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CONSERVATION OF THE WATERS OF THE COLORADO RIVER FROM THE STANDPOINT OF THE RECLAMATION SERVICE[1]

THE Colorado River Basin includes the largest river system lying entirely within the arid region. Its average annual discharge is nearly 18,000,000 acre-feet and it drains 244,000 square miles of territory, nearly all in the United States, less than one per cent. of the area and an insignificant part of the water coming from Mexico. The basin lies in seven different states of the Union and all of them can and should receive benefit from the use of its waters. The trunk stream was navigated for many years from the gulf northward a distance of over 400 miles and before the advent of railroads this navigation was important. It has recently been largely abandoned but the stream is technically and actually navigable. Most of the course of the main stream is in the United States, but for a distance of about 20 miles it forms the boundary between Mexico and Arizona and for about 80 miles flows through Mexican territory. It is therefor an international stream, an interstate stream, and a navigable stream. The waters of the stream not heretofore appropriated to private use are the property of the United States government and the lands necessary for its proper development and use are mainly public lands. Its problems and their administration are therefore distinctly national.

Like most of the streams of the world the discharge of the Colorado River varies greatly in volume. Its low water discharge frequently falls below 5,000 cubic feet per second, and its flood sometimes peaks above 200,000 cubic feet per second. Numerous small valleys are

[1] Presented at the joint meeting of the American Association for the Advancement of Science and the Pacific Division, Salt Lake City, June 23, 1922.

irrigated from the tributaries of the Colorado River and their aggregate use of its waters is very important. The largest valley which the Colorado irrigates is the Imperial Valley in southern California. Smaller diversions from the river are in the Palo Verde Valley of California and the Yuma Valley of Arizona. These valleys can of course receive only the waters left after the diversion in the basin above and in years of low water the entire available flow of the river is utilized in the lower valleys. A much larger quantity is needed to fully develop these valleys and this can not be secured without the storage of the flood flow at some point above. Hence arises the problem of the conservation of the waters of the Colorado River.

This problem has been under investigation by the Reclamation Service ever since the year of its organization, 1902. In this it has had the cooperation of the Geological Survey in the measurement of streams and of the Agricultural Department in the examination of soils. The investigation has been carried on in all parts of its vast basin, many dam sites have been explored with diamond drill, and the results have been condensed in various reports, the latest and most comprehensive of which has been recently published as Senate Document No. 142 entitled "Problems of Imperial Valley and vicinity."

The topography of the Colorado River Basin is admirably adapted to the conservation of its waters and their use for power. Several good reservoir sites have been found at advantageous locations. The main stream below its junction with Green River has a total fall of nearly 4,000 feet to sea level, fully three fourths of which are physically capable of being developed for power, and the greater portion of the waters of the basin can be made available for use in this stretch. The main trunk of Green River above the junction falls over 2,000 feet and the upper fork or Grand River has a fall of nearly 4,000 feet. The average potential power in the basin at present is over 8,000,000 horse power. Some of this is unavailable for development for various reasons and some of the water will ultimately be consumed in irrigation, so that the ultimate available is about 6,000,000 horse power, of which more than two thirds is on the main stream, mostly within the state of Arizona or on its boundaries.

During the past twenty years many engineering examinations of the main stream of the Colorado River have been made by power interests, with a view to the estimation of its power possibilities, and though these were uniformly reported as great, the engineers have until recently agreed in the conclusion that there was no available market; but the markets have been growing and the feasibility of transmitting large blocks of power has also been improving. It is believed that the time has at last arrived when the development of power on the lower Colorado River has become feasible at such points as are most accessible and nearest to adequate markets.

The use of the waters of the Colorado for irrigation presents problems of considerable difficulty. Most of the river is in canyons where no valleys are adjacent and its use in irrigation is impossible. In the lower reaches the river has formed some alluvial valleys which are in part being irrigated by the natural flow of the stream, but which for full development require a much larger flow of water than is available in the late summer and fall. The present irrigated area can be more than trebled if the water supply is conserved and the complete regulation of the river will furnish a supply greater than the available valley areas. Their reclamation, however, presents great engineering difficulties and imposes upon those lands heavy charges for construction which would be difficult if not impossible for settlers to pay if the entire burden of the conservation and diversion had to be borne by those settlers. Fortunately, however, the conservation for power purposes will so nearly fit with the requirements for irrigation that the utility of the storage sites for the development of power may be utilized as an asset to defray the expenses of regulating the river and thus through the power asset render feasible irrigation enterprises that would not otherwise be feasible.

One of the greatest, and by far the most pressing problems on the Colorado, is the control of the mighty floods that are sometimes furnished by its drainage basin and which annually threaten to overwhelm and destroy the valleys in its lower reaches. Problems of this kind are presented on every large river flowing through alluvial valleys, but the case of the Colorado is unique and the flood problem is far more important and imminent than usually is the case. This situation is due to the peculiar topographic conditions of the valleys which the river serves.

The Gulf of California formerly extended northwestward to a point a few miles above the town of Indio, about 144 miles from the present head of the gulf. The Colorado River, emptying into the gulf a short distance south of the present international boundary, carried its heavy load of silt into the gulf for centuries, gradually building up a great delta cone entirely across the gulf and cutting off its northern end, which remains as a great depression from which most of the water has been evaporated, leaving in its bottom the Salton Sea of 300 square miles, with its surface about 250 feet below sea level.

The river flowing over its delta cone steadily deposits silt in its channel and by over flow on its immediate banks, so that it gradually builds up its channel and its banks and forms a ridge growing higher and higher until the stream becomes so unstable that it breaks its banks in the highwater period and follows some other course. In this manner the stream has in past centuries swung back and forth over its delta, until this exists as a broad, flat ridge between the gulf and the Salton Sea, about 30 feet above sea level, and on the summit of this the river flows at present, the water finding its way to the southward into the gulf.

The direct distance from Andrade on the Colorado River, where it reaches Mexico, to the head of the gulf is about 75 miles, and the distance to the margin of Salton Sea is but little more. As that latter is about 250 feet lower than the gulf, the strong tendency to flow in that direction needs no demonstration. This, coupled with the inevitable necessity for such an alluvial stream to leave its channel at intervals, constitutes the menace of the lands lying about Salton Sea, called the Imperial Valley. As there is no escape of water from Salton Sea except by evaporation, the river flowing into this sea would, unless diverted, gradually fill it to sea level or above and submerge the cultivated land and the towns of Imperial Valley, nearly all of which are below sea level. Any flood waters that overflow the bank to the north must therefore without fail be restrained and not allowed to flow northward into Salton Sea. This is now prevented by a large levee, north of Volcano Lake, extending eastward and connecting with high land near Andrade. This levee is in Mexico and its maintenance is complicated thereby.

In 1905 the river scoured out the channel of the Imperial Canal and turned its entire volume into the Salton Basin, eroding a deep gorge and raising the level of Salton Sea. It submerged the salt works and forced the removal of the main line of the Southern Pacific Railroad. At great difficulty and expense, after several unsuccessful attempts, the river was returned to its old channel in February, 1907. The control of the river would be greatly facilitated if the floods were reduced in volume by storage. Investigations have been made concerning the feasibility of storing the floods and reducing their volume to an amount easily controlled.

The regulation of the Colorado River has been examined and discussed a great deal. Some engineers have expressed opinions that the storage of the waters of the Colorado should be accomplished entirely in the upper basin and on the tributaries of the river because in those regions good storage sites can be found which will intercept the major portion of the water supply and will receive those waters very largely free from sediment and nearly clear, whereas the erosion rapidly in progress throughout the canyon region gradually loads the river with sediment so that the water reaching the reservoir sites below the canyon is heavily laden with sediment. Where the river leaves the canyon region it is estimated that it carries on an average about 80,000 acre-feet of sediment annually.

There are, however, many and serious objections to this plan. Reservoirs above the canyon region, while in the long run intercepting the major portion of the waters, leave unregulated the sudden floods to which the lower and more arid portion is subject. The Gila Basin alone, while comprising less than one fourth of the area of the basin, sometimes furnishes floods which at their maximum may equal or even exceed those of the main stream above its mouth with nearly four times the drainage area and about fifteen times the mean annual discharge. Complete regulation therefore requires the control of the waters of the Gila as well as those of the Colorado, and the same is true of any other large portion of the basin. If we confine storage to the streams above the Arizona line we can intercept over 80 per cent. of the mean annual flow, but we leave unregulated about 150,000 square miles of drainage area or three fifths of the basin. This area while arid and unreliable as to water supply, is, like the Gila Basin, subject to torrential rains and would in the aggregate leave a flood menace that would have to be met in some other way if the lands are to be protected.

It is obvious that the nearer the reservoir can be built to the lands in the lower valley the more complete will be its flood regulation, and it also happens that the lowest reservoir site of adequate capacity, which is at Boulder Canyon, lies at a point within transmission distance of the Pacific Coast and thus renders available for its construction the vast power asset which is not available to any adequate reservoir site existing above this point. Fortunately it is possible here to build a dam as high as may be required and to furnish thereby not only complete regulation of the river flow but a surplus capacity which will store the sediment for centuries to come without impairing the head on the power plants to be served therefrom. In the distant future it will become necessary to furnish additional storage by building reservoirs above, but this requirement will be more than a century away and in that time certain regulation of the river is likely to be accomplished by reservoirs on its tributaries and the problem can be easily and practically met when it arises.

Investigations have demonstrated the feasibility of building a dam of sufficient height to form a reservoir in Boulder Canyon of more than 30,000,000 acre-feet capacity, which is more than actually required to accomplish the proposed solution of the conservation problems that are now imminent. The feasibility and perfection of this accomplishment and the economy with which it will conserve the waters of the Colorado River for their best uses, are in strong contrast to the results that would be obtained by reservoirs in the upper basin. Good sites for storage and the development of power exist on the Green, the Grand and the Yampa, all of which have been carefully surveyed by the Reclamation Service, and their possibility established. These reservoirs could be built one at a time as needed and individually would cost much less than a large reservoir on the lower river, but if their construction were undertaken to meet the present needs of the lower valleys, they would necessarily be operated in accordance with those needs and this would destroy their usefulness for power development and irrigation in the upper basin where they are needed and for which purposes there are no substitutes. To attempt such a solution would therefore interpose obstacles of a legal and financial nature to the proper development of the upper states and virtually destroy a large part of the potential resources of those states because most of the projects would become infeasible if loaded with the additional burdens of the extinguishing rights which such a program would establish. The preservation of the resources of the upper states and the elimination of serious obstacles to their development is the strongest argument in favor of storage on the lower river and the preservation of the reservoir sites in the upper basin for local use. It is thus seen that the conservation and proper use of the waters of the Colorado Basin are in some sense one great problem which must be considered as a whole, otherwise there is danger of virtual destruction of natural resources by throwing obstacles in the way of the development which at best is in many cases difficult and expensive.

The recognition of this relation has led to common action on the part of the seven states affected and of the Congress of the United States, which has provided for a commission to consider the equitable division of the waters of the Colorado River. On this commission the United States is represented by its chairman, Honorable Herbert Hoover, secretary of commerce, whose ability and fidelity to public duty are recognized in every household of the land. It is hoped that under his leadership an agreement can be reached among the states which can be ratified by the United States and which will provide for the full use of the waters of the Colorado River without imposing unbearable burdens on any part of the basin nor destroy any of its resources.

In order to make a large storage reservoir in the lower basin financially feasible, it will be necessary to charge the major portion of the cost of the storage dam to power. The development of power and irrigation are closely related in that the amount of power which it is practicable to develop depends largely upon the extent of the development of the irrigable lands in the entire drainage basin. The extremely arid and semi-tropic character of the lands in the lower Colorado Basin makes it necessary to irrigate throughout the year and irrigation requirements therefore conform more nearly to the requirements for power than do those in northern latitudes. The capacity of the reservoir provided for power purposes will depend wholly on the relation of its cost to the value of additional power obtainable therewith.

As the point of complete utilization of the streams is approached, the excess water will occur in such widely separated periods as to require a disproportionate amount of storage for its utilization. It has been assumed that all the water must primarily be conserved for irrigation use. By utilizing the minimum head on the turbines as determined by silt storage in the entire Colorado River Basin, 600,000 firm horsepower of electric energy can be developed at Boulder Canyon and 700,000 horsepower is feasible with the same reservoir in connection with the full development of the irrigable lands in the upper basin and about 1,500,000 acres in the lower basin which it is practicable to develop in the near future. In either case there will be a large amount of secondary power which will be of considerable value. Installation of a power plant to develop a large amount of power may be desirable for the reason that although the development of the upper basin will doubtless proceed steadily it will be a long time before the full development is reached. The immense amount of power to be generated and the variable head under which the turbines will be required to work will make the Boulder Canyon plant one of the most remarkable ever built. Under present plans the power house would be located on the downstream toe of the dam in the event a gravity dam is built, or along the canyon wall below the dam if an arch dam is constructed.

Among the more important reservoir sites in the upper basin which have been carefully investigated by the Reclamation Service are the following: the Flaming Gorge on the Green River, where a dam 327 feet high would create a reservoir with storage capacity of 4,000,000 acre feet; the Juniper on the Yampa River, where a dam 268 feet high would create a reservoir of 1,500,000 acre feet capacity; the Dewey located on the Grand River with a dam 275 feet high, which would create a reservoir of 2,270,000 acre feet capacity. The foundations of these sites have been tested with diamond drill and the foundations are known to be satisfactory.

The choice of a reservoir site on the lower Colorado River depends upon numerous factors of which a few may here be enumerated:

First, for flood control the reservoir should be as near the area to be protected as possible.

Second, for irrigation with ultimate supply but little in excess of demands, control must be had as near the ultimate diversion as possible for the prevention of waste due to inability to coordinate demand and supply.

Third, the generation of power, incidental to irrigation operations, should be carried on as near as possible to its market.

Fourth, the site should be as close to established railroads as possible to cut down construction costs.

Fifth, with due allowance for costs the reservoir should be as deep as possible in order to expose the minimum possible area for evaporation losses and prevent waste of water thereby.

Sixth, lowest possible cost giving due weight to other considerations.

From all data available to date, the Black or Boulder Canyon sites, only 18½ miles apart by river, seem to fill the above requirements more nearly than any other site or sites which have been found.

The proper size of the reservoir is a matter not yet fully determined, the factors entering into this feature being irrigation storage, flood detention storage, silt storage and power development.

The maximum capacity so far considered is 31,400,000 acre feet, including 5,000,000 acre feet of silt storage, 11,400,000 acre feet for irrigation storage, 10,000,000 acre feet for power development and 5,000,000 acre feet for flood control. Other capacities considered have varied from 8,000,000 acre feet up to the maximum. Recent estimates include a reservoir, with dam located in Black Canyon to store 23,500,000 acre feet, which would leave a 200 foot head available for the development of power between this reservoir and the so-called Diamond Springs power project.

If built for flood control purposes alone, a reservoir with capacities of 5,000,000 and 8,000,000 acre feet is estimated to be sufficient to hold discharges at Yuma due to upstream floods down to 75,000 and 50,000 second feet respectively except in rare instances. In connection with a reservoir for irrigation purposes, the addition of 5,000,000 acre feet storage for flood control alone is expected to provide the desired reduction in floods.

In order to visualize the size of the reservoir to be impounded it may be said that in case of the largest reservoir considered, the lake when full will have a surface of 240 square miles and will be about 90 miles long, with a 40 mile arm extending up the Virgin River. If all the water in the reservoir were to be discharged through a conduit 10 feet in diameter at the rate of 10 feet per second it would require six years to empty the reservoir provided no water entered it during that time and neglecting evaporation losses.

A great many preliminary designs and estimates have been prepared of various types of dam for both Boulder and Black Canyons in connection with various plans for the development of power. The conclusion reached is that a dam of the gravity type, built on a curved plan, is the most conservative in design and best suited to a dam of such unprecedented height.

The dam in Boulder Canyon proposed for the largest reservoir considered would be 600 feet high above the present low water surface in the river and 750 feet from the lowest point in the foundation to the highest point on the dam. This would be more than twice the height of Arrowrock Dam, which is 348½ feet high and which, at present, is the highest dam in the world. The length on top would be approximately 1,250 feet and at the bottom the dam would be nearly as long up and down stream as it is high. The amount of concrete required to build the dam and appurtenant structures with a reasonable allowance for contingencies is roughly estimated at 4,700,000 cubic yards. This would be four times the concrete contained in Arrowrock and Elephant Butte dams combined, and if used to build a column 100 feet in diameter, the height of the column would be three miles and would weigh 9½ million tons.

The preliminary estimate of the cost of this dam is about $58,500,000. About 700,000 firm horsepower could be generated with a power plant costing $28,000,000 and the transmission line will cost about $20,500,000 more, or a total of about $107,000,000.

In connection with the dam, it is proposed to provide outlet capacity for the discharge of 25,000 second feet of water for irrigation use and a spillway capacity of 200,000 second feet with water surface in the reservoir 10 feet below the top of the dam. Under conditions of extreme floods the latter will be increased to 300,000 second feet at the time the water surface in the reservoir reaches the top of the dam. As a part of the spillway it is proposed to provide an opening at the bottom of the flood storage with no provision for closure. By this means water would start discharging as soon as the reservoir is full to the top of the irrigation storage and would continue to discharge as long as there is any water in the space provided for flood detention. This permanent opening would prevent encroachment upon that portion of the reservoir provided for flood detention and will be so designed as not to allow water to pass in excess of the capacity of the levee system in the lower basin.

Excellent dam sites exist in both canyons and after examining them in February, 1921, Dr. F. L. Ransome of the United States Geological Survey pronounced them as geologically feasible for the construction of a high dam.

Probably the most difficult task to be encountered in the construction of a dam on the Colorado River is the turning of the river during construction of the foundation and considerable thought has been given to this feature. A study of the hydrograph of the Colorado at Yuma over the period 1902 to 1921 shows that, if the discharge at Boulder Canyon is assumed to approximate that at Yuma with the exception of the flash peaks thrown into the river from the Gila, a diversion works of 50,000 second feet capacity would have been overtopped every year of the twenty and that the average time of submergence would have been about 11 per cent. of the total, the maximum being about 84 days in 1920 and the minimum 2 days in 1904.

Diversion works of 75,000 second feet capacity would not have been overtopped during nine of the twenty years. The average time of submergence would have been 5 per cent. of the total, the maximum being about 50 days in 1907 and 1909.

Seven of the twenty years of record show peaks of from 115,000 to 190,000 second feet at times occurring in two successive years. In 1920 the peak was 190,000 second feet, while in 1921 it reached 185,700 feet, and the present year promises to be one of high discharge.

With so great an amount of work to be done in excavating and laying concrete below water surface in so short a season it is essential that diversion works of ample capacity be provided to avoid being flooded out, thus losing much valuable time. It is therefore considered necessary to provide for diverting the river during years of ordinary high water and it is proposed to design the works with a capacity of 150,000 second feet. The years 1920 and 1921 are the only ones of record when the discharge exceeded 150,000 second feet at Yuma and it is thought that the expenditure necessary to increase the capacity of the diversion works above 150,000 second feet is unwarranted. Diversion would be by means of cofferdams and tunnels through the rock abutments of the main dam.

In order that the diversion problem may be properly attacked and in order that methods to be used in construction of the dam may be properly worked out, diamond drilling operations to ascertain foundation conditions at the possible dam sites were commenced in September, 1920, and are still under way. To date three sites have been investigated in a preliminary way and considerable detail information has been obtained at one of them. A total of 88 holes have been put down including approximately 3,500 feet of wash borings and 2,100 feet of diamond drilling. The results of the investigations at Boulder Canyon indicate that bed rock will be found at depths not to exceed 140 feet below low water surface. At Black Canyon, bed rock in the deepest hole drilled to date was found at a depth of 62 feet below low water surface. However, the investigations have not been carried far enough for it to be said that this is the maximum depth to bed rock at the Black Canyon site.

The following recommendations by Director Davis conclude his report as provided for in the Kincaid Act:

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

2. It is recommended that the public lands that can be reclaimed by such works be reserved for settlement by ex-service men under conditions securing actual settlement and cultivation.

3. It is recommended that through suitable legislation the United States undertake the construction with government funds of a reservoir at or near Boulder Canyon on the lower Colorado

River, to be reimbursed by the revenues from leasing the power privileges incident thereto.

4. It is recommended that any state interested in this development shall have the right at its election to contribute an equitable part of the cost of the construction of the reservoir and receive for its contribution a proportionate share of power at cost to be determined by the secretary of the interior.

5. It is recommended that the secretary of the interior be empowered after full hearing of all concerned to allot the various applicants their due proportion of the power privileges and to allocate the cost and benefits of a highline canal.

6. It is recommended that every development hereafter authorized be required in both construction and operation to give priority of right and use:

First, to river regulation and flood control.
Second, to use of storage water for irrigation.
Third, to development of power.

These recommendations have been embodied in a House bill by Representative Swing of California, introduced April 25, 1922. This bill provides for an advance of $70,000,000 to the reclamation fund to be used for the construction of the Boulder Canyon dam and the Imperial Valley system to be repaid to the general treasury in accordance with the Reclamation Act of 1902.

F. E. WEYMOUTH
U. S. RECLAMATION SERVICE

THE ELECTOR PLAN FOR THE ADMINISTRATION OF RESEARCH FUNDS[1]

ONE of the most effective uses of wealth for the good of mankind lies in the wise encouragement of the search for truth through sustained scientific investigation.

A history of the methods followed through the last two hundred years reveals an astonishing record of unwise provisions in wills and bequests and shows that only in the last few years have economic and legal authorities devoted systematic efforts to the organization of permanent trust funds given for benevolent purposes.

During the last few years, the Community Trust movement has developed a valuable type of organization. The result of this plan has been most gratifying. To cite a single example, in the first six years of its existence, the Cleveland Foundation accumulated a fund of more than one hundred million dollars.

The specific interests of research in science have not yet enjoyed any such encouragement or facilitation through the organization of general public interest. With but slight exceptions, donors are left to hit or miss methods of organization and without appropriate encouragement or aid.

It would therefore seem timely to present an outline of a method of organization which shall be safe and permanent, flexible and adjustable to changing conditions, simple and economic of operation, and inviting as a means of disposing of wealth in the service of science and the establishment of a monument to commemorate some cherished object or ideal.

The plan should be devised to meet the changing conditions of the times, conceding to each succeeding generation the largest measure of ability to administer its own affairs, and should afford the opportunity for the maintenance of some broad, scientific project in which the donor is interested, while, at the same time, granting great flexibility in the meeting of unforeseen future contingencies. It should avoid specifically those methods of organization which history has shown to be undesirable, particularly as to methods of perpetuating the governing board, the designation of objects to be served, and the safeguarding of the capital. It should utilize legal and economic principles which in recent investigations have been pronounced sound.

The approval and promulgation of some plan by recognized scientific bodies should give a new significance and opportunity to the ownership of wealth and should furnish an incentive for generosity in the disposal of a fortune,

[1] The present note is a skeletal outline of a preliminary report prepared by the writer as chairman of the Committee on the Stabilizing of Scientific Funds. The committee is continued for further work on this problem and welcomes discussion and criticism of the plan from those who are interested in the allocation of funds in trust from wills, bequests, or grants for the encouragement of scientific investigation and service.