridge Canyon	do	650,000	3,440,000,000
Total			1,922,000	10,174,000,000

[1] All in Arizona.

TABLE CII.—*Present and potential stream depletions, Boulder division*

State River	Estimated average annual depletion (acre-feet)			
	Existing or authorized projects		Potential projects	Total ultimate depletion
	Present depletion	Future increase		
Arizona:				
Colorado River	205,000	571,000	346,000	1,122,000
Williams River	3,400	0	0	3,400
Subtotal	208,400	571,000	346,000	1,125,400
California:				
Colorado River	2,680,000	2,946,000	176,000	[1] 5,802,000
Nevada:				
Colorado River	20,000	0	177,000	197,000
Reservoir losses	713,000	66,000	91,000	870,000
Total	3,621,400	3,583,000	790,000	7,994,400

[1] Includes export of 5,445,000 acre-feet from the natural drainage basin of the Colorado River, made up of 2,535,000 acre-feet present, 2,798,000 acre-feet future increase from existing or authorized projects, and 112,000 acre-feet from potential projects.

Gila Division

The Gila division, consisting of the area drained by the Gila River above Sentinel and adjacent small independent drainage areas, embraces 53,000 square miles, 47,380 of which are in south and central Arizona, and 5,620 in western New Mexico.

WATER RESOURCES

Surface water.—The flow of the Gila River under virgin conditions is estimated at 1,752,000 acre-feet annually at Gillespie Dam and 1,270,000 acre-feet at Dome, Ariz., near its mouth. Recorded stream flows in the Gila division are shown in table CIII.

Streams within the Gila Basin attain their maximum flows during late winter and early spring when mountain snows are melting. Precipitation on the watershed falls mainly in late winter and late summer, the intervening

TABLE CIII.—*Average annual stream flows in the Gila division*

Station	Period of record	Average annual flow (a.-ft.)	
		For period of record	For 1931–40 period
San Francisco River near Glenwood, N. Mex	1929–43	51, 800	50, 000
San Francisco River at Clifton, Ariz	1914–43	172, 000	123, 000
Gila River near Gila, N. Mex	1929–43	103, 000	93, 400
Gila River near Red Rock, N. Mex	1910–43	140, 000	127, 000
Gila River below Blue Creek near Virden, N. Mex	1928–43	137, 000	126, 000
Gila River near Clifton, Ariz	1913–43	192, 000	112, 000
Gila River near Solomonsville, Ariz.[1]	1915–43	302, 000	271, 000
Gila River at Calva, Ariz	1929–43	246, 000	209, 000
Gila River below Coolidge Dam, Ariz.[2]	1914–43	328, 000	214, 000
Gila River at Kelvin, Ariz.[3]	1911–43	444, 000	299, 000
Gila River below Gillespie Dam, Ariz	1922–43	302, 000	149, 000
Gila River near Dome, Ariz	1930–43	84, 600	57, 900
San Carlos River near Peridot, Ariz	1929–43	45, 800	38, 300
San Pedro River at Charleston, Ariz	1913–43	50, 700	45, 900
Santa Cruz River near Nogales, Ariz	1930–43	15, 400	16, 900
Santa Cruz River at Tucson, Ariz	1912–43	15, 800	15, 000
Salt River near Chrysotile, Ariz	1924–43	493, 000	479, 000
Salt River near Roosevelt, Ariz	1914–43	721, 000	584, 000
Salt River at Granite Reef Dam, Ariz	-------	-------	1, 060, 000
Tonto Creek near Roosevelt, Ariz	1902–40	97, 800	85, 000
Verde River near Pine, Ariz	1935–39	425, 000	381, 000
Verde River above Camp Creek, Ariz	1925–43	433, 000	417, 000
Agua Fria River above Lake Pleasant, Ariz	1933–43	55, 300	53, 500
Hassayampa River at Box Canyon dam site, Ariz	-------	-------	41, 400

[1] Includes Brown Canal diversions.
[2] Flow regulated by Coolidge Dam beginning 1929.
[3] Regulated after 1928.

seasons being almost devoid of rainfall. During these dry months flows of the rivers are usually small, but they increase enormously after a big storm or when sudden warm temperatures rapidly melt the mountain snow. About 45 percent of the annual run-off of the Gila River occurs during February, March, and April. Storage is imperative for efficient utilization of the available water. Numerous reservoirs already store the waters of the Gila River and its tributaries, which are almost completely utilized by existing irrigation projects. In fact, during protracted dry years the water available within the basin is inadequate to meet the demand. The Gila Basin, therefore, must look to other basins for an additional supply of surface water.

Ground water.—There is no law in Arizona regulating the development of percolating ground waters. In the absence of legal protection, development of ground water resources for any purpose would be hazardous, and this factor should be recognized in planning future developments.

Considerable portions of the broad basins of southwestern Arizona are underlain with uncemented valley-fill material, generally several hundred feet deep. This porous material absorbs much of the flow of streams as they enter the valley areas, thus creating great underground reservoirs. Irrigation seepage contributes substantial recharge to the reservoirs, but the scanty precipitation on valley lands adds little to the ground water supply.

Large quantities of water for irrigation and domestic use are obtained from ground water. Artesian wells of importance have been drilled in the upper Gila Valley, and small artesian flows have been encountered in the upper San Pedro and Santa Cruz Valleys. Yields of individual wells within the division range in discharge from .5 to 2,250 gallons a minute.

Small to moderate-sized springs are scattered through the watershed area. Only a small amount of land is irrigated directly from springs, but springs contribute a substantial amount of water to the perennial flows of the larger rivers. Spring water is particularly valuable in the semiarid outlying ranges, where creeks used for watering livestock are dry during large parts of the year.

With few exceptions, ground water within the basin has been developed beyond its economic limit, and in all but a few areas, ground-water withdrawals exceed replenishments.

Arizona lacks comprehensive legislation regulating the use of ground water, but the State Water Code provides that "water flowing in definite underground channels" is subject to appropriation. Since it is difficult to prove that such water does flow in a definite channel, little regulation of ground water exists in the State. In New Mexico the State Engineer can declare any area with underground water, the boundaries of which can be reasonably determined, to be an underground water basin. Underground water within the area must then be appropriated in much the same manner as that of surface streams. Present water users are thus protected, and expansion is permitted only where supplies are more than adequate for existing developments.

Quality of water.—Surface waters of Gila River and its tributaries carry considerable quantities of dissolved solids, chiefly sodium chloride and the sulphates and bicarbonates of sodium, calcium, and magnesium; however, the percentage of sodium is reasonably low. Low flows of the Gila River at Gillespie Dam in the lower part of the division carry over 6,000 parts per million total dissolved solids, while flood flows carry as little as 300 parts per million.

The quality of the ground water obtained from artesian wells and springs varies with location. Some waters have less than 100 parts per million dissolved salts, while others range as high as 5,000 parts per million. The total hardness of these waters, expressed as calcium carbonate, ranges from less than 5 to over 700 parts per million.

Gila Division of the Colorado River Basin

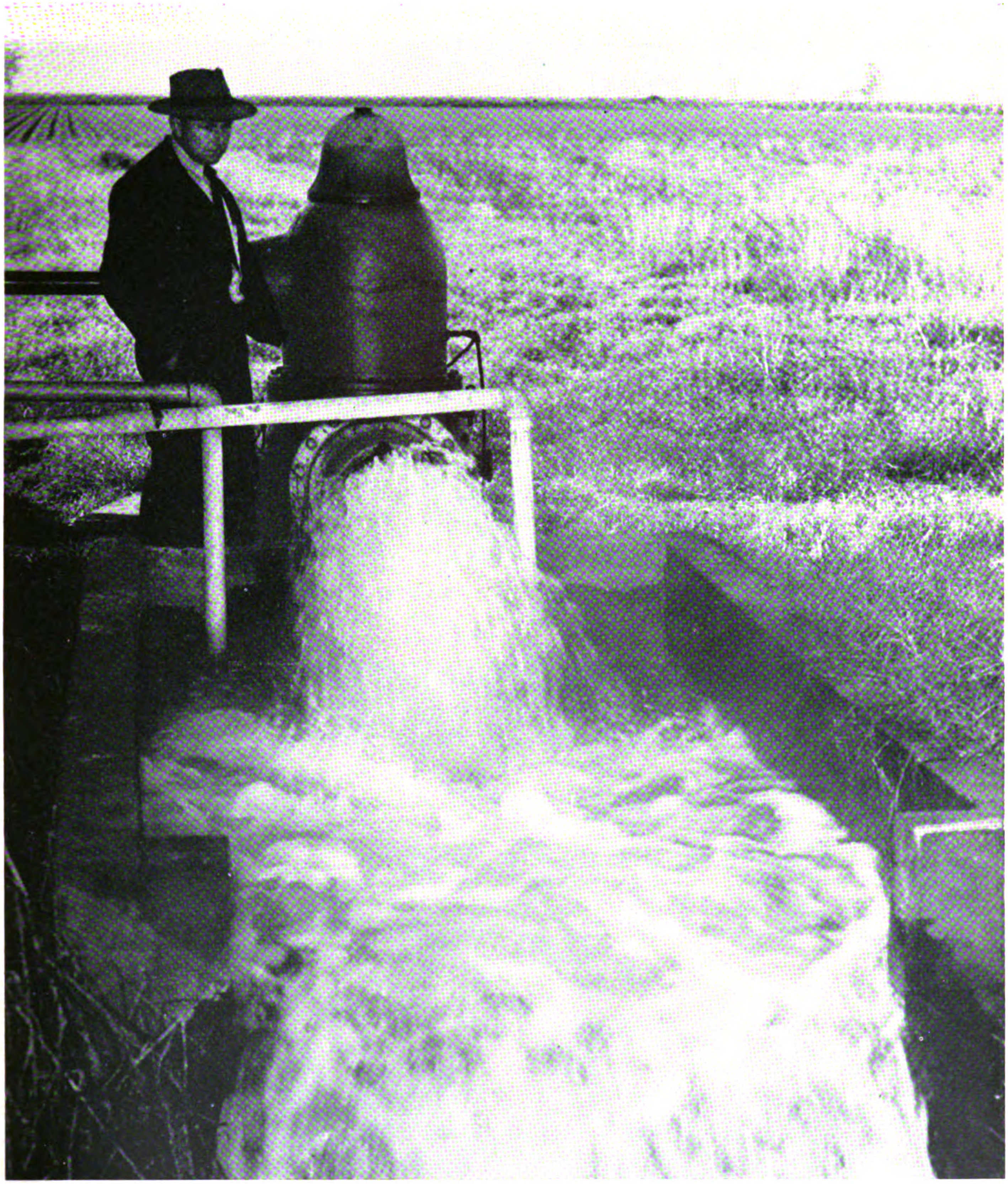
Ground waters of unsuitable quality for either irrigation or domestic use are found in wells in the upper Gila Valley, lower Salt River Valley, and in the Casa Grande and Coolidge districts. Ground waters of the division are generally unsuitable for industrial use.

Some of the surface water in the smaller tributaries and much of the ground water in the basin contain fluorides in such high quantities that it is quite often difficult to obtain a satisfactory domestic water supply.

Present Development of Water Resources

General

The surface and ground-water supplies of the Gila division are the basis for practically all its agricultural development, and stream flow, through the generation of hydroelectric energy, makes possible many of the area's industries. Surface waters, with the exception of



PUMPING GROUND WATER

Overdraft of underground supplies in Arizona is serious threat to agriculture. Thousands of acres may be abandoned unless more irrigation water is supplied a few small tributary flows, are almost completely utilized by lands now under irrigation; and an estimated 1,600,000 acre-feet of ground water is pumped annually for irrigation and domestic use. Ground-water pumping greatly increases during dry years when reservoirs are low, throwing a tremendous strain on generating facilities already curtailed by low water conditions. The output of power plants in the division has been augmented recently by energy from Parker Dam on the Colorado River.

Rivers of the area transport large quantities of silt each year. Although river flows in dry weather are fairly clear, a load of sand constantly is being moved along the river bed even during the lowest river stages. High discharges, resulting from torrential rains and rapid run-off, carry in suspension heavy loads of fine silt and clay in addition to enormously increased bed loads.

The fine material carried in suspension presents no problem in canal maintenance, except when flows are exceptionally low. Coarser bed-load material, however, settles in canals and ditches and must be removed to maintain the capacity of the conduits. Both bed loads and suspended loads settle in storage reservoirs. This accumulation is important in determining the length of life of a reservoir. Records of the Salt River Valley Water Users' Association show a total silt accumulation of 108,000 acre-feet in Roosevelt Reservoir on Salt River during the period 1905 to 1934, inclusive. Other streams in the basin notably the Gila, are known to carry greater proportions of silt than Salt River, so this figure is lower than the average to be expected.

The suspended material found in the waters of the Gila River and its tributaries contains considerable organic matter and but little coloidal clay. When applied to sandy land, this material gives body to the soil and is beneficial. When spread on tight land, however, it clogs the pores of the soil, reducing its permeability and making its cultivation more difficult. In municipal water works, it clogs intakes and makes water clarification costly.

The only practicable solution of the silt problem lies in providing adequate silt storage capacity in reservoirs on major streams contributing silt and in limiting erosion by better watershed control.

Irrigation

Gila River.—Irrigated areas along the Gila River and its tributaries, San Francisco River, San Simon Creek, Queen Creek, and Centennial Wash, total 213,400 acres. Irrigation projects located above Coolidge Dam have no water-storage facilities and must depend on diversions from the unregulated flow of the Gila River supplemented by pumping from ground water for their irrigation supplies. These upstream projects cover an area of approximately 51,000 acres and require additional water to irrigate adequately all project lands.

The San Carlos Reservoir, with a capacity of 1,200,000 acre-feet formed by Coolidge Dam (Office of Indian Affairs), stores water used for irrigation on several downstreams projects. The San Carlos project, largest of these irrigation developments, serves 100,500 acres, about half of which is farmed by Indians. Project lands require more water than is supplied to them by existing irrigation developments on the Gila River.

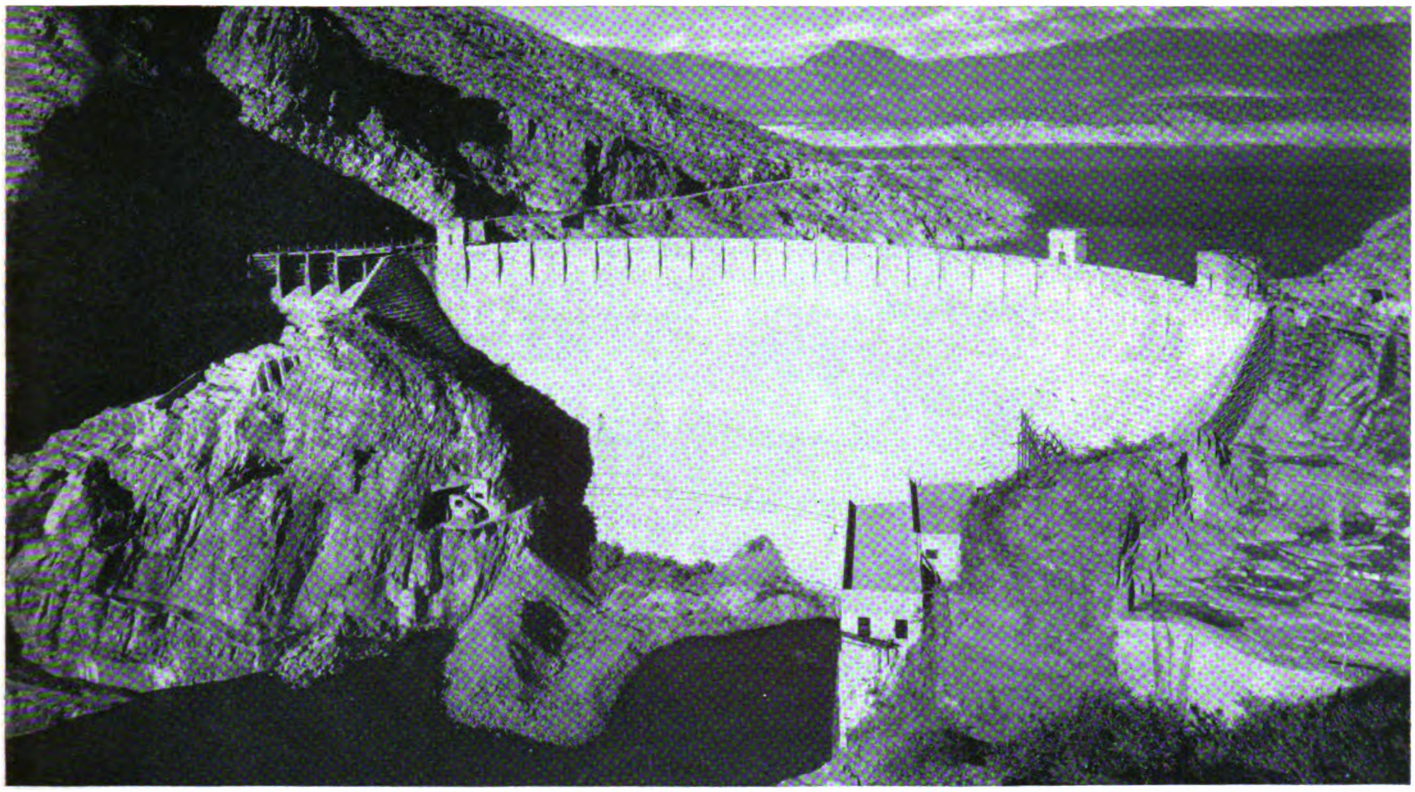
Other downstream developments include those made by the Buckeye Water Conservation and Drainage District, Arlington Canal Co., Gillespie Land & Irrigation Co., and others. These lands obtain much of their water supply by pumping from underground sources. At the present time ground-water depletions exceed recharges to a considerable degree, and unless replacement water is supplied, some land must be taken out of cultivation within a few years.

San Pedro River.—About 2,600 acres of land are irrigated in the Benson-St. David area of the upper San Pedro River watershed and a few hundred acres are dry-farmed. No surface water storage is available and irrigation supplies depend on the extremely variable flow of the river, the output of several small flowing wells, and a limited amount of pumping from ground water.

All of the dependable surface water supply of the San Pedro is now divided among irrigators in the San Pedro Valley and in the Gila River Valley downstream from the confluence of the two streams. The only possibility of irrigating additional lands in the San Pedro Valley is through the importation of water to the Gila Basin, so that San Pedro River water now used there may be released for use in the San Pedro Valley. Ground-water resources along the San Pedro River are not fully developed, and increased pumping would yield valuable but limited supplemental water supplies.

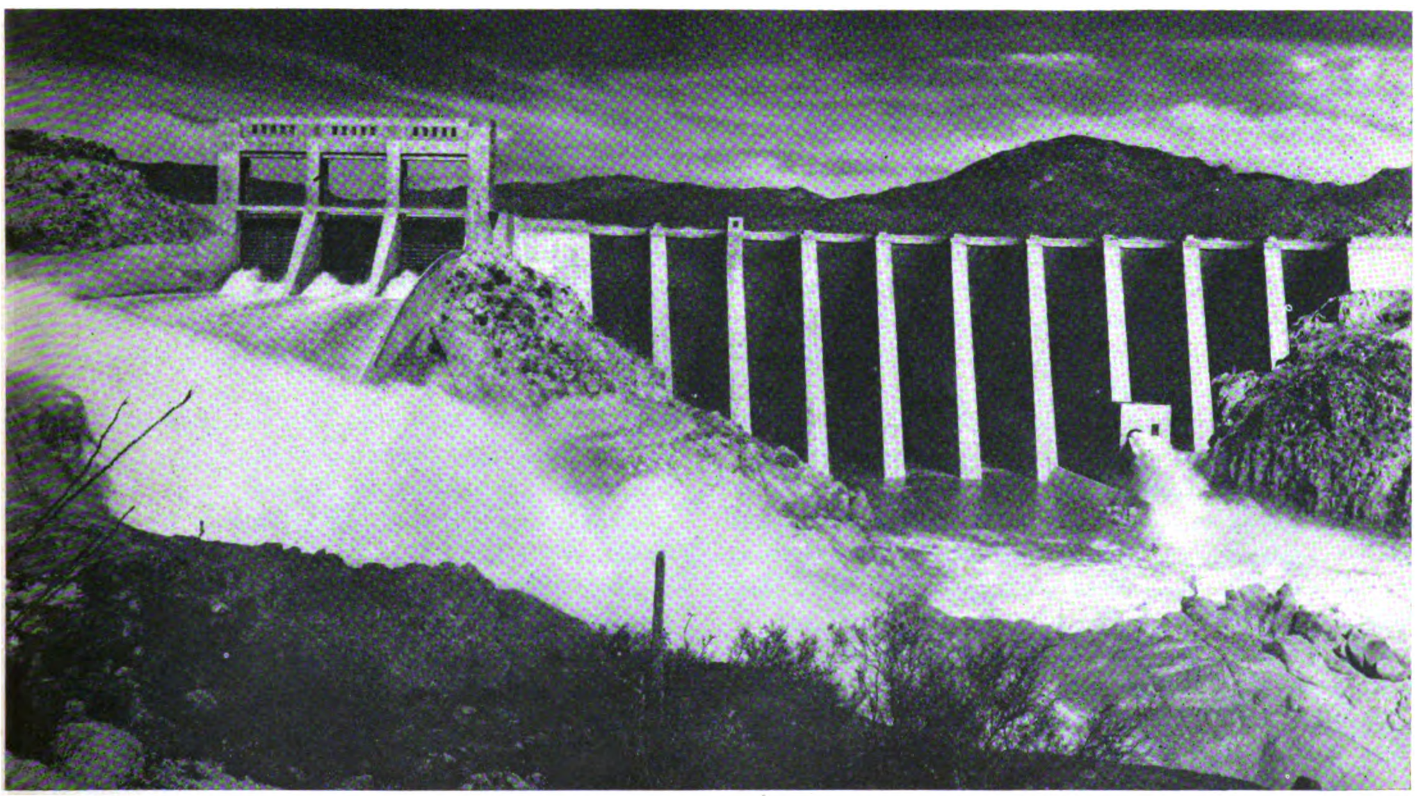
Salt and Verde Rivers.—Diversions of irrigation water from Salt River were first made by white settlers in 1867. Because of erratic river flows and lack of storage facilities, water supplies during dry years were inadequate to supply the demands of the lands in cultivation. The Bureau of Reclamation constructed Roosevelt Dam and power plant to provide storage and regulation of Salt River. Diversion works, canals, laterals, and other power plants were also built by the Bureau before turning the project over to the Salt River Valley Water Users' Association in 1917, subject to payment of the unpaid balance of construction charges. During the years between 1922 and 1930, the association constructed the Horse Mesa, Mormon Flat, and Stewart Mountain Dams for irrigation and power, and the Cave Creek Dam for flood control. The Bureau of Reclamation, during the 1936–39 period, built Bartlett Dam on the Verde River, principal tributary of Salt River.

Large areas of fertile land surrounding the Salt River



ROOSEVELT DAM ON SALT RIVER

First Bureau of Reclamation storage in Colorado River Basin



BARTLETT DAM ON VERDE RIVER

Another Reclamation dam to irrigate Arizona's thirsty lands project are irrigated with water wholly or partly supplied by pumping from wells. The Salt River project also supplements its surface-water supplies with ground water.

Approximately 336,000 acres of land were irrigated in the Salt River and Verde River Valley region in 1939. This included 14,000 acres of Indian land, not all of which is irrigated at the present time. The Office of Indian Affairs contemplates ultimate development of the full acreage. Of the total area 240,000 acres were irrigated principally with surface water and the remainder with water from wells.

Pumping from underground storage exceeds recharges and unless ground-water supplies are supplemented, the amount of land under cultivation will have to be reduced.

An earth and rock-fill dam is at present being constructed at the Horseshoe site on the Verde River by the Phelps Dodge Corporation in cooperation with Defense Plant Corporation. Under the terms of an agreement between these corporations and the Salt River Valley Water Users' Association, water conserved by this dam will be exchanged for water diverted from Black River, another tributary of Salt River, for use at the Morenci Mine and Reduction Works, owned by the Phelps Dodge Corporation. The Horseshoe Dam will conserve a part of the Verde River flood water for use on the lands of the association, and in return the association will permit Phelps Dodge and Defense Plant Corporation to divert from Black River an amount of water equal to that conserved by Horseshoe Dam, but not in excess of 14,000 acre-feet a year, nor in excess of 250,000 acre-feet total.

The reservoir formed by Horseshoe Dam will have a storage capacity of 60,000 acre-feet, but the dam will be so constructed that it may be enlarged ultimately to increase the reservoir capacity to 300,000 acre-feet.

Santa Cruz River.—Wells furnish practically all of the water used by the 115,400 acres of irrigated land in the Santa Cruz River Valley. Electric energy for pumping purposes is imported from the Salt River Valley and Parker Dam power plants.

Because of the high fertility of the lands in this region the acreage under cultivation has increased greatly with a consequent increase in the amount of ground water pumped for irrigation use. Ground-water withdrawals exceed replenishments and unless additional water becomes available, much land must go out of cultivation within a few years.

Agua Fria and Hassayampa Rivers.—Approximately 48,700 acres of land are irrigated in and adjacent to the Agua Fria River Valley through the utilization of both surface and ground-water supplies. Surface waters are stored in a 178,000-acre-foot reservoir formed by Lake Pleasant Dam, and ground water is made available by means of numerous deep-well, electrically-driven pumps. As no electrical energy is generated in the area, all energy used is purchased from power plants located in other regions. Ground-water pumping should be reduced and, if possible, replaced by surface water.

Some 500 acres of land lying near the Hassayampa River is presently irrigated. Much fertile land in the valley would be very productive if adequately supplied with irrigation water.

Independent drainage basins.—Approximately 10,400 acres of irrigated farm land in the Gila division are in small independent drainage basins or in basins draining into Mexico. These lands derive their water supplies principally from artesian or pumped wells, although surface flows are used when available.

TABLE CIV.—*Irrigated areas in independent basins*

Basin	County and State	Drainage	Area irrigated (acres)
Sulphur Springs Valley	Cochise, Ariz	Independent	3,000
Whitewater Draw	do	Yaqui River	2,000
Vamori	Pima, Ariz	Independent	[1] 5,200
Animas Valley	Hidalgo, N. M.	do	200
Total			10,400

[1] Indian lands.

Power

Power plants supplying electrical energy to the Gila division fall into two classes: (1) those which generate energy for sale, and (2) those which were constructed for the sole purpose of furnishing energy to some nearby industrial development. Both publicly and privately owned plants are located in the area. Those owned privately have by far the greater installed capacity and have been constructed mainly to supply the energy demands of mines, mills, and smelters. The total installed capacity of power plants in the division is about 327,000 kilowatts.

The Bureau of Reclamation's power plant at Parker Dam supplies large amounts of energy to power-marketing agencies located at Phoenix, Coolidge, and Tucson, Ariz. These agencies in turn distribute this energy over a wide area.

Power plants of the Gila division are hydroelectric, steam, or internal combustion. Steam plants predominate.

Drainage

Soils and topography within the Gila division are such that drainage under irrigation is generally adequate and in some cases excessive. Subsurface drainage is usually good because of the open, permeable subsoils found through most of the region. Some areas of the Salt River Valley are drained by pumping from wells. Not only does this result beneficially in lowering the ground-water level but also makes available a dependable supply of irrigation water.

Several farming districts surrounding the Salt River project are wholly dependent upon this drainage water for their irrigation supply. The drainage system comprises about 190 wells. Electrically operated pumps lift the water about 86 feet to distributing canals, where it flows by gravity to the irrigated lands. Some 240,000 acres are thus drained and about 95,000 acres of this area are irrigated by pumped water.

Flood control

Cave Creek Dam, situated just north of Phoenix, Ariz., is the only dam constructed for flood control in the region. Its reservoir capacity is 14,000 acre-feet. Although other storage dams were constructed primarily for irrigation and power development, they offer some degree of protection. Considerable damage, however, still results from flash floods.

Summary

Important dams, irrigated acres, and the net effective stream depletion due to present irrigation development are summarized in the following tables:

TABLE CV.—*Important dams in the Gila division*

Name of dam	River	Purpose	Capacity of reservoir (acre-feet)
San Jose	Gila	Irrigation diversion	
Coolidge	do	Irrigation, flood control, power	1, 200, 000
Ashurst-Hayden	do	Irrigation diversion	
Sacaton	do	do	
Gillespie	do	do	
Roosevelt	Salt	Irrigation, power	1, 400, 000
Horse Mesa	do	Power	245, 000
Mormon Flat	do	do	57, 800
Stewart Mountain	do	do	70, 000
Granite Reef	do	Irrigation diversion	
Bartlett	Verde	Irrigation, flood control	182, 600
Cave Creek	Cave Creek	Flood control	14, 000
Lake Pleasant	Agua Fria	Irrigation	178, 000
Horseshoe	Verde	do	60, 000
Total			3, 407, 400

TABLE CVI.—*Present irrigated areas in the Gila division*

Stream basin	Acres irrigated		
	Arizona	New Mexico	Total
Gila River	202, 600	10, 800	213, 400
San Pedro River	2, 600	0	2, 600
Salt and Verde Rivers	336, 000	0	336, 000
Santa Cruz River	115, 400	0	115, 400
Agua Fria River	48, 700	0	48, 700
Hassayampa River	500	0	500
Independent Basins	10, 200	200	10, 400
Total	716, 000	11, 000	727, 000

TABLE CVII.—*Estimated present average annual stream depletion in the Gila division*

Division	Depletion (acre-feet)		
	Arizona	New Mexico	Total
Gila division	1, 135, 000	16, 000	1, 151, 000

POTENTIAL DEVELOPMENT OF WATER RESOURCES

The water supply of Gila division is inadequate to meet the requirements of lands now irrigated. Ground-water supplies are being exhausted, and surface supplies are inadequate. In general, the area is suffering from a continual water shortage. The only source of water for supplemental, replacement, or additional use is the Colorado River.

Central Arizona project.—Several plans have been advanced for diverting Colorado River water to central Arizona. Preliminary investigations by the State of Arizona and by the Bureau of Reclamation have reduced the number of alternatives considered to three; these three are receiving study at the time this report is being prepared to determine which plan shall receive the detailed investigation necessary for project report.

All plans would serve the purpose of delivering Colorado River water to Granite Reef Dam, on the Salt River at the nominal head of irrigation. Brief descriptions of these routes follow: (1) *Marble Canyon route (grav-*

ity)—Colorado River water would be diverted from the potential Marble Canyon Reservoir, the dam site for which is about 320 miles upstream from Boulder Dam, through 143 miles of continuous tunnel, to discharge into the Verde River 95 miles upstream from its confluence with the Salt River. A series of reservoirs and power plants on the Verde River would regulate the diverted water, as well as Verde River water, for irrigation use, and develop power through the head available. In common with the other alternative routes, water imported from the Colorado River would be delivered finally at Granite Reef Dam on the Salt River. (2) *Bridge Canyon route* (*gravity*)—Colorado River water would be diverted from the potential Bridge Canyon Reservoir, the dam site for which is located 118 miles upstream from Boulder Dam. The diverted water would flow by gravity through a 78.5-mile continuous tunnel south to the Big Sandy River, thence by 235 miles of aqueduct and through 11 shorter tunnels totaling 13.7 miles, into the potential McDowell Reservoir, which would be located on the Salt River immediately upstream from Granite Reef Dam. (3) *Parker route* (*pumping*)—Under this plan Colorado River water would be pumped from Havasu Lake through a series of four pumping lifts totaling 985 feet, and thence would flow by gravity through 235 miles of aqueduct to Granite Reef Dam.

For simplicity in presenting the potentialities of the Central Arizona project, it has been necessary to limit discussion to one alternative plan. That employing the Bridge Canyon route has been selected arbitrarily for that discussion; likewise, an annual diversion by the project of 2,000,000 acre-feet has been assumed arbitrarily. Estimates of cost and of power potentialities are consistent with these assumptions. The plan finally selected may differ materially from that assumed herein, both as to route and as to quantity of water diverted, and it should not be assumed that the plan selected arbitrarily for discussion herein has been shown to have the greatest merit.

The Salt River unit would utilize Colorado River water delivered to Granite Reef Dam by diversion at points along the Salt and Gila Rivers through existing facilities. Supplemental water could be supplied to approximately 384,900 acres now inadequately irrigated in this area and to 20,000 acres of new land lying within the boundaries of existing irrigation districts.

The Paradise Valley unit would utilize Verde River water now required by the Phoenix area, that area receiving Colorado River water instead. Enlargement of Horseshoe Dam on the Verde River to increase the reservoir capacity to 300,000 acre-feet would provide additional regulation of this stream. Installation of a 10,000-kilowatt power plant at this site would provide replacement power for the Stewart Mountain power plant on Salt River. Diversion at the Bartlett Dam on the Verde River into a 64-mile canal would permit utilization of Verde River water on 85,000 acres of land in this unit north of Phoenix.

The San Carlos unit could divert water through a short tunnel from the Saguaro Reservoir (formed by Stewart Mountain Dam) on Salt River and through a canal extending over 100 miles to 157,400 acres of irrigated lands in the San Carlos Irrigation District and pumping developments in the Gila River Valley. Ground-water pumping could thereby be decreased to the safe yield of the ground-water basin. Reduction in energy generation at Stewart Mountain Dam, as a result of such a diversion, would be offset by energy generated at the proposed new plant at Horseshoe Dam.

A dam at the Buttes site on the Gila River below San Carlos Reservoir could be constructed to form a reservoir with a capacity of 400,000 acre-feet. This storage would regulate floods from tributaries entering the main stream below San Carlos Reservoir and thus provide protection for irrigated lands downstream. The stored water could be released as required by downstream users. An annual average of 17,000,000 kilowatt-hours of power could be generated at a plant at the Buttes site with an installed capacity of 5,800 kilowatts. This plant would operate only when water is required for irrigation purposes. The energy thus generated, while not firm, would be available for irrigation pumping and could be used for that purpose.

With demands of the San Carlos unit satisfied, irrigators on the upper Gila and tributaries could increase their diversions beyond any present legal limitation. In many cases, however, regulation of stream flow would be necessary to make such diversions physically possible.

The Charleston unit would involve construction of a dam at the Charleston site on San Pedro River and a 70-mile pipe line to deliver 12,000 acre-feet of water annually to the city of Tucson. With a safe source of supply thus provided, the city could discontinue or decrease its present pumping from a diminishing underground supply. A reservoir with a capacity of 240,000 acre-feet formed by Charleston Dam would provide sufficient storage to protect downstream irrigators from flood damage. Supplemental irrigation water could be furnished to 2,600 acres of land lying below the dam site.

The Safford Valley unit, through construction of a dam at the Elliott site on the Gila River, one-fourth of a mile below the mouth of San Francisco River to provide a reservoir of 70,000 acre-feet capacity would supply supplemental water to 32,460 acres of land in Safford Valley. Although the reservoir would be operated primarily for irrigation, it would serve also to control floods.

The San Francisco unit would furnish additional supplemental water to the Safford Valley unit by regulation of the San Francisco River. Storage could be obtained by the construction of a system of small reservoirs, the number, location, and capacity of which have not been determined. By distributing these reservoirs in the upper reaches of the basin, regulated flows could also be utilized to supplement supplies to approximately 2,500 acres of land now irrigated in the San Francisco unit. In addition, approximately 2,000 acres of new land could be brought under irrigation. Although considered as a part of the Central Arizona project, it is possible that this unit could be developed independently on a modified scale.

The Duncan-Virden Valley and New Mexico units would provide storage at the Hooker site on Gila River near Cliff, N. Mex., to provide supplemental water and some flood-control protection for 13,600 acres of land now irrigated near Duncan, Ariz. A 3,000-kilowatt capacity power plant at Hooker Dam could supplement available electric energy in the area. A permanent lake in this vicinity would furnish valuable reactional opportunities. As presented, this dam would be an integral part of the Central Arizona project. Should Colorado River water not be diverted to central Arizona, a project in this area may warrant independent consideration.

Chino Valley project.—Approximately 2,540 acres of inadequately irrigated land in the upper Verde River Basin about 15 miles north of Prescott, Ariz., could be furnished an additional supply by concrete lining an existing canal leading from the diversion points on Granite and Willow Creeks to the project lands and by making certain other improvements to reduce water conveyance losses. No new lands could be brought under cultivation, and a full supply could not be furnished to the entire project area. However, distress occasioned by recurrent water shortages could be alleviated.

Hassayampa project.—By construction of a dam at the Box Canyon site on Hassayampa River a storage reservoir of 210,000 acre-feet capacity could provide sufficient water to irrigate 8,800 acres of desert land west of Wittman, Ariz. This reservoir also would help to control floods in the area.

Sentinel project.—Although the reservoir which would be formed by a flood-control dam near Sentinel, Ariz., would extend into the Gila division, the dam site and project lands are in the Boulder division. The project, therefore, is discussed under that division.

Summary

Potential developments in the Gila division are summarized in the following tables:

TABLE CVIII.—*Potential projects in the Gila division*

Project and unit	Location of project	Source of water supply	Purpose to be served [1]	Estimated construction cost [2]
Central Arizona	Arizona	Colorado River	I, F, P, M, U	$432, 800, 000
Salt River				
Paradise Valley				
San Carlos				
Charleston				
Safford Valley				
San Francisco				
Duncan-Virden Valley				
New Mexico				
Chino Valley	do	Granite and Willow Creeks	I	150, 000
Hassayampa		Hassayampa River	I, F	6, 650, 000
Total				439, 600, 000

[1] Symbols used: I=irrigation, F=flood control, P=power, M=municipal, U=underground water discharge. [2] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE CIX.—*Potential reservoirs in the Gila division*

Name of site	Source of water supply	Project served	Total capacity (acre-feet)
		Central Arizona:	
McDowell	Salt River	Salt River unit	250, 000
Horseshoe Enlargement	Verde River	Paradise Valley unit	300, 000
Buttes	Gila River	San Carlos unit	400, 000
Charleston	San Pedro River	Charleston unit	240, 000
Elliott	Gila River	Safford Valley unit	70, 000
Hooker	do	New Mexico unit	150, 000
Miscellaneous	San Francisco River and tributaries	San Francisco unit	(1)
Box Canyon	Hassayampa River	Hassayampa	210, 000
Total			[2] 1, 620, 000

[1] Not determined. [2] Exclusive of potential reservoirs in San Francisco unit.

TABLE CX.—*Potential irrigation development in the Gila division*

Project and unit	State	Area to be benefited (acres)		
		New land	Furnished supplemental water	Total
Central Arizona:				
Salt River	Arizona	20,000	384,900	404,900
Paradise Valley	do	85,000	0	805,000
San Carlos	do	0	157,400	157,400
Charleston	do	0	2,600	2,600
Safford Valley	do	0	32,460	32,460
San Francisco	New Mexico	2,000	2,500	4,500
Duncan-Virden Valley	Arizona-New Mexico	0	8,100	8,100
New Mexico	New Mexico	0	5,500	5,500
Subtotal		107,000	593,460	700,460
Chino Valley	Arizona	0	2,540	2,540
Hassayampa	do	8,800	0	8,800
Total		115,800	596,000	711,800

TABLE CXI.—*Potential irrigation development in the Gila division by States*

State	Area to be benefited (acres)		
	New land	Furnished supplemental water	Total
Arizona	113,800	585,200	699,000
New Mexico	2,000	10,800	12,800
Total	115,800	596,000	711,800

TABLE CXII.—*Potential power development in the Gila division*

Project and unit	Name of power plant	Stream	Power plant installed capacity (kilowatts)	Annual firm generation (kw.-hrs.)
Central Arizona:				
Paradise Valley	Horseshoe	Verde River	[1] 10,000	[1] 37,000,000
San Carlos	Buttes	Gila River	5,800	8,000,000
New Mexico	Hooker	do	3,000	8,000,000
Total			18,800	[2] 43,000,000

[1] Replacement power for Stewart Mountain power plant.
[2] Net annual firm generation would be 16,000,000 kilowatt-hours.

TABLE CXIII.—*Present and potential stream depletions in the Gila division*

State and river	Estimated average annual depletion (acre-feet)		
	Present depletion	Potential increase	Total ultimate depletion
Arizona:			
Gila River	1,135,000	20,000	1,155,000
Colorado River		1,588,000	1,588,000
Subtotal	1,135,000	1,608,000	2,743,000

TABLE CXIII.—*Present and potential stream depletions in the Gila division*—Continued

State and river	Estimated average annual depletion (acre-feet)		
	Present depletion	Potential increase	Total ultimate depletion
New Mexico:			
Gila River	16,000		16,000
Colorado River		8,000	8,000
Subtotal	16,000	8,000	24,000
Total	1,151,000	1,616,000	2,767,000

Summary of Present and Potential Development in the Lower Basin

The following tables summarize in the lower basin present irrigated areas, potential development of water resources with estimated construction costs, and present and potential stream depletions.

TABLE CXIV.—*Present irrigation development in the lower basin* [1]

Division	Acres irrigated					
	Arizona	California	Nevada	New Mexico	Utah	Total
Little Colorado	39, 230			8, 770		48, 000
Virgin	2, 800		9, 800		23, 500	36, 100
Boulder	[1] 244, 800	[2] 803, 000	1, 200			1, 049, 000
Gila	716, 000			11, 000		727, 000
Total	1, 002, 830	[3] 803, 000	11, 000	19, 770	23, 500	[3] 1, 860, 100

[1] Includes 166,900 acres not yet irrigated under existing projects.
[2] Includes 342,100 acres yet to be irrigated under existing projects.
[3] Includes 416,400 acres irrigated and 296,600 acres not yet irrigated under the All-American Canal system outside the Colorado River natural drainage basin

TABLE CXV.—*Present hydroelectric generating capacity in the lower basin*

State and division	Present installed capacity (kilowatts)	Authorized or planned capacity (kilowatts)	Total capacity (kilowatts)
Arizona:			
Little Colorado	40		40
Gila	87, 950		87, 950
Subtotal	87, 990		87, 990
Arizona-California:			
Boulder	120, 000		120, 000
Arizona-Nevada:			
Boulder	1, 030, 000	512, 500	1, 542, 500
California:			
Boulder	16, 600	68, 000	84, 600
Utah:			
Virgin	3, 440		3, 440
Total	1, 258, 030	580, 500	1, 838, 530

TABLE CXVI.—*Potential development of water resources in the lower basin* [1]

State and division	Acres to be irrigated [2]		Power plants		Estimated construction cost [4]
	New land	Furnished supplemental water	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours) [3]	
Arizona:					
Little Colorado	32, 250	600			$24, 700, 000
Virgin	3, 000	1, 000			2, 000, 000
Boulder	80, 000	7, 800	1, 922, 000	10, 174, 000, 000	563, 200, 000
Gila	113, 800	585, 200	15, 800	8, 000, 000	425, 500, 000
Subtotal	229, 050	594, 600	1, 937, 800	10, 182, 000, 000	1, 015, 400, 000
California:					
Boulder	16, 000				3, 100, 000
Nevada:					
Virgin	9, 500	4, 500			4, 800, 000
Boulder	33, 600				11, 700, 000
Subtotal	43, 100	4, 500			16, 500, 000
New Mexico:					
Gila	2, 000	10, 800	3, 000	8, 000, 000	14, 100, 000
Utah:					
Virgin	13, 000	8, 200	4, 600	15, 000, 000	9, 100, 000
River rectification and control					5, 000, 000
Transmission grid					192, 100, 000
Total	303, 150	618, 100	1, 945, 400	10, 205, 000, 000	1, 255, 300, 000

[1] In addition to irrigation and power production, many potential projects would have value for flood control, silt retention, recreation, and fish and wildlife conservation and recharge for underground water supplies.
[2] Does not include irrigable lands under constructed or authorized projects.
[3] Net firm generation, exclusive of replacement power.
[4] Preliminary estimates based on construction costs of Jan. 1, 1940.

TABLE CXVII.—*Present and potential stream depletion in the lower basin*

State and division	Estimated average annual depletion (acre-feet): Existing or authorized projects: Present depletions: Consumed in basin	Present depletions: Exported	Future increase: Consumed in basin	Future increase: Exported	Potential projects: Consumed in basin	Potential projects: Exported	Total ultimate depletion
Arizona:							
Little Colorado	58, 700				48, 700		107, 400
Virginia	5, 100				12, 700		17, 800
Boulder	208, 400		571, 000		346, 000		1, 125, 400
Gila	1, 135, 000				1, 608, 000		2, 743, 000
Subtotal	1, 407, 200		571, 000		2, 015, 400		3, 993, 600
California:							
Boulder	145, 000	2, 535, 000	148, 000	2, 798, 000	64, 000	112, 000	5, 802, 000
Nevada:							
Virgin	23, 800				36, 000		59, 800
Boulder	20, 000				177, 000		197, 000
Subtotal	43, 800				213, 000		256, 800
New Mexico:							
Little Colorado	13, 000						13, 000
Gila	16, 000				8, 000		24, 000
Subtotal	29, 000				8, 000		37, 000
Utah:							
Virgin	45, 000				56, 300		101, 300
Reservoir losses	713, 000		66, 000		91, 000		870, 000
Total	2, 383, 000	2, 535, 000	785, 000	2, 798, 000	2, 447, 700	112, 000	11, 060, 700

SUMMARY OF PRESENT AND POTENTIAL DEVELOPMENT IN COLORADO RIVER BASIN

The following tables summarize present and potential development of water resources in the entire Colorado River Basin.

Table CXXI shows that the "total ultimate depletions" are over 20,000,000 acre-feet annually. The long time average annual undepleted flow of the Colorado River at the International Boundary is estimated at 17,720,000 acre-feet. (See appendix I, Water Supply, Colorado

TABLE CXVIII.—*Present irrigation development in the Colorado River Basin*

State	Upper basin: Irrigated (acres)	Upper basin: Irrigable [1] (acres)	Lower basin: Irrigated (acres)	Lower basin: Irrigable [1] (acres)	Total (acres)
Arizona	6, 000		835, 930	166, 900	1, 006, 830
California			460, 900	342, 100	[2] 803, 000
Colorado	770, 170	32, 670			802, 840
Nevada			11, 000		11, 000
New Mexico	38, 000		19, 770		57, 770
Utah	274, 820		23, 500		298, 320
Wyoming	236, 070	11, 470			247, 540
Total	1, 325, 060	44, 140	1, 351, 100	509, 000	3, 229, 300

[1] Land that will be irrigated under present development.
[2] Includes 713,000 acres outside the natural Colorado River drainage area.

TABLE CXIX.—*Present hydroelectric generating capacity in the Colorado River Basin*

State and division	Present installed capacity (kilowatts)	Authorized or planned (kilowatts)	Total (kilowatts)
Colorado:			
Green	200		200
Grand	49, 667		49, 667
San Juan	4, 650		4, 650
Subtotal	54, 517		54, 517
New Mexico: San Juan	280		280
Utah:			
Green	2, 050		2, 050
Grand	50		50
San Juan	170		170
Subtotal	2, 270		2, 270
Wyoming: Green	150		150
Total, upper basin	57, 217		57, 217
Arizona:			
Little Colorado	40		40
Gila	87, 950		87, 950
Subtotal	87, 990		87, 990
Arizona-California:			
Boulder	120, 000		120, 000
Arizona-Nevada:			
Boulder	1, 030, 000	512, 500	1, 542, 500
California:			
Boulder	16, 600	68, 000	84, 600
Utah:			
Virgin	3, 440		3, 440
Total, lower basin	1, 258, 030	580, 500	1, 838, 530
Total, Colorado River Basin	1, 315, 247	580, 500	1, 895, 747

River.) The required delivery to Mexico, assuming ratification by Mexico of the pending treaty, with ultimate development in the United States is estimated to average 1,500,000 acre-feet annually, which would leave an average annual flow to be used in the United States of about 16,220,000 acre-feet, or about 80 percent of the sum of the present and potential development possibilities listed in the report.

It is evident that the list of potential projects selected for actual development will need to be modified to conform to the available water upply. A plan of modification is not suggested in this report. Final selection of projects will depend upon their relative merits, the final allocations of water among the States, the desires of each State as to alternative possibilities, and the findings of future investigations.

TABLE CXX.—*Potential development of water resources in the Colorado River Basin*

State and division	Acres to be irrigated [1]		Power plants		Estimated construction cost [2]
	New land	Furnished supplemental water	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)	
Arizona:					
San Juan	18, 680	6, 000	400, 000	2, 188, 000, 000	$65, 628, 000
Little Colorado	32, 250	600			24, 700, 000
Virgin	3, 000	1, 000			2, 000, 000
Boulder	80, 000	7, 800	1, 922, 000	10, 174, 000, 000	563, 200, 000
Gila	113, 800	585, 200	15, 800	8, 000, 000	425, 500, 000
Subtotal	247, 730	600, 600	2, 337, 800	12, 370, 000, 000	1, 081, 028, 000
California:					
Boulder	16, 000				3, 100, 000
Colorado:					
Green	197, 800	30, 360	170, 500	944, 000, 000	96, 300, 000
Grand	135, 300	158, 270	88, 000	453, 000, 000	57, 232, 000
San Juan	110, 960	37, 920	67, 000	264, 000, 000	69, 227, 000
Subtotal	444, 060	226, 550	325, 500	1, 661, 000, 000	222, 759, 000
Nevada:					
Virgin	9, 500	4, 500			4, 800, 000
Boulder	33, 600				11, 700, 000
Subtotal	43, 100	4, 500			16, 500, 000
New Mexico:					
San Juan	224, 960	15, 100			76, 882, 000
Gila	2, 000	10, 800	3, 000	8, 000, 000	14, 100, 000
Subtotal	226, 960	25, 900	3, 000	8, 000, 000	90, 982, 000
Utah:					
Green	150, 520	145, 010	288, 000	1, 579, 000, 000	116, 500, 000
Grand	88, 700	1, 950	200, 000	1, 141, 000, 000	80, 975, 000
San Juan	12, 560	14, 200	498, 000	2, 663, 000, 000	150, 298, 000
Virgin	13, 000	8, 200	4, 600	15, 000, 000	9, 100, 000
Subtotal	264, 780	169, 360	990, 600	5, 398, 000, 000	356, 873, 000
Wyoming:					
Green	291, 330	95, 360	1, 500	9, 000, 000	47, 100, 000
River rectification and control					5, 000, 000
Transmission grid					362, 100, 000
Total	1, 533, 960	1, 122, 270	3, 658, 400	19, 446, 000, 000	2, 185, 442, 000

[1] Does not include irrigable lands under existing or authorized projects.
[2] Preliminary estimates based on construction costs of Jan. 1, 1940.

Table CXXI.—*Present and potential stream depletion in the Colorado River Basin*

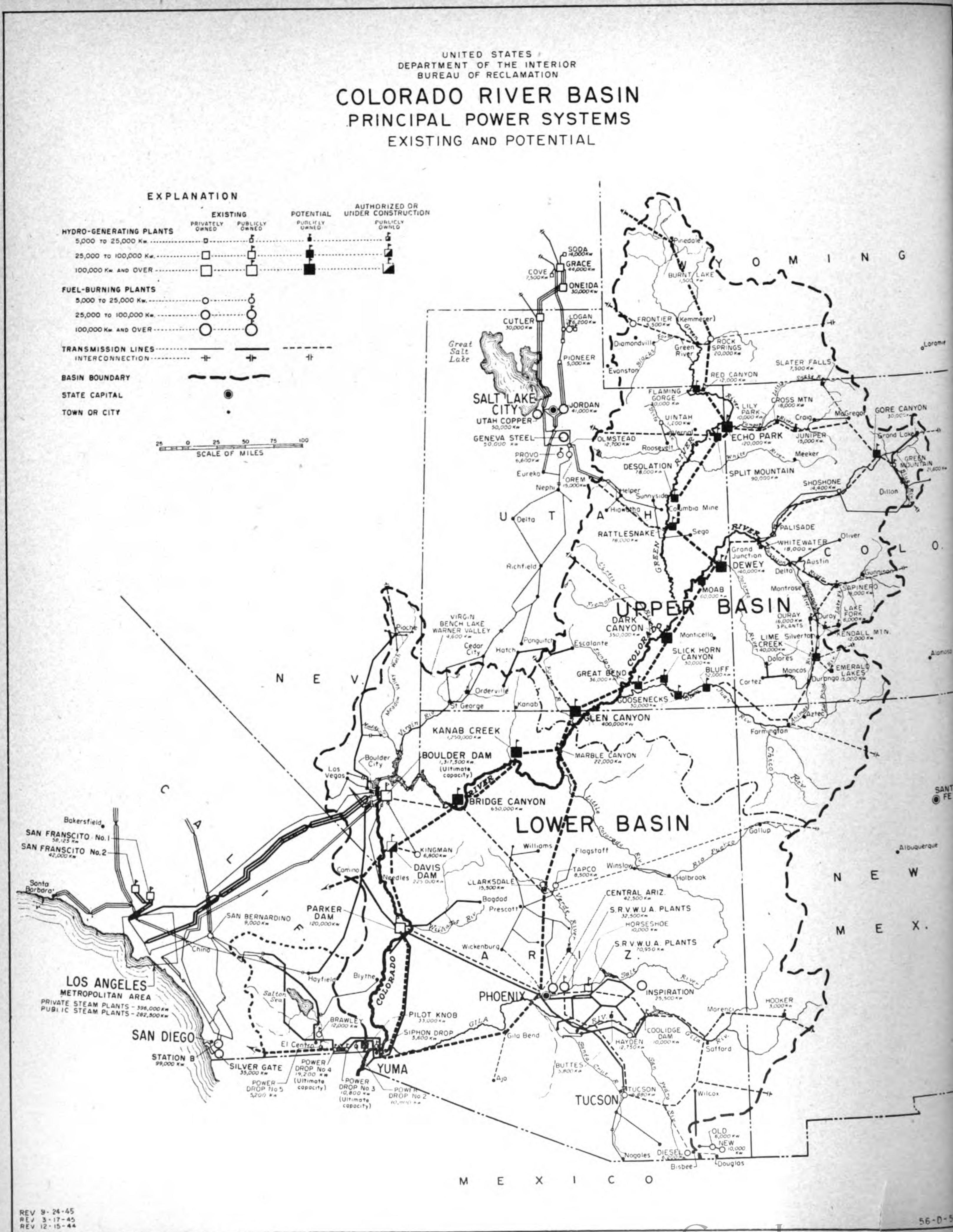
State and division	Estimated average annual depletion (acre-feet)						
	Existing or authorized projects				Potential projects		Total ultimate depletion
	Present depletion		Future increase				
	Consumed in basin	Exported	Consumed in basin	Exported	Consumed in basin	Exported	
Arizona:							
San Juan	10, 200				39, 000		49, 200
Little Colorado	58, 700				48, 700		107, 400
Virgin	5, 100				12, 700		17, 800
Boulder	208, 400		571, 000		346, 000		1, 125, 400
Gila	1, 135, 000				1, 608, 000		2, 743, 000
Subtotal	1, 417, 400		571, 000		2, 054, 400		4, 042, 800
California:							
Boulder	145, 000	2, 535, 000	148, 000	2, 798, 000	64, 000	112, 000	5, 802, 000
Colorado:							
Green	115, 000				324, 000	75, 000	514, 000
Grand	776, 000	98, 300	65, 000	421, 000	295, 000	1, 492, 000	3, 147, 300
San Juan	238, 000	4, 000		21, 000	251, 000	85, 000	599, 000
Subtotal	1, 129, 000	102, 300	65, 000	442, 000	870, 000	1, 652, 000	4, 260, 300
Nevada:							
Virgin	23, 800				36, 000		59, 800
Boulder	20, 000				177, 000		197, 000
Subtotal	43, 800				213, 000		256, 800
New Mexico:							
San Juan	68, 400				450, 000		518, 400
Little Colorado	13, 000						13, 000
Gila	16, 000				8, 000		24, 000
Subtotal	97, 400				458, 000		555, 400
Utah:							
Green	358, 000	81, 500		32, 000	264, 000	975, 700	1, 711, 200
Grand	13, 000				186, 000		199, 000
San Juan	63, 400				30, 000	7, 000	100, 400
Virgin	45, 000				56, 300		101, 300
Subtotal	479, 400	81, 500		32, 000	536, 300	982, 700	2, 111, 900
Wyoming:							
Green	374, 000		17, 000		489, 000	87, 000	967, 000
Pasture irrigation in upper basin					500, 000		500, 000
Reservoir losses	713, 000		66, 000		922, 000		1, 701, 000
Total	4, 399, 000	2, 718, 800	867, 000	3, 272, 000	6, 106, 700	2, 833, 700	20, 197, 200

Power From Water

"A prerequisite for industrial growth in any area is the availability of a sufficient amount of low-cost electric power. . . .

"Opportunities exist for the installation of 1,713,000 kilowatts of hydroelectric generating capacity on the Colorado River and its tributaries above Lee Ferry. This is nearly 17 times the capacity of all plants now in the area. The potential power output of these plants would be 28 times the total upper basin power production of 1943. . . .

"Development of the potential multiple purpose projects in the lower basin would make available an additional 1,900,000 kilowatts of installed capacity. It is estimated that by 1960 the demands for power will exceed the output from all existing, authorized, and potential plants."


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN
PRINCIPAL POWER SYSTEMS
EXISTING AND POTENTIAL
EXPLANATION
EXISTING
PRIVATELY OWNED
PUBLICLY OWNED
POTENTIAL
PUBLICLY OWNED
AUTHORIZED OR UNDER CONSTRUCTION
PUBLICLY OWNED
HYDRO-GENERATING PLANTS
5,000 TO 25,000 Kw.
25,000 TO 100,000 Kw.
100,000 Kw. AND OVER
FUEL-BURNING PLANTS
5,000 TO 25,000 Kw.
25,000 TO 100,000 Kw.
100,000 Kw. AND OVER
TRANSMISSION LINES
INTERCONNECTION
BASIN BOUNDARY
STATE CAPITAL
TOWN OR CITY
SCALE OF MILES
WYOMING
UTAH
NEV.
CALIF.
ARIZ.
COLO.
NEW MEX.
MEXICO
UPPER BASIN
LOWER BASIN
SALT LAKE CITY
Great Salt Lake
SODA
GRACE
COVE
ONEIDA
CUTLER
LOGAN
PIONEER
JORDAN
UTAH COPPER
GENEVA STEEL
PROVO
OREM
OLMSTEAD
FLAMING GORGE
UINTAH
RED CANYON
LILY PARK
CROSS MTN
ECHO PARK
SPLIT MOUNTAIN
DESOLATION
RATTLESNAKE
DEWEY
MOAB
DARK CANYON
SLICK HORN CANYON
GREAT BEND
BLUFF
GOOSENECKS
GLEN CANYON
MARBLE CANYON
KANAB CREEK
BOULDER DAM
BRIDGE CANYON
DAVIS DAM
KINGMAN
PARKER DAM
CLARKSDALE
TAPCO
CENTRAL ARIZ.
S.R.V.W.U.A. PLANTS
HORSESHOE
INSPIRATION
COOLIDGE DAM
HAYDEN
HOOKER
PILOT KNOB
SIPHON DROP
YUMA
SILVER GATE
STATION B
SAN DIEGO
LOS ANGELES
METROPOLITAN AREA
SAN BERNARDINO
SAN FRANSCITO No. 1
SAN FRANSCITO No. 2
PHOENIX
TUCSON
FRONTIER
ROCK SPRINGS
BURNT LAKE
SLATER FALLS
GORE CANYON
JUNIPER
GREEN MOUNTAIN
SHOSHONE
PALISADE
WHITEWATER
SAPINERO
LAKE FORK
OURAY
KENDALL MTN.
LIME CREEK
EMERALD LAKES
SANTA FE
REV 9-24-45
REV 3-17-45
REV 12-15-44
56-D-554

CHAPTER VI

Power From Water

Full development of the resources of the Colorado River Basin requires that the waters of the Colorado River system be brought under control by the construction of suitable regulatory structures. Additional storage projects on upper basin streams are necessary for full utilization of its land and water resources. In addition, the production of hydroelectric power and energy will be possible by using the heads made available by the construction of dams and appurtenant works. These dams will also reduce flood damage by providing storage space to hold flood waters. Many thousands of tons of silt are now carried down the Colorado River each year, damaging irrigated areas and curtailing storage capacity in present reservoirs in the lower basin. Proper watershed management is proposed as an aid in the solution of this problem, but storage reservoirs located in the upper basin will aid also by retaining silt which reaches the streams. The reservoirs will have value also for recreational purposes and for the propagation of fish and wildlife.

The Bureau of Reclamation has constructed many multiple-purpose projects throughout the Western States for irrigation, power production, flood control, silt retention, recreation, and fish and wildlife conservation. One of the earliest projects involving power was built in Arizona in 1906 with construction of the Roosevelt power plant on the Salt River. The early plants were used primarily as a source of power for the pumping of irrigation water or for project construction purposes. Later, power was made available to project settlers and to other people in rural areas, towns, and cities where economical service could be rendered.

To date only a small part of the potential hydroelectric power available in the Colorado River Basin has been harnessed by man. (See map, Colorado River Basin, Principal Power Systems, Existing and Potential.) The development and utilization of electric power have progressed at widely different rates in the upper and lower basins. This has been the result of great differences between the two basins with respect to location, climate, population growth, agricultural development, commercial and industrial activities, and transportation facilities. Power development and utilization are far less advanced in the upper basin than in the lower basin and the area served from it. The discussion on power in this chapter is divided into two sections, the upper basin and the lower basin.

UPPER BASIN

Although the upper basin has great potentialities for the production of electrical energy, it now produces a comparatively small amount and consumes less than it produces. In 1943 the installed capacity of all plants was only 101,082 kilowatts, of which 57,217 kilowatts were in hydroelectric plants.

Some of the energy produced in the upper basin in Colorado is carried by transmission lines eastward over the Continental Divide to the Denver and Leadville load areas, while requirements in the Utah part of the upper basin are largely supplied with energy imported from adjoining areas to the west and north. To date it has not proved practicable to connect the two areas for power supply purposes.

Opportunities exist for the installation of 1,713,000 kilowatts of hydroelectric generating capacity on the Colorado River and its tributaries above Lee Ferry. This is nearly 17 times the capacity of all plants now in the area. The potential power output of these plants would be 28 times the total upper basin power production in 1943. Growing power markets within the basin and in adjoining areas are expected to require eventually the maximum power output of these plants. A system of interconnected transmission lines will be needed to carry power to markets.

Potential power developments described herein indicate the hydroelectric possibilities of the upper basin. Cost allocations have not been included but will be considered in later specific project reports.

The multiple-purpose projects involving power production would create artificial lakes with an aggregate surface area of 555 square miles. In addition to the production of power, many of these reservoirs would have value for irrigation, long-term stream flow regulation, flood control, silt retention, recreation, and propagation of fish and wildlife.

Present Power Development

The extent of present power development in the upper basin has been determined principally by the needs of the mining industry. Coal mines use most of the energy available in the Utah and Wyoming areas, while in the Colorado area coal and metal mines are the largest industrial users. These mining areas are served by the largest utility systems and industrial plants in the upper basin. A number of communities receive service from isolated generating plants, both hydroelectric and fuel-burning. In general, loads are comparatively small and the development of power generating and transmission facilities has been limited in the upper basin.

In Colorado the availability of desirable hydroelectric power sites has resulted in the installation of generating plants and high voltage transmission lines which are mainly to supply loads to the east of and outside the basin area. In Utah the coal mining industry in Carbon and Emery Counties is supplied with power and energy imported over high voltage lines from utility systems located outstide the basin. Wyoming coal mining interests have built their own generating plants to supply their requirements and the needs of people located nearby. Metal mining, which has developed in southwestern Colorado, uses most of the power and energy generated in that locality.

With a total of 101,082 kilowatts of capacity installed in plants in the upper basin, generation in 1943 amounted to 330,149,000 kilowatt-hours. Load requirements (sales plus losses and utility use) for that year totaled 238,870,000 kilowatt-hours, leaving a net export surplus of 91,279,000 kilowatt-hours. The total maximum demand of all loads in the upper basin area was approximately 52,404 kilowatts in 1943.

Power Facilities

Colorado area.—By far the greatest part of the installed electric generating capacity in this area of the upper basin is hydroelectric. Although large coal deposits are available in western Colorado, it has been more economical generally to install hydroelectric rather than coal-burning plants. In some isolated areas where loads are small internal combustion engine plants have been provided.

The principal power systems are those of the Public Service Co. of Colorado, the Bureau of Reclamation, the Western Colorado Power Co., and the Colorado Utilities Corp. The interconnected systems of the Public Service Co., of Colorado, the Bureau of Reclamation, and the Redlands Water & Power Co. together form the largest electric generating and transmission system in the Colorado area and also in the upper basin. These interconnected facilities include some 250 miles of transmission lines, extending eastward from a point a few miles west of Grand Junction to the Continental Divide and on into the Denver metropolitan area. The total generating capacity connected to this system in the upper basin amounts to 45,675 kilowatts, of which 90 percent is hydroelectric and 10 percent is steam-electric capacity. Included in this total area are the 21,600-kilowatt Green Mountain hydroelectric plant (Colorado-Big Thompson project) of the Bureau of Reclamation and the 3,000-kilowatt Palisades hydroelectric plant (Grand Valley project) owned by the Bureau but operated by the Public Service Co. of Colorado. The latter plant is considered a part of the company's system in this report. No internal combustion engine-driven generating plants are connected to any of these major systems.

Southwestern Colorado is served by the system of the Western Colorado Power Co., which has 11,700 kilowatts of connected generating capacity, including 9,700 kilowatts of hydroelectric and 2,000 kilowatts of steam-electric capacity.

At McGregor in the northern part of Colorado the Colorado Utilities Corp. operates a 4,250-kilowatt steam-electric plant, with transmission lines extending to nearby communities.

Principal municipal plants are located at Gunnison (550 kilowatts, steam-electric), Delta (1,100 kilowatts, internal combustion), and Meeker (200 kilowatts hydroelectric, and 375 kilowatts steam-electric), all of which are isolated plants. Other generating plants are operated by smaller utilities.

The installed generating capacity of all plants in the Colorado area was 68,429 kilowatts in 1943. Energy generating in that year amounted to 245,083,000 kilowatt-hours, while total load requirements (sales plus losses and utility use) were 88,228,000 kilowatt-hours. The difference of 156,855,000 kilowatt-hours was transferred into the Denver and Leadville load areas over the 100,000-volt transmission line of the Public Service Co. of Colorado.

Utah area.—Although the Utah area of the upper basin contains a large amount of potential water power and large coal reserves, very few generating plants have been installed, the principal electric loads being supplied with power imported from outside the basin. The largest installation is the 1,200-kilowatt hydroelectric plant of the Uintah Power & Light Co. The Utah Power & Light Co. also operates two isolated plants, one at Vernal (840 kilowatts) and one at Moab (210 kilowatts). The towns of Monticello and Blanding operate small plants to serve their citizens. Two rural electric cooperatives financed by the Rural Electrification Administration have 1,090 kilowatts of installed generating capacity.

Power for the important coal mining area is supplied by two lines of the Utah Power & Light Co., one a 44,000-volt line extending from the Olmstead plant near Provo to

Sego and Hiawatha, and the other a 132-000-volt line extending from the Olmstead plant to Helper. These lines are extensions of the company's main Utah-Idaho system.

Only 3,400 kilowatts of generating capacity were installed in the Utah area of the Upper Basin in 1943. Energy generated in that year amounted to 6,677,000 kilowatt-hours. Load requirements totaled 72,253,000 kilowatt-hours, thus requiring 65,576,000 kilowatt-hours to be imported.

Wyoming area.—Nearly all power generated in the Wyoming area of the upper basin is from steam-electric plants. Coal mining companies operate the greatest amount of generating capacity. A 20,000-kilowatt plant at Rock Springs operated by the Union Pacific Coal Co. is the largest steam-electric plant in the upper basin. Most of the energy produced by this plant is used for coal mining, but about one-fourth is being distributed by the Southern Wyoming Utilities Co. to other consumers in the Rock Springs area. At Kemmerer the Lincoln Service Corp. operates a 5,500-kilowatt steam-electric plant, and at Diamondville the Diamond Coal & Coke Co. operates a 1,000-kilowatt steam-electric plant, both being used mainly to supply power to coal mines.

The Southern Wyoming Utilities Co. has recently acquired the 1,240-kilowatt capacity steam-electric plant at Green River, Wyo., from the Utah Power & Light Co., and has constructed a transmission line from the plant to Rock Springs.

No municipally owned plants have been installed in the Wyoming area. One system financed by the Rural Electrification Administration operates a 180-kilowatt internal combustion engine plant.

The combined capacity of all plants in the Wyoming area amounted to 28,423 kilowatts in 1943. Transmission facilities are limited, being designed to serve load areas in close proximity to the power plants. Energy generation in 1943 totaled 77,049,000 kilowatt-hours, which met the load requirements of the area.

New Mexico area.—This area of the upper basin is served by the Aztec-Farmington division of the New Mexico Public Service Co. Installed generating capacity in 1943 totaled 830 kilowatts of which 280 kilowatts were hydroelectric and 550 kilowatts were internal combustion. The energy generated in that year was estimated at 1,340,-000 kilowatt-hours, all of which was consumed in the area.

Summary.—The amount of installed generating capacity in the upper basin in 1943 is given in table CXXII and the amount of energy generated and load requirements are shown in table CXXIII.

TABLE CXXII.—*Installed generating capacity in the upper basin (1943)*

State area and class of utility ownership	Installed capacity (kilowatts)			
	Hydro	Steam	Internal combustion	Total
Colorado:				
Privately owned	30, 942	10, 721	766	42, 429
Publicly owned	23, 575	1, 000	1, 425	26, 000
Total	54, 517	11, 721	2, 191	68, 429
Utah:				
Privately owned	1, 500	0	750	2, 250
Publicly owned	770	0	380	1, 150
Total	2, 270	0	1, 130	3, 400
Wyoming:				
Privately owned	150	6, 740	353	7, 243
Publicly owned	0	0	180	180
Subtotal—Utilities	150	6, 740	533	7, 423
Industrial plants	0	21, 000	0	21, 000
Total	150	27, 740	533	28, 423
New Mexico:				
Privately owned	280	0	550	830
Upper Basin:				
Privately owned	32, 872	17, 461	2, 419	52, 752
Publicly owned	24, 345	1, 000	1, 985	27, 330
Subtotal—Utilities	57, 217	18, 461	4, 404	80, 082
Industrial plants	0	21, 000	0	21, 000
Total	57, 217	39, 461	4, 404	101, 082

Plant Factor

Although the amount of installed generating capacity is of importance when considering the power facilities in an area, the real standard of power plant utilization is the amount of energy that can be generated for sale to the ultimate consumer. The degree of plant or system utilization is determined by comparing the amount of energy actually generated with the maximum it is possible to generate with the plant or system continually operated at full capacity. The percentage thus obtained is called the "plant factor."

Plant factors for interconnected systems are higher than for isolated plants because isolated plants need a greater part of their installed capacities as "reserve" to insure continuity of service. Also the operation of plants on an interconnected system may be coordinated to take advantage of the operating characteristics of the individual plants. Recently an annual plant factor of 61 percent was attained by the group of generating plants connected to the system of the Public Service Co. of Colorado in the upper basin, while plant factors on individual isolated plants ranged from 14 percent to 31 percent.

Energy Production Costs

Hydroelectric plants.—Hydroelectric plants in the upper basin in 1943 produced electric energy at average costs ranging from 0.65 to approximately 2.7 mills per

TABLE CXXIII.—*Energy generated and load requirements in the upper basin (1943)*

State area and class of utility ownership	Energy generated (thousand kilowatt-hours)				Load requirements (thousand kilowatt-hours)
	Hydro	Steam	Internal combustion	Total	
Colorado:					
Privately owned	168, 642	12, 738	358	181, 738	73, 430
Publicly owned	59, 142	1, 810	2, 393	63, 345	14, 798
Total	227, 784	14, 548	2, 751	245, 083	88, 228
Utah:					
Privately owned	4, 512	0	579	5, 091	65, 091
Publicly owned	1, 111	0	475	1, 586	7, 162
Total	5, 623	0	1, 054	6, 677	72, 253
Wyoming:					
Privately owned	100	13, 941	175	14, 216	29, 561
Publicly owned	0	0	500	500	614
Subtotal—Utilities	100	13, 941	675	14, 716	30, 175
Industrial plants	0	62, 333	0	62, 333	46, 874
Total	100	76, 274	675	77, 049	77, 049
New Mexico:					
Privately owned	450	0	890	1, 340	1, 340
Upper basin:					
Privately owned	173, 704	26, 679	2, 002	202, 385	169, 422
Publicly owned	60, 253	1, 810	3, 368	65, 431	22, 574
Subtotal—Utilities	233, 957	28, 489	5, 370	267, 816	191, 996
Industrial plants	0	62, 333	0	62, 333	46, 874
Total	233, 957	90, 822	5, 370	330, 149	238, 870

kilowatt-hour. In general, plants operating at the higher plant factors had the lowest average annual production costs. The costs include operation and maintenance items, but excluded fixed charges on the investment and taxes.

Steam-electric plants.—An analysis of production cost figures for steam-electric plants in the basin for which data are published by the Federal Power Commission shows that the total production cost is approximately 7 mills per kilowatt-hours. This includes operation, maintenance, and fuel costs, but does not include interest, depreciation, or taxes. Fuel cost is a major item of expense incurred in the operation of a steam-electric plant and for the plants selected this cost ranged from 2.1 mills to 3.18 mills per kilowatt-hour.

Internal combustion engine plants.—Cost data recently available on two internal combustion engine plants, with installed capacity totaling 750 kilowatts, show that the total production cost was 3.46 cents per kilowatt-hour, with fuel costing 0.86 cent per kilowatt-hour. The largest item of expense, amounting to 1.35 cents per kilowatt-hour, was for supervision, engineering, and labor.

POWER UTILIZATION

For the upper basin as a whole it is estimated that approximately 50 percent of the total amount of electricity used is consumed by industrial concerns connected with mining. Most of that industrial load is in the coal mining areas of Utah, Wyoming, and Colorado and in the metal mining area of Colorado. Other customers are residential, rural, and commercial users, and municipalities.

Area in the Rocky Mountain region where large-scale mining developments have taken place have the highest average annual load requirement per capita. The general lack of such development in the upper basin area compared with the Rocky Mountain region as a whole largely accounts for the much lower average annual load requirement per capita within the upper basin.

Selling price of electric energy.—The amount of energy used by residential consumers depends mainly on the selling price of electric energy. In the upper basin the average selling price to residential consumers, as taken

TABLE CXXIV.—*Electric energy load requirement in the upper basin (1943)*

State area	Total annual load (kw.-hrs.)	Population [1]	Average annual load requirement per capita (kw.-hrs.)
Colorado	88, 228, 000	119, 929	736
Utah	72, 253, 000	46, 957	1, 539
Wyoming	77, 049, 000	28, 331	2, 720
New Mexico	1, 340, 000	8, 262	162
Upper basin	238, 870, 000	203, 479	1, 174

[1] Bureau of the Census, estimated civilian population Mar. 1, 1943.

TABLE CXXV.—*Electric energy load requirements in the Rocky Mountain Region (1943)*

State [1]	Average annual load requirement per capita [2] (kw.-hrs.)
Colorado	1, 244
Utah	2, 859
Wyoming	1, 073
New Mexico	912
Arizona	2, 876
Montana	4, 869
Idaho	2, 266
Nevada	2, 146
Rocky Mountain Region	2, 241

[1] Entire State.
[2] Based on the electric utility and industrial energy requirements in 1943 and Bureau of the Census, estimated civilian population Mar. 1, 1943.

from reports made by the principal utilities operating therein, is 3.5 cents per kilowatt-hour and the average annual amount used per customer is approximately 1,000 kilowatt-hours.

With resepect to the sale of energy for commercial and industrial uses, those utilities operating in the basin whose industrial load is a substantial part of the total load, have average selling prices ranging from 0.98 to 1.89 cents per kilowatt-hour. Other utilities having small industrial loads compared with commercial loads reported considerably higher averages.

Power Market Survey and Load Trend

In making a power market survey and future load estimate for a given area, a knowledge of the area's physical characteristics, natural resources, principal economic activities, population distribution and growth, and other related factors is fundamental. Detailed discussions of those factors are included elsewhere in this report. They will be discussed in this chapter only to the extent necessary to develop the power market survey and to show how they affect the future load estimate.

The most important industries in the upper basin are livestock raising, farming, and mining. There is practically no manufacturing. Principal power loads are in the mining areas.

The development of the basin's resources, including the potential low-cost hydroelectric power, land, water, minerals, and timber would provide for considerable expansion of present industries and the establishment of many new industries. Such industries would include mining and refining of minerals, production of petroleum from oil shale and oil-bearing sandstone and by hydrogenation of coal, production of chemicals, development of lumber and related industries, manufacture of plastics, and the processing of foods.

FUTURE POWER CONSUMPTION

The following factors have been considered in estimating the total power load growth in the upper basin to the year 1980: the past load growth trends, the present status as compared with other areas, and economic trends and their probable effect on the future power market.

Estimates of future loads for each class of consumer have been made on the assumptions that low-cost power will become available, that the population will continue to grow at the rate of the past 40 years, that the number of farms will increase proportionately, and that the future labor force will more nearly resemble the present National labor force with respect to the distribution of workers in industrial classes.

Residential use.—In 1943 the average amount of energy used per residential consumer served by principal utilities in the upper basin was approximately 1,000 kilowatt-hours per year. Past records indicate that the average use has been increasing at the rate of about 5 percent per year. The average of the Nation for 1943 was 1,060 kilowatt-hours a year per consumer, and has been increasing at a rate of approximately 6 percent per year over the past 20 years.

The amount of electricity used in the home depends upon many factors, among them being the cost of electrical energy and equipment and the cost of completing fuel and equipment for cooking and heating. Development of the potential hydroelectric power projects in the upper basin would make it possible to supply the customer with low-cost energy. The present average residential rate is over 3 cents per kilowatt-hour. With respect to the United States as a whole those States having the highest residential use have the lowest rates. Furthermore, those same States are among the leading States in the amount of hydroelectric power developed.

Although rates are higher in the upper basin than in some other sections of the country, they have been decreasing in recent years. The production of low-cost hydroelectric power will lower rates.

Electrical manufacturing concerns are carrying on research and experimental work to produce a greater variety of better and cheaper electrical appliances and equipment for use in the home, such as refrigerators, ranges, water-heaters, ironers, washers, air-conditioning and house-heating equipment and a host of other conveniences.

Heating devices, whether used for cooking, water heating, or house heating, are the largest consumers of electrical energy in the home. In areas where natural fuels, such as coal, oil, gas, or wood, are plentiful and low in price, they are used for heating. In the greater part of the upper basin extensive deposits of coal have been and will continue to compete with electric energy for home heating purposes.

Various estimates of the future average annual use per residential customer in the United States range from 2,000 kilowatt-hours by 1960 to 14,000 kilowatt-hours by 1980, provided that the heating of homes with electricity is then common. Considering the present average consumption, cost of energy to the consumer, the availability of competing forms of energy, and the length of time expected to elapse before large-scale hydroelectric developments are completed, it appears that an average of 3,000 kilowatt-hours per year for the residential customer in the upper basin is a reasonable estimate for 1980. With an estimated 91,250 homes, urban and rural nonfarm, in the upper basin in 1980, and on the assumption that 95 percent will be electrified, the total annual residential use would be 260,000,000 kilowatt-hours.

Farm use.—Farmers have less electricity available for use than any other class of people, although they need electricity not only as a matter of convenience but as a necessity on farms and in farm homes. In 1943 the Rural Electrification Administration reported that 44 percent of the farms in Colorado were electrified, 76 percent in Utah, 34 percent in Wyoming, and 19 percent in New Mexico. These percentages apply to the entire State. In the more sparsely settled areas in the upper basin the percentages were lower.

The census data for 1940, compiled by county areas of the upper basin, showed that 33 percent of farm dwelling units in the Colorado area, 42 percent in the Utah area, 25 percent in the Wyoming area, 11 percent in the New Mexico area, and 32 percent in the entire upper basin had electric lighting. Of the 27,402 rural farm dwelling units in the four State basin areas, only 8,741 had electric lighting equipment.

Expansion in rural electrical service in postwar years is to be expected. The Rural Electrification Administration has plans for an extensive program. Utilities also are preparing to build more rural extensions as soon as materials become available.

Data on present power use by farms are generally lacking as most utilities do not maintain a separate classification for sale of power to farms. An indication of average farm use, however, may be obtained from rural sales data where available. In west central Colorado the average rural sales including home, commercial, and rural power uses amounted to 875 kilowatt-hours per customer in 1939 and 1,083 kilowatt-hours in 1943, an average rate of increase to 5.9 percent per year. The 11 systems financed by the Rural Electrification Administration supplied an average of 728 kilowatt-hours per customer annually in the basin area.

Electricity is used on the farm and in the farm home for lighting, refrigeration, cooking, water supply, water heating, sterilizing, and to operate hotbeds, brooders, milking machines, and other equipment, depending on the type of farm. As the cost of energy and equipment becomes lower the farmer will use more electricity.

It is estimated that by 1980 the average annual use per farm in the upper basin will amount to 5,000 kilowatt-hours, and that the number of farms will be increased to 42,500. On the assumption that 85 percent of the total number of farms will be electrified, the total farm use will amount to 180,000,000 kilowatt-hours annually.

Commercial use.—Since commercial and industrial sales data have been combined in utility reports, separate data on commercial use are not available. Types of commercial enterprises using electricity include wholesale and retail trade; finance, insurance, and real estate businesses; business and repair services; personal services (hotels, lodging houses, etc.); amusement, recreation, and related types of businesses; professional and related services; Government (local, State, Federal); and transportation, communication, and other public utilities.

One method of estimating the commercial load is to determine the average use of energy per employee engaged in the above enterprises. A survey made by the Federal Power Commission in 1941 of a number of establishments in Washington, D. C., showed that the average use per worker was 2,700 kilowatt-hours per year, excluding air conditioning. Future requirements for lighting and air conditioning of offices, hotels, stores, restaurants and other establishments will undoubtedly be much higher than at present. Low-cost electricity will make electric cooking devices attractive for hotels, restaurants, and other places. For the upper basin area, it is estimated that by 1980 the average annual commercial energy use per worker will be 3,000 kilowatt-hours and the total energy use will amount to 271,000,000 kilowatt-hours annually.

Mining use.—Little has been done to develop the vast mineral resources in the upper basin. Geologists, mineralogists, and others interested the subject claim that presently worked mineral deposits in some areas are rapidly becoming depleted and new sources of supply will be required within a few years. As an example, known petroleum reserves are estimated to be sufficient for only 15 years at the 1940 rate of consumption. The exhaustion of the high-grade iron ores at Mesabi, Minnesota, now threatening, may have important effects on the western iron and steel industry.

Among the more important possibilities for developing reserves of minerals are the production of petroleum from coal, oil shale, and oil sandstone; production of fertilizer from phosphate rock and potash bearing minerals; and production of chemicals from coal.

Large amounts of power are used by the mining industry, particularly since the mechanization of mining has been increasing. In 1940 the average amount of energy used in the United States in all mining operations was approximately 10,000 kilowatt-hours per worker. New mining enterprises that will be developed in the upper basin will be more highly mechanized, thus requiring much more energy per worker than is presently used. It is estimated that by 1980 the use per worker will average at least 20,000 kilowatt-hours annually, and with a total of 21,400 workers the mining industry in the upper basin will use 428,000,000 kilowatt-hours per year.

Manufacturing use.—As resources are developed new manufacturing plants to process and refine the raw materials from the farms and mines will arise in the basin. They will include food-processing plants, smelters, refineries, and chemical works, most of which require large quantities of electric power in their operation. An average use of 15,000 kilowatt-hours per worker a year by 1980 is a conservative estimate. With a total of 21,400 workers, manufacturing will use 321,000,000 kilowatt-hours annually.

Transportation use.—No railways in the upper basin are electrified at present. The electrification of sections of the following main-line railroads has been considered: the Denver and Salt Lake Railway over the Rocky Mountains from Denver to Bond, Colo. The Denver and Rio Grande Western Railroad from Ogden to Helper, Utah; the Union Palific Railroad from Cheyenne to Granger, Wyo., and on into Ogden, Utah; and the Oregon Short Line from Granger to Pocatello, Idaho. The estimated annual energy use or electrification of these railroad sections located in the upper basin will amount to 180,000,000 kilowatt-hours.

Progress in railway electrification will depend upon many factors, including the financial condition of the operating companies, new developments in the design of locomotives, and cost of power, as well as future volume of travel. The Diesel locomotive may not be used extensively in the future if petroleum supplies are conserved for other purposes. The gas-turbine locomotive is still in the experimental stage. Because of the higher speed and smoke-free operation of electric locomotives, it is possible that at least some of the existing lines will be electrified and possibly new ones constructed. It is estimated that by 1980 transportation facilities will consume 180,000,000 kilowatt-hours annually.

Estimated Future Load Summary

Future loads for each class of consumer in the upper basin are estimated as follows:

Class of consumer:	*Estimated total load, 1980 (kilowatt-hours)*
Residential	260,000,000
Farm	180,000,000
Commercial	271,000,000
Mining	428,000,000
Manufacturing	321,000,000
Transportation	180,000,000
Total consumption	1,640,000,000
Losses and utility use	245,000,000
Total load requirements	1,885,000,000
Maximum demand at 65 percent annual load factor	330,000 kilowatts

The trend of estimated future load growth is shown on figure 14. The following tables summarizing future load growth indicates an average annual compound rate of increase of 5.9 percent per year as compared with the past 20-year National average annual rate of increase of 7.2 percent. The per capita requirements in the Upper Basin for 1980 thus would be approximately 3,500 kilowatt-hours per year, as compared with the present average of 1,174 kilowatt-hours per year.

Table CXXVI.—*Estimated load growth in the upper basin*

Year	Estimated annual energy requirements (kilowatt-hours)		
	Total	Load increase	
		Increment for 10 years	Accumulative (total)
1943	239,000,000		
1950	360,000,000	[1] 121,000,000	[1] 121,000,000
1960	695,000,000	335,000,000	456,000,000
1970	1,215,000,000	520,000,000	976,000,000
1980	1,885,000,000	670,000,000	1,646,000,000

[1] For 7 years.

Potential Power Development

Power Plants

Included in the potential multiple-purpose projects for the upper basin are a number of developments that will produce hydroelectric power and enegry. These developments include 29 power plants which would have a

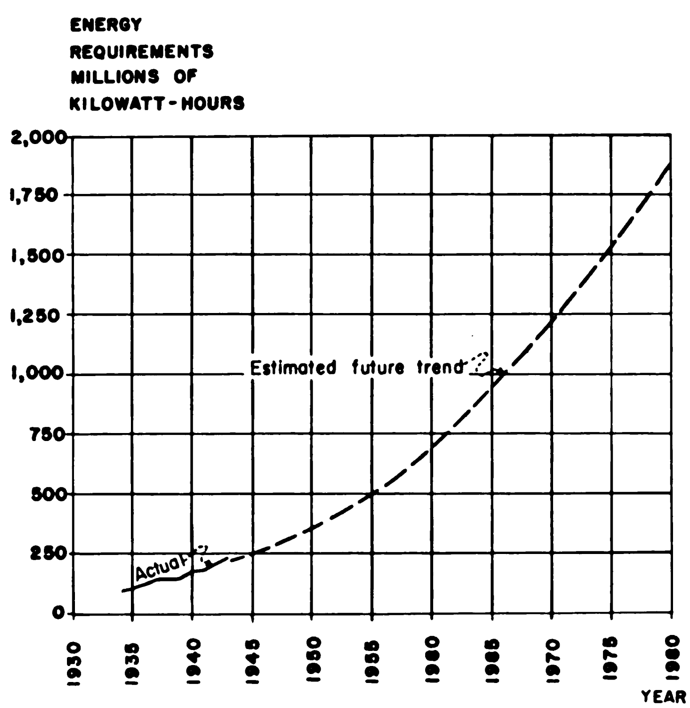


Figure 14.—*Upper Colorado River Basin, estimated trend, electric power load of basin*

total installed capacity of 1,713,000 kilowatts and an annual firm production of over 9 billion kilowatt-hours of electric energy. Plant capacities would range from 1,500 kilowatts to 400,000 kilowatts.

Potential power plants in the Upper Colorado River Basin are listed in table CXXVII which gives the stream location, project, installed capacity, and the annual firm generation of each plant.

Transmission System

The sites of the potential power plants in the upper basin are located away from principal load centers. In order to make power available to load areas, the plants would be connected with transmission lines to form an interconnected power system. This system would be connected to systems in other basins. Such a system would permit maximum flexibility of operation and maximum utilization of available water. Tentative locations of principal transmission lines are shown on the map entitled, "Colorado River Basin, Principal Power Systems, Existing and Potential," included in an appendix of this report.

The total cost of the upper basin potential transmission lines, terminal substations, and intermediate switching and transformation facilities is estimated, on the basis of 1940 prices, at $171,000,000.

Steam-electric generating equipment may be desirable as a supplementary source of power and for stand-by, firming up, or peaking purposes on the hydroelectric system; in some cases steam-electric capacity may be needed to supply power for construction purposes.

Cost Allocations

Cost allocations have not been included in this report because further investigations will be necessary in order to obtain sufficient data to evaluate properly the multiple benefits. Although the cost of producing power has not as yet been definitely determined, it is believed the production cost will permit the sale of hydroelectric power at such low rates as to enable industrial establishments, communities, rural users, and others to make liberal use of electric energy.

Summary

Hydroelectric power is one of the most important resources of the upper basin. Only a small part of the

Table CXXVII.—*Potential hydroelectric power plants in upper basin* [1]

River basin and power plant	Project	Stream	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)
Green River:				
Burnt Lake	Sublette	Fall Creek	1, 500	9, 000, 000
Flaming Gorge	Flaming Gorge	Green River	30, 000	158, 000, 000
Red Canyon	Red Canyon	do	12, 000	68, 000, 000
Echo Park	Echo Park	do	120, 000	668, 000, 000
Split Mountain	Split Mountain	do	90, 000	486, 000, 000
Desolation	Desolation	do	78, 000	433, 000, 000
Rattlesnake	Rattlesnake	do	78, 000	434, 000, 000
Yampa River:				
Juniper	Deadman Bench	Yampa River	15, 000	87, 000, 000
Cross Mountain	Cross Mountain	do	18, 000	99, 000, 000
Slater Falls	Little Snake River	Slater Creek	7, 500	43, 000, 000
Lily Park	Lily Park	Yampa River	10, 000	47, 000, 000
Colorado River:				
Gore Canyon	Gore Canyon	Colorado River	30, 000	177, 000, 000
Dewey	Dewey	do	140, 000	797, 000, 000
Moab	Moab	do	60, 000	344, 000, 000
Dark Canyon	Dark Canyon	do	350, 000	1, 843, 000, 000
Glen Canyon	Glen Canyon	do	400, 000	2, 188, 000, 000
Gunnison River:				
Sapinero	Sapinero	Gunnison River	18, 000	100, 000, 000
Whitewater	Cisco-Thompson	do	18, 000	100, 000, 000
Lake Fork	Lake Fork	Lake Fork	6, 000	12, 000, 000
3 plants	Ouray	Uncompahgre	16, 000	64, 000, 000
San Juan River:				
2 plants	Animas-LaPlata	Animas River	52, 000	192, 000, 000
Emerald Lake	Emerald Lake	Pine River	15, 000	72, 000, 000
Bluff	Bluff	San Juan River	52, 000	289, 000, 000
Gooseneck	Goosenecks	do	30, 000	152, 000, 000
Slick Horn Canyon	Slick Horn Canyon	do	30, 000	176, 000, 000
Great Bend	Great Bend	do	36, 000	203, 000, 000
Total			1, 713, 000	9, 241, 000, 000

[1] In addition to the plants listed, there are other sites in the upper basin where power could be developed, but the lack of information on those sites precludes the inclusion of their power possibilities. Further investigations may result in additions or deletions of power plants listed or changes in capacity and output of particular plants.

power resources has been developed. Full development of these power resources would result in an energy production equivalent to 6 percent of the Nation's power needs in 1940. Large-scale hydroelectric power developments would have far-reaching effects on the economic future of the upper basin and in adjoining areas. From an economic standpoint, the upper basin is one of the least developed regions in the United States. Future growth will depend upon development of the basin's agricultural and mineral resources, which will result in the expansion of ~~existing~~ industries and the creation of new ones.

A prerequisite for industrial growth in any area is the availability of a sufficient amount of low-cost electric power. Many attractive power sites exist on the streams in the upper basin and can be developed by construction of the multiple-purpose projects outlined in the previous chapter. With the construction of power plants and transmission lines, electric service can be provided to practically all parts of the basin and to many places outside of the basin. The availability of large quantities of low-cost hydroelectric energy will be an important factor in the establishment of new mining, manufacturing, and agricultural industries, all of which need electric power for the efficient operation required in modern industrial competition.

Power developments in the upper basin, including present and potential generating capacity (name-plate rating) and output, and load forecasts are summarized as follows:

	Kilowatts	Kilowatt-hours
Present installed generating capacity:		
Hydroelectric	57, 217	----------
Fuel-burning	43, 865	----------
Total	101, 082	----------
Present load requirements (1943)	52, 404	238, 870, 000
Potential installed generating capacity, hydroelectric	1, 713, 000	----------
Potential firm output	----------	9, 241, 000, 000
Estimated load requirements (1980)	330, 000	1, 885, 000, 000
Estimated increase in load requirements (1943–80)	277, 596	1, 646, 130, 000
Estimated energy available for export (1980)	----------	7, 594, 870, 000

The capacity of potential hydroelectric plants in the upper basin is greatly in excess of the upper basin's estimated power load by 1980. Studies of power needs in neighboring basins, however, indicate that their loads by 1980 will far exceed their possible hydroelectric developments. Power developments in the upper basin can be used in part to supply loads in areas outside the basin, including the Bonneville Basin (Salt Lake area), and the lower basin power area. Some power could also be supplied to western areas of the Missouri River and the Rio Grande Basins, and the extreme southeastern portion of the Columbia River Basin, if needed. In the power area of the lower basin annual deficiencies are estimated at 5 billion kilowatt-hours by 1970 and 9 billion by 1980, over and above the possible output of all present facilities, including those authorized and planned, and potential hydroelectric developments in the lower basin.

LOWER BASIN

A vast reservoir of potential hydroelectric power in the Lower Colorado River Basin awaits development. Only minor steps had been taken toward full development of this natural power resource until the construction of Boulder Canyon and Parker Dam projects, which completed two links in a chain of dams and power plants to harness the waters of the Colorado River and provide large quantities of low-cost power to meet urgent and growing demands in Arizona, southern California, and southern Nevada. Now low-cost electrical energy from these two sources is pouring into industrial plants, pumping plants, and municipalities of the region. In 1943 installed generating capacity, including additional units planned and authorized projects, in the lower basin power area was 3 million kilowatts, of which about 2 million kilowatts were in hydroelectric plants, yet a power shortage existed.

Development of the potential multiple-purpose projects in the lower basin would make available an additional 1,900,000 kilowatts of installed capacity. It is estimated that by 1960 the demands for power will exceed ~~the output~~ from all existing, ~~authorized~~, and potential ~~plants~~.

Potential power develop~~ments described~~ herein indicate hydroelectric possibilities of the Lower Basin. Early construction of some of these plants is urgently needed to avoid power shortages and consequent curtailment of economic development. Cost allocations have not been included, but will be considered in later special project reports.

Power Area

For the purpose of this report the lower basin power area includes the drainage basin of the Colorado River below Lee Ferry, the Salton Sea Basin, and the Pacific coastal area south of the Tehachapi Mountain Range. Some sections of this power area are now being supplied wholly and other sections in part by the power plants located in the Lower Basin.

This power area is divided for discussion into five divisions; (1) Arizona—entire State; (2) southern California—San Diego, Imperial, Riverside, Orange, San Bernardino, Los Angeles, and Ventura Counties, and part of Santa Barbara County; (3) southern Nevada—Clark and Lincoln Counties; (4) Utah—that part included in the lower basin in Washington, Kane, and Iron Counties; and (5) the part of New Mexico included in the lower basin in McKinley, Valencia, Catron, Grant, and Hidalgo Counties.

Present Power Development

Present power development and utilization vary considerably throughout the area. Much electricity is used in the thickly populated metropolitan areas. Extensive power developments in or feeding into these areas include both hydroelectric and fuel-burning plants. In the remaining expansive but sparsely populated parts of the area most power loads are small and widely scattered. Many communities are served by small isolated power systems or local power plants, chiefly of the fuel-burning type. Some of the present generating and transmission facilities in the power area rapidly are becoming obsolete and are neither adequate nor properly designed for full coordination of operation. In addition energy is now being generated at three different frequencies, and transmitted at various voltages.

Construction of Boulder and Parker power plants and high-voltage transmission lines from these plants to major load centers in central Arizona and southern California has made it possible to deliver large blocks of low-cost power and energy to distant load centers. These developments together with a comparatively small amount of modern equipment in several local systems constitute the present electrical development within the basin which is suitable for supplying economically substantial quantities of power.

In 1943 the total installed capacity of the generating units in the principal power plants, both hydro and fuel-burning types, within the power area, exclusive of authorized projects, was about 2.5 million kilowatts. (This included one 82,500-kilowatt unit being installed in Boulder Dam power plant in 1943). Interconnections with plants outside the area made available to the area approximately 0.4 million kilowatts of additional capacity, thus bringing the total installed capacity available to the area in 1943 to 2.9 million kilowatts. It is estimated that of this total capacity only about 2.5 million kilowatts were classed as dependable capacity available at all times to supply system loads and reserve requirements in the area. Additional units which have been authorized and planned but which have not as yet been installed in the area will increase the capacity by about 0.6 million kilowatts.

Total electric energy consumed in the power area in 1943 was in excess of 11 billion kilowatt-hours. This large amount of energy had been generated by operating many of the plants at or near maximum capacity for extended periods because of war demands. Normal operation will permit shut down of the less efficient fuel plants and operation of the more efficient ones for peaking and stand-by service. This is important because of the growing necessity to conserve the diminishing oil supply and to reserve the natural gas fields for long-time domestic and industrial requirements.

Although power deficiency in the power area was rather critical during the year 1943 owing to the tremendous war load, it has eased considerably since that time. With war demands lessened and the production of magnesium, aluminum, and certain other war products curtailed, the rapid rate of load growth is slackening. With further reduction in war industries and with the installation of new generating capacity now under construction or authorized, available power supply will be sufficient to meet estimated normal load requirements in the immediate future.

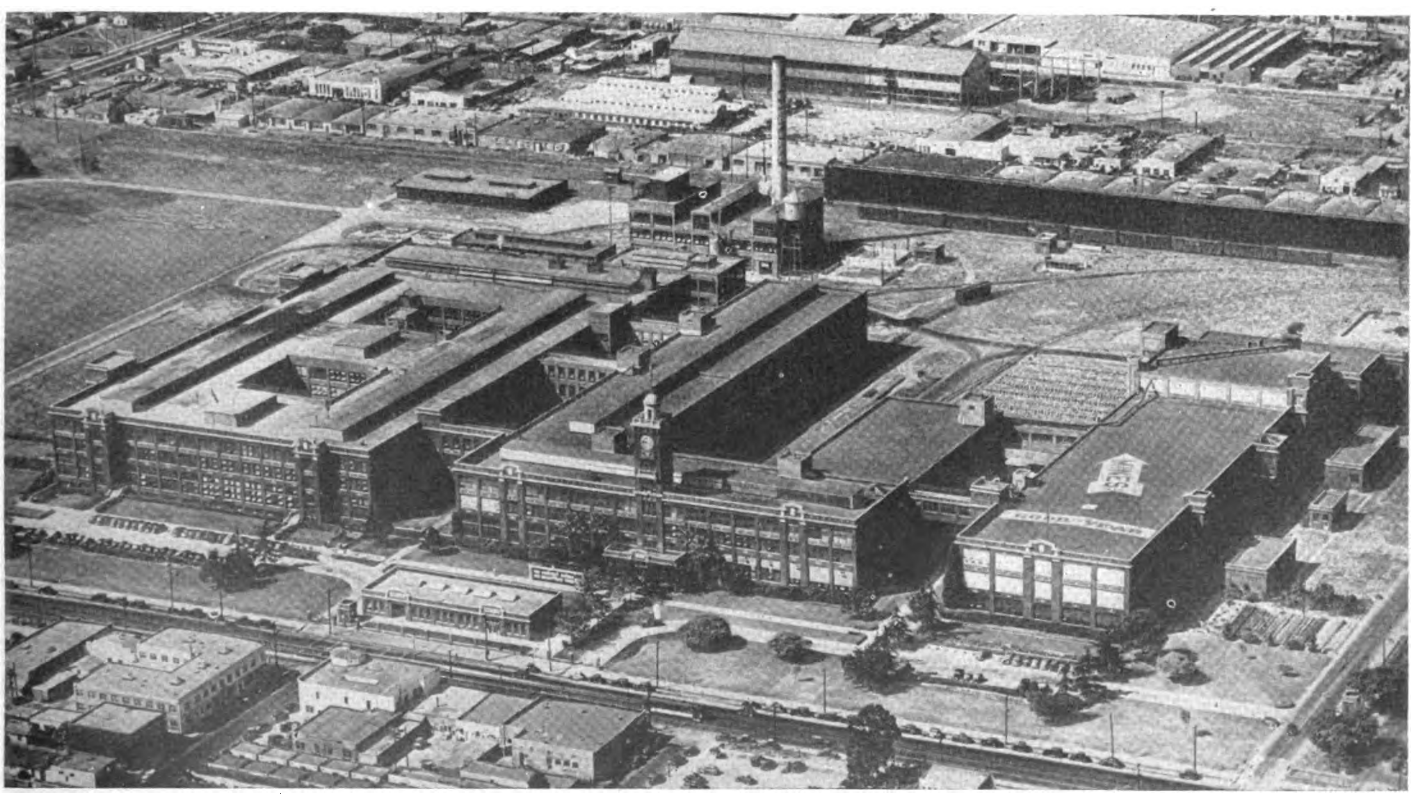
Power Facilities

Present power facilities in the power area are discussed by States, except for the major power developments on the lower Colorado River, which are considered separately as they involve distribution of large quantities of power and energy to two or more States.

Lower Colorado River plants.—Construction of Boulder Dam power plant by the Bureau of Reclamation was begun in 1931 and the first of the main generating units was placed in service in 1936. The power plant is designed for an ultimate installed capacity of 1,317,500 kilowatts provided by fifteen 82,500-kilowatt and two 40,000-kilowatt generating units. The installation of one 82,500-kilowatt unit completed in 1944, brings the present installed capacity to 1,030,000 kilowatts. Lake Mead has a maximum storage capacity in excess of 32 million acre-feet of water. The great amount of generating capacity installed in the power plant, together with the tremendous storage of water, provides the flexibility of operation needed to meet daily, monthly, and seasonal fluctuations in electrical load. Moreover, this vast storage will be useful in coordinating the operation of many present and potential plants in the power area. The firm energy output of the Boulder Dam power plant was established at 4,330,000,000 kilowatt-hours for the year of operation ending May 31, 1938, and thereafter reduced by 8,760,000 kilowatt-hours annually as an average adjustment for upstream depletions. Total generation, firm and secondary, for the calendar year 1943 was 5,727,906,714 kilowatt-hours, and was near that same amount in 1944.

Parker Dam power plant is located on the Colorado River 155 miles by river downstream from Boulder Dam, just below the confluence of the Williams and Colorado Rivers. Parker Dam was originally constructed as head-

DOWNTOWN LOS ANGELES
Boulder Dam power lights cities and homes



GOODYEAR TIRE AND RUBBER COMPANY, LOS ANGELES
This plant uses Colorado River power and water

works for the Colorado River aqueduct of the Metropolitan Water District of Southern California, but later provision for construction of a power plant was made. The Bureau of Reclamation rushed the construction of the Parker Dam power plant in order to relieve a severe shortage of power in Phoenix, Ariz., and to furnish power for pumping on the Gila irrigation project in southwestern Arizona. By June 1943 the 120,000-kilowatt power plant was completed with four units in operation. This was years ahead of schedule. Power produced at this plant is delivered by means of high-tension transmission lines to load centers at Phoenix, Tucson, and Yuma, Ariz. These lines also connect with the Imperial irrigation district lines in Imperial Valley, Calif. Havasu Lake, the reservoir formed by Parker Dam, has a storage capacity of 716,000 acre-feet and makes available a maximum head of 75 feet. During the period June 1, 1943, to May 31, 1944, the Parker Dam power plant generated a total of firm and secondary energy of 781,642,000 kilowatt-hours. It is estimated that the plant can produce an average of about 500,000,000 kilowatt-hours of energy a year on a firm power basis.

Approximately 67 miles downstream from Boulder Dam and about 88 miles upstream from Parker Dam is the site of Davis Dam power plant. The Davis Dam project was authorized by the Congress and a contract for construction was awarded by the Bureau of Reclamation in June 1942; however, the War Production Board later issued a revocation and the contract was terminated in February 1943, with very little work having been accomplished. This action was considered necessary because of shortages of critical materials and manpower. Although the additional energy that Davis power plant would have generated was urgently needed, the length of time necessary to complete construction did not warrant continuance of the project during the war emergency. Construction will be resumed as soon as practicable. The reservoir will have an active storage capacity of 1,600,000 acre-feet and will back water up to the tailrace of the Boulder Dam power plant. The Davis Dam power plant will utilize the 140-foot head made available and will have an ultimate installed capacity of 225,000 kilowatts. Transmission lines will connect with Parker Dam power plant and with the power area transmission grid. The initial firm energy that the Davis Dam power plant can generate is estimated at 800 million kilowatt-hours annually. It is expected that future upstream developments and other factors affecting stream flow will reduce the amount of water available to the extent that the firm energy will be reduced ultimately to approximately 600 million kilowatt-hours annually.

Existing hydroelectric plants not located on the river but utilizing Colorado River water diverted at Imperial Dam and delivered by the All-American Canal include the 1,600-kilowatt Siphon Drop power plant of the Yuma irrigation project, Arizona, and Drop No. 3 and No. 4 plants of the Imperial irrigation district, California. Additional plants planned for in the building of the All-American Canal but not yet constructed include plants at Canal Drops No. 2 and No. 5, and at Pilot Knob.

Arizona.—The Bureau of Reclamation by virtue of its Boulder Dam and Parker Dam power plants is the largest producer of electrical energy in the State. Other principal agencies, exclusive of mining companies, contributing to the power supply are the Salt River Valley Water Users' Association; Central Arizona Light & Power Co.; the Tucson Gas, Electric Light & Power Co.; Arizona Power Corp.; Arizona Edison Co.; and Office of Indian Affairs (San Carlos project).

A number of mining companies produce electricity for their own use and a few of them generate some energy for public consumption. Only about one-fourth of the total generating capacity in the State exclusive of Colorado River plants of the Bureau of Reclamation is hydroelectric.

Transmission systems of the State are entirely inadequate to meet the requirements of the rapidly growing electric power load. Two generating frequencies, 25 and 60 cycles, and many transmission voltages are now used. Interconnections between systems are inadequate and some smaller systems are completely isolated. Initial steps have been taken toward rectification of these conditions. Since 1940 the Bureau of Reclamation has constructed transmission lines that connect Parker Dam power plant with Phoenix, Tucson, and Yuma, and an interconnection has been made through lines of the Metropolitan Water District of Southern California with Boulder Dam power plant.

Southern California.—The power area in southern California is supplied principally by the following agencies: Southern California Edison Co., Ltd.; California Electric Power Co.; city of Los Angeles Department of Water and Power; city of Burbank; city of Glendale; city of Pasadena; Metropolitan Water District of Southern California; San Diego Gas & Electric Co.; California-Pacific Utilities Co.; and Imperial irrigation district.

Most of the power systems of these organizations are interconnected, although some of the ties are not of adequate capacity for the desired integration of operation. A substantial connection with a capacity of 157,000 kilowatts is maintained between the Southern California Edison Co., Ltd., and the Pacific Gas & Electric Co., the principal generating agency in the central part of the State. The largest amount of power available to the area comes over eight transmission lines from Boulder Dam power plant. Three lines are operated by the city of Los Angeles, two lines are operated by the Southern California Edison Co., and one line by each of the following agencies: the California Electric Power Co., the Metropolitan Water District of Southern California, and the

California-Pacific Utilities Co. Power is also available from plants owned by Southern California Edison Co., Ltd., city of Los Angeles Department of Water and Power, and California Electric Power Co. located outside of the power area.

Southern Nevada.—Clark and Lincoln Counties are almost entirely dependent for their power supply upon Boulder Dam and Parker Dam power plants. The operating agencies for this region are: Southern Nevada Power Co., Lincoln County Power District, California-Pacific Utilities Corp., and United States (Boulder City).

The power demand for operation of the reduction plant of Basic Magnesium, Inc., reached about 200,000 kilowatts during periods of peak production, but by the end of 1944 the demand decreased owing to curtailed operations in this war plant.

Present power requirements in this area, exclusive of the magnesium plant and town site, are about 41,000 kilowatts. Transmission lines of sufficient capacity for the present load extend from Boulder Dam power plant to load centers.

Utah.—Electric service is supplied in the Utah area by the Southern Utah Power Co. and the St. George municipal plant. A total of 4,569 kilowatts of generating capacity is installed in the area, 3,440 kilowatts hydro and 1,129 kilowatts internal combustion.

New Mexico.—Gallup, N. Mex., operates a municipal distribution system and purchases its electric energy requirements from a nearby coal mining company which operates a 4,000 kilowatt steam-electric plant.

Summary.—A summary of the present power generating facilities in the power area of the Lower Colorado River Basin is given in table CXXVIII. Total capacity includes units installed, under construction, authorized, or for which installation has been definitely planned in the construction of existing projects. It is estimated that these facilities can produce approximately 11 billion kilowatt-hours of energy annually.

Energy Production Costs

The average expense of power production in 1940 reported by the Federal Power Commission for five leading private utilities in Arizona, exclusive of taxes, depreciation, and allowance for return on investments, was 4.13 mills per kilowatt-hour. The addition of taxes and depreciation on production plants brings this average up to a little more than 6 mills per kilowatt-hour. The average cost of power purchased by these agencies during the same period was over 8 mills per kilowatt-hour. Energy is produced by fuel-burning plants at relatively high costs throughout most of the power area. Small plants and isolated plants, in general, produce power at very high costs. Boulder Dam and Parker Dam power plants are

TABLE CXXVIII.—*Installed generating capacity in the lower basin power area (1943)*

Division area ownership	Generating capacity (kilowatts)					
	Present installed				Authorized or planned (hydro)	Total installed, authorized or planned
	Hydro	Steam	Internal combustion	Total		
Lower Colorado River: Publicly owned	[1] 1, 151, 600	0	0	1, 151, 600	516, 500	1, 668, 100
Arizona:						
Privately owned	7, 040	224, 567	40, 180	271, 787	0	271, 787
Publicly owned	80, 950	22, 500	15, 492	118, 942	0	118, 942
Subtotal	87, 990	247, 067	55, 672	390, 729	0	390, 729
Southern California:						
Privately owned	11, 870	509, 000	31, 084	551, 954	0	551, 954
Publicly owned	124, 225	282, 500	12, 000	418, 725	64, 000	482, 725
Subtotal	136, 095	791, 500	43, 084	970, 679	64, 000	1, 034, 679
Utah:						
Privately owned	2, 890	0	329	3, 219	0	3, 219
Publicly owned	550	0	800	1, 350	0	1, 350
Subtotal	3, 440	0	1, 129	4, 569	0	4, 569
New Mexico: Privately owned	0	4, 000	0	4, 000	0	4, 000
Lower Basin:						
Privately owned	21, 800	737, 567	71, 593	830, 960	0	830, 960
Publicly owned	1, 357, 325	305, 000	28, 292	1, 690, 617	580, 500	2, 271, 117
Total	1, 379, 125	1, 042, 567	99, 885	2, 521, 577	580, 500	3, 102, 077

[1] Includes one 82,500-kilowatt unit of the Boulder Dam plant placed in operation in 1944.

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generating large quantities of energy at much lower cost. A market is now available for still larger quantities of such low-cost energy.

Fuel Supply for Generation of Electricity

Oil and natural gas are the principal fuels utilized in fuel-burning electric generating plants in the area. The war has caused a heavy drain on these natural resources. Above ground reserve supplies of oil in California have been greatly depleted even with an increased production of crude oil. Many steam-electric plants normally using oil for fuel have been converted to utilize natural gas. It is evident, however, that the known sources of both oil and natural gas in the region will not continue indefinitely to supply these fuels at the present rate of consumption. Unless extensive new reserves of these fuels are discovered, it is certain that their use for generation of electricity will be sharply curtailed in a very few years. An increase in the cost of producing electricity in fuel-burning plants in the near future is anticipated. If coal were to replace present fuels, it would have to be transported for long distances, probably from mines in Utah, as there are no known extensive coal deposits in the area.

A number of fuel-burning plants may be retired in the future because of their obsolescence and the high cost of fuel. It is anticipated that the larger and more efficient plants will continue to be used for peaking and stand-by purposes. Minimum generating capacity which should be held in reserve to meet probable emergency requirements of the present power systems in the power area is considered to be about 300,000 kilowatts. A substantial amount of capacity in fuel-burning plants is required for such stand-by when hydroelectric energy must be transmitted long distances over transmission lines, as is the case in this power area. Energy generation by fuel-burning plants, however, will be reduced appreciably as the supply of low-cost hydroelectric energy increases.

Power Utilization

Electrical energy requirements (sales plus losses and utility use) in the power area of the lower basin during the year 1943 were a little more than 11 billion kilowatt-hours with a corresponding peak-load demand of about 2,100,000 kilowatts. Approximately 95 percent of the area's 1943 energy requirements was generated within the area, while about 5 percent was imported. Annual energy requirements had increased over 4.5 billion kilowatt-hours from 1940 to 1943. Much of this increase resulted from the great expansion of war industries. Increasing amounts of power and energy were also required in agriculture for farm use and irrigation pumping, in mining, and in many other service and trade industries.

The following tabulation shows the total energy requirements and the requirements per capita in the lower basin power area.

Table CXXIX.—*Electric energy load requirements in the lowr basin power area (1943)*

Division area	Total annual load [1] (kilowatt-hours)	Population [2]	Average annual load requirement per capita (kilowatt-hours)
Arizona	1, 206, 324, 000	578, 756	2, 084
Southern California	8, 506, 391, 000	3, 986, 847	2, 134
Southern Nevada	[3] 1, 445, 009, 000	45, 823	31, 534
Utah	9, 300, 000	11, 000	846
New Mexico	7, 000, 000	31, 870	220
Lower Basin area	[3] 11, 174, 024, 000	4, 654, 296	2, 400

[1] Exclusive of energy generated by industrial concerns for their use.
[2] Estimated civilian population by Bureau of Census, Mar. 1, 1943.
[3] Includes 1,315,261,000 kilowatt-hours load requirements of Basic Magnesium, Inc.

The average annual energy requirement per capita for the United States, comparable to the figures shown in the above table, is 1,677 kilowatt-hours.

Selling Price of Electrical Energy

Domestic requirements comprise a large portion of the electrical load and were rapidly increasing even prior to the war period. About 27 percent of the total energy sold in 1939 was delivered to residential customers, both urban and rural, at an average cost to the consumer of 2.8 cents per kilowatt-hour. Corresponding combined sales to commercial and industrial establishments amounts to 44.7 percent of the total energy sold at an average cost of 1.6 cents per kilowatt-hour.

Rates for sale of power and energy vary considerably in this power area. Throughout most of the area with exception of the cities on the west coast, rates have been high. In general, communities receive power from Boulder Dam and Parker Dam plants at a comparatively low cost and isolated communities still pay very high prices for power from smaller local plants.

Power Market Survey and Load Trend

Demand for electric power in the area has increased at a rapid rate during the past decade. Even prior to the stimulating influence of war conditions a remarkable growth was being experienced. Indications are that the potential power market in the area will continue to grow for many years in the future. With the cessation of hostilities, however, it is to be expected that there will be some temporary dropping off or leveling of power loads.

Opportunities exist for greatly expanding agriculture, mining, manufacturing, recreational areas, and health centers. The expansion of these industries will increase the demand for more low-cost power.

Since 1900 population has grown much more rapidly in the metropolitan areas on the west coast than in other parts of the power area. Some sections are very sparsely settled. Only 4,650,000 persons were living in the lower basin power area in 1943. It has ample room and resources to support a population considerably in excess of this number and by 1980 it is estimated the population will have increased to at least 8,500,000.

Future Power Consumption

Residential use.—Domestic utilization of electricity in the past has been limited somewhat because of the high cost to the consumer and because of the lack of widespread knowledge and acceptance of the many services and conveniences which electricity can provide in the home. An increasing demand for more power for domestic use is expected in future. The climate throughout most of the power area is especially suited to electric heating and air conditioning because excessive consumption of electricity for these purposes is not required. Also, there is a lack of natural fuels, such as coal, oil, gas, and wood in the greater part of this area. Refrigeration for food preservation has become a necessity in the modern home. Introduction of new type equipment, such as "deep freeze" units, and the expansion of the use of present domestic-type refrigerators, stoves, heaters, and washing machines would increase greatly the use of electricity in homes. Total energy requirements for heating, air conditioning, and for other conveniences for an "all-electric" home would be about 14,000 kilowatt-hours annually. If favorable rates for sale of power and energy are made available to practically all communities in the power area it is estimated that an average yearly domestic consumption of 4,000 kilowatt-hours per home would be reached by 1980.

Farm use.—The agricultural industry in the area is largely dependent on irrigation. Dry farming is of little consequence. Any plan for development of the potential irrigation projects would necessitate the use of a substantial amount of power and energy for irrigation and drainage pumping. It is also anticipated that farms will use additional amounts of electricity under extensive programs of rural electrification, possibly reaching an average annual consumption of 4,000 kilowatt-hours per farm, or 8,000 kilowatt-hours including the farm residence.

Commercial use.—The use of electricity by commercial establishments is comparatively high. The long, hot summers make the use of air conditioning equipment highly desirable in many parts of the area, especially in hotels, office buildings, restaurants, and in places of public gatherings. Electricity is used for cooking in many places and is becoming more and more popular every year as better appliances and lower rates are made available. With the possibility that lower cost energy and better appliances and lighting equipment will continue to be made available throughout the area a steady and substantial increase in the commercial load is foreseen.

Mining use.—The mining industry has been greatly stimulated by the war emergency. Large, important underground supplies of minerals, however, remain undeveloped in the area. The availability of large amounts of low-cost power would help to reduce mining costs and would encourage greater use of electricity in the industry. Substantial quantities of such cheap power would also be used to replace present generation of many fuel-burning plants which are owned and operated by mining companies. It is anticipated that the future consumption of electric energy in the mining industry within the power area will average about 1 billion kilowatt-hours annually.

Manufacturing use.—More manufacturing industries in the area are needed. Some industries have sprung up and expanded greatly under the war impetus but in some instances industrial expansion has been limited by the lack of available low-cost electric power. The construction of the potential hydroelectric developments would provide for broad industrial expansion. Low-cost electric power and energy would encourage the processing of agricultural products and special metals as well as the production of many finished goods that previously have been produced in other parts of the country and transported long distances to markets in the area.

Transportation use.—Some consideration has been given to the possibility of electrification of that section of the Atchison, Topeka & Santa Fe Railroad between San Bernardino, Calif., and Winslow, Ariz. The increasing scarcity of fuel supply in the region and the availability of low-cost power in the future would increase the desirability of converting this section of main line railroad from steam to electric operation. Electrification of this section would probably consume 300 million kilowatt-hours of electric energy annually.

Estimated Future Load Summary

Future loads for each class of consumer in the lower basin power area are estimated as follows:

Class of consumer:	*Estimated total load, 1980 (kilowatt-hours)*
Residential	8, 000, 000, 000
Farm	2, 200, 000, 000
Commercial	5, 500, 000, 000
Mining	1, 000, 000, 000
Manufacturing	10, 000, 000, 000
Transportation	300, 000, 000
Total consumption	27, 000, 000, 000
Losses and utility use	3, 000, 000, 000
Total load requirements	30, 000, 000, 000

Maximum demand, 5,300,000 kilowatts.

Total energy requirements for all purposes in the lower basin power area rose from an average of about 350 kilowatt-hours per capita in 1910 to approximately 2,400 kilowatt-hours in 1943. It is anticipated total annual requirements will reach at least 3,500 kilowatt-hours per person by 1980.

An estimate of future load growth for the lower basin power area is shown in table CXXX and figure 15. Studies previously made through extensive research by the Federal Power Commission, by individual power-generating agencies, and by State and local planning boards and commissions have been used as guides in preparing this forecast.

TABLE CXXX.—*Estimated load growth in the lower basin power area*

Year	Estimated annual energy requirements (kilowatt-hours)		
	Total	Load increase	
		Increment for 10 years	Accumulative total
1940	6, 512, 000, 000		
1950	14, 164, 000, 000	7, 652, 000, 000	7, 652, 000, 000
1960	20, 687, 000, 000	6, 523, 000, 000	14, 175, 000, 000
1970	25, 971, 000, 000	5, 284, 000, 000	19, 459, 000, 000
1980	30, 000, 000, 000	4, 029, 000, 000	23, 488, 000, 000

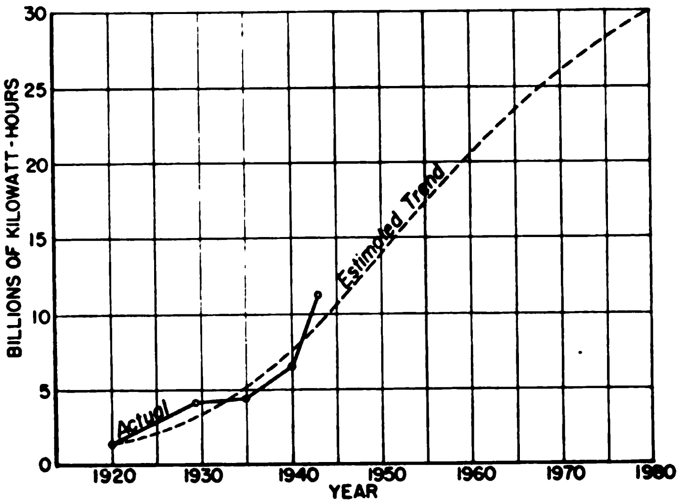

FIGURE 15.—*Lower Colorado River Basin, estimated trend, electric power load of market area*

Potential Power Development

POWER PLANTS

Potential generating capacity in the lower basin would be concentrated fairly well, as 1,922,000 kilowatts, or 99 percent of the total capacity of 1,945,400 kilowatts, would be installed in three plants located on the main stem of the Colorado River between Lee Ferry and Boulder Dam. The remaining capacity, 23,400 kilowatts, would be installed in six small widely separated plants in Arizona, Utah, and New Mexico. The locations of the potential power plants are shown on the map "Colorado River Basin, Principal Power Systems, Existing and Potential" included in the appendix.

The potential power plants in the Lower Basin would have a total firm energy generation of 10,242,000,000 kilowatt-hours per year. Of this amount 37,000,000 kilowatt-hours would replace loss of generation at the Stewart Mountain hydroelectric plant because of a potential upstream diversion from Salt River. The net increase in firm generation therefore would be 10,205,000,000 kilowatt-hours. It is estimated that the present power developments, including units operating, under construction, authorized or planned, can produce about 11 billion kilowatt-hours annually. The present and potential plants described herein would be capable of a total output of more than 21 billion kilowatt-hours of firm energy annually.

Potential plants in the Lower Colorado River Basin are listed in table CXXXI which gives the location by stream, project, the installed capacity, and annual firm generation of each plant.

TRANSMISSION SYSTEM

A tentative plan for construction of a high voltage power transmission grid for the delivery of power and energy to principal load centers in the lower basin power area is indicated on the map in the appendix. This map shows the general location of potential transmission lines which would complement the existing lines and connect the present and potential major generating plants with the principal load centers and with each other. Such a transmission system would permit a high degree of coordination in the operation of the power plants. This is desirable from the standpoint of economy of power system operation and of conservation of water and fuel resources. Some of the generating plants would be located at great distances from the load centers. Operating characteristics of hydroelectric plants vary greatly because of the fluctuation in water supply and in reservoir releases for irrigation, flood control, and other purposes. Under these conditions an extensive transmission system is required to produce a maximum amount of firm power and energy and to provide for supplying economically large quantities of power and energy to widely scattered load centers.

The total cost of the potential transmission system for the lower basin area including transmission lines, terminal substations, and intermediate switching and transformation facilities is estimated, on the basis of 1940 prices, at $195,000,000.

TABLE CXXXI.—*Potential hydroelectric power plants in the lower basin*

River basin power plant	Project	River	Installed capacity (kilowatts)	Annual firm generation (kilowatt-hours)
Colorado River:				
Marble Canyon	Marble Canyon—Knab Creek	Colorado	22, 000	164, 000, 000
Kanab Creek	do	do	1, 250, 000	6, 570, 000, 000
Bridge Canyon	Bridge Canyon	do	650, 000	3, 440, 000, 000
Gila River:				
Buttes	Central Arizona	Gila	5, 800	8, 000, 000
Horseshoe	do	Verde	[1] 10, 000	[1] 37, 000, 000
Hooker	do	Gila	3, 000	8, 000, 000
Virgin River: [2]				
Virgin	Hurricane	Virgin	2, 000	3, 000, 000
Bench Lake	do	do	800	2, 000, 000
Warner Valley	do	do	1, 800	10, 000, 000
Total			[3] 1, 945, 400	[3] 10, 242, 000, 000

[1] Would be used to replace loss of generation at Stewart Mountain plant.
[2] In addition to the firm energy shown there will be 17,800,000 kilowatt-hours generated annually to be used as replacement for energy now being generated at the LaVerkin plant, project pumping, and secondary energy.
[3] Net increase in installed capacity 1,935,400 kilowatts and net increase in annual firm generation 10,205,000,000 kilowatt-hours.

Cost Allocations

Construction of some of the potential power plants in the lower basin probably will be needed in the near future. Any plan for full development of the water resources will require the construction of many multiple-purpose projects. The costs of construction and operation of such multiple-purpose projects should, therefore, be distributed among the purposes served in accordance with benefits received. From available information it is estimated that the total cost for production and delivery of power and energy will permit the sale of large quantities of electricity at rates sufficiently low to be very attractive to the future growing power market.

Summary

Requirements for electric energy by the metropolitan areas of southern California, and by people in Arizona and southern Nevada, have resulted in the construction of large hydroelectric power developments in the lower basin power area. The total hydroelectric generating capacity now installed, authorized, and planned to be installed in the power area is 1,959,625 kilowatts. Another 1,142,452 kilowatts of capacity are installed in fuel-burning electric generating equipment. Although the present power developments in the area are on a very large scale and supply a vast area, the potential hydroelectric developments would double the amount of hydroelectric capacity available to the lower basin power area. The greater degree of coordinated generation of the area's power plants, present and potential, which will be made possible by more extensive interconnecting transmission lines and better stream flow regulation, will result in a higher energy output per kilowatt of installed capacity than is now being obtained.

Load growth in the past has been at a high rate of increase from year to year, and the average consumption for the area is now well above the national average. In view of the expected increases in population throughout the area, and the resultant increases anticipated in the demand for electricity for use in the home, on the farm, and by mining, industrial, commercial, and other users, it is estimated that by 1980 the total load requirements of the area will be nearly three times the present load requirements.

Power developments in the lower basin power area, including present and potential generating capacity (name plate rating) and output, and load requirements are summarized as follows:

	Kilowatts	Kilowatt-hours
Present installed generating capacity: [1]		
Hydroelectric	1, 959, 625	
Fuel-burning	1, 142, 452	
Total	3, 102, 077	
Present load requirement (1943)	2, 100, 000	11, 174, 024, 000
Potential installed generating capacity: Hydroelectric	[2] 1, 935, 400	
Potential firm output		[2] 10, 205, 000, 000
Estimated load requirements (1980)	5, 300, 000	30, 000, 000, 000
Estimated increase in load requirements (1943–80)	3, 200, 000	18, 825, 976, 000
Estimated energy deficiency (1980)		8, 620, 976, 000

[1] Existing, authorized, and planned installed capacity.
[2] Excludes Horseshoe plant, 10,000 kilowatts installed capacity, and 37,000,000 kilowatt-hours output for replacement.

At the estimated rate of future load growth shown on the load trend curve (fig. 15) the load requirements by about 1960 will require the entire output of the potential plants in the lower basin. The deficiency after 1960 could be supplied from some of the upper basin potential plants. Although such energy would have to be transmitted long distances, it is believed technical advances in electrical engineering will make this transmission practicable.

SUMMARY—COLORADO RIVER BASIN

Power in the Colorado River Basin has been developed in the upper basin on a much smaller scale than in the lower basin mainly for the reason that a much smaller market for power is available to the upper basin as compared with the large metropolitan markets in southern California available to the lower basin. The use of power in those metropolitan areas has made possible the great developments on the lower Colorado River. The only city of over 10,000 inhabitants in the upper basin is Grand Junction, Colo. Development of the vast land, water, and mineral resources in the upper basin area has been on a very small scale. Present power developments in the two basin areas are summarized for comparison in table CXXXII.

Future load requirements in the Colorado River Basin and its electric service areas will grow as the demand increases for products from the basin and the service areas. As more people move westward to live, the demand for western products will increase; wants of the millions of people living on the west coast will also create an increased market for the products of Western States. These new marketing possibilities will stimulate industrial development throughout the Western United States; and the Colorado River Basin area will benefit greatly by increased population, and industrial and economic growth. Development of water resources on a basin-wide basis, as now being planned by the Bureau of Reclamation, will do much to stimulate future activities in the basin.

The future economic growth of the Colorado River Basin will depend upon more extensive utilization of the basin's land and water resources. Electricity, a product of water development, is used by people in all walks of life—in homes, on farms, in offices, in mines, in factories, and wherever else they may be. The benefits of large amounts of low-cost electric energy accrue to everyone. Industry uses great amounts of electric energy in modern practice. The greatest benefit to industry within the basin is likely to come from the development of low-cost hydroelectric power by the basin's potential power plants. The combination of large quantities of low-cost electricity with the abundant mineral resources in the basin offers untold possibilities. The people of the basin, the Mountain and Western States, the Pacific coast, the Nation, and the world would all benefit.

Mining and processing of minerals within the basin would be greatly stimulated if abundant low-cost power were made available. The high cost of electricity and undependable service from the present isolated plants are important handicaps to the expansion of mining and processing activities. In the upper basin are vast deposits of minerals including phosphates, magnesium, potash, coal, and oil shales; while in the lower basin are reserves of copper, gold, silver and zinc, along with other metals and nonmetallic minerals.

Transmission lines could be constructed to carry electricity from the basin's potential power plants to adjoining areas outside the basin, and thus stimulate growth in those areas. Lines into central Utah, interconnecting potential upper basin plants and Bonneville Basin plants, would result in industrial development in combination with materials from within and outside the basin. A basic steel industry has been started in the West by construction of the new Geneva steel plant near Provo, Utah. This industry with its associated and allied industries will require electricity in quantity and at low cost if it is to be developed on a large scale. Copper and zinc refining by the electrolytic process offers important possibilities in Arizona, Utah, Colorado, and New Mexico. As an example of what can be accomplished by the generation and transmission of large amounts of low-cost electricity, the lower Colorado River power system can be cited. Electric power from those plants is used in quantity in the lower basin areas in Nevada, Arizona, and California, while transmission lines carry large amounts of power to the metropolitan areas in southern California located many miles from the basin. These large developments have made profound changes in the economic structure of the lower basin power area. The construction of similar

TABLE CXXXII.—*Present power development in the Colorado River Basin (1945)*

Power area	Installed generating capacity [1]			Total annual load requirements (kilowatt-hours)	Average annual load requirements per capita (kilowatt-hours)
	Hydro (kilowatts)	Fuel-burning (kilowatts)	Total (kilowatts)		
Upper basin	57, 217	43, 865	101, 082	238, 870, 000	1, 174
Lower basin	1, 959, 625	1, 142, 452	3, 102, 077	11, 174, 024, 000	2, 400
Total	2, 016, 842	1, 186, 317	3, 203, 159	11, 412, 894, 000	2, 348

[1] Includes total installed, authorized, or planned.

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projects will be of the utmost importance to the Colorado River Basin States and the Nation.

Estimates of future electric power load growths have been based on past trends and future possibilities resulting from potential developments. Low-cost electric power will be used in large amounts not only by industrial consumers to stimulate industrial developments, but by the residential, farm, commercial, railway, and municipal classes of consumers. The estimates of future load growth, taking all classes of users into consideration, indicate total annual load requirements by 1980 of 31,885,000,000 kilowatt-hours for the entire Colorado River Basin area, or 1,885,000,000 kilowatt-hours for the upper basin and 30,000,000,000 kilowatt-hours for the lower basin.

Potential hydroelectric power developments would total 3.6 million kilowatts of installed capacity for the Colorado River Basin, with 1.7 million kilowatts in the upper basin in 29 plants and 1.9 million kilowatts in the lower basin in 9 plants. The firm energy output of the basin's potential plants would total slightly over 19 billion kilowatt-hours annually with 9 billion kilowatt-hours from the upper basin plants and 10 billion kilowatt-hours from the lower basin plants. The locations of potential plants and reservoirs are shown on figure 16, "River profile showing reservoirs and hydroelectric power plants, Colorado River Basin."

Estimated load requirements of the lower basin power area for 1980 are far in excess of the output of the lower basin plants, while the upper basin load is expected to be much less than the output of the potential plants located there. Energy from upper basin potential plants could therefore be used to supply at least a part of the load increase anticipated in the lower basin power market area, as well as in other basin areas where energy deficiencies may materialize in future years.

Power development in the Colorado River Basin including present and potential generating capacity (name plate rating) and output, and load forecasts is summarized as follows:

	Kilowatts	Kilowatt-hours
Present installed generating capacity [1]	3, 203, 159	
Present load requirements (1943)	2, 152, 404	11, 412, 894, 000
Potential installed generating capacity hydroelectric	[2] 3, 648, 400	
Potential firm output		[2] 19, 446, 000, 000
Estimated load requirements (1980)	5, 630, 000	31, 885, 000, 000
Estimated increase in load requirements (1943–80)	3, 477, 596	20, 472, 106, 000
Estimated energy deficiency (1980)		1, 026, 106, 000

[1] Existing, authorized, and planned installed capacity.
[2] Excludes Horseshoe plant, 10,000 kilowatt installed capacity, and 37,000,000 kilowatt-hour output for replacement.

Cost and Benefits from Power Production

Further investigation and study will be necessary before cost allocations of all the multiple-purpose potential projects can be determined. However, results of preliminary studies indicate that the sale of firm commercial energy at an average rate of approximately four mills per kilowatt-hour would provide for repayment of the power features and would provide additional funds which could be applied toward repayment of other project features.

Wealth From Water

"The whole Nation has a stake in the Colorado River . . .

"Water can be brought to this land to produce crops; . . . trade can be established; and in general, the wealth produced can be converted into more and better opportunities for the American people. . . . A great potential market for electric energy is provided by the mineral resources of the Colorado River Basin, among the richest and most varied in the world. . . ."

CHAPTER VII

Wealth From Water

Thousands of acres of desert land in the Colorado River Basin produce nothing more than sagebrush or cacti. Millions of acre-feet of water waste annually into the Pacific Ocean. Billions of tons of copper, coal, and other minerals lie buried in mountains. In their present state this land, this water, and these minerals are not wealth because they are not being utilized economically. They can, however, become wealth or produce wealth. Man's ingenious nature has assured him of this. Water can be brought to this land to produce crops; these minerals can be mined and processed with an abundance of low-cost hydroelectric energy made available; trade can be established; and in general, the wealth produced can be converted into more and better opportunities for the American people.

In the 169 years since the United States become a Nation its people have increased from a handful of 3 million dwelling along the eastern seaboard to 135 million distributed to all corners of the land. The average annual increase has been 780,000 persons. The current rate of growth is nearly 1 million annually. One million people must be absorbed each year into the National economy. Each must be provided with food, clothing, and shelter and given an opportunity to share in the advantages of the American way of life, contributing his bit toward the National welfare.

There are nations where the population has reached the saturation point, the maximum that the natural resources will support. In some of these, poverty and starvation stalk the land. Each new birth in effect brings death to the most feeble of the living.

America as a whole has not felt the pinch of overpopulation. Throughout its rapid growth its standard of living has continued to improve until it now surpasses anything the world has ever known. America's vast resources have been more than sufficient. Its frontiers have been rolled back as necessary. Virgin natural resources have awaited exploitation, and fertile land has stood ready to produce as soon as turned by the plow. American ingenuity and spirit have reached new heights in adapting the offerings of nature to the advantage of the people.

Today, however, the Nation faces a changing situation. The people pushing across the country have reached boundary lines or oceans on all sides. No longer do exterior frontiers invite exploitation. Yet the population continues to increase by almost a million a year. Since the area cannot be expanded to provide for these newcomers, the resources within its borders must be developed more intensely if the American standard of living is to be maintained and improved. Fortunately nature has provided opportunities for such development. Upward trends in both population and living standards can be maintained for many years to come. To achieve this goal, however, Americans must continue with the agressiveness and resourcefulness of their pioneer fathers, but henceforth the pioneering will have to be done on interior frontiers.

The undeveloped resources of the Colorado River Basin present one of the most inviting of the interior frontiers. Full control and utilization of these waters of the Colorado River system will create new wealth and new opportunities in America. The benefits will not be confined by basin boundaries but will extend throughout the land.

Water is perhaps the world's most important single resource. Without water no living thing, either plant or animal, can exist. Man requires it in abundance, not only to quench his thirst and cleanse his linens but in vastly greater quantities to produce and process the food that he eats and the other materials necessary to his welfare. The Colorado River Basin is in the heart of the arid west where water, because of scarcity, is especially precious. The basin has vast resources in land, fuels, oils, fertilizers, timber, metals, and recreational attractions, all dependent on water in one way or another for their development. Only by irrigation can this parched land become productive. Water is required to preserve and enhance the excellent fishing and recreational allurements. Water and the electric energy that can be generated by falling water are necessary to bring forth and process the basin's great mineral wealth. Water, so important, and yet so limited in this area, is the resource that above all others will determine the extent to which the bounties of the Colorado River Basin can be pressed into the service of the Nation.

Some resources, such as minerals, can be preserved in their natural depositories and hoarded until taken up for man's use. If little is used in this generation more will be available for the next. The flowing water of the

CITRUS GROVES

Irrigation makes possible these citrus groves in the desert

ONIONS ON UNCOMPAHGRE PROJECT

A former cat-tail swamp becomes productive with drainage and irrigation

Colorado River cannot be preserved in this sense. Any water unused today is lost forever to useful purpose. Each year that development is delayed diminishes the potential cumulative value of the water to mankind. Delay means waste, loss of potential wealth. Said Herbert Hoover, "Every drop of water that runs to the sea without rendering a commercial return is a public waste."

Uncontrolled, the Colorado is a "natural menace." Frequently it becomes a destroyer, overflowing its banks and cutting away its channel to bring ruin to farms, homes, and other property. Its heavy silt fills reservoirs and clogs diversion works. The river will continue to bring havoc to some areas, thus destroying wealth until completely subdued and its great energy turned to useful purposes.

The welfare of the Nation demands that the most be made of this "National resource," the waters of the Colorado River. The Congress foresaw this need in 1928 and wrote into the Boulder Canyon Project Act a directive to the Secretary of the Interior to make investigations and public reports of the feasibility of projects for irrigation, generation of electric power, and other purposes for the purpose of formulating a comprehensive scheme of control and the improvement and utilization of the water of the Colorado River and its tributaries.

The potentialities for development outlined in chapter V are presented in response to that directive. Possibilities for using the water substantially exceed the water resources of the river system. A final and complete selection of projects for construction in the ultimate plan of development must await completion of more detailed surveys, an allocation of available water supplies among the several States of the Colorado River Basin, and an expression by those States of preferences between alternative possibilities within their borders. It is anticipated, however, that certain key projects or projects otherwise urgently needed can be constructed immediately as the next phase of river development and that various intrastate, interstate, and international problems involved in the formulation of an ultimate plan will be solved in an orderly manner as needs arise.

Until a selection of projects has been made for inclusion in the final plan construction costs for full river development cannot be estimated. Neither can an accurate estimate be made of the value of benefits expected. There is ample proof, however, of the economic justification of a program for full control and utilization of these waters. Direct comparisons of costs and benefits for each phase of the development will be presented as construction is proposed.

Benefits to the West and to the Nation

Irrigation.—In 1939 there were 530 million acres available to grow crops in the United States—4 acres for each person. About 45 million acres of this land formerly used to grow forage for horses and mules are now producing for human consumption. This country still relies heavily upon imports, however, to support its population. Agricultural imports in 1937 were equivalent to the normal production of 87 million acres. Many of the products imported can be produced successfully on American farms. In more recent years because of wartime conditions great quantities of foodstuffs have been exported, but at the expense of shortages and rationing of food in the United States.

Not all of the land now in cultivation can be relied upon for perpetual production. The Department of Agriculture in 1937 estimated that 61 percent of the domestic cropland, about 253 million acres, is either subject to continued erosion or is of such poor quality as not to return a satisfactory income to farmers. Part of this can be saved from early retirement by improved farm practices. An expanding, not a diminishing farm area is the National requirement. With the population increasing at the rate of a million a year, maintenance of the present population-farm land ratio would require four million additional acres each year. The current level of living, however, could be maintained with a lesser expansion in farm acreage if the productivity of lands now farmed is increased by more irrigation in the arid regions and by improved farm practices.

The National objective is not merely to maintain present dietary standards, but to improve them. It is well established that the diets of low-income groups in the United States tend to be lacking in certain protective foods, and it is highly in the National interest that this situation be corrected. J. P. Calvin, Hazel K. Stiebeling, and Marius Farioletti writing for the 1940 Yearbook of Agriculture state:

> If the average consumption of protective foods by all families in this country could be raised to the level of those whose present diets may be rated "good" from the standpoint of nutrition, there would be large increases in National consumption. The figures would be approximately as follows: milk, 20 percent; butter, 15; eggs, 35; tomatoes and citrus fruit, 70; leafy, green, and yellow vegetables, 100. These figures are not maximum, however, because many freely chosen "good" diets do not include nearly as much of the protective foods as many nutritionists believe they should include. For example, internationally recognized experts on nutrition recommend that we double our average consumption of dairy products. * * *
>
> From a dietary standpoint the Nation urgently needs an increased consumption of protective foods that would require 8 to 10 million acres to produce. And if all could secure the "expensive good diet" now available to those who do not have to guard their food dollars too closely, we might need to utilize 30 to 40 million acres more than has been required for actual consumption in recent years.

In the 17 Western States the acreage of farm land per person is only half the National average. Most of these sparsely populated States do not raise sufficient food for their people and rely in part upon imports, chiefly from the Middle Western States. Furthermore, western population is increasing at a rate much faster than the National average. Even with the most efficient use of water for irrigation, increasing quantities of food must be shipped into the Western States.

In the Colorado River Basin agriculture and irrigation are almost synonymous. Successful crop production with reliance only upon rainfall is of negligible importance. Irrigation has provided farm homes for hundreds of thousands of people, created cities, and established markets for many millions of dollars worth of eastern and middle western farm and industrial products. Continued expansion of such developments will depend on how wisely the meager supply of water is utilized.

Potential irrigation projects described in chapter V, exclusive of export diversions, could bring water to 1,533,960 acres of land now dry and largely unproductive, and supplement present inadequate supplies on 1,122,270 acres. All of these projects may not be constructed, but any reduction in these acreages from this cause could be offset by the expansion of irrigation in adjoining basins with water diverted from the Colorado River. Ten thousand new farms could be created on land now uncultivated. Present farms could be made more productive. Some large holdings could be subdivided into family-sized units. Other small farms could be enlarged to economically sized units. The new farms would provide agricultural opportunities for some of the 100,000 servicemen who are returning to the Colorado River Basin.

Increased agricultural production resulting from such a program would have an annual value of $65,000,000. Compared with the growing needs of the Nation this increase is small but important. It represents beef, hides, wool, citrus and other fruits, vegetables, seeds, dairy products, honey, sorghums, and other foods and fibers—goods not produced domestically in sufficient quantities to meet domestic needs.

These crops are complementary to, rather than competitive with, crops produced on agricultural lands of other sections. Most of the forage and grain crops, considered National surplus crops, are consumed in the livestock regions of the irrigated West in greater quantities than produced. New irrigation developments thus create uses for surplus crops. A study of the 11 Western States shows that over and above what is produced locally for home consumption, there are purchased from other sections of the country annually: $120,000,000 of corn and hog products; $97,000,000 of cotton, cottonseed, and textiles; $90,000,000 of tobacco and tobacco products; $15,000,000 of hard wheat flour and processed cereals; and large amounts of other commodities.

Power.—The deep canyons cut by the Colorado River as it falls over 10,000 feet in its wild dash to the ocean provide some of the best power sites in the world. With full development the river channel could become a great stairway of reservoirs—quiet mill ponds—extending upstream from Parker Dam on the boundary between Arizona and California, through Arizona, Nevada, and Utah, into Wyoming and Colorado. In most cases each dam would back reservoir water to the toe of the dam next upstream. Branches of the stairway would reach up the San Juan, Green, and Yampa Rivers, a total continuous length of 1,600 miles. Other power dams would be distributed on tributary streams. Many dams would be multiple-purpose structures serving also for irrigation, flood control, and silt retention; providing opportunities for fishing and recreation; and making accessible many scenic wonderlands.

These power developments could generate 19 billion kilowatt-hours of electrical energy each year to add to that now being produced at Boulder Dam and other existing plants on the river system. The annual value of this energy delivered at power markets would be $72,000,000.

The market for this power was discussed in chapter VI. The experience of recent years shows that power markets move to areas where abundant low-cost energy is available. A great potential market for electric energy is provided by the mineral resources of the Colorado River Basin, among the richest and most varied in the world. A good start has been made in the extraction of a few of these minerals but processing within the basin, especially stages requiring large amounts of electrical energy, is almost nonexistent. Arizona and Utah together are mining 70 percent of the copper produced in the United States but most of this is shipped all the way across the continent for electrolytic refining.

The Upper Basin's vast deposits of bituminous coal are the nearest substantial coal deposits to the Pacific Coast. They will become increasingly more important as petroleum reserves approach exhaustion. Likewise the great beds of oil shale in the Upper Basin are a potential source of oil.

Without recounting the value to the Nation of greater development of the vast and numerous mineral resources of the Colorado River Basin, and without reiteration of the many requirements for electricity in the process, it can be plainly stated that nothing else would give such impetus to that development as would the availability of low-cost power accompanied by agricultural expansion through greater control of water resources.

In the last 3 years intensive exploration in California has located only as much new oil as is being taken from wells every year. As a conservation measure production is expected soon to drop below normal peacetime demands, making imports necessary. Oil cannot be shipped in at the low price of $1.15 a barrel to which California is accustomed. Dr. Joe S. Bain, for the Haynes Foundation, has estimated that the price of both domestic and imported crude oil might rise to $2 a barrel. If this happens many oil-burning power plants may be retired to standby

YUMA CANTALOUPES

Sacks of cantaloupes grown on the Yuma project of the Bureau of Reclamation are dumped into a truck to be carried to the picking sheds

PRIZE PRODUCE

Prize vegetables and fruits are grown in irrigated areas of the west. This picture shows an assortment of Grand Valley produce service, and hydroelectric power will be required to fill the gap. Industrial plants also might be forced to convert from oil to electricity for heat and power. Western railroads, powered almost exclusively by fuel oil and coal, might turn to electrification, probably starting with lines in the more mountainous sections where electric locomotives would have distinct advantages.

Abundant low-cost electric power would stimulate activity in other directions. Already Boulder Dam has enabled the Los Angeles area to climb to first place in the manufacturing of aircraft and oil-well machinery, to assemble more cars than any other city except Detroit, to make more furniture than Grand Rapids, to manufacture almost as many tires as Akron, and to jump to third place in the Nation in food processing and oil refining, and to fourth in clothing manufacture. The Colorado River could supply sufficient energy for a $2-billion industrial expansion that would give employment to 350,000 workers. Such an industrial development, including accompanying business and trade establishments, would support an additional population of 2 million people.

The tremendous defense value of abundant electric energy has been demonstrated by the war. By 1940 recent hydroelectric power developments had made electricity in quantity available to Pacific Coast States. Upon this foundation great war industries hurriedly sprang up on a scale almost unequaled elsewhere in the Nation. Ships, airplanes, and light metals were turned out in great quantities. The dollar volume of aircraft produced in Los Angeles County exceeded that of the whole Detroit industry in peacetime. In the Los Angeles and San Diego areas the population increased by 600,000, or 18 percent, from 1940 to 1944. The labor force grew at an even faster rate. Between 1940 and 1943 the working force covered by unemployment compensation in California, Oregon, and Washington increased from 1,900,000 to 3,100,000—some 63 percent.

How much the war was shortened and how many American lives were saved because this electric power was ready to produce weapons cannot be estimated, but the contribution was enormous. Great dams and hydroelectric power plants, built when labor and materials were abundant in time of peace, stood ready under the stress of war to pour out energy with only minimum expenditure of manpower for operation and maintenance.

Flood and silt control.—Boulder Dam now provides full control of the Colorado River at Black Canyon. It now impounds the great destructive floods that before continually harassed the people living along the river's lower plains. This area is still subject to floods of lesser degree originating in the watershed areas of the Colorado and Williams River below Boulder Dam. Above Boulder Dam there are no flood control structures of significance to the river system as a whole. Local damage occurs frequently along tributary streams. For hundreds of miles above Boulder Dam the river and the lower stretches of its tributaries are confined to deep and barren canyons where floods can do no damage, but from these regions great quantities of silt are carried away to be deposited in Lake Mead. The silt problem on the Colorado River is discussed in chapter V under the Boulder division.

Boulder Dam has provided the basis for the great industrial and agricultural expansion of the Pacific Southwest in recent years. It is presently doing much to control floods and silt but this great dam and its many appurtenant structures will some day succumb to the silt it now controls unless aid is received from other basin developments. Not in this generation or even in this century will the threat to Boulder Dam become acute, but prudence dictates that the problem be recognized and attacked now. The capacity of Lake Mead will constantly diminish until a remedy is provided. The potential Bridge Canyon and Marble Canyon-Kanab Creek projects upstream from Lake Mead will provide comparatively little reservoir capacity. Reservoirs to retain silt should be provided on tributaries concurrently with construction of these projects.

Plainly, full control of floods and silt cannot result from a few large dams at strategic locations along the river. Flood waters would deposit silt and debris in the first reservoir reached and eventually fill and destroy it. This process of nature can be combated only by proper watershed management and by construction of a sufficient number of dams to control destructive flows of the Colorado River and its chief tributaries in the canyon areas of Utah and Arizona. Each reservoir built to conserve and control water anywhere in the drainage area would contribute its bit.

The San Juan and Little Colorado Rivers are the principal contributors of silt to the Colorado River. On each of these, large reservoirs are urgently needed to prevent floods and retain silt. The Bluff project on the San Juan River and Coconino project on the Little Colorado River are proposed to be constructed for these purposes. The Alamo project would control floods and silt from the Williams River and the Sentinel project would serve the same purpose on the lower Gila River.

These additional projects to control floods and silt are necessary to protect the vast stake the Nation now has in the Colorado River Basin. The developments outlined will have the dual benefit of providing this protection and also of forming the basis for greater use of the waters of the Colorado River system. There can be little doubt as to the economic justification of such a program.

Municipal and industrial water supplies.—No modern community can thrive without a good supply of pure water for domestic and municipal purposes. These uses are usually recognized as more important than other demands for water. When necessary it is possible to obtain water for domestic use by condemnation of prior rights for power production, irrigation, or other purposes. A water supply is indispensable to any community. If the community is justified economically, its water system is also justified. Some cities are required to make enormous expenditures to bring water from great distances while others find it at their door. In most parts of the Colorado River Basin municipal water can be provided at nominal cost.

Industrial uses are closely related to municipal uses and are commonly supplied through the municipal pipe lines, although it is not unusual for large or isolated industrial plants to have their own water systems. Few industrial operations actually consume large quantities of water. Where the water is used only for cooling or similar purposes it can be returned to the stream channel almost undiminished in quantity. Other processes polute the water to a degree that it is harmful to fish and wildlife or downstream water users. In such cases the water must be either purified after use or disposed of in evaporating ponds or otherwise.

Projects are outlined which would provide municipal water to Grand Junction, Colo.; Tuscon, Ariz.; and San Diego, Calif.; in addition to the expanded municipal and industrial uses to be supplied from the Colorado River aqueduct, the Duchesne tunnel of the Provo River project, and the Moffat tunnel of the Denver municipal system.

Other requirements for municipal and industrial water will arise from time to time but cannot be anticipated sufficiently to justify present planning of specific projects. As these needs arise they can be satisfied by relatively minor adaptations in the basin plan of development. Expansion of cities and towns will be largely on irrigated or irrigable land. Experience has shown that about the same quantity water will be required for municipal use as would have been required to irrigate the land occupied by the community.

Recreation and fishing.—With the peacetime trend toward a shorter work week, more leisure time, widespread vacation privileges, improved transportation, and greater prosperity, recreational facilities are becoming more important. The great variety of natural attractions in the Colorado River Basin together with the highest dam and the world's largest man-made reservoir make it one of the most outstanding recreational regions in the United States. The value of these attractions will be enhanced through development of the basin's water resources. Improved roads constructed to remote reservoirs, power plants, or tunnel portals will make accessible great scenic wonders, fishing spots, and hunting areas not now reached by modern travel. The reservoirs will add scenic beauty and have recreational value for boating, swimming, and fishing. Lake Mead, formed by Boulder Dam, is called the "Eden of all bass fishermen" and is famous throughout the country for its scenic beauty. Many of the numerous reservoirs that will be required for full river control will be provided with sufficient capacity below the outlet structures to provide permanent habitats for fish. The reservoirs can be operated to control unnecessary turbidity at high flows and to maintain sufficient water in the streams to support fish during dry seasons. The desilting of the main Colorado River and the formation of large reservoirs along its course will multiply the fishing and recreational benefits already provided by Boulder Dam. Cooperation in this phase of the basin development will be required of the National Park Service, Fish and Wildlife Service, Forest Service, and various State and local agencies.

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Widespread Benefits From Colorado River Development

Trade created.—The whole Nation has a stake in the Colorado River. Its full development would bring to American tables foods required for balanced and healthful diets, and to American factories, minerals and other raw materials for which there is an ever growing demand. These things, important in peacetime are doubly important in war when self-sufficiency is a bulwark of national strength and safety. But potential benefits to the Nation are not confined to the basin's exportable products. New homes erected in the Colorado River Basin will require lumber, steel, plumbing fixtures, heating equipment, wire, roofing materials, glass, paint, floor covering, hardware, and numerous other items from industries throughout the land. To make them inhabitable will require furniture, appliances, carpets, fabrics, clocks, pottery, and utensils produced elsewhere. The inhabitants of these homes will purchase from other parts of the Nation a continual flow of such items as tools, implements, machinery, automobiles, magazines, books, rayon and cotton goods, clothing, shoes, furs, processed cereals, fish, rice, peanuts, paper, tobacco, sweet potatoes, and many other items of everyday use. These people will be customers for various forms of insurance centralized in other parts of the country. Railroads, bus, and truck lines and airplanes will benefit from the commerce created by both imports to and exports from the basin.

Long-time records show that only about one-fourth of the irrigation farmer's income is used for operation, taxes, labor, and local supplies, while three-fourths of it goes into the general industrial and trade stream. For every dollar spent for irrigation development, a business increase amounting to about $30 is created. In making a home on irrigated land, each settler creates the need for at least another family in the trading circles and still another in the industrial centers.

New taxable wealth.—In the Colorado River Basin arable land without water is covered mostly with sagebrush and valued at $1 to $5 an acre. Improved and irrigated it will be worth from $75 to $300 an acre. Thus irrigation creates new taxable wealth and has proved a good investment for the Government. Federal Reclamation projects have created taxable values exceeding $400 for every person living on the projects either on farms or in cities and towns which the farms have created. State and county governments benefit from this enlarged base, for property taxes. In addition, a large amount of revenue from taxes, direct and indirect, constantly flows from Reclamation projects to the Federal treasury.

In irrigated sections local institutions receive adequate income to maintain good schools, roads, medical services, churches, civic improvements and public utilities, the many comforts and conveniences that are essential to the American standard of living, which cannot be satisfactorily maintained by scattered populations of uncertain income.

Employment opportunities provided.—Construction of many of the projects could be scheduled for timely widespread employment of returning servicemen and released workers from war industries. Later phases of the development could be intensified during periods of economic recession and widespread unemployment. Less than half of the amount spent for labor would go to workers at project sites and the remainder to workers at producing centers principally in the 31 States east of the western irrigation states. Construction of all projects outlined in the report would employ a quarter million men for nearly 4 years.

Summary of Costs, Benefits, and Repayment

A definite economic analysis of basin-wide development of water resources cannot be presented until a final selection of projects has been made. The following estimates and approximations are based on development of all potential within-basin projects summarized in the report. Although there would be enough water in the river system to serve all of these projects if no further exportation of water is made, it may be found more economical and the States may elect to forego construction of some irrigation projects within the natural drainage basin in order to make water available for exportation to adjacent watersheds within the basin States. When final allocations of water are made, moreover, some states may be unable to use their full amount unless part is exported. Power projects do not consume water except by evaporation from power reservoirs, but most of these reservoirs serve multiple purposes and are required for full river regulation and control. Virtually all power projects outlined in the report could be constructed, therefore, without regard to the depletory effect upon stream flows.

Estimates of cost

Construction costs.—The total construction cost of basin-wide development, likewise cannot be estimated until the plan is definite but preliminary cost estimates of the potential projects described in the report within the natural drainage basin and excluding alternative projects, amount to $2,185,442,000, based on January 1940 prices. Increases in the total cost may result if projects for exportation of water to adjacent basins are selected, but such increases will be partly offset by the elimination of projects within the natural drainage basin for which water then would not be available.

Annual costs.—After projects are constructed, there are annual costs for operation, maintenance, replacements and repairs necessary to keep the projects in good operating conditions, transmit the electrical energy to load centers and distribute the irrigation water to the farms. Roughly the annual operation and maintenance costs of all within-basin developments described and summarized in the report may amount to $23,000,000.

To amortize the total construction cost as described above in 50 years with interest at 3 percent would require annual payments of $85,000,000, which added to the cost of operation and maintenance results in a total annual cost of $108,000,000.

Annual benefits

Benefits from the irrigation of new land are represented by the increase in gross crop returns. With the irrigation of 1,533,960 acres of new land and the furnishing of 1,122,270 acres of inadequately irrigated land with supplemental water that would be possible if all within-basin projects were constructed, a gross increased crop return of $65,000,000 annually, based on January 1940 prices, may be expected. If exportations are made, the return may be greater.

Revenues from the sale of power from the potential multiple-purpose projects will approximate $72,000,000 a year at a rate of 4 mills per kilowatt-hour for power delivered at market area. Revenues from the sale of municipal water may amount to $500,000 annually. A flood control benefit of $1,000,000 annually may be expected if all projects summarized are constructed. The total measurable annual benefits thus would total $138,500,000, which is substantially in excess of the estimated annual cost.

In addition to these benefits which are susceptible of evaluation there are the numerous other intangible benefits, none the less real, that have been described previously in this chapter. Studies of a general nature show that a program for complete river development would be fully justified. Direct evaluated benefits would exceed the costs even though many public benefits are not considered.

Repayment and flood control allocation

Repayment laws now in effect provide for water and power users directly benefited to be charged with the cost of construction works that serve them and for costs to be allocated to irrigation, power, municipal use, flood control and other miscellaneous uses. Repayment of construction costs are made on four different bases: (1) Costs allocated to irrigation are repaid in 40 annual installments without interest. The national benefits are recognized in that construction money is advanced by the Government interest free. (2) Costs allocated to power with interest at 3 percent may be returned over a period designated by the Secretary of the Interior. (3) Costs allocated to municipal water supply are repaid over a period not to exceed 40 years with interest not exceeding 3½ percent annually. (4) Costs allocated to flood control are largely nonreimbursable. Flood control is considered a national benefit and for that reason costs allocated to flood control are financed in large measure by the Federal Government.

Under existing reclamation laws nonreimbursable funds are not available for allocating costs to the many other direct benefits resulting from river development. For example, the value of fishing and recreational resources of the Colorado River Basin would be greatly enhanced by construction of the many potential multiple-purpose projects, but there is no means at present for allocating costs to these benefits.

Although increased gross crop returns amounting to $65,000,000 are estimated from potential irrigation projects in the Colorado River Basin, a large share of the increase will be used to meet costs of production, taxes, return on farm investment, and living costs. From experience on other projects operated by the Bureau of Reclamation it is estimated that the farmers could pay $8,000,000 annually to meet operation and maintenance costs and repay the portion of the construction costs allocated to irrigation. The gross revenue from power, estimated at $72,000,000 annually, would be sufficient to pay operation and maintenance costs and cost allocations to power. Municipal revenues estimated at $500,000 could be used to repay cost allocations and interest. Of the total construction cost it is estimated that an allocation of $25,000,000 may reasonably be made to flood control reducing the total estimated reimbursable cost of basin development to $2,160,442,000.

Gross annual revenues of $80,500,000 from irrigation power and municipal use would cover all charges for operation and maintenance and leave $57,500,000 annually to pay interest and construction costs. Interest charges cannot be determined until cost allocations are made to the various benefits. It is quite likely, however, that when interest charges are considered the cost of the entire development will not be fully reimbursable. Authorization is necessary for the use of nonreimbursable funds to cover costs allocable to certain other benefits of a public nature which cannot appropriately be considered repayable by water users under Reclamation law.

The above approximations and estimates are presented merely to indicate the justification of basin-wide development. The benefits to the people of the West and to the Nation would exceed the costs of constructing all projects that would develop and utilize fully the available water resources of the Colorado River Basin.

Cooperating Interests in the Basin

"The various agencies of the Department of the Interior having an interest in development of resources in the basin have teamed together in the preparation of this comprehensive report . . . Their cooperation is . . . practical, and essential, as evidenced in this chapter, which presents their specific comments and programs.

"Other Federal agencies that are involved in the development of the resources of the basin have likewise cooperated with the Bureau of Reclamation and their reports appear as parts of this chapter."

CHAPTER VIII

Cooperating Interests in the Basin

Integrated development of the resources of the Colorado River Basin can best be achieved by the cooperation of all Federal, State, and local interests in the region. This cooperation is necessary not only in the formulating of a comprehensive, coordinated plan, but in the execution of a unified program that will be keyed to the welfare of the people in the basin.

The various agencies of the Department of the Interior having an interest in development of resources in the basin have teamed together in the preparation of this comprehensive report in the development of the water resources of the basin. These agencies have cooperated to the extent of funds and personnel available. Their cooperation is vital, practical, and essential, as evidenced in this chapter, which presents their specific comments and programs. The Geological Survey has outlined a program for stream gaging and has furnished basic data on stream flow, quantity and quality of surface and underground water supplies, and water utilization. The National Park Service has surveyed the recreational possibilities of the potential projects and appraised the benefits with a view to preserving the parks and areas of historic and scenic interest. The Fish and Wildlife Service has made recommendations that will assure the restoration and conservation of game and fish resources. The Grazing Service has outlined the objectives of its range improvement program and the benefits that will result from the potential projects in the stabilization of livestock industry and the conservation of land and its resources. The Bureau of Mines has probed the minerals of the basin to discover how they might best be mined, processed, and utilized to support the metallurgical and industrial economy that is envisioned. The Office of Indian Affairs has outlined projects that will benefit the Indians of the basin. The General Land Office has presented a program to obtain optimum use of these public lands and to coordinate their utilization with the development of water resources.

Other Federal agencies that are involved in the development of the resources of the basin have likewise cooperated with the Bureau of Reclamation and their reports appear as parts of this chapter. The Forest Service, United States Department of Agriculture, has emphasized the need for careful management of watersheds on the national forest lands to insure adequate safeguarding of their water yields. The Federal Power Commission has furnished data upon which power utilization and market trends are based and has commented generally on the power resources of the basin.

The interests and cooperation of State and local groups as well as other Federal agencies in the basin are reflected throughout the report.

GEOLOGICAL SURVEY

Quantity and Quality of Water

Factual information, systematically collected and arranged, relative to both quantity and quality of water, is a prerequisite of the successful utilization of water. This information is necessary because of the fluctuations in quantity caused by the vagaries in climate, especially in precipitation and temperature, and by the changes resulting from the activities of man; and because of the differences in quality caused by sediment and the varieties of soluble matter with which the water comes into contact in its flow over and through the crust of the earth, by the variations in the length of time that the water remains in contact with the various soluble substances, and by the changes in pollution caused by the activities of man, especially in the use of water for agriculture, industrial processes, and municipal supplies, the return flow from which reaches and mixes with other surface and ground waters. Such information is needed as a basis not only for planning and constructing but also for operating plants and systems that utilize water.

Although the conspicuous uses of water in the basin relate to irrigation and the generation of hydroelectric power, there are many other important uses such as those for industrial, municipal, domestic supplies, and water for stock on the range. These uses, which are not spectacular, affect the life, prosperity, and security of many people and therefore are for serious consideration. For example, the stock business in the basin is of major proportions. It depends largely on the capacity of range lands to carry stock, and that capacity is affected largely by the ability to get water for stock at many places so distributed as to permit a maximum use of the range. The finding and developing of stock water is therefore of major importance.

There are many conflicting interests in the use of water because there is either not enough water to serve all needs or its use for one purpose may impair or prevent its use for another purpose. The general basic information must be collected and published without reference to the use that may be made of the water or to the public or private agency that may utilize it. It must, therefore, be collected, assembled, and presented without bias as to kind or place of use or to particular projects. Because of the fluctuations in the quantity and quality of water, the information concerning it must be collected over a period of years and at some places indefinitely. In order to satisfy everyone that the records are free from bias, they must be collected by an organization that has no administrative or construction responsibilities. The United States Geological Survey is primarily an investigational agency whose reports are recognized as reliable, to which Congress appropriates funds for the study of the general basic aspects of water without reference to uses or projects. In accordance with that Congressional mandate, the Geological Survey measures the daily flow of surface streams and records fluctuations of reservoirs to ascertain the availability of water for conservation and use; investigates ground-water resources to ascertain availability, depth, recharge, discharge, and storage; makes chemical analyses of both surface and ground water with reference to fitness for use in agriculture and industry, and to treatment for public and domestic water supplies; and prepares statistical and interpretative reports—all with a view to furnishing reliable information that is essential as a basis for the full and best use of the water resources. This investigational work is supported in part by funds appropriated by Congress "for gaging streams and determining the water supply of the United States, investigating underground currents and artesian wells and methods of utilizing the water resources," in part by funds furnished by other Federal agencies for use in specific investigations related to the activities of those agencies, and in part by cooperating States and municipalities.

The cooperation with States is based on the understanding that both Federal and State governments are interested and that responsibility for the work is divided properly between them. The work is conducted through field offices of the Geological Survey placed generally in State capitols in order that State officials may be easily consulted as to State problems and needs. Permanent Federal employees assigned in these field offices, through long residence and service, become local citizens familiar with local problems and requirements. The agencies of the States participating in the cooperation also contribute valuable experience and knowledge to the conduct of the investigations. In these ways local needs are served and reliable Government records are assured that are uniform in accuracy and form of publication for all sections of the country.

Accordingly, the Survey is now maintaining four offices in the basin as follows:

Las Vegas, Nev., for ground water.
Tucson, Ariz., for surface water and ground water.
Phoenix, Ariz., for ground water.
Safford, Ariz., for surface water and ground water.

It maintains seven other offices outside the basin from which work in the basin is done, as follows:

Salt Lake City, Utah, for surface water, ground water, and water utilization.
Logan, Utah, for surface water.
Cheyenne, Wyo., for ground water.
Denver, Colo., for surface water.
Santa Fe, N. Mex., for surface water.
Albuquerque, N. Mex., for ground water and quality of water.
Los Angeles, Calif., for water utilization.

The investigational work of the Geological Survey on the quantity, quality, and utility of water in the Colorado River Basin is essential to the stable development of the basin because water in great or small quantities enters into all activities. Interstate and international character of the river serve to complicate the situation as to water supplies because of the necessity for equitable division of the water among the States of the basin, and because of the interest of Mexico in the water that flows across the international boundary. The interstate and international problems which are of far reaching importance emphasize the requirement that basic water information shall not be related to particular use or projects but shall serve the needs of all purposes equitably.

As the canyons of the Colorado River divide the basin into two parts with respect to both utilization of water and routes of transportation, and as the interstate compact for the division of water between the upper basin and lower basin divides the basin in the same way, the description of the water work of the Geological Survey in the basin is similarly divided. Because of the differences in qualifications of personnel and methods used for investigating the different aspects of water and its utility, the work of the Geological Survey in investigating water is organized and will be presented in its relation to the Colorado River Basin, under the following four headings: surface water, ground water, quality of water, and water utilization.

Upper Basin

The Colorado River Basin above Lee Ferry, defined by the Colorado River Compact as the "upper basin," has an area of mountains, plateaus, and valleys of approximately 110,500 square miles. It contains literally hundreds of streams, lakes, and underground reservoirs. Thus far the principal use of water in this vast area is for irrigation. A few small hydroelectric power plants use the flow of small streams, and a negligible amount of water is used for municipal and industrial purposes. Since the white man first diverted water into ditches in this region for irrigation and community use (1854) more than 1,300,000 acres (U. S. Census 1940) have been put under irrigation in the upper basin and many millions of dollars have been invested in irrigation works. As the water problems are becoming increasingly complex, more information covering more streams and underground water resources is necessary for proper and orderly future development. Records of measurements of water resources have their principal value in their continuity. Therefore, the necessity for continuance of key gaging stations and observation wells in no wise diminishes with the increasing necessity of additional stations and wells. This necessity, for more than a decade past, has become more or less critical in the upper basin, and many temporary gaging stations have been established in order to expedite the program of current investigations.

Summary of Estimated Costs

For acquiring necessary equipment, conducting investigations, and preparing reports on the water resources of the upper basin a continuing program is essential. For the first 3 years of that program, participation by the Geological Survey as here outlined will require funds as shown in the following table of estimated costs.

TABLE CXXXIII.—*Estimated cost of program—Upper Colorado River Basin*

Program	First year	Second year	Third year	Total
For installation of 85 new gaging stations, at an average cost of $1,000 per station	$50, 000	$35, 000	-------	$85, 000
For operation of new stations at an average annual cost of $600 per station	30, 000	51, 000	$51, 000	132, 000
For rehabilitation of existing gaging stations	20, 000	15, 000	15, 000	50, 000
For operating 237 existing stations at an average annual cost of $600 per station	142, 200	142, 200	142, 200	426, 600
For investigations of ground-water storage and withdrawal, for drilling test holes and permanent observation wells, and for progressive appraisal of ground-water resources	50, 000	50, 000	50, 000	150, 000
For studies of the sediment loads in streams with relation to reservoir and channel capacities, and of the chemical quality of stream waters and of ground water with respect to uses in agriculture and industry	81, 000	62, 000	62, 000	205, 000
For miscellaneous studies of water facts, advisory service, and preparation of water utilization reports	15, 000	12, 000	12, 000	39, 000
Total	388, 200	367, 200	332, 200	1, 087, 600

Surface Water

Colorado.—The Colorado portion of the upper basin is mountainous, and the chief industry is livestock raising, with agriculture subordinated to it. With the exception of the Uncompahgre and Grand Valleys, where large irrigation projects were built by the Bureau of Reclamation, the valleys are narrow and irrigation has been effected by means of cooperative and individual ditches. Although the total water supply is abundant, it is necessary to store the high-water flow for use in the late irrigation season. Many small reservoirs, most of them with capacities of 1,000 acre-feet or less, have been constructed. Also, there are half a dozen larger ones, among which the largest are Green Mountain, Vallecito, and Taylor Park, each with a capacity greater than 100,000 acre-feet.

The chief value of stream-flow records is in connection with irrigation, particularly transmountain diversions. The bulk of irrigable land in Colorado is east of the Rockies and the surplus water is in the Colorado River Basin, where physiographical conditions limit the opportunities for additional irrigation.

At the present time, several transmountain diversions take from the Colorado River Basin an average of 170,000 acre-feet annually. This will be increased by several hundred thousand acre-feet by the Colorado-Big Thompson project, under construction, and the Blue River-South Platte diversion, under investigation. A study in the Gunnison River Basin indicates a possible diversion to the Arkansas River Basin, and similar studies in the San Juan River Basin indicate several possible diversions to the Rio Grande Basin for use chiefly in the San Luis Valley where the operation of the Tri-State Compact limits the water supply available for use in that valley. All of these projects have important bearing on the final allotment of waters of the Colorado River Basin to the individual upper basin States as contemplated by the Colorado River Compact. Accordingly, records of flow of the streams involved are fundamental to that allotment.

Stream-flow records are not particularly needed for flood studies in the Colorado portion of the upper basin because the basin is not subject to disastrous floods. Likewise, such records at this time are not an important factor in water administration except in certain areas where water shortages occur. In the case of water-power developments it is quite probable that, with the exception of small plants in the national forests, they will be developed chiefly at storage reservoirs constructed primarily for irrigation and designed as "multiple-use" projects.

At present (1945) 149 gaging stations are being maintained in cooperation with the State Engineer and also with the Colorado Water Conservation Board. Cooperation with the former started in 1933 and with the latter in 1941. The cooperation with the State Engineer comprises a general study of the State's water resources, and with the Colorado Water Conservation Board it enables the Survey to maintain additional gaging stations urgently needed by the Bureau of Reclamation in its basin-wide studies. Of the stations being maintained, the Bureau of Reclamation equipped 60 and transferred them to the Survey for operation.

Forty-four of these stations are situated in the Colorado River Basin above and including the Roaring Fork Basin where all the existing and prospective transmountain diversions from the Colorado River and tributaries are located except those from the Gunnison and San Juan Basins. Records at these stations are of particular value to the Grand Lake-Big Thompson diversion, now under construction, and to the Blue River-South Platte diversion, being studied, and to the Fraser River diversion for the city of Denver. At six stations records are made of the inflow and outflow of Green Mountain Reservoir on Blue River. This reservoir, the largest in Colorado, provides active storage of more than 100,000 acre-feet, primarily for late irrigation in the Colorado River Basin to replace waters taken out of the basin by transmountain diversions, and secondarily for the development of power. The base station in this area is on the Colorado River at Glenwood Springs. It has been operated continuously since 1900.

Seven stations are situated between Roaring Fork and Gunnison River. The possibilities of additional irrigation are limited in this section.

In the Gunnison River Basin 38 stations are being maintained, of which 18 are for studying the possibility of diverting water from the Gunnison to the Arkansas River Basin, 9 are for small irrigation projects, 3 are base stations at various points in the basin, and the remainder are chiefly for administrative purposes. The third largest storage reservoir in the State, Taylor Park Reservoir, is in this basin and 3 gaging stations are maintained in connection with its operation.

Sixteen gaging stations are being maintained in the Dolores River Basin, one a long-term base station, and the others for possible irrigation projects.

In the San Juan Basin 34 stations are in service, of which 3 are for administration of the La Plata River Compact between Colorado and New Mexico, 2 are base stations, 6 are for administrative purposes, and the remainder are for determining the amount of water that can be diverted from the San Juan to the Rio Grande Basin.

The northwestern part of Colorado is drained by the Yampa and White Rivers, both tributaries of Green River. Ten stations are maintained in these basins, two base stations, one on each stream, and eight for irrigation investigations.

Wyoming.—As in Colorado, the chief use of stream-flow records is for irrigation, present and future. About 200,000 acres are now irrigated in the Green River Basin in Wyoming by community and individual ditches, and although the total water supply is abundant, there is need for additional storage for irrigation during the late summer months. There are opportunities for developing additional areas in the basin, and also in adjacent basins, the latter by means of transmountain diversions. Three of such diversions are under study—one to the North Platte River Basin, and two to the Bear River Basin.

Water administration at present is a very minor use of the records. Water power, except in relatively small amounts in the national forests will probably be developed at storage reservoirs constructed primarily for irrigation. Disastrous floods are not characteristic of the basin, and stream-flow records are not particularly needed for flood studies.

Through cooperation with the State Engineer, which began in 1915, 35 gaging stations are being maintained. Since 1939 additional cooperation has been carried on with the State Planning and Water Conservation Board covering 35 stations, some of which were installed and maintained by the Bureau of Reclamation. That agency still contributes directly to the maintenance of 4 of the 35 stations. The stations are located as follows:

In the Green River Basin, exclusive of the Henrys Fork, Blacks Fork, and Little Snake River Basins, 19 stations are being maintained. One of these, the Green River near Linwood, Utah, is the base station, supported wholly by Federal funds. It has been operated since 1928, and replaces the former base station at Green River, Wyo., operated since 1915.

Six stations are located in the Blacks Fork area where irrigation has long been practiced and where supplemental supplies are needed.

Five stations are located in the Henrys Fork Basin, and four in the Little Snake River Basin.

Utah.—The Utah portion of the upper basin consists largely of high plateaus, rugged mountains, and limited valleys. The Uinta Basin and the valleys of the Price and San Rafael Rivers are the principal agricultural areas where extensive irrigation is practiced. Stock raising is an important part of the agricultural industry. Rapid agricultural development began in the Uinta Basin in 1905 following the opening of lands that were set aside by Executive order of October 3, 1862, as an Indian reservation for some of the Ute tribes.

This development created serious need for reservoirs, and many of the lakes and basins on the headwater areas of the Duchesne River and its tributaries have been developed for storage; others are under study. The Moon Lake Reservoir is one notable development recently made by the Bureau of Reclamation.

Along the Price and San Rafael Rivers, irrigation development has outrun the natural regimen of the streams, and storage problems are of fundamental importance to future irrigation expansion. Several important reservoirs have been built by private enterprise and other important projects are planned.

Water power in the upper basin in Utah is an important resource on the Green and Colorado Rivers but of relatively small importance on the smaller streams. When large reservoirs are built on these main streams, considerable hydroelectric power will be available at the dams.

Settlement and growth of agriculture in the Utah area have created a growing need for additional stream-flow information. Accordingly, the cooperative stream-gaging program conducted by the Geological Survey with the State engineer was expanded in 1941.

At the present time 45 gaging stations are maintained in the upper basin in Utah. New stations are of temporary construction and some are not provided with equipment for high-water discharge measurements. Several need rehabilitation or rebuilding. For more complete coverage of the streams of the basin at least 31 additional stations are needed and 14 stations should be rehabilitated. A number of these are necessary to supply factual water data for the State's small reservoir program and for small transmountain diversions of considerable importance.

Some of these stations would be situated in high remote areas and their accessibility would be relatively difficult—a condition which requires relatively high maintenance costs.

Water studies have not as yet shown the origin of much of the silt now reaching Lake Mead. There are no gaging stations at suitable locations on the San Rafael, Fremont, and Escalante Rivers, three important tributaries of the Colorado River between Green River, Utah, and Lees Ferry. Stations are proposed on these streams near their mouths. Stream-flow measurements, silt samples, and quality of water data, would be collected by a resident engineer assigned to each area because of the isolated and remote desert character of the region.

New Mexico.—In the San Juan River Basin in New Mexico, eight stream-gaging stations are being maintained. Four of these are situated at the following places on the main stream: one at Rosa which records the flow into the State from Colorado; one near Blanco which records the stream flow at Pump Canyon Dam Site; one at Farmington, installed in 1912 for general surface-water study and continued for long-time record, shows the stream flow below the mouth of the Animas River and inflow from arroyos below Blanco; and one at Shiprock which records the stream flow below irrigation diversions and into Utah. The other stations are situated on tributaries as follows: one on Animas River near Cedar Hill which records the flow into the State from Colorado; one on Animas River at Farmington which records the discharge of the Animas River into the San Juan River; one on the La Plata River near Farmington which records the flow from La Plata Valley into the San Juan; and one on Los Pinos River at Ignacio, Colo., near the Colorado-New Mexico State line, that records the flow into the State from Colorado.

Summary.—The total number of stream-gaging stations now being maintained in the upper basin is 237. Stream-flow records obtained at all of these stations are published annually in the water-supply papers of the Geological Survey. Many stations are on small streams and are relatively close together, whereas others are isolated and not easily accessible. Under these conditions, costs of operation vary from approximately $275 to $1,000 annually per station. Many of the stations have temporary installations as some of them will not be needed after a few years. Others will be continued indefinitely and these must be rehabilitated.

Present analysis of the needs for additional stations in the upper basin indicates a total of 85. It is estimated that within the next few years 10 of these will be required to furnish data for water administration of the large transmountain diversions now under construction or investigation and for determining natural inflow into large reservoirs.

No fewer than 61 additional stations are required at this time to furnish more information to the Bureau of Reclamation during its current investigations and to furnish the States with water data for small reservoirs, etc., and at least 14 new stations are suggested for supplying stream-flow data to the Forest Service for its studies of water-power resources within the national forests.

Ground Water

The development and utilization of ground water in the upper basin to date has been negligible. Geologic and hydrologic records are quite inadequate and ground-water areas are little known. There is need for thorough systematic study of the occurrence of ground water throughout the basin and the inauguration of the systematic collection of water-supply records in order that the available supply may be determined and put to optimum use in its relation to surface-water supplies. Return flow from irrigated areas and the operation of extensive canal systems create a great demand for factual information on which to base estimates of the effects of ground-water conditions on the development of water projects.

The principal objective of the comprehensive ground-water study in the upper basin is the quantitative evaluation of ground-water recharge, discharge, and storage. Such study will furnish data for solving the many problems that are controlled or affected in some degree by the occurrence of water below the surface. The study can be made either by countries or by drainage basins; in either case giving first attention to those areas in which critical ground-water problems now exist or in which water project developments are in prospect. Items in this program include the collection of records of the quality of water, fluctuations of water levels in wells, measurements of water taken from wells, measurements of the gain in flow of streams that yield large quantities of water during fair weather, determination of direction and quantity of movement of the ground water, depth of the ground water below land surface, water-yielding properties of the formations and their thickness and areal extent, areas in which large quantities of ground water are used by vegetation, amount of rainfall penetration to the subterranean reservoirs, seepage from canals and reservoirs, and the mapping of areas in which artificial recharge may be practiced successfully.

The evaluation of these factors will provide basic information for determining the effect of diversions from streams on the flow of these streams in their lower reaches, the trend of the ground-water levels in areas of heavy development, and the perennial yield of the water-bearing formations, the effect of pumping from wells on the flow of streams, and the effect of the construction of dams, irrigation canals, reservoirs, and drainage ditches on the level of the water table and on the flow of streams.

The following procedure for conducting ground-water studies in the upper basin is proposed:

(1) Devote first attention to those areas in which critical ground-water problems now exist or in which water project developments will soon take place.

(2) Ascertain by drilling test holes, the character, thickness, and areal extent of the water-bearing formations; the character, thickness, and areal extent of the alluvium in the valleys of the streams; and the location of permeable deposits beneath the uplands. This method of exploration will be particularly valuable where geologic conditions cannot be ascertained by inspection and where the development of new water supplies is vital.

(3) Make pumping tests wherever possible. Recent advancement in pumping-test methods facilitates the determination of the water-yielding properties of formations and provides practical means for determining well spacing, quantities of water to be expected from wells of different size, draw-down of ground-water level, interference of one well with another, amount of water derived from flow of nearby streams, local geologic conditions affecting the occurrence of ground-water, and the design of wells.

Geologists with ground-water experience will study and correlate the samples obtained from the test holes and outcrop of the formations. Such study will aid in planning further test drilling in locating new supplies, and improving existing supplies.

(4) Records will be obtained of the quantities of water withdrawn from wells throughout the basin in order that these data may be available for use in conjunction with studies of fluctuations of water level in determining the perennial yield of the formations. Records will be obtained from each town, irrigated area, and railroad and industrial plant, and measures will be developed for obtaining continuing records of this kind for keeping a current inventory of ground water.

In order to determine the trends of ground-water levels and the changes in ground-water storage, the inventory records will include measurements of water levels in wells. The number and location of these observation wells will depend upon the importance and complexity of the ground-water conditions. Some of the wells will be equipped with automatic water-stage recorders, others will be measured once a week, once a month, or only a few times a year. New observation wells will be placed in areas of heavy ground-water pumpage and in areas in which water development projects are to be made. They will also be established near dams, reservoirs, irrigation canals, and drainage ditches, in order to determine the effects of the operation of these structures on ground-water conditions. Maps will be prepared, where feasible, showing lines of equal depths to water level.

(5) The study will include mapping of areas where there may be a building up of ground-water storage through artificial recharge from reservoirs and irrigation canals and where the flood flows of some of the streams can be diverted in such a manner that there will be seepage into the subterranean reservoirs where geologic conditions are favorable. Lowering of the water table along streams produces conditions favorable for artificial recharge in the sense that seepage in them is induced from the streams into the subterranean reservoirs. The location of wells near streams to take advantage of this source of water, including the filtering action of the sands and gravels and more uniform temperature of the ground water, will undoubtedly prove valuable in the solution of many water-supply problems. The ground-water study of the basin will include the mapping of stretches of the stream valleys that are favorable for this kind of ground-water development.

(6) The data gathered in the field study will be interpreted by competent engineers and geologists and both the data and the interpretation will be presented in comprehensive reports, which will constitute an inventory of

the ground-water resources of the basin. The interpretation of the data will be directed toward specifying new sources of water supply for cities, railroads, farms, industries, and irrigation, and methods of improving the present supplies.

The experience of the Geological Survey indicates that studies made in the detail outlined above require an average total expenditure of $10,000 or $15,000 per project area, consideration being given to the fact that some areas will require a much larger expenditure than others.

Quality of Water

The available information on the quality of water in the upper basin serves as an indication of the chemical character and concentration of the water at certain points in the basin, but information is needed on the quality of the water in the headwaters of the main stream and its principal tributaries, and also on changes that are taking place and may take place through changes in the regimen of the stream. Because of diversion from the headwaters to other drainage basins there will be changes in the quality of the water in the streams below the diversions, through utilization of water for irrigation and other purposes there will be changes in the quality of water, and during storage in reservoirs there will be changes caused by evaporation of large volumes of water and the accompanying concentration of dissolved solids. Water utilization in the headwaters, which will cause changes in chemical character of the water, will have an effect on the quality of water available below the headwaters and the effect may be noticeble at the lower end of the lower basin.

Sediment records for the upper basin will be of value in planning for utilization of the water in both the upper and lower basins.

Brief descriptions of quality of water and sediment studies for the upper basin are given in the following paragraphs:

Quality of water for industrial and agricultural purposes.—It is desirable to have information on the changes in concentration and character of waters that are potential sources for industries and public supplies. The requirements for industries are rigid and complete information on the quality of the available supplies is needed in making plans for industrial processes. The value of a water supply for industrial purposes may be seriously impaired because of previous uses to which the water has been put, especially when the source may be contaminated because of such uses. The comprehensive records proposed for this study will give the data necessary to determine the usefulness for most industrial purposes.

The quality of a water for irrigation purposes is dependent on the nature and the amount of dissolved constituents in the applied water, and on the amount of dissolved solids that can be removed from the irrigated area, so that studies must include the determination of the concentration and chemical character of the waters used as irrigation waters and also of the drainage waters. For the computation of quantities of dissolved solids carried onto and removed from an irrigated area, it is necessary to have adequate stream-gaging records, and all samples must be collected at points for which stream-flow records are available.

In the upper basin information is needed on the quality of the available ground-water supplies. In irrigated areas it will be necessary to collect samples of the normal ground waters and also of drainage waters. Such a sampling program is needed for the Grand Valley project area near Grand Junction, Colo., because of the high concentrations of dissolved solids in the drainage waters and because of the increase in concentration of the river water between the head and lower end of the project area. For most ground-water sources, one complete analysis and the partial analysis of from 3 to 12 samples each year will be needed to give the desired information. For surface-water sources, it will be necessary to have daily samples on which one or more determinations will be made to determine changes in concentration. As a rule, the samples for ten consecutive days will be made into one composite sample for a complete analysis.

Sediment transportation.—Sediment samples have been collected regularly for a number of years at the following gaging stations: Colorado River near Cisco, Utah; Green River near Green River, Utah; and San Juan River near Bluff, Utah. The records for these three stations show the loads of sediment carried at the chosen sampling points, but no other information is available to show the sources of the sediment. Moreover, the sum of the loads carried past these three stations has amounted to about 90 percent of the flow at Grand Canyon. Studies should be made to determine the source of this unmeasured sediment. It is likely that considerable quantities of sediment come in from the San Rafael, Fremont, and Escalante Rivers. It will be expensive to obtain records of discharge and sediment in these streams because of the isolation of the lower reaches of these rivers, but to obtain a complete picture of the sediment transportation in the Upper Colorado, it will be necessary to obtain these records for a period of years.

The concentration of sediment will be determined for all samples and an average concentration will be computed, which with the discharge records, will furnish data for computation of the daily loads of suspended sediment. Extra samples will be collected for the determination of the sizes of the particles of sediment and with similar information for deposited sediment, it will be possible to estimate the nature and rate of deposition of sediments in reservoirs below the sampling points.

Water Utilization

The international and interstate aspects of the Colorado River and the unique basic importance it has in the settlement and development of the Southwest make numerous the problems incident to the utilization of the waters of its drainage basin. Among these problems are those involved in the determination and delivery of quantities of water to Mexico in the administration of treaty provisions and to the several States as provided in the Colorado River Compact, those of administration by the respective basin States of their water resources, and those of operation by Government and private agencies. In ways that will contribute most effectively to the solution of these problems the water program of the Geological Survey is designed. This program embraces not only the collection of basic information relating to quantity and quality of stream flows and ground waters—comprising an inventory of the water resources—but it also includes special physical and economic information for analytical and interpretative reports that will be useful in the consideration of the best method of utilizing the water supplies and to rendering advisory service on the subject.

Field investigations and surveys constitute an integral part of the work incident to these special studies and reports. In the program for the Colorado River the reports would present authoritative historical data concerning floods and droughts, the development and status of utilization of the surface and ground-water resources, and other data that would clarify questions regarding natural flow and the possible influence of climatic oscillations and changes wrought by man. Such information is fundamental in the determination of the respective interests of the States in the waters of the basin and in the consideration of the availability and suitability of the water supply for various industries and activities which may be considered for establishment in the basin.

The reports also may include studies of specific plans of water development with such surveys of sites and projects including physical and economic aspects as are necessary for evaluating the merits of different schemes of development.

One type of survey is the "river survey" which comprises a plan and profile of the stream with elevations of water surface, and contours showing the detailed topography of the land adjacent to the stream bed. These surveys are primarily for determining possibilities of developing storage and water power. Some of the earlier maps show only the plan and profile of the stream with very little topography. The more recent surveys show topography, usually to a height of 200 feet or more above the water surface. The scale generally used by the Geological Survey for river surveys is 1:31,680 or half a mile to the inch. The contour interval ordinarily is 20, 25, or 50 feet on land and 5 feet on the water surface. Dam sites and reservoir sites are often shown in greater detail on larger scale.

Where the more detailed river surveys have not been made, studies of river development are greatly aided by the information contained on the standard topographic maps of the Geological Survey in areas where such maps are available.

Water Supply Paper 558, Preliminary Index to River Surveys made by the United States Geological Survey and other Agencies, and supplements thereto now list and briefly describe all of the river surveys available. They are also delineated on the indexes to topographic maps that are published from time to time to show areas covered by standard topographic maps, geologic folios, etc.

In the matter of advisory service, the program embraces close cooperation with State engineers and other officials charged with duties involving water resources, also with the Committee of Sixteen which is the agency of the seven Colorado River Basin States created for the purpose of coordinating the respective interests of the States in the waters of the basin and determining the comprehensive and orderly development of them.

Advisory service is unbiased. It is based on analysis and treatment of statistical facts, the significance of which is not always readily apparent. It has been found that some kinds of analysis enter into nearly every water-supply problem, and indeed, the availability of such basin analysis may encourage, or hold to wise limits, as the case may be, the application of the records to the solution of water problems.

The upper basin is one of the numerous basins of the West where deficiencies in hydrologic research are common and many basic studies and investigations are needed. These should include studies in precipitation, temperature, and run-off and all phases of climatological history that will aid in extending knowledge of climatic behavior. Furthermore, a quantitative hydrologic inventory will provide a great many facts regarding the water resources for use in statistical analyses, and studies of the intimate relationships of streams with such factors as precipitation, interception by vegetation, infiltration, soil moisture, run-off, surface and ground storage, evaporation and transpiration.

The administration of land and water uses and conservation programs involve many kinds of water problems that are common to the arid region and in many areas where no gaging station records are available the information developed in these studies serves as a basis for estimating available water supplies. Hydrologic conditions are, of course, different in most basins and for that reason the technique applied in hydrologic research is modified by the adequacy of the data on hand and the conditions peculiar to the basin under study.

Thus far, four water-utilization reports on the Colorado River are available as published water supply papers.

The first one of these, Water-Supply Paper 395, Colorado River and its Utilization (1916), covers the pioneer work of assembling the principal facts relating to the subject, and especially of studying the possibility of controlling the flow of the whole river and rendering it available for profitable use.

The second, Water Supply Paper 556, Water Power and Flood Control of the Colorado River below Green River, Utah (1925), was at that date latest compilation of data relating to the water supply of the Colorado River Basin and the results of all surveys of sites for reservoirs and power dams. Only a small part of the upper basin is covered in this report.

The third, Water Supply Paper 617, Upper Colorado River and its Utilization (1929), presents important facts relating to the water resources of the Upper Colorado River and its tributaries to afford a basis for comprehensive consideration of their development and utilization.

The fourth, Water-Supply Paper 618, The Green River and its Utilization (1930), sets forth the available physical facts with respect to the present and probable utilization of the Green River and its tributaries to serve as a guide in the agricultural and industrial growth within that basin.

In addition to these published reports, the following manuscript report has been prepared and is open to public inspection in the offices of the Geological Survey in Washington, D. C., and Denver, Colo.: Water utilization in the San Juan River Basin, by E. C. La Rue.

Water development for stock use.—Stock raising is one of the major industries in the upper basin, which contains many thousands of acres of grazing lands under the administration of the Grazing Service and Office of Indian Affairs. The quantity and availability of the forage crop on these lands are dependent on the availability of stock water at suitable locations. Only a portion of the range lands has ample water so distributed as to make full and efficient use of the forage crop year after year. Forage on lands situated far from water is unused while lands near water are overgrazed, often to the point where serious deterioration of the vegetative cover and destructive erosion of the soil mantle is taking place. There is pressing need for numerous and properly spaced range-water supplies in order that overgrazed areas may be relieved and given opportunity for recovery. This can be accomplished with little or no interference with the livestock industry if presently unused areas are made available for grazing by providing additional range water.

The Department of the Interior, Office of Land Utilization, looks to the Geological Survey for information and advice concerning water supplies on the public range. Immediate and pressing needs for such service on the part of the land-management agencies of the Department have taxed beyond limit the inadequate facilities of the Survey, and in some instances developments have been undertaken without benefit of adequate geologic investigation. Demands for ground-water prospecting too often crowd the driller onto the heels of the geologist, and advice given under such conditions is without the background of geologic mapping, exploratory drilling, or geophysical surveys that are essential to intelligent application of geologic and hydrologic principles.

With the anticipated future development in the upper basin, requests for advice and information on well locations and other water-development projects will increase materially during the postwar period.

Stock tanks for impounding surface water are an important item in the water development program for stock use. Construction of these tanks, too often, is considered a simple task of excavation without regard for geologic formations which are so vitally important in connection with seepage losses, run-off characteristics of the contributing drainage area, silt movement, spillway capacities, and evaporation losses that contribute to the safety, life, and efficiency of the tank. Ineffective stock tanks emphasize the necessity of factual data on which to base design and select locations. Tanks, of necessity are usually constructed on washes and stream courses where the flow is erratic and infrequent. Virtually no hydrologic data are extant on drainages of this character. For this reason, specially designed stream gages are needed on representative "dry washes" to obtain water supply data. Such installations are proposed by the Survey as funds and equipment become available. For determining evaporation and seepage losses, staff gages have been installed in a few tanks. This study should be expanded to other areas having different hydrologic and climatic characteristics. Rainfall and direct evaporation losses are obtained from gages installed at strategic locations and from nearby Weather Bureau stations. Analysis and correlation of the information above mentioned provides the necessary factual data for design of stock-water tanks and gives reasonable assurance of successful performance and long-life service of the tanks. Such a program also reduces the tremendously high aggregate cost of haphazard development so commonly associated with inadequate base data. It is equally applicable and important in the lower basin.

The upper basin is scarred by myriads of erosion channels, and many valleys are being trenched by deep gullies that drain the ground-water level beyond the reach of plant roots, thus drying up and making valueless large tracts of land that formerly produced quantities of excellent forage. Silt from these areas becomes a potential menace to farm lands, irrigation canals, reservoirs, and sometimes to towns. The cause of what is often called "accelerated erosion" has been the subject of repeated cross-arguments for some years. The Survey program with respect to this problem involves the collection of factual information on the subject, and the recommendation of remedial measures.

In the San Juan Basin, the Geological Survey in 1934–36, made detailed surveys of three washes that had eroded through deep valley fill to bedrock and had indications of active and aggressive head cuts. These surveys were made with a view to remapping at intervals in the future to note the changes taking place. The areas were resurveyed in 1944. Continuous observations of this kind will furnish factual information to be used in determining causes of the ensuing changes and for making plans to arrest or control the erosion. Similar studies are needed in many parts of the entire Colorado River Basin. These studies should include buried horizons or other evidence of previous cycles of cutting and fill, and with geologic and climatic facts a detailed historical chronology of gully erosion will add valuable information to assist in solving the problems of so many western valleys.

Lower Basin

The Lower Colorado River Basin embraces approximately 131,500 square miles in the United States. Since it is international and interstate, contains mountain plateaus and desert valleys, is arid to semiarid in climate, extends through 8° in both latitude and longitude with elevations varying from 100 feet to 12,000 feet above sea level and has vegetation ranging from heavily forested areas and rich irrigated farm lands to desert growths, its water problems are many and varied, and exceptionally important because of the limited supply in spite of seasonal flood menaces. As precipitation is heaviest in the mountains, water is most abundant in the eastern and northern regions, with perennial stream flow utilized largely for irrigation in the southwestern regions. Problems of water availability and use, including those which result from Colorado River water originating in the Upper Colorado River Basin but available to the lower basin and Mexico, arise in all parts of the basin and are very acute in many sections.

The Survey's current program of water investigations in the Lower Colorado River Basin is conducted in cooperation with the States which are wholly or partly within the basin, and with other Federal bureaus, notably the Corps of Engineers, United States Army, and the Bureau of Reclamation. Its plans, which contemplate expansions of the program along all lines of the Survey's activities related to water in an attempt to meet the diverse and growing Federal, State, and local needs, are included in the statements set forth below.

Summary of Estimated Costs

Recommendations for water resources investigations in the Lower Colorado River Basin during 3 years in the postwar period for expansion of activities beyond current programs are given in the following table:

TABLE CXXXIV.—*Estimated cost of program—Lower Colorado River Basin*

Program	First year	Second year	Third year	Total
Surface water.—For installation of 29 new gaging stations at an average cost of $2,050; for operation of 29 new gaging stations at an average of $910 per annum; for rehabilitation work on the existing program of 101 gaging stations, $3,330 per annum	$31, 000	$41, 000	$50, 800	$122, 800
Ground water.—For inventories of ground-water storage and withdrawal, drilling test wells and permanent observation wells, geophysical and geological surveys, experiments of clearing river-bottom growth, and estimates of perennial ground-water yield	125, 000	175, 000	125, 000	425, 000
Quality of water.—For quality of water studies, including both chemical quality with special reference to uses in agriculture and industry and to silt content in its relation to reservoir and channel capacities	104, 000	85, 000	85, 000	274, 000
Water utilization.—For utilization studies related to problems in water power, navigation, irrigation, and range development and operation	7, 000	6, 000	6, 000	19, 000
Total	267, 000	307, 000	266, 800	840, 800

Surface Water

Surface water is used largely in the Lower Colorado River Basin for irrigation, hydraulic power, industry, mining, and domestic supply. The supply necessary to meet these needs or uses is limited, and therefore, records resulting from an investigation of the quantity and distribution of surface water are of prime importance. The investigation of the availability of surface water is a continuing one, each record increasing in value with each passing year, records of 10, 20, and 50 years increasing proportionately in value and importance because of seasonal changes and hydrologic cycles in precipitation and stream flow. Emphasis of the necessity for continuation and extension of such a program cannot be stressed too often. Data resulting from these investigations are published annually in the water-supply papers of the Geological Survey.

As mentioned in the introductory statement, these investigations are financed by Federal funds, by cooperative funds provided by States and municipalities, and by funds furnished by other Federal agencies. The various non-Federal agencies in the respective States providing funds for support of this work are as follows:

Arizona: Office of State Land Commissioner, O. C. Williams; Salt River Valley Water Users' Association; San Carlos Irrigation and Drainage District; Maricopa County Municipal Water Conservation District No. 1.

California: Metropolitan Water District of Southern California (for certain stations on Colorado River in Arizona and California and on Williams River).

New Mexico: Office of State Engineer, T. M. McClure; New Mexico Interstate Stream Commission, T. M. McClure, Secretary.

Utah: Office of State Engineer, E. H. Watson.

Federal agencies providing financial assistance are the Corps of Engineers, United States Army; the Bureau of Reclamation, United States Department of the Interior; and the Defense Plant Corporation.

The program in the Lower Colorado River Basin necessarily relates to problems of an intrabasin, interbasin, interstate, and international nature. It relates to development plans that include the possibilities or irrigating large areas of fertile lands, coordinated with the development of hydraulic power. It must be related not only to present and future developments for industrial, mining, municipal, domestic, irrigation, or power uses, but also to administrative requirements with reference to political boundaries, to the Colorado River Compact and possible international agreements, to court decrees, to hydrologic studies such as reservoir and channel losses, flood control and recharge to ground-water reservoirs, and to transmountain diversions. Thus gaging station sites must be selected carefully to meet present requirements and the program should be expanded to new sites where records are needed for new needs or projects.

At the end of August 1944 the Geological Survey in cooperation with other Federal and State agencies was operating 101 gaging stations in the Lower Colorado River Basin, including 21 stations pertinent to the main stem of the Colorado River itself, 5 of which are in subbasins near the mouth of tributary streams. For a more complete coverage of the streams in the basin and for meeting fully current and postwar needs for the development, utilization, adjudication, and administration of the waters in the Lower Colorado River Basin and to aid, enlarge, and develop inadequate records now being obtained for present requirements, the establishment and operation of 29 additional stations is recommended. The existing stations and those proposed are not limited to any one use but relate to many; in addition they establish a general surface-water pattern over the entire area.

The distribution of the existing stations, and of the additional stations, among the principal areas of the basin and among the States is as follows:

	Existing stations	*Additional stations*
Areas:		
Kanab Creek Basin	1	0
Virgin River Basin	6	4
Little Colorado River Basin	13	5
Colorado River main stem	16	5
Williams River Basin	4	0
Gila River Basin	61	15
Total	101	29
States:		
Arizona	74	22
California	7	3
Nevada	0	2
New Mexico	14	0
Utah	6	2
Total	101	29

The existing program of 101 gaging stations requires approximately $112,000 per annum for operation. Because of the inevitable deterioration of structures and equipment during the war period when maintenance was reduced or stopped because of scarcity of material, $10,000 is now needed for the rehabilitation of existing gaging stations. For the expansion to 29 additional gaging stations, $59,500 is required for installation, and amounts cumulative to $26,400 per annum for the third of 3 years for the operation of the 29 additional stations.

Ground Water

Current need.—The importance of ground water in the Lower Colorado River Basin is apparent from the fact that in 1943 a total of more than 2,000,000 acre-feet of ground water was pumped in the basin for public works, industrial supplies, domestic supplies, and farms and ranches. In several parts of the basin the ground-water supply is already being depleted and in others it is rapidly approaching that stage; in other parts, however, the supply is ample for increased development and there are probably areas where the resources have not been discovered.

A large amount of the water supplies of the basin are wasted through transpiration by worthless valley-bottom vegetation. The amount lost by this process in the basin is roughly estimated as 1,000,000 acre-feet annually. The problems related to the destruction of this vegetation, the prevention of its future growth, and the erosional and other changes that would ensue, are so complicated that much more investigational work must be done to insure their economic and safe solution.

The increasing mineralization of the ground water and possible means of abatement should be investigated in several of the greatly developed parts of the basin.

The water-bearing formations tapped by wells, and from which springs issue, vary greatly in character, thickness, and areal extent over the basin, as do the hydrologic factors that control the development and utilization of the ground water. The development to date has been chiefly unplanned owing to inadequate geologic and hydrologic records and imperfectly understood ground-water principles. Thorough systematic study of the occurrence of ground water throughout the entire basin is needed, as well as the systematic collection of water records, in order that the available supply may be put to the most advantageous use. The necessity for such a study has been made apparent by the declining water levels accompanied by the diminution of the supplies obtained from wells in some places; by the difficulties encountered by cities and railroads, farmers, stock raisers, and others in obtaining adequate supplies of good quality; by prolonged legal controversies over water rights; and by the great demand for factual information on which to base estimates of the effects of ground-water conditions on the development of water projects.

The principal objective of a ground-water study of the Lower Colorado River Basin is the quantitative evaluation of ground-water recharge, discharge, and storage, and the obtaining of data for solving the multitude of problems arising from the occurrence and use of ground water. The study should be made systematically by valleys and should include the collection of records of quality of the water, pumpage from wells, fluctuations of water levels in wells, measurements of the gain or loss in flow of streams, determination of direction and quantity of movement of the ground water, depth of the ground water below the land surface, water-yielding properties of the formations and their thickness, and areal extent, areas in which large quantities of ground water are used by vegetation, amount of rainfall penetration to the subterranean reservoirs, seepage from canals and reservoirs, and the mapping of areas in which artificial recharge may be practiced successfully. The evaluation of these factors will provide basic information for determining the effect of diversions from streams, the trend of ground-water levels in areas of concentrated developments, and the perennial yield of the water bearing formations, the effect of pumping from wells on the flow of streams, and the effect of the construction of dams, irrigation canals, reservoirs, and drainage ditches on the level of the water table and on the flow of streams. To a large extent the future development of the basin will depend on obtaining permanent and adequate supplies of good water and obtaining the maximum use from the supply perennially available. The results of the study will, therefore, be of great practical and economic importance to the residents in the basin who must always depend largely upon wells and springs.

General ground-water conditions in the basin.—For this discussion the basin is described in two parts, the plateau region, and the basin and range region.

The plateau region is in northeastern Arizona, southeastern Utah, southwestern Colorado, and northwestern New Mexico. It constitutes most of the physiographic division known as the Colorado plateaus. It is arid to semiarid and includes all of the Little Colorado River Basin, the eastern part of the Virgin River Basin and the headwater basins of the Gila and Salt Rivers. The region is underlain by sedimentary formations and laval flows of Carboniferous to Recent Age. The formations are sufficiently warped and broken to cause a close relation between rock structure and the occurrence of ground water and a marked variation in ground-water conditions from place to place. The Coconino sandstone is the principal aquifer of the area with other standstones and conglomerates supplying water in local areas. Large flowing wells are obtained from the Coconino sandstone in some localities but usually the supply is only sufficient for domestic and stock use. Northeast of the Little Colorado River this standstone usually produces salt water only. The limestone beds and lava flows are also fair aquifers in local areas and at the edges of the high mountains large amounts of water are recharged into them. One of the major problems of the area is to find what becomes of this water. Another major source of water is from the valley fill of Tertiary to Recent Age in the valleys of the Little Colorado River and its larger tributaries. This source is supplying water for some irrigation and can probably supply more, especially if the waste by transpiration from large areas of valley-bottom vegetation along the Little Colorado River can be eliminated. In some parts of this region, water even for stock or domestic use is extremely hard to obtain. One large ranch expended more than $100,000 for test drilling with very little success.

The basin and range region is part of the physiographic division known as the basin and range province. It forms the southern part of the lower Colorado River Basin. It is an arid region of mountain ranges elongated in a northwesterly direction with wide intervening valleys filled with debris from the erosion of the mountains. Much of this fill is relatively unsorted sand, silt, and gravel, but some of the material, deposited in old lake basins, is well sorted. The lake bed clays give rise to artesian conditions in some of the valleys. In the area near Las Vegas, Nev., large amounts of water are used from artesian wells for irrigation and city use, and for a large army camp. A large part of the artesian supply in this area is wasted through uncontrolled flowing wells and faulty casing.

Drafts on ground water.—In the Gila and Santa Cruz River Basins of Arizona, a pumpage inventory made in 1943 indicated the approximate pumpage from the alluvial fill by counties to be as follows: Pinal County 515,000 acre-feet, Pima and Santa Cruz Counties 115,000 acre-feet, Graham County 36,000 acre-feet, and Greenlee County, Ariz., and Hidalgo County, N. Mex. 7,000 acre-feet. It is estimated that the pumpage in Maricopa County was 1,000,000 acre-feet. During the past several years, water-level measurements showed that in several areas water levels were continuously declining, indicating that the pumpage was in excess of the safe perennial yield.

This was true in the Eloy area of Pinal County, the areas concentrated pumping in Pima and Santa Cruz Counties, and the parts of Maricopa County that depend solely on ground water for irrigation. Accelerating the decline in water levels was the waste of water by transpiration from valley-bottom vegetation. In the Gila and Salt River Basins, in Maricopa and Pinal Counties, it is estimated that this waste probably amounts to between 400,000 and 500,000 acre-feet a year, and in Safford Valley in Graham County the annual waste amounts to 70,000 acre-feet. The value of the water for irrigation is also deteriorating as its mineral content increases through concentration resulting from irrigation use.

Methods of study.—The following procedure is proposed: To study each valley separately and to give each one special attention according to the nature of its ground-water problems. The valley unit is a logical subdivision in the basin and range region because each valley is a separate ground-water basin. The county unit is the logical division in the plateau region. First attention should be given to those valleys or counties in which critical ground-water problems now exist or in which water-project developments will soon take place.

Test drilling.—The character, thickness, and areal extent of the water-bearing formations can best be ascertained by drilling small test wells. These wells can often be used as permanent observation wells. For this purpose it would be desirable to purchase drilling rigs and to operate them continuously throughout the period of investigation. This method would also aid in determining the location of permeable deposits beneath the uplands as well as in the valley lowlands.

Geophysical prospecting.—The value of the test wells drilled in the above program could be greatly extended by the use of geophysical prospecting. This has already been proved in connection with the drilling of water wells for army camps in the area.

Geologic correlation.—Geologists with ground-water experience should study and correlate the samples obtained from the test wells and outcrops of the formations with the results of the geophysical probes. Such study will aid in planning further test drilling, in locating new supplies, and improving existing supplies.

Pumping tests.—Pumping tests should be made wherever possible, usually on existing wells. The recent advance in pumping-test methods makes possible the determination of the water-yielding properties of formations and provides practical means for determining well spacing, quantities of water to be expected from wells of different size, draw-down of the ground-water level, interference of one well with another, amount of water derived from flow of nearby streams, local geologic conditions affecting the occurrence of ground water, and the design of well fields.

Pumpage inventory.—Records should be obtained of the quantities of water withdrawn from wells throughout the basin in order that this information may be available for use in conjunction with studies of fluctuations of water level in determining the perennial yield of the formations. Records should be obtained from each town, irrigated area, railroad, and industrial plant, and measures should be developed for obtaining continuing records of this kind for the future.

Water-level measurements.—In order to determine the trends of ground-water levels and the changes in ground-water storage, an enlarged program of measurements of water levels in wells should be started and periodic observations should be made. The number and location of the observation wells in each valley or county would depend upon the importance and complexity of the ground-water conditions. Some of the wells should be equipped with automatic water-stage recorders in order to obtain daily records. Other wells should be measured once a week, once a month, or only a few times a year. New observation wells should be placed in areas of heavy ground-water pumpage and in areas in which water development projects are to be made. They should be established also near dams, reservoirs, irrigation canals, and drainage ditches, in order to ascertain the effects of the operation of those structures on ground-water conditions. Observations of this kind are now being made in the Santa Cruz River Basin in Santa Cruz, Pima, and Pinal Counties, and in parts of Maricopa, Graham, and Greenlee Counties.

Depth to water level.—The study should include an inventory of existing wells and the collection of information on the size, depth, and diameter of the wells, the kind and size of pump, and the use to which the water is put. Maps should be prepared where feasible, showing depths to water level.

Delimiting areas in which vegetation draws heavily on ground water.—Where ground water occurs at shallow depths, the roots of plants and trees extend to the capillary fringe or to the zone of saturation and they extract water in a manner similar to pumping from a well. It is roughly estimated that 1,000,000 acre-feet of ground water is consumed in this manner in the Lower Colorado River Basin, most of it by useless vegetation. Probably the greatest potential source of salvage of ground water lies in the reduction of use by vegetation that has little or no value; areas having such vegetation should be mapped with view to the effecting of measures for reducing the wastage of water. Some work has been done on this problem in Arizona and the results indicate a tremendous use of ground water by this type of vegetation. Salt cedar is one of the heaviest users and also one of the worst types in choking the flood channels. Along the Gila River from the Ashurst-Hayden Dam to the junction with the Salt River, more than 100,000 acre-feet of water are wasted annually by this type of growth. Similar conditions prevail at many other places in the basin including localities where irrigation has raised the ground-water levels and has created new areas of vigorous plant growth.

Determining water used by valley-bottom vegetation and experimental clearing.—An area would be carefully chosen where full cooperation of all interested parties could be obtained. Tests would be run on this area which would then be cleared and the salvage of water determined.

Mapping areas favorable for artificial recharge.—The building up of ground-water storage through artificial recharge from reservoirs and irrigation canals is accomplished in many places and the extension of this practice to new projects in the basin will undoubtedly augment ground-water storage. In addition, the flood flows of some of the streams could be diverted in such a manner that there would be seepage into the subterranean reservoirs where geologic conditions are favorable. Such possibilities should be mapped, especially where it may be expected to become over-developed in the future. Artificial recharge may be effected in some of the cities through recharge wells in which water is fed into the water-bearing formation during certain seasons of the year in order that it will be available for use in other seasons. The lowering of the water table along streams produces conditions favorable for artificial recharge in the sense that seepage is then induced from the streams into the subterranean reservoirs. The location of well fields near streams to take advantage of this source of water, including the filtering action of the sands and gravels and the more uniform temperature of the ground water, will undoubtedly prove to be the most logical solution for many water-supply problems of the basin. The ground-water study of the basin would include the mapping of stretches of the stream valleys that are favorable for this kind of ground-water development.

Interpretation of data and preparation of reports.—The data gathered in the field studies should be interpreted by competent engineers and geologists, and both the data and the interpretation should be presented in comprehensive reports. These reports should constitute an inventory of the ground-water resources of the Lower Colorado River Basin. They should form a reference library of information on the subject that would be invaluable in future planning for all kinds of water development. The interpretation of the data would be directed toward specifying new sources of supply for cities, railroads, farms, industries, and irrigation, determining the safe yield of developed areas, and methods of improving the present supplies.

Estimates of cost.—The collection of the data, the interpretation of these data, and the preparation of the reports should be carried on simultaneously, in large part by the same group of geologists and engineers. It does not appear practical, therefore, to estimate the total cost of the comprehensive study on the basis of individual items. Moreover, the annual cost of the study would depend upon the number of valleys or counties in which investigations were made each year. The experience of the Geological Survey indicates that studies made in the detail outlined above would require an average annual expenditure of about $125,000 with the addition of $50,000 the second year to cover the cost of a clearing project.

Quality of Water

There are two aspects of the quality-of-water problems in the Lower Colorado River Basin, namely: (1) The quality of the waters now available in surface- and ground-water sources, and (2) the quality of the water in surface sources that will be available after further development of irrigation in the upper basin and after diversions have been made from the headwaters into other drainage basins. By the withdrawal of water of good quality, these diversions will deteriorate the quality of the water in the streams below the diversions. Utilization of water for irrigation and other purposes will also cause changes in the quality of the water. The evaporation of large volumes of water stored in reservoirs and the resulting concentration of dissolved solids will obviously deteriorate the quality of the water that remains. Water utilization in the headwaters that causes changes in the chemical character of a river water will have an effect on the quality of water available below the headwaters, and the effect may be noticeable at the lower end of the lower basin.

Sediment records are needed for several streams in the lower basin, and the sediment records obtained for streams in the upper basin will be of value in planning for utilization of existing and new reservoirs in the lower basin.

Brief descriptions of quality-of-water and sediment studies that should be made are given in the following paragraphs:

Quality of water for industrial and agricultural purposes.—It is desirable to have information on the changes in concentration and character of waters that are potential sources of industrial and municipal supplies. The requirements for industries are rigid, and complete information on the quality of the available supplies is needed in making plans for industrial uses. The value of a water supply for industrial purposes may be seriously impaired because of previous uses to which the water has been put, especially when the source may be contaminated because of such uses. The comprehensive records proposed for this study will give the data necessary to determine the usefulness for most industrial purposes.

The quality of a water for irrigation uses is dependent on the nature and the amount of the dissolved constituents in the applied water, and on the amount of dissolved solids that are carried by the drainage from the irrigated area. Studies must, therefore, include the determination of the concentration and chemical character of both the waters used in irrigation and those in the drainage ditches. For the computation of quantities of dissolved solids carried to and removed from an irrigated area, it is necessary to have adequate stream-gaging records and all samples must be collected at points where stream-flow records are available.

In the Lower Colorado River Basin, information is needed on the quality of available ground-water supplies. In irrigated areas, it will be necessary to collect samples of the normal ground waters and also of the drainage waters. For most of these sources, one complete analysis and partial analysis of three to twelve samples a year will be needed to give the desired information. For surface water sources, it will be necessary to have daily samples on which one or more determinations will be made for showing change in concentration. As a rule, the samples for ten consecutive days will be made into a composite sample for a complete analysis.

The proposed quality-of-water studies will include the analysis of samples from reservoirs for the purpose of studying changes that may take place during storage. Because of the high rates of evaporation in the lower basin, there are appreciable changes in concentration and chemical character during storage, but records of these changes are meager.

The estimated cost of the quality-of-water studies in the Lower Colorado River Basin, including the quality studies in irrigated areas, quality studies in reservoirs, equipping of the laboratory, field work, and analyses of the samples, will amount to $44,000 for the first year and $35,000 for each subsequent year. It is likely that the existing gaging stations will be satisfactory for the sampling program and no new stations will be needed.

Sediment transportation.—Sediment studies have been carried on for a number of years at the Lees Ferry, Grand Canyon, and Yuma gaging stations on the main river. Prior to the closing of Boulder Dam, samples were collected at the Topock and Willow Beach gaging stations. The records for Lees Ferry and Grand Canyon should be continued, and sampling points should be established in the Little Colorado, Paria, Virgin, and Williams Basins. In addition, studies should be made to determine the nature and rate of sedimentation along the course of the river and in reservoirs. Such studies would be in the nature of a reconnaissance and would not duplicate the work done in a comprehensive sedimentation survey of the existing reservoirs. The estimated cost of the sediment studies, including the collection of samples, equipment, field and laboratory work, is $60,000 for the first year, and $50,000 for each subsequent year.

Water Utilization

In addition to the collection of basic information concerning stream flow, ground waters, and the quality of both, the water program of the Geological Survey embraces special compilations or arrangements of these data for purposes of general utility and the interpretation of the data, as well as other related physical and economic information.

Compilation of water facts.—An essential item of the program for the Lower Colorado River Basin is the collection of comprehensive water information pertaining to the quantity and quality of surface and ground waters, the status of their utilization, and the publication of such information in reports of convenient form for use and reference. The reports would present data regarding storage, diversion, and types of water use. The inclusion of a series of monthly charts of the Lower Colorado River Basin and adjoining areas showing in detail the relation between monthly and normal stream flow, would be useful in evaluating or expanding short or broken stream-flow records. The reports would give authoritative historical and other data concerning floods and droughts that would be helpful in the consideration of problems of natural flow and possible influences of climatic oscillations and changes wrought by man. Such information is a primary need in the adjudication of the conflicting interests of the political subdivisions and various industries now or propectively involved in the utilization of the limited water resources of the Lower Colorado River Basin. It is also needed for determining the availability and suitability of the water supply for various industries and activities that may be considered for establishment in the basin.

Interpretation of water facts.—Statistical records pertaining to water often require supplemental analysis or treatment in order to reveal their significance. The form of the analysis depends largely on the nature of the problem at hand, but it has been found that certain kinds of analyses enter into nearly every water-supply problem, and indeed, the availability of such basic analysis may encourage, or hold to wise limits, as the case may be, the application of the records to the solution of water problems.

"Deficiencies in Hydrologic Research," published by the National Resources Planning Board in 1940, describes the great number of needed investigations, some of which have singular bearing on the surface-water hydrology of the Lower Colorado River. Much fundamental work needs to be done in the Southwest and only the most preliminary or basic treatments are planned. The most general types of study that can be undertaken are statistical and inventorial.

A study of trends in precipitation, temperature, and run-off is included among the statistical investigations planned. Trend graphs shown in Water Supply Paper 772, reveal an irregular though marked downward trend in precipitation and an upward trend in temperature over most of the country. This combination produced a substantial reduction in run-off during the period of record then available. These analyses should be brought up to date, expanded, and examined more in detail with particular emphasis on the Lower Colorado River and with such reference to tree-ring chronology or other possible ways of extending knowledge of climatic behavior as may seem applicable or prudent.

In addition to statistical analyses, a great many facts regarding the water resources can be gained from the preparation of a quantitative hydrologic inventory. Such studies consider water in streams not by itself, but as one phase in a cycle containing other intimately related phases and factors including precipitation, interception by vegetation, infiltration, soil moisture, run-off from surface and ground sources, surface and ground storage, evaporation, and tranpiration. The information developed is useful in many kinds of water problems, particularly in administration of land use and conservation programs, and in flood control. Moreover, it can serve as a basis for estimating stream flow in areas where no gaging-station records are available, and as a supplemental method in combination with rainfall records for the synthesis and extension of stream-flow records, especially through critical period of drought or flood.

The technique for the preparation of an inventory as outlined above is available but must be modified by the adequacy of the data on hand as well as by the hydrologic conditions peculiar to the basis under examination.

Water for stock use.—As in the upper basin, stock raising is one of the major industries in the Lower Colorado River Basin. Vast areas of grazing lands are administered by the Grazing Service and the Office of Indian Affairs. The usable forage crop is dependent upon available stock watering places; forage on lands remote from water is unused whereas that on lands near water is overgrazed, often to the extent of accelerating destructive erosion of the soil mantle. Numerous and properly spaced range water supplies are necessary in areas now unused in order that overgrazed areas may be relieved and given opportunity for recovery.

Information and advice about water supplies on the public range is supplied by the Geological Survey for use by the Grazing Service, Office of Indian Affairs, and other land management agencies of the Department of the Interior. However, the extremely limited facilities of the Survey have prevented it from keeping abreast of current requests for advice on water supplies, and in some instances developments have been undertaken without benefit of competent geologic investigation. It is anticipated by the agencies administering the public range that the urgent need for water-development projects for stock use will greatly increase after the war.

In order to supplement well-water supplies and to open up new areas where it appears impractical or impossible to obtain water from wells, stock-watering tanks are constructed on washes and intermittent stream courses to catch some of the "flash" run-off. Virtually no hydrologic data are available for water courses of this type, and specially designed stream gages for obtaining such data are an item in the water program of the Survey. Evaporation and seepage losses are studied by means of staff gages installed in tanks at strategic sites. Weather data from nearby Weather Bureau stations are analyzed and correlated with all water information obtainable for the region under study and basic data are thus obtained for design of stock-watering tanks with reasonable assurance of successful performance and long life.

Accelerated erosion is an important problem in the lower basin. Deep gullies are trenching many valleys and draining the ground-water level below the reach of plant roots, making valueless large tracts that formerly produced excellent forage crops, and producing vast amounts of silt that became a troublesome problem to reservoirs, irrigation canals, and farms. The collection of factual information on this subject and recommendation of remedial measures is contemplated in the Survey program.

NATIONAL PARK SERVICE

The forthcoming report of the National Park Service, Recreational Resources of the Colorado River Basin, will cover this subject in more detail and will supplement the material contained herein.

The National Park Service is primarily a conservation and recreation agency performing functions which are an integral part of a program of land use of the Department of the Interior. The prime function of the Service is the administration of the National Park and Monument System. The Service seeks to preserve and render available to the public outstanding scenic, scientific, historic and prehistoric areas of national importance. The act of June 23, 1936, "authorized and directed the Secretary of the Interior—to cause the National Park Service to make a comprehensive study, other than on lands under the jurisdiction of the Department of Agriculture, of the public park, parkway and recreational area programs of the United States, and of the several states and political subdivisions thereof, and of the lands throughout the United States which are or may be chiefly valuable as such areas . . . The said study shall be such as, in the judgment of the Secretary will provide data helpful in developing a plan for coordinated and adequate public park, parkway and recreational area facilities for the people of the United States."

With this responsibility and the fact that several areas in the National Park and Monument System would be directly affected by certain water-control possibilities being considered by the Bureau of Reclamation, it was determined that the National Park Service should investigate and furnish the Bureau with essential facts basic to the establishment of Departmental policy regarding the classification, development and administration of possible water-control projects and related areas in the basin, in which recreation is or will become an important dominant or collateral resource. On January 27, 1941, Secretary Ickes approved the proposal of the National Park Service and the Bureau for including a basin-wide recreational survey as a part of the studies and investigations for the formulation of a comprehensive plan of utilization of the waters of the entire Colorado River system.

Colorado River Basin Water Utilization Program and its Effect on Recreation

From Gannett Peak in the Wind River Mountains, highest point in Wyoming, elevation 13,785, Milner Pass in Rocky Mountain National Park, and the 14,000-foot mountain peaks in southwestern Colorado to the Salton Sea, 241 feet below sea level, stretches a vast region of forests, deserts, plains, mountains, canyons, and plateaus. The Colorado River Basin is one of the most outstanding recreational regions in the United States, because of great variety of natural scenery, climatic conditions, and areas and objects of scientific interest, its early romantic history, archeological background, and present Indian, Spanish, and Anglo cultures.

Here is the world's greatest canyon, the largest natural bridge, the largest man-made lake, and the highest dam. Here, too, one may enjoy the largest percentage of possible sunshine of any place in the United States and find perfect climates for outdoor recreation the year around. Hunting, fishing, photography, snow sports, boating, swimming, horseback riding, camping, mountain climbing, exploration, the entire realm of outdoor recreational activities may be enjoyed. Five national parks and 28 national monuments have been established within the basin to preserve some of the most outstanding natural, scientific, and cultural features. Large sections have been included in national forests, wildlife refuges, and grazing districts, and vast areas set aside as Indian reservations. Much of the basin is in public ownership, but this is not surprising when one sees the country and knows that about half the basin has a population of less than 2 people per square mile, and that the most densely populated county, Maricopa County, in which Phoenix, the largest city is located, has a population of only 20.2 people per square mile.

It is only natural in a region so endowed that recreation should become one of the major industries. Agriculture is restricted almost entirely to irrigated sections. Mining, lumbering, and the raising of cattle and sheep first attracted settlers to the basin, but the recreational features are now attracting many more; and as the various sections of the basin become better known and more accessible to the densely populated regions of the United States through improved highways and air transportation, catering to the recreational business should become a major industry. To foster this industry it must be recognized that recreational use of land may in certain places be the highest or best use of the land for the general welfare of the people in the basin, and in vast sections of the basin should be on an equal basis with other uses, such as grazing or production of timber. One of the most important recreational features of the basin is the great stretches of open range, unobstructed by buildings, fences, transmission lines, and other signs of modern civilization. As other sections of the United States become more and more highly developed, this one feature of the Colorado River country, if preserved, will have unusual appeal.

The major portion of the basin is desert or semidesert. Here water is the most precious single item. The life of the region is dependent upon the wise use of the streams and ground water. In the development of the water, recreational use should be considered along with other uses, such as irrigation, power, municipal water supply. In the mountains and high plateau sections of the Colorado Basin the clear, cold streams and lakes offer excellent fishing, amid delightful surroundings, and in some instances the recreational value of these streams and lakes may be such as to make this their most important use. In other sections the construction of dams for irrigation or power create new water areas of recreational importance, for example: Lake Mead, which has been called the "Eden of all bass fishermen," is famous throughout the country for its scenic beauty. There are also instances where the raising of water behind dams would submerge areas of scenic and scientific value or archeological importance. In such cases it must be decided whether a reservoir in that location is more or less desirable than the preservation of these existing features. If in the case of existing archeological features the decision is in favor of the reservoirs, there should be a thorough survey and excavation where found desirable, so that knowledge of the archeological material will not be lost forever. In the larger proposed reservoir areas surveys should also be made of the flora and fauna and records kept of the original biota.

The importance of recreational resources in the basin is recognized by the Bureau of Reclamation in planning for water conservation projects. Through a cooperative agreement with the National Park Service, the latter is carrying on a general survey of the recreational resources of the Colorado River Basin for the Bureau. Although it has not yet been possible to cover the entire basin, a number of proposed reservoir sites have been investigated and considerable information gathered concerning the recreational features of large sections of the basin. In many instances the project plans have not advanced sufficiently to determine definitely what effect the proposed reservoir would have on existing recreational values or to determine the potential recreational values of the proposed reservoir area. The location and accessibility of the reservoir, the physical characteristics of the reservoir area; size and elevation of minimum, normal and maximum pool; the season and frequency of maximum draw-down; all have an important bearing on the potential recreational value of the reservoir, and the determination of the effect the reservoir would have on existing conditions.

Potential Projects on Main Stems of Colorado and Green Rivers

On the main stems of the Colorado and Green Rivers the plan lists 13 potential power dam sites, in addition to the Davis Dam project on which work has been stopped during the war emergency. The majority of sites are in spectacular canyons and in most cases the reservoirs created would provide means of access to outstanding scenic country which at the present time is almost wholly or entirely inaccessible to the average person. At the same time this complete harnessing would change them from great rugged rivers grinding their way down from the mountains to the sea to a series of quiet mill ponds. The rivers as Powell knew them would be gone—a definite loss.

Davis Dam and Reservoir.—Davis Dam site is located due west of Kingman, Arizona, 23 miles by existing roads, and about 67 miles below Boulder Dam, and the backwater will extend to the tailrace of the Boulder Dam power plant. At the present time the clear, cool water released by Boulder Dam offers excellent trout fishing. It would be expected that the Davis Reservoir should rival or possibly excell Lake Mead as a bass fishing area, but scenically will not compare with it. The upper third of the reservoir area from Boulder Dam south almost to Eldorado Canyon is in the lower Black Canyon, a volcanic area marked by rugged mountains and deep canyons. This section, while scenically interesting, is not comparable to the Grand Canyon section of Lake Mead, or the canyon scenery which would be made accessible by the proposed Bridge Canyon, Marble Gorge, or Glen Canyon Dams. Below Black Canyon the mountains draw back from the river and begin to flatten out. Long gravel ridges and benches lead gradually down to the river. The widest portion of the reservoir will begin about 12 miles above the dam and extend for some 8 miles, average around 3 miles wide. The lower portion of the reservoir will be in Pyramid Canyon, formed by low mountains coming in closer to the river. Creosote bush and mesquite trees are the most conspicuous of all the desert plants in the reservoir area. There are numbers of mountain sheep and a few desert deer. Beaver are very common, as are rabbits, ground squirrels and other desert rodents, upland game birds, ducks, geese, and other aquatic birds.

Since construction of Davis Dam was expected to begin at an early date, of first importance was an archeological survey of the reservoir area to determine desirable archeological work which should be done before the water began to rise. Such a survey was made by Dr. Gordon C. Baldwin in the Spring of 1943. One hundred and fifty-five archeological sites were located and Dr. Baldwin estimated there are at least 200 sites in the reservoir. He considered 15 of the sites to be of sufficient importance to be tested and at least partially excavated at a later date. Most of the sites are located on small benches or flats bordering the river. Of the 15 important sites, at least seven should be thoroughly explored. Dr. Baldwin estimated that the excavations could be completed in 8 months, and the desired work accomplished for about $8,000.

U. S. Highway 66 is scheduled to be one of the national superhighways. The present route between Kingman, Ariz., and Needles, Calif., is unsatisfactory and consideration is being given to routing it across Davis Dam. If this is done at least 182,500 cars per year would cross the dam on the basis of the 1940 traffic count. There is certain to be a demand for recreational facilities in the vicinity of the dam.

The upper two-thirds of Davis Reservoir will be within the present boundaries of Boulder Dam National Recreational Area. It would be logical to have the recreational phases of the entire reservoir area administered by one agency. Further study of recreational use and administration is required.

Bridge Canyon Dam and Reservoir.—The Bridge Canyon Dam site is in the Grand Canyon at the head of Lake Mead about 20 miles airline northwest of Peach Spring, Ariz., on U S 66 and the Santa Fe Railroad. Various heights for the dam have been considered, but the one favored by the Bureau of Reclamation at present would have a maximum water-surface elevation of 1,866. This would raise the water 666 feet above the stream-bed at the dam and place the head of the reservoir less than a mile down stream from the mouth of Kanab Creek. It would raise the water surface about 85 feet at the mouth of Havasu Creek, backing the water approximately one half mile up Havasu Canyon in Grand Canyon National Park.

The dam site and reservoir area are entirely within areas now administered by the Federal Government through the Office of Indian Affairs, National Park Service, Fish and Wildlife Service, Forest Service, and the Bureau of Reclamation. Access to the dam site is across the Hualpai

Indian Reservation, which extends along the south side of the Colorado River from the Grand Wash Cliffs on the west to National Canyon where it joins the south portion of Grand Canyon National Monument. East of the monument is Grand Canyon National Park. Boulder Dam National Recreational Area overlaps the canyon portion of the Hualpai Reservation. On the north side of the river the land is included in Boulder Dam National Recreational Area, Grand Canyon National Monument, and Kaibab National Forest.

The Grand Canyon is one of the world's outstanding recreational areas of scenic and geologic interest. As stated by Edwin McKee, Assistant Professor of Geology, University of Arizona:

From the mouth of Nankoweap Canyon in the east to the Grand Wash Cliffs in the west—over 200 miles by river—the Grand Canyon maintains approximately the same 5,000-foot depth and a width between rims measured in terms of miles. All sections of Grand Canyon are parts of one natural physiographic unit. Although the general character and form of the canyon change greatly from the area of alternating cliff and slope and of butte and temple at one end to a canyon of nearly sheer walls at top and bottom, separated by the wide, red "Esplanade" bench at the other, it is not correct to say that one part is better than another. All parts of Grand Canyon go to form a whole and there is an imperceptible transition from one section to the next. Man-made boundaries and divisions in Grand Canyon mean nothing in indicating the relative value of different portions. It is not possible to say that one part is either inferior or superior to another; each is different but each is great and part of the entire.

Of first consideration in the recreational survey of the proposed Bridge Canyon project was the appraisal of the effect the proposed reservoir would have on existing natural conditions in Grand Canyon and Grand Canyon National Park. Frederick Law Olmsted, collaborator with the National Park Service on the survey of the recreational resources of the Colorado River Basin, has submitted a preliminary report on this subject.

Water conditions in the canyons of the Colorado, including height of water, are, and will continue to be, far from static and constant at any given place. This is true both for localities where the water is controlled by fluctuating reservoirs and also for localities where the water is wholly uncontrolled. Under natural conditions the water level in the narrower parts of the canyon bottom (such as near the mouth of Havasu Creek) fluctuates 40 feet or more. The water level controlled by a reservoir of a given nominal elevation fluctuates even more largely and quite differently.

The water and its immediate banks in the upstream portions of the canyon where flooded by Lake Mead at times present a combination of physical conditions and a general appearance which are most deplorable from a recreational and scenic point of view, and similar conditions can be expected in similar parts of the Bridge Canyon Reservoir. They contrast in a very striking manner with the conditions and appearances presented at other times in the very same parts of the canyon subject to flooding by Lake Mead. The point to be made here is that there are almost equally striking differences in physical conditions and appearances between low-water and high-water stages in the parts of the canyon *not* affected by Lake Mead.

1. Boat trips in the Lake Mead portion of Grand Canyon which are extraordinarily impressive experiences would be completely free from obstruction and disagreeable appearance at all times. 2. Bad accumulations of floating debris would occur in Bridge Canyon Reservoir generally during May, June and July in a limited locality downstream from Havasu Creek. They would interfere with boating, and for anyone obtaining a reasonably close view of the water would detract from the natural appearance of the canyon. It is unlikely that visitors, in general, would want to take a longer boat trip than from the vicinity of the dam to Toroweap (about 57 miles) and back, in any case. That would take them through three of the four types of inner canyon scenery and show them the lower end of the fourth. 3. After the breakup of the unsunken portions of each season's accumulation of debris, the dispersed fragments, if not controlled, would be more troublesome for boating than they have been on Lake Mead.

As to probable significant changes in the canyon in respect to elevations of water surface, physical conditions and appearance of deposits of silt, sand and other heavy material, Mr. Olmsted summed up his discussion by saying, "The differences in water surfaces and in exposed deposits, as between the canyon without a dam and the canyon in the upper reaches of Bridge Canyon Reservoir, or as between the latter with a high dam and with a low dam, may perhaps fairly be regarded as differences of degree more than of kind. There is no precise, critical point at which it can fairly be said that beyond this point any increase in height of water surface or any increase in amount of fluctuation would produce a radical change of kind in the general appearance of things in the depths of the canyon. What can be said definitely is that *some* unmistakably artificial modifications of existing conditions, scenically unpleasant in greater or less degree, will extend to whatever limit is reached by the reservoir's raising of high-water levels."

The impounding of water behind Bridge Canyon Dam to an approximate elevation of 1,866 feet will conceal few geological features that are unique or of special importance as documents of geological history, according to Edwin McKee.

The greatest loss, so far as geological features are concerned, would be in the area of volcanic activity at and west of Toroweap Valley. This is one of the most outstanding geological sections of the canyon. Edwin D. McKee and Edward T. Schenk in their report entitled "Lava Dams in Grand Canyon" say, "The spectacle of lavas that have cascaded down the steep canyon walls and cinder-cones perched on the sides and brink of the chasm usually makes a profound impression on the layman, while to the geologist the problems presented are intriguing."

Toroweap Valley slopes gently toward the canyon rim and ends with a sheer cliff almost 3,000 feet above the river. The views down into the canyon are spectacular and awe-inspiring. Any height of reservoir will increase the width of the strip of water in the bottom of the canyon through submergence of the talus slopes, by an amount roughly proportionate to the height of the water above the natural river level, which is here about 1,675 feet.

The lower section of Havasu Canyon would be materially affected by raising the reservoir above the 1,772-foot elevation. Havasu Creek, an unfailing spring-fed stream of crystal-clear water, produces the distinctive feature of this locality. The notable and beautiful, though seldom seen, mingling of the blue waters of Havasu Creek with the brown water of the Colorado would be radically altered for the worse, if the full reservoir elevation is raised higher than the 1,772-foot elevation. But the more frequently visited waterfalls and other features that have made Havasu Canyon famous would not be physically affected by Bridge Canyon Reservoir.

The places now in the Grand Canyon National Park upstream from Havasu Creek that would be physically modified by raising Bridge Canyon Reservoir above elevation 1,772 are all close to the river in the bottom of the narrow inner canyon and the resulting changes would be observable almost exclusively from boats.

Mr. Olmsted said:

This section of the Grand Canyon as a whole is notable for the distinctive character of its scenery, especially as seen from certain places on the upper rim on both sides of the canyon. It was completely included from rim to rim in the portion of the Grand Canyon originally set apart in 1908 as a national monument for preservation of the noneconomic values of its unique and inspiring scenery. It was, and is worthy of selection for such a purpose.

When the Grand Canyon National Park was established in 1919, its boundaries were so drawn as to leave the entire north side of the canyon between Tapeats Creek and Havasu Creek under the administration of the Forest Service, which had previously administered all parts of the Grand Canyon set apart for preservation of its natural scenery in 1908. The investigators have found no record indicating that the omission of that area from the park was due to a deliberate and reasoned decision to reverse the earlier intention of protecting the scenery of this entire unit of the canyon from rim to rim.

If that is to remain the policy of the Government concerning this entire unit of the Grand Canyon, in accordance with the decision made in 1908 and adhered to in essence ever since, then the limitation of Bridge Canyon Reservoir to an elevation that will not encroach on that protected area should be continued, for the following points are clear, viz: A higher elevation would substantially alter natural conditions and injuriously affect the natural scenery along the Colorado River as far as the backing up of the water extends, for the sake of an exclusively economic gain, in direct contradiction of that policy. The conclusion above stated is not invalidated by the fact (*a*) that the impairment of natural scenery within the supposedly protected area would be relatively limited in extent in comparison with the entire area of the Grand Canyon that is supposedly protected, and would probably be observed by no more than a small fraction of the people who visit various parts of that entire area in order to enjoy its scenery, and (*b*) that the economic gain would be relatively large.

If, on the other hand, it is decided that the justifying reason for existence of a national park extending into the canyon downstream from Tapeats Creek is not that of protecting, in conjunction with the Forest Service, natural conditions and scenery in the Grand Canyon from rim to rim, but merely to protect Havasu Canyon Unit and adjacent areas *south* of the river; then the logical procedure would be Congressional action making a marginal modification of the present boundary of the park west of the Tapeats Creek watershed, shifting it from the north bank of the river to a contour on the south bank that would keep it clear of the prospective reservoir.

Choice between those alternative policies depends not primarily upon technical details such as have been discussed in this report, but upon broad considerations of public purpose; in the last analysis upon how much the people of the United States care about preserving the natural conditions and scenery in the portion of the Grand Canyon selected for such preservation in 1908, and whether they are able and willing to pay the economic price of such preservation.

The spectacle of a great dam under construction and after completion in the bottom of the Grand Canyon is certain to attract many visitors. On the basis of 1940 attendance figures for the south rim of Grand Canyon National Park and highway traffic counts, it is estimated that 20 percent of the automobiles traveling U S 66 go into the park. Considering the facts that the minimum side trip into the park is 118 miles, whereas, it will be only about 42 miles round trip from U S 66 to the rim of the canyon where one may look down on the Bridge Canyon Dam over 2,000 feet below, the visitor traffic into Bridge Canyon should be at least 20 percent of the traffic on U S 66. On the basis of 1941 figures this would mean that over 200 automobiles per day would make the side trip. With an average of 3 persons per car the annual attendance would be around 220,000. It is likely that travel on U S 66 will increase considerably in coming years, and bring at least 250,000 visitors per year to the Bridge Canyon Dam area. Many more will come by air and there are sites for landing fields within five miles of the canyon rim. It is possible that visitors to the dam site may reach 300,000 per year. The opportunity of driving down into the Grand Canyon or of taking an elevator from the rim down about 2,000 feet to the top of the dam and another 650 feet to the bottom of the canyon will be a great attraction. Added to this will be the opportunity for boat trips through many miles of the canyon.

Facilities to accommodate between 250,000 and 300,000 visitors per year should be planned and developed as part of this project, parking areas, overlook and observation platforms, camp and trailer grounds, restaurants, overnight accommodations, boat docks and landing fields.

There is no point on the north side of the proposed reservoir where the water will be easily accessible by land, and Peach Spring Draw offers the only opportunity on the south side. It would be comparatively easy to construct a road from Highway 66 down Peach Spring Draw to the shore of the reservoir, a distance of 20 miles. This may prove a desirable location for limited development of boat landings, parking areas, and other facilities for the recreational use of the reservoir.

Marble Canyon—Kanab Creek Project.—This proposal calls for a dam in Marble Gorge, 36½ miles downstream from Lee Ferry, which would create a reservoir with a normal water-surface elevation of 3,125 feet above sea level, approximately the elevation of the Colorado River at Lee Ferry. The reservoir at maximum elevation would be deep in the gorge to a point above Navajo

Bridge where it would spread out slightly beyond the present river. From the scenic and recreational point of view the reservoir would have little potential value except to afford easy access by boat to this section of Marble Gorge. However, the project involves a 42.5-mile diversion tunnel under the Kaibab Plateau to a power plant site at Kanab Creek.

Probably the most serious effect upon scenic and related values from building the suggested tunnel to Kanab Creek would be the curtailment of the flow of the Colorado River through Grand Canyon National Park, reducing it to a minimum arbitrary allotment for purely scenic effect. Certainly such a project should not be considered until there is a need for the power thus generated which cannot be met by other means. Then the decision should be made as stated by Mr. Olmsted in the case of Bridge Canyon Reservoir, "not primarily upon technical details—but upon broad considerations of public purpose—upon how much the people care about preserving the natural conditions and secenery in the portion of Grand Canyon selected for such preservation in 1908 and whether they are able and willing to pay the price of such preservation."

Glen Canyon project.—The Glen Canyon site is in the deep sheer walled canyon just around the bend above Lee Ferry. Preliminary figures suggest an elevation of 3,528 feet for the top of spillway gates in raised position, 401 feet above stream bed. Access to the lower end of the reservoir would be extremely difficult.

The Glen Canyon Dam would create a reservoir extending upstream 182 miles to the Dark Canyon site. At the Dark Canyon Dam site there is a possibility of raising the water 432 feet, forming a reservoir extending up the Colorado to Moab, Utah, and up the Green River almost to Green River, Utah. For the most part the Glen Canyon and Dark Canyon Reservoirs would be confined between canyon walls and have only minor effect on the scenery of the spectacular Colorado River country of southeastern Utah. Throughout this country the immediate canyon of the river is at least 1,000 feet deep and in places, such as in the vicinity of Dark Canyon, it is over 2,000 feet deep. Most of the streams and washes entering Glen Canyon have a fairly rapid fall near the Colorado, and the reservoir would not extend any distance up most of them. Back-water would extend 30 miles up the San Juan River and 14 miles up the Escalante River, but here again it would be confined in high walled canyons. Much of the country bordering the Colorado and the Green Rivers through this section of Utah is of high recreational value. It is a region of great colorful spaces, mountains, plateaus, canyons, desert, forest and weird rock formations, probably the greatest display of erosional effects in the United States, other than the Grand Canyon, and equally grand, though of a different character. In providing a means of access to this remote canyon country, the Glen Canyon Reservoir would increase rather than detract from the recreational values of the region. Power lines from the dams would detract from the enjoyment of the open country.

Moab project.—The plan includes a concrete gravity dam on the Colorado River just above the highway bridge at Moab, Utah, which would raise the water 138 feet at the dam. A reservoir at that elevation would inundate the lower slopes and bottom of an unusually scenic canyon and eliminate the existing road which runs through the canyon between Moab and Dewey, Utah. At the present time this is the only place where it is possible to drive through one of the great canyons of the Colorado River. It would be indeed unfortunate from the scenic and recreational standpoint if a dam were to be constructed that would flood this canyon section.

Dewey project.—The Dewey Dam site, 3 miles below the mouth of Dolores River and 30 miles upstream from Moab, Utah, is at the beginning of the great canyons of the Colorado River. The greater part of the reservoir area is arid, treeless, grazing land, having little or no scenic or recreational value. The principal scenic feature is Westwater Canyon, near the upper end of the reservoir area, about 12 miles long and several hundred feet deep, cut in reddish sandstone, but it is of secondary importance as compared with the canyon of the Colorado River below the dam site.

While the Dewey Reservoir would not be of special recreational importance to the immediate vicinity, since the local population is very sparse, the lower portion would be of some recreational usefulness to the residents of Moab (providing the proposed power dam on the Colorado River at Moab is not constructed), and the Westwater Canyon section would be of interest to travelers using U S 50, and to residents of the Grand Junction area.

A permanent road should be built from U S 50 to the dam site and connect with the present State Highway 128, which runs through the spectacular red canyon of the Colorado between Dewey and Moab. This would, in effect, retain the present route from Moab to U S 50 which not only is used as a short cut from Moab to Grand Junction but affords access to the remarkable scenery of this part of the Colorado River Canyon. The reservoir area is reported to contain several archeological sites, and while it seems doubtful that any unmolested sites remain, it is recommended that an archeological investigation be made prior to construction of the dam. The paleontology of the area should also be investigated.

Gore Canyon project.—This project located just below Kremmling, Colo., involves a low diversion dam near the head of Gore Canyon and a tunnel to a power plant located at the foot of the 5-mile canyon. The site has not been investigated by the survey, but it is likely that it would have little important effect on existing or potential recreational values.

Rattlesnake and Desolation Canyon projects.—The plan for development of power on the Green River includes six dam sites. The lower two, Rattlesnake and Desolation, are located in the remote section of the Green River between Green River, Utah, and Ouray, Utah, characterized by the name Desolation. Although the recreational resources of the two sites have not as yet been investigated, it is doubtful that the scenic or recreational value, either existing or potential, will be found important. General information indicates that scenically this section does not compare with sections along the Green River above Jensen, Utah, and below Green River, Utah. Certain archeological sites have been found near the reservoir areas, and a survey should be made to determine the archeological importance of the reservoir areas.

Split Mountain and Echo Park projects.—These two power sites are in Dinosaur National Monument. Functionally, Dinosaur National Monument consists of two sections referred to as the Quarry unit and the Canyon unit. The former comprises 3,000 or 4,000 acres in the vicinity of the Dinosaur Quarry and includes the original 80-acre monument. The Canyon unit, consisting of the remainder of the area, is about 200,000 acres in extent.

The geological formations in the Quarry unit are of scientific importance and of distinct scenic value, but the major significance of the unit is considered to be in the dinosaur beds.

The Canyon unit is characterized by a notable combination of geological, scenic, biological, and archeological values and by its wilderness quality. Its most spectacular features are the canyons of the Green and Yampa Rivers, where interesting geological formations and impressive landscapes are displayed in great variety. One of the exceptional attributes of the unit consists of contrasts in the geological formation and the scenic character of the canyons of the two rivers. There are also biological and archeological values of real interest. The Canyon unit possesses great importance for the part it can play as an introduction to the geology and scenery of the West, for the residents of the Middle and Eastern States. It is of national significance for the combination of its qualities; it is distinctive of its kind, and justifies its existence as a unit in the National Park System.

The Quarry unit would be little affected by the proposed projects, but the Canyon unit would be materially affected by them, depending upon their location and other influencing factors. Such facilities as dams, roads, transmission lines, and structures for administration, operation, and maintenance would more or less adversely affect natural and archeological values, but the most far-reaching alteration would be caused by the reservoirs. The Echo Park Reservoir, which would be impounded by a dam about 500 feet high, would extend upstream from the dam throughout the length of the Green River within the national monument and to a point about 30 miles by river course beyond the north boundary of the area. It would also extend up the Yampa River to a point in Lily Park east of the eastern boundary. The Split Mountain Reservoir, which would be created by a dam about 118 feet high at the head of the Split Mountain Canyon, would inundate Little, Rainbow, and Island Parks and would extend up Whirlpool Canyon to about the base of the Echo Park Dam. The Echo Park and Split Mountain Reservoirs, particularly the former, would cover wholly or in part a number of notable geological formations, would reduce the visible height of canyon walls in some sections, and would substitute long bodies of still water, widening here and there into bays or lagoons, for the natural streams and vegetations in canyon bottoms. The most radical alteration would occur in the general vicinity of Pats Hole, where the nearly vertical walls of Echo Park and Steamboat Rock, which in places rise to about 900 feet above the valley floor, would be inundated to nearly one-half their height. The notable fault in the neck of Steamboat Rock, now seen so clearly from the tip of Harpers Corner, would be partly submerged. A considerable lagoon, two or three square miles in surface area, would extend up the drainage of Pats Hole, covering the refreshing greenness of the Chew ranch locality. Farther to the east, some of the intrenched meanders of the Yampa River would largely disappear, for the sloping goosenecks separating them would be covered.

Split Mountain Canyon, Whirlpool Canyon, and the Canyon of Lodore, all on the Green River, would be adversely affected from the viewpoint of geologic and scenic values, although less materially so than the canyons of the Yampa River.

Submersion of the parks and the bottom slopes of canyons and entering draws would also affect the biota of the area unfavorably, through changes in wildlife habitats. Also, a number of interesting archeological sites, particularly along the Yampa River, would be submerged. However, a good deal that is of geologic and scenic interest would remain. Some parts would be wholly unaffected, such as Jones Hole, the precipitous canyons of the Yampa River near Thanksgiving Gorge and Cactus Park, and the dramatic entrance of the Yampa River into its canyon near the east boundary of the national monument. In some sections, the reduction in the visible height of canyon walls would be a relatively small proportion of the present total height, and some of the canyons would still be impressive, as for example, Split Mountain Canyon, the portion of Whirlpool Canyon below the Echo Park Dam, the upper part of the Canyon of Lodore, and sections of the Yampa Canyon where walls would rise several hundred feet above the high-water level of the Echo Park Reservoir.

Not only would some geologic and scenic values remain, but new scenic and recreational values would be added, and even though they would not compensate in kind for the losses described, they would be of real importance. Although artificial, the fiord-like reservoirs and their bays in the side drainages would create impressive landscapes, and they would provide avenues by which to see parts of the canyons which visitors would otherwise rarely enter. Under the proposed water-control development, the unaffected natural resources and the values could, in combination, be of national importance from a recreational viewpoint.

The policy of the National Park Service, as the administrative agency responsible for the national monument, has been and is to make the protection of the natural and archeological values of the area the controlling factor in administering it. The question of whether this policy is to be changed to permit development for water-control would require for its solution a review of all probable advantages and disadvantages by authorities superior to either the National Park Service or the Bureau of Reclamation. Before changes in the status of the Canyon Unit are authorized in order to recognize water control as the principal consideration in administering the unit, it should have been clearly and certainly shown that it would be in the greater national interest to develop the area for such use than to retain it in its natural state for its geologic, scenic and associated values and for the enjoyment of them by the Nation.

Red Canyon and Flaming Gorge projects.—The comprehensive plan lists two power dam sites above Dinosaur National Monument; the Red Canyon site about 63 miles upstream from the Echo Park site and seven miles above the mouth of Red Canyon of the Green River, and Flaming Gorge site in the lower end of Flaming Gorge, 31 miles above the Red Canyon site, and 65 miles by road from Green River, Wyo. Both sites are in scenic country on the north side of the Uinta Mountains. The Red Canyon Reservoir site is in an impressive but not outstanding canyon in the Ashley National Forest. However, the Forest Service has considered it of sufficient scenic interest to warrant building a four-mile road to an overlook parking area on the rim of the canyon some miles above the dam site which is about one mile outside of the forest. At maximum elevation the reservoir will only extend upstream about 13 miles, leaving 8 miles of the canyon in which the river falls 120 feet undisturbed. With the Flaming Gorge Dam above, the water should be fairly free of silt and fishing should be good. However, due to the sparse population of the region and the competing good fishing lakes and streams in the Uinta Mountains, this use of the reservoir would be limited.

The mile long Flaming Gorge is unusually colorful for that section, but is not unique or outstanding compared with the colorful scenery found further down the Green River. However, the combined scenic and geologic interest of Flaming Gorge, Horseshoe Canyon, and the nearby canyons of Sheep Creek, plus the reservoir would make this section of considerable recreational value. The scenic forest road over the Uintas between Green River, Wyo., and Vernal, Utah, connecting U S 30 and U S 40, goes through Sheep Creek Canyon and passes within 5 miles of the dam site.

There is certain to be a demand for recreational facilities in the vicinity of the dam. The Forest Service has provided a camp ground in Hideout Canyon on the river about 6 miles below the dam site and in Sheep Canyon. Plans for recreational use of the lower end of the reservoir should be made in cooperation with the Forest Service.

Potential Projects on Tributaries of the Green and Colorado Rivers

The comprehensive plan lists numerous reservoir sites on the tributaries of the Green and Colorado Rivers for power, irrigation, and silt control. Some of the sites have been covered by the survey of the recreational resources of the Colorado River Basin, many others are still to be investigated and in most cases final appraisal of the recreational values cannot be made until the project plans are further along.

Green division.—Of the several potential projects in the Upper Green River Basin in Wyoming, the proposed Elkhorn and Paradise units of the Sublette project would have the most important relationship to scenic and recreational values. These units lie near the foot of the western slope of the Wind River Range. They involve the proposed Kendall Reservoir (capacity 340,000 acre-feet) and the development of Burnt Lake (capacity 25,000 acre-feet) and Boulder Lake (capacity 180,000 acre-feet) for irrigation storage and power. A tunnel 1,800 feet long through the terminal moraine of Burnt Lake would tap the lake for power production. The power plant tailwater would be caught in Boulder Lake. Under the tentative plans there would be a difference of 44 feet in the level of Burnt Lake, and 460 acres in surface area between dead-storage elevation and spillway crest.

The western slope of the Wind River Range is a mountain area of such exceptional scenic quality and recreational value as to be of national importance. The finest of the larger natural lakes in the region are the Green River Lakes, at the headwaters of the Green River, within the primitive area of the Bridger National Forest, and because of their superlative scenic values, it is hoped that they will be retained permanently in their natural condition. Nearer the project areas are five other natural lakes which are but slightly less notable; New Fork, Willow, Fremont, Half Moon, and Burnt Lake, also within the National Forest but not within the primitive area. None of these lakes has been materially injured by existing water-control structures. The scenic values of Boulder Lake have been impaired by existing developments and would be suitable for further utilization.

Burnt Lake is one of the more notable and potentially valuable scenic and recreational assets of the district and it would be unfortunate, from the standpoint of such assets, to alter the natural lake level at all. It is a fortunate circumstance that, with the exception of Boulder Lake, the excellent natural resources of the western slope of the Wind River Range have been relatively little exploited. Ultimately, the region's scenic resources, if so managed as not to be impaired or expended, will prove to be one of its greatest and most lasting economic assets.

Agencies and individuals interested in development of the district should consider the exceptional possibilities of improving access to Burnt, Half Moon, Fremont, Willow, New Fork, and Green River Lakes by a scenic route or parkway lying east of the present U S 87. This road should lie near the eastern brow of ridges to take advantage of excellent panoramic views of the Wind River Range and their foreground of irrigated valleys and benches.

In the Yampa River drainage 11 sites are listed. Seven of these, have been investigated and it was found that none of them has scenic or recreational attributes of sufficient importance to require special protection or preservation, nor would the proposed reservoirs have any major recreational values. If conditions are found suitable for stocking and maintenance of fishlife, fishing would be of value locally in the case of Juniper Reservoir. Archeological reconnaissance of a portion of the Juniper Reservoir site has disclosed a number of Indian camp sites and a more complete survey of the area should be made before the dam is constructed. The other seven sites should be investigated but their recreational value is doubtful as present plans do not include any dead storage. Four are in or near national forests.

There are 11 potential irrigation reservoir sites listed for the *Uinta Basin* area. The majority of the sites are of little recreational importance with respect to scenic qualities, existing or potential. Most of them are in sagebrush or ranching lands of no great distinction. Such values as might be created would in general be of only local benefit and would result from the development of fishing if found practical and from the interest of any body of water in a semidesert landscape. The proximity of the Duchesne and Ashley Valleys to the excellent lakes and streams of the Uinta Mountains lessens the need to use the reservoir sites for recreation. Yet, it may be desirable to provide for local day use of the reservoirs near Vernal, Roosevelt, and Duchesne. In such cases the Bureau should provide for public access to the water but facilities should be furnished by local agencies.

The Hades Reservoir site within the Wasatch National Forest could be recreationally useful if planned with good conservation pools and good fishing maintained, but in view of the superior attractions of natural lakes at higher elevations, the recreational need at this site is limited. The Forest Service is the agency which should determine the extent of recreational development at this reservoir. Strawberry Reservoir enlargement is of potential recreational value to the people of the Provo Salt Lake region.

The four reservoir sites in the upper part of the Price River drainage, and the two sites on Cottonwood Creek near Castle Dale, Utah, have not been investigated as yet, but their potential recreational value is limited by the fact that only two, Mammoth and Joes Valley Dams would have a dead-storage pool. These two are located in the Manti National Forest at fairly high elevations and with proper planning should be of recreational value to the residents of the nearby valleys. This is particularly true of the Joes Valley Reservoir which would serve the residents of the semidesert Castle Dale area.

Grand division.—Of the 31 potential reservoir sites for irrigation development within the Colorado River Basin listed in the plan, the McPhee site has the greatest potential recreational value on the basis of our present information. It would have a minimum water surface of 1,530 acres at dead-storage elevation, as compared to the next two largest, Vega and Spring Creek Reservoir sites, which would each have a dead-storage pool of 90 acres. The plan of operation for all of the reservoirs calls for the maximum draw-down in September, which is not particularly favorable for recreational use during the vacation months of July and August, and the large draw-down contemplated each year would in all probability be unfavorable to fish culture. Of the 23 sites for which minimum water storage figures are available, 12 would have a minimum water surface of less than 10 acres.

Fourmile, Rifle Gap, Haystack, Vega, Spring Creek, Eggleston, Lake Brennan, Banana Ranch, and McDonough sites are in or near national forests and available data indicate they may be of potential recreational value.

The McPhee Reservoir site is in the beautiful Dolores River Valley, a short distance downstream from the town of Dolores, Colo. The natural conditions are ideal for creating an artificial lake of considerable beauty and recreational value. Fishing is good in the upper sections of the Dolores River and should be good in the reservoir. This section of the Dolores Valley is now used for picnicking, camping and fishing, and with the reservoir these uses should increase. There were 12,421 people living within easy access of the site in 1940. It is recommended that plans for development of the area include acquisition of all the shore land and the provision of recreational facilities for public enjoyment of the reservoir including boat docks, swimming beach, picnic areas, camping areas, and the relocation of the present road through the reservoir to maintain the scenic drive down the Dolores Valley. Part of the reservoir will be in the Montezuma National Forest and the Forest Service should have a hand in planning the recreational development and use.

A number of reservoirs, tunnels, and canals are planned in connection with water export projects. The majority of the projects involved would be located in high mountain country in National Forests of considerable scenic and recreational value. It is possible that some of the reservoirs would have potential recreational value. It is also likely that some scenic and recreational values would be lost. A study of this phase of the project should be made.

San Juan division.—O'Neal Park Reservoir site is in the scenic mountain country of the San Juan National Forest about 13 miles northwest of Pagosa Springs, Colo. With a minimum water surface of 1,144 acres at dead-storage elevation and an area of 1,609 acres at spillway elevation with fluctuation only 10 feet, this reservoir should have considerable recreational value.

The Teft site on the Animas River and the Hermosa Park site on the Hermosa Creek north of Durango, Colo., are also in the scenic San Juan National Forest where hunting and fishing are important recreational activities. Present plans for these reservoirs do not include a conservation pool (dead storage) without which their potential value for recreation is questionable. Further study may show that the reservoirs can be made to serve the irrigation needs and at the same time add to the attractions of this excellent recreational region.

The Lemon Reservoir site on Florida River is 15 miles northeast of Durango and 5 miles west of the Vallecito Reservoir on Los Pinos River. The plan calls for a 53-foot dam with a reservoir area at spillway elevation of 487 acres. There would be no conservation pool. In that section the Florida River is a clear fast-flowing mountain stream running through a pleasant mountain valley bordered on three sides by the San Juan National Forest. From the recreational viewpoint the impounding of the river at the proposed site would destroy much that is most attractive in a mountain stream landscape. And there is no recreational need for still water in this location since the Vallecito Reservoir can better provide this type of recreation. If there is no conservation pool, as planned, the reservoir will have little or no recreational value.

The State line dam site is located 1 mile south of the Colorado-New Mexico line, 20 miles north of Farmington, N. Mex. Although the potential recreational value of the reservoir is not great, it would provide water recreation for the local residents. Opportunity should be given for the establishment of a public beach, fishing piers, and picnic grounds at some suitable location along the shore. It is reported that there are pueblo ruins in the vicinity of the dam site. If relocation of the dam is not possible, a thorough investigation and excavation of the ruins should be undertaken before construction of the dam is started.

The potential Long Hollow Reservoir, 10 miles southwest of Durango with a 103-acre dead-storage pool and 446-acre pool at spillway level, may have some recreational value, but the planned 50-foot draw-down will detract from the scenic quality of the area and the fishermen in the Durango region will probably prefer the lakes and mountain streams in the San Juan National Forest to the north.

We are not yet sufficiently familiar with the Arboles Dam site on the San Juan and the Meadows and Monument sites in the Southern Ute Indian Reservation to comment on their recreational values. They are, however, in an area rich in archeology, and surveys of the reservoir areas should be made prior to construction of the dams.

Between Bluff, Utah, and the mouth of the San Juan River the plan lists four power dam sites. At the Bluff site, 13 miles downstream from the town there would be a 340-foot dam for power and silt control. Twenty-four miles farther down in the Goosenecks of the San Juan would be a 177-foot power dam. The Slick Horn Dam about 25 miles below would raise the water 208 feet and a 265-foot power dam at the Great Bend, 30 miles above the mouth of the San Juan, would back water to the foot of the Slick Horn Dam. Although these dam and reservoir sites on the San Juan have not been investigated so far by the survey being made by this Service, it is certain they would have adverse effects on the scenic values of this impressive section of the San Juan and that they would flood a number of sites of archeological importance. At the same time the potential recreational value would be limited.

Little Colorado division.—In the Little Colorado River Basin there are five potential reservoir sites which have potential recreational values. The Forks Dam on the Little Colorado near the town of Woodruff, Ariz., would create a water area of 3,600 acres at dead-storage elevation and 5,000 acres at spillway level, with an average water surface of 4,300 acres. A water area of that size which would have a maximum fluctuation of only 10 feet is certain to be of recreational value, even though it is in comparatively uninteresting open, grassland country. It will be used by the people in the vicinity, and attract some attention from travelers using U S 66, U S 260, and State Highway 77, as it is located only 13 miles southeast of Holbrook, Ariz., and 20 miles by existing roads from the south entrance of Petrified Forest National Monument. Holbrook had a population of 1,184 in 1940, and that same year 199,420 people visited Petrified Forest National Monument. It is possible that 8 percent or about 16,000 might visit this reservoir. Plans for the reservoir should provide for a protective strip of land around the entire reservoir and a suitable area for public recreational use where facilities for picnicking, camping, swimming, and boating may be provided. It is likely that the reservoir would be attractive to waterfowl and other wildlife of the region.

The next largest reservoir area planned is on Black Creek in the Navajo Indian Reservation, just west of the Arizona-New Mexico State line. While this reservoir is for irrigation and may be drawn down 48 feet, from a spillway elevation covering 1,900 acres to dead-storage area of only 110 acres, the average water area would be 1,000 acres. If conditions are favorable for fish life it should attract fishermen from Gallup, and also be of recreational value to the Indians on the reservation.

Plans for the Shumway Dam, located just south of the town by the same name at the edge of Sitgreaves National Forest, include a reservoir area of 540 acres at spillway elevation, and a dead-storage pool of 185 acres. It should be of considerable recreational value as it is in an area already popular for fishing, hunting, and summer vacations, and will be easily accessible from U S 60 and State Highway 77.

The Willow Creek Dam site is in Clear Creek Canyon, a couple of miles below the mouth of Leonard Canyon, about 35 miles southwest of Winslow. The reservoir would have an average water surface of 340 acres, an area of 570 acres at spillway level, and a possible draw-down of 55 feet from spillway level to dead storage. Being in the Sitgreaves National Forest at an elevation of 6,100 feet, the reservoir should be of recreational value to Winslow, population of 4,577 in 1940. Fishing will be the main attraction and provisions should be made for public access to the shore, and facilities for picnicking, camping, and fishing, in cooperation with the Forest Service.

Wild Cat Dam site is also in the Sitgreaves National Forest on Chevelon Creek, about 27 miles due south of Winslow. The reservoir would be slightly larger than Willow Creek Reservoir, and the average draw-down would be 10 feet less. It will, therefore, compete with Willow Reservoir. However, if good fishing is available at both reservoirs it would stimulate interest in the sport, and increase the number of visitors at both reservoirs.

The sections of the Little Colorado River Basin in which the five reservoir sites are located are known to contain pueblo ruins and other archeological sites of importance. Archeological surveys of each of the five reservoir sites should be made before construction of the dams is started.

Gila division.—Down on the Hassayampa River, 6 miles from Wickenburg, called the "Dude Ranch Capital," is the Box Canyon Dam site. This dam planned for irrigation and flood control would have an average water surface of 2,000 acres, but might on occasion be drawn down 90 feet to dead storage, leaving only a 440-acre lake. At spillway level 36 feet above the average, the surface area would be 2,900 acres. Located in the desert just below the rim of high country this reservoir should receive considerable recreational use by winter visitors and some year-around use by the people living in the irrigated districts west of Phoenix. The dam is 60 miles from Phoenix, and 68 miles from Prescott, via U S 89, the main north-south highway through Arizona. U S 60 and 70 join U S 89 at Wickenburg. The annual average 24-hour travel on U S 89 south of Wickenburg in 1940 was about 1,600 vehicles.

Boulder division.—In the Joshua tree country northwest of Wickenburg near Alamo is a site for a water control dam on the Williams River. Present plans indicate the reservoir would have a dead-storage pool covering 2,800 acres, while at average water-storage level the water would be 105 feet higher and cover 9,500 acres. At spillway level 11,950 acres would be flooded. Located 37 miles west of U S 89, and 32 miles north of U S 60 and 70 in sparsely populated desert country the recreational use will probably be limited to hunters and fishermen.

Virgin division.—From the recreational viewpoint the most important reservoir site in this basin is the one on the Virgin River near Virgin City, Utah. Here it is proposed to create an irrigation reservoir which will have a dead-storage pool 236 feet deep at the dam site with a surface area of 2,300 acres, while at water-storage elevation 12 feet higher there would be a 2,700-acre lake. The total reservoir area would include about 3,800 acres and the maximum fluctuation of water-level would be 32 feet. Located in the Virgin River Valley near Zion National Park this reservoir would have considerable recreational value. In 1941, 190,016 people visited Zion National Park and probably most of these people passed by the reservoir site. It is expected that the number of visitors will increase as the scenic beauty of this section of Utah becomes more widely known. Many of these visitors will use the reservoir area for picnicking, camping, swimming, fishing and boating. It is particularly important that sufficient land be acquired around this reservoir to provide ample public recreational lands and to protect the scenery. State Highway 15 will be relocated above high warterline along the north side of the reservoir. The recreational value of this section of the highway and the reservoir would be greatly increased if all the land between the road and the water were made available for public recreational use.

The Lower Gunlock Dam Site is on the Santa Clara River. Primarily for irrigation, the reservoir with a dead-storage pool of 100 acres and an average water-storage pool of 250 acres would be suitable for swimming, fishing, and boating and such recreational activities should be attractive to the people in that locality where the summers are long and warm.

The Delmue Dam on Spring Creek, although primarily for an irrigation and silt control reservoir, would be of some recreational value to the 2,682 people living in the nearby towns of Pioche and Caliente, Nev. The plan calls for an average water-storage pool of 1,000 acres, and a dead-storage pool 32 feet lower, covering 600 acres. Provision should be made for picnicking, swimming, boating and fishing.

Summary of potential recreational projects and estimated annual benefits of potential reservoirs in the Colorado River Basin

Site	Estimated construction cost of recreational facilities	Annual estimated benefits
Green division:		
Fontenelle	$17,000	$3,110
Big Basin		1,120
Flaming Gorge	41,000	9,093
Red Canyon		2,903
Columbus Mountain	9,000	2,325
Juniper	13,000	4,771
Lily Park	8,250	4,718
Pelican Lake	18,600	2,232
Starvation	25,000	8,160
Mammoth	24,500	6,461
Joes Valley	28,900	8,658
Desolation	18,700	7,430
Rattlesnake	19,000	7,430
Grand division:		
Red Mountain	19,000	6,960
Barbers Basin	15,400	7,515
Missouri Heights	15,000	5,540
Rifle Gap	22,500	9,113
Haystack	9,000	3,963
Owens Creek	6,000	1,982
Vega	6,000	1,190
Almont	7,000	2,542
Castle Creek	4,000	2,330
Tomichi	17,700	7,418
Banana Ranch	5,700	2,227
Sapinero	46,000	16,370
Spring Creek	15,400	4,980
Gorsuch	17,000	5,385
McPhee	70,000	10,080
Dewey	55,500	13,975
Glen Canyon	228,800	111,757
San Juan division:		
O'Neal Park	30,800	9,290
Arboles	23,850	7,206
Long Hollow	4,000	1,316
State Line	28,000	5,585
Monument Rocks		554
Ironton Park	13,405	5,422
Howardsville	4,500	2,646
Recapture	11,250	1,780
Mill Meadows	16,500	7,312
Torrey	6,000	1,700
Escalante	6,000	1,300
Little Colorado division:		
Shumway	13,700	1,400
Forks	34,600	6,880
Willow Creek	18,000	4,040
Wild Cat		2,800
Virgin division:		
Delmue	28,000	2,680
Virgin City	210,000	37,128
Lower Gunlock	6,000	261
Boulder division:		
Marble Canyon	38,500	12,760
Bridge Canyon	581,000	277,370
Davis	160,600	40,465
Gila division:		
Buttes	19,100	5,075
Box	157,000	24,666

A number of potential reservoirs have been omitted from the summary for one of the following reasons: (*a*) there is not sufficient information available at present to make an estimate of the potential recreational value; (*b*) present information indicates that the reservoir may be empty sometime during the year, or have so large a fluctuation as to make it undesirable for recreational use; (*c*) the existing recreational values of the reservoir area or the immediate vicinity are such that there would be a loss of recreational values or the potential recreational values of the reservoir would only compensate for the losses.

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Method Used in Evaluating Recreational Benefits of Potential Reservoirs

The method of analysis and evaluation of recreational benefits used intends to show only that if the reservoirs are formed and the conditions are suitable for fishing and other recreational uses, the recreational benefits inherent in them will be worth so much in terms of dollar value. Recreational values or benefits are, in general nonvendible; something upon which a monetary scale cannot be used. There are, however, through experience, observation and knowledge and by comparison with similar existing areas certain factors which can be appraised.

The recreational benefits have been based on the estimated attendance. The annual attendance was determined by calculating the percent of total population within 50-mile radius by existing roads that might be expected to use the area, and the number of visitors that might be expected from beyond the 50-mile radius. The percent of local population varies with the accessibility of the reservoir, the recreational values of the area, the appeal or drawing power of the area as compared with other or similar recreational features in the region and the percentage of urban population within the 50-mile radius. The following factors were considered in estimating the number of visitors from beyond the 50-mile radius: nearness of area to major highways and volume of traffic on such highways; general recognition of the recreational resources of the region; and the appeal or drawing power of the dam and reservoir as compared with other or similar recreational features in the region. In the Colorado River Basin the density of population, the recreational resources, the volume of tourist travel, and the vacation use vary to such an extent that it is not possible to use constant percentages. For example, no local attendance can be figured for Glen Canyon Reservoir. The estimated annual attendance was assumed to be 20 percent of the travel on U S 89 at Navajo Bridge, a few miles downstream from the dam site. At the other extreme is Shumway Reservoir where it is estimated that approximately 100 percent of the total attendance will be local.

Having determined the estimated annual attendance, the recreational benefits were obtained by using four factors:

(1) *Travel value.*—Travel values representing an amount that it will cost the visitor to travel to and from the area and a portion of an amount he is willing to pay for his recreation. It is assumed that it costs an average

of 5 cents per mile to operate an automobile, and that the local attendance will come by auto and truck, bring the average to five persons per automobile. At 5 cents per mile the travel value per visitor is then 1 cent per mile times the average travel distance to and from the reservoir. Travel value for the portion of the attendance other than local was included in per diem value, because it is impossible to determine how far they traveled or the percentage of their travel that can be definitely assigned to the particular area. In the case of Bridge Canyon, Marble Gorge and Glen Canyon Dams, however, a travel value was included to cover round-trip distance from major highways traveled by the portion of the visitors who would spend only a few hours at the dam.

(2) *Per diem value.*—Information gathered by the Colorado Highway Planning Survey shows the average out-of-state tourist party, staying at cottage camps, to consist of 3.6 persons spending $12.25 or $3.41 per person per day. On this basis a figure of $3.40 was used in estimating the expenditures of visitors from beyond the 50-mile radius, assuming in all cases that these visitors would spend an average of one day at or near the reservoir, directly chargeable to the area. In a number of cases local visitors may be expected to stay over night in the area and tourists may spend several days. However, no per diem figure has been used for local visitors and only one day per diem is applied to other visitors.

(3) *Recreational value to visitors.*—Being in an area and enjoying its features and opportunities, whether he spends money or not, is worth something to a visitor. To estimate this benefit, a direct hypothetical value of 10 cents per visitor has been used. This is the amount actually charged for admission to the State parks in several States, notably Indiana. The 10-cent figure is a conservative estimate. It should not be assumed that by using such an arbitrary value, that an entrance fee is advocated.

(4) *General value.*—It was not possible at this time to determine the specific factors for evaluating the benefits to the communities through which the visitors travel and to the concessioner within the area.

For this report the value to the communities and the concessioner has been estimated as 20 percent of the travel value and the per diem value. This represents a gross profit to business. While the net may be only 10 percent, the labor, capital, and related business activities involved in sales will benefit at least 10 percent, therefore, the 20 percent total seems reasonable.

Cost of Recreation Projects

The facilities for recreational use and the costs therefore have been estimated from experience and by comparison with existing similar areas, giving consideration to the recreational opportunities available in the area and facilities deserved by the visitors.

Only by a comprehensive survey, study and planning can a more accurate estimate be made of facilities needed. It is believed that the estimated project costs will be sufficient to provide adequate development for the estimated number of potential visitors.

Annual operation and maintenance of the recreational facilities is estimated to average about 10 percent of the cost of the facilities.

FISH AND WILDLIFE SERVICE

The Colorado River Basin comprising 13 percent of the land area of the United States with a population of only four persons per square mile (or one-tenth of the national average) constitutes one of the chief recreation and primitive wildlife and fishing areas in the United States. The stream conditions vary from clear, cold, high, mountain streams to warm and often silt-laden waters at lower elevations. Because of this tremendous variety of habitat, conditions that apply in one part of the basin may not apply in another. By proper preliminary planning it should be possible to safeguard and, in some cases, to increase the abundance of both fish and wildlife.

The report touches upon 114 potential reservoirs for the Upper Basin (above Lee Ferry, Ariz.), including 26 projects that would serve for power production. There are 25 proposed reservoirs in the Lower Basin. Because of their large number and diversity these projects cannot be treated individually in this report but their main aspects will have to be considered, leaving the details to be worked out later for each individual project through actual field surveys. The Fish and Wildlife Service has made stream and lake surveys within the boundaries of six national forests and two Indian reservations in the basin.

Upper Colorado Basin

Evaluation of resources affected by the project.—The tributaries of the Green River division in the upper basin originate in high mountains. The streams are clear and cold.

The principal headwaters of Green River lie in the western slope of the Wind River range of mountains in Wyoming. Lakes at the origin of many of these streams have a variety of trout, principally cutthroat and mackinaw. In the upper reaches of the streams, the cutthroat trout is the most abundant species, being replaced by the rainbow trout at lower levels. Brook and brown trout are present, but not numerous. A fairly abundant form, which is becoming increasingly popular, is Williamson's whitefish. Below the city of Green River, Wyo., trout fishing becomes less and less important, and in the main stream within Utah the only species of importance is the channel catfish. The California golden trout has been planted in a few of the high streams.

In the Grand division, the headwaters of the Colorado River and its principal tributaries in Colorado have cutthroat and brook trout as the main species, but at lower levels, the rainbow trout is most numerous. Brown trout are abundant in several places, notably the Gunnison River. Some miles east of the city of Grand Junction, channel catfish replace trout and become the important species thence down stream in the main river. Largemouth black bass are present also. Few fish of value are found in the reaches above and below Moab, Utah.

In the San Juan division, the upper reaches of the eastward-flowing tributaries of the Colorado River in southern Utah contain the usual forms of trout in some abundance. The main stream in this area is practically inaccessible, for no roads cross it. Its value as a fishing stream may be discounted for the present. The San Juan River and tributaries provide a satisfactory general trout habitat at the higher elevations and channel catfish habitat in the lower reaches.

Unquestionably that portion of the western slope of the Continental Divide falling within the Upper Colorado River Basin constitutes one of the greatest hunting areas in continental United States. Deer abound through most of the drainage basin and elk are numerous at the higher elevations. Moose occur in the wilderness areas of the upper reaches of the Green River and several large herds of mountain sheep are found in Colorado.

Upland game birds include several species of grouse, particularly sage grouse, which are fairly numerous along the Yampa River and the Duchesne River in Utah. Ptarmigan are found in the high mountain country of Colorado and wild turkey still exist in the upper reaches of the San Juan River of New Mexico and Colorado.

Present waterfowl habitat is rather limited, but the Colorado River is a strategic migration route and appreciable acreages of marshlands exist along the headwaters in Wyoming particularly in the vicinity of Daniel. The importance of preserving the relatively limited acreage of marshland in that part of a major waterfowl flyway is of utmost importance in the preservation of a natural resource. As conditions now are, the small acreage of such food and cover habitat is a factor in limiting the use of the flyway by waterfowl. Without such habitat, rest areas supplied by irrigation reservoirs may be of little value.

Fur bearers, with the possible exception of beaver, are of secondary importance in the basin and it is thought that the proposed reservoirs will have little effect upon them.

Effects of the projects.—In the upper tributaries fish maintenance depends to a large extent upon an ample supply of cold water and protection of the fish from being drawn into major water diversions. In the Green River below the town of Green River, Wyo., and in the Colorado River below Grand Junction, Colo., and in the San Juan below the Colorado-Utah line, the streams become silt-laden and gravel bottoms are generally replaced by sand and mud and the riffles become less numerous. This reduces the value of these portions of the streams for fish.

On these trout streams of the upper basin, it is important that the methods of operation be fully studied in the early planning stage of each project to insure that provision is made to release sufficient water from all impoundments to safeguard stream conditions adequately. In most of the reservoirs on the warmer portions of the streams, it may be advantageous to withdraw water from the lower levels of the reservoirs in order to provide cold waters.

The project plans as at present outlined do not contain sufficient data to be able to judge the effect of the individual projects so that no comment can be made at this time on the adequacy of the conservation pools or the effect of the method of operation. Reservoirs for irrigation usually contain a certain amount of dead storage for silt deposition. Even in the clear upper waters it is important that the wildlife conservation pools be made a feature of all reservoirs so that fish will not be destroyed by excessive draw downs.

Stream surveys made in previous years by the Fish and Wildlife Service showed that a great many of the existing irrigation reservoirs are either drained completely or so reduced in volume during the late summer that they are worthless for fish production. Even in cases where a conservation pool was present the extreme fluctuations in water level prohibited the growth of plant food and made the reservoirs unsuitable for fish spawning. This condition can be ameliorated both by provision for a larger wildlife conservation pool and by subimpoundments to provide permanent areas with a stable water level.

The projects outlined in the report call for a number of diversions of water from the Colorado into other basins. The exact effect of such diversions cannot be determined without specific studies but if these usually result in a great reduction in the volume of stream flow, those proposed will undoubtedly be harmful to fish and wildlife because of habitat destruction. It is possible that this may be partly compensated for by the provision of large stable level reservoirs at the points of water diversions. Such reservoirs, if they have their diversions properly screened and provisions are made for stocking, may provide fishing to some degree, but the danger exists that natural balances between tributaries, riffles, pools and other habitat factors will be so disturbed as to offset in part the advantages gained by these diversional reservoirs. As most of these diversions are at high elevation, they should be suitable for cold-water species of game fish but it is doubtful that these storage reservoirs will contain sufficient direct tributary streams to provide sufficient spawning areas. Therefore, it may be necessary to provide increased hatchery facilities.

The value of these reservoirs for recreation and fishing should be protected by providing public access, and in most cases setting aside land for public use.

On the Colorado River it is not necessary to provide fishways for anadromous fish and most of the resident fish are nonmigratory except for short migrations to obtain favorable spawning conditions. Therefore, there will be but few dams if any which will require fishways. Where water is being diverted for irrigation, it may be necessary to screen many of these diversions but this will be a matter requiring study of the conditions at each specific point.

Pollution of the Upper Colorado River as a whole is negligible at present. Wastes from mines, mills, and smelters, however, threaten to create or are creating pollution problems in the vicinity of Rock Springs, Wyo., and Price, Utah. When pollutants are permitted to enter a reservoir, they have a chance to accumulate and their effect can be serious. Therefore, steps should be taken to remove or greatly to alleviate these conditions before a project is constructed below a source of major pollution.

The projects in the upper basin that are not designed for transmountain diversion will in many cases be used to provide storage to refill reservoirs many miles downstream. Certain of these reservoirs will also be utilized for power production. In both of these cases it should be possible to work out a schedule of operation that will provide for a minimum continuous release of water to maintain fishing. This will in many cases well compensate for the flooding out and the destruction of a great many miles of trout water and will be especially helpful on many streams that tend to be intermittent during the summer months over their lower courses.

Insufficient data on stream mileages involved and on the proposed reservoirs and their operation are available to the Fish and Wildlife Service on which to compute wildlife values. For 10 of the power reservoirs it is possible to evaluate migratory waterfowl values gained, but it is impossible to compute damages until the amount of natural habitat destroyed is known. Any silt reduction will result in benefit to wildlife as well as fish, depending primarily upon the management of silt deposition. The methods of reservoir operation, therefore, will be the determining factors in mitigation of damages and possible creation of benefits.

Lower Colorado Basin

Evaluation of resources affected by the project.—In the four divisions of the lower basin the cold-water fish are confined almost wholly to the higher elevations in the Virgin, Little Colorado, and Gila divisions. In the Boulder division a beautiful trout stream has been created immediately below Boulder Dam by drawing off cold, clear water from the depths of the reservoir and stocking this portion of the river with rainbow trout.

In the lower divisions of the Colorado the main Colorado River flows largely through a deep canyon and receives water chiefly from a few principal rivers that are sufficiently large to flow throughout the year. It also receives flood waters of many intermittent streams. Trout are found only at the higher elevations. Rainbow and brown trout are the chief species. After these streams flow out of the mountains, they contain catfish, bass, sunfish, crappies, channel catfish, and bonytails. A great many of these streams sink into the desert and disappear along their lower reaches. Surveys made of many of these headwater streams, having heavy fishing pressure, show them to have considerable recreational value.

In the Boulder division a rather complete survey of the river from the Nevada-California line to the Gulf of Mexico has been made by the California Division of Fish and Game. This lower section of the Colorado is characterized by warm, silty water fluctuating considerably in volume with a shifting bottom. It is very deficient in fish food due to the high turbidity, the unstable bottom, and the fluctuations in level. Fishes are not abundant except in backwaters, the small temporary lakes that are formed behind the shifting sand bars of the channel in the reservoirs, and in the main irrigation canals. The chief fishes at present are introduced varieties, most of the native fishes apparently suffered from the man-made changes in the river and are no longer abundant.

Largemouth bass, carp, catfish, and bluegill sunfish are the most abundant species in the reservoirs of the main river. Mullet are abundant as far upstream as Imperial Dam. Trout are not ordinarily found in the main river except for the stretch of from 20 to 30 miles of cold, clear water that is drawn off from the deeper portions of Boulder Dam. The main irrigation canals in the lower portions of the basin are ordinarily filled with water throughout the year and contain large numbers of fish wherever the current is not too swift. The main power reservoirs that are proposed for almost the total length of the Colorado River will flood several hundred miles of the main stream. The degree of turbidity of the water in the main Colorado River is so great due to the tremendous loads of silt carried that it is quite unproductive of fish foods. The shifting bottom also smothers food organisms. Therefore, it is felt that the desilting of the river and the formation of these tremendous lakes will undoubtedly add considerably to the fishery values of the main river.

When the upper basin reaches its ultimate development there is some possibility that the fisheries in the lower basin may suffer from the excess quantities of alkali that will be leached out of the irrigated land and returned through drains into the river. When Davis Dam is completed it will flood the trout waters below Boulder Dam and destroy this fishery. It will have some beneficial effect, however, in reducing the silt carried into Havasu Lake.

In the Lower Colorado River basin there are 10 national wildlife refuges located in Arizona, Nevada, and California. These are for the preservation of bighorn sheep, mule deer, antelope, peccary, upland game birds, and waterfowl. A major portion of the lands within the lower basin is under Federal administration. It is on such areas, administered primarily by other agencies that the national wildlife refuges have been established and are being maintained in line with the policy of providing multiple use of each project so far as is consistent with its primary purpose. Such secondary use of areas is not so productive of results as would be the case under primary control, but these do make possible a substantial contribution to wildlife conservation. This is particularly true of rare and important forms whose range and habitats are restricted. Their continued preservation, therefore, will be dependent upon the multiple use of areas along the lower Colorado where suitable habitat and water may be provided. Likewise it is imperative that desirable habitat for waterfowl be maintained in the lower Colorado where two major continental flyways converge.

Means for mitigating losses and deriving maximum benefits.—The existing and potential wildlife resources of the Lower Colorado River Basin are well known, and in any coordinated development of the basin appropriate recognition should be given these assets.

The Fish and Wildlife Service, as indicated in the report, has established 10 wildlife refuges and 1 trout fish hatchery within the basin and recognizes the opportunities for further, needed development that is presented through the Bureau of Reclamation reservoir program. Agriculture and hydroelectrical projects are being benefited primarily by such development, but in many areas, including some of the arid and semiarid regions where conditions do not lend themselves to agriculture or other economic interests, wildlife, and recreational development offers much to the future of the states and communities concerned.

The importance of development requires that a detailed survey of the project areas be made and refuges established where location, reservoir operation, and physical features will serve to promote development of habitat for wildlife. Where conditions do lend themselves to such development, the Bureau of Reclamation should make every possible effort to operate the reservoirs with full consideration of the wildlife interests. Such operation would include limiting the minimum draw-down to an elevation that would provide a pool of sufficient depth and area to sustain fish life.

Where the operation of a reservoir requires maximum draw-down to the detriment of wildlife or its habitat, consideration should be given to construction of underwater or retaining dikes or upstream development to preserve aquatic food plants for waterfowl. Proper development of waterfowl areas will influence an increased use of this flyway and add materially to the over-all value of the Bureau of Reclamation reservoir program.

The fish-stocking demands in the area are increasing each year, and it will be necessary to construct additional facilities to meet this added demand. A modern combination trout-bass fishery station should be constructed for this purpose near Page Springs in Oak Creek Canyon about 40 miles south of Flagstaff, Ariz. The cost of such a plant would be about $105,000. In addition, it will be necessary further to develop the Williams Creek Station for the incubation of trout eggs because of the Page Spring water being too warm for incubation but ideal for rearing rainbow trout fry and fingerlings. The rainbow eggs would then be processed at the Williams Creek Hatchery and moved to the Page Spring station in the advanced fry stage. The Williams Creek development will involve one additional fish culturist and need for approximately $20,000 for expansion of the facilities.

It is desirable that, where required, fish screens of a type acceptable to the Fish and Wildlife Service be installed in the "turn-out" structures.

Recommendations

It is recommended that:

1. All reservoirs provide suitable dead storage capacity to meet the requirements for protection of fish and wildlife; such capacities to be advocated upon the basis of the surveys to be made in compliance with recommendation 12 hereinafter.
2. Release of water from all impoundages be sufficient to safeguard adequately or improve fishing conditions in streams below reservoirs through stabilized flows. To determine the minimum adequate amounts to meet fish and wildlife needs detailed surveys will be required.
3. In respect to all reservoirs, operation of the gates shall be at such rates as will give adequate protection to fish and wildlife as shown by detailed surveys to be made hereafter.
4. Diversions, where necessary, be adequately screened for fish protection.
5. Plans for each headwater reservoir be presented to the Fish and Wildlife Service for study prior to construction in order to permit determination of advisability of incorporating therein provision for fish ladders or similar devices to facilitate natural spawning.

6. Where reservoirs are to be established on streams subject to mine tailings, oil, industrial, sawmill wastes, and other forms of pollution, provisions be made to remove the hazard.

7. Engineering studies be conducted to determine the feasibility of sill dyking to provide as extensively as possible shallow lateral pools with stable water-spawning and rearing areas for fish and feeding and resting areas for wildlife.

8. Studies be made of all reservoirs to determine those, if any, which should be designated as wildlife refuge and management areas.

9. Adequate facilities be provided at each reservoir for access by the public for appropriate fishing, hunting, and other forms of recreation.

10. Engineering plans of all reservoirs provide for outlet facilities so constructed as to release water from as close to the bottom of the reservoir as is practicable.

11. Hatchery facilities be provided for such increased stocking as may be required for new reservoir construction to satisfy fishing demands. This should include doubling the present capacity of the Fish Cultural Station at Springville, Utah, for the production of legal-sized trout. It is estimated that the cost of the latter will be about $56,200. In addition, a modern combination trout-bass fisheries station should be constructed near Page Springs in Oak Creek Canyon about 40 miles south of Flagstaff, Ariz., at a cost of approximately $105,000. To supplement the facilities of this new hatchery the Williams Station should be further developed for the necessary incubation of trout eggs not possible at Page Springs, at a cost of about $20,000.

12. An allotment be established to provide for surveying the proposed reservoirs within the basin to determine their possible effects on fish and wildlife so as to mitigate damages and to increase benefits. Such a task is beyond the present personnel and appropriation limits of the Fish and Wildlife Service. To make the essential field surveys the estimated costs for the fiscal year 1946 are $132,000 for personnel and expenses.

GRAZING SERVICE

Objectives and Functions of the Grazing Service

Under the Taylor Grazing Act of June 28, 1934, as amended, the Secretary of the Interior is authorized to established grazing districts from the public domain (exclusive of Alaska) including not to exceed 142,000,000 acres of vacant, unreserved, and unappropriated public land. The primary objectives of this act are: (1) to stop injury to the public grazing lands by preventing overgrazing and soil deterioration; (2) to provide for their orderly use, improvement, and development; and (3) to stabilize the livestock industry dependent upon the public range.

The Grazing Service is the designated agency responsible for the administration of grazing districts. Operating on a decentralized plan, it is headed by the Director of Grazing, who is responsible for the conduct of policies and programs approved by the Secretary of the Interior. The Director's immediate staff consists of an assistant director, a chief counsel, and the chiefs of four major functional branches: Operations, Range Management, Range Improvements, and Land Acquisition and Control. The assistant director, who also acts as liaison officer, is stationed in Washington, D. C. The Director's office is located in Salt Lake City. Ten regional headquarters, each in charge of a regional grazier, have been established within the States affected. As of June 30, 1944, there were 60 grazing districts organized and operating, each of which is in charge of a district grazier. In each district there is a district advisory board composed of from 5 to 12 stockmen and 1 wildlife member who advise with the district grazier and make recommendations on all matters pertaining to the internal affairs of the district they represent.

Grazing districts are composed of Federal, State, and private lands, with a gross acreage of 264,609,700 acres. The break-down of land ownership in the districts as of June 30, 1944, is as follows:

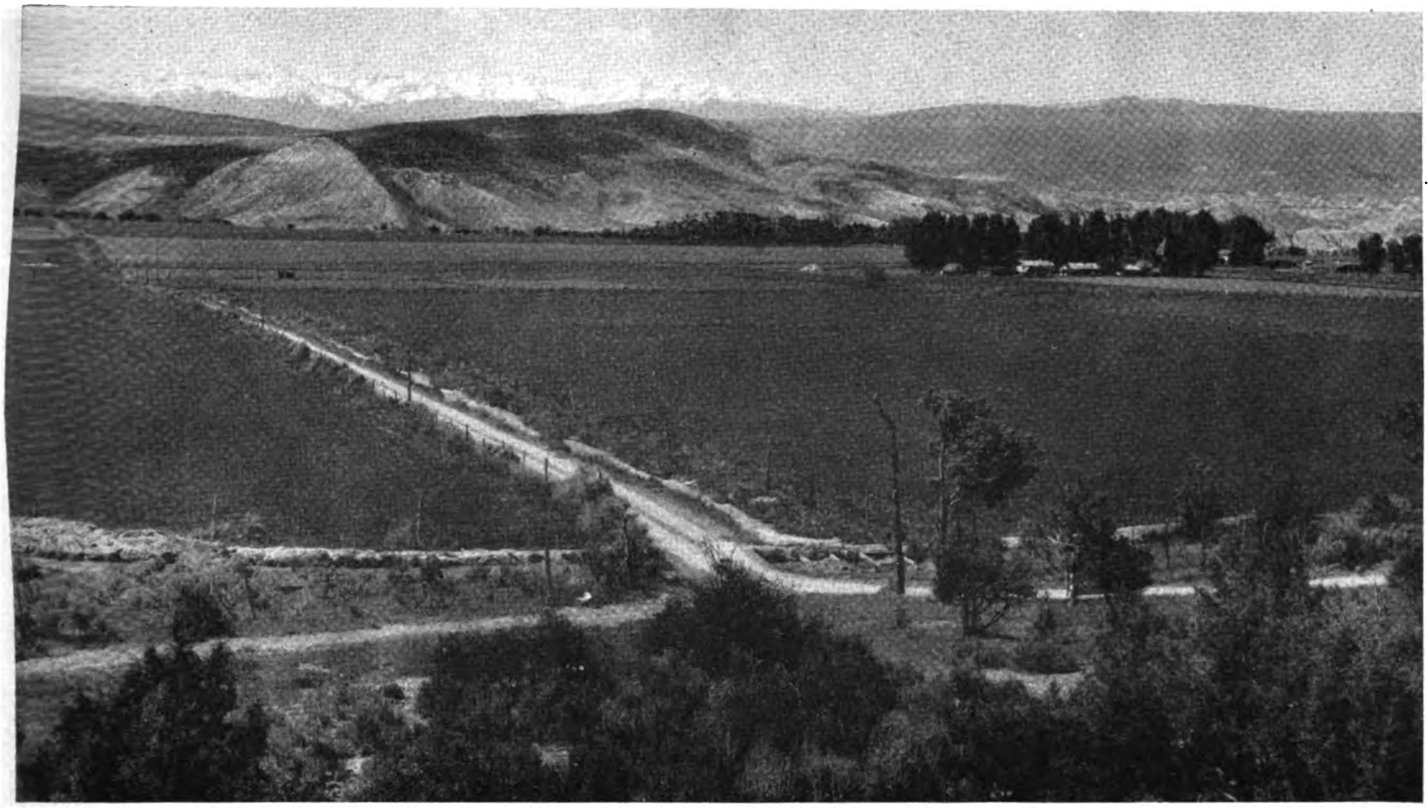
	Acres
Federal land withdrawn by establishment of grazing districts	132,281,035
Other Federal land	8,617,082
Total Federal land administered by the Grazing Service	[1] 140,898,117
Other land [2]	123,711,583
Gross area	264,609,700

[1] In addition, the Grazing Service administers 1,806,885 acres of non-Federal land within grazing districts in 6 States under leases authorized by the Pierce Act of June 23, 1938, and under cooperative agreement with the owners.

[2] Includes State, private, county, and certain withdrawn lands which the Grazing Service does not administer.

The long-time objectives of the Grazing Service are to protect, develop, and improve grazing-district lands through proper management for sustained yield and economic use; to coordinate this use with that of related lands; to cooperate fully with agencies and individuals having related interests and responsibilities; and to create and establish a practical range economy consistent with sound conservation and resource management principles.

Administration of the 60 grazing districts includes the protection and development of the natural resources and in particular the management and allocation of the use of range resources; the examination and classification of lands with respect to grazing or agricultural uses; and cooperation with agencies and individuals in the correlation of land use, development and improvement of the range resources, and in the prevention and suppression



IRRIGATED HAY FIELDS UNDER UNCOMPAHGRE PROJECT
Canal carries water that transforms desert (foreground) into hay land (background)

of range and timber fires. Grazing use is made of the approximately 142,000,000 acres of Federal range during a part of all of each year by upwards of 11,000,000 livestock owned by more than 22,000 permittees. This public range use is coordinated with that of private properties as an aid to the proper and economic year-round use of both public and private lands. Without the use of the public range the values of the dependent privately owned properties would decline sharply.

In line with the control and beneficial use of all the resources involved, the Grazing Service program includes watershed protection and other related activities of predominant public interest. The proposed reclamation program in the Colorado River Basin will no doubt enlarge the benefits to be derived from the grazing land administered by this Service. Regulated range use can be augmented by the proposed program and benefits will accrue not only to the livestock industry but to the entire Nation through a greater stabilization of livestock production, conservation of the land and its resources, reduced silting of irrigation works, clearer streams, and more uniform stream flow on the watersheds.

CATTLE ON MOUNTAIN RANGE
Range cattle depend upon irrigated pastures for supplemental feed

Grazing Districts in the Colorado River Basin

General

Twenty-six of the sixty grazing districts established under the Taylor Grazing Act of 1934, as amended, are located in whole or in part within the Colorado River Drainage Basin by States as follows: Arizona, 4; Colorado, 6; Nevada, 2; New Mexico, 4; Utah, 7; and Wyoming, 3.

The grazing-district area within the basin totals 74,405,000 acres, of which 52,648,000 acres (approximately the size of Utah) are federally owned. Of the remainder, 16,030,000 acres are privately owned and 5,727,000 acres belong to the States and counties affected. The total land area administered by the Grazing Service within the basin is 50,005,000 acres. In addition to their importance for grazing, these lands are an integral part of the entire watershed to which they are closely allied. Federal lands (withdrawn for various purposes) not administered by the Grazing Service total 2,657,000 acres.

The population density is less than 2.7 persons to the square mile totaling approximately 308,000 people (1940 census) in the 26 grazing districts.

Elevations range from a few feet above sea level in southwestern Arizona, affording a year-long growing season, to more than 8,000 feet in northern foothill or mountain areas, where only a 60- to 90-day growing season prevails. Rainfall ranges from less than 5 inches to more than 20 inches, with a great proportion of the area receiving less than 10 inches annually.

Vegetation types consist of creosote bush, bursage, and desert annuals on the southern deserts; desert saltbush types in the lower areas of Utah, Colorado, and Wyoming; and sagebrush, bunch grasses, mountain meadow, woodland, and timber at the higher elevations. Seasons of range use are from year-long in the southwest to a short spring-fall or summer season in higher altitudes. Large parts of the deserts of the upper basin are grazed principally during winter months because of scarcity of stock-water supplies for use in other seasons. Grazing capacities vary widely. As a rule the perennial forage is more plentiful in the northern districts and forage production is correspondingly higher as indicated by the permitted use.

Grazing Use

Stock raising is the principal agricultural pursuit within the grazing-district area of the basin. In certain localized areas, however, some general farming, or even specialized farming, is practiced, with livestock assuming a relatively unimportant part. Throughout the basin generally most farming land is intermingled with range land. In such areas, as well as in some areas devoted strictly to farming operations, the lands are used mainly for the production of hay and feed crops to supplement range forage during seasons when range feed is not available. There is, therefore, a direct correlation between the livestock ranch, the valley farm, and the upland ranges. Even specialized crops such as sugar beets in the north and cotton in the southwest, the primary products of which are sugar and fiber, are directly related to range livestock production through their byproducts. Beet pulp, cottonseed cake, and other similar byproducts furnish an important part of the feed requirements for range livestock. Any program for the development of arable areas by irrigation must therefore take into consideration the range livestock industry where the climate, topography, and native vegetation are such that livestock production will always be an important part of the agricultural economy of the basin.

Grazing use of the Federal range is controlled by a system of permits and licenses to stock owners who also own or control private properties consisting of forage-producing lands or stock waters used in connection with the Federal range. Permits and licenses have been issued to 7,325 livestock operators for 3,486,000 head of livestock (cattle, horses, sheep, and goats) on grazing-district lands in the basin for various periods of the year. Two-thirds of the permittees and four-fifths of the livestock are in the upper basin area (above Lee Ferry), which contains 58 percent of the Federal range in the entire basin. Permitted use of the upper and lower parts of the basin is shown as follows:

	Upper basin	Lower basin	Total
Number of permittees	4, 898	2, 427	7, 325
Number of livestock	2, 913, 000	573, 000	3, 486, 000

Relationship of Range Management to Soil and Moisture Conservation

The Taylor Grazing Act of 1934, the Soil Conservation Act of 1935, and the President's Reorganization Plan No. IV of 1940 place a responsibility on the Grazing Service and the Department of the Interior to study soil erosion and surface run-off and to perform such work as may be necesary to stabilize the soil and conserve moisture in order to protect and rehabilitate areas subject to grazing administration.

Much of the silt carried in the streams of the Colorado River system and later deposited in Lake Mead or other reservoirs of the basin is picked up from the foothills and plains of the more arid portions of the basin as well as from the ravines and gorges of the steeply sloping mountain areas.

Since grazing districts are an important part of the Colorado River watershed, from which water is provided for the major reclamation projects, as well as for hundreds of minor irrigation systems scattered through the basin, the protection of these watersheds is a most important function of grazing-district administraion. Watershed protection not only aids forage production for livestock use but it also promotes the conservation of both soil and moisture for the general benefit of the locality and the Nation.

The Grazing Service is undertaking to rehabilitate and promote the orderly use of lands which for the most part were abused through overstocking and exploitation during the time when the public domain was free and unregulated. Because of the advanced stages of deterioration reached by some of the lands prior to the initiation of regulated use, there is yet a sizable job to be accomplished in further protecting and improving the lands and their resources and in preventing further deterioration through the loss of forage, timber, water resources, and even the soil itself, incident to erosion and other destructive processes.

The principal means of rehabilitation and watershed protection by the Grazing Service are (1) range management and proper stocking; (2) fire prevention and control; (3) reseeding and range rehabilitation; and (4) mechanical treatments to retard erosion.

The soil and moisture conservation program has been limited during the past 3 years chiefly to maintain existing improvements, reseeding, and to related work requiring a minimum of critical materials. Extensive plans for postwar development of the range resources in this and other drainage basins have been prepared. These plans contemplate additional water developments, reseeding, fences, control of predatory animals and rodents, fire lookouts, and other fire control facilities. All of these activities are destined to have a direct influence on sedimentation of storage facilities and in the stability of important reclamation works.

Possible Effects of Additional Reclamation Development

The land pattern in the areas proposed for reclamation development is such that both tillable privately owned and public lands undoubtedly will be involved. This will result in the loss for grazing purposes of a considerable area of private and public lands in grazing districts. Such grazing losses will likely be more than offset by increased production from irrigated lands. It would appear therefore that neither the range users nor the Grazing Service would object to the decreased grazing-district range since such losses will be overcome by additional production resulting from the reclamation program.

In many instances it is probable that the development of the area through irrigation will actually relieve the remaining public ranges of a certain amount of grazing by reason of the production of more irrigated pastures and suppemental feeds for use by range livestock and farm animals, including dairy and work stock. Such additional feed can also be used to advantage in the finishing of cattle and sheep for market in localities adapted to such practices, thus providing more pounds of meat without increasing livestock numbers on the diminished acreage of range.

Local Grazing Service officials in each grazing district will furnish the Bureau of Reclamation with any needed assistance in working out practical farm and ranch units. Within the grazing-district areas proposed for reclamation development, stockmen own land and water upon which grazing privileges are based. In these areas it is felt that prior to final disposition of the public lands and water rights to new settlers a survey should be made to determine to what extent this program will disrupt or unbalance existing livestock outfits. An effort should then be made to permit operators who may lose grazing privileges as a result of the program to bring their year-long livestock operations into balance through securing some of the irrigable land and water rights if they so desire. In short, an attempt should be made to stabilize existing operations simultaneously with setting up new operational units. Failure to give such consideration may offset partially any benefits resulting from the program.

Although most of the results of the proposed reclamation program in the basin will be favorable from a Grazing Service viewpoint, there will undoubtedly be a considerable number of adjustments necessary in existing licenses and permits as a result of the program. A review of the proposed reclamation program indicates that the development program will be carried on in substantially all of the grazing districts of the basin. Accordingly, some of the public lands, which are now and which have been for a number of years in grazing allotments, will probably be removed from these allotments to be used in the reclamation program. In such instances it will be necessary to adjust grazing licenses and permits to include only areas which are not to be reclaimed for irrigation purposes.

In certain other areas new demands for public range grazing privileges will probably be made by newly created ranch and farm units lying adjacent to or in the vicinity of Federal range. Since most public ranges in grazing districts are now stocked to capacity, there is little likelihood of supplying new applicants with public-land grazing privileges except in special areas. Any activity on the part of new ranch and farm set-ups to gain public-land privileges will result in the necessary studies by the Grazing Service before any determination is made relating to demands for such privileges.

In still other areas stock ranches which have heretofore been used as base properties in connection with public-land grazing privileges are likely to be converted into farms under the proposed plan to irrigate all lands in the basin practicable of irrigation. Such conversion of hay and feed ranches into farms for the production of general farm crops would probably lead to a considerable number of applications on the part of ranch owners to have the grazing privileges attaching to these ranches transferred to other ranches. The Federal Range Code provides for the transfer of public-land grazing privileges from one base property to another under certain conditions. It is therefore expected that some activity toward transfers of grazing privileges between base properties will result in this and other basins from the program of the Bureau of Reclamation to place new lands under irrigation.

Since complete details are lacking relating to the specific areas which will be reclaimed in the immediate future, it is impossible to make accurate estimates of all the work which will be necessary by the Grazing Service as a result of this new irrigation program. Accordingly, in addition to the three types of work above mentioned, there may be other work not now foreseen which should be given consideration in any estimate of necessary manpower and funds. In all of the new work anticipated, administrative and technical personnel of the Grazing Service will be required to make on-the-ground studies involving all licenses and permits which might be disturbed or all new applications which must be given consideration for grazing privileges. Such studies would involve both field and office work, together with statistical and narrative reports concerning the effects of the proposed irrigation plans on the grazing picture and steps to be taken to make the necessary adjustments with the least possible upset to the economy of the area generally. This additional work by the Grazing Service will also involve close coordination and planning among local representatives of both the Grazing Service and the Bureau of Reclamation in order that the programs of both agencies may be in harmony with respect to the over-all land-use situation in the affected areas.

Should the additional work to be placed on the Grazing Service be accomplished during the fiscal year 1946 as a result of the Colorado River Basin reclamation program, the full amount of money estimated as necessary for carrying on this work should be made available for use during that fiscal year. Estimated funds necessary to accomplish the Grazing Service work involved in anticipated adjustments during the fiscal year 1946 total $120,000 for the basin. This estimate is based on the premise that the program will not assume its full scope during the early stages of development.

BUREAU OF MINES

Program of the Bureau of Mines on Water Utilization

The mineral industry has an interest in the water of flowing streams as a source of water necessary for mining, milling, and extracting metals or minerals from their ores. Except for hydraulic mining, these demands are not large.

The power generated by flowing water is of great interest to the mineral industries whenever it can be generated at sufficiently low cost to compete with power at existing electrochemical centers. A very wide range of products can be made from very common raw materials and many products prepared that are almost impossible by any other technique. The emphasis must be on low cost of the power.

Whereas many mineral commodities are sparsely distributed and their mines have relatively short life, leading to the recognition by tax officials that a mine is wasting asset, the electrochemical industries are often based on raw materials available in abundance. This leads to more stable communities that can hope to survive indefinitely and not become ghost towns.

Mineral industries sometimes create nuisances in streams and the mitigation of these nuisances has included certain restrictive legislation largely by the State governments. Hydraulic mining of unconsolidated deposits of gold and other minerals is a highly efficient form of mining. However, it leaves the streams loaded with clay, soil, and heavier debris that causes annoyance to other interests farther down a stream. When planned in advance, an hydraulic mining enterprise can provide for complete or sufficient partial prevention of this nuisance. Mill tailings are not often turned directly into streams in the way they once were. While this was the cheapest way to get rid of them, history has too often recorded the profitable retreatment of impounded tailing as technologic advances made a retreatment economic. The mineral industries recognize the disposal of tailing into streams as shortsighted management and are glad to have the legislation that prevents such management by certain elements. Objectionable soluble salts like cyanides from gold mills or iron salts and acid in coal mine drainage waters are other nuisances recognized by the mineral industries and to the extent that these can be vented without injury to other interests are often allowed to continue but are best controlled only when there are certain restrictive laws designed to determine when a waste product becomes a pollution. It is the policy of the Bureau of Mines to cooperate in all possible ways to help determine these permissible limits and avoid destruction of units of the mineral economy by ultra restrictive measures.

Outside of the pollution problem the mineral industries come into little conflict with other interests in the utilization of water. The volume demanded is not large in comparison to the needs of irrigation, navigation, or the development of electric power. The existing priorities on water rights do not often conflict with mineral economy. However, its must be recognized that the average mine while of short relative life, is usually a site for more concentrated production of wealth that builds up the community, particularly from the standpoint of transportation and similar facilities and leaves these as an inheritance to the long-lived agricultural interests. In an occasional case the water, power, and other services developed by a mining enterprise are separately operated under a separate corporation that can continue to serve adjacent communities after the mine is exhausted.

The organic act of the Bureau of Mines directs it to increase safety and efficiency in the mineral industries and prevent mineral wastes. Efficiency in the mineral industries demands conservative use of water and the utilization of water power wherever its use increases efficiency in the mineral industries. It is here that the greatest constructive effort can be exerted. Electrochemical practices of the remainder of the world are only beginning to be adopted and improved in the areas where large dams have made available low-cost power. The war has accelerated the building of dams, caused over-building of certain mineral industries like aluminum and magnesium, but only a feeble beginning has been made in the adaptation of hundreds of electrochemical and electrometallurgical techniques based on mineral raw materials. Much of the power is now developed and will soon be inviting new users. The duty of the Bureau of Mines is clear and it has organized within the last 7 years its electrotechnical laboratory at Norris, Tenn.; electrometallurgical laboratory at Boulder City, Nev.; and its electrodevelopment laboratory at Albany, Oreg., in the order named. It is part of the program to enlarge these laboratories and to work out the problems in adaptation of local conditions and local raw materials to electrical techniques. These three centers are expected to collaborate with the other services of the Government in the building up of electrochemical centers like that at Niagara Falls. While the war has provided problems and funds for plenty of constructive work these three centers should receive a regular peacetime appropriation to continue their work and help prevent another Muscle Shoals fiasco. Each laboratory can well use $500,000 per year for its regular work and special projects that demand separate appropriations for final proof should be thus separately funded.

While the programing of work like reclamation of water in streams for multipurpose use is something that can be specifically done, such a detailed program for research is difficult. Some of the researches prove fruitless and the time to arrive at an endpoint is unpredictable. The objective is definitely known and acknowledged to be desirable but the time table indefinite. What can be said is that the following main projects will be followed continuousy:

(1) Adaptation of known electric techniques to American raw materials, markets and transportation, wherever an economic result is thought possible. Example: electric melting of glass.

(2) Development of new products made uniquely possible by application of electrict power, like fused basalt.

(3) Development of metals and minerals available in abundance but not now utilized to the extent that they might, like titanium, zirconium, and other metals. The Bureau of Mines is already making a start on production of pure ductile titanium and zirconium.

Low-cost power and mineral development

The mineral industries in the Colorado River Basin constitute one of the most obvious outlets for power generated at multiple-purpose dams. Some of these industries are consumers of mechanical power for which ordinary industrial rates can be paid, but the electrochemical industries usually call for low-cost power, and commonly buy large blocks of power. Mining and processing centers using low-cost power build up communities and transportation. The communities increase demand for agricultural products of a greater variety than those that can be cultivated when there are fewer consumers near the farms. The need of attracting electrochemical industries in building up the area is so obvious that it needs no emphasis. The consideration that needs more attention is the fact that to attract industries to isolated localities the power must be priced attractively and rates should not be set at "all that the traffic will bear."

The State of Arizona is the largest copper producer and yet makes no finished copper. Electrolytic refining of most of the copper takes place almost entirely on the Atlantic seaboard with the exception of a portion that is refined near El Paso, Tex. Copper does not require much electric energy in its preparation and higher cost power can be tolerated. However, fuel is not cheap in Arizona. There is only one electric smelter of copper in the world and it is located in Finland where electric heat is used in place of fuel. An economic study of the opportunity for electric smelting and electrolytic refining in Arizona seems justified.

The metal magnesium requires a great deal of low-cost electric power for its preparation. The magnesium plant at Las Vegas, Nev., was erected hurriedly during the war and based on raw materials hundreds of miles north of the plant and with an expensive haul between mine and plant. Sea water is probably the cheapest source of magnesium oxide and magnesium chloride and is at present the most popular source. However, the hills near Las Vegas have huge amounts of dolomite of good quality, whose magnesia content might well be extracted by a number of good processes in order to make the plant attractive for permanent use. Contiguity of mine and reduction plant is of fundamental economic importance in any mineral industry.

Aluminum, another heavy power consumer, has not received the same enthusiastic attention that magnesium

TABLE CXXXV.—*Data based on U. S. Bureau of Mines exploration of mineral deposits in the Colorado River drainage basin*

Mineral area	Location		Classification of deposits	Ore reserves	Tenor of ore	Important components	Method of exploration	Remarks
	County	State						
Manganese deposits				[1]	[2]			
Artillery Peak	Mohave	Arizona	Sedimentary	Large	Low grade	Manganese	Sampling, drilling, mining.	Reserve deposit important for future production.
Patagonia	Santa Cruz	do	Veins	Small	do	do	Sampling, trenching, mining.	Idle reserve deposits.
Parker	Yuma	do	Replacement	do	Medium grade	do	Sampling, mining.	Do.
Tombstone district	Cochise	do	Veins replacement.	do	Low grade	do	Sampling, drilling, mining.	Do.
Pershing mine	Saguache	Colorado	Vein	do	do	do	do	Do.
Three Kids	Clark	Nevada	Replacement	Large	do	do	do	Large war-time producer. Operation handicapped by technical and operational factors.
Boulder City	do	do	do	Large	Extra low grade	do	do	Grade too low for consideration as a source of manganese.
Virgin River	do	do	do	Medium	Low grade	do	Sampling, drilling, trenching.	Idle reserve deposits.
Whedon mine	Imperial	California	Veins	Small	Medium grade	do	Sampling	
Iron deposits				[3]	[4]			
Apache and Chediski.	Navajo	Arizona	Replacement	Large	Low grade	Iron	Sampling, trenching drilling.	Idle reserve deposit.
New Planet	Yuma	do	do	Small	Medium grade	do	Sampling, drilling.	Do.
Iron Mountain district (the majority of this district is outside the Colo. Basin area).	Iron	Utah	Contact metamorphic.	Large	do	do	Sampling, magneto-meter, drilling, mining.	Producer of 140,000 tons of ore per month for Colorado Fuel and Iron, Geneva Steel, Columbia Steel and several small steel operations.
Bull Valley	Washington	do	Veins	Small	do	do	Sampling, drilling.	Idle reserve deposit.
Eagle Mountain district.	Riverside	California	Replacement	Large	do	do	do	Do.
Lead, zinc, and copper deposits.				[5]				
Zonia mine	Yavapai	Arizona	Disseminated	Medium	Low grade	Copper	Sampling, trenching, drilling.	Do.
Old Reliable	Pinal	do	Breccia Pipe	do	do	do	Sampling, mining.	Do.
Aravaipa	Graham	do	Veins, contact metamorphic.	Small	Medium grade, low grade.	Lead, zinc, copper.	Sampling, drilling, mining.	Small producer.
Reward Zinc	Pinal	do	Replacement	do	Medium grade	Zinc	Sampling, drilling.	Idle reserve deposit.
Amargosa	Pima	do	Breccia Pipe	do	Low grade	Molybdenum copper.	Sampling	Do.
Christmas Copper	Gila	do	Disseminated	do	do	Copper	Sampling, drilling, mining.	Producer of 1,700 tons of siliceous fluxing ore per month.
San Manuel	Pinal	do	Disseminated	Extra large	do	do	Sampling, drilling.	Virgin porphyry copper recently discovered and explored by the Bureau of Mines.
Big Four	Summit	Colorado	Vein	Small	Medium grade, low grade.	Zinc, lead	Sampling, drilling, mining.	Small producer.
Colorado Copper	Montrose	do	Disseminated	do	do	Copper	Sampling, mining.	
Magnesium minerals				[6]				
Thompson magnesium.	Grand	Utah	Sedimentary	Large	High grade	Magnesium potash.	Sampling, drilling.	Idle reserve of magnesium-potash salts.
Miscellaneous metal and mineral deposits.				[7]				
Asbestos	Gila	Arizona	Replacement	Small	High grade	Asbestos	Sampling, mining.	Limited producer of excellent qualtiy asbestos.
Great Eastern	Clark	Nevada	Metamorphic replacement.	Medium	Extra low grade	Nickel	do	Grade of ore below operating possibilities.
Vanadium area of southeastern Utah and southwestern Colorado.		Utah and Colorado.	Replacement	do	Medium grade	Vanadium, uranium.	Sampling, drilling, mining.	Largest producer of vanadium in the United States.

[1] Small equals 1 to 100,000 tons; medium equals 100,000 to 1,000,000 tons; large equals 1,000,000 to 10,000,000 tons; extra large equals 10,000,000 tons plus.
[2] Extra low grade equals 1 to 5 percent manganese; low grade equals 5 to 20 percent manganese; medium grade equals 20 to 40 percent manganese.
[3] Small equals 1 to 1,000,000 tons; medium equals 1,000,000 to 10,000,000 tons; large equals 10,000,000 to 100,000,000 tons.
[4] Low grade equals 40 to 50 percent iron; medium grade equals 50 to 60 percent iron.
[5] Small equals 1 to 100,000 tons; medium equals 100,000 to 500,000 tons; large equals 500,000 to 5,000,000 tons; extra large equals 5,000,000 tons plus.
[6] Large equals 100,000 tons plus.
[7] Small equals 1 to 10,000 tons; medium equals 10,000 to 50,000 tons.

has in the Colorado River Basin. The standard raw material does not occur in the basin and bauxite, if shipped from the north coast of South America through the Panama Canal would probably have to be converted into alumina, ready for reduction, at Los Angeles, as bauxite is treated in transit at Mobile, Ala., before sending the aluminum oxide up the railroad to the lowest cost power area. Cost of power is doubled by transmitting it from the power stations to Los Angeles and a pound of aluminum calls for about 10 kilowatt-hours in its production. Up to the present time alumina has had to travel to the low-cost power area for reduction.

Silicon, ferrosilicon, and silicon carbide require low-cost power, quartzite and low ash coke. In normal times all of the production is carried on at low power cost electrochemical centers where raw materials are nearby. These specifications can be met in the basin. Another consideration in connection with ferrosilicon is the fact that much of the ferrosilicon produced is an intermediate product, used in the same plants for reducing other ores to produce low-carbon metals, alloys and ferroalloys. In this respect ferrosilicon in certain metallurgical industries is like sulphuric acid in the chemical industry, a key intermediate.

Manganese ores, generally of low grade, occur in several localities in Nevada, Arizona, and California and the Boulder City station of the Bureau of Mines has operated a pilot electrolytic manganese plant for several years, developing the fine points in technique of operation. Part of the manganese went to the mint for production of the new 5-cent pieces, designed to conserve nickel. The remainder has gone largely into tonnage tests of electrolytic manganese for the production of a number of low-carbon manganese alloys that show promise of large scale demand. As the scale of operation is increased the cost of production goes down and it should not be long before a commercial operation may be justified. The Three Kids manganese deposit near Las Vegas, Nev., is not far from the Basic Magnesium Co. magnesium plant where the necessary electrolytic equipment exists and only the tankage required by a manganese plant need be added. The magnesium plant is too large for normal peacetime demands and part of it might well be converted into a manganese plant.

Manganese ores and chromite ores can also be electrically smelted into the corresponding ferroalloys. Chromite occurs in many areas of California. Ferromanganese is required in the production of steel and finds a market in Los Angeles, San Francisco, and the other steel centers of the Southwest. Ferrochromium is needed in the chrome steels and chrome irons also made in the same areas. Electrolytic chromium is under development by the Bureau of Mines at Boulder City, Nev., and may well meet the need for a low carbon metal in production of such items as stainless steel.

These are only prominent examples of electrochemical industries that can be developed first of all for local needs and that later may reach more distant markets.

OFFICE OF INDIAN AFFAIRS

Indian Projects in the Colorado River Basin

Undoubtedly the oldest as well as the most extensive of the prehistoric Indian agriculture on the North American continent took place within the basin of the Colorado River. There is ample evidence to show that many hundreds of years ago the Indians were builders of substantial irrigation projects covering large acreages of land served by wide and numerous canals. The first recorded observations or historical accounts were those made by the Spaniards who ventured into this basin as early as the middle of the sixteenth century. The records of these explorers are replete with descriptions of Indian irrigation enterprises located at various places within the range of their travels, but the most imposing accounts were those concerning the activities of the Pimas along the Gila River and its tributaries. Elsewhere, however, throughout this whole general territory various Indians made efforts toward obtaining at least a part of their subsistence from "what they planted." With the coming of the whites and the subsequent confinement to reservations their earlier methods and customs have changed but through the assistance of the government their present agricultural activities have become considerably enlarged and modern methods are being adopted.

Within the Colorado River Basin, as defined in the text of this report, are 29 Indian reservations, 1 nonreservation Indian school, and 2 sanatoria. The Indian land totals 26,823,062 acres, of which 1,271,117 acres are in trust allotments, 24,557,040 acres in tribal ownership and 994,905 acres in Government ownership. The combined Indian population of the area totals more than 80,000, the majority of whom are full-bloods. The largest single group is the Navajos in Arizona and New Mexico, who total more than 50,000, practically all of whom are full-bloods.

These Indians and their resources in land and water rights are the special concern of the Federal Government. The Federal responsibility is specifically set out in various treaties, statutes, and agreements under which definite legal rights have been vested in individuals and tribes. There are also certain moral obligations of the Government to these Indians because of its disregard of their legal rights over a long period. These rights and obligations were recognized by the Colorado River Compact Commission as evidenced by article VII of the compact which reads as follows: "Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian Tribes." One of the Government's objectives in the development of the basin must be not only the protection of the Indian's purely legal rights but the discharge of its moral obligations as well.

With few exceptions the Indians within the Colorado River Basin exist on a much lower than average standard of living. The Federal Government is obligated to provide them with resources sufficient to enable them to attain economic independence at a level comparable with other citizens of the area. In some instances the full development of the Indian's present resources in land and water will accomplish this result. In other cases some additional resources must be acquired. Only after their economic independence at a reasonable level is attained can these Indians be expected to become integrated with the social, economic, and political life of the Nation. The guidance, protection, and assistance necessary to attain this end are Federal responsibilities.

In carrying out its obligation to establish these Indians on a firm economic base the first step of the Government should be to develop fully their present resources and educate them in the utilization and protection thereof. Many Indians are now in the armed services and many more are engaged in war work. This will undoubtedly result in an increasing number of Indians leaving the reservations permanently to engage in industry. The great majority, however, will continue to rely upon reservation resources for a livelihood. It is, therefore, urgent that all feasible Indian irrigation projects be developed fully at an early date. The need for this is so acute that unless detailed plans can be developed and construction work started immediately, conditions on most of the reservations will be such as to require the expenditure of large sums for relief or "made" work. This alternative must be avoided.

Tentative plans have been prepared over the past several years by the Irrigation Division of the Office of Indian Affairs for the development of all potentially irrigable Indian lands. Additional detail surveys and studies are required in connection with many of the projects before the ultimate areas can be defined definitely and adequate facilities designed. As the development of the Indian projects will have a material bearing on plans for the development of the basin as a whole they should be given an early priority when funds and manpower become available. The total area in Indian projects within the basin now supplied with irrigation facilities is 262,290 acres and plans contemplate expanding this area to 566,440 acres. The present average annual diversion is 1,034,308 acre-feet and the average annual diversion requirement for the ultimate area is 2,845,420 acre-feet. The areas and water use by States including non-Indian land within Indian irrigation projects are as follows:

Arizona

Within the Colorado River Basin in Arizona are 19 Indian projects containing a total of 148,070 acres now supplied with irrigation facilities. The ultimate irrigable area of these projects is estimated at about 291,055 acres making an increase of 142,985 acres for the State. The present diversion duty is approximately 610,470 acre-feet annually and the annual diversion requirement for the ultimate area is estimated at 1,671,342 acre-feet. The individual projects are described as follows:

Ak Chin.—This small project is located on the Maricopa Reservation near the town of Maricopa. The population of the reservation is 284 persons, most of whom are full-blood Maricopas. The reservation was established by Executive order of May 28, 1912. The water supply is secured from four wells equipped with electrically operated turbine pumps, installed in 1915. Approximately 1,500 acre-feet is pumped annually, and it is estimated that when the irrigated area, which is divided into small subsistence garden tracts, is cultivated more intensively the annual water requirement will increase to about 2,680 acre-feet. The distribution system consists of 10 miles of ditches and 2,600 feet of 16-inch concrete pipe. The irrigable area is 670 acres and present plans do not contemplate any material expansion on account of the relatively high cost of pumping.

Camp Verde.—This small project is located on the Camp Verde Reserve in central Arizona, the total area of which is 458 acres. The Indian population is 453. Water is secured by direct diversion from the Verde River. The present irrigable area is 170 acres, and it is planned to expand it to approximately 425 acres. The present annual diversion is 950 acre-feet and the average annual diversion requirement for the total area of 425 acres is estimated at 2,337 acre-feet.

Chiu Chiu.—This small project is located on the Papago Reservation approximately 9 miles south of Casa Grande. The water supply is secured from two wells equipped with electrically operated turbine pumps installed in 1915. Approximately 615 acres are now being irrigated and present plans contemplate increasing the area to about 700 acres. The present pumping amounts to 1,550 acre-feet annually and the estimated average annual requirement for the ultimate area is 2,800 acre-feet. The estimated cost to complete the project is $5,000.

Cocopah.—This small project is located about 18 miles south of Yuma where approximately 530 acres were set aside by Executive order of September 27, 1917. Water is secured from the Yuma project of the Bureau of Reclamation through a lateral of about 100 second-feet capacity. The present annual water use is about 600 acre-feet and the estimated annual requirement for the ultimate irrigable area of 425 acres is 2,550 acre-feet. The estimated cost of completing the project is $5,000.

Colorado River.—This project is located on the Colorado River Reservation which was established by the act of March 4, 1865 (13 Stat. 559). It was on this reservation that the Federal Government made its first attempt to reclaim arid lands. The act of March 2, 1867 (14 Stat. 514), appropriated $50,000 for beginning construction of an irrigation canal from the Colorado River. Water was first turned into this canal on July 4, 1870, but due to faulty design and construction of the headgate and to the unusually high stage of the river the canal was destroyed for a considerable distance below the intake structure. Several attempts to reconstruct the canal and heading were made and it was actually used during 1871 when the stage of the river was such as to allow the diversion of water. On account of the great variation in the flow of the river, however, attempts to irrigate these lands by gravity diversion were discontinued and a pumping plant was installed in 1898. This plant was subsequently enlarged to a capacity of 125 second-feet and has now been replaced with permanent diversion facilities.

The irrigable area extends about 45 miles north and south from near Parker to a point near the old town of Ehrenberg. The water supply is secured by direct diversion from the Colorado River at the Headgate Rock diversion dam. This is one of the major Indian projects in the Colorado River Basin and the first major project downstream from Boulder Dam.

The project is designed and is being constructed to irrigate 100,000 acres. The Headgate Rock Dam together with about 17 miles of the main canal and about the same length of the main drainage canal have been completed at a cost of about $8,000,000. Construction work was suspended at the beginning of the war with the exception of extending facilities to serve some 3,000 acres within the Poston relocation center of the War Relocation Authority. The present area supplied with distribution facilities is approximately 9,400 acres. Detail plans for extending the irrigation and drainage facilities including the construction of a small hydroelectric generating plant at a drop in the main canal, are complete. The estimated cost to complete the project for the ultimate area of 100,000 acres is $12,425,000. The present average annual diversion is approximately 56,400 acre-feet and the estimated annual diversion requirement for the ultimate area is 600,000 acre-feet.

The early completion of this project will assist materially with the rehabilitation of the Indians within the Colorado River Basin. Plans for the utilization of the area by Indians are being made in accordance with the act of March 4, 1865, which established the reservation for the Indians of the Colorado River and its tributaries. The completion of the project for the total irrigable area of 100,000 acres should be given a high priority when materials and manpower become available in the postwar period.

Fort Apache.—This project consists of several small units on the Fort Apache Reservation. Water is secured by direct diversion from White and Black Rivers and various tributary creeks. The area now being served is approximately 2,000 acres, and it is planned to extend irrigation facilities to an additional 4,000 acres, making 6,000 acres in all. The present annual diversion amounts to about 10,000 acre-feet and the estimated diversion requirement for the ultimate area is 30,000 acre-feet. The estimated cost to complete the developments is $47,000.

Fort Mojave.—This small project is located on the Fort Mojave Reservation across the Colorado River from Needles, Calif. The present project consists of 20 acres, which are irrigated by pumping. There is a total area of approximately 9,000 acres of Indian land lying along the Colorado River which will be susceptible of irrigation by pumping when low-cost power is available and the river becomes stabilized after completion of Davis Dam. This area would be particularly valuable for the production of pure seed at it is isolated from other agricultural areas. The present average diversion is 100 acre-feet and the average annual diversion for the ultimate area is estimated at 54,000 acre-feet.

Fort McDowell.—This small project is on the Fort McDowell Reservation north of Phoenix. The water supply is secured by direct diversion from the Verde River. The present area is 600 acres and it is contemplated to increase it to 1,400 acres through extension of the canal and lateral systems at an estimated cost of $16,000. The present annual diversion amounts to approximately 3,600 acre-feet and the annual diversion requirement for the ultimate area is estimated at 8,400 acre-feet.

Gila Bend.—At one time the Indians of the Gila Bend Reservation were irrigating a small area adjacent to the Gillespie project. These Indians are now mostly in the armed services or engaged in war work and the irrigated area is not used temporarily. There are 400 acres, however, which these Indians can reasonably be expected to utilize eventually. The water supply will be secured from the Gila River and the annual diversion is estimated at 2,400 acre-feet. The estimated cost of the development is $40,000.

Gila River.—Irrigation was practiced on the reservation by the Pima Indians in prehistoric times. The first historical record probably comes from the visit of Fra Marcus De Niza in 1539, who found a successful agricultural community of Pima Indians along the Gila River. Most of the irrigable lands within the reservation are included in the San Carlos project which is described separately, but approximately 7,400 acres outside the San Carlos project are being irrigated by Indians. This area is in small scattered tracts, the largest of which is the 1,080-acre Maricopa unit near the confluence of the Gila and Salt Rivers. Water for these scattered units is secured both by gravity diversion from the Gila and Salt Rivers and by pumping.

The total present irrigable area in these units is 7,400 acres, and it is planned to extend irrigation facilities to an additional 5,525 acres making 12,925 acres in all. The present annual diversion is approximately 37,320 acre-feet and the annual diversion requirement for the ultimate area is estimated at 77,955 acre-feet. The estimated cost of providing irrigation facilities for this additional area is $250,000. This additional development of Indian lands outside the San Carlos project will depend upon securing a supplemental water supply through the proposed delivery of Colorado River water to central Arizona.

Hopi.—Within the Hopi Reservation are eight small irrigation developments and several small garden tracts aggregating about 660 acres. It is planned to extend irrigation facilities to an additional 70 acres making 730 acres in all. Water is secured from miscellaneous small streams tributary to the Little Colorado River. The present annual diversion is about 3,300 acre-feet and the annual diversion requirement for the ultimate irrigable area is estimated at 3,650 acre-feet.

Havasupai.—This small project lies in Supai Canyon near the western terminus of the Grand Canyon. A total of 175 acres is being irrigated and it is expected the area will be expanded to a total of 200 acres. Water is secured from springs and the present diversion is about 1,050 acre-feet annually. The annual diversion requirement for the ultimate area is estimated at 1,200 acre-feet.

Hualapai.—This small project is located on the Hualapai Reservation. At present 40 acres are being irrigated and it is planned to extend irrigation facilities to an additional 130 acres, making 170 acres in all. Water is secured by direct diversion from Big Sandy Creek, a minor tributary of the Colorado River. The present diversion is about 200 acre-feet annually and the annual diversion requirement for the ultimate area is estimated at 1,020 acre-feet.

Kaibab.—This small project is on the Kaibab Reservation. At present 40 acres are being irrigated from a spring. The annual diversion is estimated at 160 acre-feet and no expansion of the irrigable area or annual diversion is contemplated.

Navajo.—On the Navajo Reservation within the State of Arizona are about 45 small irrigation developments aggregating 13,740 acres. Twenty of these units totaling about 5,000 acres lie within the Little Colorado River watershed and 25 units with an area of about 8,740 acres are within the San Juan River Basin. It is planned to provide irrigation facilities for an additional 31,530 acres which will make the ultimate irrigable area within Arizona approximately 45,270 acres, about 23,265 acres of which will be in the Little Colorado River watershed and 22,005 acres in the San Juan watershed. The water supply is secured by direct diversion from miscellaneous streams and the present annual diversion is estimated at 68,700 acre-feet, of which 25,000 acre-feet is from tributaries of the Little Colorado River and 43,700 acre-feet from tributaries of the San Juan. The average annual diversion requirement for the ultimate area is estimated at 226,350 acre-feet of which 116,325 acre-feet will be from the Little Colorado River watershed and 110,025 acre-feet from the San Juan watershed.

Salt River.—This project is located on the Salt River Reservation which was set aside for use of Indians by the Act of February 28, 1859 (11 Stat. 401), and Executive order of June 14, 1879. The present irrigation project was started by the Indians in 1871 and has been improved and extended from time to time until at present the irrigable area is 9,800 acres. An additional 200 acres will be brought under the canal system within a short time, making a total project area of 10,000 acres. Water is secured through the canal system of the Salt River project built by the Bureau of Reclamation. Delivery of 17.5 second-feet constant flow is made through the Arizona Canal to lands lying north of the Salt River and 8.75 second-feet through the Utah Canal for lands in the Lehi district. In addition to this normal flow water the Indians are entitled to 20 percent of the storable water in the reservoir created by Bartlett Dam on the Verde River in accordance with a contract between the Office of Indian Affairs and the Salt River Valley Water Users' Association, dated June 21, 1935. This amounts to an average of approximately 20,000 acre-feet annually. The present diversion averages 39,200 acre-feet annually and the annual diversion for the ultimate area will average 40,000 acre-feet.

San Carlos project.—The San Carlos Indian irrigation project was authorized by the act of June 7, 1924 (43 Stat. 475–476), commonly known as the San Carlos Act. This act authorized the construction of the Coolidge storage dam on the Gila River and the merger, in whole or in part, of the 62,000-acre Florence Casa Grande project with the San Carlos project. The Coolidge Dam was completed in 1928. This dam creates the San Carlos Reservoir which has a capacity of 1,285,000 acre-feet. Water is diverted from the Gila River at the Ashurst-Hayden Dam above Florence and at the Sacaton Dam near Sacaton. In addition to the gravity supply the project operates about 85 turbine pumps which provide adequate drainage and augments the water supply for irrigation.

The project contains a total of 100,000 acres of which 50,000 acres are Indian lands within the Gila River Reservation and 50,000 acres of privately owned lands in the Florence-Casa Grande Valley. Water rights for the project lands were defined in a Federal district court decree entitled "Glove Equity No. 59" entered June 29, 1935. This decree known as the Gila River decree provides a water right with immemorial priority for 35,000 acres of Indian lands within the San Carlos project; a water right for 1,000 acres in the San Carlos Reservation with a priority second only to that of the 35,000 acres of Pima lands; water rights with varying priorities from 1868 to 1921 between privately owned lands in the San Carlos project and lands in the upper Gila Valley; and a right with a priority of not later than June 7, 1924, to the San Carlos project to store 1,285,000 acre-feet in the San Carlos Reservoir at all times.

The present average annual diversion for the project lands is about 370,000 acre-feet which has been the average flow available during the past several years. It is planned to secure a supplemental supply of about 230,000 acre-feet annually through the construction of the proposed Buttes Dam on the Gila River to store flood flows of the San Pedro River and partly from the Colorado River through facilities proposed to bring Colorado River water into the central valleys of Arizona. This will result in a total annual diversion of 600,000 acre-feet of which 450,000 acre-feet will be from the Gila River watershed and 150,000 acre-feet from the Colorado River.

The project works are complete with the exception of the proposed Buttes Dam and facilities for securing the supplemental supply from the Colorado River. The area actually irrigated each year varies with the available water supply which heretofore has been inadequate for the entire project area of 100,000 acres. The construction of these additional facilities should receive a high priority in the basin development and work started when materials and manpower become available in the postwar period.

San Carlos Reservation.—On the San Carlos Reservation 1,000 acres are under cultivation. The irrigable area includes several tracts, the principal ones being near Bylas and Calva on the Gila River and near the San Carlos Agency along the San Carlos River. Water is secured both by direct diversion and by pumping. The average annual diversion is 6,000 acre-feet. No substantial expansion either in the irrigable area or the diversion of water is contemplated.

San Xavier.—On the San Xavier Reservation near Tucson approximately 1,640 acres are being irrigated by direct diversion from the Santa Cruz River and by pumping. Irrigation was practiced by these Papago Indians before the area was first visited by Father Kino in the sixteenth century. It is proposed to increase the irrigable area from 1,640 to 1,700 acres. The present annual diversion amounts to 9,840 acre-feet and no increase is contemplated.

California

Within the Colorado River Basin in California are two Indian projects. The combined present irrigable area amounts to 7,975 acres and plans contemplate expanding this area to 22,350 acres. The present average annual diversion is 47,718 acre-feet and the diversion requirement for the ultimate area is estimated at 134,218 acre-feet. The two projects are described as follows:

Coachella Valley.—Within the Coachella Valley are three reservations which, under the Bureau of Reclamation plans, will receive water from the Colorado River through the Coachella Valley canal. These reservations are Augustine, Cabazon, and Torres-Martenez. There are at present approximately 125 acres in small tracts being irrigated on these reservations and it is planned to increase that area to 14,500 acres. The present water supply is secured from artesian wells and pumps and the average present annual diversion is 500 acre-feet. When the Coachella Valley canal is completed water for the larger acreage can be secured therefrom. The average annual diversion requirement for the ultimate irrigable area of 14,500 acres is estimated at 87,000 acre-feet. The estimated cost of providing the necessary irrigation facilities and subjugating the land is $4,350,000. This work should be accomplished as soon as possible.

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Fort Yuma.—On the Fort Yuma Reservation 7,850 acres of irrigable land are included in the Yuma project of the Bureau of Reclamation. Water is delivered by the Bureau of Reclamation from its canal system. The present average annual diversion is estimated at 47,218 acre-feet. No expansion of the irrigable area or increase in diversion is contemplated. Some additional subjugation work is necessary to permit the irrigation of the total area and the economical use of water. The estimated cost of this work is $350,000.

Colorado

Within the Colorado River Basin in Colorado are two Indian projects. The combined present irrigable area amounts to 8,600 acres and plans contemplating expanding this area to 20,350 acres. The present average annual diversion is 43,000 acre-feet and the average annual diversion requirement for the ultimate area is estimated at 72,750 acre-feet. The two projects are described as follows:

Southern Ute.—On the Southern Ute Reservation 8,400 acres are now supplied with irrigation facilities of which 2,400 acres are in non-Indian ownership, and plans contemplate expanding the area to 19,850 acres of which 3,700 will be non-Indian. The water supply is secured from Pine River and tributary creeks. The present average annual diversion is 42,000 acre-feet and the average annual diversion requirement for the ultimate irrigable area is estimated at 70,250 acre-feet. The tentative estimated cost to provide irrigation facilities for the additional area is $860,000.

Ute Mountain.—On the Ute Mountain Reservation there are 200 acres being irrigated and plans contemplate expanding the area to 500 acres. The water supply is secured from Mancos Creek. The present average annual diversion is 1,000 acre-feet and the average annual diversion requirement for the ultimate irrigable area is estimated at 2,500 acre-feet.

Nevada

Within the Colorado River Basin in Nevada is one Indian project. This small project is on the Moapa Reservation and contains an irrigated area of 325 acres. It is proposed to increase this area to 600 acres. The water supply is obtained from the Muddy River. The present average annual diversion is 1,950 acre-feet and the average annual diversion requirement for the ultimate Indian area is estimated at 3,600 acre-feet. The work required to complete the irrigation facilities includes the construction of a small storage dam for irrigation and flood control. The estimated cost of this dam is $335,000, of which about $55,000 will be a charge against the Indian land, $135,000 will be allocated to flood control, and

$160,000 will be charged to the approximately 3,800 acres on non-Indian land which will be benefitted. In addition it is proposed to install a concrete pipe-distributing system for the Indian lands at an estimated cost of about $65,000.

New Mexico

Within the Colorado River Basin in New Mexico are five Indian projects aggregating 19,000 acres now supplied with irrigation facilities. It is proposed to increase this area to 133,000 acres. The present average annual diversion is 95,000 acre-feet and the average annual diversion requirement for the ultimate area is estimated at 655,000 acre-feet. The five projects are described as follows:

Jicarilla.—On the Jicarilla Reservation 800 acres are now being irrigated and plans contemplate increasing this area to 5,000 acres. The water supply is secured from LaJara and Dulce Creeks. The present average annual diversion is 4,000 acre-feet and the average annual diversion requirement for the ultimate area is 25,000 acre-feet. The estimated cost of providing irrigation facilities for the additional area is $250,000.

Monument Rocks.—Within the Navajo Reservation north of the San Juan River is a reasonably compact area of potentially irrigable land which is included in the proposed development of the Animas-LaPlata project by the Bureau of Reclamation. This potentially irrigable area totals 25,500 acres. It is estimated that the average annual diversion requirement would amount to 127,500 acre-feet. Detail surveys are required in order to define the area and prepare cost estimates. The cost of such surveys is estimated at $10,000.

Navajo.—Within the Navajo Reservation in New Mexico are about 30 small irrigation developments and several additional small projects are proposed for development. The present irrigated area aggregates 12,000 acres and the proposed additional developments total 10,500 acres making a total aggregate area of 22,500 acres. The water supply is secured from the San Juan River and numerous miscellaneous streams tributary to the San Juan River. The present average annual diversion is 60,000 acre-feet and the average annual diversion requirement for the ultimate irrigable area is estimated at 112,500 acre-feet. The development cost of these small projects including subjugating the land is estimated at about $2,000,000. Although additional surveys are required to define the areas and prepare accurate cost estimates, the cost of such additional studies will be approximately $10,000.

Shiprock.—Within the Navajo Reservation in the vicinity of Shiprock is a compact area of reasonably good land comprising 70,000 acres. Irrigation of this area would require the construction of a storage reservoir on the San Juan River together with a canal and lateral system. The Bureau of Reclamation has studied the possibility of constructing a storage dam on the San Juan River near the Colorado-New Mexico State line to form a 125,000 acre-foot reservoir, a diversion dam near Blanco, and a gravity conduit extending about 75 miles to the land. A pumping lift of about 100 feet would be required to irrigate part of the area which lies above the conduit location. The average annual diversion requirement for this project regardless of the plan adopted would be approximately 350,000 acre-feet. The estimated cost of the development is $21,000,000 or about $300 per acre.

Summary—Navajo

The need for the full and early development of all feasible irrigation projects on the Navajo Reservation is acute. Within the Navajo Reservation in Arizona and New Mexico there are approximately 30,000 acres now provided with irrigation facilities. Some of the many separate developments are merely floodwater projects and are of little value during years of extreme drought. Additional storage is required to provide a dependable water supply. Additional subjugation work also needs to be done in order to conserve water and make it possible for the Indians to carry on farming operations. With the full development of all feasible irrigation units on the Navajo Reservation in Arizona and New Mexico including the Monument Rocks area, the Shiprock area, and the miscellaneous small projects there would be a total of approximately 135,000 to 150,000 acres of irrigable land available for use by these Indians. The estimated cost of the new developments including the subjugation of land is $27,000,000 or an average of about $260 per acre for the new acreage.

Living on and adjacent to the reservation are approximately 52,000 Navajo Indians practically all of whom are full-bloods. This population comprises about 11,000 families. It is the obligation of the Government to provide these people with resources sufficient for them to attain economic independence at a reasonable standard of living. The present carrying capacity of the grazing range available to them is estimated at 611,000 sheep units. This would permit the grazing of approximately 70 sheep per family whereas at least 400 sheep per family are required to provide a minimum standard of living. Assuming that 3,000 of these Indian families will find their way into industry or otherwise secure their living off the reservation there remain 8,000 families to be provided for. With the range land divided equally they could each have not to exceed about 75 sheep per family. With the full development of all potentially irrigable lands totaling 135,000 to 150,000 acres it would be possible to assign an average of 15 to 20 acres of irrigable land to each

TABLE CXXXVI.—*Indian projects in the Colorado River Basin*

State project	Source of water supply	Irrigable area		Annual diversions	
		Present (acres)	Ultimate (acres)	Present (acre-feet)	Ultimate (acre-feet)
Arizona:					
Ak Chin	Wells	670	670	1, 500	2, 680
Camp Verde	Verde River	170	425	950	2, 337
Chiu Chiu	Wells	615	700	1, 550	2, 800
Cocopah	Colorado River	100	425	600	2, 550
Colorado River	Colorado River	9, 400	100, 000	56, 400	600, 000
Fort Apache	White River	2, 000	6, 000	10, 000	30, 000
Fort Mojave	Colorado River	20	9, 000	100	54, 000
Fort McDowell	Verde River	600	1, 400	3, 600	8, 400
Gila Bend	Gila River	0	400	0	2, 400
Gila River	Gila and Salt River	7, 400	12, 925	37, 320	[1] 77, 955
Havasupai	Spring	175	200	1, 050	1, 200
Hualapai	Big Sandy Creek	40	170	200	1, 020
Kaibab	Spring	40	40	160	160
Hopi	Miscellaneous streams	660	730	3, 300	3, 650
Navajo	Miscellaneous streams	13, 740	45, 270	68, 700	226, 350
Salt River	Salt and Verde Rivers	9, 800	10, 000	39, 200	40, 000
San Carlos	Gila River	100, 000	100, 000	370, 000	[1] 600, 000
San Carlos Reservation	Gila and San Carlos Rivers	1, 000	1, 000	6, 000	6, 000
San Xavier	Santa Cruz River	1, 640	1, 700	9, 840	9, 840
Subtotal		148, 070	291, 055	610, 470	1, 671, 342
California:					
Coachella Valley	Colorado River	125	14, 500	500	87, 000
Fort Yuma		7, 850	7, 850	47, 218	47, 218
Subtotal		7, 975	22, 350	47, 718	134, 218
Colorado:					
Southern Ute	Pine River and Creeks	8, 400	19, 850	42, 000	70, 250
Ute Mountain	Mancos River	200	500	1, 000	2, 500
Subtotal		8, 600	20, 350	43, 000	72, 750
Nevada:					
Moapa	Moapa River	325	600	1, 950	3, 600
Subtotal		325	600	1, 950	3, 600
New Mexico:					
Jicarilla	LaJara and Dulce Creek	800	5, 000	4, 000	25, 000
Monument Rocks	San Juan River	0	25, 500	0	127, 500
Navajo	Miscellaneous streams	12, 000	22, 500	60, 000	112, 500
Shiprock	San Juan River	0	70, 000	0	350, 000
Zuni	Zuni River	6, 200	10, 000	31, 000	50, 000
Subtotal		19, 000	133, 000	95, 000	665, 000
Utah:					
Shivwits	Santa Clara River	70	85	420	510
Uintah	Uintah, Duchesne, Lake Fork and White-water Rivers.	77, 000	77, 000	232, 000	232, 000
Uncompahgre	White and Green Rivers	1, 250	22, 000	3, 750	66, 000
Subtotal		78, 320	99, 085	236, 170	298, 510
Total		262, 290	566, 440	1, 034, 308	2, 845, 420

[1] Includes a supplemental supply from the Colorado River in connection with the proposed Central Arizona development.

of the 8,000 families in addition to which each family could graze an average of 75 sheep. This would not solve all the economic problems of the Navajo but would raise his present standard of living considerably. Many of these Indians were in the armed services and many more were engaged in war work. Now the war is over these people must inevitably return to the reservations. Unless detail plans can be developed and construction work started on these proposed irrigation developments immediately, the conditions on this reservation will be such as to require the expenditure of large sums for relief or "made" work; this alternative must be avoided.

Zuni.—Within the Colorado River Basin is the Zuni Pueblo. On the pueblo lands 6,200 acres are now provided with irrigation facilities and it is proposed to expand the irrigated area to 10,000 acres. Water is secured from the Zuni River, a tributary of the Little Colorado River. The present average annual diversion is 31,000 acre-feet and the average annual diversion requirement for the ultimate area is 50,000 acre-feet. Additional surveys and studies are necessary in order to define the ultimate irrigable area and prepare cost estimates.

Utah

Within the Colorado River Basin in Utah are three Indian projects. The total present irrigated area is 78,320 acres and it is proposed to expand the area to 99,085 acres. The present average annual diversion is 236,170 acre-feet and the average annual diversion requirement for the ultimate area is estimated at 298,510 acre-feet. The projects are described as follows:

Shivwits.—On the Shivwits Reservation there are 70 acres being irrigated and it is proposed to expand the area to 85 acres. The present average annual diversion is 420 acre-feet and the average annual diversion requirement for the ultimate area is 510 acre-feet. The diversion is from the Santa Clara River.

Uintah.—On the Uintah Reservation there are 77,000 acres now provided with irrigation facilities. The average annual diversion is 232,000 acre-feet. The water supply for this project is secured from the Uintah, Duchesne, Lake Fork, and Whitewater Rivers. No expansion of the project area or increase in diversion is contemplated.

Uncompahrgre.—On the Uncompahgre Reservation there are 1,250 acres now provided with irrigation facilities and it is planned to expand the irrigated area to 22,000 acres. The water supply is secured from the White and Green Rivers and several small creeks. The present average annual diversion is 3,750 acre-feet and the average annual diversion requirement for the ultimate area is estimated at 66,000 acre-feet.

Summary

Table CXXXVI lists the various Indian projects by States, showing the present and ultimate irrigable areas, the present and proposed annual diversions in acre-feet, and the source of water supply.

Of the Indian projects listed, the Navajo in Arizona and New Mexico, and the Colorado River in Arizona, are of major importance in the rehabilitation of the Indians of the basin. The need for the early completion of all Indian projects is acute but the need for the full development of these two is most urgent and their completion should be given a first priority. The employment provided during the construction period will greatly alleviate the problems involved in the return of the Indians in the armed services and those engaged in war work to a peacetime economy.

GENERAL LAND OFFICE

Colorado River Basin

Since the organization of the General Land Office in 1812 the legislative framework built up in relation to public land policy has been incorporated in over 5,000 public land statutes. While many of these laws are concerned with the disposal of the public domain, much of the more recent legislation deals with the management and conservation of the remaining public lands and their resources, through leases, exchanges, and reservations.

Public domain in the Colorado Basin.—In the Colorado River Basin there are about 6,000,000 acres of unappropriated and unreserved public domain under the jurisdiction of the General Land Office. This is land area outside of grazing districts and other public land programs. The General Land Office exercises immediate and sole jurisdiction over all activities on these 6,000,000 acres. It has the major responsibility for all nongrazing activities in grazing districts and is responsible for all land titles and the administration of the mining and mineral leasing laws affecting lands in the national forests and within many other public land projects.

Within the Colorado River Basin there are eight major subareas in which the activities of the General Land Office will be largely concentrated to assist in obtaining the highest development and use of the resources in connection with the basin development program. These areas are (1) the Imperial Valley, California, (2) the lower portion of the Gila River in southwestern Arizona, (3) southern Arizona in the vicinity of Tucson, (4) central Arizona from Phoenix north to the Colorado River, (5) east central Arizona in the upper reaches of the Little Colorado River, (6) western New Mexico, (7) Duchesne and Carbon Counties, Utah, near the Green River, and (8) the Yampa River in northwestern Colorado.

There are many problems now being experienced in administering the public land in these areas largely arising from conflicts in use between irrigation and dry-farm crop production, grazing, homesites, and mining. As water and land improvements are made in the basin for expanding irrigation, power production, industrial production, and for numerous other purposes there will be many more and considerably intensified conflicts in land use. The administration of the public lands is also especially difficult and complicated due to the scattered nature of the tracts remaining in the public domain as the result of the earlier land disposal practices and the importance of many of these tracts in the utilization of adjacent lands in the localities in which they lie and in the area economy. The problem will be further complicated if large reservations of public lands for military purposes in the basin are released, requiring major readjustments in the use of large areas for peacetime pursuits.

Land classification.—Prior to designating land for a certain use, or acting upon an application for sale, settlement or exchange of public domain, it is required that such land be classified as to its suitability for the purpose intended. As a rule due to the limited staff and funds and the large area of public domain located in disconnected tracts throughout the 29 public land States, the past procedure has been mainly limited to the classification of a tract of land after an application is received from an individual or State. A few small areas of land have been classified or are in the process of classification as to the best adaptable use. While such area classifications are not static and are subject to modification, they provide a more practical basis for guiding public land policy and administration.

Only cursory information has been assembled for most of the unappropriated and unreserved public domain acreage. The absence of detailed physical and economic information has tended to handicap the General Land Office in its administration of public lands. The need for classifications embracing broader areas has become increasingly pronounced, especially for the integration of the development and use of the public lands with other lands. It is essential in the shift from war to peace and in the program for attaining the fullest development of the Colorado Basin that the land classification studies be made in greater detail and over larger areas. Considerably more detailed land classification is required to indicate better the purpose for which lands are physically and economically suited and to provide the necessary basis for determining the most feasible conservation and land management programs in line with local as well as national needs.

The physical survey will develop information on soils, relief, slope, drainage, elevation, water supply, and vegetative cover which involves considerable field work, mapping, and use of aerial photographs. Economic studies involve the relationships between those persons utilizing public and privately-owned lands; thus taking into consideration such factors as pattern of ownership, public improvements, private improvements, the type of grazing, forestry, industrial, agricultural, and other operations in the locality, and the cost and coordination of land development, utilization and management.

Coincident with and a part of land classification is the determination of which lands should be retained in public ownership and the planning of a unified management program that encourages the most productive use of these lands from a public viewpoint. Proper management encompasses policies dealing with multiple land uses, such as grazing, forestry, mining, and recreation.

The grazing of livestock is now the most important present use, but it is not in all instances the highest or the proper use, for many portions of the public lands. The most fruitful management program for grazing lands will be consolidation of ownership through planned exchanges and range improvements to promote the optimum retention of range resources after considering the protection of watersheds and the long-time benefit to stock ranches. The General Land Office has, in cooperation with lessees, made soil and moisture range improvements that enhance the value of the range resources, which is in the interest of the public as well as the individual. However, this improvement program has been on a small scale considering the total area involved and the need for such work. More specific land classification information is needed concerning areas where new sources of surface or ground water supplies can be developed to permit a better distribution of livestock on the range, and to open up areas that now have little value because of stock water problems. Extensive studies are needed on the carrying capacity of grazing land to indicate those areas where seeding programs are desirable or special precautions are required to minimize soil erosion. These studies will also denote the needs for flood control works and reservoir siltation reduction that may include the diversion and spreading of water on favorably located range lands and other measures. Irrigation development creates the need of additional land economic studies, for example, to determine the extent of disturbance on range management programs through the opening of newly irrigated lands. It is through such development that a vital need for increasing the range forage supply is created, since high feed production on irrigated lands must for the greatest economy be supplemented with grazing lands. The end result should lead the way for action programs involving (1) construction of stock-watering facilities; (2) building stock trails; (3) reseeding range lands; (4) construction of range fences; (5) rehabilitation of eroded range areas; and (6) better control of predatory animals.

Land classification on a broad basis will also bring into better focus the ownership and tenure pattern in localities concerned with composite range areas. It will provide the basis for a program designed to attain a better ownership pattern through acceleration of land exchanges that will make for better use of land and more efficient administration.

Practically no public lands remain that can be used for agricultural purposes in their natural state. Irrigation and drainage are in most instances necessary. Lands susceptible of irrigation at a cost within the reach of private enterprise have generally been reclaimed by the States, operating under the Carey Act, or by individuals or irrigation companies. The areas which may be reclaimed by irrigation through individual initiative are small and isolated. The irrigation of any considerable body of arid public land, such as commonly found in the Colorado Basin, now largely depends upon its inclusion in a project similar to those handled by the Bureau of Reclamation. Any public lands which are included in these projects are withdrawn from other disposition by the General Land Office under the established public land laws. The problem of eliminating adverse ownership in the reclamation project areas has occurred in other river basins and it will probably be significant in the Colorado Basin. This can be alleviated through a properly planned land exchange program.

Through its land classification investigations in the Colorado Basin, the General Land Office, in cooperation with other agencies, will also endeavor to determine the extent and availability of surface and ground water supplies of those public lands capable of irrigation from the standpoint of soils and topography which are not to be included in the Bureau of Reclamation projects and ascertain the economic feasibility of irrigating these lands. Any of these lands which are found to be suitable for irrigation will be mainly utilized in connection with established farming and ranching enterprises.

The General Land Office administers sustained forest yield units on public lands in cooperation with individuals, corporations, States and their political subdivisions, and other Federal agencies. While it is not anticipated that much of the public land in the Colorado Basin will be found to be forest in character, consideration will be given to the establishment of sustained forest yield units, if feasible, for the protection of downstream lands and reservoirs from siltation and rapid water run-off and to promote improved management and utilization of any timber resources.

Technological advancement and other factors are constantly raising public lands to considerably higher uses which in the past have been considered to be practically worthless. Large areas of these lands are in demand for airfields, industrial plants and supplementary facilities for these plants, home, recreation, and business sites. The direction of public lands to these higher uses is an important phase of land classification in attaining maximum public benefits from the advanced development of the Colorado Basin.

Cadastral surveys.—As a part of the General Land Office's participation in basin developmental programs, it has been found that cadastral surveying must necessarily be expanded and accelerated to facilitate the land classification work and the activities of other participating bureaus. The amount of this work is especially dependent upon the needs of the cooperating bureaus.

The cadastral survey consists of the surveys of unsurveyed lands and the resurvey of lands surveyed many years ago for the reestablishment of boundary lines and obliterated corners. The only official surveys in the public land States are those made by the General Land Office. These surveys are a highly important function for identifying land in the basin developmental programs where dams requiring large reservoir sites and other improvements are involved.

The cadastral survey work in the Colorado Basin will not be limited to the unappropriated public domain as it is necessary in areas administered by other public agencies and even on patented lands. To promote greater efficiency in the conduct of the departmental basin programs there are indications that it might be helpful to expand the scope of the cadastral surveys to include surveys for purposes such as rights-of-way.

Mineral claims.—Title may be obtained under the mining laws for lands which contain metalliferous minerals. In many patents issued for public lands in recent years the mineral rights are reserved to the United States and the right to develop nonmetalliferous minerals may be acquired under the mineral leasing laws which are administered by the General Land Office.

Generally, the right to extract metalliferous minerals is established by a prospector through a claim which does not ordinarily come to the attention of the General Land Office until an application for patent is made or until some interest of the United States intervenes, but such claims when properly located, recorded in the applicable county office, and maintained and based on the discovery of mineral are valid. It is often found that reservoir sites include mining claims of record, though valueless for mineral and not properly maintained. The record must be cured before reservoir or other improvements can be made without danger of a suit for damages when the claim is flooded or otherwise endangered. The General Land Office makes investigations to determine validity of such claims and where the claims are found invalid conducts appropriate proceedings for the cancellation of the claim, and in many instances, at the request of the Bureau of Reclamation or other agencies, conducts investigations to determine the value of such claims as are found to be valid. There will in all probability be a pronounced need for these services in the development of the Colorado River Basin.

The right to exploit nonmetalliferous minerals, as indicated above, is handled by the General Land Office through leases. The return to the Federal Government from these leases is high, although the maintenance of the resource is the principal object in their administration.

All determinations relating to the mineral character of land are made in close cooperation with the Geological Survey.

Summary of proposed general land office program.—The General Land Office program for the Colorado River Basin will largely consist of land classification, cadastral surveys, and investigation of mineral claims.

Under the program of the General Land Office, land classification studies will be conducted primarily in the eight areas mentioned. They will be concentrated at the oustset on those areas where the departmental basin development activities demand the most immediate action. The work will be interrelated and coordinated with the programs of other Federal agencies as well as the activities of States and counties. It is estimated that the classification can be completed for the 6,000,000 acres of unappropriated public domain in from five to six years with an annual expenditure of approximately $100,000. This figure only provides classification for small areas that may be released from military reservations. Should large areas of public land reserved for military purposes be returned to the jurisdiction of the General Land Office it may be necessary to extend the time for land classification.

Since the amount of cadastral survey work is so dependent upon the needs of the cooperating bureaus, it is difficult to estimate at this time. From the experience being gained in basin developmental programs, it is believed that the work will require annual expenditures in the Colorado River Basin during the planning and early development stage of approximately $150,000.

The work in connection with investigating and evaluating mineral claims is separate and distinct from land classification. This activity will be accomplished to a large extent at the request of the cooperating bureaus as a service function. The annual cost of the work for an expanded program in the Colorado River Basin may amount to approximately $60,000.

FOREST SERVICE

National Forests and Reclamation in the Colorado River Basin

About one-eighth of the Colorado River drainage basin is national forest land under the jurisdiction of the Forest Service, United States Department of Agriculture. These lands embrace most of the high mountains and plateaus which rim the basin. Though separated by extensive benchlands and foothills from the semiarid valley where most of the settlements are situated, the humid uplands provide a wealth of resources—especially water, but also wood, forage, minerals, wildlife, and recreation—which are essential to the economic development of the basin.

Although their areal extent is relatively small, the national forests play a disproportionately large role in basin water supplies, since they produce well over half of the annual (undepleted) water yields of the basin; and, in terms of unit yields, these forested mountain watersheds produce annual gross water yields ranging up to an acre-foot or even more per acre.

Man cannot control the amount of seasonal distribution of precipitation; but he can do much to influence the volume, quality, and duration of streamflow through a series of manipulations starting with watershed management, extending through stream developments, and ending with irrigation and domestic use at some distance from the source of the water. Of these cultural practices, watershed management stands high in importance because of the strong influence of watershed vegetation on water yields. On the one hand, vegetation reduces their total volume by consuming water, although in doing so it produces wood and forage to supply human needs; on the other hand, it influences the quality and distribution of stream flow by retarding floods and minimizing soil erosion and siltation. Hence good management involves the balanced use of forest and range resources so as to reduce water losses on the watershed and to produce a maximum volume of clear, usable water as well as to provide wood products, forage, wildlife, and recreation.

Thus it can readily be seen that water is the key resource of these national forests, and that the management of these forests for maximum production of usable water is one of the most important responsibilities of the Forest Service in the Colorado River Basin. For this reason the Forest Service has maintained as one of its dominant objectives the protection and management of the watershed lands under its jurisdiction. Wherever floods and erosion have been aggravated by misuse of these lands, good watershed management has required carefully restricted timber cutting and grazing use, or in some instances complete protection of the vegetative cover.

Recently research by the Rocky Mountain Forest and Range Experiment Station has begun to show that revised management practices on many high-altitude watersheds will not only result in an increase in stream flow but also will make available additional wood products. In a lodgepole pine forest, for example, like that which occupies about 3 million acres of water-yielding land in Colorado and Wyoming, the removal of commercially salable timber has increased the amount of water available for stream flow about 3¼ inches, or about 30 percent, over that which is ordinarily available on uncut virgin forest—and without noticeable damage to the soil resource or the watershed as a productive area.

The implications of these results are clear, although their quantitative interpretation requires some qualification. If similar findings can be applied to other watersheds in the lodgepole pine type and to other high-altitude forest types in the Colorado River basin, substantial increases in water yield may be accomplished by properly managed timber cutting. As compared with the observed increases on local areas, however, their average magnitude over the national forests of the basin will be considerably smaller, because the full effect of timber cutting can be obtained on only a portion of the total area at a time. Other portions are inaccessible or must await the development of the most intensive management; others must be protected against floods and erosion; and still others will be producing a new forest after they have been cut-over. But even so, worthwhile increases in

COTTONWOOD CAMP, BIG PINEY, WYO.
High mountains in upper basin support extensive stands of timber

water yield would be obtained by any expansion on managed timber cutting. And, incidentally, millions of board feet of lumber and other forest products would be released for human use; simply because, on high-altitude forest lands, all the trees are not required to protect the watersheds.

In addition to these high-altitude forested watersheds, large areas of other watershed land at both high and low elevations are in depleted condition due to past and present overgrazing and cultivation. As a result these lands present a serious problem of erosion and siltation; a problem which is still by no means solved. However, research by the Intermountain Forest and Range Experiment Station has shown, on limited areas, that these eroding lands can be healed by changes or reductions in land use, by artificial revegetation, and by small mechanical structures—often at an actual profit to the private owner. Watershed improvements such as these when extended to larger areas, will help minimize the silt content of our mountain rivers, and thus will actually increase the yield of usable, silt-free water, and will decrease excessive high irrigation project maintenance costs.

Up to now, because of limited funds and personnel, this watershed research on stream flow and soil stability problems has been restricted in scope and confined to relatively small areas. Hence the results do not yet permit broad recommendations for the management of other forests and range types or even other watersheds within a single type, because the most desirable management will change with variations in the forest, climate, and soil. Thus, in order to broaden the basis for establishing and modifying watershed-management policies, this productive research needs to be intensified and extended to other valuable water-producing areas. In addition, more information is needed on how to cut timber and graze forage in order to insure a future crop of wood and ranch products as well as water, and how to log and utilize the timber most completely and efficiently, so that private operators can afford to cut timber where and when it should be removed.

Since the production of ample supplies of usable water is intimately bound up with the other natural resources of the national forests, it is worth while also to appraise the relative importance of these other resources in the reclamation picture; to see how their use is associated with agrculture; and to evaluate the requirements of good resource management. The national forests, for example, contain nearly all of the merchantable and much of the nonmerchantable timber stands within the basin. The commercial timber volume totals about 30 billion board feet, the principal species being ponderosa pine, Douglas fir, lodgepole pine, fir, spruce, aspen, juniper, and piñon pine. These forest areas thus far have provided all of the rough lumber, posts, poles, and fuel-wood needed in the basin, but have furnished only about one-fourth of the demand for finished lumber. Inaccessibility, insects, disease, and fire have been the chief deterrents to a fuller use of the forest lands. Expansion of irrigation and related enterprises within this basin will create a demand for more timber products. Preliminary studies indicate that at least 50 percent of the finished lumber can be obtained locally, but detailed surveys and silvicultural investigations are needed to guide the more intensive utilization of the forested areas that will be required to reach this goal.

The herbaceous and shrubby forage on the national forest lands constitute an important part of the year-round food supply for a large range livestock industry within the basin. These lands are grazed by about one-third of a million cattle and 2 million sheep. A small portion of these animals graze year-long on parts of some of the forests in the lower basin. Most, however, graze on the forests only during the summer season and are then moved to adjacent ranges and farm pastures, fields, and feed lots for the remainder of the year. A dominant fact about the national forest range lands is that they are now fully stocked and in local areas are overstocked. Future

HAULING LOGS, ASHLEY NATIONAL FOREST

Timber resources will be more fully utilized with basin development

irrigation developments in the basin therefore should be planned with a view toward balancing the amount of pasturage, hay, and grain feed to be produced on the new farms with the sustained grazing capacity of the range lands.

The national forests are the home of big game, fish, and upland birds. Generally speaking there is room for more game on these lands except for restricted localities where big game populations, especially deer, have become excessive. Expansion of irrigation agriculture by regulation of stream flow and occupation of the winter grazing lands of deer will encroach upon the habitat of both fish and game. Moreover, expansion of settlement no doubt will increase the number of hunters and fishermen. These prospective impacts will require intensification of wildlife management on the national forests with a view toward eliminating local overpopulations of game and providing greater numbers on other areas which are now deficient.

The recreational opportunities on the national forests have long been an attraction for the general public. The number of forest recreationists increased by leaps and bounds during the prewar years. This trend will be revived after the war and any expansion of irrigation and related enterprises within the basin no doubt will augment this trend. The Forest Service is preparing to accommodate these visitors with adequate facilities. However, experience has demonstrated that man-caused forest fires mount rapidly with each increase in number of visitors. Obviously, any expansion of settlement within the basin which results in increased fire hazard will require intensified fire control to prevent damage to the forest, range, wildlife, recreation, and watershed protection values on the national forest lands.

The national forests already have contributed to the settlement and development of this basin area. Expansion of settlement through new irrigation and related projects will result in heavier demands upon all national forest resources. These increased demands in turn will require intensification of research, management, and protection in order that the wild lands may continue to contribute to the economy and welfare of the basin.

FEDERAL POWER COMMISSION

Power Resources of the Upper Colorado River Basin

Colorado, Utah, and Wyoming.—Water to transform through irrigation the latent soil resources of the arable portions of the Colorado River drainage in the upper basin States and the potential power, developed as a byproduct of irrigation and river regulations, to transform treasures of past ages buried in the rocks of the basin into products of industry, should be the objectives of current studies by Federal and State agencies. Both the water and power possibilities are of such magnitude and importance that they should be developed simultaneously to improve the economic conditions of the area and add to the wealth of the Nation.

The use of these prime resources cannot be fully or soundly planned without a prior complete inventory of all of the other resources of the basin. There are physical limitations to the extensive use of water for irrigation within the area which are receiving study by interested agencies. The irrigation possibilities now are fairly well known. Lack of personnel during the war period has prevented the Commission's staff from as adequately studying the power possibilities and uses. Such planning activities are properly of the postwar period and are high in the list of planned studies by the Commission's San Francisco regional office.

These will include investigations of uses to which power developed in the Colorado River Basin as a byproduct of other water uses may be put; first, to extend existing industries and to create new industries within the upper basin which will make the products of the soil and mines available for the use of man; and second, to supply the power requirements in neighboring areas, especially in the developed area along the Wasatch front. These studies will contemplate the development of the raw materials from the soil and mines as a first step only, followed by those industries and processes that produce finished products from the raw materials. The objective will be to produce through the power and material resources of the basin a balanced economy.

Coal and oil shales are presently known resources of the area capable of influencing to a great extent the basin economy. Oil and gas possibilities are now being explored. These fuels for a time may offer competition with hydroelectric developments, especially so should steam or gas turbine development permit the use of these fuels in electric production more economically than at present. Other important uses for these fuels are continuously being developed and although the extent of the deposits appears unlimited at the present time, sound economic planning may reserve these great resources for higher uses. Hydro- and fuel-electric plants, therefore, may well supplement each other in any plan of basin development.

The power possibilities inherent in the Upper Colorado should be so developed ahead of the demand as to provide an incentive for the development of the basin's resources, to make increased agricultural development possible, and to permit a fuller life for those within the area. The replacement of power now generated during the nonirrigation season in plants located on the Wasatch front by Colorado River power, appears to offer possibilities for large economic gains. Water now wasted in the Great Salt Lake could then be utilized to irrigate thousands of acres of additional lands, creating new homes and providing food for those needed to man the industries made possible by the development of the basin's resources.

The development of the power resources of the Colorado River Basin may have a profound effect on the program of development in adjoining areas, affecting power markets in Colorado, Wyoming, Idaho, and Arizona, and, by present interconnections, even in California, Montana, Washington, and Oregon. Utah at present depends in large measure for its power supply upon importations from Idaho. A survey of the power market and supply of any area must take account of conditions far distant from the immediate area under consideration.

In any broad study of the ultimate development of the Colorado River in the upper basin States, consideration must also be given to the necessary transportation system. The Upper Colorado area is completely surrounded by high mountain ranges and the major streams enter and leave through deep, impassable gorges. As the resources are developed the transportation systems must be greatly extended. Electric power may assist materially in improving and extending existing transportation facilities.

These and other possibilities are well recognized. Such analysis as is possible within the limits of the personnel available will be undertaken to the end that the power resources may contribute their full share to the development of the region without conflicting with the uses of other resources nor detrimentally affecting other important water uses.

Power Resources of the Lower Colorado River Basin

Arizona, California, Nevada, and New Mexico.—In this region water for irrigation and domestic supply is extremely valuable and must be very carefully controlled and utilized. Without development of the water resources, this region will remain forever static, mostly in the form of desert. The irrigation possibilities are vast when it is considered that only a very small percentage of this latent, fertile area is under irrigation. The highly successful irrigated areas in Arizona and southeastern California are evidence of the desirability of such development. Likewise, the long-distance transmission of domestic water to large urban areas in southern California indicates that the water of the Colorado is virtually the lifeblood of our Southwestern States.

Even after water is supplied from the Colorado to the lands or is transmitted to urban centers, there is still an enormous amount of potential hydroelectric power which should be developed along with irrigation to reduce the cost of land development and to develop a balanced economy in the region. Most of the undeveloped power projects are very large, and in some instances step construction may be in order.

The Commission's staff has made detailed studies of several power sites on the main Colorado and certain of its tributaries. Although some of the sites, for instance Bridge Canyon and Glen Canyon, are great distances from present load centers, large blocks of power could be used for pumping, and development of the large mineral (magnesium chloride and other) resources of southern Utah. The balance of this power could be transmitted to Boulder for use there, and to Arizona; and Boulder power could be transmitted in its entirety to California. Furthermore, the art of power transmission is being steadily developed, which no doubt in time will allow direct transmission to large load centers.

To develop and improve the economy of the region in all its phases and to add in the greatest measure to the wealth of the Nation should be the objective of the State and Federal planning agencies. To this end, the first step should be to collect all available information relative to the region, its resources, and its potential markets. The Commission's staff has prepared an intensive study pertaining to the economy and the development of Arizona. After the war, when manpower is available, the Commission's staff in San Francisco plans to look further into the possibilities of this and adjacent regions.

Both the irrigation and power possibilities for the Lower Colorado River are fairly well known and have been studied by several agencies; but a great deal of planning is still necessary to coordinate properly the various uses of the water to obtain the greatest over-all and equitable benefits to the States involved and to the Nation. Such studies would include investigations of uses to which power produced in the Lower Colorado River Basin, as a byproduct of irrigation and other uses, may be put. The expansion of existing industries and the creation of new industries, thereby developing the products of the soil including minerals, is the first step. This would be followed by studies of industries which would produce finished products from the raw materials, thereby obtaining, through the use of irrigation power, industries, and other uses, a balanced economy in the basin.

Extensive coal and oil shale deposits in Utah may also be an important influence in the basin economy. It may be that these fuels will offer some competition to hydroelectric development. However, it is believed that they will be found most useful in furnishing steam support to the hydroelectric developments during critical periods.

In order to provide rapid development and industrial growth in the Lower Colorado River Basin, the inherent hydroelectric as well as irrigation possibilities should be developed ahead of the demand. This will provide incentive for the development of the basin's resources and will accelerate agricultural and industrial development. Experience has shown that it is not necessary to have a large existing market before constructing hydroelectric projects. This is borne out in the case of the Columbia River Basin and the extensive TVA development.

Further possibilities of development aside from those discussed above are recognized, flood control being one of the most important. Such analyses, as are possible with the personnel available in San Francisco, will be made of the power resources taking into account the economic and orderly development of the region and the recognized higher use of water for land development, domestic supply, and other important uses.

The following reports on the Colorado and its tributaries and adjoining areas, have been prepared by the Federal Power Commission's staff:

(*a*) Report on State of Arizona's application for preliminary permit to develop power on the Colorado River at Bridge Canyon, by E. W. Kramer, May 31, 1940, and John S. Cotton, January 1, 1942. (This report also deals with, to a limited extent, Glen Canyon, Davis and Parker projects.)

(*b*) Report on Bill Williams River Project, by John S. Cotton, September 1943.

(*c*) Report on application on Mineral County, Nevada, Power system, by W. A. Froggatt, October 1942.

(*d*) Gila River Power Investigation, by Neil F. Meadowcroft, August 1943.

(*e*) Arizona Power Survey, Federal Power Commission Staff, March 1942.

Water Supply,
Colorado River

APPENDIX I

Water Supply, Colorado River

Historical Flow at Lee Ferry

The Colorado River Compact made allocations of Colorado River Basin waters between the upper and the lower basin, with Lee Ferry, below the mouth of the Paria River near the Utah-Arizona boundary, the point of division.

Systematic stream-flow records have been secured at the Lees Ferry gaging station on the Colorado River above the mouth of the Paria River since June 1921 and on the Paria River at its mouth since October 1923. The sum of the records secured at these two stations determines the flow at the point "Lee Ferry" described in the Colorado River Compact. To determine the flow at this point prior to the period of record at Lees Ferry estimates were made, using the results of stream-flow measurements on the principal tributaries (Colorado at Cisco, Utah; Green at Little Valley, Utah; and San Juan at Farmington, N. Mex.) since 1897 and on the main stem of the Colorado River at stations below Lees Ferry, where records have been maintained as follows:

Hardyville, Ariz., May 1905 to September 1907.
Yuma, Ariz., Since January 1902.

For the years 1897–1901, inclusive, the estimated flow at Lee Ferry is based entirely on the records of the principal tributaries, with due allowance for unmeasured gains between the points of measurement on these tributaries and Lee Ferry. For the years 1902 and 1921, inclusive, the estimate considered both tributary flows and flows at downstream gaging stations, with due allowance for both measured and unmeasured gains and losses between Lee Ferry and the point of measurement. When basing the estimate on the Yuma record, allowances were made for the flow of the Gila River at its mouth and for diversions by the Yuma project.

The following table shows the recorded and estimated annual flows of the Colorado River at Lee Ferry for the years 1897–1943, inclusive. It also shows the combined flows at the principal tributaries and at the main stem base station used in making the estimates. Because of the numerous estimates necessary in extending the record, the flow for any individual year may be considerably in error, but the long-time average flow is believed to be reasonably correct.

TABLE CXXXVII.—*Recorded and estimated historical discharges—Colorado River at Lee Ferry*

Calendar year	Main-stem station		Sum of Colorado River at Cisco, Green at Little Valley, and San Juan at Farmington (thousand acre-feet)	Historical flow, Colorado River at Lee Ferry [1] (thousand acre-feet)
	Name of station	Recorded flow (thousand acre-feet)		
1897 [2]			18, 721	19, 797
1898 [2]			12, 206	12, 948
1899 [2]			16, 925	17, 899
1900 [2]			11, 996	12, 686
1901 [2]			12, 925	13, 668
1902 [2]	Yuma, Arizona	7, 959	8, 245	8, 454
1903 [2]	do	11, 328	12, 550	12, 346
1904 [2]	do	10, 118	12, 505	11, 675
1905 [2]	do	19, 712	13, 800	15, 290
1906 [2]	Hardyville, Ariz	19, 162	18, 131	18, 656
1907 [2]	do	21, 547	20, 755	21, 179
1908 [2]	Yuma, Ariz	13, 688	10, 852	12, 065
1909 [2]	do	25, 975	20, 543	23, 295
1910 [2]	do	14, 335	12, 392	13, 583
1911 [2]	do	17, 840	14, 688	16, 473
1912 [2]	do	18, 406	17, 686	18, 393
1913 [2]	do	11, 748	12, 394	12, 581
1914	do	20, 684	18, 206	19, 868
1915	do	14, 641	10, 964	12, 396
1916	do	23, 140	16, 865	18, 380
1917 [2]	do	20, 598	19, 918	20, 436
1918 [2]	do	13, 158	13, 373	13, 775
1919 [2]	do	10, 747	9, 980	10, 611
1920 [2]	do	21, 444	18, 764	20, 387
1921 [2]	do	19, 428	18, 728	19, 572
1922				16, 198
1923				16, 868
1924				11, 707
1925				12, 412
1926				13, 080
1927				17, 549
1928				14, 714
1929				19, 632
1930				12, 414
1931				6, 229
1932				15, 180
1933				9, 750
1934				3, 966
1935				10, 283
1936				12, 145
1937				12, 006
1938				15, 661
1939				8, 872
1940				7, 617
1941				17, 888
1942				14, 809
1943				11, 435
Average				14, 400

[1] Determined in following manner: 1897-1901, estimated from flow of principal tributaries; 1902-1921, estimated from flow of principal tributaries, and flow at main-stem station; 1922 and 1923, flow at Lee Ferry increased by estimated discharge Paria at mouth; and 1924-1943, Colorado at Lee Ferry plus Paria at mouth.

[2] Flow at one or more base stations on principal tributaries estimated in whole or part by comparison with records elsewhere on stream.

TABLE CXXXVIII.—*Acreage irrigated above Lee Ferry*

Year	Colorado	New Mexico	Utah	Wyoming	Totals	Rounded totals	Source of data
1899 [1]	323, 000	15, 000	77, 000	100, 000	515, 000	515, 000	Census.
1902	417, 839	20, 467	80, 778	118, 566	637, 650	638, 000	Do.
1909 [1]	615, 000	32, 000	169, 000	195, 000	1, 011, 000	1, 011, 000	Do.
1919	766, 532	43, 825	332, 984	211, 507	1, 354, 848	1, 355, 000	Do.
1922	800, 000	42, 000	370, 000	235, 000	1, 447, 000	1, 447, 000	Reclamation.
1929	856, 413	40, 253	324, 681	228, 699	1, 450, 046	1, 450, 000	Census.
1935 [2]	767, 060	32, 190	276, 630	236, 070	1, 311, 950	1, 312, 000	Reclamation.
1939	844, 494	36, 178	305, 628	273, 971	1, 460, 271	1, 460, 000	Census.

[1] Estimated from Census data by counties.
[2] Field surveys conducted during years 1932 to 1938, inclusive.

Past Upstream Depletion at Lee Ferry

The historical discharges shown in the preceding table represent the flow of the Colorado River as it occurred each year. If the same meteorological and climatological conditions of any particular year had occurred in the past, prior to the inception of irrigation development, the resulting stream flow would have been greater by an amount equal to past depletions due to irrigation consumption, reservoir evaporation losses, and transmountain diversions from the basin.

The history of past irrigation development in the Colorado River watershed above Lee Ferry is shown in the following table, which was taken largely from reports of Bureau of Census and from field surveys conducted by the Bureau of Reclamation.

With the exception of the 1935 areas, which were determined by plane-table surveys in the field, information on the area irrigated for each year reported was secured largely from information furnished by individual farmers, irrigation organizations, and State officials. The results are in fairly close agreement with the actual field survey made by the Bureau of Reclamation in 1935 (work in progress from 1932 to 1938, inclusive).

Since the Census data are available for a number of years, these have been used as the basis of estimating the past depletion due to irrigation within the basin. A uniform rate of increase in irrigated area has been assumed for the intervening years shown by the Census figures, except that all of the increase between 1919 and 1929 was assumed to occur between 1919 and 1922. The acreage irrigated since 1939 has been assumed to be the same as that shown by the Census as irrigated in 1939.

From experimental data on Reclamation and other projects the average annual depletion for the area irrigated above Lee Ferry has been estimated at 1.5 acre-feet per acre. In years of high run-off there is a tendency for overdiversion of stream flow, with a corresponding increase in depletion, particularly when reservoirs are available; conversely, in years of low run-off there are declines in the normal quantities of water available for diversion with a corresponding decrease in depletions. Allowances have been made for these conditions and for the year-to-year regulatory effect of the reservoirs by varying the normal depletions by an amount which is proportional to one-half of the divergence of the annual undepleted flow at Lee Ferry for the year in question from the mean annual undepleted flow.

In 1945 there were 80 reservoirs in the Upper Colorado River Basin having capacities of 1,000 acre-feet or more, with an aggregate storage capacity of about 1,080,000 acre-feet. In addition there are numerous small reservoirs of less than 1,000 acre-feet capacity each. No separate allowance has been made in this study for evaporation losses from the existing storage reservoirs above Lee Ferry. As indicated by the preceding table the acreages reported irrigated by the Bureau of Census in 1929 and 1939 are somewhat in excess of the acreage determined by actual field survey by the Bureau of Reclamation in 1932–38. In view thereof the past irrigation depletion, computed as described herein, is assumed to be adequate to include past evaporation losses from reservoirs above Lee Ferry.

Transmountain Diversions

Data on transmountain diversions now exporting water from the Colorado River watershed above Lee Ferry are summarized in the following table:

TABLE CXXXIX.—*Transmountain diversion above Lee Ferry*

Name of diversion	Basin where water is used	First year of operation	Present average annual diversion (acre-feet)
Grand River Ditch	South Platte	1903	19, 000
Moffat Tunnel [1]	do	1936	27, 000
Jones Pass Tunnel [2]	do	1940	6, 000
Busk-Ivanhoe Tunnel	Arkansas	1925	5, 900
Wurtz Ditch	do		2, 000
Twin Lakes Tunnel [3]	do	1935	32, 000
Tarbell Ditch	Rio Grande	1914	2, 000
Daniel Creek Ditches	Bonneville		4, 000
Strawberry Valley	do	1913	66, 000
San Pete	do	1936	8, 000
Miscellaneous small diversions.[4]	Various	Various	14, 000
			185, 000

[1] Project under construction. Average diversion for 1936–43, inclusive.
[2] Project not fully developed. Average diversion for 1940–43, inclusive.
[3] Project not fully developed. Average diversion for 1935–43, inclusive.
[4] Earliest diversion made in 1880.

To make allowance for the tendency to overdivert in years of high run-off and for shortages in years of low run-off the actual diversion for any particular year is assumed to deviate from the normal by an amount which is proportional to one-half the deviation of the undepleted stream flow at Lee Ferry from the normal.

TABLE CXL.—*Estimated virgin flow Colorado River at Lee Ferry*

[Thousand acre-feet]

Calendar year	Historical flow Colorado River at Lee Ferry	Estimated normal depletions		Estimated actual upstream depletion	Estimated virgin flow at Lee Ferry
		Irrigation within basin	Export from basin		
1897	19, 797	650	5	741	20, 538
1898	12, 948	711	5	658	13, 606
1899	17, 899	772	5	836	18, 735
1900	12, 686	834	5	764	13, 450
1901	13, 668	896	5	853	14, 521
1902	8, 454	957	6	751	9, 205
1903	12, 346	1, 036	6	948	13, 294
1904	11, 675	1, 118	11	1, 005	12, 680
1905	15, 290	1, 197	21	1, 230	16, 520
1906	18, 656	1, 276	21	1, 450	20, 106
1907	21, 179	1, 358	21	1, 655	22, 834
1908	12, 065	1, 437	21	1, 327	13, 392
1909	23, 295	1, 516	21	1, 960	25, 255
1910	13, 583	1, 568	21	1, 535	15, 118
1911	16, 473	1, 620	22	1, 740	18, 213
1912	18, 393	1, 671	22	1, 902	20, 295
1913	12, 581	1, 724	30	1, 646	14, 227
1914	19, 868	1, 774	35	2, 127	21, 995
1915	12, 396	1, 826	55	1, 760	14, 156
1916	18, 380	1, 878	85	2, 225	20, 605
1917	20, 436	1, 929	105	2, 449	22, 885
1918	13, 775	1, 982	105	2, 058	15, 843
1919	10, 611	2, 032	115	1, 890	12, 501
1920	20, 387	2, 080	115	2, 651	23, 038
1921	19, 572	2, 127	115	2, 652	22, 224
1922	16, 198	2, 175	115	2, 457	18, 655
1923	16, 868	2, 175	115	2, 508	19, 376
1924	11, 708	2, 175	115	2, 120	13, 828
1925	12, 411	2, 175	115	2, 171	14, 582
1926	13, 080	2, 175	115	2, 221	15, 301
1927	17, 551	2, 175	117	2, 560	20, 111
1928	14, 714	2, 175	120	2, 350	17, 064
1929	19, 632	2, 175	120	2, 723	22, 355
1930	12, 414	2, 175	120	2, 175	14, 589
1931	6, 229	2, 175	120	1, 707	7, 936
1932	15, 180	2, 175	120	2, 386	17, 566
1933	9, 750	2, 175	120	1, 973	11, 723
1934	3, 966	2, 175	120	1, 535	5, 501
1935	10, 283	2, 190	135	2, 043	12, 326
1936	12, 145	2, 190	160	2, 212	14, 357
1937	12, 006	2, 190	170	2, 212	14, 218
1938	15, 661	2, 190	180	2, 508	18, 169
1939	8, 872	2, 190	180	1, 973	10, 845
1940	7, 617	2, 190	180	1, 878	9, 495
1941	17, 888	2, 190	185	2, 688	20, 576
1942	14, 809	2, 190	185	2, 447	17, 256
1943	11, 435	2, 190	185	2, 180	13, 615
Mean	14, 400	1, 786	87	1, 870	16, 270

Virgin flow at Lee Ferry

Table CXL shows the estimated normal depletions due to irrigation development and transmountain diversions, the estimated past depletion above Lee Ferry (differing from the sum of estimated normal depletions by annual adjustments explained in preceding paragraphs) and the virgin (or reconstructed undepleted) stream flow at Lee Ferry for the 47-year period 1897 to 1943, inclusive.

Net Inflow between Lee Ferry and Boulder Dam

Between Lee Ferry and Boulder Dam there are about 55,000 square miles of drainage area, most of which is desert plateau. The two main tributaries in this area, the Little Colorado and Virgin Rivers, arise in the mountains and high plateaus bordering the basin; however, their principal source of run-off is from the torrential rains, which are characteristic of this locality. The Colorado River also receives water from numerous creeks and washes and from springs along the bed and sides of the deeply entrenched river channel.

From a study of the characteristics of the drainage area and by comparing discharges at Lee Ferry, Bright Angel (Grand Canyon), and Boulder Dam for the relatively short period when these stations were operated concurrently, prior to the storage of water in Lake Mead, it is concluded that about one-half of the net inflow between Lee Ferry and Boulder Dam occurs between Lee Ferry and Bright Angel.

The average annual discharges at these stations during the 21-year period 1923 to 1943, inclusive, are as follows:

	Acre-feet
Colorado River at Bright Angel	12, 988, 000
Colorado River at Lee Ferry (below Paria)	12, 582, 000
Net gain Lee Ferry to Bright Angel	406, 000

The estimated net gain from Lee Ferry to Boulder Dam in this period would be twice the gain to Bright Angel, or 810,000 acre-feet. With due allowance for the average annual depletion in this period by reason of irrigation development to the extent of about 60,000 acres on the tributaries between Lee Ferry and Boulder Dam, the average gain under virgin conditions in the 21-year period, 1923 to 1943, inclusive, would be about 900,000 acre-feet annually.

During the period 1923 to 1943, inclusive, the run-off from this region was somewhat below the long-time mean as indicated by the following comparisons:

TABLE CXLI.—*Comparison of average annual flows—long-time period with 1923–43 period*

Stream	Period used to determine long-time average annual flow	Average annual flow (thousand acre-feet)		Flow 1923–43 in per-cent of long-time mean
		Long-time period	Period 1923–43, inclusive	
Estimated undepleted flow, Colorado River at Lee Ferry	1897–1943	16, 270	14, 800	91
Salt River at Granite Reef Dam [1]	1895–1943	1, 484	1, 264	85
Virgin River at Virgin City, Utah	1909–1943 [2]	161	143	89

[1] Discharges corrected for storage changes in upstream reservoirs and past upstream irrigation depletions to reflect natural conditions.
[2] Fragmentary records prior to 1926.

From this comparison it is estimated that the inflow to the Colorado River in the 1923–43 period was about 85 percent of the long-time average. Thus the normal annual net gain, Lee Ferry to Boulder Dam, under virgin conditions would be 900,000 divided by 0.85 or 1,060,000 acre-feet annually.

Virgin flow at Boulder Dam Site

The long-time average virgin stream flow at Boulder Dam site, for the period 1897 to 1943, inclusive, is determined by adding to the longtime average virgin stream flow at Lee Ferry the estimated net gain under virgin conditions as follows:

	Acre-feet
Average virgin flow at Lee Ferry	16, 270, 000
Average virgin gain to Boulder Dam site	1, 060,000
Average virgin flow at Boulder Dam site	17, 330, 000

Inflow between Boulder Dam and mouth of Gila River

The area drained by the Colorado River between Boulder Dam and the mouth of the Gila River is typically desert country broken near the Colorado River by several small mountain chains. Only one permanent stream, the Williams River, enters the Colorado in this region. The remaining area is drained by washes, dry except for short periods following heavy localized rains.

Discharge records are available of Williams River at a point about 12 miles above the mouth (drainage area 5,140 square miles) for the years 1913 to 1915 and 1929 to 1943, inclusive. The average annual discharge in these periods was 110,000 acre-feet.

Precipitation data in this vicinity and run-off of the Verde River at McDowell during the period of run-off record on the Williams River, in comparison to the long-time averages, are given in the following table:

TABLE CXLII.—*Precipitation and run-off near Williams River*

Location	Average for years 1913–15 and 1929–43, inclusive	Long-time average	Average of short period in percent of long period
Precipitation at Prescott, Ariz.	19.42 inches	18.85 inches	103
Precipitation at Seligman, Ariz.	11.37 inches [1]	11.96 inches	95
Precipitation at Kingman, Ariz.	10.94 inches	11.31 inches	97
Precipitation at Parker, Ariz.	5.76 inches [2]	5.45 inches	106
Run-off Verde River at mouth.	485,000 acre-feet.	553,000 acre-feet.	88

[1] 1 full year and occasional months estimated to complete record.
[2] 1 year (1937) estimated from incomplete records.

Data presented in the preceding table indicate that average recorded flow of the Williams River is about equal to the long-time average.

From available topographic maps of the States of Arizona, California, and Nevada the drainage area between Boulder Dam and the mouth of the Gila, other than the Williams River, which likely contributes to the Colorado River following periods of intense precipitation, is measured as 4,500 square miles. The unit rate of run-off from this area is considerably less than that of the Williams River watershed. The long-time average annual run-off from such area is estimated to be 40,000 area-feet annually, making a total average annual inflow between Boulder Dam and the mouth of the Gila (exclusive of the Gila River) of 150,000 acre-feet.

Losses Under Virgin Conditions in Colorado River Between Boulder Dam and Mouth of Gila River

Under natural conditions there was loss resulting from: (1) Seepage to adjacent valley lands, from which it is subsequently largely evaporated; (2) water entrapped in sloughs and former river channels during floods and later evaporated; (3) evaporation from the stream surface; and (4) possible seepage losses to underlying strata.

In addition to natural losses, water is lost by man's activities from: (1) Depletions due to irrigation consumptive use in the Colorado River valley; (2) water diverted out of the natural watershed to the metropolitan district near Los Angeles and the Imperial Valley, Calif.; and (3) evaporation losses from reservoirs back of Parker, Imperial, and Laguna Dams.

Since it is desired to determine losses under virgin conditions and since the discharge records at Boulder Dam largely reflect the results of a regulated river, the losses between Boulder Dam site and the mouth of the Gila River are based on measured losses between Topock and Laguna Dam (Yuma record corrected for flow of Gila at mouth and diversions for Yuma project), for the 12-year period 1923 to 1934, inclusive, with an estimated loss, based on comparison of physical conditions, between Boulder Dam and Topock.

Average annual discharges at Topock and Laguna, during the 12-year period 1923 to 1934, inclusive, compare as follows:

	Acre-feet
Colorado River at Topock	13, 300, 000
Colorado River at Laguna Dam	12, 610, 000
Net annual loss and use between Topock and Laguna	690, 000

The average run-off during the 12-year period of study is somewhat less than normal. It is to be expected that over a long period the losses would be somewhat greater. A figure of 700,000 acre-feet annually has been adopted as representing the long-time net loss and use between Topock and Laguna Dam.

Depletions due to the irrigation of lands in the Parker and Palo Verde Valleys are estimated to be 120,000 acre-feet, which subtracted from the total loss leaves a natural net loss of 580,000 acre-feet. This loss occurs despite inflow to the river previously estimated at 150,000 acre-feet, so that the actual natural loss between Topock and Laguna Dam is 730,000 acre-feet.

The Colorado River Valley sections between Boulder Dam and Topock and between Topock and Laguna Dam compare as follows (prior to construction of Parker and Imperial Dams):

TABLE CXLIII.—*Comparison of sections of Colorado River Valley above and below Topock*

Feature	Between Boulder Dam and Topock	Between Topock and Laguna Dam	Areas above Topock in percent of areas below Topock
Stream channel area.[1]	11,000 acres	25,000 acres	44
Valley floor area [1]	80,000 acres	250,000 acres	32
Irrigated area	None	35,000 acres	0
Tributaries entering Colorado River.	Minor washes	Williams River and small washes.	------

[1] Measured from river survey sheets of Colorado River below Black Canyon, published by the U. S. Geological Survey in 1927.

Considering that all of the valley floor areas are not inundated every year, it is believed that channel losses from the region above Topock will be about 40 percent of the channel losses below Topock or about 300,000 acre-feet annually. This added to losses below Topock makes the total natural channel losses between Boulder and Laguna Dams 1,030,000 acre-feet annually.

Virgin flow, Colorado River at Laguna

The average annual virgin flow of the Colorado River at Laguna Dam (above mouth of Gila) is estimated as follows:

	Acre-feet
Virgin flow, Colorado River at Boulder Dam	17, 330, 000
Plus tributary inflow, Boulder Dam to mouth of Gila	150, 000
Less natural channel losses	1, 030, 000
Virgin flow, Colorado River at Laguna Dam (above Gila River)	16, 450, 000

Virgin flow, Gila River at Yuma

Throughout the Gila River Basin, the securing of stream-flow records is made difficult by violent floods, shifting channels, and sand and silt. Except in the Phoenix area, where extensive irrigation development has been made, there are no reliable long-time records of the Gila River and its tributaries. Using the available records, which are often fragmentary, and never fully reliable, estimates have been prepared of the virgin stream flow of the Gila River at its mouth (Dome or Yuma, Ariz.) for the years 1897 to 1943, inclusive. The results of the calculations are shown in table CXLII. The method used is briefly outlined as follows:

(*a*) The annual inflow above the irrigated area surrounding Phoenix was determined by extending the records on the Salt River at Granite Reef Dam (fairly reliable estimates) and on the Gila River at Kelvin (estimates subject to considerable error). From a study made in 1934 of fragmentary records of tributaries entering the Phoenix area below the Granite Reef Dam and the Kelvin gaging station, the unmeasured inflow below the two base stations is estimated to equal 45 percent of the annual unregulated run-off of the Verde River at its mouth.

(*b*) The base records of the Salt and Gila Rivers were corrected for past irrigation depletions and past storage changes and evaporation losses from reservoirs to reflect conditions as they would have been prior to irrigation development. Past upstream irrigation depletions were assumed to vary uniformly between amounts at various periods as follows:

TABLE CXLIV.—*Past upstream irrigation depletion, Gila and Salt Rivers*

Year	Gila River above Kelvin (acre-feet)	Salt River above Granite Reef Dam (acre-feet)
1899	42, 000	12, 000
1909	85, 000	12, 000
1922	77, 000	12, 000
1933	79, 000	12, 000
1943	79, 000	12, 000

(*c*) An estimate was made of the channel losses, prior to irrigation development in the Phoenix area. Direct determination of such channel losses is impossible because of the lack of discharge records prior to the initiation of irrigation development. By comparing the physical conditions of the stream channels in the Phoenix area above Gillespie Dam (located at the lower end of the Phoenix area) with stream channel conditions along the Gila River between the Gillespie Dam and the mouth of the Gila River, it was estimated that natural channel losses in the Phoenix area would bear the same relationship to measured inflow at Granite Reef and Kelvin as natural channel losses below Gillespie Dam bear to the flow at Gillespie Dam. By subtracting the natural channel losses, thus determined, from the estimated virgin inflow to the Phoenix area, there was determined the virgin (or natural) flow of the Gila River at Gillespie Dam.

The channels of the Gila and Salt Rivers in the Phoenix area compare with the Gila River channel below the Gillespie Dam as shown in the following table:

TABLE CXLV.—*Gila River Channel characteristics and climatological data*

	Area between Gillespie Dam and mouth	Phoenix area
Length of river channel:		
Gila River	145	Above Salt River 90 miles Below Salt River 35 miles
Salt River		40 miles
Total	145 miles	[1] 165 miles
Average river gradient:		
Gila River	4 feet per mile	6 feet per mile.
Salt River		9½ feet per mile.
Average	4 feet per mile	7 feet per mile.
Climatological data:		
Average annual precipitation	5 inches	69 inches.
Average annual temperature	72 degrees	9 degrees.

[1] In addition to Gila and Salt River channels, water will be lost from tributary channels such as Agua Fira, Hassayampa, and Queen Creeks.

(*d*) Using concurrent records of Gila River discharge at Gillespie Dam and at the mouth (Dome, Ariz.) for the period August 1921 to December 1934, and making due allowances for the small irrigation use in this area and for the fact that flows at Gillespie Dam were largely controlled by storage during the period of concurrent record, a curve was defined which shows the relationship between annual (unregulated) discharges at Gillespie Dam and annual channel losses between Gillespie Dam and the mouth of the Gila River. The curve was applied to the entire period to determine channel losses.

The channel losses, thus determined, subtracted from the computed natural (or virgin) flows at Gillespie Dam, give the virgin flows of the Gila River at its mouth. The basic computations are summarized in table CXLVI.

While these estimated virgin flows may not be entirely dependable, they are the best that could be made from available information on stream flows. For the purpose of this study the average virgin flow at the mouth of the Gila River has been rounded to 1,270,000 acre-feet annually.

Virgin flow, Colorado River at International Boundary

The long-time average annual virgin flow of the Colorado River at the International boundary is estimated by adding to the virgin flow at Laguna Dam the virgin flow of the Gila River at the mouth as follows:

	Acre-feet
Average annual virgin flow, Colorado River at Laguna Dam	16, 450, 000
Average annual virgin flow, Gila River at mouth	1, 270, 000
Average annual virgin flow, Colorado River at International boundary	17, 720, 000

TABLE CXLVI.—*Estimated virgin flow of Gila River at mouth (thousand acre-feet)*

Year	Flow of Salt River at Granite Reef	Flow of Gila River at Kelvin	Unmeasured natural inflow to Phoenix area	Total natural inflow to Phoenix area	Natural loss in Phoenix area	Natural flow of Gila River at Gillespie Dam	Natural loss of Gillespie Dam to Gila River at mouth	Natural flow of Gila River at mouth
1897	[1] 1, 289	605	231	2, 125	550	1, 575	501	1, 074
1898	[1] 537	401	97	1, 035	372	663	302	361
1899	[1] 514	302	98	914	345	569	272	297
1900	[1] 269	[1] 274	52	595	262	333	193	140
1901	[1] 765	[1] 352	136	1, 253	415	838	348	490
1902	[1] 442	[1] 223	99	764	302	462	240	222
1903	[1] 436	[1] 266	98	800	314	486	248	238
1904	527	[1] 336	121	984	355	629	290	339
1905	5, 542	[1] 1, 582	821	7, 945	904	7, 041	900	6, 141
1906	2, 396	[1] 688	360	3, 444	690	2, 754	659	2, 095
1907	2, 021	[1] 1, 013	337	3, 371	685	2, 686	650	2, 036
1908	1, 828	[1] 483	270	2, 581	610	1, 971	564	1, 407
1909	1, 736	[1] 395	262	2, 393	588	1, 805	540	1, 265
1910	930	[1] 206	216	1, 352	416	936	376	560
1911	[1] 2, 143	521	326	2, 990	650	2, 340	612	1, 728
1912	[1] 1, 041	535	187	1, 763	502	1, 261	443	818
1913	888	310	160	1, 358	430	928	374	554
1914	1, 350	1, 342	167	2, 859	651	2, 208	598	1, 610
1915	2, 490	1, 487	306	4, 283	760	3, 523	728	2, 795
1916	5, 301	1, 716	435	7, 452	901	6, 551	885	5, 666
1917	2, 819	420	384	3, 623	702	2, 921	673	2, 248
1918	1, 018	250	258	1, 526	444	1, 082	408	674

[1] Basic run-off record estimated in whole or part.

TABLE CXLVI.—*Estimated virgin flow of Gila River at mouth (thousand acre-feet)*—Continued

Year	Flow of Salt River at Granite Reef	Flow of Gila River at Kelvin	Unmeasured natural inflow to Phoenix area	Total natural inflow to Phoenix area	Natural loss in Phoenix area	Natural flow of Gila River at Gillespie Dam	Natural loss of Gillespie Dam to Gila River at mouth	Natural flow of Gila River at mouth
1919	2, 201	949	375	3, 525	697	2, 828	666	2, 162
1920	2, 478	627	440	3, 545	691	2, 854	670	2, 184
1921	1, 826	536	170	2, 532	616	1, 916	558	1, 358
1922	1, 569	189	339	2, 097	534	1, 563	501	1, 062
1923	1, 754	575	325	2, 654	610	2, 044	573	1, 471
1924	967	299	140	1, 406	443	963	380	583
1925	693	303	143	1, 139	388	751	330	421
1926	1, 334	493	241	2, 068	546	1, 522	492	1, 030
1927	1, 927	366	417	2, 710	607	2, 103	582	1, 521
1928	643	214	153	1, 010	353	657	300	357
1929	1, 025	338	188	1, 551	462	1, 089	409	680
1930	857	420	158	1, 435	446	989	384	605
1931	1, 360	577	224	2, 161	560	1, 601	507	1, 094
1932	2, 045	534	390	2, 969	635	2, 334	610	1, 724
1933	701	304	107	1, 112	390	722	315	407
1934	372	256	84	712	285	427	220	207
1935	1, 516	481	255	2, 252	560	1, 692	520	1, 172
1936	1, 109	328	146	1, 583	472	1, 111	410	701
1937	2, 101	511	408	3, 020	640	2, 380	615	1, 765
1938	971	232	222	1, 425	414	1, 011	385	626
1939	749	263	136	1, 148	410	738	320	418
1940	1, 070	462	126	1, 658	490	1, 168	515	653
1941	3, 491	1, 250	557	5, 298	808	4, 490	790	3, 700
1942	884	288	147	1, 319	427	892	355	537
1943	974	288	143	1, 405	440	965	380	585
Average	1, 508	527	244	2, 279	527	1, 752	480	1, 272

Index to Projects, Existing and Potential

Index to Reservoirs and Reservoir Sites

APPENDIX II

Eleven Colorado River Basin Maps

TITLES

Water Resources Development—Colorado River Basin—Arizona

Water Resources Development—Colorado River Basin—California

Water Resources Development—Colorado River Basin—Colorado

Water Resources Development—Colorado River Basin—Nevada

Water Resources Development—Colorado River Basin—New Mexico

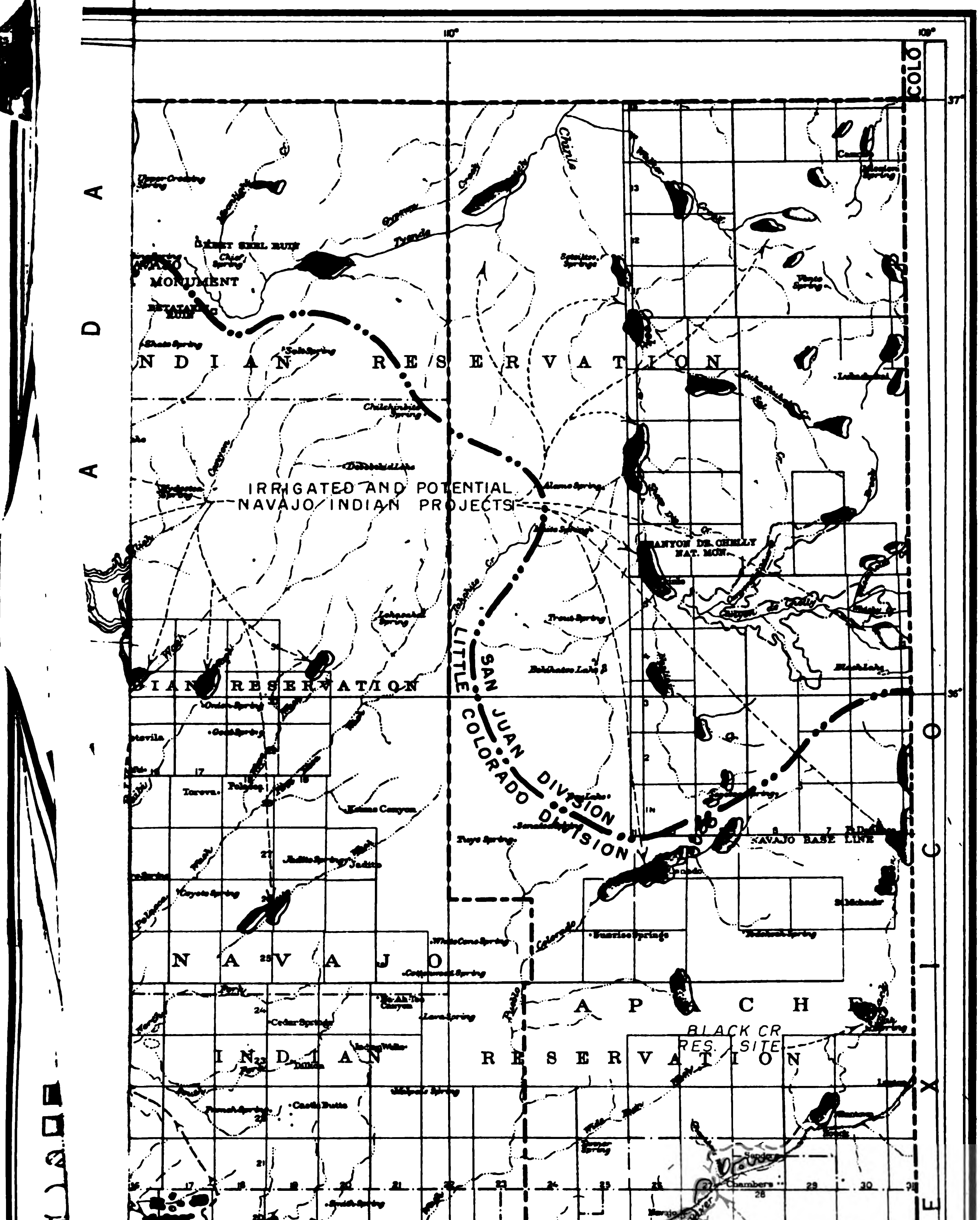
Water Resources Development—Colorado River Basin—Utah

Water Resources Development—Colorado River Basin—Wyoming

Principal Power Systems—Existing and Potential—Colorado River Basin

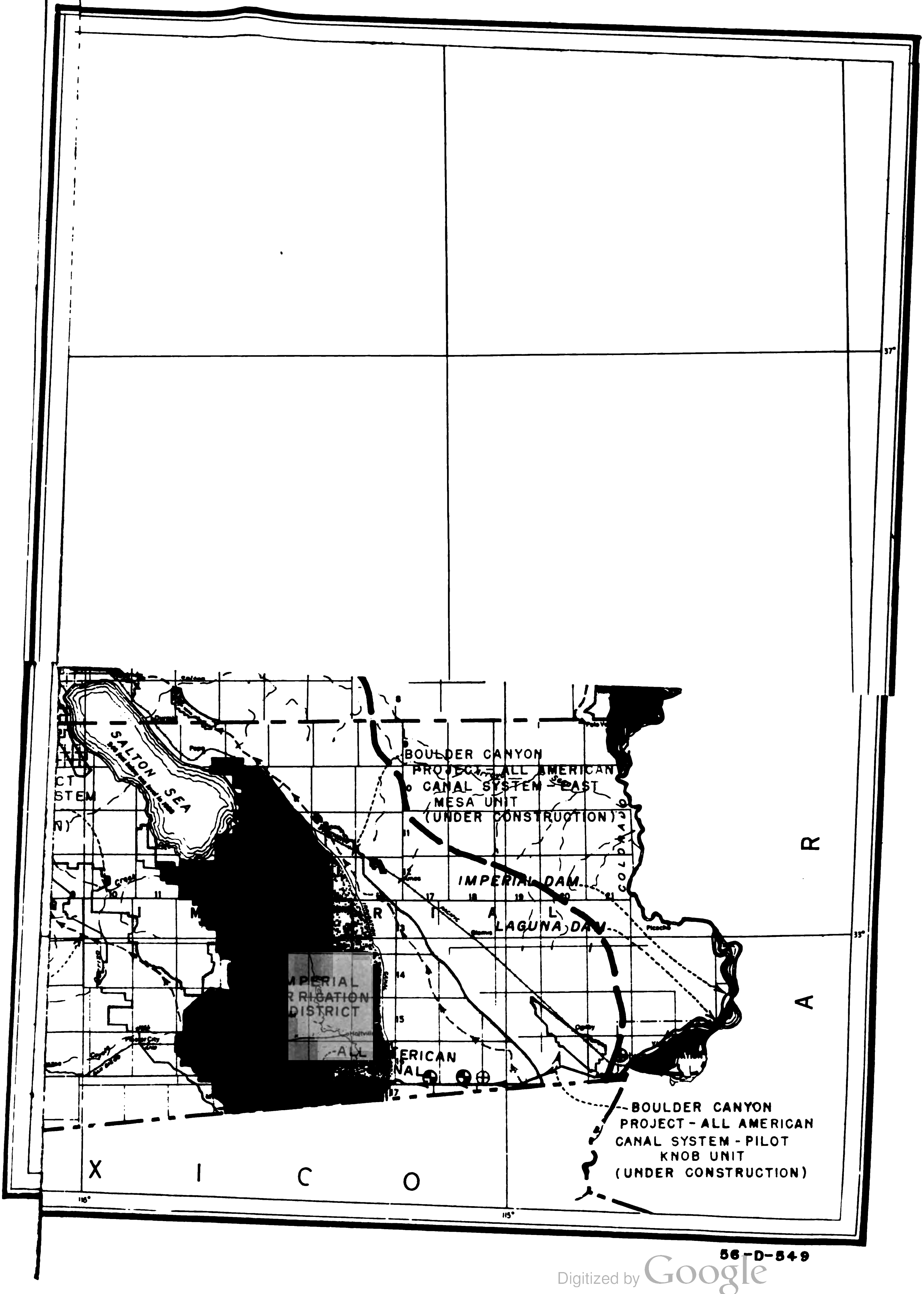
Conservation Areas and Facilities—Colorado River Basin

Mineral Resources—Colorado River Basin (two maps)



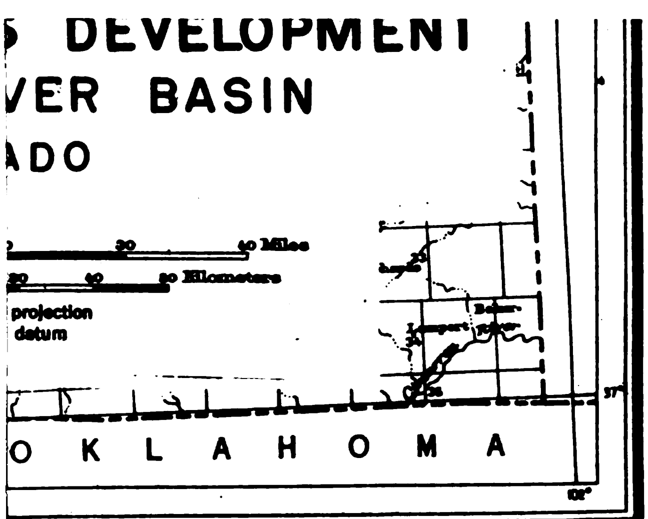
COLORADO RIVER BASIN
ARIZONA

56-D-548



SALTON SEA
BOULDER CANYON PROJECT - ALL AMERICAN CANAL SYSTEM - EAST MESA UNIT (UNDER CONSTRUCTION)
IMPERIAL DAM
LAGUNA DAM
COLORADO
IMPERIAL IRRIGATION DISTRICT
BOULDER CANYON PROJECT - ALL AMERICAN CANAL SYSTEM - PILOT KNOB UNIT (UNDER CONSTRUCTION)
R
A
X I C O
37°
33°
115°

56-D-549



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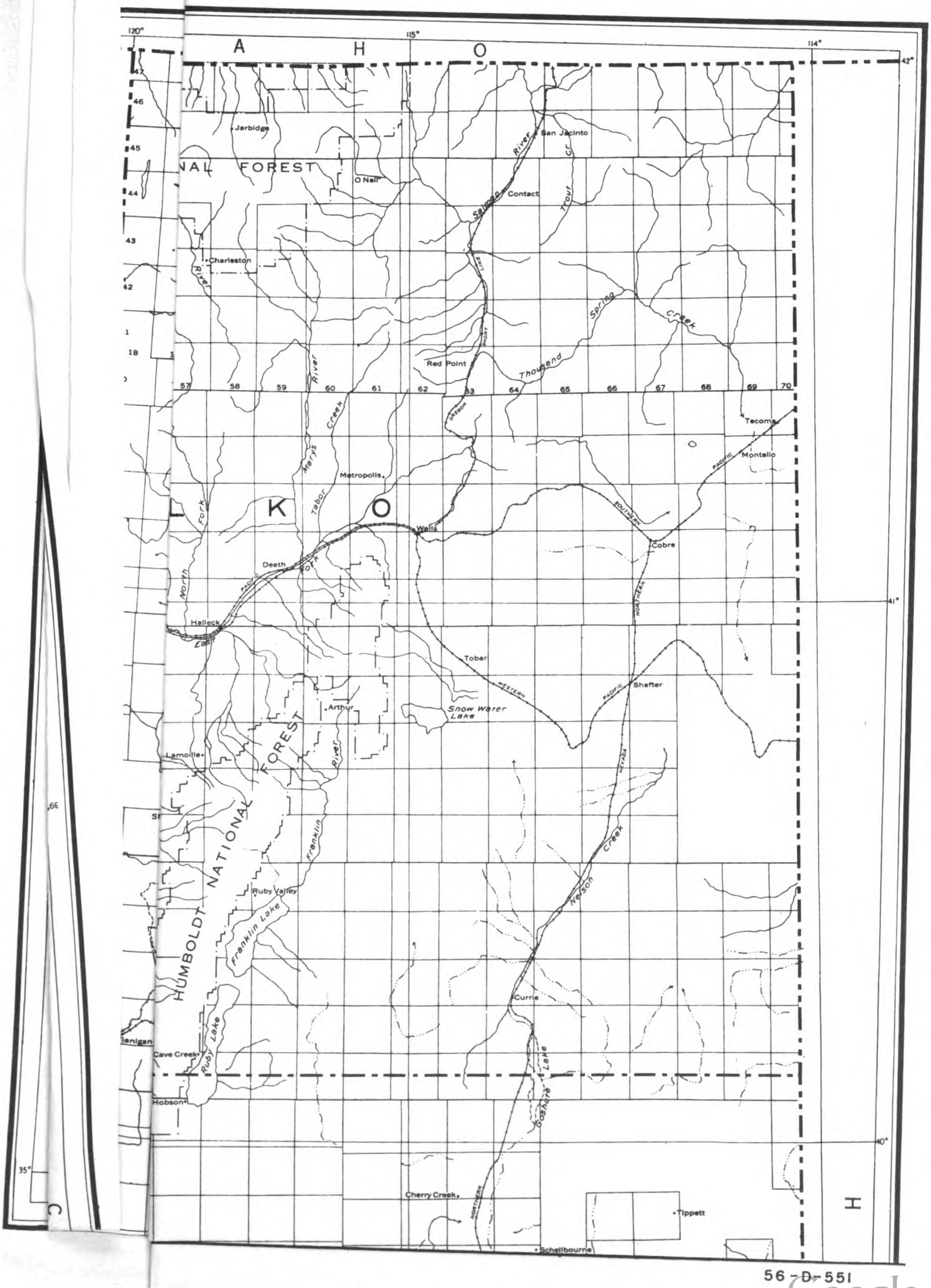
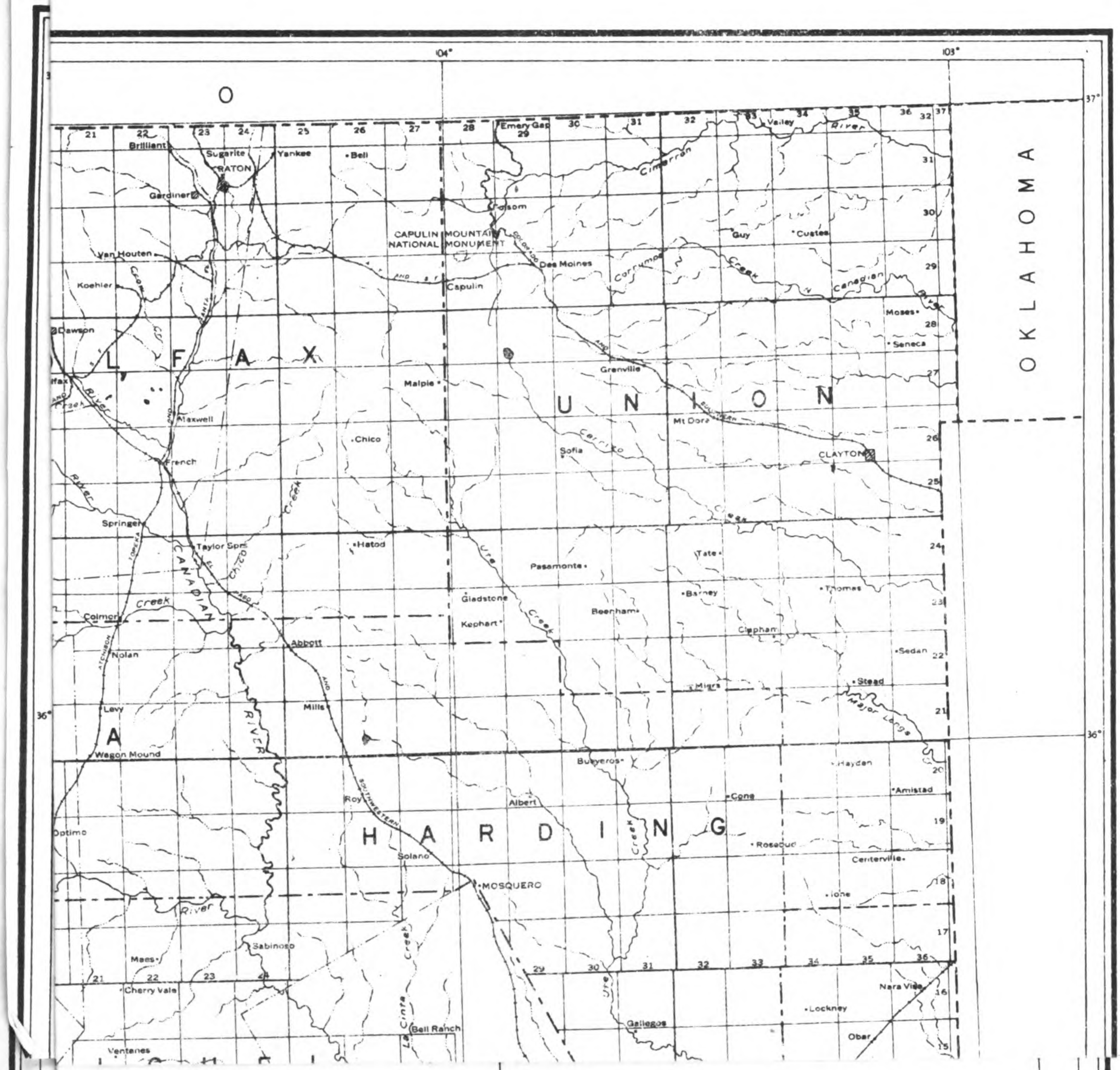


A H O
ELKO
NAL FOREST
HUMBOLDT NATIONAL FOREST
Jarbidge
San Jacinto
O'Neil
Contact
Charleston
Red Point
Tecoma
Montello
Metropolis
Wells
Cobre
Deeth
Halleck
Tobar
Shafter
Arthur
Snow Water Lake
Lamoille
Ruby Valley
Franklin Lake
Currie
Cave Creek
Ruby Lake
Hobson
Goshute Lake
Cherry Creek
Tippett
Schellbourne
Salmon River
Trout Cr
Thousand Spring Creek
Marys River
Tabor Creek
North Fork
East
Franklin River
Nelson Creek
OREGON SHORT LINE
SOUTHERN PACIFIC
WESTERN PACIFIC
NEVADA NORTHERN
115°
114°
42°
41°
40°

56-D-551



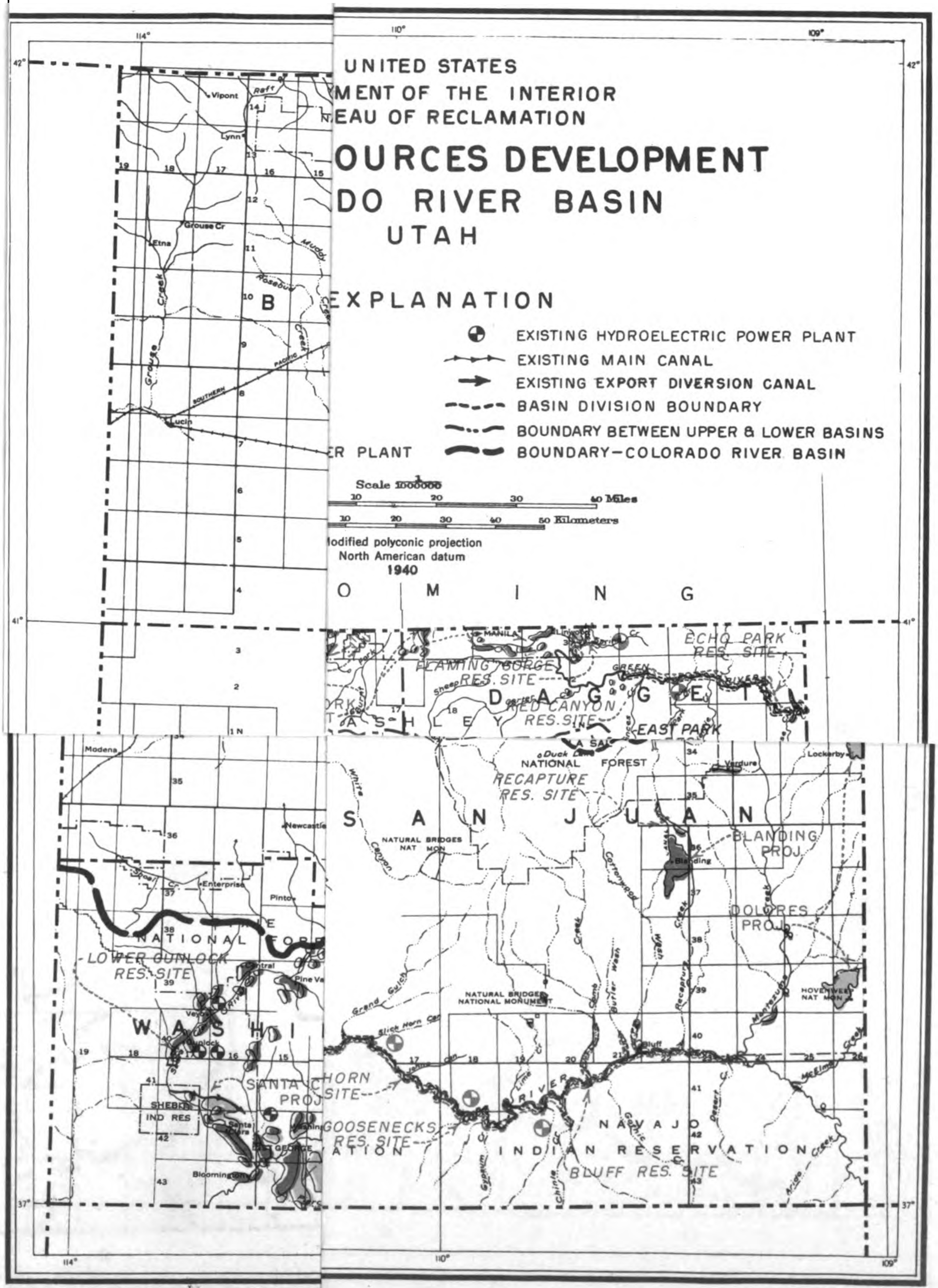
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WATER RESOURCES DEVELOPMENT
COLORADO RIVER BASIN
NEW MEXICO

104°

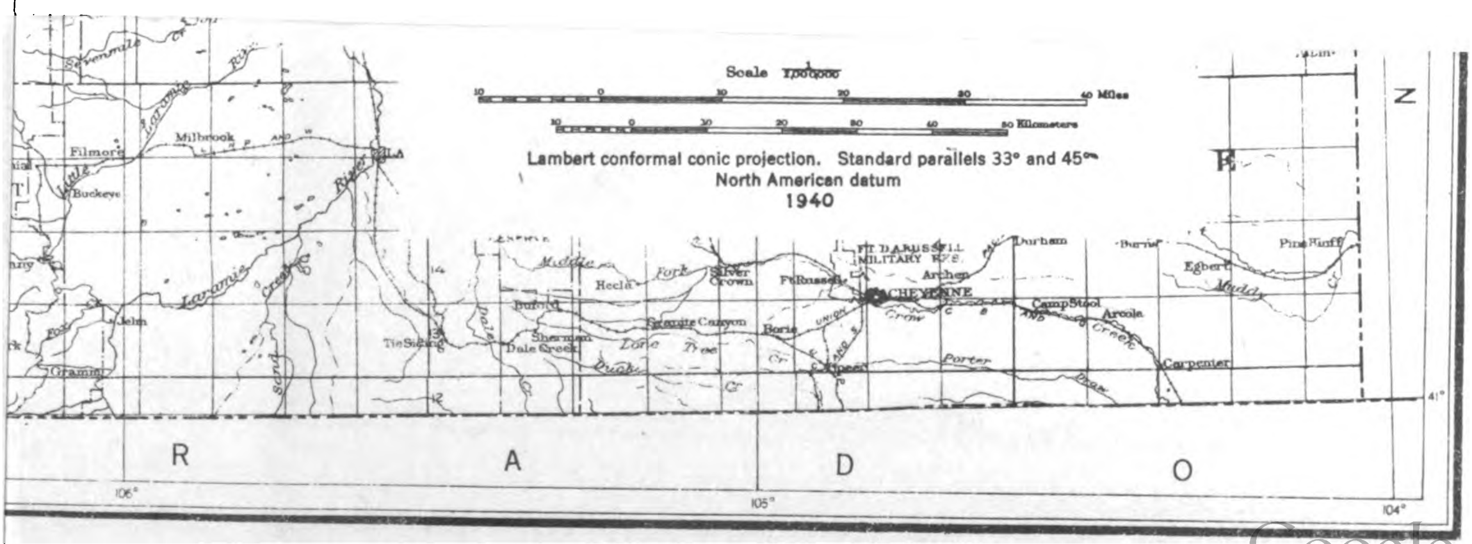
103°

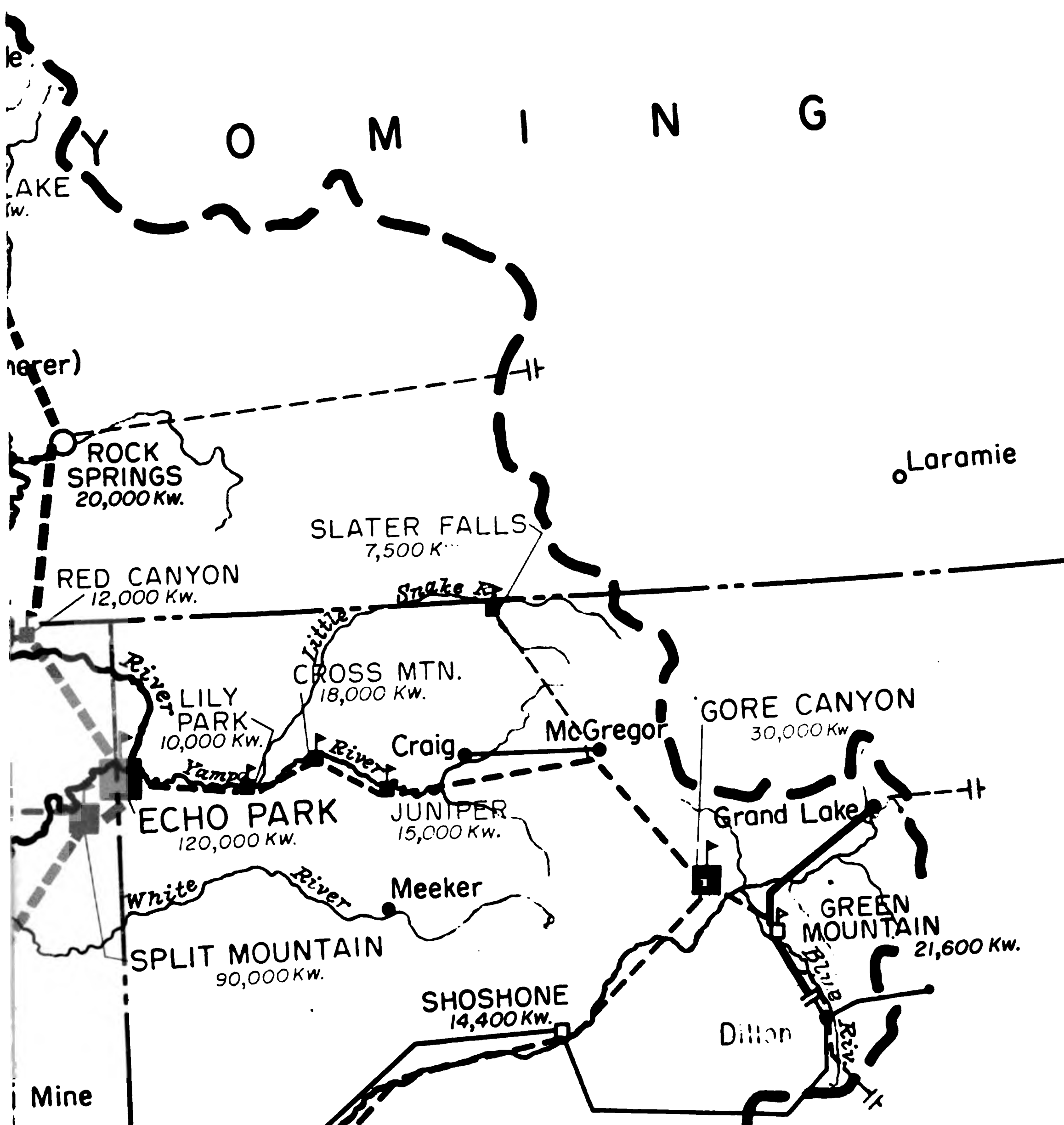
56-D-552



UNITED STATES
MENT OF THE INTERIOR
EAU OF RECLAMATION
OURCES DEVELOPMENT
DO RIVER BASIN
UTAH
EXPLANATION
EXISTING HYDROELECTRIC POWER PLANT
EXISTING MAIN CANAL
EXISTING EXPORT DIVERSION CANAL
BASIN DIVISION BOUNDARY
BOUNDARY BETWEEN UPPER & LOWER BASINS
BOUNDARY—COLORADO RIVER BASIN
ER PLANT
Scale 1/1000000
10 20 30 40 Miles
10 20 30 40 50 Kilometers
Modified polyconic projection
North American datum
1940
O M I N G
ECHO PARK RES. SITE
FLAMING GORGE RES. SITE
RED CANYON RES. SITE
EAST PARK
D A G G E T T
NATIONAL FOREST
RECAPTURE RES. SITE
S A N J U A N
NATURAL BRIDGES NAT MON
BLANDING PROJ.
Blanding
DOLORES PROJ.
HOVENWEEP NAT MON
NATURAL BRIDGES NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION
BLUFF RES. SITE
GOOSENECKS RES. SITE
RIVER
LOWER GUNLOCK RES. SITE
NATIONAL FOR
W A S H I
SANTA C PROJ
SHEBIT IND RES
Bloomington
Enterprise
Pinto
Newcastle
Modena
Vipont
Lynn
Grouse Cr
Etna
Lucin
B

56-D-553


Scale 1/1,000,000
Miles
Kilometers
Lambert conformal conic projection. Standard parallels 33° and 45°
North American datum
1940
Filmore
Milbrook
Buckeye
Jelm
Laramie
Hecla
Silver Crown
Ft. Russell
CHEYENNE
Archer
Durham
Egbert
Camp Stool
Arcola
Carpenter
Granite Canyon
Sherman
Dale Creek
Lone Tree
Crow
Porter
Muddy
R
A
D
O
41°
106°
105°
104°



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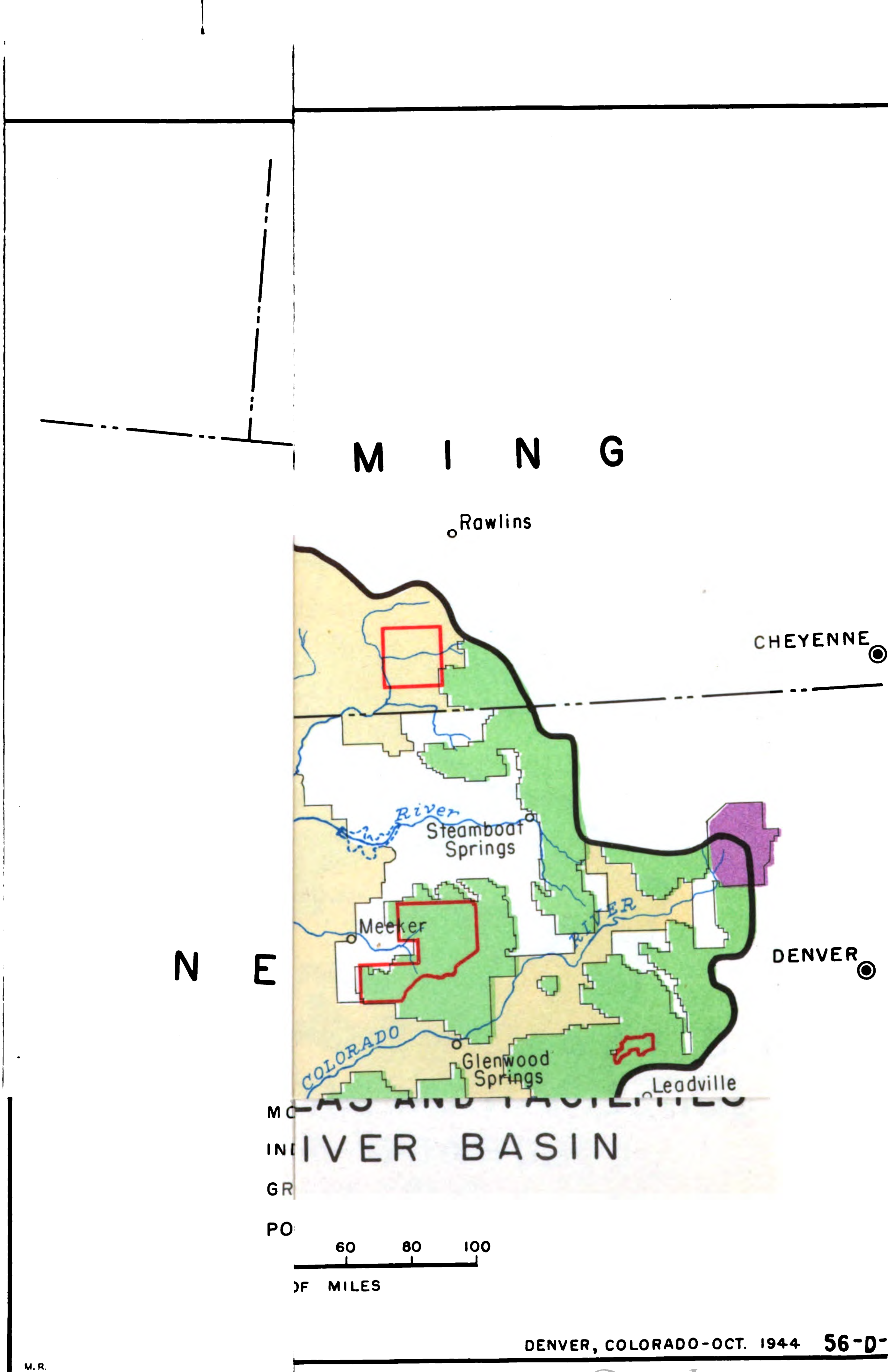
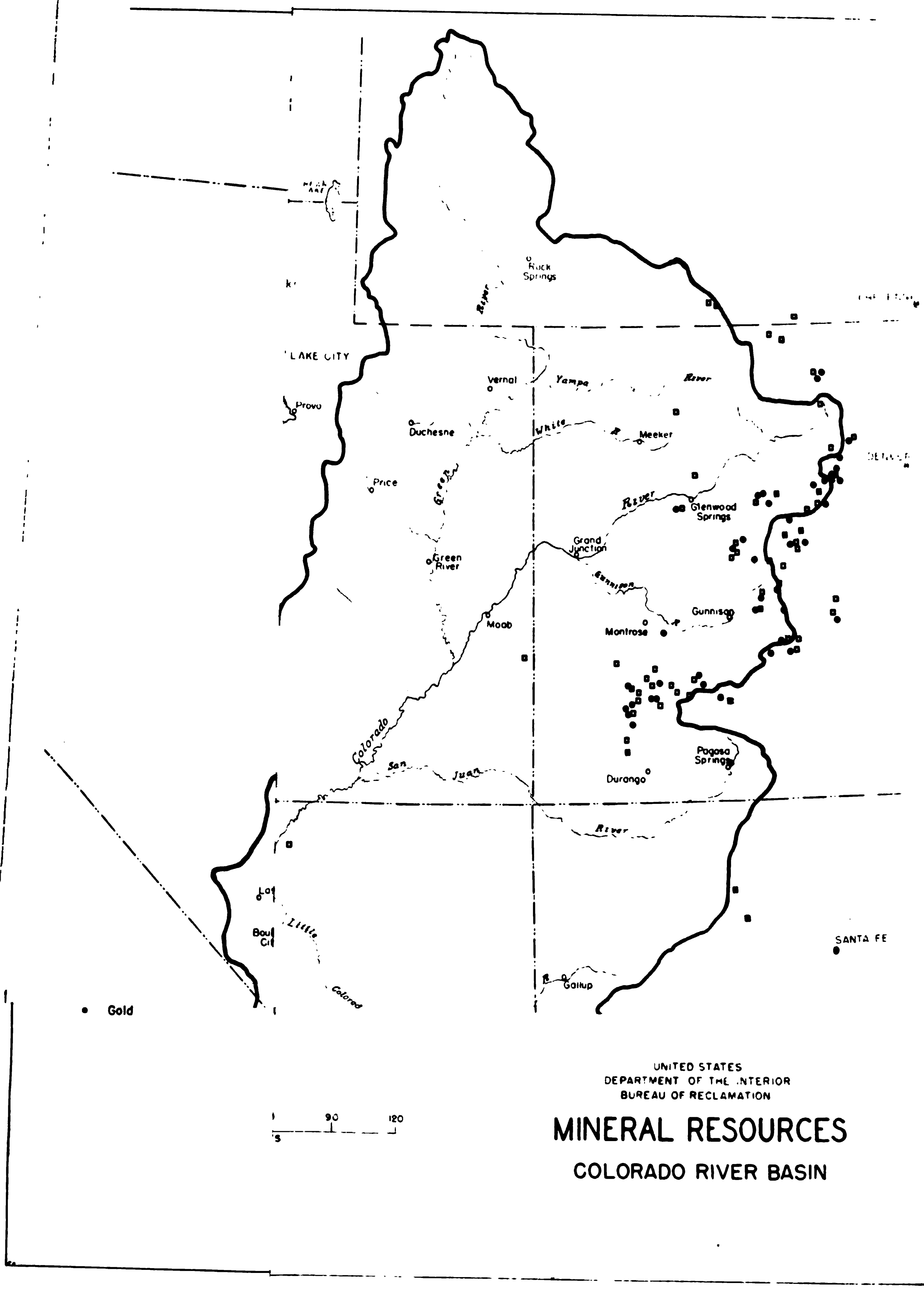


DENVER, COLORADO-OCT. 1944 56-D-5



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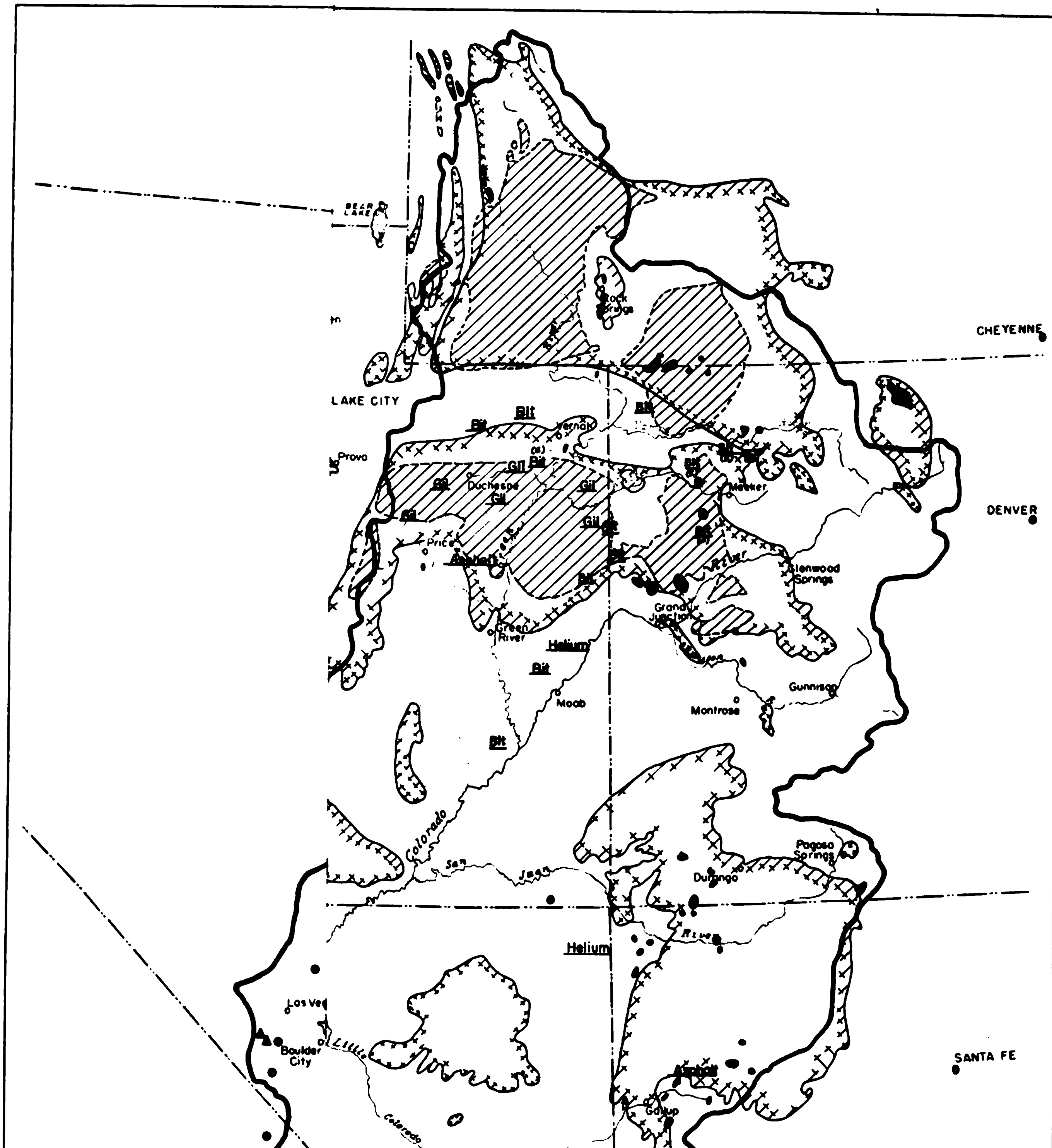
MINERAL RESOURCES

COLORADO RIVER BASIN

56-D-557



- ● Diatomite
- ○ Clay
- ■ Kyanite, Andalusite, Sillimanite, etc
- □ Aluminite and other aluminum bearing
- + Asbestos
- Celestite
- Dumortierite
- X Pyrophyllite
- Barite
- # Mica
- Corundum
- H Graphite
- Fluorspar
- Feldspar

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COLORADO RIVER BASIN

56-D-558