DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 33

STORAGE OF WATER ON GILA RIVER, ARIZONA.—LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1900

IRRIGATION REPORTS.

The following list contains titles and brief descriptions of the principal reports relating to water supply and irrigation, prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps, showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnaissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts; Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee "Natural mineral waters of the United States," by A. C. Peale; "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

 (Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STORAGE OF WATER

ON

GILA RIVER, ARIZONA

BY

JOSEPH BARLOW LIPPINCOTT

WASHINGTON
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1900

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, December 1, 1899.

SIR: I have the honor to transmit herewith a manuscript prepared by Mr. J. B. Lippincott, giving the results of surveys of reservoirs on Gila River, Arizona, and to recommend that it be printed in the series of Water-Supply and Irrigation Papers.

The investigations upon which this report is based were originally intrusted to Mr. Arthur P. Davis, as he was familiar with the conditions through a preliminary survey. Before the field work was completed, however, his services were required by the Nicaragua Canal Commission, to extend the studies of the water supply of Central America. The responsible oversight was then intrusted to Mr. J. B. Lippincott, who up to that time had been assisting Mr. Davis.

This report has been written by Mr. Lippincott, and his conclusions have been verified by Mr. James D. Schuyler. The latter has prepared a concise discussion of the matter, but at this time it is necessary only to quote his general conclusions and recommendations, as follows:

(1) That a minimum of 40,000 acre-feet of water annually should be stored for the supply of the Indian reservation.

(2) That it is not feasible to obtain this supply from Queen Creek, although the construction of the dam and reservoir proposed on the stream is feasible if a sufficient water supply were available.

(3) That the Gila River is the only available source of permanent supply.

(4) That it is not feasible or advisable to build a dam and reservoir on the Gila for storing so small a quantity as 40,000 acre-feet, on account of the rapidity with which a small reservoir must be filled with silt.

(5) That it is not feasible to construct a reservoir outside of the immediate channel of the Gila River of sufficient capacity to provide for the wants of the Indians, filling the same annually by a conduit from the river.

(6) That it is not advisable to build a dam and reservoir on the channel of the river of less capacity than one-half the total annual flow of the river in minimum years.

(7) That feasible reservoir and dam sites exist on the Gila at the Buttes, Riverside, and San Carlos.

(8) That it is not feasible to build a masonry dam at the Buttes, on account of the rotten quality of the rock, the great depth to bed rock, and the excessive height of dam required to obtain a storage of 174,000 acre-feet, or about one-half the minimum flow of the stream.

(9) That the construction of a combination rock-fill and masonry dam is feasible at the Buttes at a cost of $2,643,327, storing 174,040 acre-feet, but that it is not feasible to construct a dam of any type of greater height or capacity.

(10) That the Buttes reservoir of the stated capacity may be expected to fill with solid matter in eighteen years, unless dredged or sluiced out.

(11) That it is feasible to construct a masonry dam at Riverside at a cost of $1,989,605, including damages for right of way and diversion dam at the head of the Florence canal, forming a reservoir with a capacity of 221,134 acre-feet.

(12) That it is feasible to increase the height of dam at the Riverside dam at least 70 feet higher than the one estimated upon, giving an ultimate reservoir capacity of about 650,000 acre-feet, which would not be filled with solid matter short of sixty-seven years.

(13) That it is feasible to construct a masonry dam at San Carlos at a cost of $1,038,926, including damages for right of way and diversion dam at the head of the Florence canal, forming a reservoir of 241,396 acre-feet capacity, and that the water supply is ample to fill such a reservoir in the years of minimum flow, and that the volume of storage will irrigate at least 100,000 acres in addition to the irrigation of the lands of the Indians.

(14) That it is feasible to construct a dam at San Carlos at least 70 feet higher than that contemplated in the estimates, forming a reservoir whose ultimate capacity would be approximately 550,000 acre-feet and whose probable life of usefulness would be sixty-three years before being filled with silt.

(15) That provision should be made in the working plans for these ultimate extensions suggested and the right of way reserved in the reservoir basin for the additional area that may ultimately be flooded.

(16) That the San Carlos dam should be built as the first step to be taken for the storage of water upon the Gila and that all other available sites should be permanently withdrawn from entry with a view to their ultimate utilization for storage purposes.

(17) That the working plans for the San Carlos dam should be drawn to permit of the complete utilization of all power which may be developed from the head of the water issuing from the reservoir and steps be taken for realizing upon the full commercial value of the power.

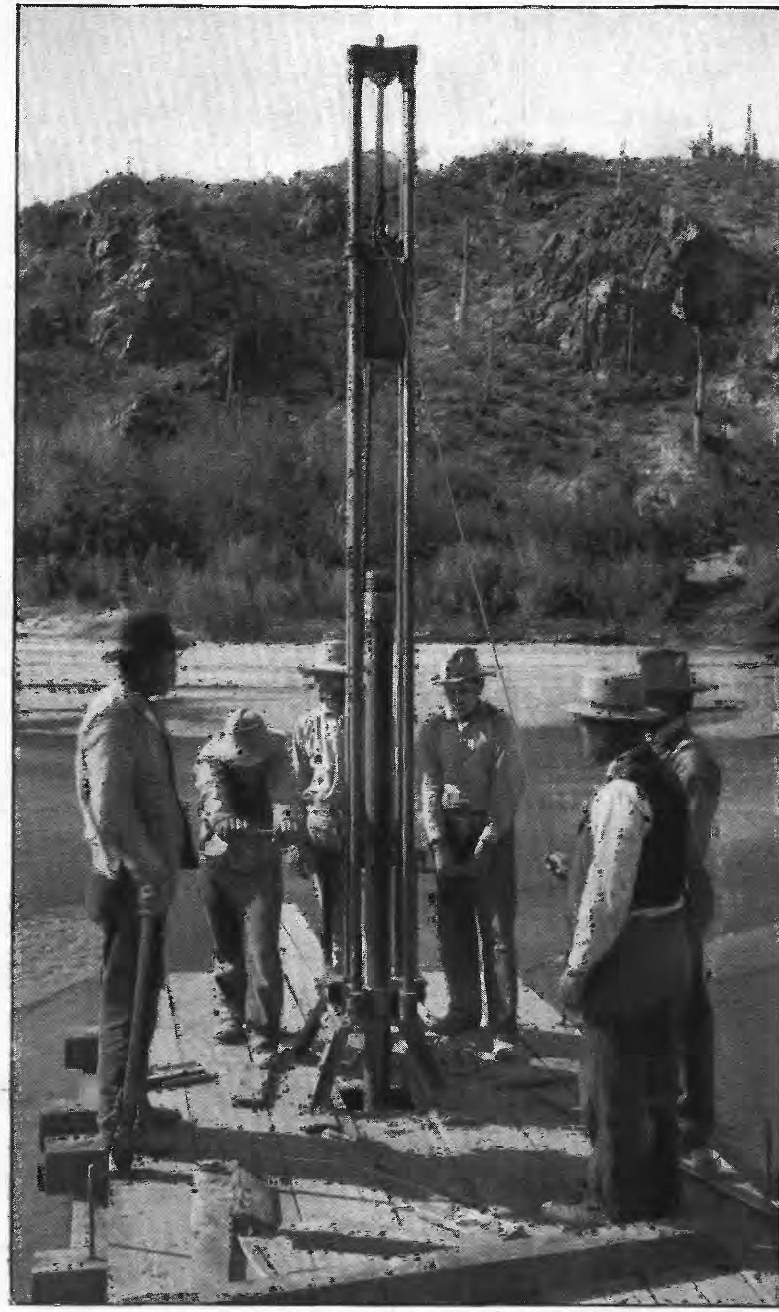
(18) That that portion of the public domain which can be irrigated and reclaimed from the surplus storage of the Gila River reservoirs, over and above what is required for the Sacaton Indian Reservation, should be withdrawn from entry, segregated into an irrigation district, provided with a system of canals of distribution, and only offered for sale at a rate commensurate with their true value as irrigable lands with water rights, the proceeds to be placed in a fund to be used only for continuing the improvement, extension, and care of reservoirs and storage dams on the Gila River.

In addition to the investigation authorized by the act of July 1, 1898, related work was carried on at the same time under the annual appropriation for measuring the streams and determining the water supply, thus furnishing general information which has been embodied in the following pages. No attempt has been made in this paper to discriminate between the data acquired by the two classes of field work.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



DRIVING PIPE IN BED OF GILA RIVER AT THE BUTTES, ARIZONA, FOR DIAMOND CORE DRILL

STORAGE OF WATER ON GILA RIVER, ARIZONA.

By Joseph Barlow Lippincott.

EXISTING CONDITIONS.

LOCATION OF RESERVATION.

The Gila River Indian Reservation consists of a tract of 357,120 acres lying on both sides of Gila River, in southern Arizona. It extends from a point about 9 miles west of Florence to the mouth of Salt River, the principal tributary of the Gila, and is approximately 12 miles south of Phenix, the capital of the Territory. The greater portion of this reservation consists of land whose gentle slopes are well adapted to irrigation. From June 1 to October 1 the weather is exceedingly warm. The relative humidity of the locality, however, is low, so that the effect of the heat is largely mitigated, and prostrations from this cause are rare. It is probably as well suited to occupation from a climatic standpoint as the great valleys of central California or the southern Atlantic coast. The winter season is delightful, the temperature seldom falling lower than 20° F.

The lands of this reservation are arid, the annual rainfall being between 7 and 9 inches, a large portion of the precipitation occurring during the winter or nongrowing months. The growth of all crops in this district is wholly dependent upon irrigation, but with water they can be raised in continuous rotation, while successful dry farming is an impossibility. What is true of the Indian reservation also applies to the adjacent lands of the Gila River Valley. Wheat, barley, corn, and alfalfa grow luxuriantly when watered. The deciduous fruits flourish, but winter temperatures are too low for the citrus species.

DESCRIPTION OF TRIBES.

The Gila River Indian Reservation is occupied chiefly by the Pima and Maricopa Indians and a limited number of Papagos. The first knowledge we have of these Indians is obtained from a narrative of Cabeza de Vaca, a Spanish explorer, who visited this region about the year 1535, after an adventurous journey overland from Florida. This traveler describes them very much as they are to-day. They occupied the same lands as at present, and have evidently long been industrious and successful farmers and irrigators, as they continued to be for many years after the acquisition of Arizona by the United States. Their average wheat crop was about 2,000,000 pounds a year, besides which corn, pumpkins, beans, sorghum, and vegetables were raised in large quantities. They manufactured ollas, or earthen jars, and baskets and wove very fine blankets and cotton fabrics. They lived in small villages and held their lands in severalty.

The Pimas have always been friends of the whites and enemies of the Apaches. They gave succor and assistance to the early white settlers, and their doors were always open to peaceable whites or Indians when hard pressed by the savage foe. It is their boast that their hands were never stained by the white man's blood. It was under such conditions that they were joined, about a century ago, by the Maricopas, who came as fugitives from the more powerful Yuma tribe. When the belligerent Apaches gave trouble to the settlers, the United States troops sometimes obtained substantial aid and comfort from the Pimas in the way of subsistence.

The agriculture of the Pima Indians was carried on entirely by irrigation with water diverted from Gila River. These tribes have always supported themselves, and their progress toward civilization has been regarded as one of the encouraging features of the Indian problem. During the last ten years, their irrigating water having been taken away from them, they have lapsed into indolence, want, and vice.

DECREASE OF WATER SUPPLY.

Their condition of prosperity, industry, and independence continued until, by the settlement of the Gila Valley above the reservation, the water supply was partly cut off and began to be deficient for the cultivated lands on the reservation. No very serious shortage occurred, however, until after the construction of the Florence canal and its diversion dam, heading about 15 miles above the eastern limit of the reservation on Gila River. When this canal was projected, early in the year 1886, Agent Wheeler called the attention of the Department of the Interior to the fact that if the construction of this canal were permitted, it "would practically destroy the farms of the Pima and Maricopa Indians living on the river," and that the effect would be to render the Indians helpless and destitute, the water being absolutely necessary to their existence. On March 2, 1886, the subject was referred by the Department to the Attorney-General, who directed the United States district attorney for Arizona to take the necessary steps to protect the Indians from the effects of the projected canal. The matter was delayed until July of the same year, when the Director of the Geological Survey was instructed by the Secretary of the Interior to investigate and report to the Department the effect which the proposed canal would be likely to have upon the water supply for the Indian reservation. As a result of the investigation the following facts were established:

(1) That the water supply of the Pima and Maricopa reservations under present conditions is no more than sufficient for the wants of the Indians.

(2) That the construction of a dam by the Florence Canal Company of the character represented in the correspondence will give the control substantially of all the water of the Gila River; and if the owners of the dam carry the water right also, they can deliver the water to the reservation or not, as best suits their plans.

(3) That the lands outside the reservation which could be economically supplied with water by such a canal greatly exceed in area the amount that the river is capable of supplying, and that the company, with the water rights established, would own the water, with a demand far exceeding the supply, and the Government would have to approach them as a competitor in the market to obtain a supply for the Indians of the reservation.

(4) That if the water supply from the river be shut off, the Indian reservation would become uninhabitable.

(5) If the dam and canal should be constructed, the present and immediate prospective needs of the reservation might be supplied therefrom, and there would be some surplus water to be used for irrigating lands outside the reservation.

(6) That if the agriculture of the Indians residing on the reservation is to have normal growth, and it be the intention to settle other Indians of the neighborhood who are not supplied with agricultural lands on the reservation, the greater part, and perhaps the whole, of the waters of the Gila will be necessary therefor.

As a result of this report the Department of Justice was again requested to take such steps as would be necessary to prevent the diversion of waters of Gila River to the injury of the Indians of the Pima and Maricopa reservations. Some offers of compromise were made by the canal company, and legal steps were held in abeyance until the canal was constructed, and no successful attempt was ever made to prevent the diversion of the river by the Florence canal or to compel such diverters to supply the Indians with water for irrigation, and the matter was finally allowed to drop by the Department of Justice. The result of the diversion was to deprive the Indians of the greater portion of their water supply during the period when the water was most needed to mature their crops. The shortage has been greater some years than others, depending to a certain extent upon the season, whether abnormally dry or otherwise, but in general there has been a progressive decrease of the water supply for the reservation, due originally, in great measure, to the diversion by the Florence canal.

Recent events have, however, altered the aspect of the question, from the fact that the supply for the Florence canal itself is now short, owing to the diversion for irrigation far above that point, chiefly in Graham and Cochise counties, Arizona. The solution of the problem has become more difficult by reason of its postponement and the condition of the Indians more deplorable. Year after year they plowed and sowed and irrigated their crops, only to have them destroyed by drought before maturity by lack of sufficient irrigation water in the drier months. Naturally they have become discouraged by these fruitless efforts, and great demoralization has resulted. A few who are favorably located at points where water appears in the dry bed of the Gila can still mature their crops; a few others are able to eke out an existence by hauling wood or other precarious employments, while the larger number have become more or less dependent upon charity or have degenerated into thieves and vagabonds.

NECESSITY FOR RELIEF.

On March 27, 1895, Mr. J. Roe Young, United States Indian agent at Sacaton, made a terse statement of the case to the Indian Bureau, closing his letter with the following recommendation:

> What is best to be done I do not know. I recommend, however, that a competent, thorough, and skillful engineer, well acquainted with irrigation questions, be employed to ascertain and report, first, whether or not under existing conditions a supply of water adequate to the needs of these Indians can be obtained and retained permanently, and then, if such a supply can be obtained, what is the best, most feasible, practicable, and economical method of doing so. To properly do this the engineer should examine carefully the past and present condition and flow of the Gila River, the amount of water which formerly passed through this reservation, and the amount we are now receiving; the number and amount of inches of water for which charters for ditches have been granted in the different counties through which the Gila flows, and the amount of water taken out under these charters, together with the number of such charters now legally in force; the underground currents and rock strata along the river, and all matters which, taken together, may lead to some solution of this question. I have been unable to get an estimate of what amount such an investigation and report will cost, but I would suggest that the sum of $5,000 be set apart from any appropriation available for this purpose. Competent and first-class engineers, with ability to make such a report as this case requires, are scarce and high-priced, and they have to be well paid. It would be money thrown away to employ a man not thoroughly posted.
>
> This matter should be taken up soon, in order that we may know what to expect for next year.

Mr. Elwood Hadley, who is now (1899) the Indian agent at Sacaton, in describing the present condition of the Indians of the Gila River Reservation, writes as follows, under date of September 25, 1899:

> Approximately 6,000 Indians—Pimas, Papagos, and Maricopas—are dependent for their subsistence upon the lands of the Gila River Reservation, which reservation contains 357,120 acres. It is estimated that half of the land could be made productive with water to irrigate it. The water supply in the Gila River the present season, owing to its use for lands above us, has not been sufficient to irrigate 1,000 acres. Fully half the crops planted have not produced enough for seed. This land is very fertile. The condition of affairs here shows that in the past three years there has been a large falling off in the water supply for irrigation. The reason is apparent in the absorption of the water by additional cultivated lands above.
>
> I notice in the Indians a restlessness as they realize their helpless condition, and and am often confronted with the solicitous queries, What are we to do? If we plant what we have, what assurance have we of getting it back? Under favorable conditions these Indians, being agricultural and pastoral, would soon become independent, prosperous, civilized citizens. Otherwise, discouragement, hunger, and destitution are their lot. A nomadic life being taken on, their old tribal nature asserts itself, and the expenditures hitherto made and being made by the Government for their education and improvement prove a curse to them rather than a blessing.
>
> It is now necessary to issue considerable subsistence to the Indians whose crops

have been a failure, and this aid will have to be largely increased under the existing limited water supply. A supply of water would permit of the Pima boarding school establishing a model farm, greatly reducing the cost of maintaining the school of 200 pupils, and be a most valuable educational factor in the school life of the pupils. The available Indian labor in the construction of the reservoir is an important factor, as it is much better to provide them labor with pay than keep them as paupers. These Indians are willing to work, and their moral status is good. Their attitude toward the United States has always been friendly. They have saved the Government in protecting the early settlers from the ravages of the Apaches. They have kept themselves within the bounds of law and order, and they are now left upon the desert without water. Humanity speaks, economical administration for the sustenance of the Indians speaks, and Nature, in her wise provisions, says, "Let man's means and intelligence be made operative, that these Indians, whose claims are meritorious, be reinstated in self-sustenance and lifted to the plane of prosperous American citizens."

INVESTIGATION IN 1896.

In November, 1895, the Secretary of the Interior instructed the Director of the Geological Survey to detail a civil engineer to make the examination recommended, and Mr. Arthur P. Davis, hydrographer, was accordingly assigned to this task, in which he was assisted by Mr. Cyrus C. Babb, assistant hydrographer, and Mr. J. B. Lippincott, resident hydrographer for California. Six months of time and $3,500 were expended in the field on the preliminary investigation, and a report was submitted in 1896,[1] entitled The Report on Irrigation Investigation for the Benefit of the Pima and Other Indians on the Gila River Indian Reservation, Arizona.

It was proposed to construct a dam of masonry to the height of 170 feet above the bed of the river, at which height natural facilities occur for the discharge of surplus waters through adequate spillways. This would afford a storage of about 200,000 acre-feet of water below the flow line of 160 feet above the bed of the river. The provisional estimate of the cost of this project aggregated $2,244,000. The great uncertainty attaching to this project was the location of bed rock at a great but unknown depth. Numerous reports were obtained of soundings varying from 40 to 50 feet in depth without striking bed rock.

Inquiry showed that it would be impossible to obtain suitable drilling machinery for a thorough exploration of the foundation, and as a preliminary makeshift the method of sounding by driving rods was resorted to. Rods were driven in eleven places, at intervals of 40 feet, in the proposed dam site, eight of the soundings being 50 feet or more and one reaching the depth of 65 feet. It was impossible with the means at hand to determine whether or not the rods had reached bed rock, but the preliminary estimates were made on the hypothesis that the depth of rock was 65 feet, and in the report of the work it was recommended that "thorough exploration should be made with a core drill before beginning of construction of the dam."

[1] Senate Doc. No. 27, Fifty-fourth Congress, second session.

INVESTIGATION IN 1899.

For the purpose of continuing the investigation along the lines recommended by Mr. Davis a paragraph was inserted in the act making appropriation for current and contingent expenses in the Indian Department, approved July 1, 1898, as follows:

For ascertaining the depth of the bed rock at a place on Gila River, in Gila County, Arizona, known as the Buttes, and particularly described in the Senate Document Number Twenty-seven, Fifty-fourth Congress, second session, and for ascertaining the feasibility and estimating in detail the cost of the construction of a dam across the river at that point for the purpose of irrigating the Sacaton Reservation, and for ascertaining the average daily flow of water in the river at that point, twenty thousand dollars, or so much thereof as may be necessary, the same to be expended by the Director of the United States Geological Survey, under the direction of the Secretary of the Interior: *Provided*, That nothing herein shall be construed as in any way committing the United States to the construction of said dam; and said Director shall also ascertain and report the feasibility and cost of the Queen Creek project mentioned in said Senate document.

In order to carry out the provisions of this act stream measurements were begun on Gila River at the Buttes and on Queen Creek at the site of the proposed dam, in November, 1898, and have been maintained to date (October, 1899). As the site at the Buttes was inaccessible by heavy wagons, a road was built to facilitate the transportation of machinery to the site for drilling. Bids were invited by advertisement for the exploration of bed rock, but were rejected, as it was found that the amount of drilling desirable would, under the most favorable proposal, cost more than the available funds. Two diamond drills, a few diamonds, and two pipe-driving machines were loaned to the Survey for this work by the Nicaragua Canal Commission, and borings were begun at the Buttes in January, 1899.

Twenty-five holes were put down to bed rock at the Buttes with a diamond core drilling apparatus. These holes were distributed up and down the narrow portions of the canyon in order to determine the most acceptable point for the location of the dam. The depths reached were unexpectedly great. This work is described in detail under the account of the diamond core drill borings on page 48. The maximum depth reached by any of the holes was 122.6 feet to bed rock. Because of this great depth an effort was made to find another location for a dam that could utilize the Buttes reservoir site as filed upon under the United States laws. The appearances were favorable for the proximity of bed rock to the surface near the head of the Florence canal, 3½ miles below the Buttes, where the canyon is quite wide, but where outcroppings of rock in places occur. The depth to bed rock at this site—82 feet 2 inches—as determined by borings shown on the map, Pl. VIII, *B*, was too great to justify the location of the dam at this place. The portion of the canyon was contoured between the old reservoir survey, which began at the Buttes dam site proper and the head of the Florence canal, so that a revised capacity of the reservoir could be computed if the dam should be built at the head of the Florence canal. At a point 4 miles above the Buttes, where a dike of volcanic rock apparently of more recent geological formation than the surrounding country crossed the canyon, another exploration for bed rock was made. The canyon at this point at the base of the cliffs is 459 feet in width. As a hole was put down to a depth of 96.3 feet without finding bed rock at this point, this location was condemned as a dam site without further exploration, particularly in view of the excessive length of dam required.

In order to determine the feasibility of constructing a dam at the Buttes, as compared with other possible locations, the Gila River above this location was explored for reservoir sites, and three were found of ample storage capacity. At Riverside, 12 miles above the Buttes, by the course of the river, an available locality was selected and fourteen holes were sunk, which determined a granite bed rock of good quality to exist at a maximum depth of 75.5 feet. At the San Carlos dam site, the next location above, three holes were put down to determine the depth of bed rock. This was the last dam and reservoir site discovered. The high water then interferred with the work to such an extent that it had to be abandoned in August. The data obtained from these three holes are very meager and should be extended, but they had to be accepted in this estimate as determining bed rock at that point. At the Guthrie reservoir site, which is above Solomonville and uppermost of three available locations examined, a detailed survey was also made. The rock at this dam site consists of a mixed volcanic product, there being strata of gravel deposited between various lava flows. This was considered sufficient in itself to condemn this site for construction purposes. A railroad passes through the length of the reservoir and through the dam site, and a change in its location would be a matter of difficulty and large expense.

The upper portion of Gila River and its principal tributaries were explored by Mr. Cyrus C. Babb, hydrographer, as well as the basin of San Pedro River. In both the Gila and San Pedro basins measurements of all canals were made in order to determine the amount of water returning to the river from irrigation and for purposes of general information. This return water has a particular bearing upon our project as contemplated in that the irrigation of 120,000 acres of land in the neighborhood of Florence and Sacaton may be expected to increase the flow of the lower portion of Gila River in a way similar to that of the cases investigated where irrigation has been practiced for a term of years. In other words, if 50 per cent of the water used for irrigation around Solomonville, on the upper portion of the river, returns to the river below the places where it is used for irrigation, and it may again be used for like purpose below, a similar action may be expected below the irrigated lands which are supplied from this proposed reservoir system. Measurements of return water, or "seepage measurements," were also made in the vicinity of Phenix, which show similar conditions.

The canyon of the Gila, between the mouth of the San Pedro and the San Carlos dam site, was explored and found to be 31 miles in length. It is a narrow gorge, as shown on Pl. II, being thus an excellent conduit for the passing of the liberated water from the San Carlos dam site to the irrigable lands below. A traverse survey was made throughout its length. Observations for determining the average evaporation, the range of temperature, and the volumes of suspended silt in the river have been maintained at the Buttes during the period of the survey. A canal line has been surveyed from the Buttes dam site past the head of the Florence canal, a distance of 4 miles. This canal would be used in connection with the Buttes reservoir site for the purpose of delivering its water to the irrigable lands, and largely for the development of power, which could be used, if desired, in the settlements that would spring up under this system.

Owing to the questionable character of the rock for building at the Buttes dam site, quarry tests were made, as described fully under the description of the Buttes dam. Mr. E. Duryee, chemist and cement expert, of Colton, California, investigated thoroughly the rocks of all the localities in question, in order to determine the feasibility of the manufacture of a natural hydraulic or a Portland cement. His investigation, as shown in detail on later pages, also determined the possibility of using the siliceous rocks of the respective localities for blending with Portland cement in the manufacture of what is known as "sand cement." The extent of public domain in the irrigable districts was determined from the land-office records at Tucson, Arizona.

Mr. J. H. Quinton was engaged to assist in the designing of the dams and other engineering works. He visited all the localities in question and made a careful field examination. Mr. James D. Schuyler was employed for purposes of consultation in the planning of the work, in an advisory capacity, and for this purpose made detailed examinations of the various dam sites on two occasions during the progress of the field investigation. The service which Mr. Schuyler has rendered in this capacity has been of prime importance to the work, owing to his very extended experience in the construction of dams for irrigation purposes.

The general plans for dams at all points have been matters of discussion during a period of months by all the engineers connected with this investigation. Each has contributed his share toward the formation of the final plans which Mr. Quinton has prepared. The office work for the report has been done in Los Angeles, where the plans and estimates have been prepared. Numerous laboratory tests of material from the dams and of the sand cements have been made. Mr. Arthur P. Davis, hydrographer, was in charge of the organization of the field work and of its execution until May 1, 1899, when he was detailed to assist the Nicaragua Canal Commission in its work on the Isthmus. Mr. Davis practically outlined the field work. His ideas with reference to plans of construction have been given most careful

A. GILA RIVER CANYON, 15 MILES BELOW SAN CARLOS DAM SITE.

B. GILA RIVER CANYON, 8 MILES BELOW SAN CARLOS DAM SITE.

consideration in reaching final conclusions, and to him is due the credit, in large part, for the successful carrying out of the work and for its breadth and scope.

AMOUNT OF WATER REQUIRED.

In order to determine the amount of water that will be required for the Indians on the Gila River Indian Reservation, Mr. Elwood Hadley, United States Indian agent at Sacaton, was requested to make a statement on the subject. In his reply, dated October 12, 1899, he writes:

> It is estimated that there are nearly 4,500 Pima and Maricopa Indians on the reservation dependent for their subsistence upon its lands. South of this reservation, in the country lying between the Southern Pacific Railroad and the border line of Mexico, it is estimated that there are nearly 2,000 nomadic Papagos, who derive much of their subsistence from the Pimas of this reservation (Gila River) in exchange for their labor. The Pimas are liberal and kind to their more unfortunate brothers, and give them a share of their products in return for their labor in harvesting the crops.
>
> The estimated number of Indians under my care is as follows: Pimas, 4,200; Maricopas, 350; Papagos, 2,700; total, 7,250.
>
> The number named above who live on reservations away from here would gladly come here if they could be furnished with water. It is estimated that 2 acres of land will sustain an Indian.

The report of the Commissioner of Indian Affairs for 1896 gives for the Pima Agency the following population: Pimas, 4,260; Maricopas, 340; Papagos, 1,224; Papagos, nomadic, 2,046—total, 7,870. This does not state, however, whether these are actually on this particular reservation or on others.

In the report of Mr. Arthur P. Davis, of 1896, it is estimated that 1.5 acres of ground is necessary for the support of each Indian. This estimate is thought to be liberal. In the irrigated districts of southern California an inhabitant to each acre is sustained. For the irrigation of grain probably 1.5 acre-feet of water is sufficient for the complete development of the crop for each season; but for the growth of alfalfa or orchards a lower duty of water will be required, and 2 acre-feet per acre is assumed in this report to be a satisfactory supply. If there are 7,250 Indians now located upon this reservation or deriving their subsistence from it, each requiring 1.5 acres of irrigated land, it would be necessary to supply 10,875 acres with water to meet present demands. At the rate of 2 acre-feet of water for each acre irrigated, it will be necessary to furnish 21,750 acre-feet to the reservation to meet this requirement. There will doubtless be other Indians on neighboring reservations on the lower portion of Gila River, whom the Department would desire to move onto the Gila Reservation in case an abundant supply of water could be furnished to them. In view of these possible transfers, and of the natural increase in numbers of the tribes now dependent upon the reservation, a prospective demand on the reservoir system of 40,000 acre-feet is considered necessary.

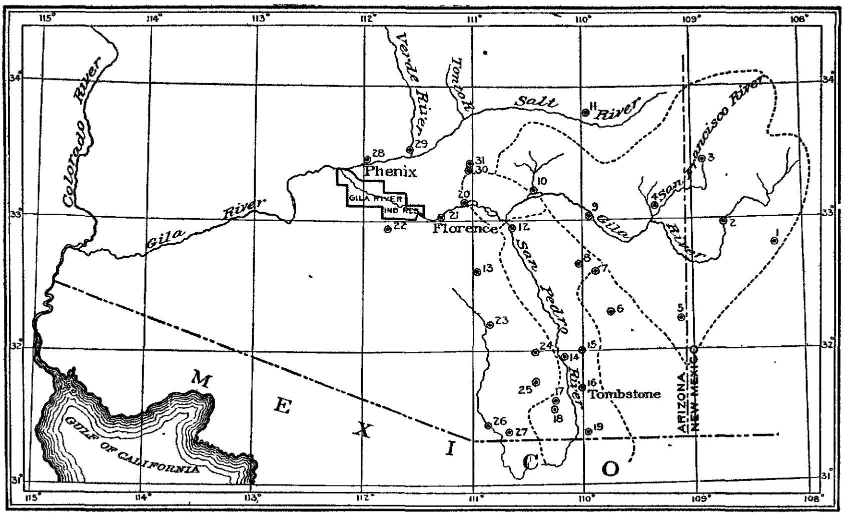
WATER SUPPLY.

PRECIPITATION.

Rainfall observations have been taken at thirty-one different points in the basin of Gila River above the Buttes, as shown on Pl. III, *A*, the earliest record beginning at Fort Bayard, New Mexico, in 1867. Undoubtedly the greatest precipitation of the basin occurs in the higher mountains, in its northeastern portion. The records for these mountain districts are rare, most of them being taken in the valleys where settlements and agriculture occur. It is probable, therefore, that the actual rainfall for the basin is greater than that indicated by the tables and diagrams. For the purpose of this report the rainfall observations in the basin of Gila River above the Buttes have been grouped in three classes in the following table—first, the Gila Basin proper, exclusive of the basin of the San Pedro; second, the basin of the San Pedro; and third, a series of observations at three stations in the vicinity of Florence, five stations in the basin of Santa Cruz River, which stream enters the Gila below the mouth of the Salt, and three sets of observations in the vicinity of Phenix. The segregation of the records into the groups named is for the purpose of comparing the relative amount of water available for storage purposes at the reservoir site at San Carlos and at the Buttes.

Annual rainfall, in inches, in basin of Gila River above San Carlos, Arizona.

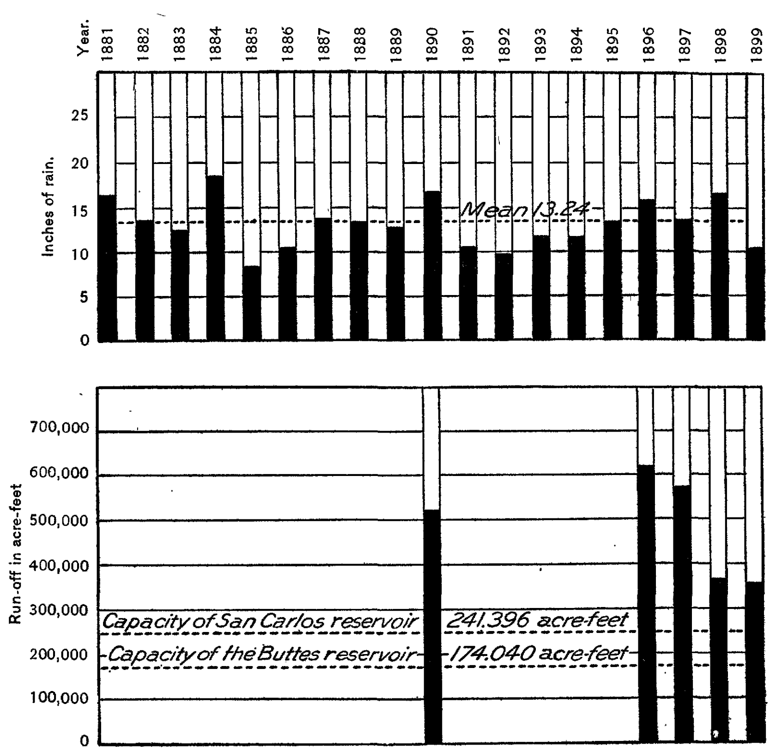
	Fort Bayard.	Gila.	Alma.	Oro.	San Simon.	Willcox.	Fort Grant.	Cedar Springs.	Fort Thomas	San Carlos.	Fort Apache.	Mean above San Carlos.
Elevation (feet)	6,022		5,500	3,610	3,611	4,164	4,860	4,900	2,700	2,450	5,050	
Year:												
1867	13.87											
1868	15.23											
1869	12.84											
1870	10.07											
1871	5.79											
1872	13.61											
1873	22.18						17.99					
1874	20.38						17.81					
1875	19.66						20.91					
1876	18.94										19.74	
1877	13.12						10.13				12.50	
1878							16.46				28.61	
1879							12.82				18.58	
1880							15.74				14.77	
1881						12.11	18.96		11.41		31.12	18.40
1882					6.50	8.58	15.42		8.66	15.27	27.62	13.69
1883					7.15	8.73	15.48		10.85	12.21	21.65	12.68
1884					10.37	14.38	25.67		18.16	20.41	29.47	19.74
1885					2.39	8.51	9.21		8.70	8.19	15.58	8.76
1886					2.02	9.37			10.86	10.44	21.06	10.75
1887	13.59				.99	16.49	24.32		16.35	8.68	17.84	14.04
1888	13.42				4.55	11.93	14.20		13.34	13.04	18.89	12.77
1889	7.21					13.68	13.32	16.44	10.89	13.40	17.10	12.60
1890				15.94	8.43		15.88		13.93	17.86	26.72	16.46
1891	10.30			10.90	4.04	7.36	12.21			11.00	13.36	9.88
1892	8.80				2.57	8.01	7.90			12.05	12.70	8.67
1893					5.65	3.95	13.85			12.53	15.08	10.21
1894	8.67				3.24	5.88	13.53			10.15	17.42	9.81
1895	14.45	12.41	16.51		2.78	8.04	13.22			14.41	18.03	12.48
1896	19.98	17.87	15.09	12.99	4.36	9.22	15.99			13.88	16.09	13.84
1897	17.00	14.44	15.68	10.69		5.66	13.87			7.90	14.93	12.52
1898	16.21	15.22	17.26	16.14		8.16	14.26			7.79	20.55	14.45
1899												
Mean	14.06	14.98	16.13	13.33	4.65	9.42	15.34		12.32	12.31	19.54	12.87



A. LOCATION OF RAINFALL STATIONS IN BASIN OF GILA RIVER.

Rainfall stations:

1. Fort Bayard.
2. Gila.
3. Alma.
4. Oro (Clifton).
5. San Simon.
6. Willcox.
7. Fort Grant.
8. Cedar Springs.
9. Fort Thomas.
10. San Carlos.
11. Fort Apache.
12. Dudleyville.
13. Oracle.
14. Benson.
15. Dragoon.
16. Tombstone.
17. Fort Huachuca.
18. Huachuca Mountains.
19. Bisbee.
20. Buttes.
21. Florence.
22. Casa Grande.
23. Tucson.
24. Pantano.
25. St. Helena Ranch.
26. Calabasas.
27. Lochiel.
28. Phenix.
29. Fort McDowell.
30. Pinal Ranch.
31. Silver King.



B. RAINFALL AND RUN-OFF IN GILA BASIN.

Annual rainfall, in inches, at stations in basin of San Pedro River, Arizona.

	Dudleyville.	Oracle.	Benson.	Dragoon.	Tombstone.	Fort Huachuca.	Huachuca Mountains.	Bisbee.	Mean San Pedro Basin.	Mean above the Buttes.
Elevation (feet)	2,360	4,500	3,580	5,436		5,100	5,000	5,500		
Year:										
1881			8.60							16.44
1882			9.64							13.11
1883			10.57							12.38
1884			8.69							18.16
1885			4.24							8.11
1886			6.27			11.47			8.87	10.21
1887			8.19			15.28			11.73	13.53
1888			7.84			19.95			13.89	13.02
1889			7.78			15.39	15.87		13.01	12.72
1890			13.83			19.60		20.22	17.88	16.93
1891	8.59		5.81	17.38		10.84	12.04	14.34	11.50	10.63
1892	10.29					11.50	12.24	12.92	11.74	9.90
1893	8.37		7.71			20.16	16.58	14.79	13.52	11.87
1894	15.12	18.36	4.57			13.95	16.48		13.69	11.58
1895	15.92	14.44				14.15		14.80	14.82	13.26
1896	15.45	19.62	16.78	16.03		21.27	20.39	20.86	18.62	15.98
1897	10.03	14.43	18.60	8.41	13.44	16.68	22.01	17.59	15.15	13.83
1898	14.96	20.89		11.44	13.50	21.82	26.38	25.87	19.26	16.69
1899										
Mean	12.34	17.55	9.21	13.31	13.47	16.31	17.75	17.67	14.13	13.24

Annual rainfall at stations in basin of Gila River, in the vicinity of Florence, Tucson, and Phenix, Arizona.

	Florence vicinity.			Santa Cruz Basin.					Phenix vicinity.			
	Buttes.	Florence.	Casa Grande.	Tucson.	Pantano.	St. Helens ranch.	Calabasas.	Lochiel.	Phenix.	Fort McDowell.	Pinal ranch.	Silver King.
Elevation	1,600	1,493	1,396	2,404	3,538		3,445	5,100	1,068	1,250	4,400	3,800
Year:												
1867										15.26		
1868										15.22		
1869										7.69		
1870										5.45		
1871										4.94		
1872										20.01		
1873										8.13		
1874										16.84		
1875										4.97		
1876		9.33		14.02						7.73		
1877		5.35		12.77					5.17	9.38		
1878		13.49		16.66					8.52	11.92		
1879		12.02		12.01					6.40	8.34		
1880		5.35		6.61					6.82	6.61		
1881		12.14	1.73	14.92	15.65				8.91	7.24		
1882				15.59	15.73				6.94	9.10		
1883			3.01	7.78					7.40	9.89		
1884			9.71	15.03					12.83	20.95		
1885			2.02	5.26	8.96				3.77	8.30		
1886			5.12	8.59	10.36				5.78	8.08		
1887			7.71	12.95						10.32		
1888			4.30	10.60						11.91		
1889		8.90	4.25	18.37	15.50					12.78		
1890		12.70	10.70	14.16	18.71			26.90				
1891		8.24	3.62	7.30	9.87		9.65	15.10				
1892		9.95	8.75	9.61	10.79		11.83		5.50			
1893		9.63	4.92	13.12	3.35		10.28		7.68			
1894			5.82	7.29	18.84		10.29		5.50			
1895				11.07	11.40		15.14					
1896				11.39	14.58				10.48		20.38	
1897	7.59		3.03	10.77	10.73	18.21	10.83	16.14	9.87		23.23	
1898				12.72	12.16				5.95		19.84	
1899												
Mean		9.74	5.33	11.68	12.62		11.34	19.38	7.35	10.48	21.15	

The records in the vicinity of Florence and Phenix apply to the districts where the water stored will probably be applied for irrigation, and indicate the need of an artificial supply. In the case of the San Pedro Basin, the greater portion of its water supply is furnished near the headwaters of that stream. The lower portion of the river, which constitutes the greater part of its area, being low in elevation, has a relatively lighter rainfall, and, owing to the flat nature of the valleys, a low per cent of run-off. The observations of precipitation in the San Pedro Basin have, with one exception—those of Dudleyville—been made in this upper portion of the basin and at points of high elevation. They indicate, therefore, a water supply in excess of conditions as they really exist.

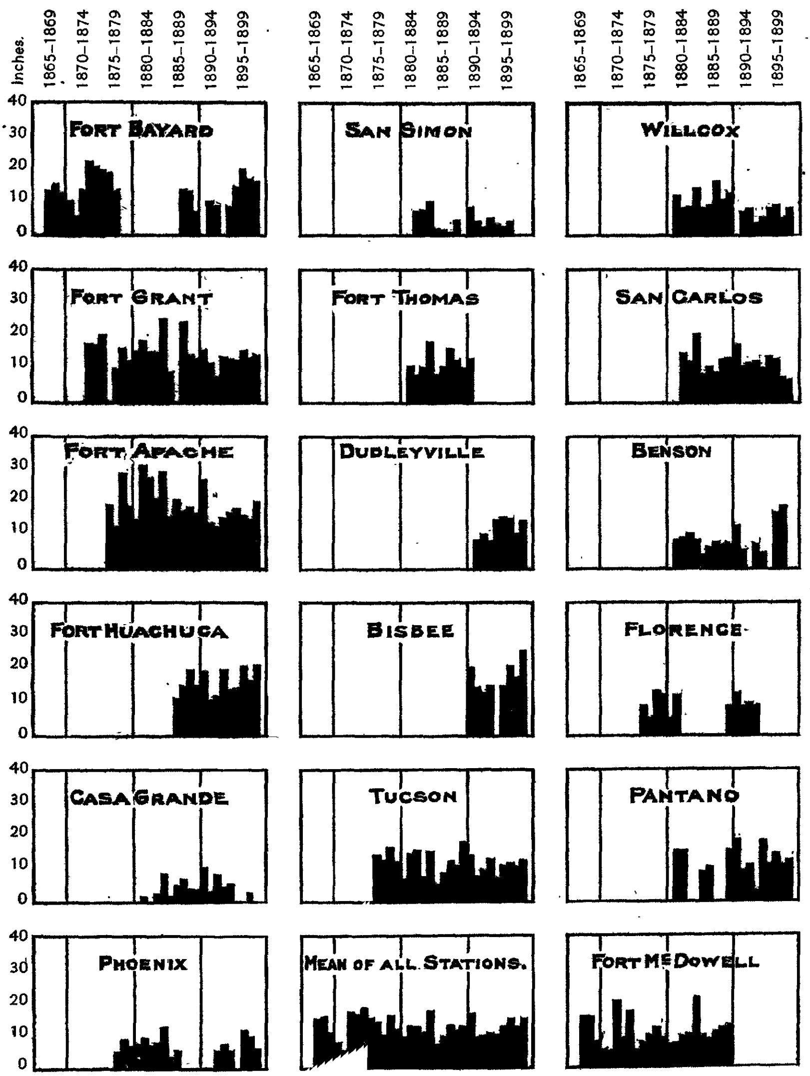
In connection with the study of the increase of rainfall with an increase in elevation, the following table is of interest:

Increase of rainfall with each 100 feet of rise in elevation, with Fort McDowell as a base.

Station.	Length of record.		Elevation.	Elevation above McDowell.	Measured rain.	Constant increase per 100 feet rise.
	Yr.	*mo.*	*Feet.*	*Feet.*	*Inches.*	*Inches.*
McDowell	23	10	1,250		10.38	Base.
Lowell	19	5	2,400	1,150	12.37	0.17
Breckenridge	6	10	3,800	2,550	17.03	.26
Fort Grant	17	2	4,860	3,610	16.85	.18
Fort Buchanan	3	11	5,330	4,080	21.58	.27
Fort Apache	18	10	5,050	3,800	21.04	.28
Verde	22		3,160	1,910	13.13	.15
Prescott	23	11	5,390	4,140	17.06	.16
						1.47
Mean						.21

Comparing the stations given in this table with the record at Fort McDowell, which is a very old one, extending from 1867 to 1888, it is found that in eastern Arizona the rate of increase for each 100 feet of rise in elevation is 0.21 of an inch of rain. It is probable that, notwithstanding the fact that the mean rainfall as measured above San Carlos for all stations is 12.87 inches, and that the mean for the San Pedro Basin is given as 14.13, the average rainfall of the basin of the Gila above San Carlos is greater than the average for the entire San Pedro Basin, and consequently the run-off per square mile of the San Pedro Basin, owing particularly to the flat valley lands through which the river flows in the greater portion of its course, is less than the run-off per square mile of the Gila above San Carlos. This is sustained by observations of flow of both streams during a period of five months.

A diagram is given (Pl. IV) showing the precipitation, in inches per



ANNUAL RAINFALL AT EIGHTEEN STATIONS IN THE BASIN OF GILA RIVER.

annum, during the years when observations of the rainfall were made at various typical stations. For 1899 the figures are estimated after September 1. Data were had from the records of the Signal Service and of the Weather Bureau showing the amount of precipitation each month at each of the eighteen stations named in the table, but they are considered too voluminous for publication. The table of annual rainfall in the basin of the Gila is compiled from this mass of detail. After careful consideration it was deemed impossible to give an average rainfall for the basin based on probable rainfall at various elevations. The means given in the table and diagrams are the direct means of the stations at which observations were made, each being given equal weight in the years when its record occurs. In the case of the upper portion of the Gila the mean has not been extended back of 1881, as sufficient data do not exist upon which to base an accurate deduction. The few points at which observations were taken prior to 1881 would probably indicate a greater rainfall for the basin than existed, owing to their relatively great elevation. In like manner, the record of the San Pedro is not extended back of 1886.

SUBDIVISIONS OF THE DRAINAGE BASIN.

The outlines of the Gila River Basin have been marked on the Land Office maps of Arizona and New Mexico and the areas measured by planimeter. The basin of the southern tributary, the San Pedro, extends into the Republic of Mexico. From the best obtainable data the area in Mexico has been determined to be 120 square miles. The following table classifies the drainage basin of the Gila above the Buttes into three parts: First, the area above the San Carlos dam site, which would be tributary to a reservoir if located at that point; second, the area of the basin of San Pedro River; third, small intermediate basins below San Carlos. The San Pedro Basin is difficult of exact determination, owing to the excessive flatness of the Sulphur Springs Valley, extending from near Camp Grant to the Mexican line and varying from 30 to 40 miles in width. This valley is a great sink from which little or no run-off occurs, and it has been eliminated from consideration in this estimate south of the Graham County line. A small area between San Carlos and the Buttes is directly tributary to Gila River, independently of the San Pedro. The principal stream in this last-named district is Mineral Creek.

Drainage area of Gila River above the Buttes, Arizona.

		Square miles.
Drainage above San Carlos:		
In Arizona	7,378	
In New Mexico	6,077	
Total		13,455
San Pedro above mouth:		
In Arizona	3,336	
In Mexico	120	
Total		3,456
Small tributaries between San Carlos and the Buttes		923
Total area of Gila Basin above the Buttes		17,834
Total area below San Carlos		4,379

The total accepted area for the basin of Gila River above the Buttes is 17,834 square miles. The total area below San Carlos and above the Buttes is 4,379 square miles, which is practically 25 per cent of the entire area above the Buttes.

RELATIVE FLOW AT SAN CARLOS AND THE BUTTES.

In the Twelfth Annual Report of the Survey, Part II, page 305, is given a tabulation of the observations made on San Pedro River at its mouth, at Dudleyville, Arizona, from May to August, inclusive, 1890. During this period there was discharged from that stream 19,488 acre-feet of water. During the same period of time, as measured at the Buttes below the mouth of San Pedro River, there was a total discharge from the basin of 207,936 acre-feet. This shows that 9.4 per cent of the total discharge of the basin above the Buttes came from the San Pedro, and that 90.6 per cent came from other portions of the stream. There are 923 square miles tributary to the Gila above the Buttes and below San Carlos other than the San Pedro drainage.

From the above figures it is considered fair to estimate that 90 per cent of the water of Gila River comes from above San Carlos and that a reservoir located at the last-named point would only lose 10 per cent of the total amount flowing by the Buttes. Moreover, the amount which enters the stream below San Carlos would not necessarily be entirely lost to a reservoir at that point, as the discharge from the reservoir could be regulated, at least in part, so as to take advantage of the amount of water available from the San Pedro. The synchronous observations which have been made from July 19 to September 23, 1899, at San Carlos and at the Buttes have not yet been of sufficient duration to admit of drawing general conclusions.

During the month of July the record indicated that 91 per cent of the total flow at the Buttes passed San Carlos. During the month of August there was deficient rainfall throughout Arizona in general. According to the statement of the Weather Bureau (report for August, 1899, Arizona section), "The average precipitation for the Territory for the month of August was 85 per cent less than the normal. The average determined from the measurements of 59 stations was 1.26 inches, which is 1.75 inches less than the average for August, 1898. The greatest amount measured at any station during the month was 5.77, at Fort Huachuca, and no precipitation was reported at several stations." Fort Huachuca is in the headwaters of the basin of the San Pedro, and the rainfall at other stations in that neighborhood was abnormally large for August. As might be expected, therefore, during the month of August the discharge from the San Pedro has been proportionately great. The record of stream measurements indicates 60 per cent of the total flow as measured at the Buttes passing San Carlos during August. From September 1 to 23, inclusive, there was 59 per cent at San Carlos. No rainfall records for September, 1899, are at present (October 3, 1899) available.

The record for the four months given in 1890 indicates 90 per cent of the total flow at the Buttes available at San Carlos, and during the two complete months (July 19 to September 23) when the measurements were maintained in 1899 at both places a mean of 74 per cent was available at San Carlos, or an average for the entire period of six months of 83 per cent at San Carlos.

The following figures are the result of comparative measurements at the Buttes and San Carlos during July, August, and September, 1899:

Comparative discharge of Gila River at San Carlos and the Buttes, in cubic feet per second.

	July.		August.		September.	
	San Carlos.	The Buttes.	San Carlos.	The Buttes.	San Carlos.	The Buttes.
1			780	1,850	80	60
2			3,188	2,850	80	50
3			960	4,100	80	45
4			780	2,260	80	42
5			520	1,040	80	24
6			520	930	230	31
7			590	660	290	1,300
8			460	1,380	7,920	10,187
9			680	905	780	2,923
10			520	717	520	1,950
11			370	460	410	1,382
12			330	515	330	734
13			330	397	290	510
14			260	397	230	399
15			260	280	200	357
16			200	215	200	288
17			200	315	200	249
18			140	210	200	205
19	11,976	1,800	140	270	170	202
20	6,568	8,700	140	175	140	147
21	2,174	4,100	140	135	110	130
22	1,836	2,260	140	100	110	126
23	1,836	1,900	110	112	110	99
24	1,498	1,550	110	90		
25	960	1,445	110	89		
26	780	1,550	110	80		
27	840	1,550	80	80		
28	750	3,640	80	70		
29	960	2,440	140	71		
30	590	2,475	80	60		
31	520	995	80	77		
Mean	2,407	2,647	405	671	555	932
Per cent	91		60		59	

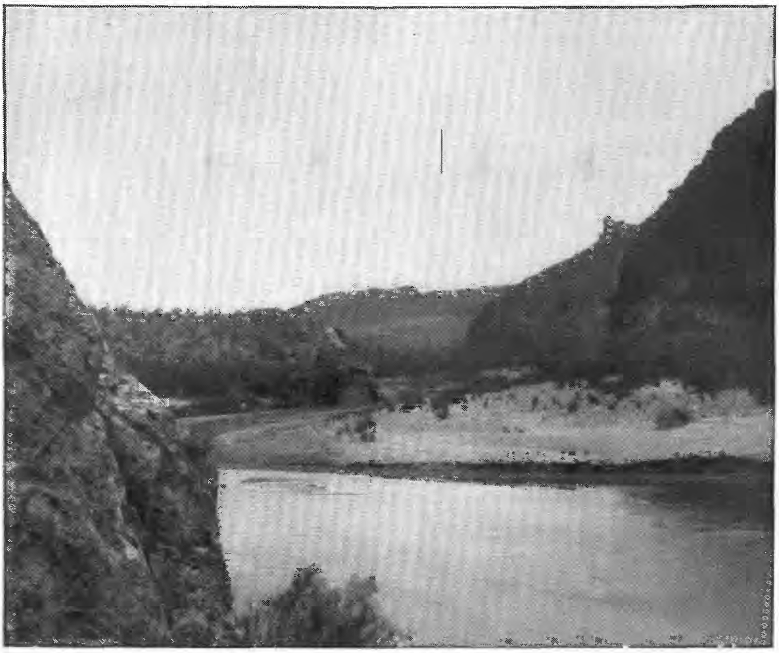
The inspection and study of the basin of the San Pedro, as well as of the Gila proper, by members of this Survey, and the study made of the relative values of their drainage areas, justify the conclusion drawn from all the measurements that 90 per cent of the total flow as measured at the Buttes is available at San Carlos. The larger part of the water of Gila River comes from the San Carlos, the San Francisco, the Blue, and the extreme eastern branches of the stream, and a small per cent enters from the San Simon Plains, which lie between Solomonville and Bowie station on the Southern Pacific Company's railroad.

Wherever irrigation is practiced a certain portion of the water is permanently lost by evaporation from the surface of the ground or from the leaves of the growing plants. Another portion of the water used for irrigation, varying in amount from 20 to 50 per cent, depending upon the nature of the soil and the slopes of the irrigated lands toward the drainage lines, sinks into the ground. This is known as seepage or return water. It fills the pores in the soil, gradually raising the water plane until it flows into natural drainage lines and becomes again available for irrigation. In the Solomonville Valley, in the Gila River Narrows, below the Sanchez ditch, there was, on April 15, 1899, 237 second-feet of water. Within a distance of 40.7 miles below this point there was diverted in ditches 429.8 second-feet of water. A small amount of water is wasted back into the river from these ditches, but the actual amount used for irrigation is 64 per cent in excess of the amount available for that purpose at the highest point of diversion. In other words, an amount equal to 64 per cent of the water found at the head works on April 15, 1899, found its way through underground courses back into the river.

In the valley of the Salt River, near Phenix, there was 40 per cent more water used for irrigation in June, 1899, than was flowing in the river at the highest point of diversion at the head works of the Arizona Canal. It must be remembered in this connection, however, that during the months of July and August there is a much larger volume of water diverted for irrigation than on the dates when these measurements were made, and that a larger amount of water is used on other occasions for the irrigation of these lands than is indicated in this report.

In order to determine the actual ratio between the return water and the amount applied to irrigation the average annual quantity used for irrigation for a term of years should be determined. This amount is at present unknown. It is, however, fair to assume that a substantial percentage of all water used for irrigation finds its way back into the channel of the two streams named above. This may be as high as 25 per cent, as it is known to be greater in other localities. Because of the exceedingly slow movement through soil the discharge is regulated and is of a constant nature. For instance, the flow of Los Angeles River, in California, which receives its water supply from the sand and gravel beds of the San Fernando Valley, which underground reservoir is charged with intermittent floods, has not varied in amount during the last three years to exceed 15 per cent.

It may be confidently expected that as a result of the irrigation of 120,000 acres of lands in the Gila River Valley between Florence and Sacaton 20 or 25 per cent of the water used in this irrigation will return to the channel of Gila River and will be available for further use at lower points on this stream. This would be sufficient to irri-



A. BUTTES DAM SITE, LOOKING UPSTREAM; PROPOSED QUARRIES ON LEFT; SPILLWAY ON LEFT OF CENTER OF FIELD.

B. BUTTES DAM SITE, LOOKING UPSTREAM FROM UPPER TOE.

gate from 24,000 to 30,000 acres of land, in addition to the areas estimated as capable of being served from a reservoir on Gila River.

MEASUREMENTS OF GILA RIVER AT THE BUTTES, ARIZONA.

Gila River leaves the mountains and enters the plains at a point 15 miles above Florence, known as the Buttes. At this place the river is in a canyon, which is approximately 450 feet wide, its bed being covered with sand and gravel to a maximum depth of 123 feet. Beyond this point, until it forms a junction with its principal tributary, Salt River, it loses in volume. A gaging station was established here and the amount of water available from the basin was accurately determined by the Geological Survey from August 26, 1889, to August 31, 1890, but the work was stopped at the end of this time by lack of available funds. The results of these measurements are given in the Twelfth Annual Report, Part II, Irrigation, pages 306 to 309, and following tables, and are shown graphically on Pl. VI, *B*. A gap occurs in the record from August, 1890, to August, 1895. In the fall of 1895 measurements were begun by the reestablishment of a station at the Buttes above Florence, at the same point that observations were made during the years 1889 and 1890.

From August 1, 1895, to December 10, 1895, gage heights and depths were observed by W. Richins, and occasional estimates of velocity were made, and with these data and the measurements made subsequent to the middle of December the daily discharge for the months of August, September, and November, and the early part of December, 1895, has been ascertained. These results can be regarded only in the light of approximations and do not compare in value with those following December 10. Measurements were continued throughout the year 1896 by W. J. Brash, daily readings of the gage being taken and current-meter measurements made from one to three times a week. The data obtained for the period following December 10, 1895, and extending to October, 1896, are of a high degree of accuracy.

During the year 1897 measurements were continued at this station by W. J. Brash and Albert T. Colton, forty-nine measurements of discharge being taken, the last measurement being made on October 24, 1897. Mr. Brash, who was connected with this work in 1896 and 1897, died in the fall of 1897, and no other person residing in that immediate locality, it was not possible, with funds available, to have the gage rod read daily.

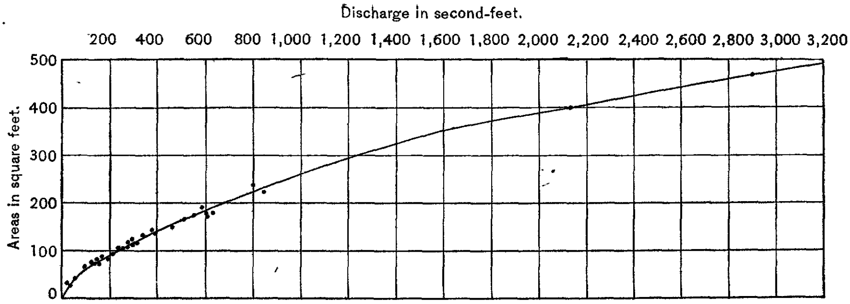
Measurements were made between March 7 and October 10, 1898, by Albert T. Colton, and subsequent to November 14 by Cyrus C. Babb and others connected with the present investigation. Sixteen meter measurements of discharge were thus made, as shown by the diagram, Pl. VI, *B*, prior to November 25, 1898. After this time a continuous record was maintained to the end of the year. In order to make the best possible use of the sixteen observations made prior to November 25, 1898, the volumes as measured on those dates were plotted in diagram, the vertical axis representing volumes measured in cubic feet per second and the horizontal axis representing intervals of one day's time each. The points thus determined were connected by straight lines, and from this diagram monthly estimates of discharge were made. Subsequent to November 25, 1898, daily observations of gage height and area were taken and frequent meter measurements of volume made. As daily measurements of areas in square feet were made, the rating curve graphically shown on Pl. VI, *A*, is in terms of areas of cross section and discharge.

During the year 1899, until October 20, measurements of area were made daily and frequent observations of velocity were taken with a meter. The results are shown graphically on Pl. VI, *B*. The rating table applying from November 25, 1898, to July 10, 1899, is used for the first portion of this year. The meter which was in service at the Buttes got out of order July 20, 1899, and until August 10 observations of gage height and area were taken daily. The discharge during this interval has been computed by using values corresponding to the gage heights determined from the rating curve shown on Pl. VIII, *A*. This exhibits the relation between gage height and discharge, and also, by the position of the small dots, the values determined by meter measurements. The following table expresses numerically the values given in the rating curve:

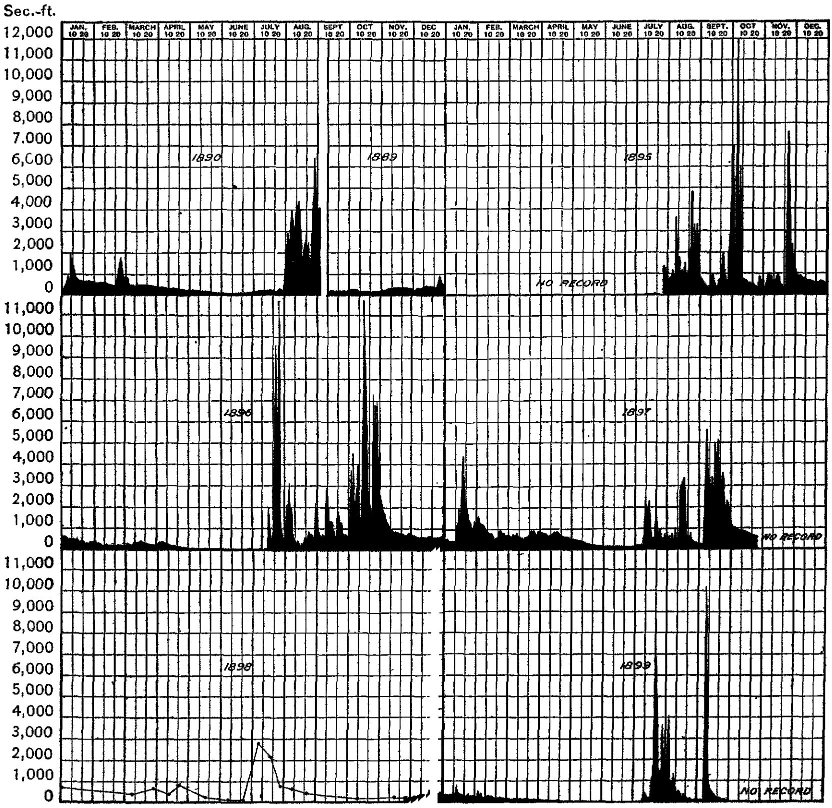
Rating table for Gila River at the Buttes, Arizona, from July 11, 1899, to August 10, 1899.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
1.5	....	2.7	250	3.9	1,445	5.1	3,364
1.6	0	2.8	320	4.0	1,550	5.2	3,548
1.7	1	2.9	410	4.1	1,670	5.3	3,732
1.8	5	3.0	500	4.2	1,800	5.4	3,916
1.9	9	3.1	605	4.3	1,950	5.5	4,100
2.0	15	3.2	710	4.4	2,100	6.0	5,020
2.1	25	3.3	815	4.5	2,260	6 5	5,940
2.2	40	3.4	920	4.6	2,440	7.0	6,860
2.3	60	3.5	1,025	4.7	2,625	7.5	7,780
2.4	90	3.6	1,130	4 8	2,810	8.0	8,700
2.5	130	3.7	1,235	4.9	2,995	8.5	9,620
2.6	180	3.8	1,340	5.0	3,180	9.0	10,540

From these daily measurements of area and frequent measurements of discharge, together with the rating tables mentioned above, the following table of volumes of discharge for Gila River at the Buttes from November 25, 1898, to September 30,1899, has been prepared.



A. RATING-CURVE OF GILA RIVER AT THE BUTTES, ARIZONA. APPLIED FROM NOVEMBER 25, 1898, TO JULY 10, 1899.



B. DISCHARGE OF GILA RIVER AT THE BUTTES, ARIZONA, 1889–1899.

Estimated daily discharge of Gila River at the Buttes.

Day.	1898.				1899.							
	November.		December.		January.		February.		March.		April.	
	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.
1	......	......	2.32	195	2.80	320	2.69	170	2.50	125	2.50	90
2	......	......	2.35	195	2.775	345	2.72	200	2.50	155	2.45	90
3	......	......	2.35	215	2.80	370	2.88	550	2.50	155	2.50	90
4	......	......	2.40	255	2.72	255	2.94	455	2.50	110	2.50	100
5	......	......	2.40	235	2.70	300	2.90	345	......	110	2.50	100
6	......	......	2.40	255	2.65	275	2.77	410	2.50	110	2.50	100
7	......	......	2.45	255	2.60	255	2.69	235	2.50	155	2.45	80
8	......	......	2.45	255	2.62	275	2.71	235	2.50	155	2.45	70
9	......	......	2.50	275	2.67	255	2.72	200	2.50	110	......	60
10	......	......	......	275	2.60	235	2.70	300	2.50	140	2.45	60
11	......	......	2.60	275	2.72	275	2.77	255	2.40	140	2.45	50
12	......	......	2.72	410	2.95	480	2.80	300	......	140	2.40	70
13	......	......	2.50	300	3.30	800	2.80	275	2.40	140	2.40	70
14	......	......	2.70	320	3.15	500	2.77	275	2.40	100	2.40	70
15	......	......	2.75	275	3.00	435	2.75	275	2.40	100	2.40	60
16	......	......	2.72	320	3.00	390	2.70	255	2.50	100	......	60
17	......	......	2.80	320	2.95	345	2.67	170	2.55	110	2.40	60
18	......	......	2.85	390	2.92	345	2.67	170	2.55	155	2.40	60
19	......	......	2.90	480	2.80	320	2.66	140	......	155	2.35	60
20	......	......	2.90	480	2.72	275	2.62	170	2.60	155	2.30	50
21	......	......	2.87	435	2.70	255	......	170	2.60	155	2.30	60
22	......	......	2.90	410	2.70	235	2.65	170	......	140	2.30	50
23	......	......	2.90	435	2.80	320	2.60	155	2.60	140	......	50
24	......	......	2.95	390	2.80	370	2.60	200	2.50	140	2.30	60
25	2.10	105	......	335	2.75	255	2.60	155	2.50	140	2.30	50
26	2.20	165	2.80	275	......	300	2.60	155	......	140	2.30	40
27	2.20	135	2.80	300	2.75	235	2.60	170	2.50	125	2.30	20
28	2.10	165	2.85	345	2.70	255	2.50	125	2.50	110	2.25	30
29	2.22	150	2.75	320	2.75	235	......	......	2.50	125	2.25	30
30	2.30	195	2.80	300	2.70	170	......	......	2.50	110	......	30
31	......	......	2.80	320	2.70	185	......	......	2.50	100	......	......
Mean	......	152	......	305	......	318	......	239	......	130.5	......	62.3

Day.	May.		June.		July.		August.		September.	
	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.	Gage height.	Dis-charge.
1	2.25	38	1.90	5	1.75	0.5	4.0	1,850	2.0	60
2	2.20	34	2.20	30	1.75	0.5	4.7	2,850	2.0	50
3	2.20	30	2.10	20	1.70	0.5	5.5	4,100	......	45
4	2.20	30	......	16	1.70	0.3	4.5	2,260	1.9	42
5	2.20	31	2.00	12	1.70	0.3	4.0	1,040	1.9	24
6	2.15	28	1.95	11	1.70	0.3	3.7	930	1.9	31
7	......	26	1.90	16	1.70	0.2	3.3	660	3.28	1,300
8	2.15	25	1.90	6	1.70	0.2	4.5	1,380	8.3	10,187
9	2.15	24	1.90	5	......	0.2	3.7	905	4.95	2,923
10	2.10	24	1.85	5	1.80	2	3.3	717	4.3	1,950
11	2.10	24	......	4	2.75	300	3.3	460	3.5	1,382
12	2.10	23	1.80	4	2.80	320	3.1	515	3.0	734
13	2.10	23	1.80	2	2.70	250	2.8	397	2.8	510
14	......	20	1.80	2	2.50	130	2.8	397	2.7	399
15	2.05	16	1.80	2	2.40	90	2.7	280	2.6	357
16	2.05	14	1.75	2	......	170	2.6	215	2.5	288
17	2.00	12	1.75	1	2.70	250	2.5	315	2.4	249
18	2.00	13	......	1	3.40	920	2.5	210	2.3	205
19	2.00	13	1.75	1	4.20	1,800	2.4	207	2.3	202
20	2.00	14	1.75	1	8.00	8,700	2.4	175	2.2	149
21	......	12	1.75	1	5.50	4,100	......	135	2.2	130
22	2.00	10	1.75	1	4.50	2,260	2.3	100	2.2	126
23	2.00	8	1.75	1	......	1,900	2.3	120	2.1	99
24	2.00	9	1.75	1	4.00	1,550	2.2	90	2.1	108
25	2.00	11	......	1	3.90	1,445	2.1	89	2.05	93
26	2.00	12	1.75	2	4.00	1,550	2.1	80	2.0	72
27	1.95	13	1.75	2	4.00	1,550	2.1	80	2.0	77
28	......	10	1.75	1	5.25	3,640	2.0	70	2.0	68
29	1.95	9	1.75	1	4.50	2,440	2.0	71	2.0	68
30	1.90	6	......	......	4.20	2,475	2.0	60	......	68
31	1.90	4	......	......	4.00	990	2.0	77	......	......
Mean	......	18.2	......	5.4	......	1,188.0	......	671.8	......	733.1

Estimated monthly discharge of Gila River at the Buttes, Arizona.

[Drainage area, 17,834 square miles.]

Month.	Discharge in second-feet.			Total for month in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1889.						
September	210	90	128	7,616	0.010	0.009
October	210	140	157	9,655	0.013	0.011
November	250	156	212	12,614	0.017	0.015
December	890	124	275	16,909	0.023	0.020
1890.						
January	2,100	310	680	41,812	0.056	0.049
February	1,514	405	578	32,100	0.043	0.042
March	710	300	387	23,795	0.032	0.028
April	333	158	238	14,161	0.019	0.017
May	150	35	87	5,350	0.207	0.206
June	35	27	28	1,666	0.002	0.002
July	3,112	11	130	7,995	0.010	0.009
August	6,330	1,115	3,137	192,888	0.263	0.228
Total for season 1889-90			503	366,561	0.447	
1895.						
August	3,910	536	1,583	97,336	0.133	0.115
September	2,880	300	812	48,317	0.065	0.059
October	12,000	400	1,577	96,966	0.133	0.115
November	7,500	300	1,103	65,633	0.089	0.080
December	1,150	518	751	46,177	0.056	0.055
Total				354,429		
1896.						
January	560	250	396	24,349	0.032	0.028
February	340	175	209	12,027	0.016	0.015
March	356	153	242	14,880	0.021	0.018
April	340	68	180	10,711	0.014	0.013
May	68	12	32	1,968	0.002	0.002
June	32	1	5	298	0.000	0.000
July	11,708	1	1,441	88,604	0.121	0.105
August	3,150	175	810	49,805	0.068	0.059
September	2,850	455	980	58,314	0.079	0.071
October	11,793	1,030	4,145	254,868	0.347	0.301
November	2,275	696	1,037	61,706	0.083	0.075
December	710	576	629	38,676	0.053	0.046
Per annum	11,793	1	842	616,206	0.839	0.062
1897.						
January	4,310	400	1,286	79,074	0.108	0.094
February	1,580	560	883	49,039	0.066	0.064
March	920	520	702	43,165	0.059	0.051
April	800	520	694	41,296	0.056	0.050
May	440	94	224	13,773	0.018	0.016
June	83	20	52	3,094	0.004	0.004
July	2,360	00	565	34,741	0.047	0.041
August	3,270	160	799	49,129	0.067	0.058
September	5,590	106	2,371	141,084	0.192	0.172
October			800	49,190	0.067	0.058
				503,585		
1898.						
January			640	39,352		
February			485	26,936		
March			473	29,083		
April			547	32,549		
May			292	17,954		
June			252	14,995		
July			2,022	124,328		
August			537	33,018		
September			270	16,066		
October			79	4,858		
November			101	6,010		
December	480	195	305	18,753		
				363,902		

Estimated monthly discharge of Gila River at the Buttes, Arizona—Continued.

[Drainage area, 17,834 square miles.]

Month.	Discharge in second-feet.			Total for month in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1899.						
January	800	170	318	19,552	0.0209	0.0178
February	550	125	239	13,273	0.0135	0.0130
March	155	100	130.5	7,993	0.0080	0.0070
April	100	20	62.3	3,689	0.0040	0.0036
May	38	4	18.2	1,107	0.0010	0.0010
June	30	1	5.4	307	0.0003	0.0003
July	8,700	0.2	1,188.2	73,060	0.0767	0.0666
August	4,100	60	671.8	41,307	0.0437	0.0376
September	10,187	24	733.1	43,622	0.0460	0.0411
	....	....	....	203,910	0.2141	....

From the foregoing data the following tables of annual discharge of Gila River at the Buttes and at San Carlos have been compiled:

Estimated annual discharge of Gila River at the Buttes and San Carlos, Arizona.

	Buttes.	San Carlos.*a*
	Acre-feet.	*Acre-feet.*
Seasonal year 1889-90, Sept. 1 to Aug. 31	366,561	329,905
Fractional year 1895, Aug. 1 to Dec. 31	354,429	318,986
Year 1896	616,206	554,585
Fractional year 1897, Jan. 1 to Oct. 3	503,585	453,227
Year 1898, approximate	363,902	327,512
Fractional year 1899, Jan. 1 to Sept. 30	203,910	183,519

a Ninety per cent of volume at the Buttes.

In order to get the greatest possible value from the records which have been compiled, and more particularly to make comparison with the annual rainfall records, the table given below has been prepared. In this statement every month in which measurements were taken is considered in the determination of an average monthly discharge for each month of the year. There are sixty months in all during which observations were made, there being five different years in which the flow was observed between January and September, inclusive, and four years in which November and December observations were made. From this table the mean monthly discharge is determined, and where a year has seven or more months of measured record, the remaining portion of it being deficient, the mean monthly discharge, as determined, is substituted for the months in which the record is defective. In this way a complete estimated record for five years is obtained, four months having been supplied for the year 1890, two for the year 1897, and three for the present year, 1899. A mean annual discharge is obtained by adding the mean monthly discharges actually measured, so that the mean annual discharge, which is 485,545 acre-feet, is determined only from actual measurements, and includes all measurements that have been made. According to the census of 1890, there were but 6,619 acres irrigated from this great water supply, or less than 3 per cent of its possible utility. Practically the same area is irrigated at present as in 1890.

Estimated monthly mean, annual, and mean annual discharge, in acre-feet, of Gila River at the Buttes, Arizona.

[Drainage area, 17,834 square miles. Sixty months of observation.]

Year.	January.	February.	March.	April.	May.	June.
1890	41,812	32,100	23,795	14,161	5,350	1,666
1896	24,349	12,027	14,880	10,711	1,968	298
1897	79,074	49,039	43,165	41,296	13,773	3,094
1898	39,352	26,936	29,083	32,549	17,954	14,995
1899	19,552	13,273	7,993	3,689	1,107	307
Mean	40,828	26,675	23,783	20,481	8,030	4,072

Year.	July.	August.	September.	October.	November.	December.	Total.
1889			7,616	9,655	12,614	16,909	
1890	7,995	192,888	*a*52,503	*a*83,109	*a*36,491	*a*30,129	523,775
1895		97,336	48,317	96,966	65,633	46,177	
1896	88,604	49,805	58,314	254,868	61,706	38,676	616,206
1897	34,741	49,129	141,084	49,190	*a*36,491	*a*30,129	570,205
1898	124,328	33,018	16,066	4,858	6,010	18,753	363,902
1899	73,060	41,307	43,622	*a*83,109	*a*36,491	*a*30,129	353,639
Mean	65,745	77,247	52,503	83,109	36,491	30,129	469,093

a Approximate.

Using the data obtained from the above table to determine the probable conditions which would exist at San Carlos and at the Buttes, the table given below has been prepared. The amount of water measured at the Buttes is the basis of comparison, 90 per cent of the volume being taken as available at San Carlos during the years in which the observations were made. This table is given in order to determine the proper heights of dams to be constructed either at San Carlos or at the Buttes. From the volumes available annually have been deducted the contents of the reservoirs with the dams agreed upon for consideration in this report, and a column both for the Buttes and for San Carlos is given, showing the surplus water each year.

Volume, in acre-feet, available at the Buttes and at San Carlos, and surplus above capacity of respective reservoirs.

[Capacity of the Buttes reservoir, 174,040 acre-feet. Capacity of San Carlos reservoir, 241,396 acre-feet.]

Year.	The Buttes.		San Carlos.	
	Available.	Surplus.	Available.	Surplus.
1890	523,775	349,735	471,398	230,002
1896	616,206	442,166	554,585	313,190
1897	570,205	396,165	513,185	271,789
1898	363,902	189,862	327,512	86,116
1899	353,639	179,599	318,275	76,879
Mean	469,093	295,053	422,184	180,788

In order to make a comparison between the years in which observations of volumes discharged at the Buttes were made and years in which rainfall records were taken in the basin of Gila River, the diagram on Pl. III, *B*, is given. The rainfall data for this diagram is taken from the summary given on page 19, and is the mean for the entire basin of Gila River above the Buttes. The record begins in 1881 and extends to 1899, inclusive, covering eighteen years of rainfall record, that for 1899 being estimated for the period after September 1. Below the record of rainfall, which is in inches of depth, is given, for corresponding years, the volume discharged in acre-feet. It is desirable to determine whether years in which discharge measurements were made were years of excessive or deficient rainfall. It will be seen that the year 1897 is one of approximately average rainfall, and that in this year twice as much water was available for storage, either at San Carlos or at the Buttes, as the reservoirs could hold. The year 1898 was one of excessive rainfall, but it shows less run-off than the year 1897. This is probably accounted for by the nature of the storms occurring in the basin during that period, a greater portion of the water being absorbed by the ground and evaporated in 1898. The run-off from a hard rain is relatively higher than the run-off resulting from a slow rain or a gentle shower.

There is no record of discharge for the years of markedly deficient rainfall, unless it be the present year, 1899, for which the record is incomplete. During the first eight months of the year 1899 the rainfall for the portion of the basin above San Carlos was 6.40 inches, or 75 per cent of the mean. During this same period the precipitation for the San Pedro stations was 96 per cent of the mean. To August 1 the rainfall for the entire basin was 80 per cent of the usual precipitation. This would indicate for the present year a probable mean rainfall of 10.59 for the basin. The year for which we have the lowest record, as determined by our table, is 1885, when the average rainfall for the basin was 8.11 inches. This comparison is quite rough, but it gives some idea of the general conditions.

It will be seen from the above that the year 1899 is among the years of low run-off and rainfall. Numerous people were asked concerning the relative dryness of the year 1899 in Arizona. There was a unanimous verdict expressed to the effect that it was the driest year which they have had in the last ten, as regards both rainfall and the amount of water in the streams. From the table of volumes available at the Buttes and at San Carlos, the surplus which is estimated for the year 1899 is seen to be 179,599 acre-feet at the Buttes and 76,879 acre-feet at San Carlos. There is still a margin for drier years than the ones through which we have just passed.

It is, of course, impossible to predict absolutely that either of the reservoirs as projected would always be filled, but there is probability, if not certainty, that in all ordinary years, in all years of excessive rainfall, and in all years of ordinary drought the reservoirs will be more than filled, and that only in conditions of excessive drought, surpassing those of record and of memory, is there a possibility that the reservoir as planned either at the Buttes or at San Carlos will not be completely filled. Even should it not be completely filled, it is certain that a partial supply will always be available, so that the irrigated lands supplied from this source can readily be brought through one season of drought without serious damage. These periods of excessive drought are not likely to occur oftener than once every fifteen years.

From the data and tables given in the previous paragraphs, it is considered that, as far as the water supply is concerned, a dam 170 feet high at the Buttes, storing 174,040 acre-feet of water, or a dam 130 feet high at San Carlos, storing 241,396 acre-feet of water, can be built with every assurance of success. The statement is ventured that there are no reservoirs in arid America that have a more certain water supply, proportional to their capacity, than these proposed reservoirs on the Gila River.

EVAPORATION.

In the Twelfth Annual Report of the Survey, page 308, there is given a table showing the probable monthly evaporation from a water surface in Arizona, from observations made in the Southwest by the Survey. This is accepted as the basis of estimates for evaporation in this report:

Loss by evaporation from a water surface.

Month.	Quantity.	Month.	Quantity.
	Inches.		*Inches.*
January	3	August	13
February	4	September	10
March	6	October	6
April	7	November	5
May	10	December	4
June	11		
July	12	Total	91

It is obvious that in order to obtain an approximate idea of the loss by evaporation from a reservoir, an estimate must be made of the area that will be exposed to evaporation. For this purpose the following table has been prepared. It is assumed that 100,000 acre-feet of water should be in the Buttes reservoir at the end of the irrigation season, or on November 1, of each year. The amount of water, in acre-feet, that will probably flow into the reservoir during November has been obtained from the table of the estimate of monthly mean, annual, and mean annual discharges of the river at the Buttes. The amount of inflow for each month is added to the amount of water available from the previous months. The annual consumption from the reservoir is assumed to be the capacity of a completely filled reservoir, which in the case of the Buttes is 174,040 acre-feet. The amount of this water consumed each month has been estimated in the column marked "Portion of reservoir used."

It is assumed that a certain amount of water will always be required in the canals, even in winter time, for the irrigation of annual plants and to provide for domestic and stock water. The fifth column of the table is entitled "Outflow for irrigation," and is given for each month of the year. This is obtained by multiplying the annual consumption by the per cent used each month. This monthly consumption is deducted from the amount available in the reservoir at the end of each month, and from these figures the mean area of the water surface in the reservoir each month is obtained and given in column six, entitled "Area exposed to evaporation." The depth of evaporation for each month is then taken from the above, and the resulting loss by evaporation is shown in the eighth column, entitled "Loss by evaporation." The next column shows the total loss from the reservoir from evaporation and irrigation; the tenth column, the remainder in the reservoir at the end of each month, and the eleventh column, the amount that is wasted from a full reservoir, the capacity of the reservoir being 174,040 acre-feet, and the annual outflow of the basin at the Buttes being estimated as 469,093 acre-feet, as shown in the table on page 30. In an average year the total waste is 198,590 acre-feet of water.

The loss by evaporation under the above conditions would be 22,370 acre-feet, but there still would be available from the reservoir for irrigation its full capacity of 174,040 acre-feet of water. It is of interest to note that under the above conditions there never would be less than 132,320 acre-feet of water in the reservoir, which is sufficient to provide for a complete summer irrigation, in case the stream should be entirely dry for a period of five months.

Hypothetical summary of amount of water in the Buttes reservoir each month, with use, evaporation, and surplus.

Month.	Contents of reservoir at beginning of month.	Inflow.	Portion of reservoir used.	Outflow for irrigation.	Area exposed to evaporation.	Depth of evaporation.	Loss by evaporation.	Total loss from evaporation and irrigation.	Balance in reservoir at end of month.	Amount wasted over dam.
	Acre-ft.	*Acre-ft.*	*P. ct.*	*Acre-ft.*	*Acres.*	*Feet.*	*Acre ft*	*Acre ft*	*Acre-ft.*	*Acre-ft.*
November	100,000	36,500	2	3,480	2,350	0.42	990	4,470	132,030	....
December	132,030	30,100	2	3,480	2,800	.333	700	4,180	157,950	....
January	157,950	40,800	2	3,480	3,070	.25	770	4,250	174,040	20,460
February	174,040	26,700	5	8,700	3,150	.333	1,050	9,750	174,040	16,950
March	174,040	23,800	7	12,180	3,150	.50	1,580	13,760	174,040	10,040
April	174,040	20,500	9	15,660	3,150	.58	1,830	17,490	174,040	3,010
May	174,040	8,030	14	24,370	3,000	.833	2,500	26,870	155,200	....
June	155,200	4,070	14	24,370	2,800	.92	2,580	26,950	132,320	....
July	132,320	65,740	13	22,630	2,770	1.00	2,770	25,400	172,660	....
August	172,660	77,200	13	22,630	3,150	1.08	3,400	26,030	174,040	49,790
September	174,040	52,500	11	19,140	3,150	.833	2,620	21,760	174,040	30,740
October	174,040	83,100	8	13,920	3,150	.50	1,580	15,500	174,040	67,600
Total	....	469,040	100	174,040	....	7.58	22,370	196,410	....	....

As the conditions above named are all assumed, the figures used are round numbers. It is probable that a more complete knowledge of the stream will permit of a greater annual consumption by irrigation than the capacity of the reservoir alone would indicate. The driest year of which we have any record would permit the use of 174,040 acre-feet of water from the Buttes reservoir, with a substantial reserve.

Accurate observations of evaporation are always difficult to obtain, owing to variation in wind velocities and general exposure of the evaporating pan. The effort should be made to have conditions in the evaporation pan that would be similar to those existing in the reservoir, from which the loss from this source is to be determined. For this reason it is necessary to float the evaporation pan in the river or in a canal, and the fluctuations of the water surface are often so great that the pan is frequently either upset or entirely lost. Rain falling on the pan has also to be considered, and it is known that the amount of catchment in a pan 3 feet square is relatively larger than the catchment in a standard rain gage, the diameter of whose cup is 8 inches. In the Twelfth Annual Report of the Survey, page 235, is given a statement of some evaporation observations made in the Southwest. These do not cover complete months and may be misleading.

Observations of evaporation from graduated tubes were made at the Buttes from January to July, 1899. These tubes were exposed in the shade, and the wind was prevented from acting directly on the water's surface. The results obtained are of doubtful value and are not used. In July, 1899, an evaporating pan was floated in the river at the Buttes, but the record was so much interfered with by high water upsetting the pan that it is considered unreliable. Later the attempt was made to float the pan in an artificial pond.

SPILLWAY PROVISIONS.

The accompanying illustrations, Pls. V, IX, and XII, exhibit the conditions at the Buttes dam site, and show the principal features of the proposed spillway. In the report by Mr. Davis, of 1896, he determined the maximum flood that would have to be provided for at the dams in this stream, as follows:

The first consideration in plans for a dam under the circumstances here presented is the provision for a safe and adequate spillway. The large catchment area of this stream, its mountainous character, the paucity of soil and vegetation on these mountains, exposing considerable area of bare rock on steep slopes, and the sudden and violent nature of the summer rainstorms indicate the necessity of a spillway of large proportions. What this capacity should be is recognized as one of the important and difficult problems. The best evidence thus far obtained regarding past freshets on this river was kindly furnished by Mr. Albert T. Colton. The greatest rise so far recorded on the Gila River occurred on the 22d of February, 1891. Considerable evidence was obtained that no such flood has occurred since a date many years before the advent of the white man. Irrigating ditches supposed to be extremely old were overflowed and destroyed. Lands were overflowed that had retained no evidence of any previous inundation.

On June 12, 1892, about sixteen months after this flood, Mr. Colton found marks of high water on both banks of the river far above any of the ordinary freshets, which he attributed to the great flood. This point was about 3¼ miles below the head of the Florence canal, or approximately 6 miles below the Buttes. With his level he took a cross section of the river at this point and measured the slope of the channel. The cross section he obtained was 6,600 square feet. The slope measured was 10.56 feet per mile. The channel was sandy and free of brush or large bowlders or other obstructions for a distance of 300 feet above and 300 feet below the cross section. This information, meager as it is, is the best we have upon which to estimate the discharge of the river at that time.

The difficulty in obtaining correct results of this discharge lies in the uncertainty of the retarding effect of the channel upon the flow of the water. This retarding effect in a rough river bed is very great. Assuming this quantity as small as it could possibly be, a computation of the discharge was made, using Kutter's formula. The factor of roughness designated in the formula as "n" was taken as 0.025. Not that this was considered the correct factor, as it is almost certainly too small, but by assuming the smallest possible value of "n" we obtain the largest discharge, and it is the largest discharge that should be provided for in the construction of a spillway. It is thought, therefore, that this computation will give conservative results, and that a spillway based upon the discharge obtained would be safe. The result obtained was 102,566 cubic feet per second. And it is to accommodate this discharge that the spillway is planned. It will be seen at once that no such spillway could be economically provided artificially, and that the accommodation of the topography to the provision of this spillway is one important determining feature of the location and height of the dam.

SILT.

The following further quotation is made from the same report of Mr. Davis:

The amount of solid material carried by such a stream as the Gila can be learned only by impounding it. As it is considerable, it is obvious that a reservoir built on this water course will eventually fill with solid matter unless means are provided for its removal. No entirely sufficient plan for this purpose has ever been put in operation. It is usually assumed, and often with truth, that the life of the reservoir is sufficiently long to justify its construction even though it will eventually fill and have its usefulness destroyed. This disposition of the problem, however, is not applicable to the present case. The amount of material carried by this stream is too large and the necessity of the reservoir to the life of the district to be irrigated from it is too vital to justify this convenient solution or, rather, evasion of the problem.

The most astonishing accounts are obtained from the inhabitants of this region of the quantity of silt carried in suspension by this stream when in flood. Many people in their emphatic expressions place the quantity at one-half the volume, though, of course, this is impossible. It is said, however, that in the months of July and August, when the surface of the ground is exceedingly dry, when it has been ground to powder even in the most isolated and apparently inaccessible localities by range cattle and horses in search of grass, when the great torrential "cloud-bursts," to which this country is subject, fall upon such ground and rush off the steep slopes into the stream with prodigious velocity, the amount of silt carried in suspension by the roaring torrent is very great.

* * * * * * *

Attempts have been made, however, by private parties from time to time to measure the amount of suspended material. The most important and reliable of these measurements were those made by Mr. Albert T. Colton in the month ending August 7, 1893, and by Mr. W. Richins at the Buttes. Mr. Colton found the percentage of silt by volume averaged 2.2 per cent. As these observations were taken and reduced by Mr. Colton, who is a competent engineer, they are adopted as correct. The observations by Mr. Richins extended from July 29 to December 31, 1895. They were taken by the following method:

A sample of the water was poured into a slender glass tube until it reached the height of 100 divisions on a convenient scale, and was then allowed to settle several days, until the main portion of the water was clear. The height of the sediment on the same scale was then read and the result recorded as the percentage of mud carried by the water. The existence of this record, and the ease with which more of such observations could be taken, made it important that an approximate relation be established between the volume of this mud and that of the actual solid matter it contained. For this purpose several laboratory determinations have been made with muddy samples of Gila water by settling and reading the volume of mud as above and then drying the residue at 100° C. and determining its volume.

These observations indicate an average ratio of dry matter to mud of about one-fifth, and this factor has been used to reduce the mud observations of Mr. Richins to solid matter.

* * * * * * *

It should be remembered that these observations take no account of material that is rolled on the bottom of the stream.

On page 32 of Mr. Davis's report of 1896 a table is given showing the percentage of mud and solid matter carried each day from July 29 to December 31 in Gila River at the Buttes. The following table gives, in columns Nos. 3 and 4, this percentage of mud and of solids. In column No. 2 the number of acre-feet discharged on corresponding dates is given, and columns Nos. 5 and 6 give the number of acre-feet of mud and solids for the same dates. During this period the volume of water discharged at the Buttes was 360,523 acre-feet, and from the table it is found that 37,984 acre-feet of mud was carried in suspension by this water. This, reduced by the ratio of 5 to 1, as adopted by Mr. Davis, gives 7,704 acre-feet of solids. The average amount of mud during this period is 10.5 per cent.

Discharge of sediment of Gila River at the Buttes for 1895.

[Observer, W. Richins.]

Day.	July.					August.				
	Water.	Mud.	Solids.	Mud.	Solids.	Water.	Mud.	Solids.	Mud.	Solids.
	Acre-ft	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*	*Acre-ft*	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*
1	....	....	....	....	....	1,161	15	3.0	159	32
2	....	....	....	....	....	1,631	20	4.0	326	65
3	....	....	....	....	....	1,505	20	4.0	301	60
4	....	....	....	....	....	2,479	20	4.0	496	99
5	....	....	....	....	....	1,733	20	4.0	347	69
6	....	....	....	....	....	1,806	20	4.0	361	72
7	....	....	....	....	....	1,956	15	3.0	293	59
8	....	....	....	....	....	6,861	20	4.0	1,372	274
9	....	....	....	....	....	3,247	15	3.0	487	97
10	....	....	....	....	....	3,406	15	3.0	511	102
11	....	....	....	....	....	3,326	15	3.0	499	100
12	....	....	....	....	....	2,554	12	2.4	307	61
13	....	....	....	....	....	2,273	7	1.4	159	32
14	....	....	....	....	....	2,475	7	1.4	173	35
15	....	....	....	....	....	2,178	7	1.4	152	30
16	....	....	....	....	....	3,168	7	1.4	222	44
17	....	....	....	....	....	2,178	7	1.4	152	30
18	....	....	....	....	....	2,030	7	1.4	142	28
19	....	....	....	....	....	1,881	7	1.4	132	26
20	....	....	....	....	....	2,109	7	1.4	148	30
21	....	....	....	....	....	2,709	7	1.4	190	38
22	....	....	....	....	....	7,742	7	1.4	542	108
23	....	....	....	....	....	7,346	7	1.4	514	103
24	....	....	....	....	....	2,485	7	1.4	174	35
25	....	....	....	....	....	2,257	7	1.4	158	32
26	....	....	....	....	....	6,376	7	1.4	446	89
27	....	....	....	....	....	3,802	7	1.4	266	53
28	....	....	....	....	....	3,326	7	1.4	233	47
29	2,851	20	4	570	114	6,376	17	3.4	1,084	217
30	2,039	20	4	408	82	2,851	15	3.0	428	86
31	1,204	17	3.4	205	41	2,020	15	3.0	302	60
Total	6,094	....	....	1,183	237	97,336	....	....	11,076	2,213

Day.	September.					October.				
	Water.	Mud.	Solids.	Mud.	Solids.	Water.	Mud.	Solids.	Mud.	Solids.
	Acre-ft	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*	*Acre-ft*	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*
1	1,683	17	3.4	286	57	13,860	20	4.0	2,772	554
2	1,683	17	3.4	286	57	1,683	15	3.0	252	50
3	1,465	15	3.0	220	44	1,980	15	3.0	297	59
4	1,386	15	3.0	208	42	23,760	20	4.0	4,752	950
5	1,267	12	2.4	152	30	5,940	20	4.0	1,188	238
6	1,109	10	2.0	111	22	11,880	20	4.0	2,376	475
7	990	5	1.0	50	10	7,920	20	4.0	1,584	317
8	891	4	.8	36	7	3,960	15	3.0	597	119
9	792	1	.2	8	2	1,980	12	2.4	238	48
10	990	5	1.0	50	10	1,624	10	2.0	162	32
11	1,980	15	3.0	297	59	1,465	10	2.0	147	29
12	1,624	15	3.0	244	49	1,386	5	1.0	69	14
13	1,267	12	2.4	152	30	1,267	3	.6	38	8
14	1,267	12	2.4	152	30	1,267	3	.6	38	8
15	792	12	2.4	95	19	1,109	2	.4	22	4
16	594	12	2.4	71	14	1,109	2	.4	22	4
17	634	8	1.6	51	10	1,109	2	.4	22	4
18	634	15	3.0	95	19	1,109	2	.4	22	4
19	1,386	20	4.0	277	55	1,109	2	.4	22	4
20	1,624	20	4.0	225	65	990	2	.4	20	4
21	3,960	20	4.0	792	158	990	2	.4	20	4
22	2,099	20	4.0	420	84	990	2	.4	20	4
23	1,782	20	4.0	356	71	792	2	.4	16	3
24	1,782	20	4.0	356	71	792	2	.4	16	3
25	1,327	17	3.4	226	45	792	2	.4	16	3
26	1,228	17	3.4	209	42	792	2	.4	16	3
27	634	17	3.4	108	22	792	2	.4	16	3
28	1,327	20	4.0	265	53	792	2	.4	16	3
29	4,356	20	4.0	871	174	1,782	15	3.0	267	53
30	5,702	20	4.0	1,140	228	990	10	2.0	99	20
31	....	....	....	....	....	792	5	1.0	40	8
Total	48,317	....	....	7,809	1,579	96,966	....	....	15,182	3,032

Discharge of sediment of Gila River at the Buttes for 1895—Continued.

Day.	November.					December.				
	Water.	Mud.	Solids.	Mud.	Solids.	Water.	Mud.	Solids.	Mud.	Solids.
	Acre-ft	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*	*Acre-ft.*	*Per ct.*	*Per ct.*	*Acre-ft*	*Acre-ft*
1	792	5	1.0	40	8	2,277	2	0.4	46	9
2	792	3	.6	24	5	2,020	2	.4	40	8
3	792	3	.6	24	5	1,822	2	.4	36	7
4	1,980	5	1.0	99	20	1,822	2	.4	36	7
5	1,822	5	1.0	91	18	1,822	2	.4	36	7
6	1,822	3	.6	55	11	1,822	2	.4	36	7
7	1,228	3	.6	37	7	1,663	1	.2	17	3
8	1,228	3	.6	37	7	1,663	1	.2	17	3
9	1,228	2	.4	25	5	1,663	1	.2	17	3
10	1,109	2	.4	22	4	1,525	1	.2	15	3
11	1,109	2	.4	22	4	1,527	1	.2	15	3
12	1,822	3	.6	55	11	1,471	1	.2	15	3
13	1,980	3	.6	59	12	1,471	0	.0	0	0
14	1,822	2	.4	36	7	1,471	0	.0	0	0
15	1,228	2	.4	25	5	1,416	0	.0	0	0
16	990	0	.0	0	0	1,416	0	.0	0	0
17	792	0	.0	0	0	1,416	0	.0	0	0
18	792	0	.0	0	0	1,360	1	.2	14	3
19	634	0	.0	0	0	1,360	1	.2	14	3
20	634	0	.0	0	0	1,360	1	.2	14	3
21	634	0	.0	0	0	1,305	0	.0	0	0
22	594	3	.6	18	4	1,249	0	.0	0	0
23	2,277	5	1.0	114	23	1,360	0	.0	0	0
24	14,850	5	1.0	743	149	1,471	2	.4	29	6
25	4,752	5	1.0	238	148	1,360	2	.4	27	4
26	4,752	3	.6	143	28	1,305	1	.2	13	3
27	4,158	3	.6	125	25	1,249	1	.2	12	2
28	3,366	3	.6	101	20	1,192	1	.2	12	2
29	2,970	3	.6	89	18	1,137	0	.0	0	0
30	2,574	2	.4	51	10	1,081	0	.0	0	0
31						1,026	0	.0	0	0
Total	65,633			2,273	554	46,177			461	89

Beginning on January 1, 1899, and continuing until July 31, 1899, silt observations were again maintained at the Buttes, the amount of mud and silt being determined as was done in 1895. The results are shown in the following table. This differs slightly in construction from the previous table, but gives results which correspond with it. Column No. 2 gives the daily discharge of the river in second-feet, column No. 3 the per cent of solids, and column No. 4 the solids in second-feet. From the mean monthly discharge in second-feet of water and of solids, the acre-feet of each for each month is determined, as indicated. The total amount of water discharged during the first seven months of 1899 was 118,981 acre-feet, and the amount of solids determined was 1,893 acre-feet, or 1.6 per cent of solids or 8 per cent of mud.

Adding the total number of acre-feet of water during the period of silt observations in 1895 to the acre-feet of water discharged in 1899 gives 479,504 acre-feet of water and a total amount of solids during the entire period of 9,597 acre-feet. From these figures an average of 2 per cent of solids for the entire period of observation is determined. It will be noted that the observations in 1895 began on July 29 and extended to December 31, while the observations of 1899 began January 1 and extended to July 31, inclusive, making one complete year and three days. The total mean annual discharge of water of Gila

Discharge of sediment of Gila River at the Buttes for 1899.

[Observer, C. W. Lemon.]

Day.	January.			February.			March.		
	Water.	Solids.	Solids.	Water.	Solids.	Solids.	Water.	Solids.	Solids.
	Sec.-ft.	*Per ct.*	*Sec.-ft.*	*Sec.-ft.*	*Per ct.*	*Sec.-ft.*	*Sec.-ft.*	*Per ct.*	*Sec.-ft.*
1	320	1.0	0.64	170	0.1	0.03	125	0.1	0.02
2	345	1.0	.69	200	.1	.04	155	.1	.03
3	370	1.0	.74	550	.3	.33	155	.1	.03
4	255	1.0	.51	455	.3	.29	110	.1	.02
5	300	1.0	.60	345	.2	.16	110	.1	.02
6	275	1.0	.55	410	.2	.16	110	.1	.02
7	255	1.0	.51	235	.1	.05	155	.1	.03
8	275	1.0	.55	235	.2	.09	155	.1	.03
9	255	1.0	.51	200	.1	.04	110	.1	.02
10	235	1.0	.47	300	.1	.06	140	.1	.03
11	275	1.0	.55	255	.1	.05	140	.1	.03
12	480	1.0	.96	300	.1	.06	140	.1	.03
13	800	1.0	1.60	275	.1	.05	140	.1	.03
14	500	1.0	1.00	275	.5	.27	100	.1	.02
15	435	1.0	.87	275	.8	.44	100	.1	.02
16	390	1.0	.78	255	.4	.20	100	.1	.02
17	345	1.0	.69	170	.4	.14	110	.1	.02
18	345	1.0	.69	170	.4	.14	155	.1	.03
19	320	1.0	.64	140	.4	.11	155	.1	.03
20	275	.3	.16	170	.3	.10	155	.1	.03
21	255	.2	.10	170	.3	.10	155	.1	.03
22	235	.2	.09	170	.3	.10	140	.1	.03
23	320	.3	.19	155	.3	.09	140	.1	.03
24	370	.2	.15	200	.3	.12	140	.1	.03
25	255	.2	.10	155	.2	.06	140	.1	.03
26	300	.2	.12	155	.2	.06	140	.1	.03
27	235	.3	.14	170	.2	.07	125	.1	.02
28	255	.3	.15	125	.2	.05	110	.1	.02
29	235	.3	.14				125	.1	.02
30	170	.1	.03				110	.1	.02
31	185	.1	.04				100	.1	.02
Mean, sec.-feet	318		.48	239		.12	130.5		.12
Acre-feet	19,552		30	13,273		7	7,993		1.0

Day.	April.			May.			June.			July.		
	Water.	Solids.	Solids.	Water.	Solids.	Solids.	Water.	Solids.	Solids.	Water.	Solids.	Solids.
	Sec.-ft.	*P. ct.*	*S.-ft.*	*Sec.-ft.*	*P. ct.*	*Sec.-ft.*	*Sec.-ft.*	*P. ct.*	*Sec.-ft.*	*Sec.-ft.*	*P. ct.*	*Sec.-ft.*
1	90	T.	0.01	38	T.	0	5	T.	0	5	T.	0
2	90	T.	.01	34	T.	0	36	T.	0	5	T.	0
3	90	T.	.01	30	T.	0	26	T.	0	5	T.	0
4	100	T.	.01	30	T.	0	16	T.	0	3	T.	0
5	100	T.	.01	31	T.	0	12	T.	0	3	T.	0
6	100	T.	.01	28	T.	0	11	T.	0	3	T.	0
7	80	T.	.01	26	T.	0	16	T.	0	2	T.	0
8	70	T.	.01	25	T.	0	6	T.	0	2	T.	0
9	60	T.	.01	24	T.	0	5	T.	0	2	T.	0
10	60	T.	.01	24	T.	0	5	T.	0	2	T.	0
11	50	T.	.01	24	T.	0	4	T.	0	300	27	16.20
12	70	T.	.01	23	T.	0	4	T.	0	320	26	16.64
13	70	T.	.01	23	T.	0	2	T.	0	250	20	10.00
14	70	T.	.01	20	T.	0	2	T.	0	130	20	5.20
15	60	T.	.01	16	T.	0	2	T.	0	90	18	3.24
16	60	T.	.01	14	T.	0	2	T.	0	170	12	4.08
17	60	T.	.01	12	T.	0	1	T.	0	250	24	12.00
18	60	T.	.01	13	T.	0	1	T.	0	920	10	18.40
19	60	T.	.01	13	T.	0	1	T.	0	1,800	22	79.20
20	50	T.	.01	14	T.	0	1	T.	0	8,700	14	243.60
21	60	T.	.01	12	T.	0	1	T.	0	4,100	10	82.00
22	50	T.	.01	10	T.	0	1	T.	0	2,260	14	63.28
23	50	T.	.01	8	T.	0	1	T.	0	1,900	15	57.00
24	60	T.	.01	9	T.	0	1	T.	0	1,550	10	31.00
25	50	T.	.01	11	T.	0	1	T.	0	1,445	10	28.90
26	40	T.	.01	12	T.	0	2	T.	0	1,550	8	24.80
27	20	T.	.01	13	T.	0	2	T.	0	1,550	7	21.70
28	30	T.	.01	10	T.	0	1	T.	0	3,640	10	72.80
29	30	T.	.01	9	T.	0	1	T.	0	2,440	15	73.20
30	30	T.	.01	6	T.	0				2,475	10	49.50
31				4	T.	0				990	12	23.76
Mean, sec.-ft.	62.3		.01	18.2		0	5.4		0	1,188.2		30.21
Acre-feet	3,689		1.0	1,107		0	30.7		0	73,060		1,854

T.—Trace.

River at the Buttes has been determined as 469,093 acre-feet. If 2 per cent of this volume be considered as solids, it will indicate an annual discharge of solids of 9,382 acre-feet, which corresponds very closely with the 9,597 acre-feet determined in the twelve months during which observations occurred.

The capacity of the Buttes reservoir, with the dam 150 feet high to the spillway, is 174,040 acre-feet. If 9,711 acre-feet of solid matter is delivered to the reservoir each month, and it all settles in passing through the basin, this reservoir would fill with solid matter in eighteen and six-tenths years. The mean annual flow of water of Gila River at San Carlos has been determined as 422,184 acre-feet. If 2 per cent of this volume is solids, there would be delivered to the reservoir 8,443 acre-feet of solids per annum. The capacity of the San Carlos reservoir, with the dam as planned, 130 feet high to the spillway, is 241,396 acre-feet. If 8,443 acre-feet of solid matter should be delivered to this reservoir each year and should be deposited therein, it would fill in twenty-eight and five-tenths years.

These figures show the exceeding gravity of the silt proposition on Gila River. No other stream is known in America which carries such large volumes of débris. It is evident that some provision must be made to avoid the destruction of the reservoir or the building of the dam would be useless. It would be cruel to develop a civilization upon irrigation which would have to be destroyed at the end of a generation. It is extremely fortunate that there is more than one reservoir site on Gila River the water from which would be available for irrigation in the neighborhood of the Gila River Indian Reservation. If a dam should be constructed at San Carlos and the reservoir become filled with silt, it would be possible to construct at the end of the twenty-eight and five-tenths years a second dam at Riverside of equal capacity, and after that reservoir became filled with silt the dam at the Buttes could be built. A fourth reservoir site of considerable value may be found at Guthrie, above the Solomonville Valley, on the same stream, and of large capacity. In the case of all these dams the capacity increases very rapidly with an increased height of dam. For instance, if the Buttes dam should be raised 10 feet above the 150-foot contour, its capacity would be increased 33,755 acre-feet; and if raised 20 feet, its capacity would be increased 72,355 acre-feet. If the San Carlos dam should be increased in height 20 feet, its storage capacity would be increased 135,780 acre-feet. It would therefore be possible to very greatly increase the storage capacity of these reservoirs by building the dams to greater heights as the basin filled with mud. The spillways of the San Carlos dam, as planned, could be raised 1.24 feet in height, increasing the capacity of the reservoir to that extent at small cost, without endangering the structure.

The silt which is carried by Gila River is exceedingly light and requires a number of days to settle in a test tube, and it is believed that a portion of it will remain in suspension until it is carried over the spillway or through the gates. As irrigation is practiced on the flat lands of the Gila Valley the water plane in that district will be raised much nearer to the surface than it is now, and less irrigation will be necessary. Numerous points are known in the San Joaquin Valley, in California, where water could not be obtained in wells prior to irrigation, and where now, after twenty years of irrigation, water is standing at the surface. Near Fresno, California, the water plane has risen to such an extent that but one irrigation a year is needed on the vineyards.

When the irrigation country has developed to the extent that all water available from the reservoir is required, and when the reservoir has reached the point where the silting endangers the community, it probably will be advisable to construct a large storm channel around the margin of the reservoir and above the maximum water line to carry as much as possible of the water of the river. Such portion of the water as is needed for irrigation below can be passed through this canal without stopping in the reservoir and may be diverted at the proper point near the irrigated fields. This canal could be constructed of large section for the first portion of its course and the section afterwards reduced. A spillway should be located at the point where the canal is reduced in capacity and the excessive water be drawn from the top of the canal into the reservoir. A larger portion of the sediment which would travel in the bottom of the channel would remain in the conduit, and the clarified water would be discharged into the reservoir. A velocity may be maintained in the remaining portion of the canal sufficient to carry the silt through it to the river below the dam.

The suggested canal, being above the maximum water line, would provide an effective head for hydraulic giants for sluicing the silt which had previously been deposited in the reservoir. On favorable occasions, when the reservoir was practically empty, this sluicing or washing out of the basin could be practiced. On July 11, 1899, there was 27 per cent of mud in Gila River at the Buttes. This is the greatest amount of sediment ever observed in this river. From this it will be seen that the suspended matter is exceedingly light, and it would therefore be possible to move large quantities of this loose mud with hydraulic giants and carry it in temporary flumes, or even in the river channel itself, through openings in the dam. Experience with light silt in constructed reservoirs elsewhere shows the greatest deposits to occur where the water is deepest, which is near the dam. Here is also the greatest storage capacity of the basin.

The drop from the storm canal to the bed of the river below the dam would probably be not less than 150 feet. If 500 cubic feet of water per second should be discharged through this canal, over 8,475 theoretical horsepower could be developed. During certain periods of the year Gila River is almost dry, and this power would not be available from the canal; but when such occasions existed in the river the reservoir would necessarily be drawn upon for irrigation, and power could be obtained from the discharge from the reservoir. It is possible that from 2,000 to 5,000 horsepower could be developed in this manner. The section of Arizona in the neighborhood of San Carlos is highly mineralized. Copper mines of great value are to be found at Globe and at Riverside. New and effective processes have been discovered for reducing copper matte electrically. Fuel is high priced. On the above basis it is reasonable to presume that when the time arrives for the building of the storm canal around the reservoir sufficient revenue can be obtained from power to pay the interest on the cost of construction of the storm ditch. This power could also be used in cleaning out the reservoir with hydraulic dredges.

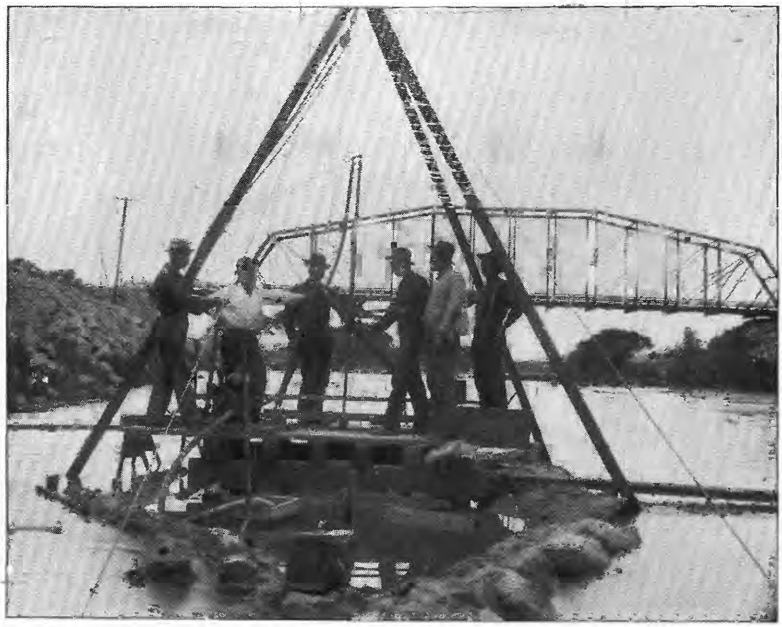
While the deposit of silt in the reservoir is probably the most serious question in connection with the impounding of water on the Gila, it is believed, on the basis of the above arguments, that the situation could be controlled and that the reservoir may be made to do service through a long period of years, if not indefinitely.

EXPLORATIONS FOR BED ROCK AT THE BUTTES.

The material that covers the bed rock at the Buttes and at Queen Creek is a sand and gravel saturated with water in the bed of a canyon, through which varying volumes of water might be expected to be discharged, ranging from 100 cubic feet per second to 1,000 cubic feet per second during the periods of low water on the river. These low stages of the river might be expected to exist from the 1st of April to the 1st of July, after which violent floods of much greater volume would probably occur at the Buttes dam site.

On Queen Creek large bowlders occur at the surface, and although the stream might be expected to be entirely dry during corresponding dates, after that time violent floods might occur any day. Great reticence was felt on the part of everyone in giving figures that should be regarded as even roughly approximate for this work. Numerous well drillers were interviewed in San Francisco and in southern California, and none cared to bid, under the conditions. Two methods of going to bed rock were suggested—one by means of open shafts, and the other by the use of the diamond core drill. Only one bid was received in reply to proposals, and that at the rate of $15 per linear foot. This was rejected as too high. It was admitted by all that the diamond core drill would work accurately and easily in solid rock, but when it came to going through bowlders of varying size it was conceded to be exceedingly difficult, if not wholly impracticable.

As stated above, the one bid was rejected, and the Geological Survey carried on this work at the points in question, and succeeded in thoroughly solving the problem, largely owing to the experience which Mr. Arthur P. Davis had acquired in work in Nicaragua.



A. DIAMOND-CORE DRILL PARTY AT WORK.

B. BUTTES RESERVOIR SITE.

DIAMOND CORE DRILL.

As this work was somewhat unique, it will be of interest to give its progress in detail, together with a description of the tools employed. In considering the matter of going down with a shaft the most serious problems would be the water encountered. In working with a shaft the river would have to be carried in a flume by the works for a long distance. A large pump would have to be kept going constantly in the shaft, and it is doubtful if under the most favorable conditions it would be able to handle the amount of water which would be encountered. Pumps with valves would be barred on account of the large amount of sand suspended in the water. It was estimated that it would cost $46 per vertical foot to sink shafts under these conditions. This would permit of putting down about four holes at the Buttes with the funds available, with bed rock at from 75 to 123 feet. The actual cost of sinking 170 linear feet of shaft at the mouths of one of the canyons of a southern California river, in an attempt to determine bed rock, was $35.87 per foot, the depths in this case varying from 15 to 30 feet, and the material through which the shafts were sunk consisting of sand and bowlders. This included the labor of building 700 feet of flume, but not the cost of the lumber, which was furnished by the company for all work. There was pumped from these shafts with a 100-horsepower boiler and engines over 100,000 gallons per hour, and yet the water could not be kept down, and the deepest shaft had finally to be abandoned before bed rock was reached.

The best estimate that could be obtained of the cost of sinking by means of the diamond core drills, as furnished by San Francisco contractors, was $12.69 per linear foot, 400 feet to be sunk, but they would not offer a bid even on these figures.

The following letter from Mr. T. F. Richardson, department engineer, dam and aqueduct department, metropolitan water board, of Boston, is of interest as bearing on this subject:

We had two diamond drills, one manufactured by the M. C. Bullock Manufacturing Company, of Chicago, called the Badger drill. This drill was intended for prospecting in tunnels, but was fitted up especially for us for surface work. This machine cost us $900, which included one set of diamonds worth about $200, and the necessary fittings to put down a 1⅝-inch hole about 200 feet.

Our second machine was bought from the Sullivan Machinery Company, of Claremont, New Hampshire, and was called "S–510." This cost was $1,132.80, but no diamonds were included. The two machines were fitted for and were capable of doing about the same amount of work, but the net cost of the Sullivan machine was over $400 more than that of the Bullock machine.

Our work here was very difficult, as the bottom of our gorge was blocked up with large bowlders, and we found it necessary to use several sizes of bits, namely, $\frac{15}{16}$-inch, 1⅜-inch, 1¾-inch. We also had to fit up so as to be able to put down 1½-inch casing, using diamond bits to bore it down, the purpose of the casing being to bore through bowlders and gravel, so as to be able to work a $\frac{15}{16}$-inch bit inside of it. Altogether we had two quite complete outfits for doing all kinds of work up to 1¾-inch bits.

The repairs necessary to the machines were not very large, the principal cost of repairs being for new bit blanks and for core lifters; but in order to do the work successfully it is necessary to have quite a number of appliances outside of the actual machines, and these cost considerable money. Our total outlay for machines was $2,625. In addition to this we spent $3,873 for diamonds, but we have at the present time about $700 worth of diamonds on hand, leaving the net cost of the diamonds about $3,173.

When we started in on our diamond-drill work the cost of diamonds was $19 per carat; but at the time we finished the cost of diamonds had risen to $36 per carat, and I believe the price is about $36 at the present time (August, 1898).

The total amount which we drilled was 2,814 feet, the deepest hole being 286 feet deep, and the average depths of holes about 60 feet. The amount accomplished per day was from 0 to 32 feet, the average amount being probably about 10 or 12 feet per day.

The cost of drilling varies very largely, both with the hardness of the rock and the condition of the rock as to being seamy.

Following is the cost of labor, diamonds, and coal for drilling, principally with 1¾-inch bits, through three different kinds of rock:

Drilling 324.2 feet of rather hard, tough diorite rock:

Labor	$341.25
Diamonds	74.30
Coal	17.50
Total	433.05
Cost per foot	1.34

(86.6 feet of this was drilled with 1⅝-inch bit, and 237.6 feet was drilled with 1¾-inch bit.)

Drilling 150.7 feet of very hard syenite rock:

Labor	158.00
Diamonds	298.69
Coal	10.50
Total	467.19
Cost per foot	3.10

(Size of drill, 1¾ inches.)

Drilling 286.1 feet of soft schist rock:

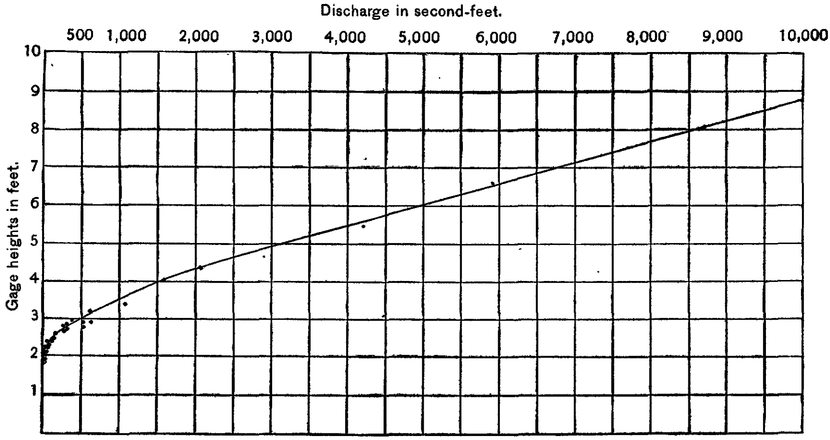
Labor	190.00
Diamonds	87.75
Coal	11.50
Total	289.25
Cost per foot	1.01

(Size of drill, 1¾ inches.)

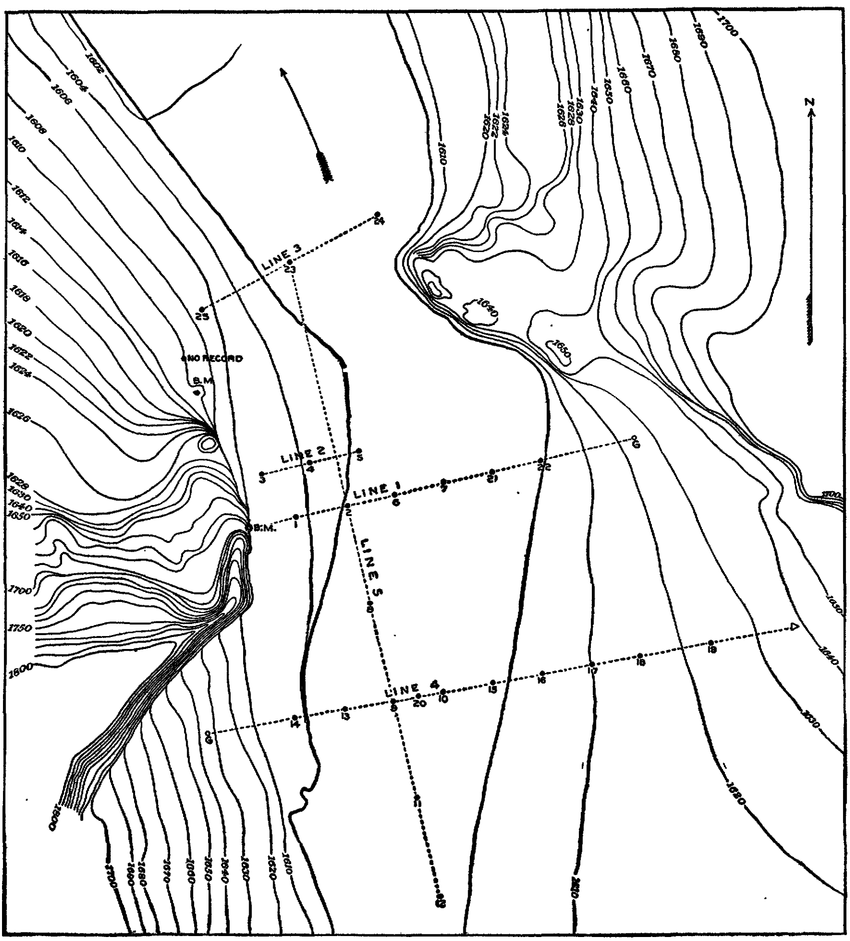
You will notice that there is a large variation in the cost of drilling through different kinds of rock. The costs as given do not include more or less lost time, and the depreciation on diamonds due to their being of smaller size after being used. Finally they get so small as to be valueless. Depreciation of plant is also not included.

Regarding the best size of hole for prospecting purposes, this depends largely on the work which you have in hand. If I were fitting up for similar work to what we did here, and only expected to fit up one size of hole, I should fit up probably for 1⅝-inch bit.

When I speak of 1⅝-inch bits, I mean bits that give cores of about this size, though generally the cores are somewhat smaller than the sizes noted.



A. RATING CURVE FOR GILA RIVER AT THE BUTTES. USED DURING PERIOD FROM JULY 11 TO AUGUST 10, 1899.



B. LOCATION OF BORINGS AT BUTTES DAM SITE.

Diamond-drill work is expensive amusement at the best, and I think you will be safe to conclude, whether you do the work yourself, buying the machines, or do it by contract, that the cost will be somewhere in the neighborhood of three or four dollars per running foot.

It was decided to attempt to explore for bed rock by means of diamond core drills, and, through Mr. Arthur P. Davis, who was in charge of the work, machines for this purpose were obtained from the Nicaragua Canal Commission. These machines had been used in Nicaragua in exploring for bed rock along the route of the proposed canal, and had done efficient service. Two foremen, Mr. P. Tierney and Mr. T. J. H. Archambault, were employed to run the machines. These men had previously used them in Nicaragua, and were entirely competent to do the work efficiently. The machinery is in two distinct parts: First, a pile-driving apparatus for putting pipe or casing down through quicksand or earth; the pipe is afterwards washed out, and inside of it the shaft with the diamond bits is operated. The second part is the drilling apparatus proper. The machinery is very light, and made so that it can be knocked down to weights that will admit of the sections being carried on the backs of men. The hammer is in sections and can be increased or lessened in weight. The bottom section is cored out and filled with wood, so that the blow of the hammer will not abrade the head of the pipe. It is raised by means of a hand winding drum, and is tripped when it reaches the tops of the guides, and falls upon the pipe. The maximum lift is 11½ feet and the maximum weight 190 pounds. A tool-steel head is screwed into the top of the drive pipe for the hammer to fall upon.

The pipe is shod at its lower end with a tool-steel shoe, which is thicker and heavier than the pipe, but equal to it in interior diameter. The size of the pipe used is 3½-inch, 2½-inch, and 2-inch extra heavy screw pipe, with extra heavy couplings which have beveled corners. The smaller diameter pipe is in each case made to fit into the larger diameter if required. It, however, requires a special make of 2½-inch pipe to go inside of the 3½-inch pipe. The pipe is driven through the sand and gravel until bed rock is reached. This is indicated by the refusal of the pipe to go any farther under driving. The pipe is cut in 5-foot sections, and as it is driven into the ground new sections are put on until the desired length is reached. When the drive pipe has reached bed rock, what is known as a chopping bit, which is a bit with openings for water to flow through its point, and to which is screwed a ¾-inch pipe, is worked into the drive pipe. The top of this ¾-inch pipe is connected with a small, double-action hand force pump by a hose.

The chopping bit is churned around in the sand which is inside of the drive pipe, and the water which is under pressure is discharged through the point of the chopping bit, and floats the loosened sand out over the top of the drive pipe. In this manner a hole can be readily cleaned to depths as great as 130 feet of sand and small gravel.

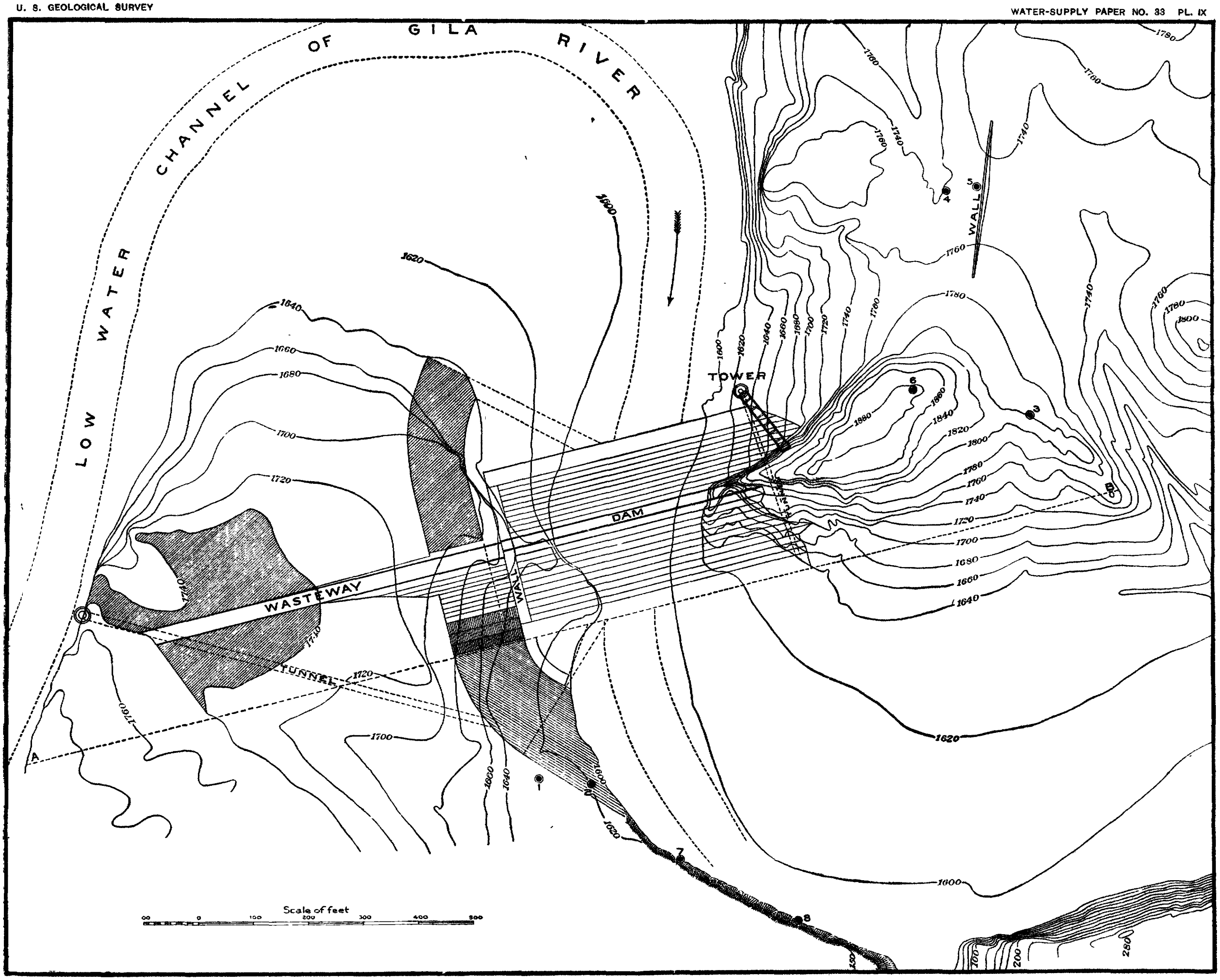
The diamond-drilling machinery is put to work when the drive pipe is cleaned out, and it is possible that it may demonstrate that, instead of being on bed rock, the drive pipe has stopped upon a bowlder. As soon as the diamond bit passes through a bowlder it drops, which is an indication that bed rock has not been reached. The diamond drill is then drawn and four or five sticks of giant powder are lowered through the pipe to the bowlder. The drive pipe is then pulled up four or five feet, and the powder discharged by means of an electric firing battery. This shatters the rock, and the drive pipe may then be forced through the splintered bowlder. In this manner pipe of these varying diameters were driven to bed rock at five different dam sites, and at every location successful results were obtained.

COST OF OPERATING.

The diamond-drilling machine used was built by the American Diamond Rock Drill Company, of 123 Liberty street, New York. One-inch bits were usually employed. The diamond drilling machinery is shown on Pls. I and VII, *A*. The drill is operated by hand power, six men being economically employed on this work, as well as on the driving of the pipe. The machine is capable of going 200 feet into the rock, and will make from 6 to 8 feet a day in hard rock, and from 10 to 15 feet a day in softer rock. The cost of the machinery complete is approximately $1,000, including two bits, which are worth about $200 each, set with six diamonds each. The diamonds are known as black diamonds, and should weigh approximately 1 carat each. Two machines were used on work in southern Arizona. There was paid for the pipe $590, including tools and fittings, delivered in Arizona; $100 of this amount being freight from New York. This would make a total cost of outfit complete of $1,590.

Cost of operation per month of bed-rock exploration.

Foreman	$150.00	
6 laborers, at $1.50 per day, 28 days	234.00	
1 cook	45.00	
		$429.00
240 rations, at 60 cents		144.00
Total repairs, pipe and lumber for one party for ten months	500.00	
Total commissary charges for team, feed, etc	350.00	
Total moving	670.00	
Total sundry incidentals	200.00	
Total supervision	350.00	
Total, ten months	2,070.00	
Sundry expenses per month		230.00
Total cost per month		803.00
Ten months, at $803		8,030.00
Total number of feet sunk		3,254.2
Total cost		$8,030.00
Cost per foot		2.46
Cost per hole, 7,227÷52		154.42



CONTOUR MAP OF BUTTES DAM SITE, SHOWING PLAN OF DAM AND LOCATION OF QUARRY TESTS.

If the original cost of machinery be distributed over this work, the results would be as follows:

Operation	$8,030.00
Machinery	1,600.00
Total cost	9,630.00

Or average cost per foot, $2.86.

Both machines are still in good repair after having been used in Nicaragua and in various localities in Arizona and California.

The total depths penetrated in all materials at the various dam sites are:

	Covering.	Rock.	Total.
The Buttes	1,621.2	196.0	1,817.2
Queen Creek	357.8	55.6	413.4
Riverside	729.8	40.2	770.0
Dikes	80.0	0.0	80.0
San Carlos	143.2	30.4	173.6
Total	2,932.0	322.2	3,254.2

The work at the Buttes at the last three holes and at the Dikes was very greatly delayed, owing to the loss of the original drive pipe by breaking beneath the surface. The pipe that was next obtained broke continually under the hammer, and a month's time of one party was lost by these interruptions. The expense of this work is included in the above estimate. Owing to the long move by teams of the outfit to San Carlos dam site and the constant interruption by floods of the work at that point and the consequent small amount of driving done there (173.6 feet), the cost of that portion of the work was about $6 per linear foot. If San Carlos is not included in the estimate, the average cost per foot for the remaining portion of the work would be reduced about 10 cents.

The advantages of this class of work over the shaft method are manifest. It is probable that not over five or six shafts could have been put down with the total funds available in case that method was practiced, and it is problematical even then if it could have been accomplished. By the drilling method employed the location of bed rock is not only determined, but an actual sample has been brought up, which can be tested for specific gravity, crushing strength, texture, quality, or in any other manner desired. The work was entirely successful, except at San Carlos, where the floods became so violent during the month of August, 1899, that the machinery could not be kept standing in the river, and but two holes reached and penetrated the bed rock.

BUTTES RESERVOIR.

EXPLORATION FOR FOUNDATIONS OF DAM.

As recommended in the report by Mr. Arthur P. Davis, made in 1896, explorations have been made to determine the depth of bed rock and the quality of the rock at the Buttes dam site. By this survey of 1899 the diamond core drill demonstrated the fact that the soundings which were made by rods and which are described in the report above mentioned were misleading. There is proved to be a limit beyond which it is impossible to drive rods in gravel and sand, and this limit, which is found to be approximately 60 feet in the material composing the bed of the Gila, prevented the correct determination of bed rock in 1896 by the rod method. Twenty-four holes were put down by the diamond core drill at various points in the canyon at the Buttes, the effort having been made to find some point where the bed rock would be shallow. The following table shows the depth and character of the bed rock determined.

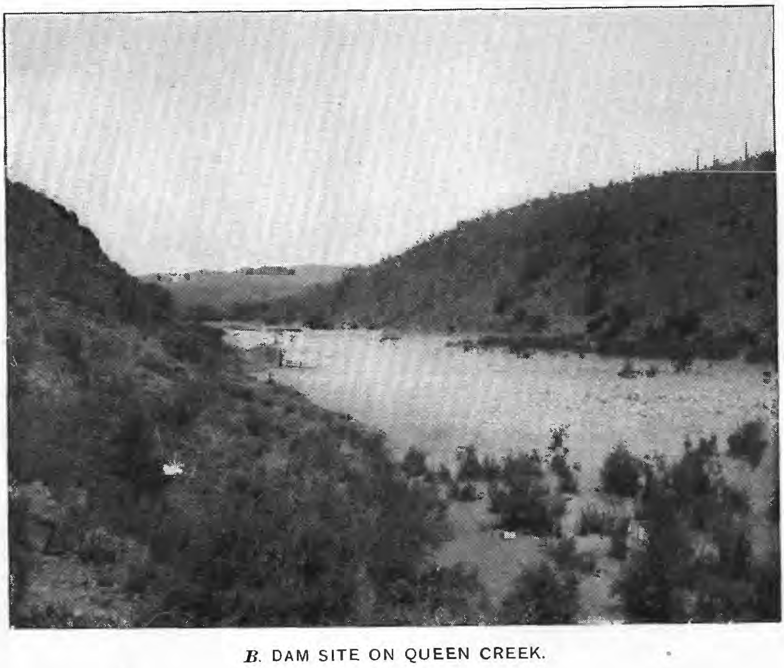
Log of borings at the Buttes dam site, Gila River, Arizona.

Line No.	Hole No.	Depth to bed rock.	Depth to bottom of boring.	Depth drilled in rock.	Correct elevation of surface June, 1899.	Correct elevation of bed rock.	Bed-rock elevations reduced to datum of contour map (= +13.38).
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
3	23	57.0	63.0	6.0	1,589.00	1,532.00	1,545.38
3	24	46.4	53.5	7.1	1,589.00	1,542.60	1,555.98
2	3	21.4	28.3	6.9	1,591.52	1,570.22	1,583.60
2	4	70.0	77.5	7.5	1,589.00	1,519.00	1,532.38
2	5	122.6	132.0	9.4	1,589.00	1,466.40	1,479.78
1	1	65.0	82.0	17.0	1,589.00	1,524.00	1,537.38
1	2	80.0	95.0	15.0	1,589.00	1,509.00	1,522.38
1	6	105.0	112.3	7.3	1,589.00	1,484.00	1,497.38
1	7	70.0	79.0	9.0	1,589.00	1,519.00	1,532.38
1	21	53.0	64.0	11.0	1,589.00	1,536.00	1,549.38
1	22	13.5	20.2	6.7	1,589.00	1,575.50	1,588.88
4	14	8.0	12.6	4.6	1,589.00	1,581.00	1,594.38
4	13	62.1	68.9	6.8	1,589.00	1,526.90	1,540.28
4	9	71.4	78.7	7.3	1,589.00	1,517.60	1,530.98
4	20	68.6	74.5	5.9	1,589.00	1,520.40	1,533.78
4	10	66.8	84.1	17.3	1,589.00	1,522.20	1,535.58
4	15	64.0	70.7	6.7	1,589.00	1,525.00	1,538.38
4	16	62.7	70.7	8.0	1,594.00	1,532.10	1,545.48
4	17	70.0	79.0	9.0	1,596.62	1,526.62	1,540.00
4	18	68.7	79.1	11.4	1,602.12	1,533.42	1,546.80
4	19	26.4	34.0	7.6	1,610.62	1,584.22	1,597.60
5	8	78.0	95.0	17.0	1,589.00	1,511.00	1,524.38
5	11	82.0	94.0	12.0	1,589.00	1,507.00	1,520.38
5	12	(*a*)	----------	----------	----------	----------	----------
	25	(*b*)	----------	----------	----------	----------	----------

a Not reached at 77 feet. *b* Not reached at 101 feet.

The contour maps of the Buttes dam and reservoir sites, which were surveyed in 1896, were based upon a datum which was taken from the local records of the Florence canal. Subsequently a line of levels

A. RESULT OF QUARRY TEST AT CLIFF ON RIGHT BANK BELOW BUTTES DAM SITE.



B. DAM SITE ON QUEEN CREEK.

was run from the railroad station of Casa Grande, on the Southern Pacific line, to the Buttes dam site, and upon this datum the topographic map of the irrigable lands in the vicinity of Florence was made. Upon this corrected datum the canal surveys were made, and a bench mark was established at the Buttes dam site. The elevations given on the large contour map of the dam site, which is on a scale of 50 feet to the inch, are based upon the first elevation of Florence canal datum, which the subsequent levels show to have been 13.38 feet too high. The elevations given on the plans and sections of the Buttes dam correspond to the elevations of the contour maps of the dam and reservoir surveys and do not correspond with corrected elevations. The elevations given in the above table are both the corrected elevations and the elevations on the same datum as that used for the contour map and plans of dam.

The holes whose surface elevation is given as 1,589 are those bored in the immediate bed of the stream. Those of higher elevations started on the alluvial benches above low-water level on either side.

QUALITY OF BED ROCK.

At each one of these points a core was brought up showing the quality of the bed rock. The following table is a description of the cores obtained at the Buttes:

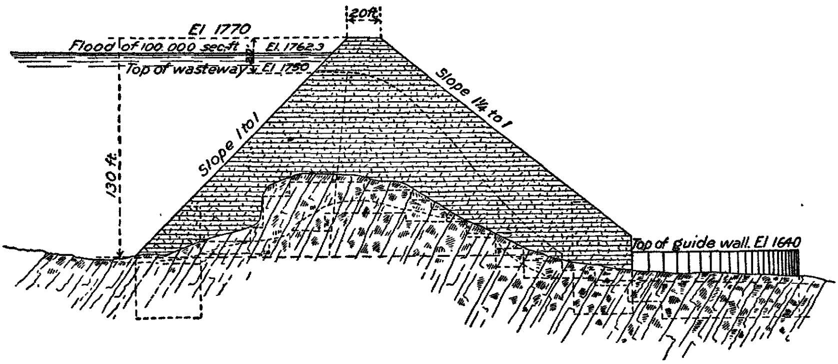
Cores obtained from borings at the Buttes.

Number of hole.	Depth drilled in rock.	Length of core obtained.	Quality of rock.
	Feet.	*Feet.*	
23	6.0	4.00	Pearlite.
24	7.1	4.40	Pearlite and ash.
3	6.9	2.40	Pearlite, very solid and brittle.
4	7.5	1.30	Volcanic ash.
5	9.4	4.25	Volcanic ash, badly pitted.
1	17.0	9.00	Pearlite, mingled with ash.
2	15.0	1.40	Porous ash.
6	7.3	2.40	Volcanic ash, badly pitted.
7	9.0	5.30	Hard ash.
21	11.0	2.40	Hard, volcanic ash.
22	6.7	5.00	Pearlite.
14	4.6	3.00	Volcanic ash.
13	6.8	1.80	Volcanic ash, very porous.
9	7.3	5.20	Blended ash and pearlite.
20	5.9	4.50	Volcanic ash.
10	17.3	4.10	Volcanic ash, quite hard, but badly pitted.
15	6.7	.85	Very porous volcanic ash.
16	8.0	5.00	Volcanic ash.
17	9.0	2.50	Do.
18	11.4	1.66	Do.
19	7.6	4.00	Do.
8	17.0	2.25	Do. very porous.
11	12.0	5.00	Hard, volcanic ash.
12			Bed rock not reached; hard pan at 40 feet.
25			Bed rock not reached.
	216.5	81.71	

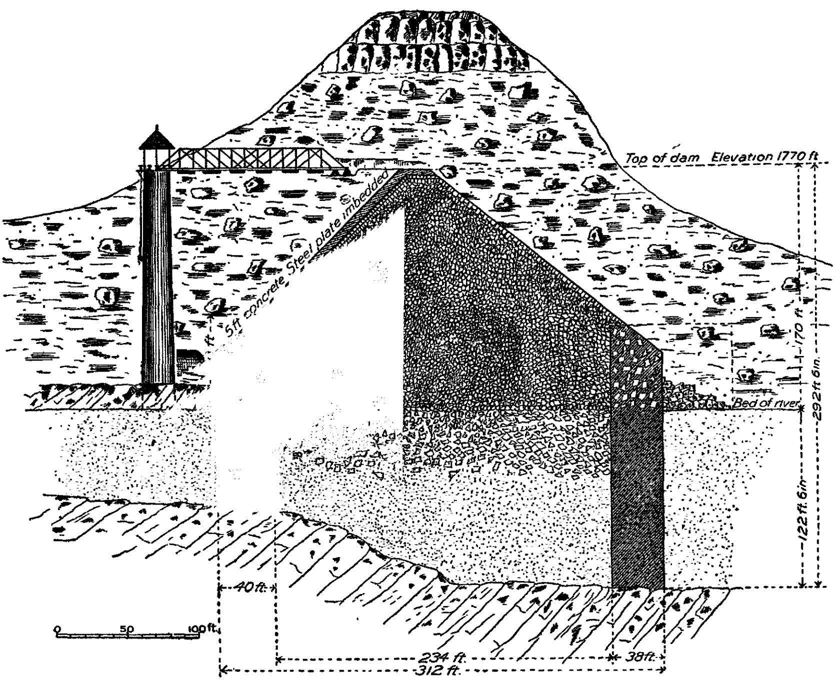
The location of these borings is shown on Pl. VIII, *B*, these being arranged in five different rows. At the relative location of each hole a figure has been placed on the diagram corresponding to the number given in the above tables. The point marked "B. M." shows the position of the bronze bench mark set in the face of the cliff. It is the initial point of the survey for the location of the borings. At the point marked "G" is a steel gad seven-eighths of an inch in diameter, set in the rock.

In taking out many of the cores it was found that, while the drill had entered the rock for distances of from 6 to 12 feet, the cores extracted were very much less in length, owing to the crumbling of the rock as it was cut. The bed rock varies between a volcanic glass, or obsidian called pearlite, and a porous ash. The obsidian is exceedingly hard, but the ashy material is full of holes, quite soft, being readily cut with a knife, and of a crumbling nature. A total depth of 216.5 feet was bored into the bed rock, and but 81.71 feet of core obtained therefrom, or only 38 per cent of the total length of the core was of such material as would permit of its extraction from the holes. It is but fair to assume that the remaining 62 per cent is of a poorer class of material than that which was extracted.

The following table gives crushing tests which were made in the laboratory of the city engineer's office at Los Angeles, California. The crushing limit of the machine used is 2,565 pounds per square inch. This would be equivalent to 184.7 tons per square foot. A good many of the samples could not be crushed on the machine, but it has been considered that all rock which could not be crushed with this pressure is reliable and could be accepted as a satisfactory foundation material. The poorest rock is undoubtedly that portion of the core which has gone to pieces under the action of the diamond drill, and which could not be extracted. Tests were obtained from the samples as low as 79.5 tons per square foot. It may therefore be assumed that the tests made are of the better class of rock, and that if any of the samples indicate a weakness below the limit of safety it would justify the abandonment of the bed rock as a proper foundation for a cement-masonry dam. The assumed maximum height of the dam being 170 feet above the bed of the stream, and 123 feet to bed rock below the same, or a total height of 293 feet, the base would have to be made so wide in order to keep the pressure at the outside toe within safe limits that the cost would be prohibitory. Some of the cores having crushed with 80 tons pressure per square foot, a rubble-masonry dam is abandoned for this site. Crushing tests were made by J. W. Robinette and S. G. Bennett. Specimens were 1 inch long and 1 inch in diameter.



A. ELEVATION OF END WALL OF BUTTES DAM.



B. MAXIMUM CROSS SECTION OF PROPOSED DAM AT THE BUTTES, ARIZONA.

Specific gravity, weight per cubic foot, and crushing tests of diamond-drill core from bed rock at the Buttes, Arizona.

No. of specimen.	Weight in air.	Weight in water.	Loss.	Specific gravity.	Weight per cubic foot.	Crushing test, pounds per cubic inch.	Crushing test, tons per cubic foot.	Remarks.
	Ounces.	*Ounces.*	*Ounces.*					
1	1.10	0.60	0.50	1.86	116.4	2,565+	184.7+	Stood 2,000 pounds.
2	0.75	0.30	0.45	1.66	103.0	1,035	79.5	Crushed at 807 pounds.
3	1.30	0.75	0.55	2.39	149.5	2,565+	184.7+	Stood 2,000 pounds.
4	0.95	0.45	0.50	1.93	120.5	2,565+	184.7+	Do.
5	0.90	0.47	0.43	1.79	112.0	2,565+	184.7+	Do.
6	0.82	0.40	0.42	1.95	122.0	2,469	177.0	Crushed at 1,926 pounds.
7	0.70	0.30	0.40	1.75	109.0	2,288	164.7	Crushed at 1,785 pounds.
8	0.85	0.40	0.45	1.86	116.4	2,565	184.7+	Stood 2,000 pounds, but developed longitudinal crack after being taken out of testing machine.
9	0.90	0.45	0.45	2.0	125.0	2,088	150.0	Crushed at 1,629 pounds.
10	0.95	0.46	0.49	1.855	116.0	2,565+	184.7+	Stood 2,000 pounds.
11	0.86	0.45	0.41	2.10	131.0	2,077	149.5	Crushed at 1,620 pounds.

QUARRY TESTS.

The rock at the Buttes appearing to be of a questionable quality for concrete or rubble masonry work, it was decided to be necessary to make quarry tests in order to determine accurately its nature. Mr. D. Anderson, mason and quarryman, of Los Angeles, California, made the following quarry tests:

At the first cliff on the right bank below the dam site at the Buttes, 12 feet back from the edge, two holes were put down, 5 feet 6 inches and 3 feet in depth, respectively. This location is marked by the figure 1 on contour map of the Buttes dam site (Pl. IX). Eight sticks of giant powder started the rock and one 25-pound keg of black powder pushed it off. The result was one 10-ton rock, one 2-ton rock, and numerous small rocks ranging from 25 to 500 pounds. The rock is a pearlite, heavy, close grained, and fairly free from seams. It dropped from 150 to 175 feet, to the foot of the cliff, falling partly on earth and partly on rock, without badly shattering it. It drills easily, two strikers going 18 inches an hour with $1\frac{1}{4}$-inch bit, but large quantities of powder are required to start the rock.

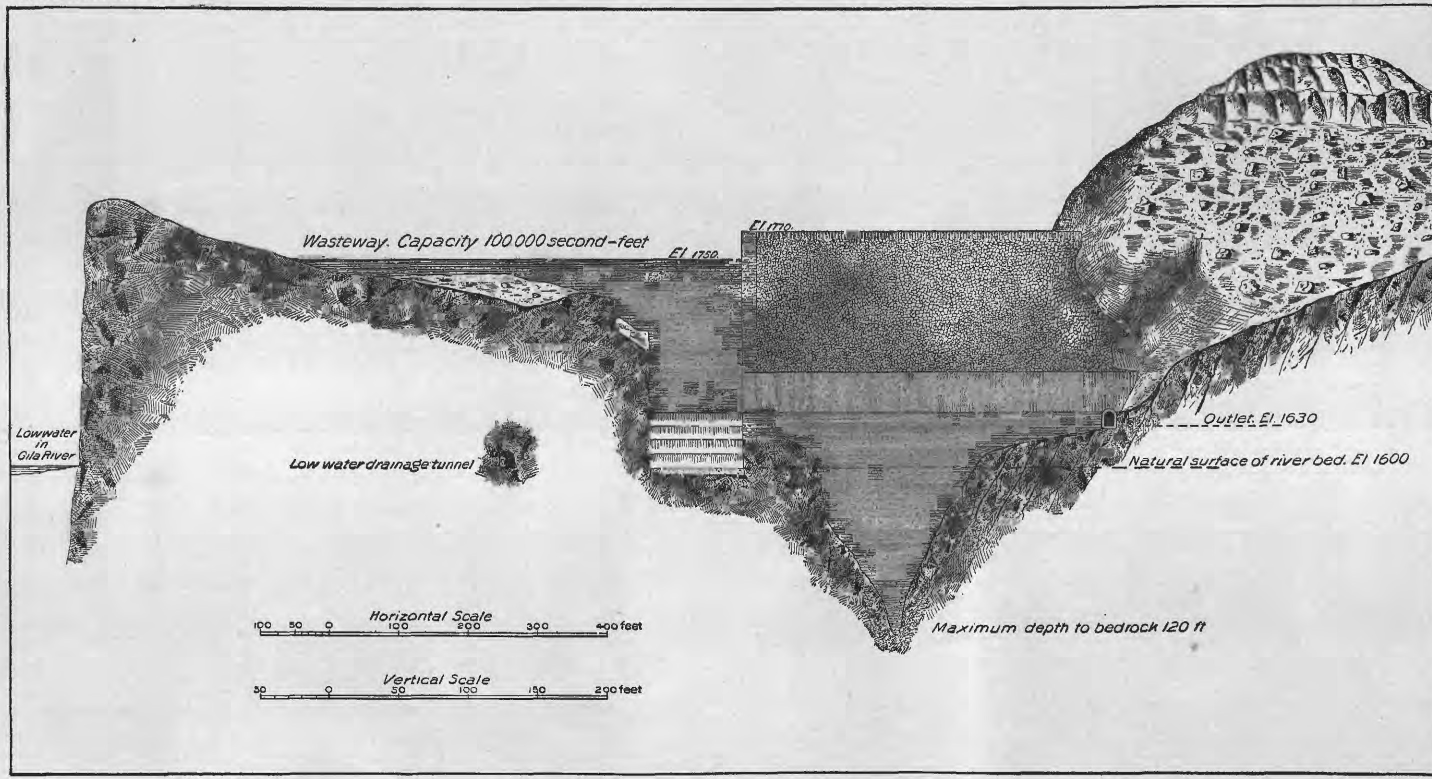
The second test, at figure 2 on Pl. IX, was on east face of same cliff. Five-foot holes were put down in a step series, $2\frac{1}{2}$ sticks of giant powder being used to spring each. Afterwards holes $2\frac{1}{2}$ feet deep were filled with black powder, 3 kegs being used in five holes. The result is hard to estimate—probably 100 to 200 tons of rock were thrown down. There were one 2-ton, two 1-ton, and about twenty quarter-ton rocks. The large pieces are pearlite; the smaller ones are a hard ashy rock.

The point west of the left spillway, at figure 3 on Pl. IX, was opened on June 10, 1899, and a hole was put down 4 feet 4 inches and four sticks of giant powder were exploded therein. The rock exposed seems to be a partly solidified pearlite, light and brittle. Soft streaks and spots are found throughout the mass, and it does not seem suited either in weight or structure to bear a rubble-masonry dam. About one-third of it is a white-colored ash and two-thirds is a gray, hard substance, brittle and light. The ashy material cuts readily with a knife, while the gray is hard to scratch. These white spots are often eroded by wind action when occurring at the surface, holes being thus formed as large as 2 feet in diameter.

At a point 100 feet northeast of the left-hand spillway (bench mark), at figure 4 on Pl. IX, a hole 4 feet 6 inches was put down on June 7 and five sticks of giant powder were used (three and one-half sticks to the pound). The rock is similar to that previously noted, but harder and ashy white, and usually resists a knife, but there are spots that cut like chalk. In the lower portion of the spillway, at figure 5 on Pl. IX, a blast was put off which showed that the material is softer and more fragile in the spillway than elsewhere and of a very questionable nature for cement-masonry work. On the southwest end of the low butte, at the left dam abutment, at figure 6 on Pl. IX, a hole 6 feet deep was put down June 10, and three sticks of giant powder were used to spring it. Twelve pounds of black powder were then used to throw down the rock. This revealed a high-grade, heavy, volcanic glass, resembling the first, tested across the river. Overlying the pearlite is a streak of ashy gray, but harder and darker than at the spillway.

The prevailing rock at the dam site is an indurated ash. It is found in the cliffs of the left bank, east of the spillway and at the proposed upper portal of the tunnel on the right bank. The lighter ash is liable to crush and erode. Probably enough of the pearlite could be selected to build a concrete or rubble dam, but it would be a matter of selection, and much of the lighter rock would have to be moved to get at the better rock. This probably would be 50 per cent of the mass. The rock in the left-hand spillway probably could not be put in a concrete dam. It could, however, be used for a core of a rock-fill dam.

On the first cliff south of the dam site, on the right bank, facing the river, two large blasts were fired at the first projecting point, at figure 7 on Pl. IX. Three holes were put down, 14 feet, 15 feet, and 16 feet deep, 18 feet back from the face of the cliff. The rock was hard and cut coarse. Three men could go down 10 inches per hour with a churn drill. Four pounds of giant powder were used to the hole. This sprung the cliff from one side to the other, about 30 feet deep. The crack was then charged with black powder, 3½ kegs being put down to each hole. The powder in hole No. 2 went into a crevice and did



ELEVATION OF BUTTES DAM. LOOKING UPSTREAM.

little good. The entire point sprung, but did not fall, but around the edge was revealed pearlite of a good quality. There were six men in all, including blacksmith and helper, who worked fifty-three hours at this point. The rock dips into the cliff, so that while the ledge was pushed off as much as 5 feet it did not fall.

On June 24 about 50 pounds of giant powder was placed in the key of this mass and shot. This brought it down with the following approximate results: Length of fallen mass, 80 feet; height above sand, 10 feet; depth in sand, 5 feet; width, 30 feet. This is about 440 cubic yards of loose rock. Pl. X, *A*, gives a view of this test. There were approximately one 10-ton rock, ten 5-ton rocks, and thirty 1-ton rocks. The mass ranges from stone that would pass through a 3-inch ring to rocks 150 pounds in weight. It is of a mixed ashy structure, and not solidified glass. There are numerous flow lines or fissures which are contorted, and the rock has gone to pieces badly. This rock fell 180 feet upon the sandy river bed. The pearlite is not so pure as was indicated by the first test; it seems to be stratified, and changes often from pearlite into an ash, or the reverse. Numerous chips knocked off the corners of base of this cliff with a hammer show it to be a hard, volcanic substance, such as is frequently penetrated by the diamond drill as bed rock.

At the west end of the first bluff below dam site on right bank at figure 8 on Pl. X five men worked fifty-three hours. The rock is softer than that at the middle of bluff, shown in last tests. It cuts very easily, but the drill holes clean hard and the dust from cutting forms paste when mixed with water. The average rate of progress with the churn drill is 10 feet an hour. Three holes, 8 feet apart, were put down approximately 16 feet in depth and 18 feet from the face of the cliff. Four pounds of giant powder were used to the hole, and the cliff was cracked across the point. The crack was opened by a second charge, consisting of 2 pounds of giant and 5 pounds of black powder to the hole. This resulted in a crack 2 inches wide, extending 38 feet. There seems to have been an error in judgment on the part of the quarryman in springing the rock too much before using the black powder, which expended its energy, in a large part, through the fissures of the rock. This crack was then charged with ten kegs of black powder, and a portion of the cliff in front of one of the holes was thrown off, knocking down about 300 tons of rock. The other portions on the cliff were not thrown off, but sufficient material was revealed to show the nature of the rock. In this, as in the former case, the rock fell 180 feet. There were from 8 to 10 large rocks displaced, ranging from 6 to 8 tons in weight, but a large portion of the fragments range from 100 to 200 pounds, while much of the rock, possibly 25 per cent, is in pieces weighing less than 50 pounds. There is a large amount of rock buried in the sand. This rock is a reddish or fused ash, rather light and brittle, but hard, and with many seams. It ranges in a very intricate way from glass to ash, and back again to volcanic glass. Fully 66 per cent is glass. At a point 25 feet south a smaller blast showed pure glassy pearlite, which falls without shattering. The first grade pearlite is rather rare and can not be obtained in large quantities. The ashy material is the prevailing rock and is of inferior grade for construction purposes.

A block of the poorer class of the volcanic ash from the spillway on the left bank, containing soft spots of light, chalk-like material, was immersed in water in June, and continued under water until the first of October, over three months. At the expiration of this time the softer portions of the rock indicated, if anything, a hardening, but still could be cut with a knife. It would be between 2 and 3 in the scale of hardness.

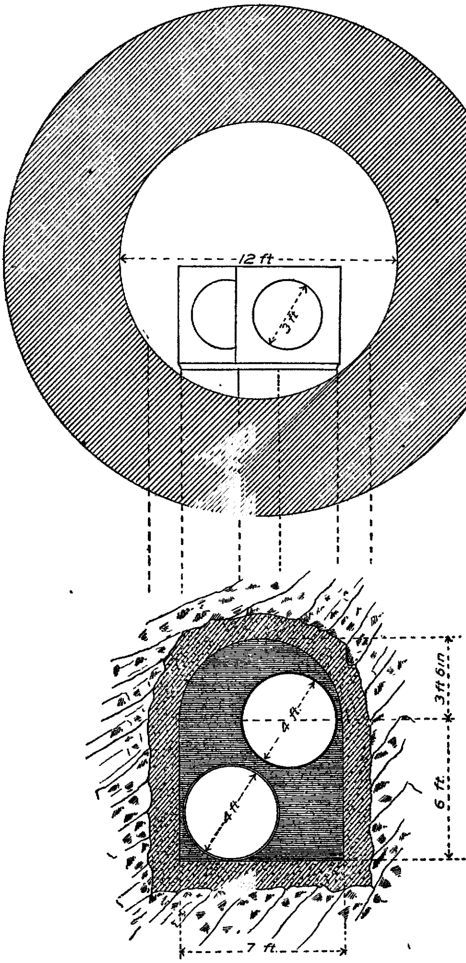
In conclusion, it may be stated that it would be difficult to select a sufficient amount of rock of first-class quality for concrete work or rubble masonry to build a dam of that type of the size required from bed rock to a line 170 feet above the bed of the stream, a total height of 223 feet, without large expense. The rock at the Buttes would be suitable for the construction of a rock-fill dam, the poorer class rock being placed in the center of the dam and selected rock on the two faces and at the spillway weir on the right bank.

It is probable that the dam could be most economically constructed from quarries at the cliffs on the right bank of the canyon below the dam, tramways being used for delivering the rock to the structure. The tramways would vary in length from 500 to 1,000 feet. If cableways were used they could not properly be placed on lines which would be near or parallel to the axis of the dam, and if they were not so located it would require a double system of cables for handling the rock, one to bring it from the quarries to the dam site, and a second set to distribute the rock at the dam.

The conclusion reached from the investigation of bed rock with the diamond core drills and from the quarry tests leads to the adoption of a rock-fill dam for the Buttes as the only class of structure which it would be feasible to build with the material available and on the foundation there existing. For this reason the estimate of cost has been made solely upon this type of dam.

TYPE OF DAM ADOPTED.

It is evident that the desired type of dam must have a very broad base, reducing to a minimum the pressure per square foot on each portion of its foundations. A dam with this breadth of base would call for a heavy expenditure for the excavation to bed rock if the entire section were taken out. In order to be stable and to retain the water impounded above it, the dam must have an impervious connection with bed rock. The style of dam selected (Pl. XI, *B*) is of the rock-fill type, with concrete retaining walls and with a concrete spillway weir



CROSS SECTIONS OF TOWER AND OUTLET TUNNEL OF BUTTES DAM.

on the right side. It is proposed to put a wall down to bed rock at the upper toe of the dam sufficient in thickness to withstand the pressure of water against its upper face when excavations are made behind it. At the lower toe of the dam it is proposed that a similar wall shall be put down to bed rock in order to protect the structure from erosion from the spillway on the right bank and to retain the inclosed mass of sand and gravel as a foundation for the riprap or dry-laid rock.

The section and rear view, looking upstream, of this proposed structure are shown on Pls. XI and XII.

Between these two walls there will be held a mass of sand, gravel, and bowlders, which constitute the natural bed of the river and which will not be excavated. The distance between these two walls is 234 feet. It is proposed that they shall be carried up above the bed of the stream to an elevation of 58 feet on the lower wall and 63 feet on the upper wall. Loose rock will be deposited between them as they are raised in elevation, and the river will be allowed to flow a portion of the time over the masonry walls onto the mass of rubble lying on the sandy bed of the stream. The churning action which will result therefrom will permit the heavy rock to settle into the bed of the river, it being desirable to have this take place as much as possible. In case this does not occur naturally, it is proposed to pump water onto this rock and force a settlement in that manner. The rock forming this portion of the dam will be as large as can be handled.

An outlet tunnel will be constructed through the point of rocks at the right abutment of the dam at the lowest possible elevation, as shown on Pl. XII. This tunnel (Pl. XIV, *A*) will be 15 feet high, 10 feet wide, and 139 square feet in area. It will discharge under pressure and with high velocity and will carry the river at all stages of low water and in ordinary floods. It will be about 1,000 feet in length and have over 1,000 second-feet capacity. This tunnel will permit, during all usual occasions, of the regulation of the river as may be desired during construction. Afterwards it can be used to carry off flood waters, and it will not ordinarily supply water for the irrigation canals. On the left bank the delivery tunnel (see Pl. XII) will be located 30 feet above the natural bed of the stream and will discharge, if desirable, into the main irrigation and power conduit.

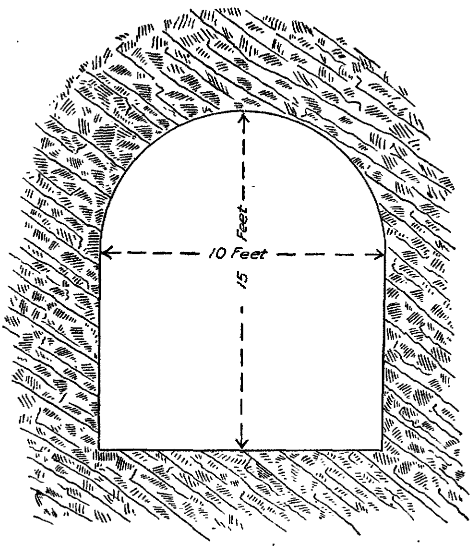
A serious problem in connection with the construction of this dam will be the handling of the great floods which possibly may occur in the river during its erection. If such a flood should occur during construction, and be permitted to pass over the dam while it is in an incomplete condition, the loose rocks would probably give way under the violence of the current and destroy the work already performed. There would then be added to the flood the volume of water resulting from the bursting of the reservoir, and disaster would follow not only to the structure itself, but to settlements and towns along the Gila River below the dam. In order to prevent this the two masonry retaining walls (Pl. XI, *B*) are carried above the bed of the river to the elevations named. If when these walls have reached their maximum height and the intervening space is filled with riprap a flood of great magnitude should pass over the dam the structure would stand, the loose rock being held between the two retaining walls would settle down into the sand bed between them. This would be exactly what would be desired. An examination of Pls. V, *A*, and XII shows that the bed rock has a very flat slope on the right abutment. It is proposed that a wall (Pl. XI, *A*) should be built from this bed rock, as shown on Pl. XII, 20 feet in thickness, as a retaining wall for the right end of the loose-rock portion of the dam, connecting the upper and lower toe walls. The purpose of this wall is to retain the loose rock and to protect it against the attacks of floods. This end wall will be made of concrete, and an excessive thickness will not be necessary, because it will be reenforced by the secondary rubble-masonry weir to its right.

A cut (shown by the crosshatching on Pl. IX) will be made into the sloping rock at the right abutment down to an elevation of 40 feet above the natural surface of the river bed and to a width of 100 feet at the bottom. This cut would be carrying water at a depth of 30 feet when the water reached the elevation of the top of the higher toe wall of the dam, and a corresponding head on the large tunnel of 70 feet would then exist. This would probably carry any ordinary flood which might occur in the river.

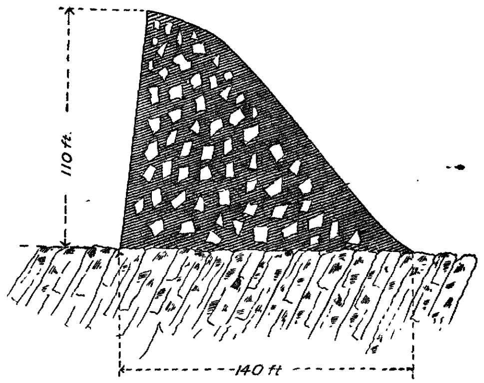
The effort should be made during the first year of construction to complete the two retaining walls from the bed rock to the surface of the stream. During the second season these walls can be completed and as much of the rock-fill dam as possible constructed. In the third year the rock-fill dam should be completed and the concrete weir constructed.

As the work on the rock-fill portion of the dam advances and its crest rises in elevation, the construction of the concrete weir on the right abutment, which is to act as the spillway for the structure, can be begun and carried on with the remaining portion of the work. The two faces of the central dam are to be laid up by hand in dry wall, and the slopes which have been accepted for the dam are practically the natural angles of repose, so that little tendency to slide is likely to exist.

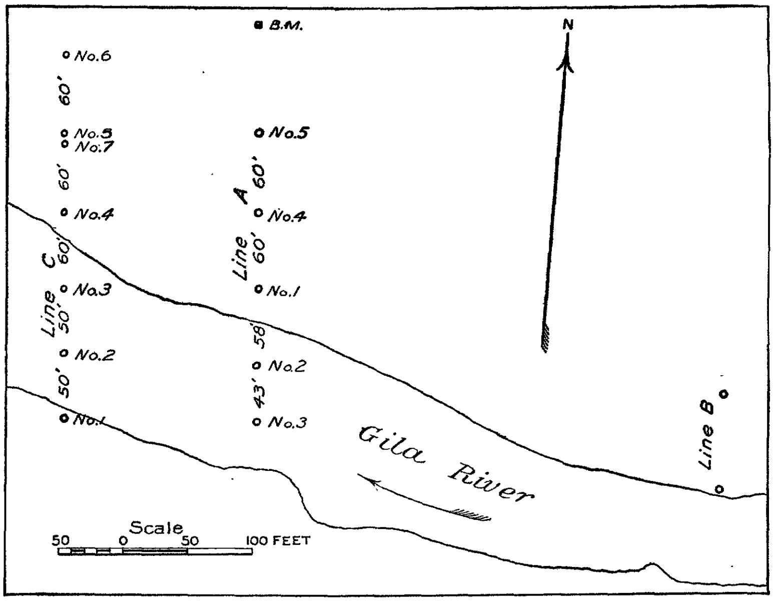
In order to make this structure water-tight it is proposed to cover the upper face with an apron of concrete 5 feet in thickness, which will be connected with the upper toe wall and the two abutments of the dam. In this apron of concrete a continuous riveted steel plate will be embedded 4 feet beneath the water face of the dam and 1 foot from the dry-laid rock wall. Angle irons will be riveted horizontally and vertically on both sides for the purpose of stiffening the plate and insuring a better connection with the concrete. The steel plate



A. CROSS SECTION OF LOW-WATER TUNNEL, BUTTES DAM.



B. MAXIMUM CROSS SECTION OF WASTEWAY, BUTTES DAM.



C. LOCATION OF BORINGS AT RIVERSIDE DAM.

will make the dam additionally impervious and lend strength to the concrete.

Gates will be placed at the upper portal of the flood tunnel and will be operated from the surface of the ground. The gates for the tunnel which is to discharge into the irrigation conduit will be operated from a tower (Pl. XIII)

Quarry tests were made of the spillway on the left bank, and the rock was found to be of such nature that it would not stand the erosion of a great flood. It is of a volcanic, ashy character, porous in spots, light in weight, and portions of it can be readily whittled with a knife. A flood approaching 100,000 cubic feet per second passing over this material would tear it to pieces, it is believed, and erode great channels. It would be exceedingly expensive to cover this spillway with concrete so as to protect it or to build a series of checks to mitigate the erosive action of the water.

On the right abutment, however, the rock is of a harder nature. It is, to a large extent, an obsidian, or pearlite, and it is believed that it will resist erosion. This bed rock on the right abutment is practically at the surface from an elevation of 20 feet or more above the bed of the stream. A concrete weir of the section shown on Pl. XIV, *B*, will be constructed on this abutment, the elevation of the top being 20 feet lower than the top of the loose rock dam, and of a length of approximately 650 feet. Any flood occurring will pass over this portion of the dam only. This concrete weir will be built into the excavation which was made for the flood waters and connected with the retaining wall at the right end of the rock-fill dam. Its section will be such that any flood may pass over it without injuring it. The dam will be protected on its flank and at its lower toe with solid walls of concrete, and the floods passing over the weir will be discharged away from the main dam into the canyon below.

As a further protection against any churning action of the water which may occur, large blocks of riprap should be laid against the lower toe wall of the dam to prevent the scouring of a large cavity in the bed of the canyon at that point. The lower toe wall should be provided with weep holes, so that hydrostatic pressure against the wall can be avoided. It is believed that the body of sand and gravel between the two toe walls of the dam, which is 234 feet in length and approximately 400 feet in width and which is rigidly sustained by two masonry retaining walls, will be a foundation of a very substantial and satisfactory character for the loose rock embankment composing the dam.

It is a frequent practice in sinking iron caissons for bridge piers to build concrete upon a retained sand foundation of this nature. When the foundations of the retaining walls are uncovered and examined, if the bed rock should prove unsuited to sustain the vertical pressure due to their weight, which will amount to a maximum of 12 tons per square foot, then the walls will have to be broadened at their base to the proper width to reduce the pressure to the desired limit.

It is believed that a dam could be constructed at the Buttes on the plan outlined that would be a reliable and creditable engineering structure, but the expense would be great, as is shown in the estimate.

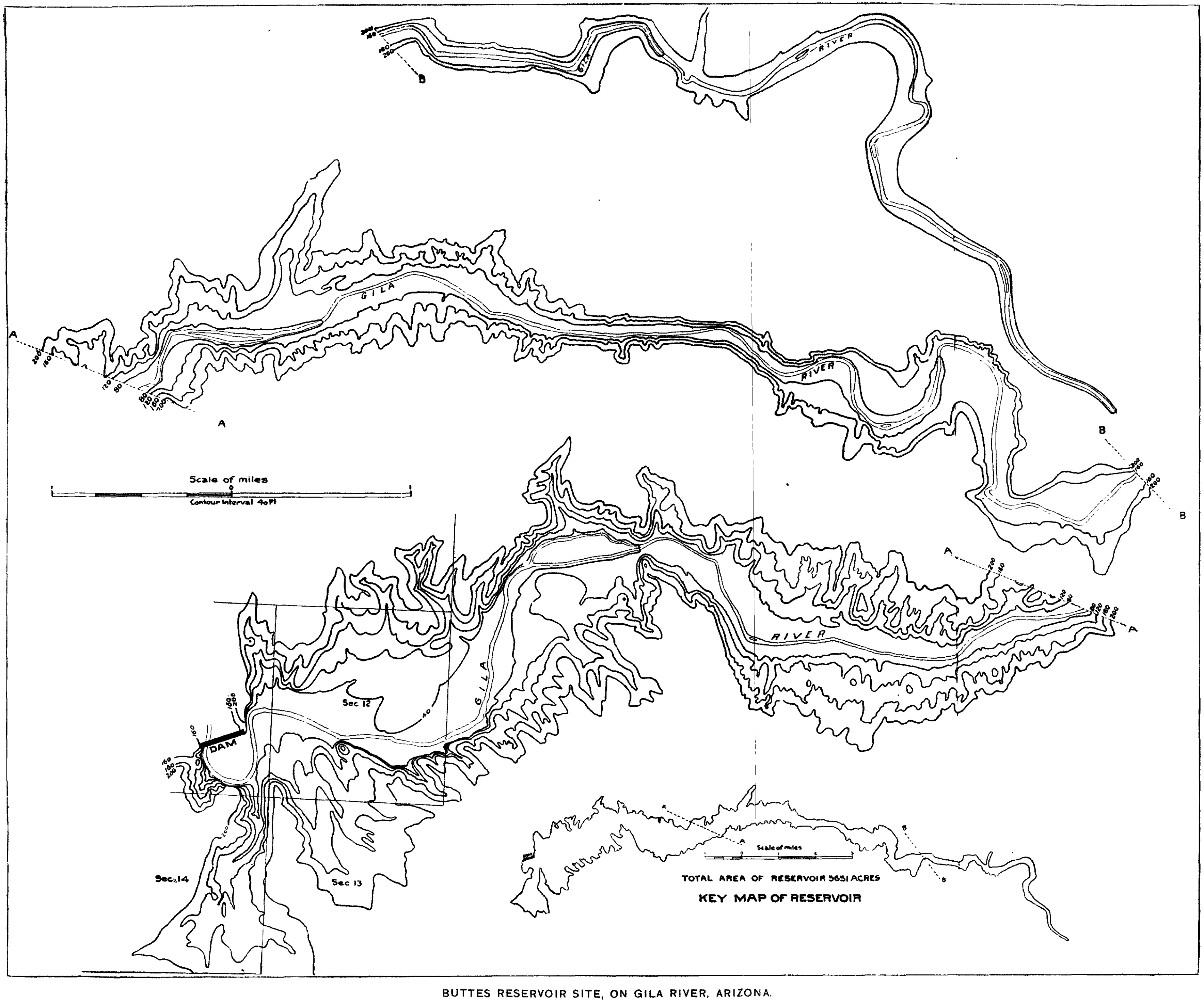
METHOD OF EXCAVATION FOR FOUNDATIONS.

The most serious difficulty in connection with the construction of a dam at the Buttes will be in the excavation for foundations. The plan suggested is the sinking of a series of open caissons. These will be put down as for bridge pier work. They would be weighted on top, and the excavation made probably below water by means of buckets on an endless chain or some similar method. As the excavation in the sand and gravel would progress, the caissons would sink on account of the superimposed weight, and new sections would then be fitted to the top as it went down. The borings with the diamond core drill did not indicate bowlders of large size, and it is believed that these caissons could be put down without serious trouble. The attempt would not be made to keep them pumped out until they reached bed rock, when pumping would be resorted to, the bed rock would be cleaned and examined, and after everything was clear they would be filled with concrete.

A row of these caissons, tangent to each other, would be put down at the upper face of the upper toe wall, and another at the lower face of the upper toe wall, each row being braced against the other. The bed rock where the upper toe wall would be put down is at a maximum depth of 71 feet, and is better than the average bed rock which intervenes between the two retaining walls. At the lower toe wall the bed rock is largely pearlite, and is at a maximum depth of 122.6 feet. The principal trouble in putting down these foundations will be in handling the volume of water to be encountered. Bed rock is nearer the surface at the upper toe than elsewhere. The wall would be naturally put down first here, and this would greatly relieve the volume of water to be handled at the lower toe wall. The two rows of caissons having been placed, the sand and gravel intervening would then be excavated. When the excavation is completed for the upper toe wall between the cylinders, the concrete to constitute the wall would then be placed in solid mass. A similar construction would be followed at the lower toe wall. With the two toe walls completed, the riprap would be placed between them and allowed to sink to the greatest depth possible into the sand.

BUILDING MATERIALS, SAND AND GRAVEL.

A drainage line enters the Gila River at a distance of about 2,000 feet above the dam site, which carries the discharge from an area lying south of the reservoir site. This drainage line for a distance of



BUTTES RESERVOIR SITE, ON GILA RIVER, ARIZONA.

3 or 4 miles varies in width from 100 to 400 feet and is filled to an unknown depth with a high-grade, coarse building sand, the voids constituting 35 per cent of the mass. This sand would have to be washed, and would then be of good quality for concrete. The cement for the dam must be shipped, probably, from California to Casa Grande, at a cost for railway transportation of $12.20 per 2,000-pound ton. The wagon haul from the railroad to the Buttes is 40 miles. The amount of cement used should, therefore, be reduced as much as possible. An examination was made for materials from which a natural hydraulic cement could be made, without successful results. Limestone exists 3 or 4 miles below the Buttes dam site, but no good clay was found. Fuel also would be an expensive element. Coal would have to come from New Mexico, if used, and wood from the neighborhood of the Indian reservation.

A test, as noted on page 16, was made to determine the possibility of making a silica cement with the Portland cement, which might be brought in, and finely ground pearlite. By mixing one portion of finely ground cement with an equal bulk of pearlite, so that no residue would remain on a 200-mesh sieve, and adding two parts of coarse sand, not ground, making a mixture of one part finely ground Portland cement and five parts sand and ground silica, a tensile strength of 80 pounds per square inch was obtained at the end of seven days and of 300 pounds at the end of twenty-eight days. When the same cement was mixed with sand on the ratio of 1 to 2, 33 per cent being left on the 200-mesh sieve, a tensile strength of 170 pounds per square inch was obtained at the end of seven days and of 385 pounds at the end of twenty-eight days. The same pure cement mixed on a ratio of 1 to 3 has a tensile strength of 140 and 240 pounds per square inch at the end of seven and twenty-eight days, respectively. The ground pearlite and finely ground cement mixed on the ratio of 1 to 7 has a tensile strength of 185 pounds per square inch at the end of twenty-eight days.

CAPACITY AND COST OF THE BUTTES RESERVOIR.

The basin of this reservoir site, shown on Pl. XV, embraces little agricultural land, and it is estimated that $10,000 will cover all the damages that would be incurred by appropriating it for reservoir purposes. Some copper prospects have been discovered in the reservoir site at a point known as the Dikes, but it was subsequent to the filing on all of this land under the United States laws for reservoir purposes. No further antagonistic interests can become vested here.

The capacity of the Buttes reservoir site is 174,040 acre-feet, and the estimated cost of constructing this dam is $2,643,327, or an average cost of $15.19 per acre-foot of capacity. The Buttes reservoir site has the advantage of being closer to the irrigable lands than any other of the reservoir sites considered on this river.

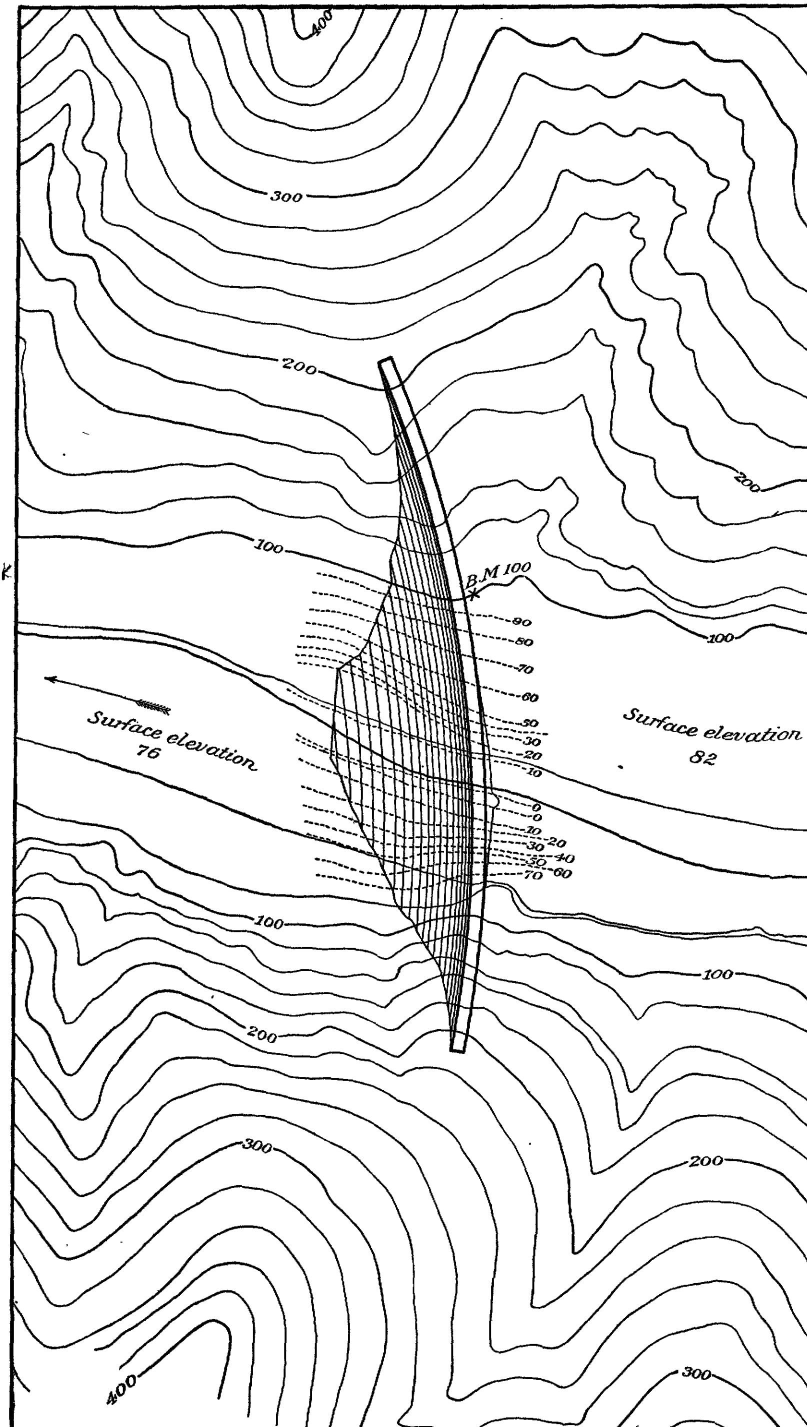
Area and capacity of the Buttes reservoir site.

Contour flow line.	Area.	Capacity, section.	Capacity, total.
	Acres.	*Acre-feet.*	*Acre-feet.*
10	20	100	100
20	71	450	550
30	229	1,500	2,050
40	397	3,130	5,180
50	533	4,650	9,830
60	741	6,370	16,200
70	928	8,345	24,545
80	1,105	10,165	34,710
90	1,329	12,170	46,880
100	1,566	14,475	61,355
110	1,769	16,675	78,030
120	2,029	18,990	97,020
130	2,367	21,980	119,000
140	2,746	25,565	144,565
150	3,149	29,475	174,040
160	3,602	33,755	207,795
170	4,118	38,600	246,395
180	4,609	43,635	290,030
190	5,133	48,710	338,740
200	5,651	53,920	392,660
		392,660	

Estimate for the Buttes dam.

Rock excavation for dam and riprap, 305,805 cubic yards, at $1	$305,805
Masonry in walls above ground, 137,032 cubic yards, at $6	822,192
Concrete tower, 37,328 cubic feet, at 50 cents	18,664
Tower house	750
8 inlets, at $500 each	4,000
4 balance valves, at $1,000 each	4,000
Footbridge, 120 feet, at $10 per foot	1,200
Masonry below water:	
Lower wall, 478,800 cubic feet, at 90 cents	430,920
Upper wall, 798,800 cubic feet, at 70 cents	559,160
Steel plates in face wall:	
1,152,000 pounds, at 7 cents	80,640
Low-water tunnel, 1,000 feet, at $15	15,000
Tower for flood gate	18,664
Tower house	750
Right of way	10,000
Upper outlet tunnel, lined, 320 feet, at $15	4,800
Bulkhead for same, 200 yards concrete, at $10	2,000
Woodcrib diversion dam at head of Florence canal, 500 feet, at $40 per linear foot	20,000
	2,298,545
Engineering and contingencies, 15 per cent	344,782
Total	2,643,327

Cost per acre-foot of water stored, $15.19.



CONTOUR MAP OF RIVERSIDE DAM SITE.

DIVERSION CANAL BELOW THE BUTTES DAM.

A topographic map was made on a scale of 100 feet to the inch, with 5-foot contours, showing possible locations of a diversion canal from the Buttes dam site to a point near the head of the Florence canal, which is practically at the head of the irrigable lands to be supplied from this reservoir. This topography was mapped by Mr. Bradford Wheeler, of Los Angeles, California. A grade line for the proposed conduit was computed. Flags were then set with a level upon the 10-foot contour nearest the grade from the dam through to the head of the irrigable lands. A transit stadia line was then run between these contour flags, transit points being set at intervals not to exceed 500 feet. This transit line was then plotted upon plane-table sheets, which were taken into the field, and the topography was filled in by means of the plane table. Instructions were to keep the accuracy of the map within the limit of the contour interval. The elevation of the contour flags was the vertical control for the work and the angular transit line was the horizontal control.

Upon this topographic map the canal location has been studied. The outlet tunnel, on the west bank of the reservoir, is placed at an elevation of 30 feet above the bed of the stream, the storage capacity lost below this elevation being immaterial. This would afford a bed-rock diversion and no loss by seepage. The capacity of the proposed canal is 500 cubic feet per second. The grade of the canal being lighter than that of the river permits of a gain in relative elevation and the possible development of power. The principal point gained by the construction of a canal as planned would be one of power.

A drop of 18.11 feet could be obtained at station 79+80, which, with 500 second-feet in the canal, would develop about 800 horsepower. If this horsepower could be sold at $50 per horsepower per annum, it would pay 5 per cent on a capital of $800,000. In a settlement such as would be built up upon the irrigation of 100,000 acres of land this power might be sold. When the time arrives that would make the power of sufficient value to justify the construction of the canal, it may then be built. Prior to that time the water from the outlet tunnels can be discharged into the bed of the Gila River and diverted at the present head of the Florence canal, where projecting ledges of rock are suitable for that purpose. The cost of the construction of this canal, therefore, should not be an element in estimating the cost of the Buttes dam. The water from either the Riverside or San Carlos reservoirs, which would be discharged directly into the Gila River, would necessarily be diverted for irrigation purposes at the head of the Florence canal, which is the point where water from the Buttes reservoir site could also equally well be diverted.

Cost of the Buttes canal.

15,510 lineal feet of lined canal, in rock, at $8.80 per lineal foot	$136,488
400 lineal feet of lined canal, in loose rock, at $6.73 per lineal foot	2,692
5,120 lineal feet of earthen canal, 57 cubic yards excavation, per lineal foot, at 30 cents per cubic yard, $1.71 per lineal foot	8,755
580 lineal feet of lined tunnel, at $10.65 per lineal foot	6,177
610 lineal feet of earthen canal, lined, at $7.94 per lineal foot	4,843
1,960 lineal feet of flume and trestle, at an average cost of $17 per lineal foot	33,320
24,180 lineal feet of conduit	192,275
Engineering and contingencies	28,840
Total	221,115

4.59 miles, or about $48,000 per mile.

EXPLORATION AT THE DIKES.

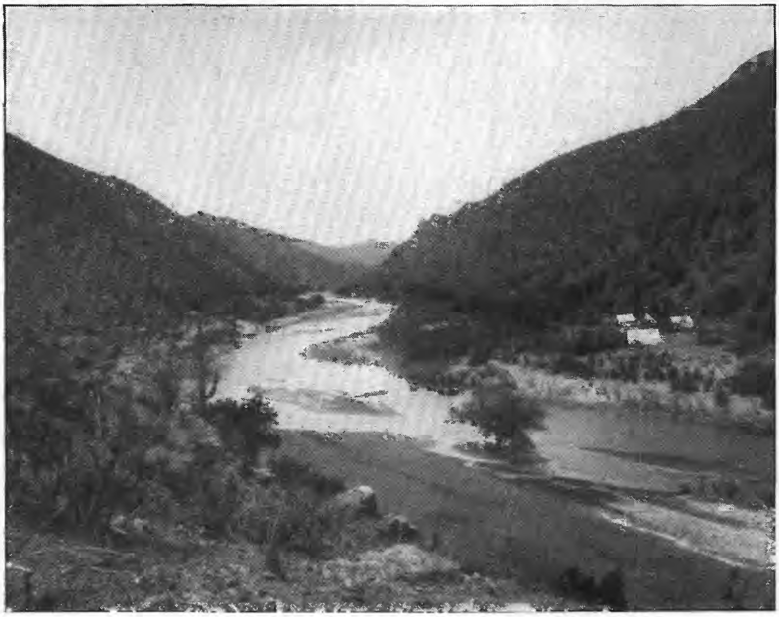
Four miles above the Buttes dam site, on the Gila River, a dike of volcanic rock, apparently of more recent geological origin than the remainder of the country, crosses the stream. After the depth to bed rock at the Buttes was determined to be disappointingly great, it was thought possible that the depths might be less at the Dikes. A test was therefore made to determine this. Pipe was driven to a depth of 96 feet and 3 inches in the center of the canyon without reaching bed rock. As the width of the canyon at this point is 459 feet between the rock croppings at the two sides of the canyon, and as the better portion of the Buttes reservoir site in the way of capacity lies between the Buttes and the Dikes, this depth to bed rock is considered as having condemned that location for the construction of a dam.

RIVERSIDE RESERVOIR.

The Riverside reservoir site is located on the Gila River, in Pinal County, Arizona, between the mouth of the San Pedro and a point one-half mile below the mouth of Mineral Creek and 12 miles above the Buttes (Pl. XVIII.) The dam site is in a canyon one-half mile below the mouth of Mineral Creek. A view of this canyon, looking downstream, is shown on Pl. XVII, *A*.

The water supply at this point will be practically the same as that at the Buttes. There are no streams or drainage lines of consequence entering the river between the Buttes dam site and the dam site of the Riverside reservoir. The discussion of the water supply in the previous pages of this report will apply equally to the Riverside reservoir site and the Buttes.

The bed of the canyon between the projecting ledges at the two abutments is 350 feet in width. A bench mark is located on the right bank, 20 feet above the bed of the stream. It is a bronze tablet, set in the rock, such as is used to designate elevations by the Geological Survey. It is considered 100 feet above the datum plane of the dam and reservoir surveys.



A. RIVERSIDE DAM SITE, LOOKING DOWNSTREAM.

B. RIVERSIDE RESERVOIR SITE.

This elevation of 100 feet is equivalent to 1,763.30 feet above sea level. The rock at this location is a granite, well suited for building purposes. The topographic survey of the dam site was made by Gerard H. Matthes, assistant hydrographer, United States Geological Survey, in 1899, on a scale of 100 feet to the inch, and with a contour interval of 10 feet. A dam has been projected upon this map as a basis for an estimate for this report at the point where bed rock was determined by the diamond core drill. The height of the dam above the bed of the stream as estimated is 133 feet; the maximum depth to bed rock is 78 feet, or a total height of structure of 211 feet. Large ledges of rocks are available for construction purposes at an elevation above the dam on either side of the canyon.

The accompanying map (Pl. XVI) shows by means of contours the walls of the canyon and also the location of the dam described above. This has been prepared from the detailed map made by Mr. Matthes, the 20-foot contour lines only being given. The dotted lines in the center of the map indicate the depth to bed rock as shown by the drill holes. The point marked "B. M. 100" on the map is at an altitude of 1,763.3 feet above sea level. The surface elevation of the bed of the stream immediately above the proposed dam is 76.8 feet, and immediately below, 76.1 feet. Five borings to bed rock were made along the upper face of the dam and six along the lower side, the position of these being shown on Pl. XIV, *C*.

PROPOSED DAM AT RIVERSIDE.

The dam at this point should be an overflow weir, as the topography is not suited to the artificial construction of spillways on either side. The bed rock developed by the borings is a heavy granite, suited to withstand any pressure that may be put upon it by a dam. The quality of the building material, the topography, compelling an overflow weir, and the substantial character of the bed rock, determine a masonry structure as the best suited for this site. The section of dam proposed for San Carlos (Pl. XXII), described in detail under the discussion of that reservoir site, is the one selected as the basis of the estimate for the Riverside reservoir.

Eleven holes were put down with the diamond drills, their position being shown on Pl. XIV, *C*, at the point selected for the dam, and cores of bed rock were obtained. These borings are distributed across the canyon on two lines 150 feet apart, the holes in each row being between 50 and 60 feet distant from one another. The specific gravity of the rock is 2.51 and its weight per cubic foot is 157 pounds. Its strength to resist pressure was beyond the limit of the testing machine used, 2,565 pounds, which is equivalent to 184 tons per cubic foot. This guarantees it to be strong enough for the purpose required. The following table gives the log of the holes at this dam site. Two additional holes were put down 380 feet above the accepted dam site, in order to determine whether bed rock was nearer the surface at this point. One hole went down to an elevation of 6 feet above the datum plane, or 76 feet in depth, and the other to an elevation of 11 feet, or a depth of 68 feet. Bed rock was not encountered at either one of these points, and as the canyon is wider here than below, it is evidently inferior to the site where the principal borings were made. Hence no alternative selection was attempted.

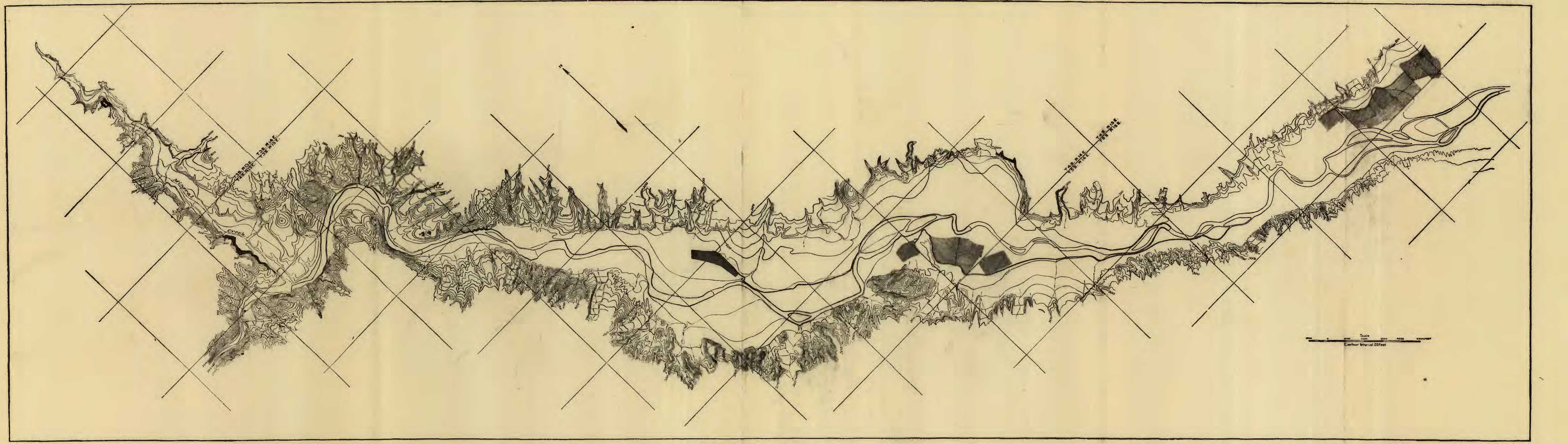
Log of holes at Riverside dam site.

Line.	Hole No.	Depth to bed rock.	Depth drilled in bed rock.	Elevation of bed rock.	Quality of rock.
		Feet.	*Feet.*	*Feet.*	
A	1	74.0	1.33	1,667.3	Hard driving.
A	2	75.5	5.00	1,664.7	Hard driving at 50 feet; bowlders.
A	3	27.00	4.00	1,713.1	
A	4	32.75	4.25	1,713.3	
A	5	16.00	.66	1,734.1	
B	1	48.00+	2.00		Bed rock doubtful.
B	2	44.33+			No bed rock; bowlders
B	3	31.00+			Very hard driving; no bed rock.
B	4	73.50+			Do.
C	1	24.00	2.00	1,716.9	Gravel and sand.
C	2	49.00	3.00	1,690.4	Bowlder.
C	3	69.00	3.25	1,670.7	Bowlders.
C	4	64.33	5.16	1,673.7	Do.
C	5	65.00+			Bed rock doubtful; possible edge of cliff.
C	6	27.00	2.25	1,729.0	
C	7	63.00	10.75	1,682.9	

NOTE.—Add 1,663.3 to elevation on contour maps for sea datum.

METHOD OF CONSTRUCTION.

As the quarries from which the material for the dam may be obtained can be properly located approximately on the axis of the structure, cableways could probably be best used for putting the rock in place. The method of excavating to bed rock at this point might be that recommended at the Buttes, although it is possible that further investigation may determine that simpler methods of excavation will be sufficient. Sand suitable for concrete work may be found in large beds throughout the canyon. Along the wagon road from the Riverside stage station to Globe large ledges of quartzite occur. Masses of this material have rolled down the drainage line practically to Gila River and at distances not exceeding 4 miles from the dam site. This quartzite when ground is suited for mixing with finely ground Portland cement for making silica cement. This would cheapen the cost of cement for the construction of a dam. The railroad station to which material for the dam will be shipped is Casa Grande. The freight on cement from Los Angeles to Casa Grande is $12.20 per ton, or $2.32 per barrel. There would then be a wagon haul of 50 miles over fairly good roads from Casa Grande to the dam site. This haul would cost approximately $1.35 per barrel. With cement at $2.85 per barrel at Los Angeles, the cost delivered at the dam would be $6.52. A dam 133 feet in height across the bed of the stream, as described above, would require 186,147 cubic yards of masonry.



CONTOUR MAP OF RIVERSIDE RESERVOIR SITE.

CAPACITY AND COST OF RIVERSIDE RESERVOIR.

The Riverside reservoir site was surveyed by Gerard H. Matthes, assistant hydrographer, U. S. Geological Survey, and mapped on a scale of 1,000 feet to 1 inch, with contour intervals of 10 and 20 feet, reaching an elevation of 214 feet above the bed of the stream at the dam site, which is the 290-foot contour of the reservoir survey. With a height of dam of 133 feet, or to the 210-foot contour, the length of the reservoir would be approximately 14 miles, and to the 230-foot contour, or a height of dam of 153 feet, approximately 15½ miles. The width varies at different points from a half mile to a mile. The principal breadth is from 3 to 6 miles above the Riverside stage station. A dam 130 feet in height to the spillway at the Buttes would store 206,000 acre-feet. A dam 133 feet in height at Riverside will impound 221,134 acre-feet, which is almost double the capacity of the Buttes reservoir site. A dam 130 feet high to the spillway at San Carlos will impound 241,396 acre-feet, which is the best of the three for this size of dam. With a dam 150 feet high to the spillway at the Buttes, which is the height upon which the estimate is based, 174,040 acre-feet would be impounded. A dam at Riverside of a height of 153 feet would impound 344,398 acre-feet, which is double the capacity of the Buttes, and a similar dam of 150 feet at San Carlos would impound 377,176 acre-feet.

The Riverside reservoir site is situated in a mineral district. Copper is found in large quantities in this neighborhood, and in August, 1899, there were 29 copper claims that would be wholly or in part flooded in case a dam 150 feet in height should be built. These claims are not being worked commercially, but are at present "prospects." With a railroad built to this mineral field, it is quite likely that a number of these claims could be worked at a profit. The Ray mine, which is being actively worked, is a short distance above the reservoir site on Mineral Creek. The owners are making an effort for the construction of a railroad to the mines. It would be undesirable to interfere with mining operations, which might develop valuable properties if interference could be avoided. The condemnation of right of way would be one of the greatest expenses in connection with the utilization of this reservoir site for storage purposes. It is probable that it would cost $200,000 without court expenses, which would easily amount to $50,000 more. There are under cultivation at present in the reservoir site 332 acres of land. These fields are irrigated by a small ditch. There is held in private ownership in the reservoir site 1,800 acres. This land would probably cost $20 an acre to condemn, or a total of $36,000.

Capacity of proposed Riverside reservoir.

Contour flow line.	Height of dam above bed of stream.	Area.	Capacity of section.	Total capacity.
	Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
80	3			
90	13	28	196	196
110	33	197	2,252	2,447
130	53	600	7,972	10,419
150	73	1,311	18,005	28,424
170	93	2,316	36,270	64,694
190	113	3,967	62,832	127,526
210	133	5,395	93,607	221,134
230	153	6,924	123,174	344,308
			344,308	

NOTE.—Elevations based on datum of dam survey; 100 feet = 1,763.30 sea datum.

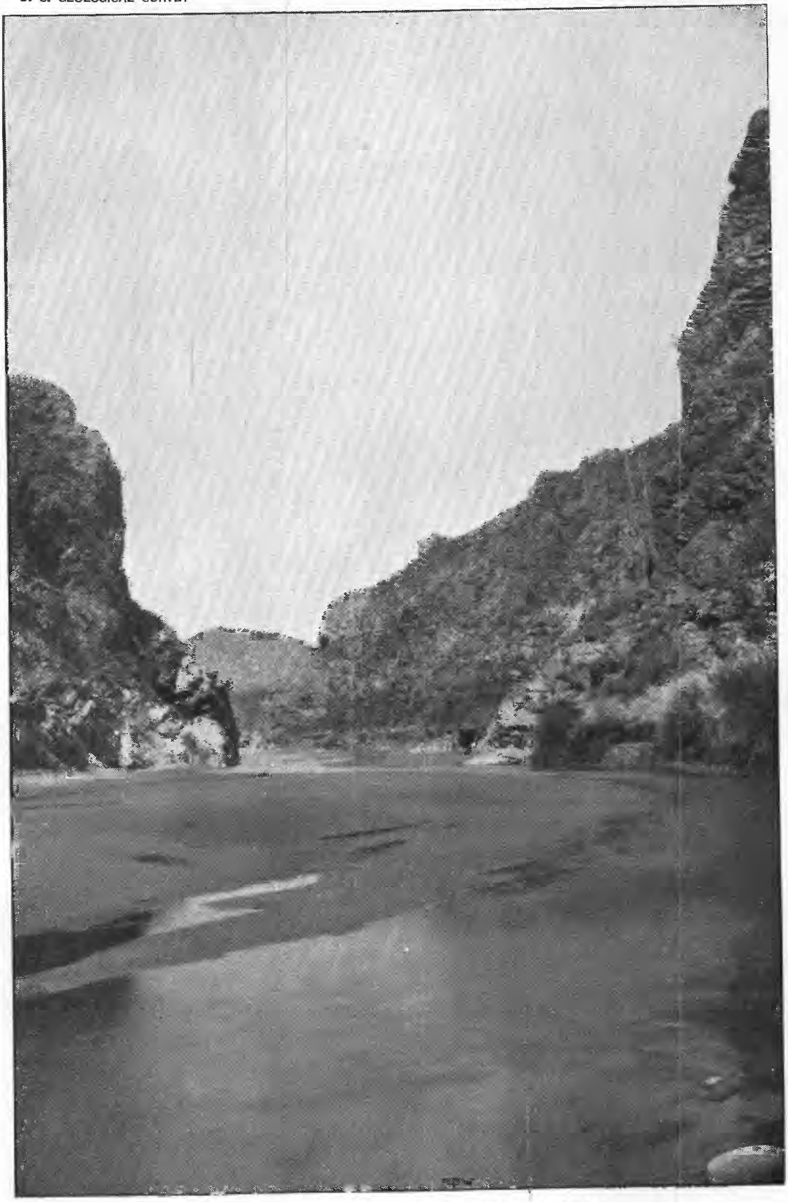
Estimate of cost of Riverside dam.

Masonry (half large rock and half concrete), 186,147 cubic yards, at $4.10 per barrel for sand cement, or $3.74 per cubic yard for cement (see Duryee's report), at $5.50 per cubic yard		$1,023,809
Excavating for foundations, 90,740 cubic yards		450,000
Towers and houses		12,000
Valves		3,500
Footbridges		6,000
Wooden crib diversion dam at head of irrigation canal		20,000
Total		1,515,309
Contingencies, 10 per cent	$151,531	
Engineering, 5 per cent	75,765	
		227,296
Total construction cost		1,742,605
Damage and condemnation proceedings		250,000
		1,992,605

Total number of acre-feet stored is 221,134, at a rate per acre, stored, of $9.01.

SAN CARLOS RESERVOIR.

San Carlos reservoir site is located on Gila River, on the White Mountain Indian Reservation, at the San Carlos Agency, in Gila County, Arizona, at a point where San Carlos River joins the Gila. The Gila Valley, Globe and Northern Railway, which leaves the main line of the Southern Pacific at Bowie Station and runs to the town of Globe, passes across this reservoir site. The Gila River at this point traverses some spurs of the Pinal range of mountains, and for a distance of 31.5 miles below the dam site the river flows in a narrow box canyon. This canyon extends to Dudleyville, which point is the upper end of the Riverside reservoir site. The river then passes through the Riverside reservoir site for a distance of 15.5 miles, after which it again enters a canyon, which is the upper end of the Buttes reservoir site. This latter canyon extends to the Dikes, which is 4 miles above the Buttes dam site. The total length of river from San Carlos dam site to the Buttes dam site is approximately 60 miles; about 40 miles of this distance being box canyon, and the remaining portion being valley land, of from 1 to 3 miles in width.



SAN CARLOS DAM SITE, LOOKING UPSTREAM.

Six miles below the San Carlos Agency, where the river enters the box canyon and approximately a half mile below the beginning of the box, is a point where the canyon is about 90 feet wide at the water line and where its walls rise very abruptly directly from the river. Pl. XIX shows a view of the dam site looking upstream. The dam will be located at the point where the wall of the canyon is shown to be most abrupt. Pl. XX shows the dam site as surveyed, with a contour interval of 10 feet. The dotted contours show bed rock as indicated by the borings. At a point approximately 100 feet above the upper face of the location selected for the dam there has apparently been a fault in the rock of the canyon. If the dam were located above this fault, there would be the possibility of a leak occurring between the strata and of water passing through the fault to the channel of the river below the dam. If the dam is built where located, this will be obviated.

The narrowest portion of the canyon is approximately 400 feet in length, and immediately below this narrow point it widens out to 300 feet at the low-water line. This admits of a spillway provision as shown in the plan of the dam (Pl. XX) and described in the account of the dam proper. The dam is located at the point shown in the plan, therefore, in order to obtain better spillway advantage, to secure better foundations and abutments, and to avoid the leakage through the strata above the line of fault.

The question of water supply available at San Carlos has been fully treated in preceding pages of this report in the discussion of supply available at the Buttes and at San Carlos, to which reference is made. The supply is ample to fill the reservoir with a dam 130 feet in height to the spillway, as planned. The table on the following page shows the amounts probably available at the San Carlos reservoir for each month. In this table the inflow, consumption, and evaporation are treated in the same manner as in the table on page 33, under the discussion of water supply for the Buttes reservoir site. It has been determined that the difference between the amount of water available for storage at San Carlos and the Buttes was 10 per cent, and this deduction of 10 per cent has been made in all estimates for the supply at San Carlos as measured at the Buttes.

The water which is released from the San Carlos reservoir site will pass through approximately 40 miles of box canyon on its way to the irrigable lands where it is to be used. Comparative measurements made at the Buttes and San Carlos during the dry season of the year, when less than 10 second-feet of water was flowing in the river at San Carlos, indicate practically an equal amount of water at San Carlos and the Buttes. There undoubtedly is a substantial loss from evaporation between these points, but this loss is compensated for by the seepage water which returns from the Riverside Valley and from the valley above the Buttes dam site. In the case of the Riverside Valley a few second-feet of water is used for irrigation, and the return from this irrigation augments the stream. In both valleys, however, the high stages of the river undoubtedly charge the sand bars and gravel beds with water, and these are gradually drained off during the lower stages of the stream and, as has been stated, give practically an equal amount of water at San Carlos and the Buttes.

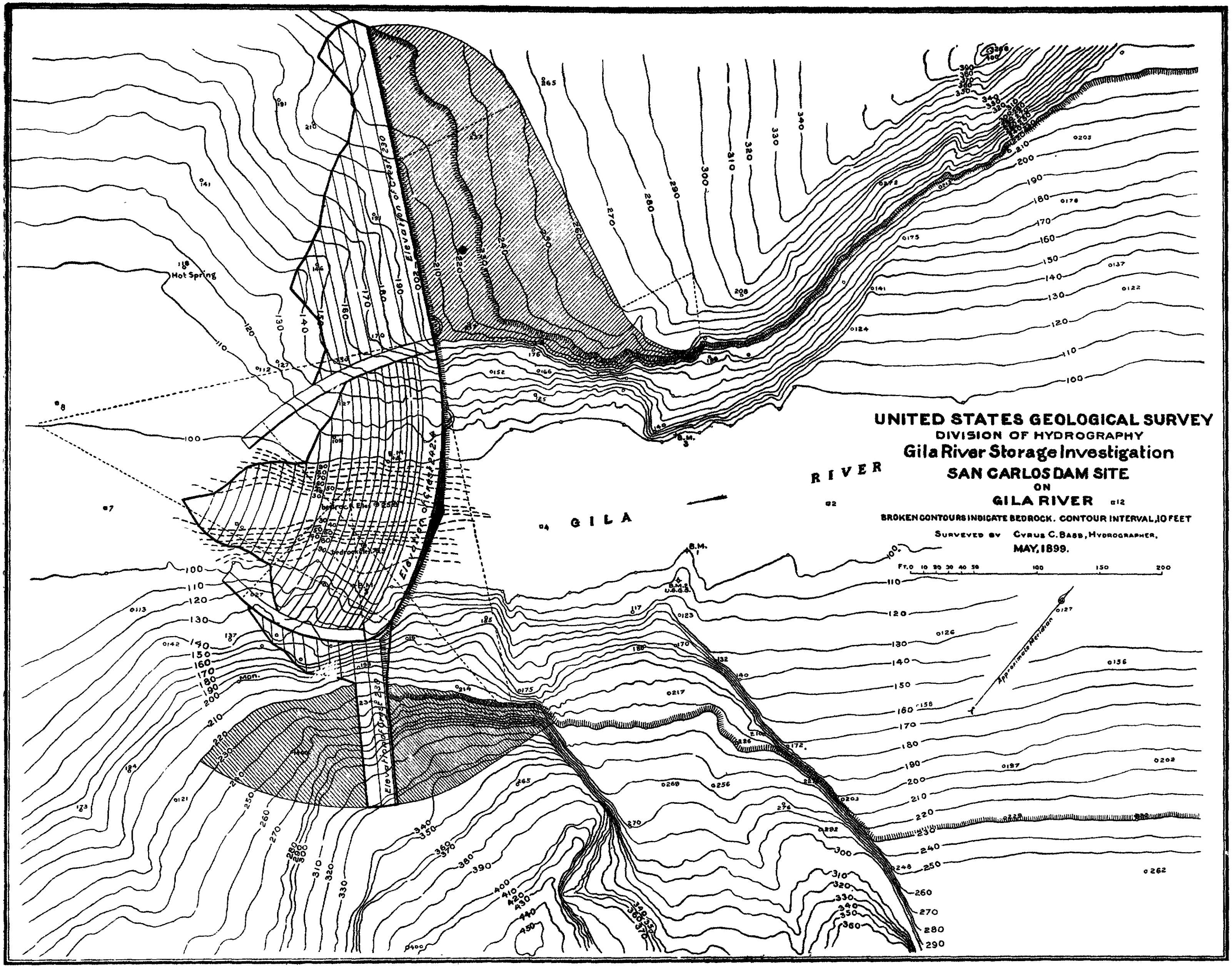
The San Pedro and the other drainage lines entering the Gila above the Buttes and below San Carlos will contribute their portion to this stream, unregulated by a reservoir built at San Carlos. This water can be used for irrigation around Florence if diverted below. If this volume of water and the return water from seepage is added to the water which is discharged for irrigation from the San Carlos reservoir site, it is probable that there will be available for irrigation at the point of diversion as much water as would be discharged from the San Carlos reservoir site.

If the Gila River from the San Carlos dam site to the Buttes dam site is 60 miles in length and 200 feet in width, it will expose to evaporation a water area of 1,454 acres. The depth of evaporation per annum has been previously determined as 91 inches, or 7.58 feet. With an area of 1,454 acres and a depth of evaporation of 7.58 feet there will be lost from this body of water 11,021 acre-feet. This would be 4.6 per cent of the total capacity of the San Carlos reservoir site, and, in order to make an allowance for all possible loss, 5 per cent of the water discharged from San Carlos is assumed as being lost for irrigation below the Buttes. The Riverside Valley and the valley above the Buttes are both largely public domain, and there is no reason why the water from the San Carlos reservoir should not be used for irrigation purposes at these points, as well as below Florence. This being the case, there will be but a slight disadvantage in storing water at San Carlos. A loss of 5 per cent in transmission is accepted in the following table and added to the amount to be liberated from the reservoir:

Estimated amount of water available from San Carlos reservoir.

[Capacity of reservoir is 241,396 acre-feet; 100,000 feet assumed to be in reservoir November 1.]

Month.	Inflow.	Per cent of capacity of reservoir used in irrigation.	Outflow for irrigation.	Loss of 5 per cent in transmission to point of irrigation.	Total amount turned out of reservoir for irrigation.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation from reservoir.	Total loss from irrigation and evaporation.	Balance in reservoir at end of month.
	Acre-ft.	*Per ct.*	*Acre-ft*	*Acre-ft*	*Acre-ft*	*Feet.*	*Acres.*	*Acre-ft*	*Acre-ft*	*Acre-ft.*
November	32,842	2	4,828	241	5,069	0.42	3,650	1,533	6,602	126,240
December	27,117	2	4,828	241	5,069	.333	4,100	1,553	6,422	146,935
January	36,745	2	4,828	241	5,069	.25	4,690	1,173	6,242	177,438
February	24,008	5	12,071	604	12,675	.333	5,130	1,710	14,385	187,061
March	21,405	7	16,898	845	17,743	.50	5,225	2,612	20,355	188,109
April	18,433	9	21,725	1,086	22,811	.58	5,760	3,341	26,152	180,390
May	7,227	14	33,795	1,690	35,485	.83	4,680	3,884	39,369	148,248
June	3,665	14	33,795	1,690	35,485	.92	3,110	2,861	38,346	113,567
July	59,170	13	31,381	1,569	32,950	1.00	4,060	4,060	37,010	135,727
August	69,522	13	31,381	1,569	32,950	1.08	4,370	4,720	37,670	167,579
September	47,256	11	26,554	1,328	27,882	.83	4,950	4,109	31,991	182,838
October	74,800	8	19,312	966	20,278	.50	5,714	2,857	23,135	234,501
Total	422,184	100	241,396	12,070	253,466	7.58	......	34,211	287,477	....



CONTOUR MAP OF SAN CARLOS DAM SITE.

There is still an amount available for irrigation below the Buttes, on the basis of the above table, for a mean year, equal each year to the full capacity of the San Carlos reservoir, of 241,396 acre-feet, with a minimum reserve in reservoir of 113,567 acre-feet, and 234,507 acre-feet on November 1, for use during the following season. The discharge of the Gila River during 1899 was less than during any other year of which we have record. The following table demonstrates that 241,396 acre-feet of water could have been delivered below the Buttes from San Carlos from November 1, 1898, to October 31, 1899, with a minimum reserve in the reservoir during that period of 12,269 acre-feet and 96,088 acre-feet in reservoir with which to begin the season of 1899–1900:

Estimated amount of water available from San Carlos reservoir during 1898–99.

[Capacity of reservoir, 241,396 acre-feet; 100,000 acre-feet assumed to be in reservoir November 1, 1898.]

Month.	Inflow.	Per cent of capacity of reservoir used in irrigation.	Outflow for irrigation.	Loss of 5 per cent in transmission to point of irrigation.	Total amount turned out of reservoir for irrigation.	Depth of evaporation.	Average area exposed to evaporation.	Loss by evaporation from reservoir.	Total loss from irrigation and evaporation.	Balance in reservoir at end of month.
	Acre-feet.	*Per cent.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*	*Acres.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1898.										
November	5,409	2	4,828	241	5,069	0.42	3,460	1,453	6,522	98,887
December	16,878	2	4,828	241	5,069	.333	3,560	1,185	6,254	109,511
1899.										
January	17,555	2	4,828	241	5,069	.25	3,710	928	5,997	121,069
February	11,946	5	12,071	604	12,675	.333	3,700	1,232	13,907	119,108
March	7,194	7	16,898	845	17,743	.50	3,600	1,800	19,543	106,759
April	3,320	9	21,725	1,086	22,811	.58	3,310	1,920	24,731	85,348
May	996	14	33,795	1,690	35,485	.83	2,650	2,200	37,685	48,659
June	276	14	33,795	1,690	35,485	.92	1,610	1,181	36,666	12,269
July	65,754	13	31,381	1,569	32,950	1.00	1,570	1,570	34,520	43,503
August	*a*24,884	13	31,381	1,569	32,950	1.08	2,050	2,214	35,164	33,223
September	39,260	11	26,554	1,328	27,882	.83	2,000	1,660	29,542	42,941
October	*b*74,800	8	19,312	966	20,278	.50	2,750	1,373	21,653	96,088
Totals	268,272	100	241,396	12,070	253,466	7.58	....	18,718	272,184	....

a Measured discharge of Gila Basin at San Carlos.
b Estimated mean discharge, in acre-feet, of Gila Basin above San Carlos for month of October, 1899.

PROPOSED DAM AT SAN CARLOS.

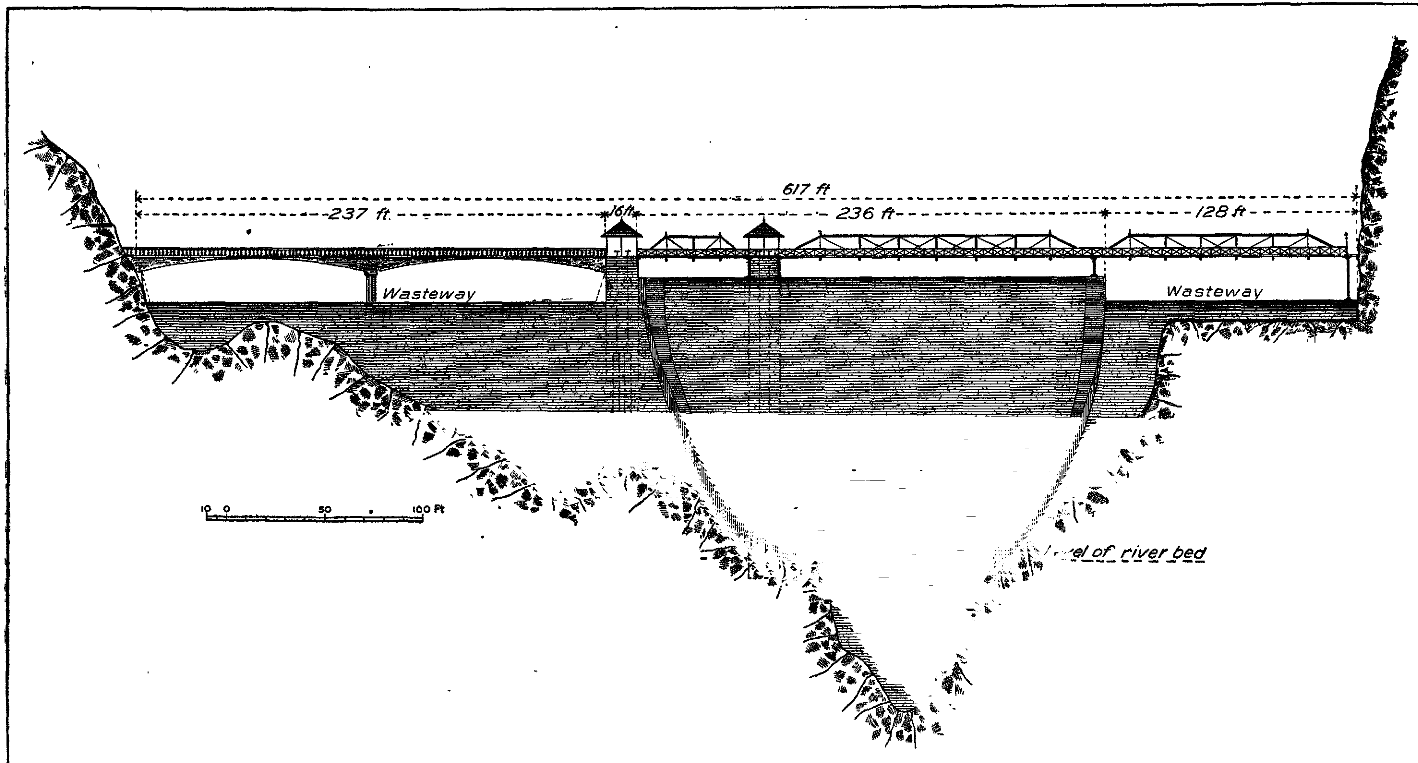
In determining the height of dam to be constructed at the San Carlos dam site two elements are to be considered. First, the amount of water available; second, the amount of expenditure which can be economically made. From a study of the water supply, shown on page 29, a dam 130 feet in height, storing 241,396 acre-feet, is justified. The year of lowest run-off of which we have a record is 1899. The discharge of the river for this year at San Carlos was measured until the 1st of October, and a monthly discharge for October, November, and December, as determined, has been added to complete the year.

This shows a surplus for the year 1899 above the capacity of the reservoir of 76,879 acre-feet. The mean surplus above the capacity of the reservoir at San Carlos is estimated at 180,788 acre-feet. The maximum height of the central portion of the dam above the bed of the stream is taken at 142 feet, and the maximum depth to bed rock below the surface of the stream at 74 feet. This would give a total maximum height of the central portion of the dam from bed rock at 216 feet. An increase of this height is considered unnecessary and as adding too much to the expense of the structure. The table on page 69 is believed to justify a dam of this size.

The San Carlos reservoir site was the last that was discovered upon the Gila River, and consequently the last point at which investigation for bed rock was made. After the completion of the borings at Queen Creek, the Buttes, and Riverside, the drilling outfit, in charge of Mr. Patrick Tierney, was sent by wagon from Riverside to San Carlos. This arrived at San Carlos in the latter part of June, 1899, and work was immediately begun at the dam site. The first flood on the Gila River in the summer of 1899 occurred on July 16 and was about 10,000 cubic feet per second in volume. This knocked over the drilling apparatus. It was restored to position, and frequent other interrupting floods occurred at intervals of two or three days during the remaining portion of July. The funds available for carrying on the work having become nearly exhausted, and the river continuing its flood discharges, it was not considered practicable to continue the investigation for bed rock during the present season.

Two holes were put down approximately on the lower toe of the dam. No. 1 was 33 feet to the right of bench mark No. 4, which is located on the left abutment, and No. 2 was 66 feet from the left abutment and approximately 30 feet from the right abutment. The depth to bed rock at hole No. 1 was 23 feet. The bed rock encountered is a very fine-grained and flinty limestone. It was so hard that only 2 feet 9 inches a day could be drilled into it with the diamond drills, which is about one-fourth the rate of progress in ordinary granite. The depth drilled into bed rock at this point was 12.5 feet.

Hole No. 2 determined the depth to bed rock to be 74 feet. Gravel was encountered at 72 feet. The rock at this hole is a blue limestone and is more easily drilled than the rock in hole No. 1. The total depth to the bottom of this hole was 81.82 feet, the depth drilled into bed rock being 7.82 feet. A third hole was put down in the center of the bed of the canyon 60 feet from the left abutment and 100 feet above line No. 1. A 2-inch pipe was driven to a depth of 56 feet and 2 inches, when it was found to be bent 2 feet from the bottom. The pipe was then pulled up and 2½-inch pipe driven to a depth of 51 feet in the same hole. No further progress could be made on account of the high water, and this hole was abandoned and all work stopped on July 31, 1899.



ELEVATION OF SAN CARLOS DAM AND WASTEWAYS.

The information concerning bed rock is meager, but it is considered fair to estimate the maximum depth of bed rock at 74 feet. The bedrock itself is a very close-grained hard limestone and all that could be desired for foundation purposes. The location of the borings at San Carlos dam site is shown on Pl. XX.

MATERIAL FOR DAM.

Pl. XXV, *B*, shows a view of the left abutment of the dam. The strata dip downstream. It would be better if the dip were upstream, as there would be less danger of leakage beneath the foundation of the dam. The limestone, however, is exceedingly dense, not easily eroded, and, as will be seen on the right-hand side of the illustration, where a slide has occurred, the rock a few feet beneath the surface is relatively free from seams. The abutment on the right is of much the same nature as the abutment on the left.

The rock for the construction of the dam will be obtained near the top of the two abutments. It will be excavated in such manner as to form a channel for the flood waters to discharge over the two weirs, which are located at the two ends of the dam. Sufficient rock will be taken from these two channels, as shown by the plan, Pl. XX, to build the entire structure, and this will be enough to furnish flood channels for the maximum flood at this point, which is estimated to be within 10 per cent of the maximum flood at the Buttes. These quarries will be located at the end of the dam and practically on its axis, and in such position that material can readily be handled by means of cable for construction purposes. The haul of the material will be on a down grade, and the average distance will not exceed 200 feet. This is considered an ideal location for the economic use of cables. The quarry rock has a specific gravity of 2.7, or a weight of 168 pounds per cubic foot.

On the left abutment it is an exceedingly fine-grained pink limestone, much resembling flint, but showing, by analysis, percentages as follows: 55.92 carbonate of lime, 31 carbonate of magnesia, 3.70 silica, 6 alumina and ferric oxide, and 1 moisture. The gray limestone from the right abutment contains 96.65 carbonate of lime, 1.40 silica, 1.30 alumina and ferric oxide, 0.65 moisture. From an engineering standpoint it has the appearance of being a first-class building rock.

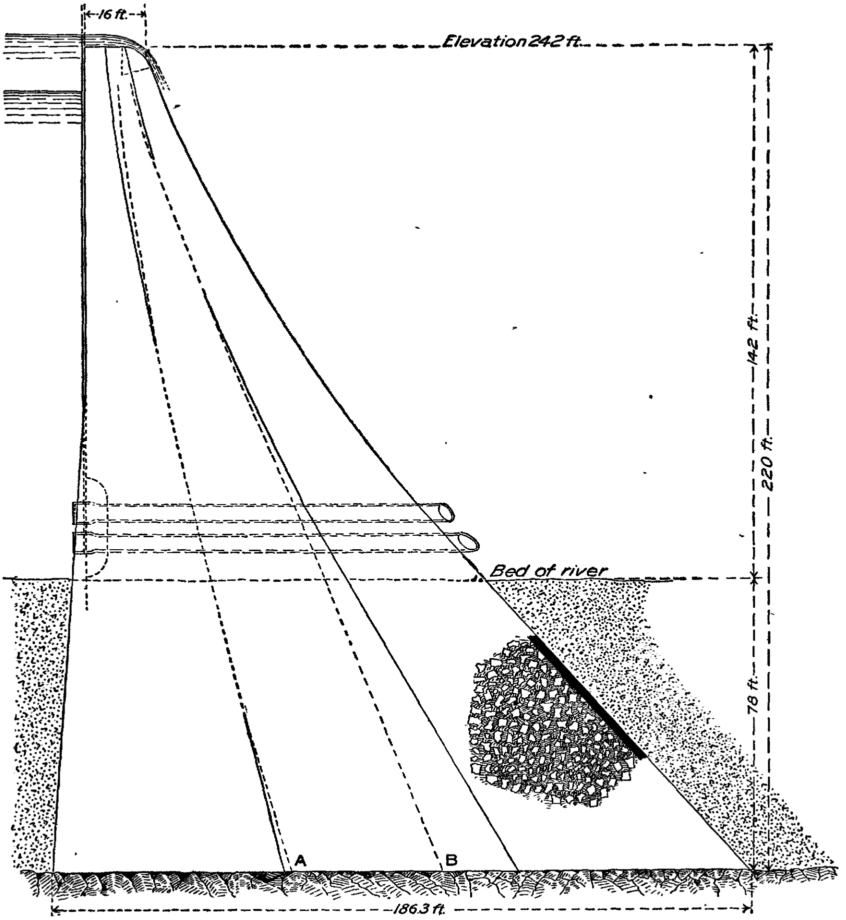
The sand required for the construction of the dam could be obtained in the canyon within a few hundred feet of the dam site. It is a good building sand, but would have to be washed before its use with cement. Gravel in varying sizes is found in connection with the sand and could be separated from it by screening. The quartzite that would be used at San Carlos is found in large ledges within 1,000 feet of the dam site. Mr. Duryee's report on cement is given on page 82.

DETAILS OF DAM.

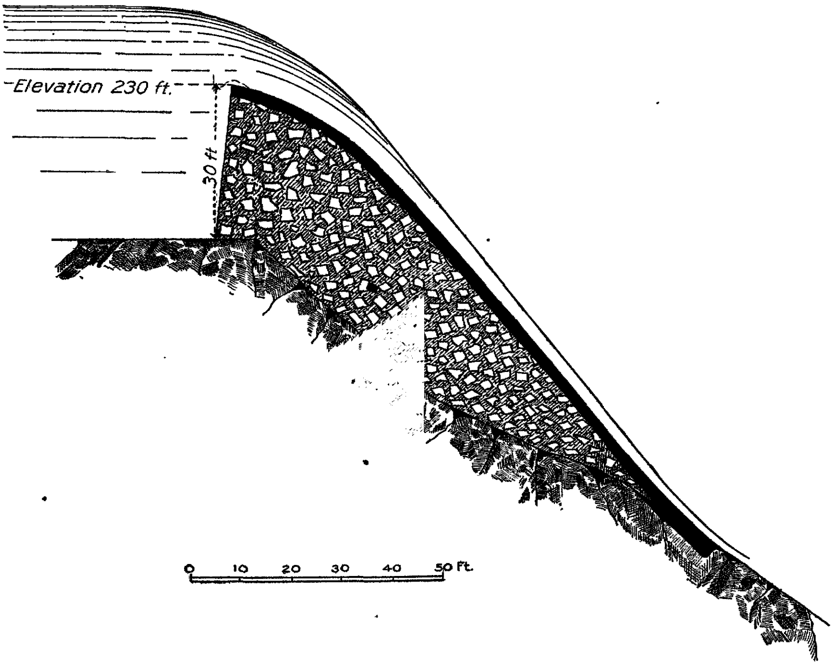
The dam selected for this site is shown in plan on Pl. XX, in section on Pl. XXII. The details are shown on Pls. XXI–XXVI. It is proposed to construct it of large irregular blocks of stone, bedded in concrete. The maximum height of this structure from deepest bed rock to the top of the central portion of the dam is 216 feet, and the maximum length is 617 feet. The total number of cubic yards contained in the dam, weir, and towers is 94,730. In order to avoid the erosion and shock which would result from a large flood passing over the central portion of the dam and falling 142 feet on its base, the middle part of the dam, for a length of 236 feet, has been planned to an elevation of 12.5 feet above the elevation of the wasteways on the sides. The section of the central portion of the dam (Pl. XXII) shows the line of pressure at B with 10 feet of water in depth passing over the crest, and also at A the line of pressure with an empty reservoir. Both these lines, for every portion of the dam, lie within the middle third, resulting in a safe gravity structure. The maximum pressure on the upper toe is 12 tons per square foot and on the lower toe 12½ tons per square foot. The weight of the masonry is assumed to be 150 pounds per cubic foot.

In addition to its strength as a gravity dam it is given an arched form. Expansion and contraction in a curved dam are more easily adjusted than in a straight dam. The spillway on the right bank (Pl. XXIII, *A*) would be 237 feet in length, and on the left abutment 128 feet in length. With 3 feet of water passing over the central portion of the dam and a corresponding depth of 15.5 feet discharged through the spillways over the two end weirs, the total discharge past the structure, exclusive of discharge through outlets, as estimated by T. C. Clarke's formula, is 83,620 cubic feet per second. This is considered as the maximum flood discharge of the Gila River at this point. It is fair to assume that the reservoir will not be wholly full at the time such a maximum flood would occur, and that the capacity of the reservoir will tend to relieve this flood discharge.

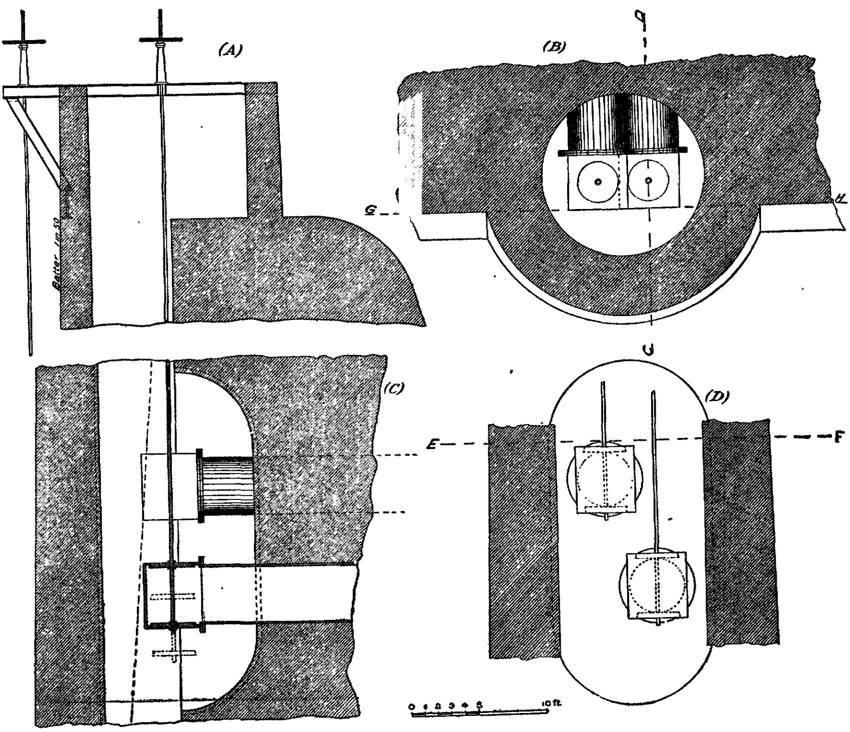
Two training walls have been planned from the ends of the central portion of the dam to protect its toe from the erosion of water passing over the spillways. This water will be discharged into the canyon below the lower toe of the dam in such manner as to project the overflow down the canyon away from the dam. The section of the wasteway weirs proposed for the two spillways is shown in Pl. XXIII, *A*. These weirs are to be built upon the sloping ledge rocks, and will have a slope on their lower face of 3 feet horizontally and 2 feet vertically. They will be of an exceedingly substantial nature, the surface being protected by from 2 to 3 feet of extra strong concrete. The water in passing over them will never leave the face, and consequently there will be no pounding action.



MAXIMUM CROSS SECTION OF THE SAN CARLOS DAM, WITH TOWERS REMOVED.

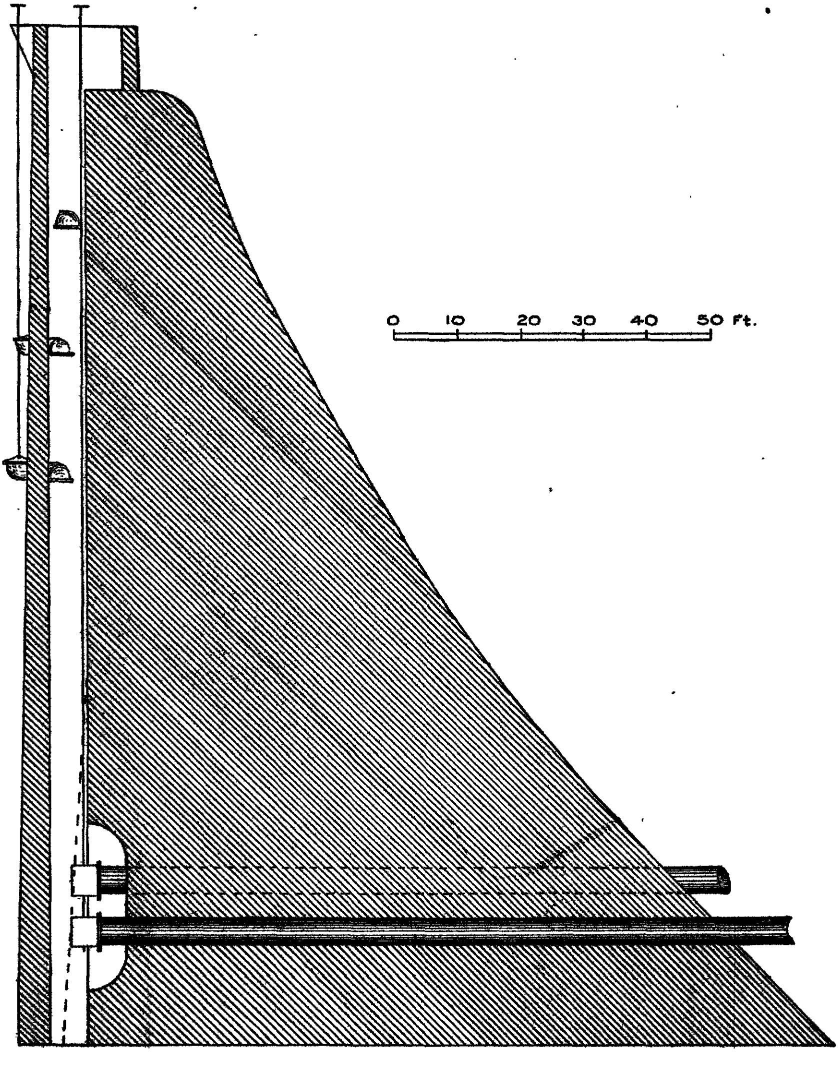


A. CROSS SECTION OF WASTEWAY OF SAN CARLOS DAM.



B. DETAILS OF TOWERS FOR SAN CARLOS DAM.

In the above figure sections are given of the outlet tower. At *B* is a horizontal section on the line *E F* of *D*; at *C* is the vertical section on the line *C D* of *B*, and at *D* is a vertical section on the line *G H* of *B*.



CROSS SECTION OF SAN CARLOS DAM THROUGH TOWER.

The outlet from the dam will be through two towers located near the right abutment. These towers will be semicircular, a portion of the opening being recessed into the dam, as shown by the details (Pl. XXIII, *B*). A series of intakes will be placed in this tower at varying elevations, the valve (Pl. XXVI, *A*) consisting of a plain cap or cover, as shown in the detail, which will be lifted by an ordinary wheel and screw. The intakes will be pipes 3 feet in diameter, and there will be six in each tower (Pl. XXVI, *B*). As the water should be drawn from near the surface of the reservoir at all times there will be very slight pressure to be overcome in lifting these valves, and this may be overcome by closing the balanced valves inside the tower, allowing the latter to fill with water through small by-pass valves, after which the pressure on the outer intake valves will be relieved. In case any one of the valves should become stuck, the water could be drawn into the tower from other valves, and when the general water plane fell below the elevation of the injured valve it could then be repaired. A second set of valves is to be located near the base of the tower. These valves will permit the water to discharge through two cast-iron pipes which will pass through the dam and which are to be 4 feet each in diameter. It will be possible to discharge water through four of these pipes, two being located in each tower, as shown in the elevation of the dam. The discharge through these pipes will vary with the depth of water in the tower.

As the valves for the discharge pipes may have to be operated under a considerable head of pressure, a balance valve has been decided upon as preferable. This valve is shown on Pl. XXIII, *B*. The action of this balance valve is in the nature of a double piston head, which is driven by a screw gear from above. One of these valves, or piston heads, is seated on each side of the valve box. They are equal in area, consequently the downward pressure on the upper valve is balanced by the upward pressure on the lower valve. When the valve is wide open one of these piston heads will be 2¼ feet below its seat, and the upper piston head will be in the center of the boxing. The water will therefore enter through both openings and discharge through the main pipe.

The towers were considered necessary in order to prevent the deposit of silt around the valves, or their clogging with drift. In case the inner valves become out of order the outer valves can be closed and the inner valves then repaired. Two towers have been designed, so that one complete set of valves can get out of order and the second set be used during the repair of the first. A bridge from each abutment to the towers has been planned, so that the dam may be crossed and all points on the top of the dam visited, even during maximum floods. Alternate designs for this crossing are shown on the elevation of dam and wasteways, one for an iron bridge and the other for a combination iron and concrete span.

The safety of this structure, considering the remarkably hard bed rock on which it is to rest, the fine character of the building stone that may be used, the heavy gravity section of the dam and the weirs that have been planned, the solidity of the abutments and the narrowness of the canyon, would be beyond question.

At a point 180 feet above the upper face of the dam, marked "B. M. No. 1" on the plan (Pl. XX), the canyon is but 88 feet in width between the abutment walls. This is apparently an ideal place to put down sheet piling to bed rock to intercept the underflow. The surface flow of the stream would then be diverted in a flume to a point below the dam. It is believed that the sand and gravel of the river bed could be solidified by injecting cement grouting through pipes into the voids of the sand between the sheet piling and the foundation excavation. This could be injected at various points and elevations and the mass sufficiently solidified to admit of the excavation to bed rock at the site of the dam.

CAPACITY AND COST.

The capacity of the San Carlos reservoir with the height of dam proposed is the greatest of any of the reservoir sites that were found on the Gila River by this survey. The elevation of the bed of the canyon at the dam site is assumed by the surveys as 100 feet and is equivalent to a sea elevation of 2,307 feet, as determined from the San Carlos railroad station. A United States Geological Survey brass bench-mark tablet has been placed at the dam site. The capacity of the San Carlos reservoir site is shown in the following table:

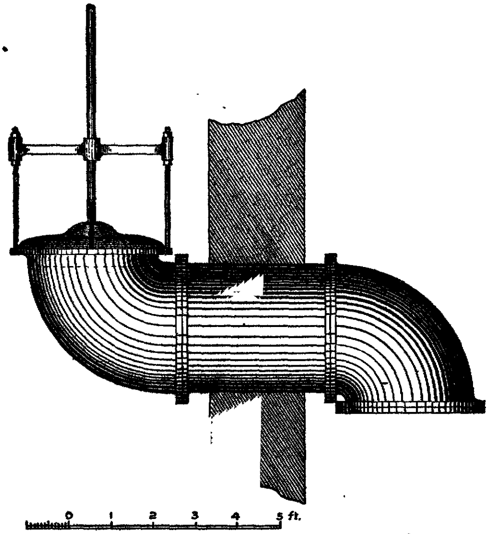
Capacity of San Carlos reservoir site.

Contour.	Area.	Contents between contours.	Total contents.	Mean depth.	Per cent of maximum depth.
	Acres.	*Acre-feet.*	*Acre-feet.*	*Feet.*	
100	0				
110	17.2	86.0	86.0	5.0	50.0
120	40.8	290.0	376.0	9.2	46.0
130	83.8	623.0	999.0	12.0	40.0
140	209.6	1,467.0	2,466.0	11.8	29.5
150	488.3	3,489.5	5,955.5	12.2	24.4
160	934.4	7,113.5	13,069.0	14.0	23.3
170	1,548.8	12,416.0	25,485.0	16.4	23.4
180	2,195.2	19,220.0	44,705.0	20.3	25.4
190	2,624.0	24,096.0	68,801.0	26.0	28.9
200	3,475.2	30,496.0	99,297.0	28.6	28.6
210	4,148.3	38,117.5	137,414.5	33.1	28.3
220	5,191.0	46,876.5	184,291.0	35.6	29.7
230	6,230.0	57,105.0	241,396.0	39.2	30.5
250	7,348.0	135,780.0	377,176.0	42.1	28.0
a 260			444,000.0		
a 270			512,000.0		
a 280			580,000.0		
a 290			650,000.0		
a 300			700,000.0		

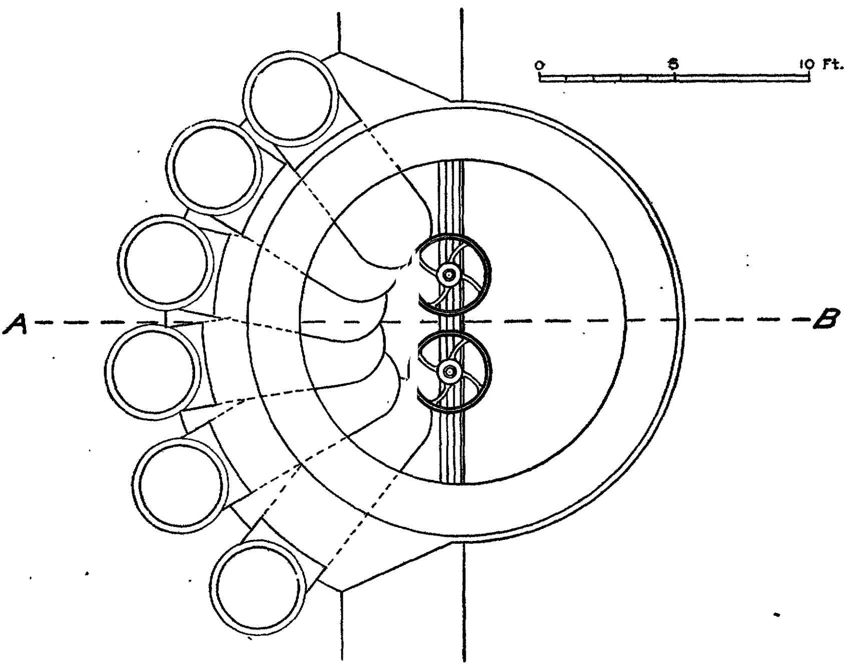
a Estimated.

A. SAN CARLOS DAM SITE, LOOKING DOWNSTREAM.

B. LEFT ABUTMENT OF SAN CARLOS DAM SITE.



A. INLET VALVE FOR SAN CARLOS DAM.



B. HORIZONTAL SECTION OF MAIN TOWER OF SAN CARLOS DAM, SHOWING ARRANGEMENT OF VALVES.

The area that will be flooded by the construction of a dam at the Narrows will be on the Apache Indian Reservation. The question of right of way would be the obtaining of the use of these reservation lands. A plane-table survey of the reservoir site was made by Mr. Cyrus C. Babb, on a scale of 2½ inches to the mile and with a contour interval of 10 feet. From this survey it was found that 587 acres of lands that have been irrigated and farmed by the Indians would be flooded; that of the remaining area, 4,405 acres are irrigable, the remainder, 3,360 acres, being nonirrigable. No improvements have been made by the Indians other than the building of brush fences and houses. The Apache Indian is of a roving nature and does not like to live for a long period of time upon one spot. It is said that when a death occurs in a family the house is abandoned and a new location is selected.

In order to provide for the damage which would be done to these Indian farms, the estimate includes $20,000 for the construction of a new irrigation system for the Indians above the reservoir site. There is as much water available from the Gila River at points between San Carlos and Geronimo as near the agency. Lands in that locality are unoccupied, are of equal fertility, could be irrigated with equal ease, and are on the reservation. If, therefore, a substantial irrigation system should be built for these Indians higher up on the river, and this should be given to them in lieu of their primitive and deficient systems that now exist, it is considered that the treatment would be fair.

When the Gila Valley, Globe and Northern Railway built through the reservation they paid the Indians at the rate of $40 an acre for the irrigated lands that were used for right of way and in addition gave the tribe in general $8,000. These Indians are industrious and anxious to work for wages whenever opportunity is offered. They built the greater portion of the railroad through their agency. The work on the dam would extend over a period of two years or more, and the Indians may be given much employment in connection with this construction. It has been found in Mexico that as the water is run off from a reservoir crops may be raised upon the uncovered lands, which have been completely saturated by the retiring water. These lands are found to be most productive. The Indians of San Carlos would have the opportunity of raising crops upon marginal lands and would doubtless avail themselves of this opportunity.

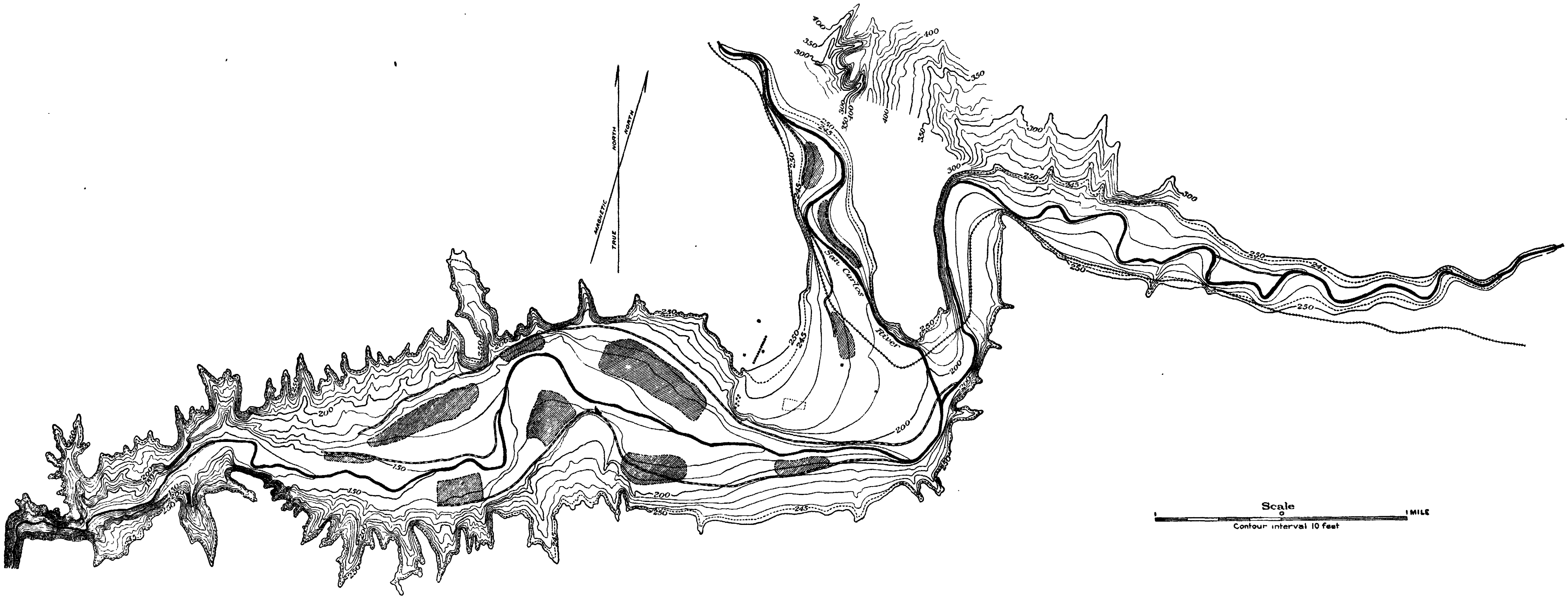
The agency grounds and military post were surveyed in detail on a scale of 200 feet to the inch, with 5-foot contours. The essential features of this map have been reproduced on Pl. XXVIII.

While the elevation of the spillway at the dam is 130 feet above the bed of the stream, the flood line of the reservoir must be considered as being at the maximum elevation of the water passing over the weirs, or approximately 145 feet above the bed of the stream, or 245 feet above the datum of the contour surveys. This contour, while it would not include all the buildings of the military post and of the Indian agency, would cover so great a portion of the grounds that the remainder would be practically useless.

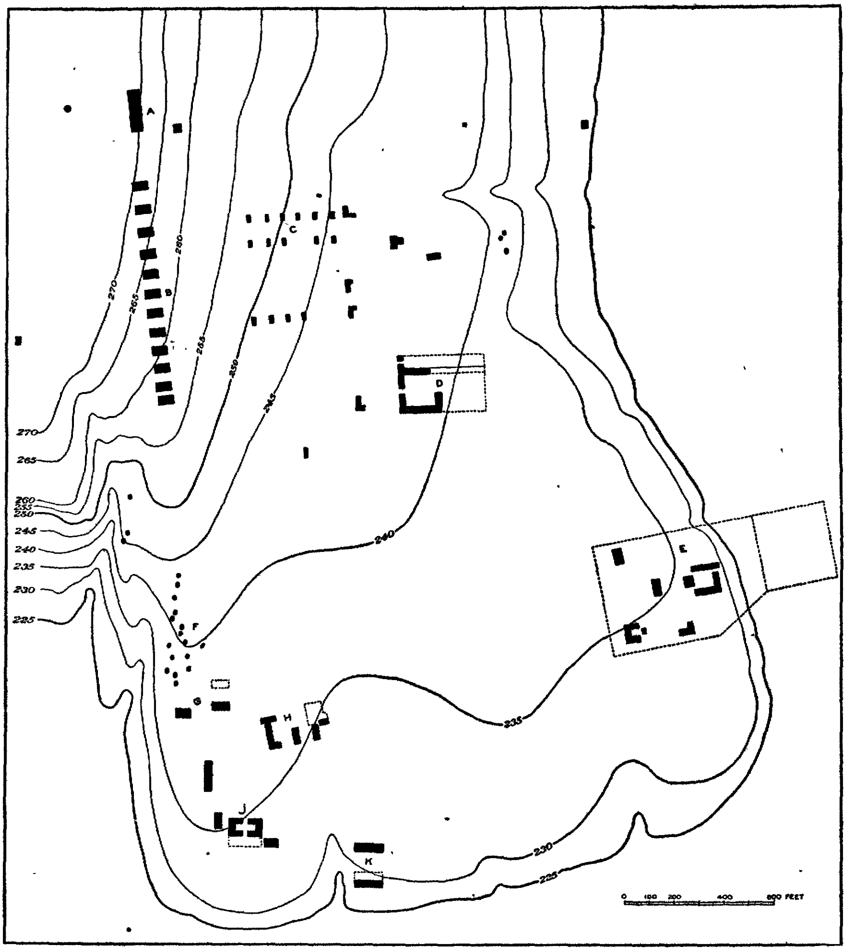
The agency and the post are both exceedingly dilapidated and old. It has been proposed that the entire agency be moved to a more desirable location about 8 miles above, on the San Carlos River, where, in fact, the greater number of the Indians are located. A handsome new school building, which has been provided for in recent appropriations, will not be located at the old agency, but at this point higher up on the San Carlos. There is a stone school building, storehouse, and blacksmith shop at the agency. The officer's quarters are adobe, the post trader's building is a frame structure, and there are twenty frame barracks. The quartermaster's department is a series of sheds, and the remaining buildings are either adobe or of rough lumber. They are all one-story structures except the schoolhouse, and are of a very ordinary type. There is a military ice and pumping plant and an agency flour mill, which would be flooded by the reservoir.

After a careful consideration of all the buildings, and a discussion of the situation on the ground with officers in charge and those familiar with the value of the property, a total price of $60,000 is considered as sufficient to provide for all damages done. This sum has been included in the estimate. In view of the probable moving of the agency to another location and the possible abandonment of the military post, and considering the general state of dilapidation which prevails, this figure of $60,000 for the building of a new post is considered as liberal.

As will be seen by reference to the map of the San Carlos reservoir site, the Gila Valley, Globe and Northern Railway enters the reservoir basin near its head, on the Gila River, and passes up the valley of the San Carlos River, a total distance of 5.75 miles in the reservoir site. This railroad was built in the fall of 1898. A better location for the road, away from the river, was recommended by the locating engineer. It provided for the crossing of the neck of land between the Gila and the San Carlos. The location of this line is indicated by the topography on the reservoir map (Pl. XXVII). The railroad could be changed from its present location, beginning at a point 2 miles above the Gila River bridge and crossing the Gila at that point, passing over a divide on the point of land mentioned above at an elevation of less than 200 feet above the bed of the stream, crossing the San Carlos 5 miles above the San Carlos station, and joining the present line at the last-named point. The length of new construction would be 5 miles. The roadway would cost about $8,000 per mile, or a total of $40,000. The material for the roadbed would cost, approximately, $4,000 per mile, but could be moved from the old location. There would be a



CONTOUR MAP OF SAN CARLOS RESERVOIR SITE.



CONTOUR MAP OF THE GROUNDS OF THE SAN CARLOS INDIAN AGENCY AND MILITARY POST, SHOWING LOCATION OF BUILDINGS.

A, hospital; building of adobe and military tank above it. *B*, adobe buildings occupied by the officers. *C*, frame buildings used as barracks. *D*, adobe buildings used as stables. *E*, school grounds; buildings mainly of adobe. *F*, huts or wigwams used by the Indian police. *G*, guardhouse. *H*, trader's store. *I*, stone warehouses. *J*, offices of the United States Indian agency; built of adobe. *K*, shops and stables built of stone.

saving of 4 miles in distance in the new line over the old, which should compensate for the moving. There would be two bridges to move, at an approximate cost of $10,000.

The Gila bridge contains thirty-three 16-foot bents and three small spans. The San Carlos bridge has thirty-four 16-foot bents. The total cost of moving this railroad has been estimated at $50,000. As all the material for the construction of the dam that will be shipped to San Carlos will have to pass over this railroad, including about 25,000 barrels of cement, and as the railroad will be shortened 5 miles without any serious additional grade and removed from a valley of two torrential streams, it would seem that this change of location might be readily arranged. The reason the railroad was placed in its present location was to enable it to reach the post and agency and secure that trade. With the agency removed, there would no longer be the occasion for its present location.

Estimate, San Carlos dam.

Rubble masonry, laid in concrete, 94,730 cubic yards, at $6	$568,380.00
NOTE.—With sand cement, at $4.63 per barrel, or $4.28 per cubic yard. (See Duryee's report.) This figure is based on half of the mass being large rock and half concrete.	
Excavation foundation, pumping, etc	150,000.00
1 semicircular tower, of concrete, 13,632 cubic feet, at 50 cents	6,816.00
1 tower, same diameter inside, 60 feet high, 4,238 cubic feet, at 50 cents	2,119.00
2 tower houses, including the semicircular base of concrete, at $750 each	1,500.00
10 inlets for towers, at $500 each	5,000.00
2 balance valves, at $1,000 each	2,000.00
2 balance valves, at $750 each	1,500.00
610 linear feet of footbridge, at $10	6,100.00
5 miles of railway, moved, at $10,000 per mile	50,000.00
New irrigation system above the Indian agency	20,000.00
Damage to agency and post buildings	60,000.00
Low water diversion tunnel	10,000.00
Wooden crib diversion dam at head of irrigation canal	20,000.00
	903,415.00
Contingencies, 10 per cent	90,341.00
Engineering, 5 per cent	45,170.00
Total	1,038,926.00

Total number of acre-feet stored is 241,396, at a rate of $4.30 per acre-foot.

GUTHRIE RESERVOIR.

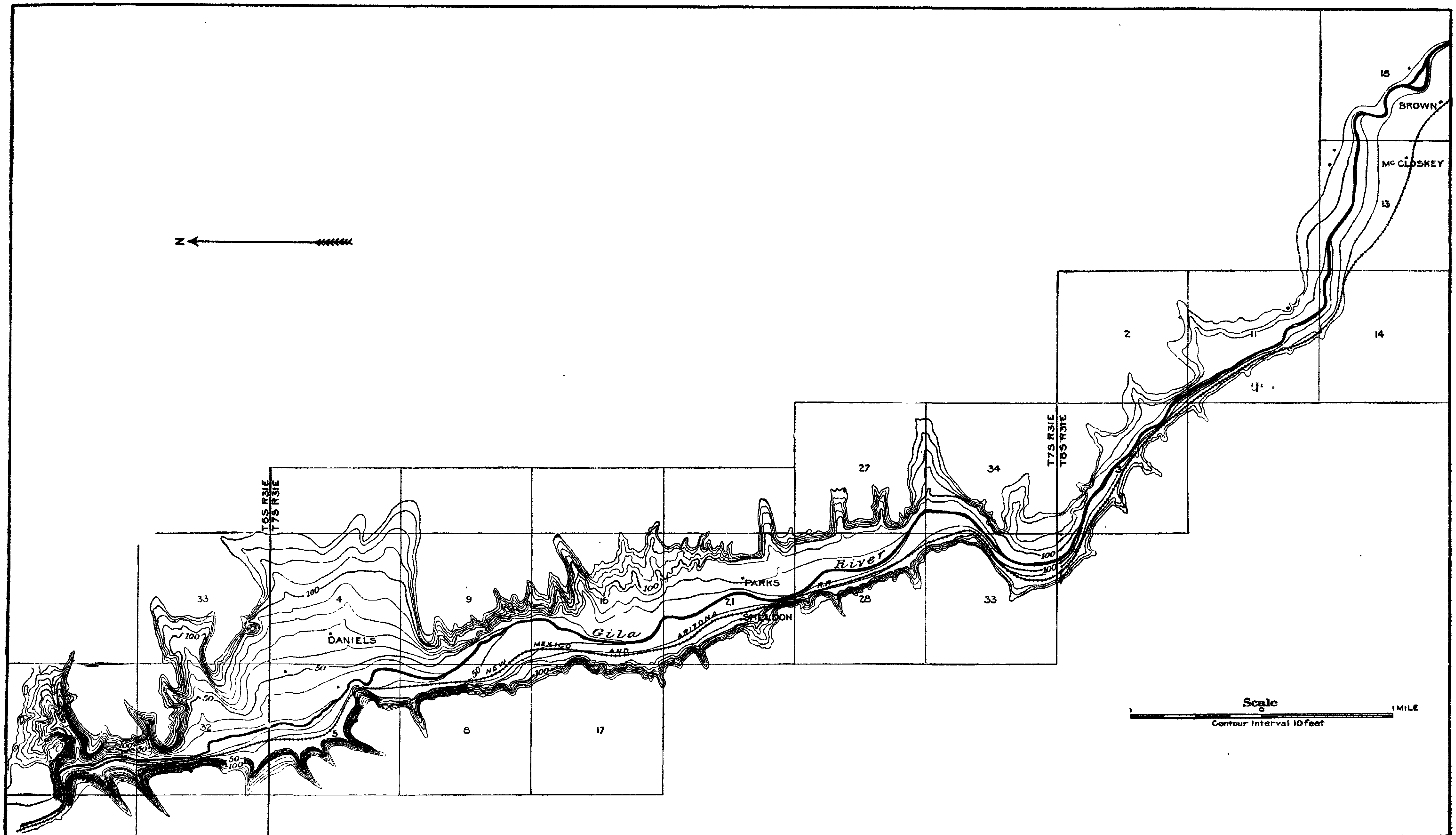
The Guthrie reservoir site is situated in Graham County, Arizona, about 30 miles northeast of the town of Solomonville, on the Gila River. The dam site shown on Pl. XXX is about 1 mile above the Coronado Ranch House, in what is known as York Canyon. This is approximately 4 miles above Guthrie and 13 miles below Duncan. The canyon is about 2,000 feet long, opening both above and below into broad valleys. The survey was made for a 140-foot dam, as a natural spillway occurs one-half mile east of the dam site, the lowest elevation of which is 130 feet. The main wagon road through the valley passes directly through this spillway. The opening varies from 200 to 300 feet in the bed of the canyon and from 800 to 900 feet in width at an elevation of 140 feet above the stream. The cliffs of the canyon are composed of volcanic rock, and quarries could be located at an elevation above the dam site. No borings for bed rock have been made at this point, because of the lack of funds, and also on account of its remoteness from other portions of the work. The walls of the canyon indicate varying conditions of lava flow. They are shattered, and in some instances there are strata of hard rock overlying cobbles and clay. It is not probable that the rock could be quarried in great quantities or in blocks, and it would be difficult to get good abutments. It has been exceedingly contorted and crushed at an elevation of about 40 feet above the bed of the river.

The survey of the reservoir site was made by Mr. Cyrus C. Babb, hydrographer, on a scale of 1 mile to 2½ inches (Pl. XXIX). The 140-foot contour runs within three-quarters of a mile of the town of Duncan. It is probable that the type of dam which would be constructed at this point, if one should be built, would be of a rock-fill type or possibly of earth. The basin of the reservoir contains no irrigated agricultural land, but it would appear to be possible to irrigate a portion of this valley. The New Mexico and Arizona Railroad, which is a narrow-gage road running to Morenci, Arizona, passes through the entire length of this reservoir site and through the dam site. The side of the reservoir site on which the railroad would have to be built is rough, and the cost of construction would be at least $20,000 per mile. Three large tributaries of the Gila—the San Carlos, the Gila Bonita, and the San Francisco—join the river below this point, so that the water supply would be considerably reduced. It was not necessary to prepare estimates on this dam site, but owing to its probable future value for irrigation purposes near Solomonville and Florence, it is recommended that the site be reserved for irrigation purposes. The capacities of this reservoir, with varying intervals, above the bed of the streams at the dam site are given in the following table:

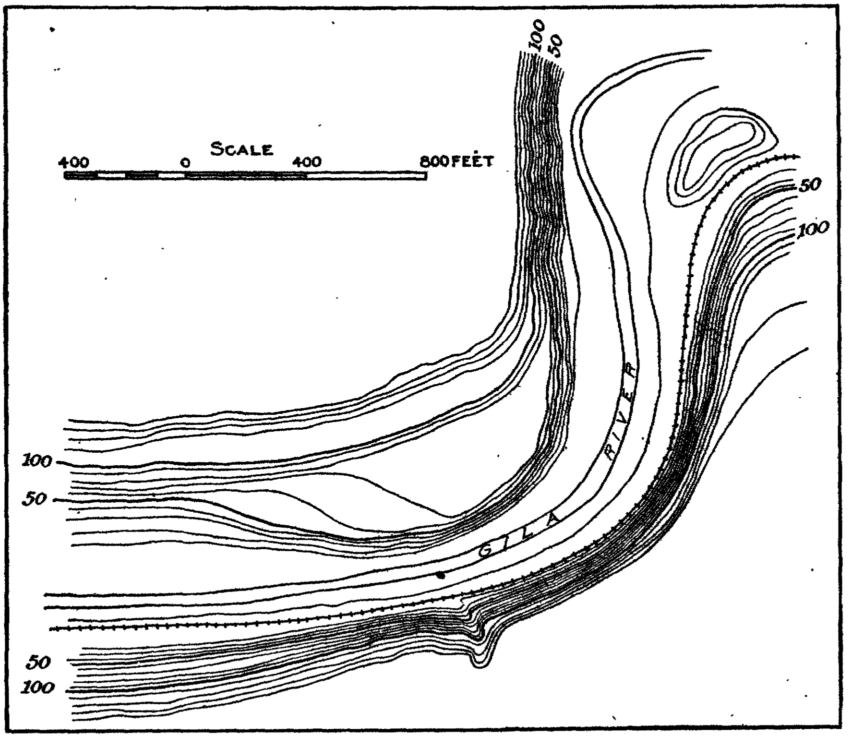
Table of capacities, Guthrie reservoir.

[Capacities calculated by averaging each two sections and multiplying by 10.]

Contour.	Area.	Capacity of each section.	Total capacity.	Contour.	Area.	Capacity of each section.	Total capacity.
	Acres.	*Acre-feet.*	*Acre-feet.*		*Acres.*	*Acre-feet.*	*Acre-feet.*
10	14	70	70	80	1,875	16,530	46,705
20	45	295	365	90	2,383	21,290	67,995
30	154	995	1,360	100	2,844	26,135	94,130
40	390	2,720	4,080	110	3,311	30,775	124,905
50	699	5,445	9,525	120	3,692	36,365	161,270
60	1,000	8,495	18,020	130	4,696	43,290	204,560
70	1,431	12,155	30,175	140	5,552	51,240	255,800



CONTOUR MAP OF GUTHRIE RESERVOIR SITE.



CONTOUR MAP OF GUTHRIE DAM SITE.

QUEEN CREEK RESERVOIR.

Queen Creek rises in the mountains to the westward of the Silver King mining camp, in Pinal County, Arizona, and flows in a general southwesterly direction, leaving the mountains below a point known as Whitlow's ranch, approximately 18 miles north of the Buttes. In ordinary years it loses itself in the desert north of the Gila River Indian Reservation. The reservoir site was surveyed with a plane table to a height of 140 feet above the bed of the stream at the dam site and contoured in 10-foot intervals (Pl. XXXI). The following table gives the capacity of this reservoir with varying heights of dam:

Area and capacity of Queen Creek reservoir.

Contour.	Area.	Capacity.	Contour.	Area.	Capacity.	Contour.	Area.	Capacity.
	Acres.	*Acre-ft.*		*Acres.*	*Acre-ft.*		*Acres.*	*Acre-ft.*
2,060	8	40	2,110	279	5,425	2,160	757	30,795
2,070	22	190	2,120	356	8,600	2,170	894	39,050
2,080	52	560	2,130	445	12,605	2,180	1,019	48,615
2,090	112	1,380	2,140	538	17,520	2,190	1,091	50,665
2,100	209	2,985	2,150	630	23,360			

A dam of the rock-fill type was estimated upon in 1895 to cost $221,000. The total area of the drainage is 142.5 square miles.

Observations on the discharge of Queen Creek were commenced in 1895, at the time of the first investigation for a water supply for the Gila River Indian Reservation. A gage rod was then placed and a gaging station established at Whitlow's ranch, at the dam site of the Queen Creek reservoir site. During the year 1896 an observer was employed and located at this station. At the time of the establishment of the station there was a slight permanent flow, averaging about 2 second-feet, which next year failed. The principal water supply of this creek consists of floods of one or two days' duration, occurring immediately after a rainfall in the basin. On this account, in order to obtain an accurate determination of the discharge, an observer has to be constantly located at the station to measure the discharge and to record its duration of flow. Such a system was employed during 1896 and until April, 1897.

The monthly discharge at this station for 1896 is published in the Eighteenth Annual Report of the United States Geological Survey, Part IV, page 295. The total discharge for the year was 10,887 acre-feet. The daily observations for 1897 are published in the Nineteenth Annual Report, Part IV, page 417. The floods were measured as they occurred, and it is assumed that they lasted twelve hours each. On this basis the total discharge to April 6, 1897, was 8,020 acre-feet.

The total discharge for the year has been estimated in the following manner, and is only roughly approximate. A rainfall record has been kept at Pinal ranch, within the drainage area, from 1895 to the present date, inclusive. The total precipitation for 1897 was 23.23 inches. For the period from January to March, inclusive, during the time in which measurements of discharge on the creek were made, the precipitation was 14.21 inches. A proportion was, therefore, made—14.21 is to 23.23 as 8,020 is to total discharge for the year. Working out this proportion gives a total discharge of 13,110 acre-feet.

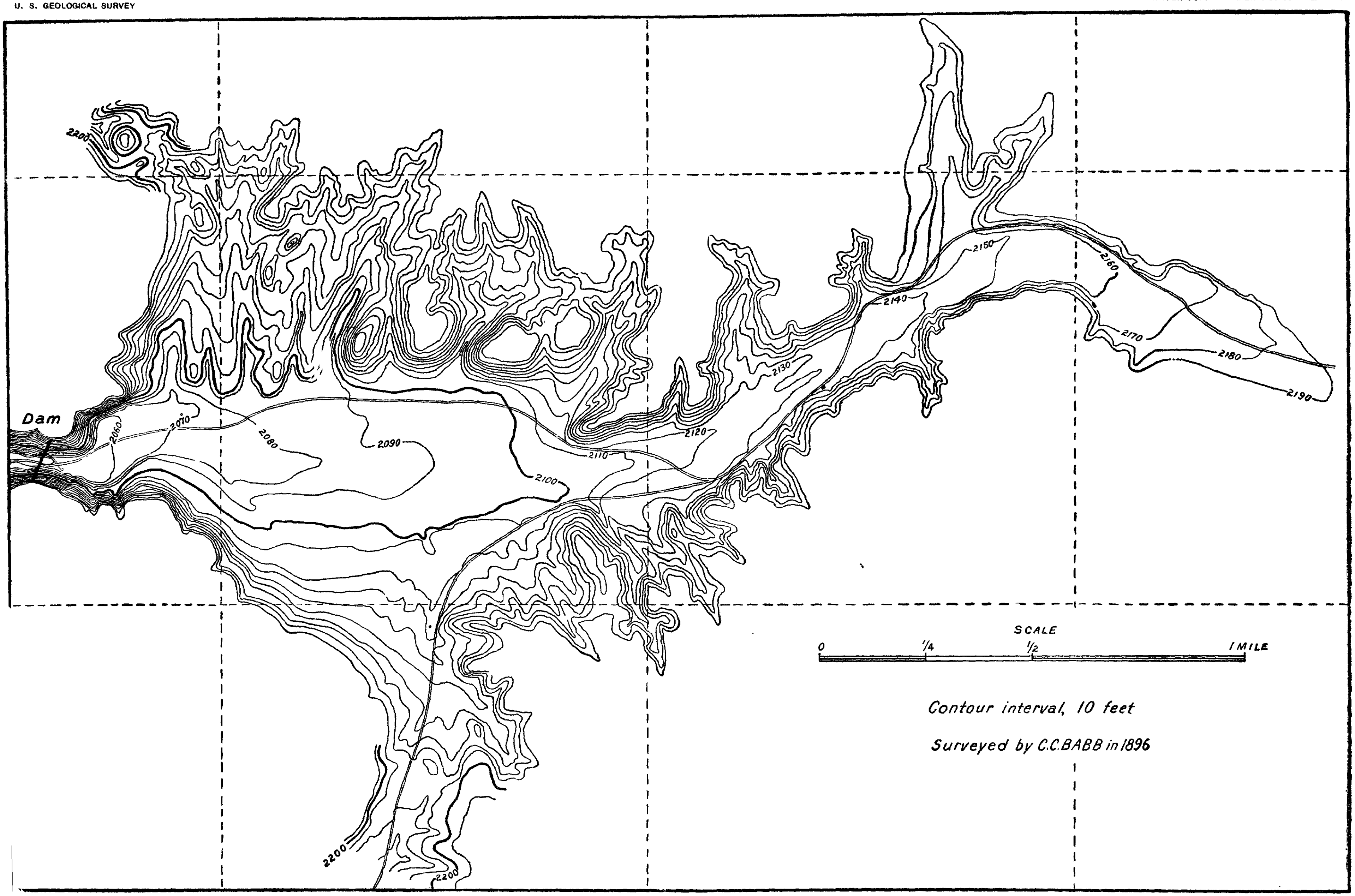
An observer was employed at this station for July, August, and September, 1898. He recorded the heights of floods on the gage rod as they occurred. From this record, in connection with the cross sections which were measured, an estimate of the discharge of the creek was made. These observations are reported in Water-Supply and Irrigation Paper No. 28 of the United States Geological Survey, page 132. The discharge for these three months has been computed as 5,140 acre-feet, including the one flood occurring in December of that year. The creek was reported dry from the 1st of March until the time the observer assumed his duties, and from September to the measured flood, December 18. One flood occurred, however, in January or February, 1898, of which no record was kept, but the quantity was not notably large. It is reported by people located in the basin that the year 1898 was characterized by an exceedingly small flow of the creek. The total discharge for the year is assumed as 6,000 acre-feet. It is probable this amount was not exceeded.

The old gaging station was reestablished in December, 1898, and an observer employed to record any floods occurring. Meter measurements were not made, but gage records were taken on both the original gage and a slope gage placed 431 feet above and referred to the same datum. Cross sections of each flood were measured. From this data the discharges of the creek were computed by means of the Kutter formula. From these computations for the period from January 1 to August 11, 1899, the discharge is found to be 12,527 acre-feet.

Summary, total annual discharge of Queen Creek at Whitlow's ranch, Arizona.

Year.	Acre-feet.
1896	10,887
1897	13,110
1898	6,000
1899, Jan. 1 to Aug. 11	12,527

As it has been shown that 10,875 acres, requiring 20,000 acre-feet of water, are needed at once for the Indians who are on or near the Gila River Indian Reservation, and as an ultimate consumption of 40,000 acre-feet is estimated as a possible future need and this amount accepted as the basis of this report, it is obvious that Queen Creek is not able to supply the full demand, either present or prospective.



CONTOUR MAP OF QUEEN CREEK RESERVOIR SITE.

BED ROCK AT DAM SITE.

A diamond core drilling outfit was sent to Queen Creek on April 17, 1899, and the work was completed on May 20, 1899. It was found difficult to drive the pipe at this point, owing to the presence of numerous bowlders in the covering of the bed rock. The pipe was frequently bent and it was often found necessary to place dynamite in the hole, raise the pipe a few feet, and explode the powder before the pipe could be driven to bed rock. There were 11 holes put down, their relative location being shown on Pl. XXXII, *A*. The elevations at each of these is given in the list below. At a point on the figure marked "Gage" is the upper gage rod, its zero being at an elevation of 2,041.7 feet. At the point near this, marked "Iron," is the northwesterly iron gad, put at an elevation of 2,049.9 feet. Opposite this is the northeastern iron gad, at an elevation of 2,060.6 feet. At the point marked "B. M." is one of the bronze tablets of the Geological Survey, placed at an elevation of 2,055.1 feet.

Borings at Queen Creek.

Hole.	Surface elevation.	Bed-rock elevation.	Depth.	Depth bored into rock.
	Feet.	*Feet.*	*Feet.*	*Feet.*
1	2,050.0	2,013.0	37.0	7.5
2	2,051.4	2,017.4	34.0	3.0
3	2,053.4	2,027.4	29.0	6.0
4	2,050.6	2,018.6	32.0	4.0
5	2,049.7	2,021.4	28.3	6.2
6	2,050.5	2,011.0	39.5	4.2
7	2,049.5	2,017.5	32.5	7.0
8	2,050.2	2,015.2	35.0	7.0
9	2,050.5	2,022.3	28.2	3.0
10	2,050.2	2,007.7	42.5	1.5
11	2,047.3	2,023.8	23.5	5.5

There is a United States Geological Survey bronze bench-mark tablet on the left bank, in line with the upper row of holes, set in the rock about 5 feet above bed of stream. Elevation, 2,055.7 feet.

The bed rock was found to be a uniform, heavy, volcanic product, having a specific gravity of 2.49, or a weight of 155.5 pounds per cubic foot. Its strength to resist crushing was greater than the capacity of the testing machine. A core three-fourths of an inch in diameter would not crush under a pressure of 1 ton. Further description of the Queen Creek dam and reservoir site may be found between pages 43 and 52 of the report on the irrigation investigation for the benefit of the Pimas and other Indians on the Gila River Indian Reservation, Arizona, by Mr. Arthur P. Davis, hydrographer, in Senate Document No. 27, Fifty-fourth Congress, second session.

CEMENT.

By EDWARD DURYEE.

Investigations were made under instructions from Mr. J. B. Lippincott, in order to ascertain means of lessening the cost of Portland cement in the construction of dams on the Gila River in Arizona. Owing to the remoteness of these proposed dams from lines of transportation, the expense of bringing cement to the sites makes a notable addition to the cost over construction elsewhere, and it is therefore of great importance to reduce the quantity of cement to the smallest allowable amount.

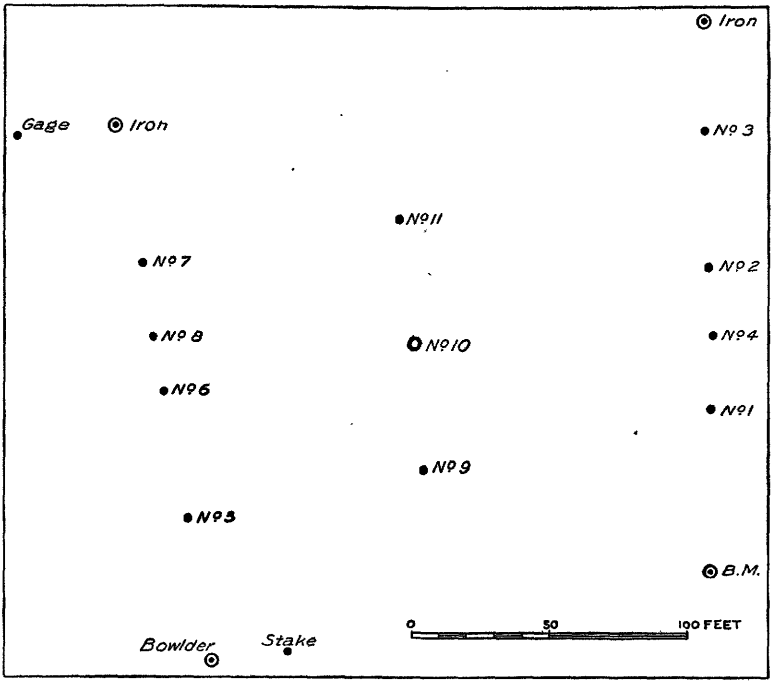
Portland cement is considered an essential element in the construction of dams subject to severe and sudden strains due to floods. It is valuable not only in giving great strength and homogeneity to the structure, but also because of the fact that exposure to moisture, which deteriorates many materials, serves to increase the strength of Portland-cement mortars. It is thus being largely used for this purpose. For example, the new dam under construction on the Nile at Assuan will require 3,000,000 barrels of Portland cement, costing, in round numbers, $12,000,000.

The investigation of cement for the Gila River dams has been along three lines: (1) To ascertain whether by unusually fine grinding of the cement its strength can be appreciably enhanced and the quantity correspondingly reduced; (2) whether it is feasible to use the rocks found at the dam sites for making a sand cement; (3) whether Portland cement can be economically made at these sites.

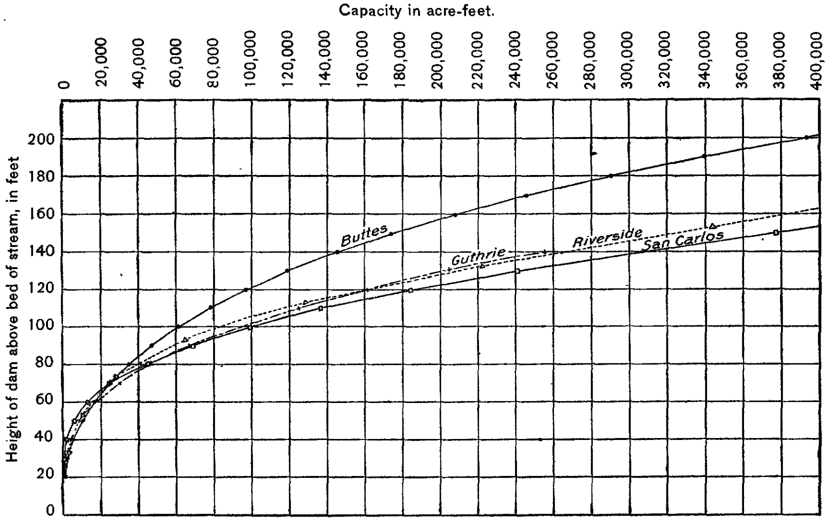
SAND CEMENT.

Sand cement is a term applied to a mixture of cement and sand ground together in a dry state to an impalpable powder. As a rule Portland cement and quartz sand are the materials thus used. This mixture is then used with ordinary sand and gravel, as in the customary practice. The proportion of pure cement is thus considerably reduced, but the strength and durability of the concrete has been found to be nearly as great as that made with the undiluted cement. The explanation offered for the remarkably good results obtained with sand cement when used with ordinary coarse sand is that the voids in the coarse sand are nearly filled with the finely ground sand. The grains are thus bonded together and to the coarse sand by the uniformly diffused particles of the fine cement. The amount of voids in the ordinary sand, in other words, is greatly reduced by the fine sand, fulfilling the requirement for a strong mortar that it is necessary to be of dense character, the grains being of such graduated size and so well mingled as to afford the maximum contact of the surfaces of the particles.

In sand-cement mortar the grains of sand are extremely minute,



A. LOCATION OF BORINGS AT QUEEN CREEK DAM SITE.



B. CAPACITY CURVES OF THE PROPOSED RESERVOIRS ON GILA RIVER, ARIZONA.

the mixture being so fine that only 5 per cent residue is left on a screen of 200 meshes to the linear inch or 40,000 meshes to the square inch. The great density thus obtained contributes to the impermeability to water and increases the compressive strength and load-bearing capacity, thus rendering the mass of value for constructing foundations, dams, and sea walls.

In the tests made in this investigation a rock known as pearlite, an acidic lava or rhyolite from the Buttes dam site, was used, and also samples of quartzite from the San Carlos dam site. These were chosen because of the abundance of these rocks at the localities named and their superior hardness. The Portland cement used was that manufactured at Colton, California, this being made nearest to the place where it will be used and being sold at a lower price than other Portland cement in the local market. All of the tests were made with the same sample of cement, portions of this being taken for the several mixtures with crushed pearlite and quartzite. The sand used with the foreign cement in making sand cement was clean beach sand from dunes along the coast.

TESTS OF SAND CEMENTS.

Results of the tests of the sand cements and comparisons with otner mixtures are given in the following table. In each case the crushed pearlite was mixed with an equal weight of cement, and the mixture was ground in a mortar until it all passed through a screen having 200 meshes to the linear inch. The same method was pursued with the quartzite from San Carlos, thus making sand cements composed of equal parts of Portland cement and pulverized rock ground to an exceedingly fine condition.

The coarse sand used in making the mortar with the sand cement and with the pure (Portland) Colton cement was of the ordinary grade of fineness used for making cement tests. It was screened from ordinary gravel, all residue on the 20-mesh screen being rejected and all left on the 30-mesh screen being retained.

The briquettes for testing were made according to the specifications recommended by the American Society of Civil Engineers. After the briquettes were made they were kept under a damp cloth for twenty-four hours, then placed in vats of water, where they were left until the time for breaking arrived, namely, seven days or twenty-eight days. The fine grinding and diluting of the Portland cement with fine sand did not materially affect the time of hardening or setting. The beginning of the setting process of the ordinary Colton cement mortar, or initial setting, was thirty-three minutes, and the time of final setting was eighty-five minutes. This applies to samples Nos. 3, 4, and 9 of the following list. The corresponding periods for the sand cement were thirty and eighty minutes. The cement mortar continues to harden and increase in firmness for a year or longer.

Results of tests of Portland sand cements.

No.	Material.	Sand.	Portland cement to sand.	Fineness.			Water.	Strength.	
				50 mesh.	100 mesh.	200 mesh.		7 days.	28 days.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*
1	Colton and Butte pearlite, 1 to 1	2	1 to 5	0.00	0.00	0.00	10	80	300
2	Colton and San Carlos quartzite, 1 to 1	2	1 to 5	.00	.00	.00	10	90	345
3	Colton, regular	2	1 to 2	.42	7.20	33.20	10	170	385
4	do	3	1 to 3	.42	7.20	33.20	10	140	240
5	Colton, fine ground	2	1 to 2	.00	.00	(*a*)	12	370	465
6	do	3	1 to 3	.00	.00	(*a*)	12	170	260
7	Colton and Butte pearlite, 1 to 1	3	1 to 7	.00	.00	.00	10	75	155
8	Colton and San Carlos quartzite, 1 to 1	3	1 to 7	.00	.00	.00	10	55	185
9	Colton, regular	0	1 to 0	.42	7.20	33.20	18	615	660
10	Imported	0	1 to 0	.80	7.80	29.33	18	345	525
11	Imported and sand, 1 to 1	2	1 to 5	.00	.00	.00	10	115	190
12	do	2	1 to 5	.00	.00	(*a*)	10	125	185
13	do	3	1 to 7	.00	.00	(*a*)	10	55	90
14	do	3	1 to 7	.00	.00	.00	10	90	140
15	Imported, regular	2	1 to 2	.80	7.80	29.33	10	210	270
16	do	3	1 to 3	.80	7.80	29.33	10	120	175

a Some left on 200-mesh screen.

NOTE.—The above cement stood the boiling test for free lime satisfactorily.

Comparison of test No. 3 with No. 5, and of No. 4 with No. 6, shows that increased fineness of grinding very materially increases the strength and sand-carrying capacity of cements. The ordinary Colton cement of tests No. 3 and No. 4 was ground finer than commercial Portland is usually ground. Recent improvements in mills for grinding render possible a reduction in size of cement grains at a cost which is small when compared with the great increase in the value of the resulting material. Where the freight charges are high, as is the case at the locations under consideration, it is especially important to take advantage of this improvement, and there is no doubt that if the specifications call for a fineness such that only 1 per cent is to be left on a 100-mesh screen, the manufacturers will respond to the requirements. Engineering specifications have ordinarily allowed a residue of 5 per cent on a 50-mesh screen, although manufacturers have for some years permitted a residue of only 1 or 2 per cent on a 50-mesh screen.

CRUSHING TESTS.

In order to obtain the crushing strength of the various cements and concrete considered, two 1-inch cubes of each were broken. The results given are the averages of the crushing strength of the two cubes. The cubes were allowed to remain thirty days in water and then thirty days in the air.

Crushing tests of 1-inch cubes.

Character of mixture.	Water.	Average crushing strength.
	Per cent.	*Tons.*
Standard Colton cement	18	3.25
Colton cement, 1 part, and ordinary testing sand, 2 parts	8	1.75
Colton cement, 1 part, and marble sand, 2 parts	8	2.38

Crushing tests were also made of 6-inch cubes of concrete after these had been immersed for thirty days in water. The portions of the mixture and the breaking strain in tons are given in the following table. In the mixture the proportions are given by volume and not by weight.

Crushing tests of 6-inch cubes.

Character of mixture.	Breaking strength.
	Tons.
Colton cement, 1 part; ordinary sand, 3 parts; pebbles from gravel, 6 parts	38
Colton cement, 1 part; sand, 3 parts; crushed marble, 6 parts	30
Colton cement, 1 part; sand, 2 parts; crushed marble, 5 parts	20

It is believed that concretes of approximately equal value can be obtained by using cements in the following proportions, measured by volume:

Portland cement, 1; sand, 3; broken stone, 7.
Sand cement, 1; sand, 2; broken stone, 6.

COST OF SAND CEMENTS.

In the Portland-cement concrete made in the proportion of cement 1 part, sand 3 parts, and broken stone 7 parts, it has been found that 270 pounds of cement will be required for a cubic yard of concrete. This, at 2.12 cents per pound, will cost $5.72 per cubic yard.

In the sand-cement concrete of the proportions 1 cement, 2 sand, and 6 stone, 340 pounds of cement would be required for each cubic yard of concrete. This, at 1.2 cents per pound, would cost $4.08.

The saving in the cost of cement to be effected by using sand cement instead of the Colton Portland will be the difference between $5.72 and $4.08, or $1.64 per cubic yard of this concrete entering into the construction of the dam. From the total saving thus realized should, however, be deducted the cost of the plant required for grinding the sand cement.

Concrete blocks composed of the above proportions were crushed at McGill University in 1898, with the following results:[1]

Sand cement, 1; sand, 2; broken stone, 6; water, 20 per cent.

Weight per cubic foot, 154 pounds. Crushing load, in pounds per square inch: Seven days, 521 pounds; twenty-eight days, 639 pounds; sixty days, 670 pounds.

A concrete of German Portland of the proportions of 1 cement, 2 sand, 6 broken stone, and 20 per cent water stood a load of 728 pounds per square inch in twenty-eight days, and one of the same proportions made from English Portland stood 698 pounds in twenty-eight days.

Tests for crushing strength on 6-inch cubes of concrete, made of 1 part sand cement, 2 sand, and 3 parts gravel, were made on concrete that was taken from the bucket just as it was ready to be laid in the foundation of the Cathedral of St. John the Divine, in New York City. Each result is the average of the crushing strength of four separate cubes, made under exactly the same conditions at different periods:

	Pounds.
7 days old crushed at	77,162
14 days old crushed at	83,225
30 days old crushed at	92,465

Approximate cost of plant for making sand cement; capacity, 240 barrels per twenty-four hours.

Crusher (required also for crushing rock for concrete)	$2,000.00
Mill for coarse grinding	2,000.00
Tube mill for finishing	2,500.00
Engine and boiler	1,500.00
Setting up machinery	1,000.00
Buildings and bins	1,000.00
Total	10,000.00
Cost of mill, per barrel of cement	.20
Add for concrete making a power mixing machine	1,500.00

In making concrete, if a good quality of stone be used, and the rock be crushed so as to be well graduated as to sizes, thus securing a minimum of voids, the compressive strength of the concrete increases as the proportion of stone increases and as the volume of voids between the stone decreases, and decreases as the proportion of sand in the mortar increases. The rule, therefore, holds that, to secure the greatest strength, mix the maximum quantity of stone with a minimum of sand mortar sufficient to bond the stone together, the sand mortar being rich in cement. An extensive bed of exceptionally good sand for mortar was found near the Buttes, the grains graduating in size from very small to large sizes. It shows only 35 per cent of voids, while the standard cement-testing sand used in laboratories has 45 per cent of voids.

[1] From Canadian Architect and Builder, 1899.

A large tube mill will grind 10 barrels of sand cement per hour to the requisite degree of fineness, at an estimated cost of 20 cents per barrel. The cost of power for grinding is calculated at 3 cents per horsepower per hour at the dam site.

Cost of sand cement with Portland cement at $8 per barrel.

One-half barrel Portland	$4.00
One-half barrel crushed and coarse-ground quartzite	.18
Grinding same in a tube mill	.20
Royalty on account of sand-cement patent	.05
Total cost of sand cement per barrel (375 pounds)	4.43

The cost of sand cement per pound, quartzite being used as the source of the sand cement, would therefore be 1.2 cents.

The cost of the mill per barrel of cement, 20 cents, is not included in the above.

It is estimated that the cost per barrel of Colton Portland cement, delivered at the dam site will be $8. This, for 375 pounds weight cement, would make the cement cost 2.12 cents per pound.

USE OF ROCKS AT THE DAM SITES.

For the purpose of ascertaining whether the rocks at the dam sites could be used in the manufacture of Portland cement the localities were visited and samples were obtained of those rocks which occurred in sufficient quantities to furnish a supply necessary for manufacturing the large amounts of cement needed. In looking for the raw materials it must be borne in mind that, chemically considered, Portland cement consists of a compound of tricalcium silicate and dicalcium aluminate, accompanied by small percentages of ferrate and sulphate of lime and traces of alkalies. It is made by grinding and burning together either natural or artificial mixtures of carbonate of lime and silicate of alumina. Limestones, chalks, or marls usually furnish the carbonate of lime, and clays are the ordinary source of the alumina and silica. The mixtures are burned at a high temperature to a blackish clinker of a semivitrified character. After cooling, this clinker is reduced by grinding to an impalpable powder, in which form it is known by the generic name of Portland cement.

ROCKS AT RIVERSIDE DAM SITE.

Limestone (No. 3 in the following table) was obtained near Riverside, on the road to the Pioneer mill, where it is found in large quantities along the roadside. The rhyolite (No. 4 in the following table) was found 2 miles south of the Riverside site. It offered the closest approach to a suitable silicate of alumina that could be found.

The source of elements of silica and alumina in the crude materials should, however, be sedimentary in character, not igneous or metamorphic. The analysis justified a trial mixture, and therefore one was calculated and made, but on burning the materials failed to effect the requisite combination for a Portland cement. Too large a percentage of the silica was in the free or uncombined condition. Fuel was not to be found near the Riverside site, and the manufacture of cement at this place is considered impracticable.

ROCKS AT SAN CARLOS DAM SITE.

The limestone from San Carlos site (No. 2 in the following table) was found to be admirably adapted to the purpose of the dam construction on account of its good specific gravity (which was 2.7), freedom from flaws, and siliceous character. It occurs in vast quantities, forming the abutments at the dam site. It forms bluffs, extending for several hundred feet, well located for quarrying. Large masses may be embedded in the concrete, care being taken that they be laid irregularly in the mass of the dam, and are well placed so as to bond into a monolith.

Analyses of rocks from the vicinity of the dam sites.

[Chemical composition, in percentages.]

No.	Name.	Color.	Locality.	Sp. gr.	Carbonate of lime, $CaCO_3$.	Carbonate of magnesia.	Silica (SiO_2).	Alumina and ferric oxide.	Moisture.	Lime per cent in the carbonate of lime.
1	Limestone	Gray	San Carlos	....	96.65	0.00	1.4	1.3	0.65	54.124
2	do	Pink	do	2.709	55.92	31.00	3.7	6.0	1.00	31.315
3	do	Blue	Riverside	....	93.10	0.00	4.7	1.4	....	52.136
4	Rhyolite	White	do	1.541	9.60	....	60.9	12.6	16.90	5.376
5	do	Pearl	Buttes	2.361	....	....	....	....	....	....
6	Limestone	Blue	Queen Creek[a]	2.81	90.10	0.00	4.1	5.8	....	....
7	do	Gray	do	2.678	55.50	0.00	34.6	1.3	....	31.08

[a] From about 1½ mile above dam site.

The analysis of the gray or bluish limestone (No. 1 in the above table) shows from its freedom from magnesia and the small percentage of free silica that it is possible to make a Portland cement with it, provided a suitable clay can be found to furnish the requisite elements of silica, alumina, and ferric oxide.

FUEL.

An extensive but undeveloped deposit of bituminous coal is located about 17 miles from the San Carlos dam site. There is a wagon trail to within about 6 miles of the coal beds, but after leaving the wagon trail the only means of access was found to be a bridle path over the hills. About ten years ago numerous prospectors' locations were made in the district, and shafts were sunk at a sufficient number of localities to prove the deposit to be of considerable extent. Most of the shafts have become filled with débris, but several were entered to depths of 15 to 30 feet. They showed the body of coal to be in beds having a dip of about 60°, the beds being from 5 to 10 feet in thickness, not of solid fuel, but showing seams of good coal interlaid with seams of slate and waste. In the bottom of the deepest shafts was found a good body of coal in a solid bed perhaps 5 feet thick. It was reported that at the time the prospecting was done on the claims some 30 tons were transported by wagons to the Southern Pacific Railroad and used in the locomotives, but that the cost of mining and transporting it to the railroad, with the crude means available at the time, was about $20 per ton.

Cement could be burned with the coal. The right to mine the coal for the use of the Government in this work could be secured readily and at a nominal cost. The cost of mining and transportation to San Carlos would, however, be high. In general practice 120 pounds of coal dust are used in burning 1 barrel of Portland cement.

Taking as a basis coal delivered at the dam site at $10 per ton, limestone at 40 cents per ton, and clay at $1.25 per ton, the cost of manufacturing Portland cement at the dam site would approximate $2.75 per barrel. The cost of erecting a plant with an output of 300 barrels of cement every twenty-four hours would be $75,000. Supposing the amount of cement to be required in the construction of the dam to be 50,000 barrels, the cost per barrel, if made at the site, would be approximately as follows: First cost of plant, $75,000; cost of manufacturing 50,000 barrels, at $2.75, $137,500; total cost, $212,500; cost per barrel, $4.25.

With reference to the degree of reliability to be placed upon Portland cement made in new localities, it may be said that the manufacture of this material has been put upon a scientific basis, such that the manufacturing chemist can predict the grade of cement to be made from the given materials and, by means of analyses of various rocks, can calculate suitable mixtures to produce the required result. The uniform system of testing cements recommended by the American Society of Civil Engineers affords a reliable means of determining the intrinsic merits of the product. The old method of buying cements on the reputation of the maker has been succeeded by tests for determining the actual value. Portland cements of American make are being extensively manufactured and are of equal or even superior quality to the foreign-made cements. During the year 1899 it is estimated that 6,000,000 barrels of Portland cement have been used, of which four-fifths were of home manufacture. In spite of this fact, on account of the failure to find suitable clays at the various localities and also the difficulty of obtaining fuel, it is impracticable to manufacture Portland cement at the dam sites.

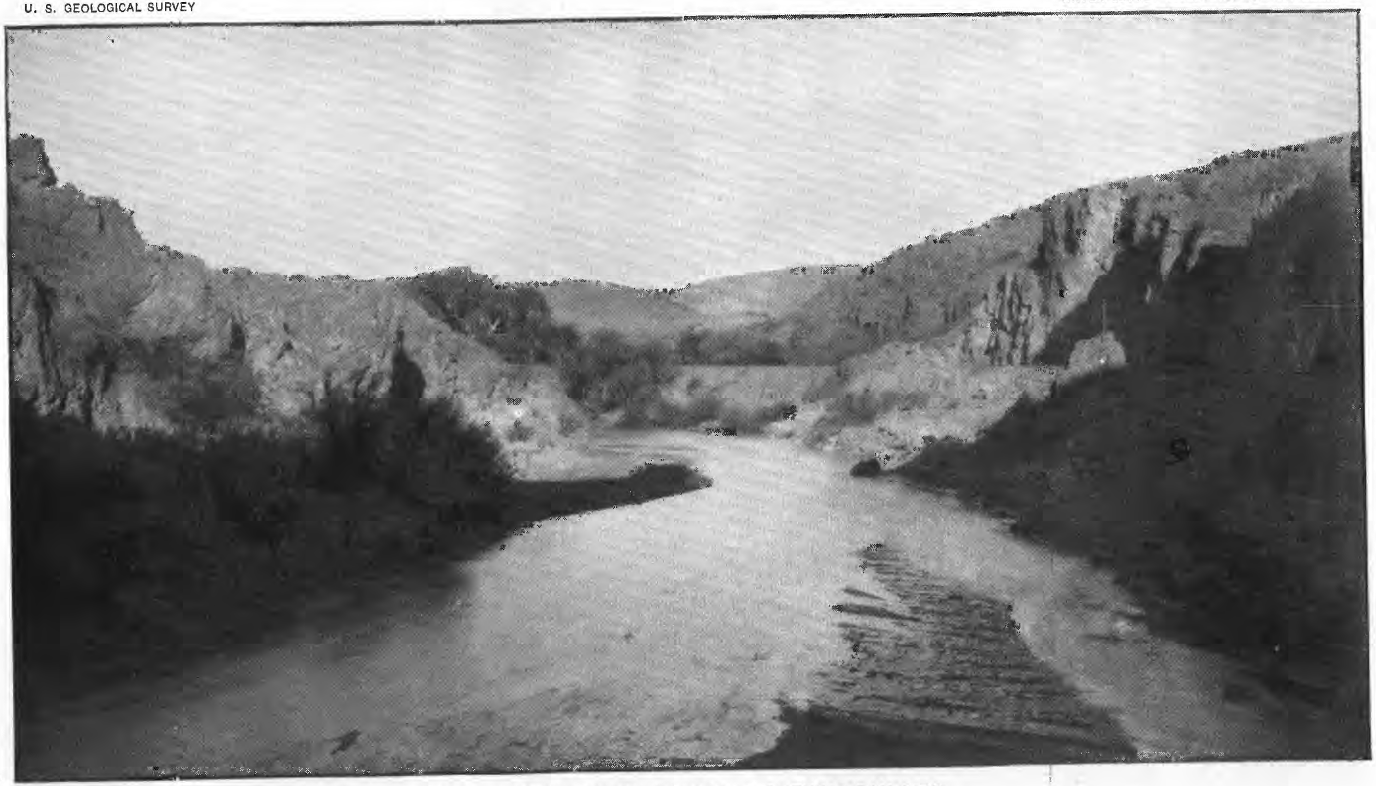
It is important, if Portland cement is used at the localities under consideration, that the specifications should require it to be ground so fine that not over 1 per cent residue shall remain on a 100-mesh screen.

Reliable sand cement can be made from the quartzite at San Carlos or the pearlite at the Buttes dam site by grinding with Colton (Portland) cement. A saving will result at the San Carlos dam site of $1.64 per cubic yard by making sand cement on the ground, this being exclusive of the cost of the plant for grinding.

IRRIGABLE LANDS.

The location where the water which is impounded in the reservoir sites on the Gila River would be used is primarily on the Gila River Indian Reservation, which has been described in previous pages of this report, and which contains 357,120 acres of land, the greater portion being irrigable. South of this Indian reservation, intervening between the Southern Pacific Company's railroad and the point where the Gila River leaves the mountains, there are many thousand acres of high-grade agricultural land suitable for irrigation. The climate is adapted to the raising of diversified crops, the grade of the country is uniform and suitable for the application of water, and the soil is exceedingly fertile. The river, which carries a large amount of sediment containing many fertilizing materials, will keep these lands in a state of continuous productiveness. Without water this land is a desert and has no value. That it is of no tangible value in its present condition is proved by the fact that many thousands of acres which have been taken up at previous times under the desert-land act and homestead laws have been permitted to revert to the Government before title was perfected by the settler, even after expenditures had been made on the land.

An examination was made of the records of the United States land office at Tucson to determine what portion of this area outside of the reservation remains public domain. The area in the valley of the Gila between Dudleyville and Riverside was also inspected, as this valley should be segregated for reservoir purposes, and in case of the construction of a reservoir at San Carlos a portion of its water could be used for irrigation in this valley. Nineteen townships were examined, and it was found that 389,211 acres therein are still public domain and that 52,162 acres, lying mostly under the Florence canal—which canal has a very deficient water right—is held in private ownership. There is, therefore, three times the area of irrigable land that can be served on the Indian reservation alone and three times the area of public land off the reservation that can be supplied.



YORK CANYON ON GILA RIVER AT GUTHRIE DAM SITE.

Public and private lands in the vicinity of Florence, Arizona.

Location.	Acres.	
	Government.	Private.
T. 4 S., R. 10 E	18,400	4,640
T. 4 S., R. 11 E	22,720	320
T. 4 S., R. 14 E	21,600	1,440
T. 5 S., R. 5 E	23,040	----------
T. 5 S., R. 6 E	23,040	----------
T. 5 S., R. 7 E	22,880	160
T. 5 S., R. 8 E	15,760	7,280
T. 5 S., R. 9 E	13,080	9,960
T. 5 S., R. 10 E	23,040	----------
T. 5 S., R. 14 E	22,960	80
T. 5 S., R. 15 E	21,000	2,040
T. 6 S., R. 5 E	17,840	5,200
T. 6 S., R. 6 E	12,800	10,240
T. 6 S., R. 7 E	19,440	3,600
T. 6 S., R. 8 E	21,732.06	3,116
T. 6 S., R. 9 E	24,359.26	486.26
T. 7 S., R. 6 E	19.800	3,240
T. 7 S., R. 7 E	22,680	360
T. 7 S., R. 8 E	23.040	----------
Total	389,211.32	52,162.26

DISTRIBUTION CANALS.

It is not the purpose of this report to definitely locate any canal line across these lands. The construction would be entirely in earth and exceedingly simple. The building of these canals could be readily undertaken by the settlers and by the Indians. The canal line to the Indian reservation would be uniformly in smooth country and with an earth section. A topographic map on a scale of 2 inches to the mile, with contour intervals of 10 feet, has been made of a portion of these valley lands. This map demonstrates the feasibility of building these canals. The Florence Canal, which diverts its water at practically the same point where diversions of reservoir water would occur, runs through the irrigable area under consideration and still further demonstrates the feasibility and the practicability of the building of the canals wherever circumstances may require.

ORGANIZATION OF IRRIGATION DISTRICT.

It is recommended, in case of the construction of any of these reservoirs, that there be appointed a Federal commission to consider the organization under Federal laws of an irrigation district which will include the lands that would be irrigated under this system. This district should be organized with proper officials to handle locally the division and the distribution of the water and for the construction of the delivery canals. The preparation of a code of laws for the operation of this district would be of great importance and should be undertaken jointly by members of the engineering and legal professions.

SUMMARY.

1. The available records of the discharge of Queen Creek at Whitlow's ranch indicates that this stream would not afford a sufficient and reliable water supply for the irrigation of an area as large as is required for the relief of the Indians on the Gila River Indian Reservation.

2. Because of the large amount of annual discharge of water by the Gila River and the high percentage of silt which it contains, it is not advisable to construct a reservoir of small capacity on this stream on account of the rapidity with which it would fill with silt.

3. In case of the construction of any of the dams on the Gila River the cost of putting the foundations down to bed rock is one of the principal elements of expense. This cost would be almost as large if a small dam was built as in the case of a large one.

4. The greatest economy to the Government, whether the relief of the Indian alone is considered, or the general development of the arid lands in the neighborhood of the reservation is taken as a basis, lies in the construction of a large reservoir. It is shown that the Government can build such a large reservoir, give water to the Indians without charging them for it, and sell the remainder of the water impounded at such figure as would rapidly return all the original investment made by the Federal authorities.

5. In the event of the construction of a large dam there will be built up in the valley of the Gila River, where a desert now exists, a community of fully 40,000 souls, and the creation of many million dollars of taxable wealth without permanent outlay on the part of the Government.

6. The cost per acre-foot of storage capacity of the dams as planned in this report at the three principal reservoir sites upon which estimates have been made is as follows:

Cost per acre-foot of water stored.

Location.	Amount.	Cost per acre-foot.
	Acre-feet.	
The Buttes	174,040	$15.19
Riverside	221,138	9.01
San Carlos	241,396	4.30

From this it will be seen that the cost of storing water at the Buttes per acre-foot is 3.5 times the cost at San Carlos, and that the cost at Riverside is 2.1 times the cost at San Carlos.

The capacity of the reservoir, the character of the foundations at the dam site, the conservative and well-known type of dam planned, and the economy of construction all point to the selection of the San Carlos reservoir site as the place for the construction of the dam.

Perhaps the most notable result of this investigation of the water supply of the Gila River has been the discovery of three large reservoir sites the existence of which heretofore has been unknown. They are the Riverside, the San Carlos, and the Guthrie sites. The relative capacities of these are shown graphically on Pl. XXXII, *B*.

The argument in favor of the construction of a reservoir for the storage of the waters of the Gila River by the United States Government is stronger, perhaps, than for any other project in the country.

1. The Government has expended large sums of money for the introduction of irrigation on the Indian reservations where it is desired to educate the Indian into agricultural habits as a means of his civilization. This is a well-established and wise public policy, and has already been productive of much good, but is always in the nature of an experiment, and more or less difficulty and uncertainty is attendant upon the attempt to induce the Indians to accept this mode of livelihood. In the present case we have a tribe of Indians who have for centuries been engaged in agriculture by irrigation, and who were until recently the only successful irrigators in Arizona. These Indians have been deprived of their water supply through the agency of the white man, directly encouraged by the United States Government. It is an imperative obligation of honor that their supply should be restored to them, and the only practical means of this restoration is by storage on the Gila River. In addition to this, there is held out the certainty that unless this is done these Indians will retrograde from a condition of industry and prosperity to one of mendicancy and vice. Instead of an uncertain possibility of elevating a savage tribe, we are confronted with the necessity of preventing the destruction of a civilization already attained.

2. It is practically certain that the storage of the Gila waters will never be accomplished by private or corporate enterprise for three reasons: (1) The direct financial returns are not sufficient to induce so large an investment of private capital; (2) the unquestionable legal right of the Indians to a large quantity of the water of the Gila River would be a perpetual cloud upon the title to the water in the hands of a private corporation; and (3) the land to be benefited being mainly in public ownership, there is no means under present laws by which a private company could realize the full benefit of their improvements.

3. Arizona being a Territory, the water right is entirely under national jurisdiction; the only material private lien on the right is the right of the Indians, who are wards of the Government, and this is essentially a Government right. The objection applicable in some of the States, that the jurisdiction of water rights is entirely in the hands of the State and would produce a confiict of authority, does not apply here.

4. The Government, being the owner of more land under the canal than can ever be watered by it, can entirely control the appropriation of the values which will be created by the construction of a reservoir and can entirely recoup itself for all expenses incurred, and thus discharge its obligations of honor with no expenditure except the utilization of its own natural resources. It is not a proposition for the Government to expend money for the benefit of private individuals nor of any particular section, and hence is not comparable with river and harbor improvements, although the general benefits are so comparable, as homes will be furnished at low rates to thousands of industrious people, who will come from all parts of the country, and a forbidding desert will be transformed into a rich oasis and a large community will be thus practically added to the domain of the United States.

5. Gila River rises in New Mexico. As the main body of the basin is in Arizona, inter-State complications might arise in the future in case the reservoir were constructed by private or local enterprise. With these questions the National Government only is competent to cope. Thus, from all points of view there is every reason why this reservoir should be constructed by the National Government and no reason why it should not, while it is not only impracticable but eminently inadvisable for private enterprise to carry out the project.

6. Owing to the erratic nature of the Gila River less than 3 per cent of its water near Florence is now being used for irrigation, and the areas now irrigated suffer intensely from summer droughts.

Financial summary of results.

Total water supply to be delivered to the point of diversion from San Carlos reservoir for irrigation each year .... acre-feet..	241,396
Ultimate requirement for Indians .... do....	40,000
Remainder available for irrigation of public domain or private lands .... acre-feet..	201,396
Assume a duty of water of 2 acre-feet or 24 inches in depth used each year on each irrigated acre; this would permit the irrigation of lands outside the reservation to the extent of .... acres..	100,698
There are 389,211 acres of arid public land in the district to be supplied from this system. Assume that the water is given to the Indians without cost to the Government and that these 100,698 acres must pay the total cost of the works, then the necessary charge per acre for the remaining water rights to be sold would be	$10.24
It is believed that the public lands with this water right could, at this rate, be sold within a year.	
If 3,000 Indians have to be fed by the Government at a cost per ration per day of 10 cents, the annual expenses would be	$109,500
The capitalization of $109,500 at 4 per cent would represent the practical permanent expense of feeding these tribes. This is equivalent to a permanent Government debt, which would be liquidated by this construction, of	$2,737,500

The value of the 100,698 acres of irrigated public lands that would be taxable would be $50 per acre, or a total of	$5,034,900
The saving, without expense to the Government, by irrigation of 20,000 acres of lands belonging to the Indians has been shown to be	2,737,500
Total increase in value, without public expense	7,772,400

There will also be a large increase in value of taxable town property, not estimated upon.

RECOMMENDATIONS.

1. Immediately withdraw from entry all the lands that may be irrigated from this source of supply pending further action by Congress on this matter.

2. Segregate all the reservoir sites on the Gila River that may be used for the irrigation of these lands. The Buttes and Queen Creek reservoir sites have already been segregated for this purpose. The Riverside, San Carlos, and Guthrie reservoirs should also be set aside.

3. Maintain observations on the Gila River.

4. Construct the San Carlos dam.

5. Give the Indians the water which they require without charge, the Government to recoup itself for all expenditures from the sale of the remaining water rights.

6. Form a Federal irrigation district for the division of the water, which is to be delivered to the head of the irrigation canals, for the construction of these canals, and for the general administration of the district.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894-95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnaissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Bighorn Range and Bighorn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895-96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett, and "Preliminary report on the artesian waters of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896-97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the calendar year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton, and "Reservoirs for irrigation," by J. D. Schuyler.

1899.

Nineteenth Annual Report of the United States Geological Survey, 1897-98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton, and "A preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

1900.

Twentieth Annual Report of the United States Geological Survey, 1898-99, Part IV, Hydrography, 1900; octavo, —— pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell, and "Hydrography of Nicaragua," by A. P. Davis.

WATER-SUPPLY AND IRRIGATION PAPERS, 1896-1900.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Postage stamps, checks, and drafts can not be accepted. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton, 1898.
13. Irrigation systems in Texas, by William Ferguson Hutson, 1898.
14. New tests of pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems in the Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett, 1899.
27. Operations at river stations, 1898, Part I, 1899.
28. Operations at river stations, 1898, Part II, 1899.
29. Wells and windmills in Nebraska, by Erwin Hinckley Barbour, 1899.
30. Water resources of the Lower Peninsula of Michigan, by Alfred C. Lane, 1899.
31. Lower Michigan mineral waters, by Alfred C. Lane, 1899.
32. Water resources of Puerto Rico, by H. M. Wilson, 1900.
33. Storage of water on Gila River, Arizona, by J. B. Lippincott, 1900.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gaging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

The maximum number of copies available for the use of the Geological Survey is 1,000. This number falls far short of the demand, so that it is impossible to supply all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or who have furnished data. Requests specifying a certain paper and stating a reason for asking for it are granted whenever practicable, but it is impossible to comply with general requests, such as to have all of the series sent indiscriminately.

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