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The Colorado River

"A Natural Menace Becomes a National Resource"

A Comprehensive Departmental Report on the Development of the Water Resources of the Colorado River Basin for Review Prior to Submission to the Congress

MARCH 1946

UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

BUREAU OF RECLAMATION
Michael W. Straus, Commissioner

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 THE BUREAU OF RECLAMATION

Michael W. Straus, Commissioner

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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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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.

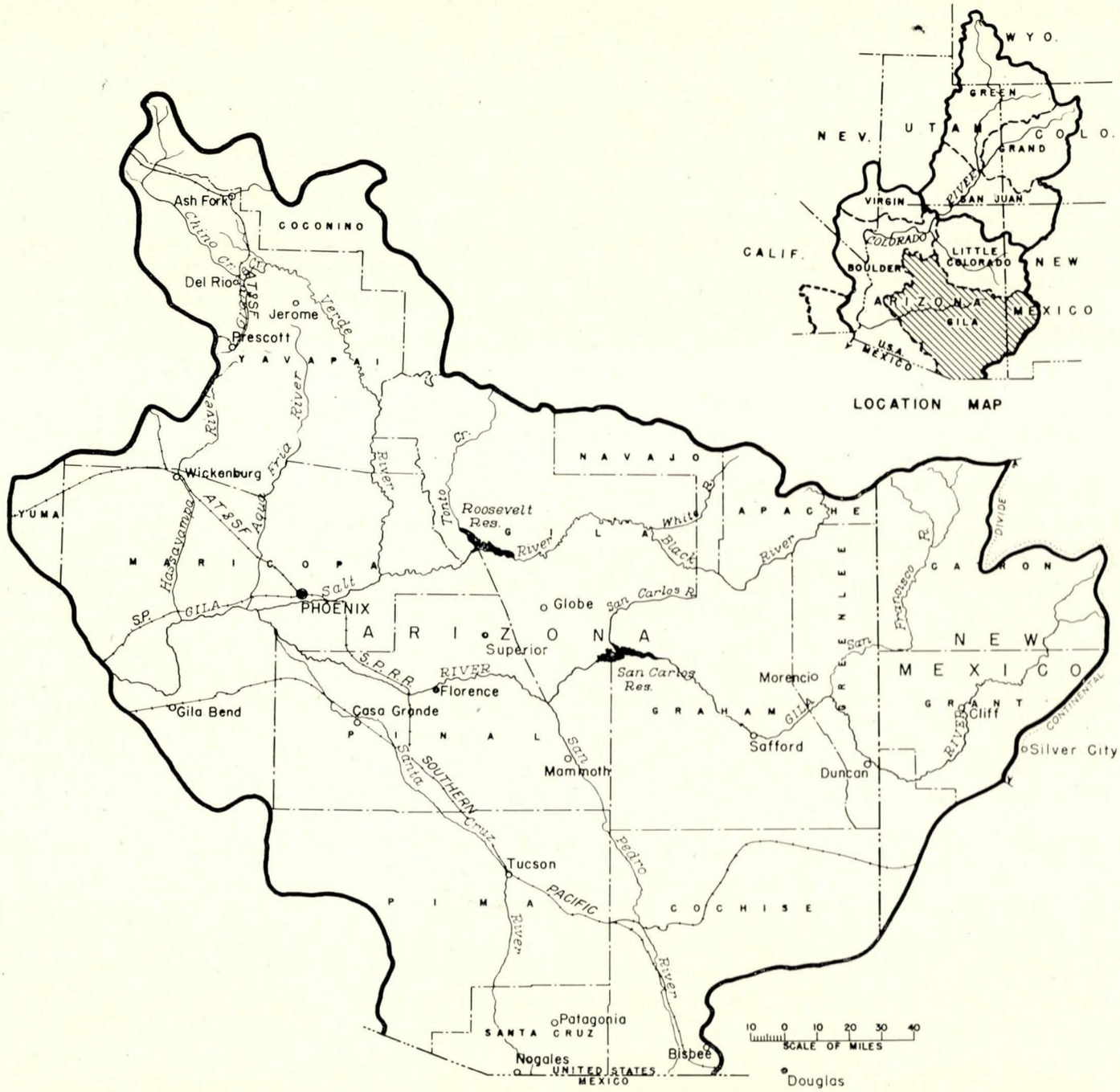
Small to moderate-sized springs are scattered through the watershed area. Only a small amount of land is irrigated directly from springs, but springs contribute a substantial amount of water to the perennial flows of the larger rivers. Spring water is particularly valuable in the semiarid outlying ranges, 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

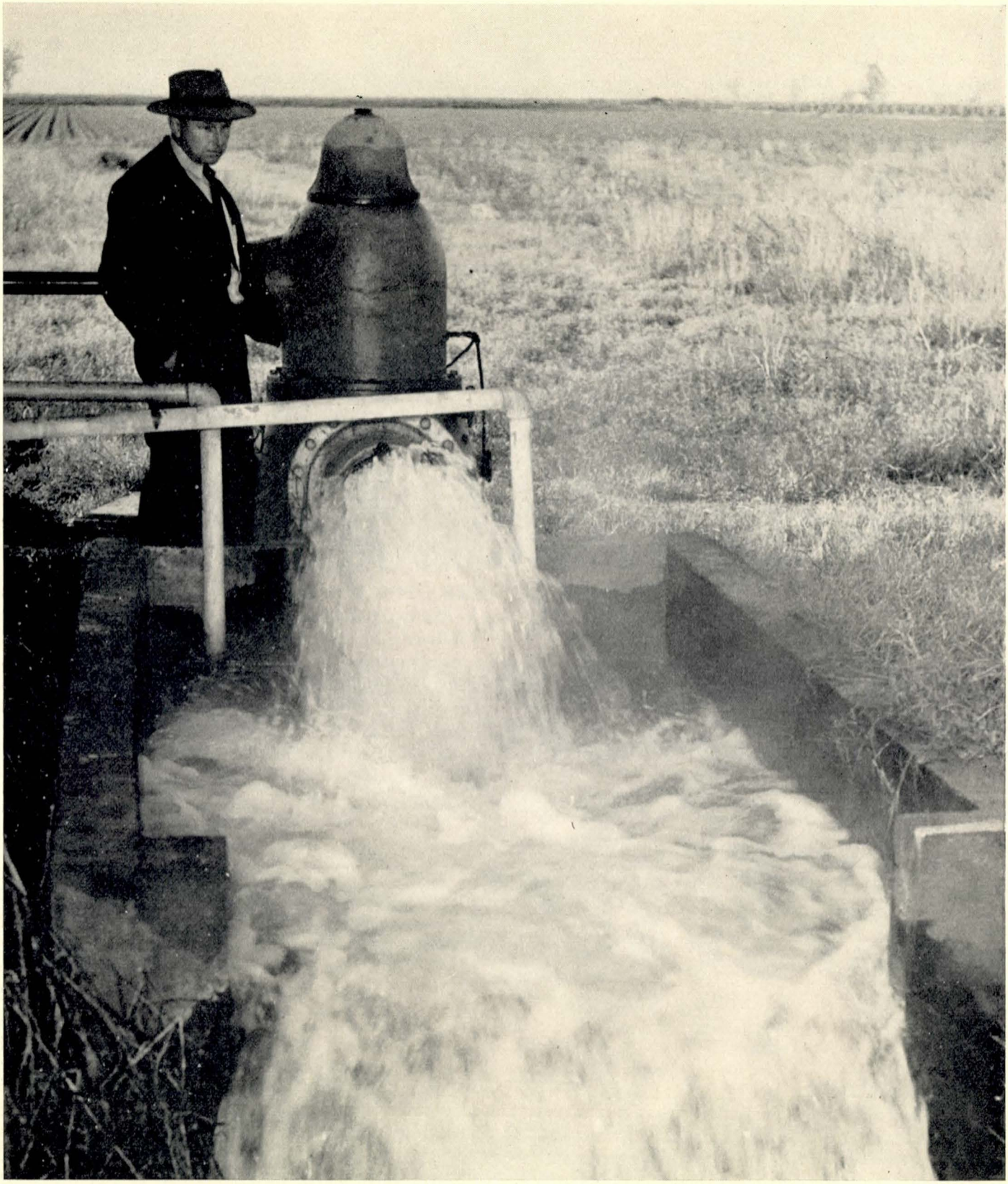
Ground waters of unsuitable quality for either irrigation or domestic use are found in wells in the upper Gila Valley, lower Salt River Valley, and in the Casa Grande and Coolidge districts. Ground waters of the division are generally unsuitable for industrial use.

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.

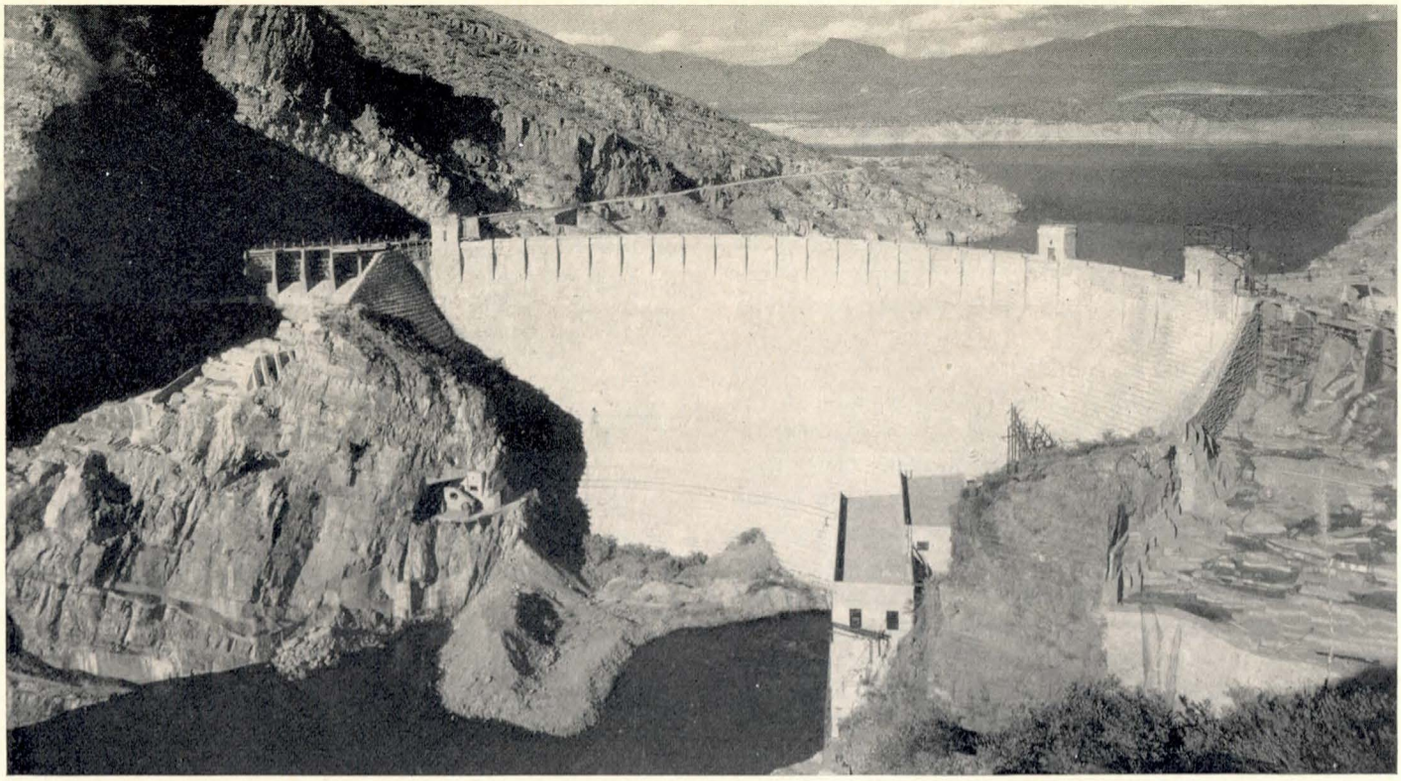
Other downstream developments include those made by the Buckeye Water Conservation and Drainage District, Arlington Canal Co., Gillespie Land & Irrigation Co., and others. These lands obtain much of their water supply by pumping from underground sources. At the present time ground-water depletions exceed 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.

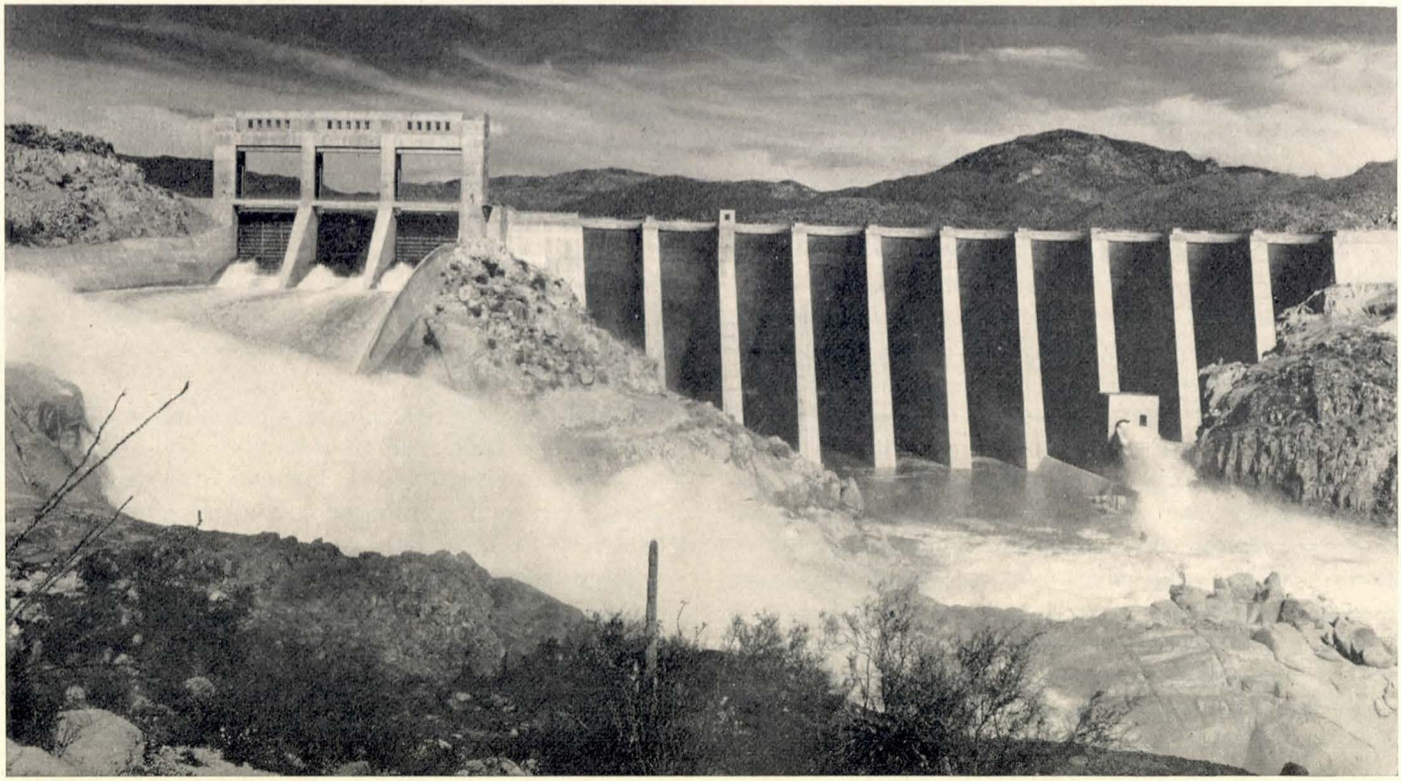
All of the dependable surface water supply of the San Pedro is now divided among irrigators in the San Pedro Valley and in the Gila River Valley downstream from the confluence of the two streams. The only possibility of irrigating additional lands in the San Pedro Valley is through the importation of 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

TABLE CXV.—*Present hydroelectric generating capacity in the lower basin*—Continued

State and division	Present installed capacity (kilowatts)	Authorized or planned capacity (kilowatts)	Total capacity (kilowatts)
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				Potential projects		Total ultimate depletion
	Present depletions		Future increase				
	Consumed in basin	Exported	Consumed in basin	Exported	Consumed in basin	Exported	
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		Lower basin		Total (acres)
	Irrigated (acres)	Irrigable [1] (acres)	Irrigated (acres)	Irrigable [1] (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.

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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

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