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Conditions and cost of water storage for irrigation on the Gila River, Arizona

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CONDITIONS AND COST OF WATER STORAGE FOR IRRIGATION ON THE GILA RIVER, ARIZONA.

DECEMBER 13, 1899.—Referred to the Committee on Indian Affairs and ordered to be printed..

Mr. WARREN presented the following

REPORT OF JAMES D. SCHUYLER, CONSULTING ENGINEER, ON THE GENERAL CONDITIONS AND COST OF WATER STORAGE FOR IRRIGATION ON THE GILA RIVER, ARIZONA, FOR THE BENEFIT OF THE INDIANS OCCUPYING THE GILA RIVER RESERVATION.

THE SCOPE OF INVESTIGATION.

The purpose of the engineering investigation authorized by act of Congress approved July 1, 1898, appropriating $20,000 to cover the expenses, was primarily to ascertain the feasibility and cost of impounding sufficient water to irrigate such portion of the Gila River Indian Reservation as may be needed to support the Indian population living thereon.

Two reservoir sites were named in the act as having been suggested for this purpose in Senate Document No. 27, Fifty-fourth Congress, second session, covering the preliminary report of a previous investigation by Arthur P. Davis, hydrographer of the United States Geological Survey, viz, the Buttes on the Gila River, and Queen Creek, a small, intermittent stream, draining a limited territory lying between the Gila and Salt rivers. The depth to bed rock at these sites had not been definitely determined in the original investigation of Mr. Davis, for lack of adequate facilities, and further examinations and study of the entire subject had been recommended prior to a definite determination by Congress as to the steps necessary to be taken for the relief of the impoverished Indians, suffering from a lack of water previously enjoyed, but appropriated in recent years by settlers higher up the river.

Mr. Davis was put in charge of the second investigation, and, with the experience obtained on similar work on the Nicaragua Canal route, secured the machinery there used with success, not only to reach the bed rock through the overlying detritus and ascertain its depth below the surface, but to penetrate it and bring samples of it to the light for testing. The interesting history of this work, which has been seldom so thoroughly done, is recorded in detail in Mr. J. B. Lippincott's report, the latter having been placed in active charge of field operations in May last, on the return of Mr. Davis to his important duties in connection with the Nicaragua Canal Commission.

The depth to bed rock at the Buttes having early been proven so great as to demonstrate that the dam would necessarily be a very costly one, if feasible at all, it was wisely decided, during the progress of the borings at that point that the scope of the investigation should be widened to cover all other possibilities of water storage on the river above the Buttes, in the hope of finding alternative sites where the purpose sought could be effected more safely, more certainly, and at less cost. Trial borings were made at the Dikes, 4 miles above; at Riverside, 12 miles above; and at San Carlos, 60 miles above, while surveys were made of a site still further up the river at Duncan, near line dividing Arizona and New Mexico. Fortunately the appropriation was sufficient, with rigid economy, to permit all of this work and obtain such results that it may be fairly said that the subject of water storage on the Gila is practically exhausted, and all feasible alternatives to the Buttes site are definitely known.

The study of the water supply involved a comprehensive examination and measurement of the Gila River and all of its main tributaries; an enumeration and measurement of the various canals and ditches diverting water from these streams above the Buttes, and an investigation of the areas of land thus irrigated; a study of the intricate and interesting phenomena attending the return of water to the river from the irrigated fields by seepage; an investigation into the loss of water by evaporation, and the compilation of rainfall statistics from all of the stations where precipitation has been observed and recorded on or near the watershed of the Gila. The feasibility of establishing reservoirs upon the stream has necessitated a detailed contour survey of all the projected dam and reservoir sites, a computation of their area and capacity, and the area of the watershed tributary to them; a consideration and determination of the volume of silt carried by the river and a computation of its probable total volume per annum, together with a compilation of all the measurements of the flow of the river at all points and times of which there is record.

The study of the cost and feasibility of the erection of dams of the types considered has necessitated the examination and test of the various building materials available; analysis and tests of strength of the rocks to determine their suitability for foundations; quarry tests of the neighboring cliffs to ascertain the behavior of the rocks when thrown down in large masses, and its quality beneath the surface exposure; investigations of limestone clays and fuel to determine the feasibility of manufacturing hydraulic lime, natural cement, artificial cement, and sand cement from imported Portland cement, in the endeavor to exhaust the possibilities in the way of overcoming the disadvantages of the remoteness of the sites from the seaboard, and thus reach the ultimate economy of construction. The successive steps taken in these various lines of investigation are treated at length in Mr. Lippincott's report. It must be concluded from this brief summary of the work accomplished that the entire investigation has been upon broad lines; that it has been thorough; and that its general scope, as determined by the engineers in charge, has been sufficiently comprehensive to secure all the collateral data necessary to form the basis for intelligent action upon the question in its entirety.

THE VOLUME OF WATER TO BE STORED.

One of the first matters to be considered in a report of the character called for by the act of Congress is as to the volume of water which would be required to fulfill the purposes sought, viz: The irrigation of the lands to be tilled by the Indians residing and to reside on the Sacaton Reservation to make them self-supporting. The reservation covers an area of 357,120 acres, most of which is arable and irrigable land if water could be had for it, but all of which is arid and unfit for habitation without irrigation. It is not stated in the act of Congress how much of this land it is desired to provide water for. It would not be possible with all the water supply of the river to irrigate more than half of it, but of course this would be vastly more than the actual requirements for the sustenance of the Indian, which Mr. Davis estimates to be about an acre and a half of ground per capita.

The number of Indians now living on the reservation is estimated by the agent to be 7,250, including the migratory Papagos. In his opinion 2 acres per capita are needed for their sustenance. On this basis nearly 15,000 acres would be tilled if water were provided for irrigation; and assuming a rate of consumption of 2 acre-feet per acre, equivalent to 24 inches of rainfall, the volume needed would be 30,000 acre-feet. Possibly a less amount would suffice for immediate needs, but to provide for future increase in population and greater demand as they progress toward civilization, a reasonable surplus should be made available, and it is believed that 40,000 acre-feet would not be an excessive allowance in the way of storage provision, more than half of which would probably be used at once if made available. This volume of 40,000 acre-feet can be better appreciated, perhaps, by practical irrigators when it is understood that it would suffice to maintain a canal 10 feet wide at bottom, 17 feet wide at top, and 3 feet deep, flowing at a mean velocity of 2 feet per second for 250 days of each year. In the Salt River Valley a canal of this size would be looked upon as an ordinary lateral of a main canal.

THE QUEEN CREEK PROJECT.

The assumed minimum storage provision required of 40,000 acre-feet is so much in excess of the mean annual run-off of Queen Creek, as determined by the measurements of the past four years, as to render it impracticable to obtain the needed supply from this source. The total run-off during the period of nearly four years from January 1, 1896, to August 11, 1899, was but 42,500 acre-feet, while the minimum year gave but 6,000 acre-feet. This site being thus so emphatically self-condemned for the purposes sought, further discussion of the dam and its construction is quite unnecessary. The sole resource for adequate water supply is therefore narrowed down to the main Gila River.

STORAGE UPON THE GILA RIVER.

From all previous measurements and available data for the years 1889, 1895, 1896, 1897, 1898, and 1899, Mr. Lippincott concludes that the minimum flow past the Buttes during that period was 353,639 acre-feet per annum, the maximum flow 616,206 acre-feet, and the mean flow 469,093 acre-feet per annum. Having a river of this large volume with which to deal, the question at once arises as to whether it is feasible, desirable, or proper to construct a dam and reservoir in the immediate channel of the Gila of so small capacity as 40,000 acre-feet, through which all the water of the stream must necessarily pass, when the maximum flow is more than fifteen times the suggested reservior capacity. That the reply to this question should be in the negative admits of no doubt or discussion.

It may be accepted as an axiom applicable to almost every reservoir site that the nearer its capacity reaches to the maximum annual run-off of the stream upon which it is located (unless it is in a basin at one side and fed by a conduit) the longer will be its period of usefulness. This is true, because all streams carry more or less sediment in suspension, the total volume of which bears a certain relation to the total volume of flow. On some streams this proportion of silt is very large, and in others it is so small as to be negligible in reservoir calculations. When a sediment-bearing stream passes through a lake or quiet body of water as a reservoir, its load of silt is mostly precipitated, and the basin in time becomes filled. If the reservoir receives barely sufficient water to fill it once a year, it will last very much longer as a useful reservoir than if it received several times as much water as would be required to fill it, with its proportionate amount of sediment. The silt problem is one of prime importance in nearly all reservoirs, but it is particularly serious on streams so heavily laden as the Gila. In short, it would be mere folly to construct a reservoir of but 40,000 acre-feet capacity across the Gila unless preparations were made to increase the height of dam every two or three years.

This latter policy would be injudicious, costly, and bad engineering. For these considerations it has been deemed wise and prudent to estimate, in the case of each of the three reservoirs discussed in the following pages, upon the maximum height of dam which could be safely built, or which would form a storage volume that could reasonably be expected to fill from the stream in driest years. The reason for this decision is manifest. The permanence of the work for accomplishing the object sought is a prime consideration, while at the same time the opportunity offers for reclaiming a very large section of the arid public domain with the water that may be stored in addition to the requirements of the Indians. It would be quite possible for the United States Government to pay for the entire outlay and provide homes for a large farming population, adding immeasurably to the wealth and population of the Territory. As a business proposition it is obviously the proper thing to do to make an enterprise of this simple and necessary act of justice to the Indians of such magnitude as to reimburse the cost and be of general public utility and advantage.

THE BUTTES DAM.

The dam site at the Buttes, 14 miles above Florence and 25 miles above the Gila River Reservation, is the first point above the great valley of the Gila where a storage reservoir can be formed. On casual inspection it appears ideal as a dam site. The cliffs rise boldly from the river bed several hundred feet in height, with a gap on one side a considerable distance away from the dam location that seems at just about the right elevation for a natural spillway. The unprofessional layman is invariably impressed with it and is apt to pronounce it a perfect dam site. A careful inspection, however, of the character of the rock composing the abutments, the quality of the ledges available for quarries, the capability of the stone at the "natural spillway" gap to withstand the erosion of floods pouring over it, and the bearing power of the underlying bed rock to sustain the weight of a heavy masonry, made additionally heavy by the great depth of the rock below the surface, all reveal the fact that the site is really disappointing and quite inferior.

The extreme height of dam required and the rotten nature of the bed rock determine the unsuitability of the site for a masonary structure which would have a maximum height, from foundation to crest, of nearly 300 feet in order to form a reservoir of 174,000 acre-feet capacity. This capacity is little more than half what it should be to properly utilize the mean flow of the stream, and no lower dam should be considered at this point. Nevertheless, to reach this volume of capacity the dam required surpasses the safe limits of a masonry structure for that purpose and exceeds all known precedents in dam construction. These considerations have rendered it unnecessary to estimate the cost of a masonry dam. The only other type of dam possible to construct at this site of the height required is a rock-fill dam—a loose-rock embankment, with concrete retaining walls at either toe, the water face being made water-tight by a covering of concrete above the toe wall 5 feet in thickness, with a web plate of sheet steel embedded in the concrete entirely over the face. This character of dam can be built successfully, although the difficulties to be overcome during construction are serious and numerous. Fully two years' and probably three years' time would be needed for the erection of the dam.

The plan agreed upon in consultation and the proposed method of construction are described with minuteness in Mr. Lippincott's report,[1] and need not be repeated here. The writer fully concurs in the general design and indorses the plans as in his opinion practicable, feasible, and operative. The estimates of cost have been prepared after careful study of the entire situation and are believed to be conservative and safe without being excessive. Improved methods and mechanical appliances for excavation to the great depths here required where water is to be encountered may serve to reduce the cost of foundations below the estimate, but there is always so large an element of uncertainty and so many unforeseen contingencies about all works to be built below the water level in the path of possible great floods that it has been thought best not to reduce the estimate below what is regarded as a safe figure by reason of such known possibilities. There are various alternative methods of performing the work of sinking the foundations for the toe walls other than that suggested in Mr. Lippincott's report. One of these is the Sooysmith freezing method, by which the quicksand on either side of the wall is kept frozen and stable excavation and construction are in progress. It is, perhaps, questionable whether this method, which has been successfully employed in sinking shafts in quicksand, could be made equally successful on so large a scale as would be necessary at the Buttes dam, or whether the cost might not be prohibitive.

A second method is that of filling the quicksand on each side of the wall from surface to bed rock with Portland cement grout, injected by pumping the liquid into it through small pipes driven at frequent intervals, the pipes being slowly raised as the cement fills the lower voids. In this way a small wall could be formed on each side of the required excavation, which, in a few weeks, would have sufficient strength to act as a retaining wall or caisson, and be sufficiently impermeable to

[1] Water-Supply and Irrigation Paper No. 33, U. S. Geological Survey.

materially reduce the difficulties of pumping the water from the pit. This method has been described by Robert L. Harris, M. Am. Soc. C. E., in a paper read before the American Society of Civil Engineers, in March, 1891, entitled "A cofferdam or caisson without timber or iron in its construction." Mr. Harris used a mixture of equal parts of cement and fine sand. He subsequently employed the method to solidify quicksands in sewer trenches in Providence, R. I., and obtained a patent upon the application of the method. Monolithic construction under water by cement grouting was also employed by Mr. W. R. Kinipple, M. Inst. C. E., in the construction of breakwaters in England, and the process was described by him in a paper read before the International Maritime Congress held in London, England, in 1893. Mr. Kinipple placed his pipes at intervals of 8 or 10 feet apart and used pure cement grout. He found that the grout displaced the water in the voids, converting blocks of broken stone and concrete into a monolith. French engineers used the grouting method for foundations under water many years ago, and Mr. William Worthen, M. Am. Soc. C. E., as early as 1845 employed it successfully in repairing the foundations of a flume.

A modification of the grouting method was described by Mr. Fr. Neukirch, of Bremen, Germany, in a paper presented at the International Engineering Congress held in Chicago in 1893. By Mr. Neukirch's process dry cement is introduced into the sand by means of compressed air. The pipe used by him is $1\frac{1}{2}$ inches in diameter, drawn to a point or nozzle at the lower end, in which there are three or more holes three-eighths inch in diameter. The air is reheated to keep moisture out of the pipe and prevent the cement from clogging, and the pipes are driven by means of air jet issuing from the point and keeping the sand and water in ebullition. The air was compressed to six atmospheres, and some 500 barrels of cement were thus injected in the works described in the paper.

These citations are made to show that the process of solidifying quicksands in place by injecting cement has been quite generally used on various classes of construction. The research made by the writer does not reveal an instance in which the application has been made to the foundations of a dam in a river bed filled with quicksands, or for the forming of a cofferdam so extensive as would be needed in the case under consideration, but there is no reason to question the feasibility of the methods for the cofferdams needed in the bed of the Gila in the construction of any of the several dams discussed in this report.

It may even be possible in this manner to solidify the entire base of the Buttes dam to such a degree of perfection as to obviate the necessity of building the toe walls below the surface, or at least to reduce the construction below to a thin wall at the upper toe, forming the filling of a trench, 8 or 10 feet wide, cut down to bed rock through the solidified quicksand. It is not suggested that this induration of the quicksand base of the dam site from bed rock up might render it advisable to reconsider the conclusion that a masonry dam is not practicable at this site, because the character of the bed rock is not deemed suitable for such a dam, however broad the artificial base thus formed might be made. An exhaustive series of tests of the density and strength of such solidified quicksand would need to be made before depending upon it as a foundation for masonry. The suggestion is made, however, to illustrate the possibility of improving the nature of the base of the rock fill in case there were doubts of the stability of the untreated quicksand as a base for the rock embankment, even though confined on all sides.

Rock-fill dams are of American origin and of purely Western American conception. They were first built in the mining regions of California for impounding water for hydraulic mining in the early days of the American occupation, and originated from the lack of materials with which to build structures of masonry. At the beginning they were made as log cribs filled with stone and faced with a skin of wooden planks in two or three layers. The first improvement upon this crude form was the omission of the log cribs and the building of the embankments with faces of dry masonry of considerable thickness, varying with the height. Many variations of the original idea have since been developed, chiefly in the character of materials used to secure watertightness, and facings of concrete, of stone masonry, of asphalt concrete, of earth, and of steel, and inner cores of steel plates riveted together and smeared with asphalt, have been tried, and a dam is now under construction in Colorado which is to have a facing of steel plates bolted to the bedrock walls on the sides and bottom and covering its entire inner slope, somewhat in the manner proposed for the Buttes dam, although only partially embedded in concrete. This Colorado dam, which is to supply the city of Denver with domestic water and power, is to have an extreme height of 210 feet from stream bed to crest. Its upper slope will be $\frac{1}{2}$ to 1, and the lower 1 to 1; the section is therefore somewhat lighter for equal height than that proposed for the Buttes dam.

The spillway provision at the Buttes dam has been confined in the plans to the right bank because of unstable character of the indurated volcanic ash composing the bed rock at the natural spillway gap. It was decided, as the result of inspection and the quarry and laboratory tests, that this material would not withstand the erosion of a large volume of water pouring over it in cascade form at high velocity. To be used at all for this purpose it would require to be covered from its crest down to the river bed below with a high class of concrete, made of the best selected materials. This construction would have been quite elaborate, extensive, and costly. The material forming the right-hand spur or buttress of the dam site is largely composed of glassy pearlite, or obsidian, much more dense, of higher specific gravity, and superior in its power to resist erosive action. This was therefore chosen as the most suitable site for the spillway, which has been planned with a length of 650 feet, and will consist of a concrete dam of heavy gravity section, in roller way form of crest. The greater portion of the length of this dam will be less than 10 feet in height. The top of the spillway will be 20 feet lower than the crest of the rock-fill dam, and its capacity of discharge will be as follows:

Capacity of spillway.

Depth of overflow.	Second-feet.	Acre-feet in twenty-four hours.
10 feet	73,270	145,000
11 feet	84,400	167,000
12 feet	96,180	191,000
13 feet	108,400	215,000
14 feet	121,200	240,000
16 feet	148,000	294,000
20 feet	206,000	405,000

The volume of capacity of the reservoir being 174,040 acre-feet to the spillway level, it will be seen from the above table that with a depth of overflow of 12 feet the discharging capacity would be a sufficient volume to fill the reservoir in twenty-three hours, and before the rock fill could be overtopped the flow must be double the estimated maximum discharge of the river, as computed by Mr. Davis from highest flood marks—a rate sufficient to discharge in one day almost as much as the mean annual flow of the river during the period of measurements taken by the Department, and sufficient to discharge in a day and a half the maximum total flow of an entire year since observations have begun. Surely greater conservatism could not be shown than this, and it may be safely concluded that the spillway provision, the lack of which has been so often fatal to the stability of dams, has been ample in these plans.

RESERVOIR OUTLETS.

The service outlets of the reservoir have been provided for in the plans by large cast-iron pipes embedded in concrete in a short tunnel cut through the narrow spur of hard pearlite rock on the left bank. This plan offers the most stable and permanent form of construction, and one that is always satisfactory. The method of controlling the discharge of water is by means of a tower provided with numerous elbows at varying levels, whose upturned mouths are closed with plain cast-iron covers. Inside the tower at the mouth of the tunnel the outlet pipes are controlled by balanced valves, whose operation is so simple and certain that one man can readily open or close them. At the outer side of the dam a third system of control can be applied by attaching gate valves to the outer ends of the pipes if it were ever necessary or desirable.

DISTRIBUTION.

It is proposed to release the water into the channel of the river at the dam and pick it up again at the points of diversion below. For the supply of the Indian reservation this diversion can be made as it always has been made in the past until such time as the demand for water will justify the construction of permanent head works near the Buttes and a proper canal to carry the water away from those head works. It would be wasteful and improvident to run the water of the reservoir in the broad, sandy bed of the Gila for the 22 miles from the head of the Florence Canal to the reservation, for it is in this stretch of the river that the loss by absorption is very great. Such a disposition of the stored supply could not be considered as a permissible permanent arrangement, although, until the demand for water were great enough outside the reservation to justify the construction of permanent canals and head works to avoid the waste, the river channel might be used and an abundance of water delivered from the reservoir to supply the Indians.

The Florence Canal is properly located to take water from the river channel at a point where all water turned in from a reservoir above could be picked up and conveyed to the public lands that can be irrigated as well as to the reservation. To serve this enlarged purpose new and permanent headworks should be built, the canal should be enlarged and extended with large laterals reaching to the reservation as well as to the greater territory of fertile public lands that may be watered from the reservoir outside the Indian lands.

Summarizing the general results of the investigation of the Buttes dam site, it appears that a safe dam can be built at this point in three years' time, at a cost of approximately $2,600,000, which would store water to a maximum depth of 150 feet, in a reservoir covering 3,149 acres of surface, and impounding 174,040 acre-feet of water, or 36 per cent of the mean annual flow of the river at this point, the dam having a maximum height of 293 feet above lowest foundations. To construct a dam which would store the minimum yearly supply, or 353,000 acre-feet, would necessitate about 40 feet increase in height, which is not deemed feasible at this site.

THE RIVERSIDE DAM SITE.

The survey of the reservoir basin at the Riverside site developed the fact that its capacity is very great. At the height of 153 feet above low water in the stream it can be made to store double the quantity of water that can be impounded at the Buttes at the 150-feet contour. This height was the limit of the survey. The topography of the site will permit of an indefinite extension of the height, limited only by practical bounds of safe construction. With 170 feet depth at the dam, the capacity would probably exceed 500,000 acre-feet, and at a height of 200 feet the indications are that the capacity would be over 650,000 acre-feet. These enormous figures are difficult to comprehend. Comparing them with the maximum yearly discharge that has been observed in the river since measurements began, the reservoir at the height of 200 feet would bottle up the entire river for one year. A dam of this height would be entirely feasible of construction and comparatively moderate in cost for a work of that magnitude.

The bed rock at the abutments and foundations, as revealed by the surface croppings and diamond-drill borings, is of hard granite weighing 157 pounds per cubic foot. No better foundations could be desired. The site is better adapted to a structure of masonry than any other type. The rock available for construction is eminently suitable for masonry or concrete of the class best adapted for dams. The maximum depth to bed rock was found to be 75.5 feet, the minimum depth was 6.1 feet, and the mean 44.3 feet of the 11 holes that reached bed rock. The materials composing the river bed are much coarser here than at the Buttes, and the underflow must be materially greater. This condition will augment the difficulties of excavation for foundations, as the percolation of water into a pit would be great in volume. It is believed, however, that the grouting process is applicable to this location, although the injection pipe could not be forced down to bed rock with equal facility. The coarser bowlders and gravel lie next to bed rock, but if the pit could be kept open by holding back the sand that would seek to slip into it, the chief source of annoyance and expense would be overcome. This much at least could be accomplished by grouting a zone of 30 or 40 feet thickness across the channel above and below the dam site as deep as the injection pipes could readily be inserted.

The height of dam adopted for the estimate was 133 feet above the stream bed, which gives a capacity of 221,134 acre-feet in the reservoir, or about 47,000 acre-feet more capacity at the Buttes at the 150-feet contour, and 20,000 acre-feet less than the San Carlos reservoir at maximum height of 130 feet. The very considerable width of the canyon at this point, requiring a dam 350 feet long at bottom, 850 feet long at top, and the fact that an overflow weir dam seemed best adapted to the situation, account for the large volume of masonry in the 133-feet dam, amounting to 186,147 cubic yards. In order to be able to reduce the section and volume of the dam it would be necessary to excavate spillways at each end in solid rock, where the slopes are so abrupt that the maximum depth of cutting would be over 100 feet to secure the width of spillway-channel required. What advantage might be gained in this way would be overcome by the cost of refilling the spillways with masonry when the dam was raised to the ultimate height.

The existence of valuable copper mining claims within the Riverside reservoir basin, and the recent addition of costly improvements in the way of reduction works for the Ray copper mines on the river, with a railway down Mineral Creek from the mines to the works, offer so many obstacles to the utilization of this reservoir site at the present time that it can only be regarded as available in the future, when it becomes desirable to provide further storage on the river, or when the mines have been worked out and exhausted. For present consideration, the cost of dam at this site, while much less expensive than that of the Buttes, compares so unfavorably with the dam projected 40 miles higher up the river at San Carlos Canyon, that even were the site free from right-of-way complications the upper location would naturally be preferred. It is assumed that it is the desire and purpose of the Government to provide water storage for the Indians at this time in the cheapest and most efficient manner possible.

THE SAN CARLOS DAM.

The thorough exploration of the Gila River above the Buttes, made by Mr. C. C. Babb, assistant hydrographer, in the spring of 1899, resulted in the discovery of a dam and reservoir site below the junction of the San Carlos River with the Gila, which subsequent surveys have proven to surpass all other sites on the watershed of the river, not only for capacity of reservoir, but for cheapness and feasibility of construction of the dam. The site had never before been explored, suggested, or known to exist, and its discovery is a notable achievement accomplished by the present investigation which appears to offer a simple solution to the grave problem presented to the Geological Survey by the act of Congress which imposed that duty upon this Department. The achievement justifies the responsibility assumed by the engineers in broadening the scope of the investigation and going beyond the latitude of the instructions conveyed by the act of Congress which prescribed the examination of and report upon the Buttes dam and the Queen Creek project alone. The discovery of the Riverside site would have been a sufficient justification, as it is in every way preferable to the Buttes—better in the matter of foundations, materials of construction, capacity of reservoir, and less costly—but the San Carlos is as far superior to the Riverside site as the latter is superior to the Buttes.

Comparing the dam sites at Riverside and San Carlos, the latter is in general terms one-third to one-fourth the width of the former, requiring about one-half of the volume of masonry, with about the same maximum depth to bed rock, as far as ascertained, and with a quality of rock for foundations, abutments, and construction purposes of higher specific gravity, greater density, and superior resistance to erosion.

The reservoir basin is also of greater capacity, with a slightly lower dam. The site for the dam is one which is eminently suitable for the erection of a masonry structure of the highest type. No other class of dam has been considered for this site, as it fulfills all requisites of stability in a more satisfactory manner than any other type that could be built and can be made as enduring as time. The plan of dam and the form and dimensions best fitted to the peculiar conditions there existing have been given careful study by all the engineers engaged upon it and, as presented in the drawings accompanying Mr. Lippincott's report, is believed to be well designed and located in the most advantageous position available.

The situation permitted of the extension of the abutment walls of the dam to such a length as to allow what is believed to be ample spillway capacity around the ends of the main dam without overtopping its crest. The capacity thus provided exceeds 57,000 cubic feet per second, with a depth of 12.5 feet in the spillways. Three feet additional depth would give a capacity exceeding 79,000 second-feet in the spillways and 4,000 second-feet over the body of the dam. There appears to be a doubt as to the volume of maximum floods in the Gila and a lack of reliable data regarding it. Attention is called in previous pages of this report to the disproportion between the assumed maximum flood discharge of 100,000 second-feet, as computed from measurements of flood marks by Mr. A. T. Colton, quoted in Mr. Davis's report of 1896, and the maximum annual discharge of the river, which would be made up in three days at the rate of 100,000 cubic feet per second. If the river ever reaches such a high rate of discharge it must be but a few hours at a time, and possibly but a portion of an hour, while the crest of the flood wave is passing.

The equalizing effect of the storage area in a large reservoir above the crest of the spillway would tend to modify the overflow at the dam to discharge very much below the assumed maximum. For example, the San Carlos reservoir could receive a flood of 100,000 second-feet (assuming it to be full when the flood wave reached it), flowing for nearly two hours before the depth over the spillways was more than 1 foot, and the maximum would have to be maintained for about twenty-four hours before the spillways were filled to the level of the top of the dam, and in the twenty-four hours the amount of discharge would be equivalent to one-half the mean annual discharge of the river, as determined by all the gaugings that have been made. This is so impossible that it is almost a demonstrable certainty that the dam proper would never be called upon to pass any water over its crest. The writer entertains the conviction that no more than 25,000 second-feet will ever be wasting over the dam at one time, unless the climate of Arizona is changed to that of western Oregon or Washington. In his opinion, therefore, the spillway provision is ample.

The estimate of cost of the dam, including damage to the buildings of the Indian agency and military post, the construction of a new system of irrigation for the Apache Indians higher up the river, and the removal and reconstruction of the railroad that now passes through the basin, is $1,015,927. This figure is a very liberal one. It includes $150,000 for the excavation of foundations, which is at the rate of nearly $5 per cubic yard for the material that would have to be taken out if a tight cofferdam were sunk to bed rock at the upper and lower toe of the dam. The estimate of $6 per cubic yard for the concrete masonry may appear low for a locality so remote that railroad freights from the seaboard bring the cost of Portland cement to about $8 per barrel. (This latter figure is used for safety on the basis of present quotations on freights, although when actual construction begins it is confidently believed that special rates may be made on large quantities that will be materially lower.)

The method proposed of regrinding cement with silica sand in equal parts and producing a product commercially known as "sand cement," as recommended by Mr. E. Duryee, C. E., in his report, offers the possibility of such a material reduction in the volume of cement necessary as to justify the figure used in the estimate—of $6 per cubic yard for first-class concrete masonry. The writer is personally familiar with the product called "sand cement;" has investigated its manufacture and tested it, and fully indorses its use in the dam in the manner proposed. The article was first brought out in Copenhagen some years ago by an engineer named F. L. Smidth, who obtained patents in Europe and this country on the tube mills used to grind it and the general principle involved in its manufacture. The tube mill consisting of a steel cylinder, is usually some 4 feet in diameter, 16 feet long, lined with cast-iron plates, and provided with longitudinal ribs a few inches in height. Several barrels of hard flint pebbles, 2 to 3 inches in diameter, usually obtained from Iceland, are placed in the cylinder, which is slowly revolved, then the dried sand and cement are fed into one end of the cylinder and in passing through are ground to exceeding fineness by the action of the pebbles, which are carried up the side of the cylinder with the cement by the longitudinal ribs, and in falling pulverize the finer material between them. The entire grinding is accomplished in passing once through the cylinder, and the finished product emerges in a constant stream at the opposite end from which the material is fed into it. Sand cement is coming into very general use in Russia, France, Australia, and South Africa, and in this country there are several plants in operation, one of which, located in Brooklyn, N. Y., manufactures 500 barrels per day. It was used in lining the canal of the new hydraulic laboratory at Cornell University, where it was particularly essential that there should be no breakage. The remarkable fineness and density of the cement made with it rendered its use especially applicable to this situation, where perfect water-tightness was desired.

Mr. George M. Newcomer, vice-president of F. L. Smith & Co., writes, under date of July 12, 1899:

> Any good clean sand will make good sand cement. At the Long Island City plant we are manufacturing regularly each day more than 500 barrels of sand cement from the dust secured at a limestone quarry where crushed stone for concrete purposes is one of the main products. These goods, in 1:1 proportions, test higher than the actual silica cement. This is probably due to the fact that, being softer than silica, it grinds much finer. Therefore please abandon the idea that pure silica is of any distinct advantage.

The tests of silica cement given in Mr. Duryee's report are confirmatory of the many published tests of the manufacturers of the article, and all prove that a superior quality of concrete can be made of it. The greater number of tests given by Mr. Duryee were made with cement manufactured at Colton, Cal., and a silica rock obtained near each of the Gila River dam sites. They make a creditable showing for the Colton cement as compared with standard brands of cement imported from Europe. If the high standard here shown can be maintained with absolute uniformity, the local product should be regarded as entitled to consideration in work of this character.

Outlets.—The plan of outlets for the San Carlos reservoir is the same as that described from the Buttes, except that the outlet pipes pass through the masonry of the dam instead of through a tunnel cut in the solid rock. The arrangement for control of the water through a tower is the same, except that two towers are provided at the San Carlos. When construction details are planned, it may be considered desirable to modify the arrangement of outlets shown on the preliminary plans to provide for the utilization of the very considerable power which will be manifestly available, and which should be made a source of revenue. Otherwise the plans are sufficiently complete for the purpose of providing the storage required and the means of releasing the water to the stream channel, by which it will be conveyed to the reservation. For the purpose of sluicing silt from the reservoir, it will be desirable to utilize the working tunnel mentioned in the estimate, by which the low water is to be carried around the excavation during construction, and make it large enough to serve as the sluicing channel, providing it with gates easily controlled.

THE SILT PROBLEM.

The determination of the probable volume of silt carried in suspension by the water of the Gila reveals the fact that the river carries on the average about 2 per cent of solid matter. This great load of sediment is exceeded by few rivers in the world. Some determinations on the gauges have shown that it carries at flood about 26 per cent, and several of the northern California rivers, during the progress of hydraulic mining, were found to carry 3.3 to 3.5 per cent, according to the samples taken by the State engineering department of California in 1878. The Mississippi in flood carries 0.12 to 0.17 per cent, and as the average of twelve months, 0.05 to 0.08 per cent; the Rhone, 0.43 per cent; the Nile, 0.15 per cent; the Indus, 0.18 to 0.50 per cent.

Mr. Lippincott's estimate[1] is that the mean annual solids carried past San Carlos is equivalent to 8,740 acre-feet. This quantity, expressed in more familiar terms, is equal to 14,100,000 cubic yards, which gives a more adequate comprehension of the magnitude of the problem of silt disposal in the construction of reservoirs, wherein the greater portion of the load carried by the river will inevitably be deposited.

It would seem to be essential in planning any reservoir on the Gila to prepare for the ultimate construction of the highest dam which is practicable to be built at the site. This ultimate height appears to have been reached at the Buttes in the dam there projected, which would be filled in eighteen years. At Riverside safe construction can be carried to a height of at least 200 feet above the stream bed, which would give a probable capacity of 650,000 acre-feet and require sixty-seven years to fill with sediment. At San Carlos a dam of 200 feet high above the stream bed is entirely practicable and would furnish a

[1] Water Supply and Irrigation Paper No. 33, U. S. Geological Survey.

storage capacity of approximately 550,000 acre-feet. This would require sixty-three years to fill at the estimated rate of deposit. The raising of the dam to its ultimate height offers the cheapest practicable disposal of the silt for the period of its life of utility, and to this end all future plans should be made. The land should be segregated below the extreme elevation to which the water might ever require to be raised by increasing the dam to its ultimate height and permanent improvements upon it avoided or prevented.

Finally, when the time came that this remedy was exhausted and the capacity of the reservoir area actually needed were being encroached upon, steps could be taken for sluicing out the silt by the construction of a by-pass channel and by hydraulic dredging. The latter process could be accomplished at a cost of 2 to 4 cents per cubic yard. This would put an annual tax of $2.50 to $5 per acre upon the land irrigated, which might by that time be borne with equanimity. The power available from the dam should, however, have a commercial value sufficient to bear this burden. It is now salable at the rate of $100 per horsepower per annum. Five thousand horsepower, net, delivered electrically to the neighboring mining regions, should command a price sufficient to do the work of dredging required annually. These suggestions are not of immediate value or application. The problem is one which future generations must meet and solve. The way is indicated, which leaves the question capable of solution when the time comes. The most urgent need for the present is to reserve all of the sites on the river for future utilization to their utmost practical limit of capacity.

One of the advantages possessed by the San Carlos site which has not been mentioned, but which has been recognized throughout the investigation, lies in the fact that it is above the mouth of the San Pedro River, which is known to carry a much heavier percentage of silt than any other tributary of the Gila. The silt determinations have been at the Buttes, below the San Pedro, hence the percentage of sediment computed for San Carlos may be slightly in excess of the truth. The watershed above San Carlos is 75 per cent of the area tributary to the Buttes, but the run-off at San Carlos is estimated at 90 per cent. The remaining 10 per cent is contributed by the San Pedro, Mineral Creek, and other minor channels, but chiefly by the San Pedro. The comfort to be obtained from this source is therefore small, and whatever the San Pedro may bring down in the way of sediment, even where it is several times the average of the main Gila, its relative discharge is so small that the estimate of the probable burden of the waters at San Carlos can not be greatly reduced. Direct determinations of the silt passing the San Carlos are highly important, however, and should be systematically carried on.

THE GILA AS AN IRRIGATION CONDUIT.

The possible losses by evaporation and infiltration in the 60 miles of river channel below San Carlos have not been overlooked in this investigation, and the canyon was carefully examined at low water between San Carlos and the Buttes. It was found that the flow of the stream was practically undiminished all the way down, and that while the loss from evaporation was considerable it was about balanced by the underflow or seepage coming in from the tributary drainage area between these points. The subject is intelligently discussed in Mr. Lippincott's report, and the conclusion is reached that for all practical purposes there are no disadvantages in storing the water supply at San Carlos, 60 miles above the Buttes, and no more loss of water to be anticipated than if the reservoir were located at the Buttes; also that the flood discharge of the stream below San Carlos will be available for diversion below the Buttes during a portion of the year, and when such diversion is thus made the storage at San Carlos need not be drawn upon, which will increase the duty of the San Carlos reservoir.

These conclusions are fully concurred in by the writer as sound and well based.

SEEPAGE MEASUREMENTS.

The growth of the river through the Solomonville Valley above San Carlos, resulting largely from the return waters of irrigation percolating back to the streams through the soil, as determined by the measurements of Mr. Cyrus C. Babb and detailed in his report, is one of the most instructing and interesting features of the present investigation. Mr. Babb found the total increase in 40 miles of the valley to be 153.8 second-feet, or 3.8 second-feet per mile. If this rate of percolation were maintained throughout the year, the annual volume thus returning to the river would be 111,400 acre-feet. This rate, however, can not be expected to continue through the entire year, although the contribution to the stream probably never ceases entirely. If the addition from this source be assumed as averaging about 50,000 acre-feet per annum, its importance can not be overestimated. If the irrigation of the 20,000 acres is capable of producing results of such magnitude, the complete irrigation of the valley above San Carlos should yield a much greater supply.

Not the least important feature of this augmentation of the stream is the fact that the water comes back to it clear and free from silt. This fact may offer a partial future solution of the silt problem, for if the clear water could thus be gathered and the silt-ladened river carried around the reservoir at times of maximum floods, the dilution of the water in the reservoirs by the clear seepage water would materially reduce the volume of silt which would have to be provided for. At present, however, the seepage water as it appears and augments in volume is successfully diverted and applied to the land again and again and the net gain to the river at low-water stage is not apparent at San Carlos.

GENERAL CONCLUSIONS AND RECOMMENDATIONS.

Summarizing the net results of the investigation the conclusions to be drawn are as follows:

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

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

Third. That the Gila River is the only available source of permanent supply.

Fourth. 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 of capacity on account of the rapidity with which a small reservoir must be filled with silt.

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

Sixth. 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.

Seventh. That feasible reservoir and dam sites exist on the Gila, at The Buttes, Riverside, and San Carlos.

Eighth. 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.

Ninth. That a combination rock fill and masonry dam is feasible to construct 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.

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

Eleventh. 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.

Twelfth. 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.

Thirteenth. 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.

Fourteenth. 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.

Fifteenth. That provisions 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.

Sixteenth. 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.

Seventeenth. That the working plans of 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.

Eighteenth. 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 to 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 reserviors and storage dams on the Gila River.

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