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COLORADO RIVER DEVELOPMENT

COLORADO RIVER INVESTIGATIONS
WATER STORAGE AND POWER DEVELOPMENT
GRAND CANYON TO THE IMPERIAL VALLEY

PRESENTED BY MR. ODDIE

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COLORADO RIVER INVESTIGATIONS

FOREWORD

In view of the rather extended discussion and series of reports relative to the development of the lower Colorado River, it is deemed advisable at this time to compile and have for ready reference all of the investigations made in connection with this development.

This work has been undertaken by George W. Malone, State engineer of Nevada and secretary of the Colorado River Commission of that State.

Reports reviewed for this compilation include the annual reports of the Bureau of Reclamation; the Weymouth report, consisting of nine volumes; Water Supply Papers No. 395 and No. 556, by E. C. La Rue; the Fall-Davis report, Senate Document No. 142; the Arizona Engineering Commission report, and various congressional hearings from the Sixty-seventh to the Sixty-ninth Congress, inclusive; and work by Louis C. Hill, consulting engineer, Los Angeles, Calif.; A. J. Wiley, consulting engineer, Boise, Idaho; F. L. Ransome, consulting geologist, Los Angeles, Calif.; H. W. Crozier, San Francisco, Calif.; Thomas R. King, consulting engineer, Reno, Nev.; J. C. Jones, consulting geologist, University of Nevada, Reno, Nev.; Stanley Palmer, consulting electrical engineer, University of Nevada, Reno, Nev.; Maxwell Adams, dean of the chemistry department and vice president of the University of Nevada, Reno, Nev.; and the Colorado River board, appointed by the Secretary of the Interior and approved by the President, with the following members: Maj. Gen. William T. Sibert, Charles P. Berkey, Daniel W. Mead, Warren J. Mead, and Robert Ridgway.

Mr. Malone is president of the Western Association of State Engineers, comprising 17 Western States—Kansas, Nebraska, South Dakota, North Dakota, Oklahoma, Texas, New Mexico, Colorado, Wyoming, Montana, Idaho, Utah, Arizona, Nevada, Washington, Oregon, and California. He is also a member of the public service commission for Nevada, major in the One hundred and fifteenth Engineers, Fortieth Division, and national vice commander of the American Legion.

The work is a summation of the authentic investigations and hearings held in connection with the development of the Colorado River from the Grand Canyon in Arizona to the Imperial Valley in California. It is not intended that full data be given in this report but references are given so that supporting data can be readily obtained.

BIBLIOGRAPHY

Weymouth Report; 9 volumes, Government report made up at a cost, including field investigations, of nearly $400,000, and is the last word in Government reports on the Colorado River. The writer has a copy of this report.

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Lower Colorado River water and power set-up, George W. Malone, Carson City, Nev.

Boulder Canyon and Colorado River Development, George W. Malone, Carson City, Nev.

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The following letters have been received from A. J. Wiley, Louis C. Hill, J. C. Jones and Maxwell Adams. They are included for the benefit of the record.

BOISE, IDAHO, *December 7, 1928.*

Mr. GEORGE W. MALONE,
Mayflower Hotel, Washington, D. C.

MY DEAR SIR: Replying to your inquiry for a copy of a letter which I wrote you about September 18, regarding the Boulder Canyon Dam, I regret that I am unable to find a copy of that letter, but will give you the information which you desire in this.

With reference to my experience in hydraulic work, I will have to refer you to the 1928–29 volume of Who's Who, but wish you would correct the information in that by substituting for consulting engineer in the Department of Agriculture, consulting engineer in the Department of the Interior. You might also add that during the year 1928 I have been engaged on a commission appointed by the Governor of California to investigate the causes leading to the failure of the St. Francis Dam; also, I have been a member of commission to report upon the safety of all the dams and reservoirs of the city of Los Angeles; also a member of a commission reporting upon the safety of the dams and reservoirs of the city of San Diego. I have also reported upon the safety of half of all the dams built by the Bureau of Reclamation. I have also acted as a member of the board of engineers and geologists to report upon the partial failure of the Lafayette Dam of the city of Oakland.

Acting as consulting engineer for the Bureau of Reclamation, I have taken part in all the investigations with regard to the Boulder Canyon and Black Canyon Dams. In this capacity I have made several trips of inspection to the above-mentioned dam sites and have spent a considerable time in the Denver office of the Bureau of Reclamation assisting in the design and estimates of the various dams and power plants for both sites.

My investigations with respect to the feasibility of the dams and power plants included the construction methods and costs as well as the designs of the various features of the work.

From the above you will be able to see that I approve of the conclusions both as to cost and feasibility of the so-called Weymouth report on the development of the Colorado River by a dam and power plant at the Black Canyon site.

Trusting that the above will answer your purpose, I remain,

Yours very sincerely,

A. J. WILEY.

LOS ANGELES, CALIF., *September 20, 1928.*

Mr. GEORGE W. MALONE,
State Engineer, State of Nevada,
Carson City, Nev.

DEAR MR. MALONE: Your letter reached here a few days ago when I was out of the city.

To answer some of your questions: My first connection with the development of the Colorado River was when I first entered the Reclamation Service in 1903. I was then directed to report on possible reservoir sites and lands which could be irrigated in northwest Colorado, and among other things investigated was the possibility of storing water on the Grand River. When I became supervising engineer there was placed in my territory all the drainage of the Colorado and the Rio Grande. One of the first things done on the Colorado River, outside of the building of the diversion dam at Laguna, was the investigation of storage sites on the Colorado and its branches. At that time, no thought existed in anybody's mind, so far as I am aware, that a reservoir site could be found on the lower Colorado. Dams of the height necessary were not then conceived of. Investigations had been started by borings on the Colorado River at its junction with the Green. These borings, however, were not run down far enough to make sure at what depth bedrock was available, and further work on this dam site and reservoir site was practically abandoned. This was just after I left the service in 1914.

The next investigation in regard to the lower river which came to my attention was when Homer Hamlin came into the office and wanted to know whether it would be possible to build a dam as high as 500 or 600 feet in the Colorado River canyon near where the present Boulder dam site is located. I told him that it was, and he went back and reported to Washington that he had found a reservoir site. Investigations of the dam site and reservoir site and the Black Canyon site had progressed for some time before I was called in as a member of a consulting board.

We visited both dam sites twice, made certain recommendations, suggested the general designs of the dams at each place, and went over in general the method of diversion and handling of the water during construction.

This is one thing that I want to call to your attention right now. You will probably find many a statement as to the great difficulty the United States is going to have if it builds a dam in the Colorado River in the neighborhood of Boulder or Black Canyon, but you will find very little criticism of the plans of the private power companies which have made the same kind of suggestions. The same amount of water runs in the river practically from the Lees Ferry site to below Black Canyon, and there is no particular reason that I know of why a private individual should have any better luck than a contractor for the Government will have in diverting the river.

The records of the river are well known for long periods, and it can readily be figured out about how large a diversion tunnel must be built around any dam site and about how high the diversion dam must be in order to by-pass the water during construction. No one would think for a moment of trying to build a diversion tunnel or diversion works to handle the greatest floods that pass down the Colorado River. If one of these floods come along it is going to fill up your excavation and do considerable damage, but it doesn't pay in any construction job, of course, to figure on diverting the greatest floods which may occur. They occur so seldom that it does not pay to attempt to protect against them. If a large enough force is put on the job, after the diversion tunnel is completed and work is started on the diversion dam and is up high enough so that all the normal water flow can be diverted, then the work on the diversion dam and foundation excavation can start simultaneously. If no greater floods than can be normally expected pass down the river, then the equipment is ample, bedrock can be reached, and some concrete placed before the next year's floods. If the next year's floods happen to be normal, or not much greater than normal, it probably will be by-passed safely and the foundation then will be brought up a long ways toward the surface. If, however, the flood is abnormal and goes over the fills and excavation, it is just too bad but it can't be helped and you just have to go down and excavate until you reach the concrete that you were able to place in the year previous. This is the way you have to do anyway on most of these western streams, as you well know.

The contractor on the Salt River project had to go only 35 feet to bedrock and it took a year and a half before he was able to place his first rock. In this time he had floods that ran from 50,000 to 60,000 second-feet and one that ran from 125,000 to 135,000 second-feet. After that year he didn't have any more trouble; that is, he didn't have any more trouble that delayed him. He had trouble enough—he had water going over the top of the dam for months, I don't know but a year at a time, but he worked on other parts of it.

In studying both sites—that is, both Boulder Canyon Reservoir sites—we investigated the locations for yards, roughed out a general idea as to the size of the plant required, how much material would have to be moved per day, the character of plant probably best adapted to it, and made what we considered a liberal allowance for the cost of diverting the river and putting in the foundation. After that the building of the dam is practically nothing but a manufacturing proposition.

In addition to studying these two dam sites we made a trip to the only other sites talked about at that time; that is, on the Colorado River above the mouth of the Paria, up near Lees Ferry. There were two or three dam sites up there, but the character of the rock is such that in none of the places would a high dam be justified. The rock was too soft.

Mr. Ransome, the geologist, spent a long time in investigating the geology at the two lower dam sites and also the geology of the basin, as we were not certain but what there might be some possibility of leakage out of this basin, although we did not really believe there was.

Since our last trip for the Government I have been retained by private individuals or companies. I visited both dam sites as a member of a board of which General Goethals and Mr. W. G. Clark were the other two members.

The Reclamation Service engineers have ample experience in all kinds of different jobs of this character, so that their estimates of cost ought to be as good as those of any contractor or group of engineers. I know of no organization in the United States which has built more dams than the Reclamation Service, and their estimates are usually justified by the actual cost.

I am sending you a copy of my professional experience. I will be very glad to do anything possible to help in this work.

Sincerely yours,

LOUIS C. HILL.

THE MACKAY SCHOOL OF MINES,
UNIVERSITY OF NEVADA,
Reno, Nev., November 27, 1928.

Mr. GEORGE W. MALONE,
Secretary Colorado River Commission for Nevada,
Mayflower Hotel, Washington, D. C.

DEAR SIR: After a visit to the Boulder and Black Canyon dam sites and a review of the reports of Doctor Ransome and Mr. Jennison on the geology of the region I submit the following conclusions:

1. The topography of the region is ideal for both dam sites and reservoirs. Both Boulder and Black Canyons are narrow, with vertical walls giving an opportunity to construct high dams with a minimum amount of material. The relatively narrow valleys above both sites will give deep reservoirs of large capacity with moderate area of water surface and with a consequent minimum annual loss through evaporation.

2. At both dam sites the rocks exposed in the canyon walls have abundant strength to support the dam with a large factor of safety. At Boulder Canyon the rocks are granitic, of exceptionally high strength, impervious, and with shallow jointing. The few faults present run at right angles to the canyon, are effectively sealed and impervious, and while slightly weaker than the wall rocks, show no evidence of recent movement. There is no evidence indicating a fault parallel to the canyon and much evidence to show that no fault exists in the canyon followed by the river. The rock is fresh within 10 feet of the surface and a cut of that depth will effectively seat the core wall of the dam and make it water-tight.

At Black Canyon the rock is an andesitic breccia, a lava extending to a great depth below the river and forming an impervious barrier to seepage below the dam. The rock is less jointed than the granite at Boulder Canyon and a 10-foot cut will be in fresh rock and effectively seat the core wall. Few faults are present and as at Boulder Canyon all extend across the canyon at approximately right angles to the river. There is no evidence of a fault down the canyon followed by the river.

3. The proposed reservoirs are impervious and there is little likelihood of leakage around the dams. The presence of bodies of salt and gypsum in the clays of Virgin Valley that will be submerged suggests that some increase in the salinity of the water stored may result. Gypsum is relatively insoluble and such small

amount as is dissolved by the water will be of benefit to lands irrigated by the water through the beneficial effect of the calcium in loosening up the soil. In any event the total salinity of the water in the reservoir will be but slightly increased due to the large volume of water in the reservoir as compared with the slight area of gypsum exposed and its insolubility. Salt, on the other hand is easily soluble but the bodies of salt are largely buried beneath clays and silts that will so hinder the dissolving of the salt that little will go into solution. In a few areas the salt appears on the surface in cliffs. As the salt is dissolved the clays above will slump and eventually no salt will be exposed. The maximum effect will be observed during the first year of the filling of the reservoir. Even then the areas of the salt exposed is such a small fraction of the volume of water in the reservoir and the rate of diffusion of the dissolved salt in the quiet water will be so slow the actual increase in the salinity of the stored water will be slight and in no case will it possibly render the water unfit for either irrigation or domestic purposes.

4. As the Pacific coast is subject to earthquakes, the possibility of damage through earth movement must be considered. In a study of the distribution of earthquakes in Nevada and California we find that the region surrounding the dam sites is unusually stable, and we have no record of an earthquake having originated in the surrounding area in recent years. Such earthquakes as have been felt in the Las Vegas region have originated in districts 150 miles or more distant. Damage from earthquakes is limited to the immediate vicinity of the active faults. As has been shown by Doctor Ransome, there is much evidence to show that none of the faults in the vicinity of the dam sites have moved for centuries at least. The broad alluvial fans extending high up on the mountains of southern Nevada indicate little or no recent movement of the faults along which the mountains were elevated and are in distinct contrast to the narrow fans and abrupt slopes of the mountains of northern Nevada, where the faults occasionally move.

The nearest active areas at present are Imperial Valley, Owens Valley, and northern Nevada. These are too far distant from the dam sites to cause damage even at the time of the most severe earthquakes that have been experienced. The actual movement of the earth at the dam sites during one of these distant quakes is less than a hundredth of an inch, and by properly locating the dam so that no fault line crosses it and securely anchoring the dam to the canyon walls it will vibrate in unison with the block supporting the dam and no damage can result from the slight movement of the earth. Study of earthquake damage in localities suffering severe shocks shows that structures that are built so as to vibrate as a unit suffer little damage, and if buildings and other structures can be built to withstand severe shocks unharmed, it is reasonable to believe that the dam can be so constructed and located that the minute tremors experiences in the Las Vegas region will be harmless.

5. I wish to concur in the more elaborate reports reviewed, and can say that everything I observed in the field accorded with the observations of Doctor Ransome and Mr. Jennison. Their reports give a fair, unbiased account of the geological features of the project.

Sincerely yours,

J. C. Jones,
Professor of Geology and Mineralogy, University of Nevada.

University of Nevada,
Reno, Nev., November 28, 1928.

Mr. George W. Malone,
State Engineer, Carson City, Nev.

My Dear Mr. Malone: I have conferred with Professor Jones and have examined the Weymouth report on the Colorado River and note the estimate given in Volume V relative to the amount of salt in the basin of the Boulder Canyon Reservoir.

While the amount of salt estimated to be present is very large, approximately 26,000,000 tons, the reservoir is also very large, 34,000,000 acre-feet. If the salt were all dissolved at once, it would not raise the per cent of salt above the tolerance of one-half of 1 per cent, which is the maximum for irrigation waters set by Hilgard and others.

I believe the general conclusions arrived at by the report on page 157 to be sound because only a small part of the salt is now exposed, and as that dissolves the sediment contained in this impure salt would gradually cover the beds until the solution would be very slow. If the water were percolating through these beds of salt of course they would all in time be leached out, but where a layer of salt and sediment overlies the bed the diffusion would be very slow.

Very truly yours,

MAXWELL ADAMS,
Dean College of Arts and Science.

In view of the above statement it is readily seen that the amount of salt that would be dissolved would not affect to an injurious extent the water supply in a reservoir of 26,000,000 acre-feet capacity.

PRESENT STATUS OF THE PROJECT

The Boulder Canyon project act becomes effective June 21, 1929, six months after its passage, by virtue of the six-State compact, and it is assumed that Congress will make the money available for construction at their regular session, 1929–30.

It is expected that the branch railroad from the Union Pacific Railroad to the dam site will be constructed during the fall and winter of 1929, most of the work being undertaken by the Union Pacific.

Definite arrangements have not been made, but it is expected that highway construction will be undertaken from Las Vegas to the dam site. This road may be constructed as a part of the project, since it is considered a proper charge against the construction fund, because the Government will need prompt and efficient stage service for express, light freight and labor turnover.

It is estimated that a maximum of 10,000 horsepower of electric energy will be required for use during the construction period. Private corporations will be allowed to bid for furnishing this power, and if prices offered are not satisfactory the Government may build its own plant.

A concrete gravity type dam, curved in plan, is proposed.

Excavations must be made to a maximum of 125 feet below the river bed to solid rock.

A cofferdam must be constructed above and below the dam site and tunnels excavated through the solid rock to divert a maximum of 200,000 second-feet of water around the site (according to the "Colorado River Board" report) before excavation may begin.

It is anticipated that a maximum of approximately 2,500 men may be employed during the construction period, employing perhaps 300 or 400 at the start of the work; the number depends largely on the construction methods employed.

Volume of material in dam, exclusive of cement	cu. yds.	5, 120, 000
Volume of concrete in dam	do	3, 560, 000
Cement in dam	barrels	4, 000, 000
Capacity of reservoir	acre-feet	26, 000, 000
Height of dam	feet	550
Power developed, installed capacity	horsepower	1, 000, 000
Power developed, firm, load factor 55 per cent	do	550, 000

It is estimated that power will be ready for delivery at the switchboard within 5 or 6 years after the first contracts are let.

BOULDER CANYON PROJECT ACT

[PUBLIC—No. 642—70TH CONGRESS]

[H. R. 5773]

AN ACT To provide for the construction of works for the protection and development of the Colorado River Basin, for the approval of the Colorado River compact, and for other purposes

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

SEC. 2. (a) There is hereby established a special fund, to be known as the "Colorado River Dam fund" (hereinafter referred to as the "fund"), and to be available, as hereafter provided, only for carrying out the provisions of this act. All revenues received in carrying out the provisions of this act shall be paid into and expenditures shall be made out of the fund, under the direction of the Secretary of the Interior.

(b) The Secretary of the Treasury is authorized to advance to the fund, from time to time and within the appropriations therefor, such amounts as the Secretary of the Interior deems necessary for carrying out the provisions of this act, except that the aggregate amount of such advances shall not exceed the sum of $165,000,000. Of this amount the sum of $25,000,000 shall be allocated to flood control and shall be repaid to the United States out of 62½ per centum of revenues, if any, in excess of the amount necessary to meet periodical payments during the period of amortization, as provided in section 4 of this act. If said sum of $25,000,000 is not repaid in full during the period of amortization, then 62½ per centum of all net revenues shall be applied to payment of the remainder. Interest at the rate of 4 per centum per annum accruing during the year upon the amounts so advanced and remaining unpaid shall be paid annually out of the fund, except as herein otherwise provided.

(c) Moneys in the fund advanced under subdivision (b) shall be available only for expenditures for construction and the payment of interest, during construction, upon the amounts so advanced. No expenditures out of the fund shall be made for operation and maintenance except from appropriations therefor.

(d) The Secretary of the Treasury shall charge the fund as of June 30 in each year with such amount as may be necessary for the payment of interest on advances made under subdivision (b) at the rate of 4 per centum per annum accrued during the year upon the amounts so advanced and remaining unpaid, except that if the fund is insufficient to meet the payment of interest the Secretary of the Treasury may, in his discretion, defer any part of such payment, and the amount so deferred shall bear interest at the rate of 4 per centum per annum until paid.

(c) The Secretary of the Interior shall certify to the Secretary of the Treasury, at the close of each fiscal year, the amount of money in the fund in excess of the amount necessary for construction, operation, and maintenance, and payment of interest. Upon receipt of each such certificate the Secretary of the Treasury is authorized and directed to charge the fund with the amount so certified as repayment of the advances made under subdivision (b), which amount shall be covered into the Treasury to the credit of miscellaneous receipts.

SEC. 3. There is hereby authorized to be appropriated from time to time, out of any money in the Treasury not otherwise appropriated, such sums of money as may be necessary to carry out the purposes of this act, not exceeding in the aggregate $165,000,000.

SEC. 4 (a). This act shall not take effect and no authority shall be exercised hereunder and no work shall be begun and no moneys expended on or in connection with the works or structures provided for in this act, and no water rights shall be claimed or initiated hereunder, and no steps shall be taken by the United States or by others to initiate or perfect any claims to the use of water pertinent to such works or structures unless and until (1) the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming shall have ratified the Colorado River compact, mentioned in section 13 hereof, and the President by public proclamation shall have so declared, or (2) if said States fail to ratify the said compact within six months from the date of the passage of this act then, until six of said States, including the State of California, shall ratify said compact and shall consent to waive the provisions of the first paragraph of Article XI of said compact, which makes the same binding and obligatory only when approved by each of the seven States signatory thereto, and shall have approved said compact without conditions, save that of such six-State approval, and the President by public proclamation shall have so declared, and, further, until the State of California, by act of its legislature, shall agree irrevocably and unconditionally with the United States and for the benefit of the States of Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming, as an express covenant and in consideration of the passage of this act, that the aggregate annual consumptive use (diversions less returns to the river) of water of and from the Colorado River for use in the State of California, including all uses under contracts made under the provisions of this act and all water necessary for the supply of any rights which may now exist, shall not exceed four million four hundred thousand acre-feet of the waters apportioned to the lower basin States by paragraph (a) of Article III of the Colorado River compact, plus not more than one-half of any excess or surplus waters unapportioned by said compact, such uses always to be subject to the terms of said compact.

The States of Arizona, California, and Nevada are authorized to enter into an agreement which shall provide (1) that of the 7,500,000 acre-feet annually apportioned to the lower basin by paragraph (a) of Article III of the Colorado River compact, there shall be apportioned to the State of Nevada 300,000 acre-feet and to the State of Arizona 2,800,000 acre-feet for exclusive beneficial consumptive use in perpetuity, and (2) that the State of Arizona may annually use one-half of the excess or surplus waters unapportioned by the Colorado River compact, and (3) that the State of Arizona shall have the exclusive beneficial consumptive use of the Gila River and its tributaries within the boundaries of said State, and (4) that the waters of the Gila River and its tributaries, except return flow after the same enters the Colorado River, shall never be subject to any diminution whatever by any allowance of water which may be made by treaty or otherwise to the United States of Mexico but if, as provided in paragraph (c) of Article III of the Colorado River compact, it shall become necessary to supply water to the United States of Mexico from waters over and above the quantities which are surplus as defined by said compact, then the State of California shall and will mutually agree with the State of Arizona to supply, out of the main stream of the Colorado River, one-half of any deficiency which must be supplied to Mexico by the lower basin, and (5) that the State of California shall and will further mutually agree with the States of Arizona and Nevada that none of said three States shall withhold water and none shall require the delivery of water, which can not reasonably be applied to domestic and agricultural uses, and (6) that all of the provisions of said tri-State agreement shall be subject in all particulars to the provisions of the Colorado River compact, and (7) said agreement to take effect upon the ratification of the Colorado River compact by Arizona, California, and Nevada.

(b) Before any money is appropriated for the construction of said dam or power plant, or any construction work done or contracted for, the Secretary of the Interior shall make provision for revenues by contract, in accordance with the provisions of this act, adequate in his judgment to insure payment of all expenses of operation and maintenance of said works incurred by the United States and the repayment, within fifty years from the date of the completion of said works, of all amounts advanced to the fund under subdivision (b) of section 2 for such works, together with interest thereon made reimbursable under this act.

Before any money is appropriated for the construction of said main canal and appurtenant structures to connect the Laguna Dam with the Imperial and Coachella Valleys in California, or any construction work is done upon said canal or contracted for, the Secretary of the Interior shall make provision for revenues, by contract or otherwise, adequate in his judgment to insure payment of all expenses of construction, operation, and maintenance of said main canal and appurtenant structures in the manner provided in the reclamation law.

If during the period of amortization the Secretary of the Interior shall receive revenues in excess of the amount necessary to meet the periodical payments to the United States as provided in the contract, or contracts, executed under this act, then, immediately after the settlement of such periodical payments, he shall pay to the State of Arizona 18¾ per centum of such excess revenues and to the State of Nevada 18¾ per centum of such excess revenues.

Sec. 5. That the Secretary of the Interior is hereby authorized, under such general regulations as he may prescribe, to contract for the storage of water in said reservoir and for the delivery thereof at such points on the river and on said canal as may be agreed upon, for irrigation and domestic uses, and generation of electrical energy and delivery at the switchboard to States, municipal corporations, political subdivisions, and private corporations of electrical energy generated at said dam, upon charges that will provide revenue which, in addition to other revenue accruing under the reclamation law and under this act, will in his judgment cover all expenses of operation and maintenance incurred by the United States on account of works constructed under this act and the payments to the United States under subdivision (b) of section 4. Contracts respecting water for irrigation and domestic uses shall be for permanent service and shall conform to paragraph (a) of section 4 of this act. No person shall have or be entitled to have the use for any purpose of the water stored as aforesaid except by contract made as herein stated.

After the repayments to the United States of all money advanced with interest, charges shall be on such basis and the revenues derived therefrom shall be kept in a separate fund to be expended within the Colorado River Basin as may hereafter be prescribed by the Congress.

General and uniform regulations shall be prescribed by the said Secretary for the awarding of contracts for the sale and delivery of electrical energy, and for renewals under subdivision (b) of this section, and in making such contracts the following shall govern:

(a) No contract for electrical energy or for generation of electrical energy shall be of longer duration than fifty years from the date at which such energy is ready for delivery.

Contracts made pursuant to subdivision (a) of this section shall be made with a view to obtaining reasonable returns and shall contain provisions whereby at the end of fifteen years from the date of their execution and every ten years thereafter, there shall be readjustment of the contract, upon the demand of either party thereto, either upward or downward as to price, as the Secretary of the Interior may find to be justified by competitive conditions at distributing points or competitive centers, and with provisions under which disputes or disagreements as to interpretation or performance of such contract shall be determined either by arbitration or court proceedings, the Secretary of the Interior being authorized to act for the United States in such readjustments or proceedings.

(b) The holder of any contract for electrical energy not in default thereunder shall be entitled to a renewal thereof upon such terms and conditions as may be authorized or required under the then existing laws and regulations, unless the property of such holder dependent for its usefulness on a continuation of the contract be purchased or acquired and such holder be compensated for damages to its property, used and useful in the transmission and distribution of such electrical energy and not taken, resulting from the termination of the supply.

(c) Contracts for the use of water and necessary privileges for the generation and distribution of hydroelectric energy or for the sale and delivery of electrical energy shall be made with responsible applicants therefor who will pay the price fixed by the said Secretary with a view to meeting the revenue requirements herein provided for. In case of conflicting applications, if any, such conflicts shall be resolved by the said Secretary, after hearing, with due regard to the public interest, and in conformity with the policy expressed in the Federal water power act as to conflicting applications for permits and licenses, except that preference to applicants for the use of water and appurtenant works and privileges necessary for the generation and distribution of hydroelectric energy, or for delivery at the switchboard of a hydroelectric plant, shall be given, first, to a State for the generation or purchase of electric energy for use in the State, and the States of Arizona, California, and Nevada shall be given equal opportunity as such applicants.

The rights covered by such preference shall be contracted for by such State within six months after notice by the Secretary of the Interior and to be paid for on the same terms and conditions as may be provided in other similar contracts made by said Secretary: *Provided, however*, That no application of a State or a political subdivision for an allocation of water for power purposes or of electrical energy shall be denied or another application in conflict therewith be granted on the ground that the bond issue of such State or political subdivision, necessary to enable the applicant to utilize such water and appurtenant works and privileges necessary for the generation and distribution of hydroelectric energy or the electrical energy applied for has not been authorized or marketed, until after a reasonable time, to be determined by the said Secretary, has been given to such applicant to have such bond issue authorized and marketed.

(d) Any agency receiving a contract for electrical energy equivalent to one hundred thousand firm horsepower, or more, may, when deemed feasible by the said Secretary, from engineering and economic considerations and under general regulations prescribed by him, be required to permit any other agency having contracts hereunder for less than the equivalent of twenty-five thousand firm horsepower, upon application to the Secretary of the Interior made within sixty days from the execution of the contract of the agency the use of whose transmission line is applied for, to participate in the benefits and use of any main transmission line constructed or to be constructed by the former for carrying such energy (not exceeding, however, one-fourth the capacity of such line), upon payment by such other agencies of a reasonable share of the cost of construction, operation, and maintenance thereof.

The use is hereby authorized of such public and reserved lands of the United States as may be necessary or convenient for the construction, operation, and maintenance of main transmission lines to transmit said electrical energy.

SEC. 6. That the dam and reservoir provided for by section 1 hereof shall be used: First, for river regulation, improvement of navigation, and flood control; second, for irrigation and domestic uses and satisfaction of present perfected rights in pursuance of Article VIII of said Colorado River compact; and third, for power. The title to said dam, reservoir, plant, and incidental works shall forever remain in the United States, and the United States shall, until otherwise provided by Congress, control, manage, and operate the same, except as herein otherwise provided: *Provided, however*, That the Secretary of the Interior may, in his discretion, enter into contracts of lease of a unit or units of any Government-built plant, with right to generate electrical energy, or, alternatively, to enter into contracts of lease for the use of water for the generation of electrical energy as herein provided, in either of which events the provisions of section 5 of this act relating to revenue, term, renewals, determination of conflicting applications, and joint use of transmission lines under contracts for the sale of electrical energy, shall apply.

The Secretary of the Interior shall prescribe and enforce rules and regulations conforming with the requirements of the Federal water power act, so far as applicable, respecting maintenance of works in condition of repair adequate for their efficient operation, maintenance of a system of accounting, control of rates and service in the absence of State regulation or interstate agreement, valuation for rate-making purposes, transfers of contracts, contracts extending beyond the lease period, expropriation of excessive profits, recapture and/or emergency use by the United States of property of lessees, and penalties for enforcing regulations made under this act or penalizing failure to comply with such regulations or with the provisions of this act. He shall also conform with other provisions of the Federal water power act and of the rules and regulations of the Federal Power Commission, which have been devised or which may be hereafter devised, for the protection of the investor and consumer.

The Federal Power Commission is hereby directed not to issue or approve any permits or licenses under said Federal water power act upon or affecting the Colorado River or any of its tributaries, except the Gila River, in the States of Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona, and California until this act shall become effective as provided in section 4 herein.

Sec. 7. That the Secretary of the Interior may, in his discretion, when repayments to the United States of all money advanced, with interest, reimbursable hereunder, shall have been made, transfer the title to said canal and appurtenant structures, except the Laguna Dam and the main canal and appurtenant structures down to and including Syphon Drop, to the districts or other agencies of the United States having a beneficial interest therein in proportion to their respective capital investments under such form of organization as may be acceptable to him. The said districts or other agencies shall have the privilege at any time of utilizing by contract or otherwise such power possibilities as may exist upon said canal, in proportion to their respective contributions or obligations toward the capital cost of said canal and appurtenant structures from and including the diversion works to the point where each respective power plant may be located. The net proceeds from any power development on said canal shall be paid into the fund and credited to said districts or other agencies on their said contracts, in proportion to their rights to develop power, until the districts or other agencies using said canal shall have paid thereby and under any contract or otherwise an amount of money equivalent to the operation and maintenance expense and cost of construction thereof.

Sec. 8. (a) The United States, its permittees, licensees, and contractees, and all users and appropriators of water stored, diverted, carried, and/or distributed by the reservoir, canals, and other works herein authorized, shall observe and be subject to and controlled by said Colorado River compact in the construction, management, and operation of said reservoir, canals, and other works and the storage, diversion, delivery, and use of water for the generation of power, irrigation, and other purposes, anything in this act to the contrary notwithstanding, and all permits, licenses, and contracts shall so provide.

(b) Also the United States, in constructing, managing, and operating the dam, reservoir, canals, and other works herein authorized, including the appropriation, delivery, and use of water, for the generation of power, irrigation, or other uses, and all users of water thus delivered and all users and appropriators of waters stored by said reservoir and/or carried by said canal, including all permittees and licensees of the United States or any of its agencies, shall observe and be subject to and controlled, anything to the contrary herein notwithstanding, by the terms of such compact, if any, between the States of Arizona, California, and Nevada, or any two thereof, for the equitable division of the benefits, including power, arising from the use of water accruing to said States, subsidiary to and consistent with said Colorado River compact, which may be negotiated and approved by said States and to which Congress shall give its consent and approval on or before January 1, 1929; and the terms of any such compact concluded between said States and approved and consented to by Congress after said date: *Provided*, That in the latter case such compact shall be subject to all contracts, if any, made by the Secretary of the Interior under section 5 hereof prior to the date of such approval and consent by Congress.

Sec. 9. That all lands of the United States found by the Secretary of the Interior to be practicable of irrigation and reclamation by the irrigation works authorized herein shall be withdrawn from public entry. Thereafter, at the direction of the Secretary of the Interior, such lands shall be opened for entry, in tracts varying in size but not exceeding one hundred and sixty acres, as may be determined by the Secretary of the Interior, in accordance with the provisions of the reclamation law, and any such entryman shall pay an equitable share in accordance with the benefits received, as determined by the said Secretary, of the construction cost of said canal and appurtenant structures; said payments to be made in such installments and at such times as may be specified by the Secretary of the Interior, in accordance with the provisions of the said reclamation law, and shall constitute revenue from said project and be covered into the fund herein provided for: *Provided*, That all persons who have served in the United States Army, Navy, or Marine Corps during the war with Germany, the war with Spain, or in the suppression of the insurrection in the Philippines, and who have been honorably separated or discharged therefrom or placed in the Regular Army or Navy Reserve, shall have the exclusive preference right for a period of three months to enter said lands, subject, however, to the provisions of subsection (c) of section 4, act of December 5, 1924 (Forty-third Statutes at Large, page 702); and also, so far as practicable, preference shall be given to said persons in all construction work authorized by this act: *Provided further*, That in the event such an entry shall be relinquished at any time prior to actual residence upon the land by the entryman for not less than one year, lands so relinquished shall not be subject to entry for a period of sixty days after the filing and notation of the relinquishment in the local land office, and after the expiration of said sixty-day period such lands shall be open to entry, subject to the preference in this section provided.

SEC. 10. That nothing in this act shall be construed as modifying in any manner the existing contract, dated October 23, 1918, between the United States and the Imperial irrigation district, providing for a connection with Laguna Dam; but the Secretary of the Interior is authorized to enter into contract or contracts with the said district or other districts, persons, or agencies for the construction, in accordance with this act, of said canal and appurtenant structures, and also for the operation and maintenance thereof, with the consent of the other users.

SEC. 11. That the Secretary of the Interior is hereby authorized to make such studies, surveys, investigations, and do such engineering as may be necessary to determine the lands in the State of Arizona that should be embraced within the boundaries of a reclamation project, heretofore commonly known and hereafter to be known as the Parker-Gila Valley reclamation project, and to recommend the most practicable and feasible method of irrigating lands within said project, or units thereof, and the cost of the same; and the appropriation of such sums of money as may be necessary for the aforesaid purposes from time to time is hereby authorized. The Secretary shall report to Congress as soon as practicable, and not later than December 10, 1931, his findings, conclusions, and recommendations regarding such project.

SEC. 12. "Political subdivision" or "political subdivisions" as used in this act shall be understood to include any State, irrigation or other district, municipality, or other governmental organization.

"Reclamation law" as used in this act shall be understood to mean that certain act of the Congress of the United States approved June 17, 1902, entitled "An act appropriating the receipts from the sale and disposal of public land in certain States and Territories to the construction of irrigation works for the reclamation of arid lands," and the acts amendatory thereof and supplemental thereto.

"Maintenance" as used herein shall be deemed to include in each instance provision for keeping the works in good operating condition.

"The Federal water power act," as used in this act, shall be understood to mean that certain act of Congress of the United States approved June 10, 1920, entitled "An act to create a Federal Power Commission; to provide for the improvement of navigation; the development of water power; the use of the public lands in relation thereto; and to repeal section 18 of the river and harbor appropriation act, approved August 8, 1917, and for other purposes," and the acts amendatory thereof and supplemental thereto.

"Domestic" whenever employed in this act shall include water uses defined as "domestic" in said Colorado River compact.

SEC. 13. (a) The Colorado River compact signed at Santa Fe, New Mexico, November 24, 1922, pursuant to act of Congress approved August 19, 1921, entitled "An act to permit a compact or agreement between the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming respecting the disposition and apportionment of the waters of the Colorado River, and for other purposes," is hereby approved by the Congress of the United States, and the provisions of the first paragraph of article 11 of the said Colorado River compact, making said compact binding and obligatory when it shall have been approved by the legislature of each of the signatory States, are hereby waived, and this approval shall become effective when the State of California and at least five of the other States mentioned, shall have approved or may hereafter approve said compact as aforesaid and shall consent to such waiver as herein provided.

(b) The rights of the United States in or to waters of the Colorado River and its tributaries howsoever claimed or acquired, as well as the rights of those claiming under the United States, shall be subject to and controlled by said Colorado River compact.

(c) Also all patents, grants, contracts, concessions, leases, permits, licenses, rights of way, or other privileges from the United States or under its authority, necessary or convenient for the use of waters of the Colorado River or its tributaries, or for the generation or transmission of electrical energy generated by means of the waters of said river or its tributaries, whether under this act, the Federal water power act, or otherwise, shall be upon the express condition and with the express covenant that the rights of the recipients or holders thereof to waters of the river or its tributaries, for the use of which the same are necessary, convenient, or incidental, and the use of the same shall likewise be subject to and controlled by said Colorado River compact.

(d) The conditions and covenants referred to herein shall be deemed to run with the land and the right, interest, or privilege therein and water right, and shall attach as a matter of law, whether set out or referred to in the instrument evidencing any such patent, grant, contract, concession, lease, permit, license, right of way, or other privilege from the United States or under its authority, or not, and shall be deemed to be for the benefit of and be available to the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, and the users of water therein or thereunder, by way of suit, defense, or otherwise, in any litigation respecting the waters of the Colorado River or its tributaries.

SEC. 14. This act shall be deemed a supplement to the reclamation law, which said reclamation law shall govern the construction, operation, and management of the works herein authorized, except as otherwise herein provided.

SEC. 15. The Secretary of the Interior is authorized and directed to make investigation and public reports of the feasibility of projects for irrigation, generation of electric power, and other purposes in the States of Arizona, Nevada, Colorado, New Mexico, Utah, and Wyoming for the purpose of making such information available to said States and to the Congress, and of formulating a comprehensive scheme of control and the improvement and utilization of the water of the Colorado River and its tributaries. The sum of $250,000 is hereby authorized to be appropriated from said Colorado River Dam fund, created by section 2 of this act, for such purposes.

SEC. 16. In furtherance of any comprehensive plan formulated hereafter for the control, improvement, and utilization of the resources of the Colorado River system and to the end that the project authorized by this act may constitute and be administered as a unit in such control, improvement, and utilization, any commission or commissioner duly authorized under the laws of any ratifying State in that behalf shall have the right to act in an advisory capacity to and in cooperation with the Secretary of the Interior in the exercise of any authority under the provisions of sections 4, 5, and 14 of this act, and shall have at all times access to records of all Federal agencies empowered to act under said sections, and shall be entitled to have copies of said records on request.

SEC. 17. Claims of the United States arising out of any contract authorized by this act shall have priority over all others, secured or unsecured.

SEC. 18. Nothing herein shall be construed as interfering with such rights as the States now have either to the waters within their borders or to adopt such policies and enact such laws as they may deem necessary with respect to the appropriation, control, and use of waters within their borders, except as modified by the Colorado River compact or other interstate agreement.

SEC. 19. That the consent of Congress is hereby given to the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming to negotiate and enter into compacts or agreements, supplemental to and in conformity with the Colorado River compact and consistent with this act for a comprehensive plan for the development of the Colorado River and providing for the storage, diversion, and use of the waters of said river. Any such compact or agreement may provide for the construction of dams, headworks, and other diversion works or structures for flood control, reclamation, improvement of navigation, division of water, or other purposes and/or the construction of power houses or other structures for the purpose of the development of water power and the financing of the same; and for such purposes may authorize the creation of interstate commissions and/or the creation of corporations, authorities, or other instrumentalities.

(a) Such consent is given upon condition that a representative of the United States, to be appointed by the President, shall participate in the negotiations and shall make report to Congress of the proceedings and of any compact or agreement entered into.

(b) No such compact or agreement shall be binding or obligatory upon any of such States unless and until it has been approved by the legislature of each of such States and by the Congress of the United States.

SEC. 20. Nothing in this act shall be construed as a denial or recognition of any rights, if any, in Mexico to the use of the waters of the Colorado River system.

SEC. 21. That the short title of this act shall be "Boulder Canyon project act."

Approved, December 21, 1928.

REVIEW OF BOULDER CANYON PROJECT ACT

The Boulder Dam legislation provides substantially:

1. That the location of the project shall be at Boulder or Black Canyon. (Sec. 1.)

2. That the purpose of the act is to control floods, improve navigation, and regulate the flow of the Colorado River, to provide for storage and use exclusively within the United States, and to generate electrical energy as a means of making the project a financially solvent undertaking. (Sec. 1.)

3. That any rights the States may have to water within their boundaries, or the right to adopt such policies and enact such laws as they deem necessary, with respect to the appropriation, control, and use of water within their boundaries, shall not be modified except by the Colorado River compact or other interstate agreement. (Sec. 18.)

4. That the Secretary of the Interior is authorized to carry out the provisions of this act, subject to the Colorado River compact. (Par. (b), sec. 8.)

5. That there is hereby appropriated the sum of $165,000,000 to carry out the purpose of this act. (Sec. 3.)

6. That the Secretary of the Interior is authorized to acquire by proceedings, eminent domain, and otherwise all rights of way, lands, and other property necessary to carry out the purposes of this act. (Sec. 1.)

7. That no expenditures out of the fund shall be made for operation and maintenance except from appropriations therefor. (Par. (c), sec. 2.)

8. That interest shall be at the rate of 4 per cent on all amounts advanced from the fund under provisions of this act, and all amounts advanced from such funds shall be checked by the Secretary of the Interior at the close of each fiscal year. (Par. (b), sec. 2.)

9. That no person shall be entitled to have the use of water for any purposes, except by contract made with the Secretary of the Interior as herein stated. (Sec. 5.)

10. That after the $25,000,000 set aside for flood control has been replaced from the 62½ per cent of any excess over the amounts due the Government, after the amortization period, it shall be placed in the fund to be expended within the Colorado River basin as may hereafter be prescribed by Congress. (Sec. 5.)

11. That the rights of the United States in or to the Colorado River and its tributaries shall be subject to and controlled by the Colorado River compact. (Par. (b), sec. 13.)

12. That 37½ per cent of any moneys collected by the Secretary of the Interior, above the amounts due the Government, shall go to Arizona and Nevada, presumably in lieu of taxes, by virtue of their natural resources being taken for a public service. (Par. (b), sec. 4.)

13. That the power to be sold at a price that may be found to be "Justified by competitive conditions at distributing points or competitive centers." (Par. (b), sec. 4.) Contracts shall be made with a view to securing "reasonable returns." (Par. (a), sec. 7.)

14. That the provisions of the Federal water power act and regulations of the Federal Power Commission shall be conformed with as far as practicable in the operation and administration of the project and for the protection of the investor and consumer. (Sec. 6.)

15. That there shall be readjustment periods for the sale price of the power, either upward or downward, as conditions at distributing points may indicate, the first readjustment after 15 years and every 10 years thereafter. (Par. (a), sec. 5.)

16. That no charge shall be made for water for irrigation and portable purposes in the Imperial or Coachella Valleys. (Sec. 1.)

17. That the water may be sold for irrigation and potable purposes in all districts except the Imperial and Coachella Valleys. (Sec. 5.)

18. That a board may be arranged for, consisting of one member from each of the seven States, to advise with the Secretary of the Interior on the sale price of water and power, and matters relative to the States. (Sec. 16.)

19. That the sum of $25,000,000 be set aside for flood control, to be replaced out of 62½ per cent of any revenue in excess of the amount necessary to repay the Government, and if not entirely replaced during the amortization period, it may, thereafter, be paid from the 62½ per cent of the net profit. (Par. (b), sec. 2.)

20. That the all-American canal may be constructed, and any dam and necessary works, under the reclamation act, which provided that all expenditures be underwritten by the lands benefited, prior to the beginning of construction, and shall not be paid for out of the proceeds from the sale of water or power. (Sec. 1.)

21. That a dam be constructed with a reservoir capacity of not less than 20,000,000 acre-feet of water. (Sec. 1.)

22. That firm contracts be made by the Secretary of the Interior for the sale of power generated, and for the use of water to generate power, and for the storage of water for irrigation and domestic purposes, and that will replace the Government investment in dam and power plants in 50 years, before construction shall be undertaken, and the charges for water for irrigation and domestic purposes shall be for permanent service. (Sec. 5.)

23. That the consent of Congress is given to the seven States of Colorado, New Mexico, Wyoming, Utah, Arizona, California, and Nevada to enter into a compact, or agreement, supplemental to and in conformity with the Colorado River compact. (Par. (a), sec. 13.)

24. That the consent of Congress is given any 6 States of the basin, including California, to enter into a 6-State compact, if said 6 States ratify the Colorado River compact without conditions except to waive the provisions of the first paragraph of article 3 of said compact, requiring 7 States, provided that California limits itself, by legislative action, to a consumptive use of not more than 4,400,000 acre-feet of water from the Colorado River, and in the event of the 6-State pact, the act shall become operative after 6 months from date of passage. These conditions have been complied with both as to the 6-State compact and the California limitation as to the use of water. (Par. (a), sec. 4, par. (a), sec. 13.)

25. The consent of Congress is given to the three States of California, Arizona, and Nevada to enter into an agreement, and specially provides for seven conditions under which this agreement may be made, and not be necessary to return to the Congress for reratification, as follows: (Par. (a), sec. 4.)

(1) That of the 7,500,000 acre-feet annually apportioned to the lower basin by paragraph (a) of article 3 of the Colorado River compact, there shall be apportioned to the State of Nevada 300,000 acre-feet, and to the State of Arizona 2,800,000 acre-feet for exclusive beneficial and consumptive use in perpetuity.

(2) That the State of Arizona may annually use one-half of the excess or surplus waters unapportioned by the Colorado River compact.

(3) That the State of Arizona shall have the exclusive beneficial consumptive use of the Gila River and its tributaries within the boundaries of said State.

(4) That the waters of the Gila River and its tributaries, except return flow after the same enters the Colorado River shall never be subject to any diminution whatever by any allowance of water which may be made by treaty or otherwise to the United States of Mexico, but if, as provided in paragraph (c) of article 3 of the Colorado River compact, it shall become necessary to supply, water to the United States of Mexico from waters over and above the quantities which are surplus as defined by said compact, then the State of California shall and will mutually agree with the State of Arizona to supply, out of the main stream of the Colorado River, one-half of any deficiency which must be supplied to Mexico by the lower basin.

(5) That the State of California, shall and will further mutually agree with the States of Arizona and Nevada that none of said three States shall withhold water and none shall require the delivery of water which can not reasonably be applied to domestic and agricultural uses.

(6) That all of the provisions of said tri-State agreement shall be subject in all particulars to the provisions of the Colorado River compact.

(7) Said agreement to take effect upon the ratification of the Colorado River compact by Arizona, California and Nevada. (Par. (a), sec. 4.)

And further provides that the three States may enter into any compact, or any two thereof may enter into any compact, subject to further approval of Congress. (Par. (b) sec. 8.)

26. That general and uniform regulations shall be prescribed by the Secretary of the Interior for awarding contracts and for the renewal of contracts, and providing that no contracts shall be of longer duration than 50 years. (Sec. 5.)

27. That any dispute or disagreement as to the fulfillment of any contract made under this act, shall be determined either by arbitration or court proceeding. (Par. (a) sec. 5.)

28. That contracts for use of power shall be made with responsible applicants, who will pay the price set by the Secretary, with a view to meeting the revenue requirements provided for in this act. (Par. (c) sec. 5.)

29. That in case of conflicting applications for the purchase of power and water, that the Secretary of the Interior shall determine the matter in conformity with the policy expressed in the Colorado River pact as to conflicting contracts for water and power rights, preference being first given to a State. (Par. (c) sec. 5.)

30. That the preference shall be given to a State for the purchase of power within six months after the Secretary of the Interior has given notice, provided, however, that time shall be given for a State to arrange for bond issues for payment. (Par. (c) sec. 5.)

31. That any agency receiving a contract for electrical energy equivalent to 100,000 horsepower may be required by the Secretary of the Interior, if deemed feasible, to allow any other agency having contracts for less than 25,000 horsepower to participate in the benefits and to use any main transmission line constructed for carrying such energy, upon payment of a reasonable share of the cost of construction, operation, and maintenance. (Par. (d) sec. 5.)

32. That the Federal Power Commission is hereby directed not to issue or approve any permits under the Federal water power act upon the Colorado River or any of its tributaries, except the Gila River, in the Colorado River Basin, until this act shall become effective. (Sec. 5.)

33. That the United States in constructing, managing, and operating the project under this act, shall be subject to, and controlled by the terms of any compact between the States of Arizona, Colorado, and Nevada, or any two thereof. (Par. (b) sec. 8.)

34. That all persons who have served in the United States Army during the wars with Germany, Spain, or the insurrection in the Philippines shall have preference, for three months, to the right of entry into any public lands thrown open by the Secretary of the Interior. (Sec. 9.)

35. That, as far as practicable, preference shall be given to persons serving in the war with Germany, Spain, or the insurrection in the Philippines, in all construction work authorized by this act. (Sec. 9.)

36. That the Secretary of the Interior is authorized to investigate the feasibility and determine the boundaries of the reclamation project known as the "Parker-Gila Valley reclamation project" in Arizona, and determine the most feasible method of irrigation of these lands. (Sec. 11.)

37. That the Secretary of the Interior is authorized and directed to make investigation and public reports of the feasible projects for irrigation, and sites for power projects in the States of New Mexico, Colorado, Wyoming, Utah, Arizona, and Nevada. (Sec. 15.)

38. The Secretary of the Interior may, at his discretion, lease the use of the water for generating power, deliver power at the switchboard, or build and lease the power plants. (Sec. 6.)

The following recommendations were submitted to the Senate Committee on Reclamation and Irrigation, January 20, 1928, by the Nevada-Colorado River Commission:

1. That Nevada and Arizona should benefit from the proposed development, at least, to the extent that they would benefit if developed by private capital, second only to Government payments and any reasonable reserve.

2. That the power be not sold as low as the repayments to the Government will permit, but should be sold at a competitive figure comparable with the cost of power available elsewhere for these markets.

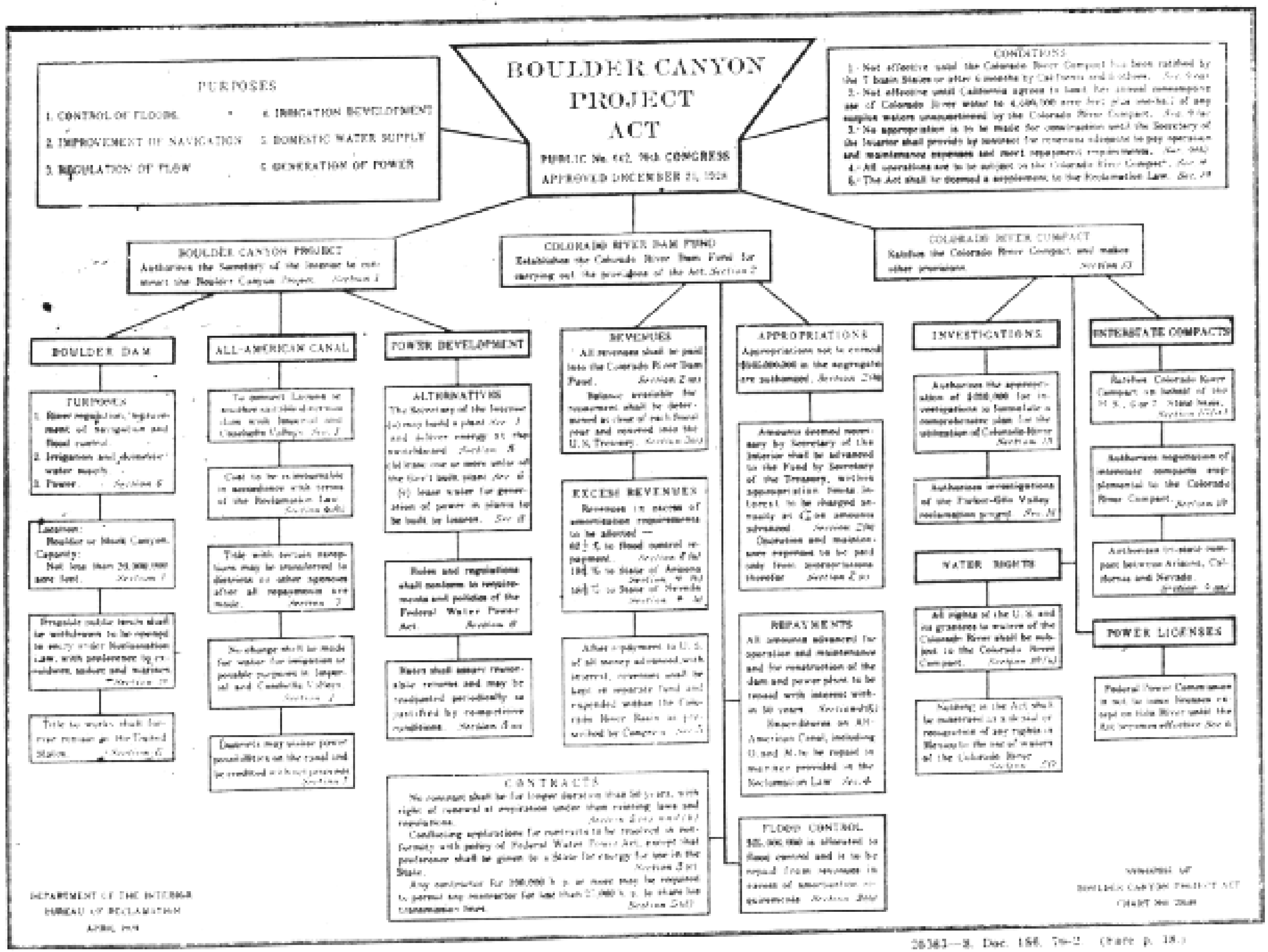
3. That arrangements be made for the sale of the power, so that fair offers may be had, and that legitimate bidders be not handicapped.

4. That suitable readjustment periods be arranged for power charges per kilowatt-hour and also for the proper charges for other service rendered.

5. That proper charges be made for other service rendered, flood control, silt control, irrigation water storage, and domestic water storage.

6. That the States shall have the right to withdraw, upon proper notice, certain blocks of power, to be used within their own States.

7. That a board be arranged for, from the three lower States to assist the Secretary of the Interior, or any agency supervising the sale of the power and other service rendered, in an advisory capacity



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to fix the proper charge per kilowatt-hour and proper charges for other service rendered.

8. That an attempt be made to equalize, in some manner, between the three States the benefits from reclamation financing.

9. That after Government advancement is entirely repaid, the benefits from this development accrue to the States.

It will be seen that the first eight of the nine recommendations are included in the bill as passed, none of which were included in the original bill; these recommendations are found in the Nevada-Colorado River Commission's report, "Colorado River Power and Water Set-up" of January 1, 1928, and printed in the Congressional Record of April, 1928.

If the power generated by this construction is disposed of on a competitive basis in the market, by the Secretary of the Interior, 37½ per cent of the net returns over the payments due the Government should provide payments to Nevada and Arizona, at least equal to the amount they would receive from the project through taxes, if developed by private capital.

THE BOULDER CANYON PROJECT ACT

TIME OF CONSTRUCTION

The Boulder Canyon project act provides that no work shall be begun within six months of the date of its passage, unless the Colorado River compact shall be ratified by the seven States of the basin, but if it shall be ratified by six States and the water limitation accepted by California through legislative act of that State, work may proceed after that period of time; both of these conditions have been met in lieu of a seven-State compact; the act, then, becomes effective when the President by proclamation so declares.

BASIS OF ACT

The theory of the Boulder Canyon project act as finally passed is not only to return the Government investment, during a specified amortization period, but to afford a reasonable return to the States in lieu of taxes, if the economic set-up justifies such payment after the power developed and the water stored, has been sold on an equitable basis.

The principle has been established and is continued in this act, that if the Government does take a natural resource from a State or States, for a public purpose, and they do make money over and above any investment the Government may have made in the transaction, then the States are allowed to benefit. Presumably in lieu of the taxes they would have received if it had been developed by private capital. This is evidenced by the forest reserve and the oil and gas leasing acts, where sales are made for what the commodity is worth.

POWER REVENUES

The power situation is handled in the bill by stating that Nevada and Arizona are each to receive 18¾ per cent of any money received in excess of the payments due the Government, and providing that the power shall be sold at a price that the "Secretary of the Interior may find to be justified by competitive conditions at the distributing points," and that no water shall be used except by contracts with the Secretary of the Interior as provided, and by providing for an advisory board made up of one member from each of the seven States to advise with the Secretary in fixing the sale price for power and water and carrying out other provisions of the act, and provides further that after the Government is repaid that a fund be established to be expended in the Colorado River Basin as Congress may direct, thus leaving the disposition of the project after the Government is repaid, for later congressional action.

STATES PREFERENCE TO PURCHASE POWER

The act provides for the States "preference to purchase" the power developed, "for use in the State." Such preference must, however, be exercised within six months following the call for bids, by the Secretary of the Interior, the purchaser must then give the Government whatever assurance it may require that the power will be taken when ready for delivery, but approximately six years will lapse before such delivery can be made and during that period no payments will be required. This is supposed to be in addition to the regular Federal Power Commission preference.

It is understood that Nevada, California, and Arizona may each exercise the "preference to purchase" upon one-third of the total amount of power developed at the price which may be offered by any private corporation or municipality at the switchboard. There will be 550,000 firm horsepower developed, and in addition whatever additional power that may be developed pending full irrigation development above. This power if used in the vicinity of the dam should cost not to exceed from 2 to 2.5 mills per kilowatt-hour with no transmission hazard, where it is estimated that transmission and "steam standby" service would bring the cost up an additional 2 mills at least in the California power market.

UPPER BASIN BENEFITS

1. Water supply sufficient for all irrigable lands is reserved in perpetuity.
2. Surveys and investigations are to proceed immediately when the act is effective to determine feasible projects and money appropriated therefor.
3. After the Government is repaid as provided in the act, and after the $25,000,000 is repaid from the 62½ per cent of the net profit, the money to remain in a special fund to be expended in the Colorado River Basin States, as Congress may direct, disposition of project after the Government is repaid is left for further Congressional action.

ARIZONA BENEFITS

1. Flood control in Yuma irrigation project.
2. Silt control in Yuma irrigation project.
3. Two million eight hundred thousand acre-feet of water in perpetuity, in case of tri-State agreement, conforming to section 4 of the act.
4. Exclusive beneficial use of Gila River, in case of tri-State agreement, conforming to section 4 of the act.
5. Surveys and investigations to determine feasibility of Parker-Gila Valley project.

6. Eighteen three-fourths per cent of all money received in excess of the payments due the Government.
7. "Preference to purchase" power for use in the State.
8. Reservoir to store water for irrigation.

CALIFORNIA BENEFITS

1. Flood control in Imperial Valley.
2. Silt control in Imperial Valley.
3. Water for irrigation and potable purposes in Imperial and Coachella Valleys, without charge.
4. All-American canal, by repaying the Government its total cost.
5. Water for southern California cities by paying for it as provided.
6. Power for use in the State by paying for it as already set up.
7. Reservoir to store water for above purposes.
8. Preference to purchase power for use in the State.

NEVADA BENEFITS

1. Three hundred thousand acre-feet of water for irrigation and potable purposes if agreement is entered into in accordance with section 4 of act.
2. "Preference of purchase" power for use in the State.
3. Surveys and investigations to determine feasible projects.
4. 18¾ per cent of all money received in excess of the payments due the Government.
5. Reservoir to store water for irrigation.

FLOOD AND SILT PROTECTION

Flood and silt protection in the Imperial Valley in California and the Yuma irrigation project in Arizona present very real and serious difficulties. There would be a tremendous property loss, if the Colorado River broke through the levees into the Salton Sea or into the Yuma district. Hundreds of thousands of dollars are expended annually in flood protection and work occasioned by the deposits of silt in these valleys. The silt problem would not be solved at once but would gradually improve. Five million acre-feet capacity has been reserved for silt control in the reservoir. This amount, it is estimated, would be deposited in the reservoir in 50 years, or during the amortization period; then it would be another 50 years or more before the capacity would become seriously impaired.

UPPER AND LOWER BASINS DIVIDE WATER IN COMPACT

Approximately one-half of the waters of the Colorado River, or 7,500,000 acre-feet, is definitely reserved for use in the upper basin on a consumptive basis and a like amount is allocated to the lower basin together with 1,000,000 acre-feet of any excess over the 15,000,000 acre-feet that may be available.

SEVEN-STATE COMPACT

If a seven-State compact is had, it means that the three lower basin States definitely limit themselves to the amount given them by the Colorado River compact, thus protecting the upper basin water supply in perpetuity.

SIX-STATE COMPACT

The Congress of the United States apparently does not attempt to limit any State's water supply without that State's consent in the set-up of the six-State compact. California is the only one limited under this pact, and it is definitely set out that before the act becomes effective under this arrangement, California must consent to such limitation by legislative action. No attempt is made to limit either Arizona or Nevada; hence, we are advised no principle of State rights is violated, the whole object of either a seven or a six State compact being to reserve their fair share of water in perpetuity to the States where development will necessarily be slow. The California Legislature has accepted the definite limitation referred to above, and Utah has entered the six-State compact, by action of its 1929 legislature, therefore the Boulder Canyon project act becomes effective on proclamation by the President after June 21, 1929, as provided in the act, Utah being the sixth State to adopt the six-State compact.

DUTY OF WATER, UPPER AND LOWER BASINS

The consumptive duty of water in the upper-basin States is from 1¼ to 1½ acre-feet per acre, then with 7,500,000 acre-feet, the upper basin will be able to irrigate approximately 5,500,000 acres, while the lower basin with their 8,500,000 acre-feet (providing there is 1,000,000 acre-feet surplus) could only irrigate approximately 2,850,000 acres, using the total amounts for irrigation and none for domestic supply, since the consumptive duty of water in the lower basin is approximately 3 acre-feet average.

CONTROL OF UNAPPROPRIATED WATERS

The question of State versus Federal control of unappropriated water has never been decided by the Supreme Court of the United States, and we are advised that none of the principles are involved in this act, as it is set-up, that no State is limited in its appropriation and use of water except by its consent and that the navigation and flood control feature without question gives Congress the right to build the dam, or any other works for that purpose, navigation is mentioned as one of the reasons for the construction.

LEGISLATION ESSENTIALLY A COMPROMISE

It is realized that the legislation as finally passed is not perfect, but all legislation where the interests of a large number of States of individuals are concerned is of course essentially a compromise, and this has been brought about after the Congress of the United States has heard all sides of the question. The important part of it is that according to engineers familiar with the conditions, the water supply of the States where development will be slow is protected by either a six or seven State compact as provided in the act, and a division of the benefits from the project has been made among the lower basin States by Congress after a six-year review of the subject.

There may be a tendency for persons not familiar with the history and entire set-up of the legislation as finally passed to suspect that the full benefit may not be had for his particular State, but if the States were to start again with new commissions representing them and no legislation passed, after the commissions had each set-up their claims, and they had met and discussed the question thoroughly, it is quite certain that after a period of years the Congress of the United States would again work out a compromise act, not essentially different from the present legislation. The lower basin States are given authority to form a compact subject to the approval of Congress if changes are made in the provisions laid down by Congress in section 4 of the act.

FEDERAL VERSUS STATE CONTROL

The Government has no interest whatever in the Colorado River compact, which divides the use of the waters of that river between the upper and lower basins, except that Congress has given the interested States authority to make a compact as provided by the Constitution of the United States. The States of the upper division then, Utah, Colorado, Wyoming, and New Mexico, by ratifying the compact, retain their proportion of the water in perpetuity, where otherwise the water would continue to be appropriated in the order of beneficial use.

The act specifically says in section 13, article B, that all of the rights of the United States shall be subject to and controlled by the Colorado River compact. The question of State versus Federal control of unappropriated water then apparently does not enter into this development, since the Government is already empowered to regulate navigation and has entered into flood control and the settlement of international complications and, further, section 19 of the act specifically gives the seven States authority to do whatever they will with the river, subject only to their own agreement.

MEXICO

We are advised that any water developed and made available by the United States could not be appropriated and held by Mexico, that this is a general international policy, under the comity of nations, so it is not a matter of concern if they do use the stored waters before our States are ready to use their rightful share. Such Mexican use would be subject to American rights.

It is estimated by students of the problem that there will be enough unallocated water under the compact to satisfy Mexico's needs, but even if there was no surplus, nothing could be gained by delay, because more appropriations are being made and put to beneficial use in Mexico and nothing but development in the United States will prevent this being done.

Mexico has at this time, it is estimated, about 200,000 or 225,000 acres in cultivation, and she may be allotted sufficient water for this amount.

TAXING GOVERNMENT PROPERTY

We are advised that Congress will not consent to the taxing of Government property in this instance, nor allow payments to any State ahead of, or on par with money due the Government, but if there is an excess above the payments due the Government, 37½ per cent may be paid to Arizona and Nevada presumably in lieu of taxes that would accrue if developed by private capital. The precedent for this is found in the oil and gas leasing act, and forest reserve act, under each of which revenue to the Government is made subject to payment of a percentage thereof to the State where the property is located, as compensation to the State for loss of revenue because the property is exempt from taxation and such commodity is disposed of on an equitable competitive basis as provided for the disposal of electrical energy under this act.

FLOOD CONTROL, $25,000,000, SET ASIDE

Under an amendment originally introduced by Senator Phipps of Colorado the $25,000,000 flood control would have been made nonreimbursable, the same as the Mississippi River flood control appropriation, but it had been contended from the start of the long fight for the project that it would be entirely self-supporting, hence several friends of the measure did not feel at liberty to accept this amendment. As a result, a compromise was reached making that amount reimbursable from the net profit of the project. It would seem from the debate on this amendment that it was the intention of Congress that it should not bear interest and is so interpreted by members of the Senate committee.

DISTRIBUTING POINTS OR COMPETITIVE CENTERS

The question has been raised as to just what is meant by "competitive centers" as used in connection with the regulation of the price of power, relating to readjustment periods mentioned in paragraph (a) of section 5 of this act.

The best explanation of the meaning as intended by Congress is found in the report of the Committee on Irrigation and Reclamation made March 20, 1928, on this measure, known as Senate Report No. 592, Seventieth Congress, first session, viz:

> The theory of this amendment is to keep the rates as high as economic conditions will justify, in order first, that the Government will receive its money at as early date as possible, secondly, that there will be excess profits for the States of Arizona and Nevada; and also, that the contractee will not unnecessarily suffer in the event economic conditions would require a lowering of rates.

AFTER GOVERNMENT IS REPAID

The Senate Committee on Irrigation and Reclamation discussed at length the disposition of the project after the amortization and decided to defer this question, and later fix a policy that would apply to all projects of a similar nature.

DOMESTIC OR POTABLE WATER

It is intended that reasonable and equitable charges be made for the use of domestic or potable water outside of the Imperial and Coachella Valleys.

Section 5 of the act specifically says that "Contracts respecting water for irrigation and domestic use shall conform to section 4 of this act. No person shall have or be entitled to have the use for any purpose of the water stored as aforesaid except by contract made as herein stated."

Section 4 of the act says "Before any money is appropriated for the construction of said dam or power plant, * * * the Secretary of the Interior shall make provision for revenues by contract, in accordance with the provisions of this act, adequate in his judgment," etc.

Section 5 of the act further says, "The Secretary of the Interior is hereby authorized * * * to contract for the storage of water in said reservoir and for the delivery thereof * * * for irrigation and domestic uses * * * upon charges that will provide revenue which * * * will in his judgment cover all expenses," etc.

Section 4 of the act further says, with reference to contracts for electrical energy that "contracts * * * shall be made with a view to obtaining reasonable returns," etc, and contains a provision for readjustable periods on this item so that the highest reasonable returns may be obtained without possible injury to the purchaser contracting over a certain period of time.

The entire set-up of the act indicates that water must be sold except where otherwise provided and the returns added to the amounts realized from the sale of electrical energy and the total returns to be used in repaying the Government the initial cost over a period of 50 years, with interest except as otherwise provided, together with operation, maintenance, etc., and any money received above the amount needed to meet the above charges to be applied to the flood control item of $25,000,000 and a fund to shorten the amortization period, and 37½ per cent of such amount received to be paid to the States of Arizona and Nevada as provided in paragraph (b) section 4 of the act.

CONSTRUCTION ESTIMATES

The Colorado River Board, appointed by the Secretary of the Interior and approved by the President of the United States, revised the estimates of the Bureau of Reclamation as follows: Dam, 550 feet high, from $41,500,000 to $70,600,000; power plant, 1,000,000 horsepower installation, from $31,500,000 to $38,200,000; all-American canal from Laguna Dam to connect with distribution system of Imperial Valley, a distance of 75 miles, from $31,000,000 to $38,500,000; interest during construction for a period of 7 instead of 10 years, $21,000,000 to $17,700,000.

	Estimated cost	Interest added
Dam, 550 feet in height	$70,600,000	$79,100,000
Power plant, 1,000,000 horsepower installed capacity	38,200,000	42,800,000
All-American canal, 75 miles in length	38,500,000	43,100,000
Interest during construction (estimated 7 years)	17,700,000	
	165,000,000	165,000,000

RECOMMENDATIONS OF THE BOARD

1. That the project is feasible.
2. That Black Canyon is the best location.
3. That the all-American canal should not be paid for out of power revenues.
4. That flood control and water stored for other purposes should be charged for according to benefits.
5. That the whole set-up would then be financially feasible.

DAM

A dam, 550 feet in height with a capacity of 26,000,000 acre-feet.. $70,600,000

Twenty-five million dollars has been set aside for flood control, providing that this amount is not replaced during the amortization period, thereafter to be replaced from the 62½ per cent of the net earnings.

POWER PLANT

A power plant of 1,000,000 horsepower installed capacity......... $38,200,000

The act provides that the Secretary of the Interior may in his discretion enter into contracts, viz:

1. Deliver power at the switchboard, which would mean Government built and operated power plants.
2. Lease the power units built by the Government, to be used in the generation of electrical energy after construction by the Government.
3. Lease of the water stored for use in the generation of electrical energy, which would mean privately built power plants.

This optional clause was inserted to give the Secretary of the Interior greater latitude in the construction of the power plants, so that the maximum economy could be effected.

ALL-AMERICAN CANAL

The all-American canal, 75 miles in length........................ $39,200,000

Authorizes the Secretary of the Interior to construct a canal located entirely within the United States, connecting the Laguna Dam, or other suitable diversion dam with the Imperial and Coachella Valleys.

Specifically states that the canal or appurtenant structures shall not be paid for out of revenues derived from the sale of power or for water for potable purposes, but that the total cost of such construction shall be reimbursable as provided in the reclamation act.

The reclamation law provides that all moneys, expended, must first be underwritten by the lands benefitted prior to starting construction, and that there are no interest charges. The act provides that there shall be no other charge made to Imperial and Coachella Valleys for the storage of water for irrigation or potable purposes; this is interpreted to mean that no charge is made for storage, but they must pay all costs incident to canals and pertinent structures.

TRANSMISSION LINES

The transmission line, 300 miles in length......................... $50,000,000

Certain agencies have already offered firm contracts for the purchase of the power output sufficient to insure the success of the project, and, in addition, construct their own transmission line. This item is not mentioned in the bill, and will be constructed by the agency purchasing the power for distribution, for further information on transmission lines, see "Weymouth report" and "Lower Colorado River power and water set-up" by George W. Malone, submitted to the Senate Committee on Reclamation and Irrigation, January 20, 1928.

AQUEDUCT FOR WATER SUPPLY TO SOUTHERN CALIFORNIA CITIES

It is proposed to construct an aqueduct from the Colorado River to the Southern California cities, to provide additional domestic water for that area; the exact point of diversion from the river is yet to be determined.

Preliminary estimates have been made for an aqueduct about 240 miles long, costing approximately $200,000,000; this expenditure is in no way connected with the Boulder Dam act, but will be financed entirely by the cities receiving the water.

It is proposed to divert 1,500 second-feet in this manner, making a total of approximately 1,100,000 acre-feet per year for domestic use in that area.

The water must be lifted approximately 1,400 feet over the divide between Coachella and Riverside Valleys, and it is estimated by the engineers for the Department of Water and Power of Los Angeles that it will require about 300,000 horsepower of electrical energy for this item.

FUEL COSTS AND RELATION TO STEAM-ELECTRIC POWER

Fuel costs are very uncertain, and are the most important variable factor in the steam-electric power set-up.

The southwestern market is at this time controlled by the oil supply, the legitimate price of which is approximately $1 per barrel, and in the judgment of men who have studied the fuel situation, coal will begin gradually taking the place of oil in a comparatively short time, and that the change will come rapidly when the cost of oil reaches $1.30 to $1.40 per barrel. Utah is probably the most favored coal supply.

Coal supply

	B. t. u. per pound
Colorado	12, 800–13, 800
Utah	11, 300–13, 000
Alaska	13, 175–14, 800
Vancouver Island	11, 100–13, 400

To utilize coal in these markets will require large storage facilities, pulverizing machinery, etc.

Due to the limited oil fields near these power markets the fuel cost will stabilize near the turning point from oil to coal which is apparently about $1.30 per barrel of oil.

It will be noted from the tables given on page 54, that $0.25 difference in cost per barrel of oil is equal to approximately 0.54 mills per kilowatt-hour so that it is concluded that the increase in fuel prices will at least offset any reduction in costs, that it is possible to make within the next few years.

The ratio of barrels of oil to tons of coal is approximately 4 to 1.

STAND-BY STEAM POWER FOR USE IN CONNECTION WITH BOULDER POWER

Conclusions of engineers appear to vary somewhat as to the necessity for steam stand-by service in connection with Boulder Canyon power delivered into the power market, meaning idle plants to take up the load in case of failure of regular service; engineers in the employ of the California-Colorado commission, including W. F. Durand, member of the Secretary's fact-finding commission, who has been employed by Los Angeles for some time, hold that idle steam stand-by service is necessary to the extent of approximately 0.5 mill, but our engineers favored the conclusion of the Government in this matter, as shown in the Weymouth report, that as very little if any stand-by service was directly chargeable to Boulder Canyon power, 0.2 mill would be the maximum for the following reasons:

1. Due to the all-western hook-up that will no doubt obtain at that time, and, in fact, does now to a certain extent.

2. Transmission lines on a 6-line basis of 200,000 horsepower capacity each, means one extra line when running full capacity, and with a possible overload to 240,000 horsepower each, would mean that four lines will carry 960,000 horsepower, which would practically mean the peak load, leaving two extra lines available, and no difficulty is anticipated in switching from one line to another in case of trouble.

3. It will require approximately 390,000 horsepower to pump 1,500 second-feet, or 1,000,000 acre-feet per year of domestic water over the divide; a total lift of approximately 1,400 feet; this will mean a substantial decrease in the distance that over one-half of the 550,000 firm horsepower developed at Boulder Dam must be transmitted, and in addition by the aid of small storage reservoirs which are already largely constructed near Los Angeles, it can be so arranged that an interruption of this service will not be serious, thus entirely obviating need for stand-by service on more than one-half of the total supply.

4. With 550,000 firm horsepower it is not anticipated that the load will be above 700,000 horsepower over 35 per cent of the time, and not over 800,000 horsepower over 10 per cent of the time; therefore, except during short periods of peak loading, three extra lines would be available in case of trouble.

5. The increase in the use of power in the available markets is at the rate of approximately 150,000 installed horsepower per year; therefore, only at the end of the absorption period would the balance of hydroelectric and steam electric power be top-heavy in favor of hydroelectric. It is contemplated that approximately 1,000,000 horsepower of steam electric power will be constructed during the period of construction of Boulder Dam, so the balance will be in favor of steam power until practically the end of the absorption period. Then when all of the Boulder power is in use, more steam electric will be generated and again gaining the economic balance of approximately 20 per cent steam and 80 per cent hydro, making more steam power available, which, with possible overload, will in part act as stand-by in addition to extra transmission lines; and after the absorption period the balance will swing back to steam, until further hydroelectric power is brought in.

SOURCE OF ADDITIONAL REVENUE

1. Flood control.
2. Silt control.
3. Water for irrigation.
4. Water for domestic use.

Five hundred thousand dollars is reported to be the amount expended annually upon levee construction and repairs. Of this amount, the greater part could be diverted toward the construction cost of the proposed dam with no greater assessment. Flood control would also remove a menace which at this time makes land values in the Imperial Valley extremely unstable, interest rates are high, and there is no demand for the lands.

Five hundred thousand dollars is expended annually in removing silt from ditches and canals; the problem will not be entirely eliminated at once, but after the proposed construction is completed it will immediately decrease, and, as the silt already deposited is worked over, will gradually adjust itself. A considerable portion of this amount could be applied to the silt-control storage, with no further assessment on the lands.

Irrigation storage will stabilize the water supply for the lands now under cultivation and bring in approximately 300,000 acres additional. This will eliminate pumping on some of these lands and furnish a gravity system. If this land alone could stand $40 per acre, it would mean an additional sum of over $500,000 annually from this source, including interest.

Domestic storage will furnish 1,000,000 acre-feet of water for southern California cities at an estimated cost of $19.50 per acre-foot. This is where a considerable amount of the Boulder Canyon power will be used to pump it over the divide. Water for irrigation is now costing from two to nearly three times the estimated cost, so that an additional charge of $2 per acre-foot should not be unduly burdensome, and that considering the per capita use in southern California cities of 150 gallons per day, and that there are nearly 326,000 gallons in 1 acre-foot, that $2 per acre-foot which would be added to the water account of 72 people per month would be hardly noticeable; $2,000,000 would be added to the revenue from this source alone.

This would make a total of $3,500,000 from the four sources mentioned above, entirely aside from returns on the power, which is not unreasonable when the savings are effected as outlined above.

Mr. Lester S. Ready, former chief engineer of the California Railroad Commission, and now in the employ of the California-Colorado River Commission, in a report to some of his California constituents in August, 1927, recommended that the service rendered in storing the irrigation silt and domestic water by the proposed construction may be worth up to $2,800,000. Even this amount would mean that the all-American canal, costing a total of $2,250,000 per year, would be carried, and $550,000 additional, or about $0.50 per acre-foot on domestic water, considering the all-American canal of $2,250,000 carried by the benefits from flood control, silt, and storage for irrigation, and would mean a delivery of the Boulder Canyon power into the power market at well under 3 mills—as against 4.89 mills for steam electric power.

Quoting Mr. Ready further, from his August, 1927, report, he finds that the annual operating cost of the dam, power plant, and all-American canal, including interest and amortization payments, is $7,515,000, which is slightly under our own conclusions, and that a 2.5-mill charge at the switchboard will probably be justified, and at that rate the return would be $9,000,000 and, with $2,000,000 from all other sources, instead of $2,800,000, would make $11,000,000 annual income, as against $7,515,000 annual outlay, leaving $3,466,000 annual surplus, and that a 2-mill charge at the switchboard on the same basis would leave $1,685,000 annual surplus—this on a basis of a 40-year amortization period.

This surplus, he concludes, could be used to retire the investment under the 40-year period, or lower the rate for power to the consumers, and finds further that the cost of the dam could be doubled and the project still be feasible.

EQUIVALENTS

WATER

One acre-foot of water is that quantity that will cover an area of 1 acre 1 foot deep.

One second-foot flowing continuously 24 hours equals 1.98 or approximately 2 acre-feet.

One second-foot of water equals 1 cubic foot of water passing a given point every second, equals 7.48 gallons per second, equals 448.88 gallons per minute.

One acre-foot equals 325,850 gallons, or 43,560 cubic feet.

POWER

One second-foot falling 8.81 feet equals 1 horsepower, 100 per cent efficiency.

One second-foot falling 11 feet equals 1 horsepower (h. p.) 80 per cent efficiency (commonly used for estimating purposes).

Load-factor is the ratio of the average power to the peak power.

One h. p. (horsepower) equals 0.75 kilowatt.

One kw. equals 1,000 watts.

Firm h. p. equals installed h. p. multiplied by the load factor.

3,600,000,000 kwh. equals 1,000,000 installed h. p. or 550,000 firm h. p. on 55 per cent load factor.

Whenever a charge of mills per kilowatt-hour is mentioned in the report, it means mills per kilowatt-hour on 3,600,000,000 kilowatt-hours per year; $500,000 additional income equals 0.14 mills per kilowatt-hour on 3,600,000,000 kilowatt-hours per year in this set-up.

One mill per kilowatt-hour on 3,600,000,000 kilowatt-hours equals $3,600,000 per year.

One mill equals one-tenth of 1 cent.

COLORADO RIVER COMPACT

The States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, having resolved to enter into a compact under the act of the Congress of the United States of America approved August 19, 1921 (42 Stat. L., p. 171), and the acts of the legislatures of the said States, have through their governors appointed as their commissioners:

W. S. Norviel for the State of Arizona;
W. F. McClure for the State of California;
Delph E. Carpenter for the State of Colorado;
J. G. Scrugham for the State of Nevada;
Stephen B. Davis, jr., for the State of New Mexico;
R. E. Caldwell for the State of Utah;
Frank C. Emerson for the State of Wyoming;

who, after negotiations participated in by Herbert Hoover appointed by the President as the representative of the United States of America, have agreed upon the following articles:

ARTICLE I

The major purposes of this compact are to provide for the equitable division and apportionment of the use of the waters of the Colorado River system; to establish the relative importance of different beneficial uses of water; to promote interstate comity; to remove causes of present and future controversies; and to secure the expeditious agricultural and industrial development of the Colorado River Basin, the storage of its waters and the protection of life and property from floods. To these ends the Colorado River Basin is divided into two basins, and an apportionment of the use of part of the water of the Colorado River system is made to each of them with the provision that further equitable apportionments may be made.

ARTICLE II

As used in this compact—

(*a*) The term "Colorado River system" means that portion of the Colorado River and its tributaries within the United States of America.

(*b*) The term "Colorado River Basin" means all of the drainage area of the Colorado River system and all other territory within the United States of America to which the waters of the Colorado River system shall be beneficially applied.

(*c*) The term "States of the upper division" means the States of Colorado, New Mexico, Utah, and Wyoming.

(*d*) The term "States of the lower division" means the States of Arizona, California, and Nevada.

(*e*) The term "Lees Ferry" means a point in the main stream of the Colorado River 1 mile below the mouth of the Paria River.

(*f*) The term "upper basin" means those parts of the States of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lees Ferry, and also all parts of said States located without the drainage area of the Colorado River system which are now or shall hereafter be beneficially served by waters diverted from the system above Lees Ferry.

(*g*) The term "lower basin" means those parts of the States of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lees Ferry, and also all parts of said States located without the drainage area of the Colorado River system which are now or shall hereafter be beneficially served by waters diverted from the system below Lees Ferry.

(*h*) The term "domestic use" shall include the use of water for household, stock, municipal, mining, milling, industrial, and other like purposes, but shall exclude the generation of electrical power.

ARTICLE III

(*a*) There is hereby apportioned from the Colorado River system in perpetuity to the upper basin and to the lower basin respectively the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum, which shall include all water necessary for the supply of any rights which may now exist.

(*b*) In addition to the apportionment in paragraph (*a*), the lower basin is hereby given the right to increase its beneficial consumptive use of such waters by 1,000,000 acre-feet per annum.

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

(*d*) The States of the upper division will not cause the flow of the river at Lees Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years reckoned in continuing progressive series beginning with the 1st day of October next succeeding the ratification of this compact.

(*e*) The States of the upper division shall not withhold water, and the States of the lower division shall not require the delivery of water, which can not reasonably be applied to domestic and agricultural uses.

(*f*) Further equitable apportionment of the beneficial uses of the waters of the Colorado River system unapportioned by paragraphs (*a*), (*b*), and (*c*) may be made in the manner provided in paragraph (*g*) at any time after October 1, 1963, if and when either basin shall have reached its total beneficial consumptive use as set out in paragraphs (*a*) and (*b*).

(*g*) In the event of a desire for a further apportionment as provided in paragraph (*f*) any two signatory States, acting through their governors, may give joint notice of such desire to the governors of the other signatory States and to the President of the United States of America, and it shall be the duty of the governors of the signatory States and of the President of the United States of America forthwith to appoint representatives, whose duty it shall be to divide and apportion equitably between the upper basin and lower basin the beneficial use of the unapportioned water of the Colorado River system as mentioned in paragraph (*f*), subject to the legislative ratification of the signatory States and the Congress of the United States of America.

ARTICLE IV

(*a*) Inasmuch as the Colorado River has ceased to be navigable for commerce and the reservation of its waters for navigation would seriously limit the development of its basin, the use of its waters for purposes of navigation shall be subservient to the uses of such waters for domestic, agricultural, and power purposes. If the Congress shall not consent to this paragraph, the other provisions of this compact shall nevertheless remain binding.

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

(*c*) The provisions of this article shall not apply to or interfere with the regulation and control by any State within its boundaries of the appropriation, use, and distribution of water.

ARTICLE V

The chief official of each signatory State charged with the administration of water rights, together with the Director of the United States Reclamation Service and the Director of the United States Geological Survey shall cooperate, ex-officio—

(*a*) To promote the systematic determination and coordination of the facts as to flow, appropriation, consumption, and use of water in the Colorado River Basin, and the interchange of available information in such matters.

(*b*) To secure the ascertainment and publication of the annual flow of the Colorado River at Lees Ferry.

(*c*) To perform such other duties as may be assigned by mutual consent of the signatories from time to time.

ARTICLE VI

Should any claim or controversy arise between any two or more of the signatory States (*a*) with respect to the waters of the Colorado River system not covered by the terms of this compact; (*b*) over the meaning or performance of any of the terms of this compact; (*c*) as to the allocation of the burdens incident to the performance of any article of this compact or the delivery of waters as herein provided; (*d*) as to the construction or operation of works within the Colorado River Basin to be situated in two or more States, or to be constructed in one State for the benefit of another State; or (*e*) as to the diversion of water in one State for the benefit of another State; the governors of the States affected, upon the request of one of them, shall forthwith appoint commissioners with power to consider and adjust such claim or controversy, subject to ratification by the legislatures of the States so affected.

Nothing herein contained shall prevent the adjustment of any such claim or controversy by any present method or by direct future legislative action of the interested States.

ARTICLE VII

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

ARTICLE VIII

Present perfected rights to the beneficial use of waters of the Colorado River system are unimpaired by this compact. Whenever storage capacity of 5,000,000 acre-feet shall have been provided on the main Colorado River within or for the benefit of the lower basin, then claims of such rights, if any, by appropriators or users of water in the lower basin against appropriators or users of water in the upper basin shall attach to and be satisfied from water that may be stored not in conflict with Article III.

All other rights to beneficial use of waters of the Colorado River system shall be satisfied solely from the water apportioned to that basin in which they are situate.

ARTICLE IX

Nothing in this compact shall be construed to limit or prevent any State from instituting or maintaining any action or proceeding, legal or equitable, for the protection of any right under this compact or the enforcement of any of its provisions.

ARTICLE X

This compact may be terminated at any time by the unanimous agreement of the signatory States. In the event of such termination all rights established under it shall continue unimpaired.

ARTICLE XI

This compact shall become binding and obligatory when it shall have been approved by the legislatures of each of the signatory States and by the Congress of the United States. Notice of approval by the legislatures shall be given by the governor of each signatory State to the governors of the other signatory States and to the President of the United States, and the President of the United States is requested to give notice to the governors of the signatory States of approval by the Congress of the United States.

In witness whereof the commissioners have signed this compact in a single original, which shall be deposited in the archives of the Department of State of the United States of America and of which a duly certified copy shall be forwarded to the governor of each of the signatory States.

Done at the city of Santa Fe, New Mexico, this 24th day of November, A. D. 1922.

W. S. Norviel.
W. F. McClure.
Delph E. Carpenter.
J. G. Scrugham.
Stephen B. Davis, Jr.
R. E. Caldwell.
Frank C. Emerson.

Approved.

Herbert Hoover.

A REVIEW OF THE COLORADO RIVER COMPACT

By Delph E. Carpenter, of Colorado

It provides in substance as follows:

All territory within the United States of America to which the waters of the Colorado River and its tributaries are or may be beneficially applied is designated as "the Colorado River Basin." The drainage area of the river consists of two great natural subdivisions, viz, the upper region, located above the head of the great canyon, and the lower region, below the great canyon (including the territory drained by the Gila, Little Colorado, and other lower tributaries). Lees Ferry is situated at the head of the canyon, in the State of Arizona, a few miles southerly from the intersection of the Colorado River with the boundary common to the States of Arizona and Utah, and is the natural point of demarcation between the upper region and the lower region.

All waters of the entire river system within the upper region (including those returning to the river from irrigated lands) unite to form a single stream at Lees Ferry, where the flow may be measured and recorded.

The compact conforms to this natural division. The upper region, plus all lands outside the drainage area which may be beneficially served by waters diverted from the river, is designated as the "upper basin." The lower region is designated as the "lower basin."

The seven States are grouped into two political divisions. Colorado, New Mexico, Utah, and Wyoming constitute the "States of the upper division." The States of Arizona, California, and Nevada constitute the "lower division."

Seven million five hundred thousand acre-feet exclusive annual beneficial consumptive use is set apart and apportioned in perpetuity to the upper basin and a like amount to the lower basin.

Any waters necessary to supply lands in the Republic of Mexico (hereafter to be determined by international treaty) shall be supplied from the surplus flow of the river. If the surplus is not sufficient, any deficiency shall be borne equally by the upper basin and the lower basin.

By reason of development upon the Gila River and the probable rapid future development incident to the necessary construction of flood works on the lower river, the lower basin is permitted to increase its development to the extent of an additional 1,000,000 acre-feet annual beneficial consumptive use before being authorized to call for a further apportionment of any surplus waters of the river.

No further apportionment of surplus waters of the river shall occur within the next 40 years. At any time after 40 years, if the development in the upper basin has reached 7,500,000 acre-feet annual beneficial consumptive use or that of the lower basin has reached 8,500,000 acre-feet, any two States may call for a further apportionment of any surplus waters of the river, but such supplemental apportionment shall not affect the perpetual apportionment of 7,500,000 acre-feet made to each basin by this contract.

The States of the upper division shall not cause the flow of the river at Lees Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years (7,500,000 acre-feet average annual flow over any 10-year period) if necessary for use in the lower basin. This is approximately 50 per cent of the river flow at Lees Ferry during the lowest 10-year period of which we have a record.

Navigation is made subservient to all other uses. Power is made subservient to domestic and agricultural uses.

State control of the appropriation, use, and disposition of water within each State is left undisturbed.

Present perfected appropriations of water are not disturbed, but such rights take their water from the apportionment to the basin in which they are located.

All future controversies between two or more States of each group are specifically reserved for separate consideration and adjustment by separate commissions, or by direct legislation, whenever such questions may arise, if ever they do.

Records of the river flow at Lees Ferry are under the control of the State engineers of the seven States and two representatives of the United States, but the authority of such officials terminates with the ascertainment and publication of the facts.

The compact may be terminated at any time by the unanimous agreement of the signatory States.

FURTHER COMMENT

I take the liberty of offering the following observations:

The upper basin constitutes the principal source of the water supply. All waters returned to the river from irrigated lands within the upper basin will pass Lees Ferry and be measured as a part of the water to be delivered to the lower basin. The upper States guarantee somewhat less than one-half the average annual flow of the river (at Lees Ferry) during the 10-year period from 1902 to 1911, inclusive, which was the period of the lowest recorded river flow. All water, both natural and return flow, which passes Lees Ferry will be credited to the delivery by the upper States. There is no minimum or maximum requirement for any particular year. The compact is satisfied by an aggregate delivery of 75,000,000 acre-feet of water during any 10-year period.

The topography of the upper basin limits the extent to which each of the upper States may go in its development and its corresponding consumption of river flow. As the various tributaries leave Colorado and Wyoming they have already entered into deep canyons and their waters are not available for diversion in Utah. The Utah development will be confined to tributary streams, and the waters of such are no longer available to Utah lands after they have entered the Green or Colorado Rivers. The waters of the San Juan are no longer available for diversion in Utah after they have served lands in Colorado and New Mexico. These natural limitations upon the use of the waters within each of the upper States will always afford ample assurance against undue encroachment upon the flow at Lees Ferry by any one of the four upper States. Colorado can not divert 5 per cent of its portion of the river flow to regions outside the river basin.

All development in Utah and New Mexico, requiring diversions from streams in Colorado, shall be subject to separate adjustment with Colorado before construction occurs.

The term "beneficial consumptive use" is to be distinguished from the amounts diverted from the river. It does not mean head-gate diversions. It means the amount of water consumed and lost to the river during uses of the water diverted. Generally speaking, it is the difference between the aggregate diverted and the aggregate return flow. It is the net loss occurring through beneficial uses.

The apportionment of 7,500,000 acre-feet exclusive annual beneficial consumptive use to the upper basin means that the territory of the upper basin may exhaust that much water from the flow of the stream each year. The aggregate annual diversions in the upper basin are unlimited. The limitation applies only to the amount consumed, and all waters which return to stream are not "consumed."

The apportionment to the upper territory is perpetual. It is in no manner affected by subsequent development. It is not required that the water shall be used within any prescribed period. Further development on the lower river will in no manner affect this apportionment or impair the right of the upper States to consume their apportionment whenever their necessities require. Any immense reservoir hereafter constructed on the lower river can not be the basis of a preferred claim which will interfere with the future development of the upper basin. The development in the lower basin will be confined to the apportionment made to that basin, with the permissible increase. Any excess of development can not infringe upon the reservation perpetually set apart to the upper territory. There can be no rivalry or contest of speed in the development of the two basins. Priority of development in the lower basin will give no preference of right as against the apportionment to the upper basin.

The 7,500,000 acre-feet annual beneficial consumptive use apportioned to each basin includes the water necessary to supply present perfected uses in each of the basins. Such present uses consume but a small part of the apportionments. By reason of a fear that further upper development might temporarily deplete the low flow of the river in the autumn and early winter of dry years, it is provided by Article VIII that present perfected appropriations upon the lower river shall not be precluded from protecting any such appropriations from encroachments upon their supplies until reservoirs have been constructed to store a definite part of the water apportioned to the lower basin.

There is no treaty between the United States and Mexico fixing any right in Mexico to the use of waters of the Colorado River. All such matters must depend upon future treaties. The compact provides that water, if any, necessary to supply the obligations of any such treaty shall be taken first from any surplus after meeting the apportionments (and right to increase) already made to the upper and lower basins. If the surplus is inadequate any deficiency shall be borne equally by the two basins.

If the time arrives when the development in either of the basins requires a supplemental apportionment (which probably will never occur) the water available for such purposes will be the surplus remaining after deducting the perpetual apportionments (and right to increase) now made plus any possible international burden. The supplemental apportionment will not disturb or impair the perpetual apportionment made by the present compact.

The repayment of the cost of the construction of necessary flood-control reservoirs for the protection of the lower river country probably will result in a forced development in the lower basin. For this reason a permissible additional development in the lower basin to the extent of a beneficial consumptive use of 1,000,000 acre-feet, was recognized in order that any further apportionment of surplus waters might be altogether avoided or at least delayed to a very remote period. This right of additional development is not a final apportionment. This clause does not interfere with the apportionment to the upper basin or with the right of the States of the upper basin to ask for further apportionment by a subsequent commission.

The compact provides that the upper basin shall not be required to deliver any water to the lower basin which can not be beneficially applied to domestic and agricultural uses. Power claims will always be limited by the quantity of water necessary for domestic and agricultural purposes. The generation of power is made subservient to the preferred and dominant uses and shall not interfere with junior preferred uses in either basin.

Article VII, protecting the obligations of the U[illegible] States to the Indian tribes, avoids necessity of conditional ratification [illegible] pact by the Congress. Such rights are negligible and the apportionment to each basin includes all such necessary diversions.

DISPOSITION OF THE WATERS OF THE COLORADO UNDER THE COLORADO RIVER COMPACT

By Delph E. Carpenter

The river is supplied by its tributaries from the Green to the Gila. Without tributaries there would be no river.

The water supply of the river consists of all water which of nature and undisturbed by works of man would pass Yuma, the point below the last tributary. It is impossible to tell the exact amount of this total supply in any year, owing to interference by diversions, but it has been estimated at from 20,000,000 to 24,000,000 acre-feet average.

This aggregate natural water supply may be divided into (1) that part entering the river above Lees Ferry and contributed by those streams which drain the upper basin; and (2) that part entering the stream between Lees Ferry and Yuma and contributed by streams which drain the lower basin.

The burdens upon this water supply are (1) those in the United States and (2) the water necessary to supply international obligations with Mexico, if any.

The Colorado River compact allocates 16,000,000 acre-feet to uses in the United States and sufficient for the international burden, whatever it may be, and then sets apart the unallocated surplus for future apportionment by the States after 40 years.

In other words, the compact specifically allocates 16,000,000 acre-feet plus the international burden, as designated burdens upon the whole supply of the river and then dedicates the unallocated surplus to future apportionment between all seven of the States. Of the 16,000,000 aggregate 7,500,000 plus 1,000,000 acre-feet per annum (beneficial consumptive use) is permanently allocated to the lower basin. These permanent allocations include all water necessary to supply all present appropriations, wherever the same may be and whether from the main stream or from the Green, the Gila, or any other tributary.

The upper basin guarantees not to reduce the water flowing past Lees Ferry below an average of 7,500,000 acre-feet per annum over any 10-year period. This is not an allocation but is simply a guarantee against depletion.

If the international burden should exceed the surplus of the whole river and tributaries (above 16,000,000 acre-feet), it will become necessary to take some international water from that allocated the two basins in which case the upper basin will contribute one-half of the deficiency and the lower basin will contribute the other half. In that event there would be no unallocated surplus. The unallocated surplus consists only of that portion of all the water of the whole river system over and above the 16,000,000 allocated to the 7 States plus the international burden. Of the water originating in the upper basin, 7,500,000 acre-feet are allocated for use in[1] that basin.

Except as used in the upper basin, the remainder will flow to the lower basin at Lees Ferry. This remainder includes (1) the upper-basin contribution to the international burden, (2) the upper-basin contribution to the common supply from which the lower basin aggregate allocation of 8,500,000 acre-feet shall be drawn, and (3) the upper basin unused portion of the unallocated surplus to be allocated among the 7 States at the end of 40 years. The upper basin States guarantee that the waters necessary to supply the first two items shall never fall below 7,500,0000 acre-feet average, reckoned in 10-year progressive periods. As already stated, this remainder is not the 7,500,000 acre-feet allocated to the lower basin but is a guaranty against depletion of the flow at Lees Ferry.

Part of the waters allocated to the upper basin are there unused and, by force of gravity, flow past Lees Ferry to the lower basin. As the uses in the upper basin increase, the quantity of this escaping water will proportionately and progressively decrease until the whole allocation is used in the upper basin. This escaping water will be available for use in the lower basin until cut off by uses in the upper basin, but such lower uses will be temporary and without right to claim a continuation thereof. Hence such waters may not be considered as unallocated, although physically present and available for use in the lower basin.

Water originating in tributaries rising in the lower basin is there available to supply the lower basin allocation and the international burden.

Supplies physically present in the lower basin consist of (1) waters originating in the lower basin, (2) 7,500,000 average annual delivery from the upper basin at Lees Ferry, (3) unallocated surplus from the upper basin, and (4) temporarily escaping waters from the upper basin allocation. The last item must be excluded and the third item conditionally included in any permanent consideration of the lower basin supply.

The water available to the lower basin (water there originating and Lees Ferry delivery) is to be used in the lower basin to care for the lower-basin allocation (8,500,000 acre-feet) and the entire international burden, unless there is a deficiency for international supply, in which case the waters allocated to each basin are to be called upon to the extent of one-half of the deficiency.

The States of the lower basin should enter into a subsidiary compact making (1) local allocation of the aggregate 8,500,000 acre-feet (out of the whole river supply) allocated to the lower basin by the compact;

(2) provision for supplying the entire international burden, if, when, and for the amount by treaty determined; and (3) disposition of the unallocated surplus pending and subject to future allocation between the seven States. They should also make provision for temporary use of allocated water escaping from the upper basin, without prejudice to the rights of the upper basin.

The upper-basin States are not concerned (except as a matter of precedent) with this local compact, providing (*a*) the three-State agreement is made subject and subsidiary to the Colorado River compact; (*b*) the international burden is provided for; (*c*) local disposition of unallocated water from either basin is without prejudice to the rights of the States of the upper basin to a future allocation as provided in the Colorado River compact; (*d*) temporary disposition of escaping allocated waters from the upper basin is made without prejudice to the future use of the entire allocation by the upper basin; and (*e*) such compact is without prejudice to the rights of Utah and New Mexico as regards that part of their territory included within the lower basin.

But it should be remembered that the Lees Ferry guaranty of annual delivery includes the upper-basin contribution to and share of the international burden, and that if this contribution by the upper States is allocated between the lower States for local uses, the international burden must then be supplied from lower-basin supplies.

CHRONOLOGY OF COLORADO RIVER INVESTIGATIONS

([2] Vol. I, 112)

December, 1901: J. B. Lippincott (*a*) and Jeremiah Ahern made a boat reconnaissance from Needles to Yuma. Mohave Valley reservoir site (Topock dam site) noted but not favorably considered account damage to railroad and Mohave Valley lands.

([2] Vol. I, 108)

October, 1902: J. B. Lippincott made a boat reconnaissance from Greggs' Ferry (26 miles above Virgin River) to Needles. Noted reservoir sites at Boulder Canyon and Black Canyon, believing them worthy of surveys.

([2] Vol. II, 123)

1902–3: Colorado River mapped from the lower end of Black Canyon to the Arizona-Sonora boundary. Drilling done at Bullshead dam sites. Investigations indicated desirability of investigation of dam sites at Parker, Bullshead, Las Vegas Wash (Black Canyon) and Virgin River (Boulder Canyon).

1904–1918: Investigation of reservoir sites on headwaters of Colorado River and its tributaries was practically continuous, including reconnaissance, reservoir and dam site surveys, drilling, and water-supply studies. Principal reservoirs covered were Kremmling, Dewey, and Junction on Colorado River; Turley and Bluff on San Juan River; Dolores on Dolores River; Animas on Animas River; Rangely on White River; Flaming Gorge, Browns Park, Island Park, and Ouray on Green River.

Brief accounts appear in the annual reports of the bureau beginning with 1904 and detailed reports in the Whistler compilation completed in 1918. Summary is found in eighteenth annual report of bureau, pages 391–408.

([2] XVIII 413)

1918: Homer Hamlin, engineer geologist of Los Angeles, delegated to make examination of Colorado River below Virgin River to locate suitable dam site for large reservoir. Geological Survey requested to assign topographer for survey of Boulder Canyon reservoir.

([2] XIX 412)

1919: Homer Hamlin reconnaissance completed. Reservoir survey continued, preparations made for drilling at Boulder Canyon dam site. Water supply studies initiated.

([2] XX 393)

1920: Diamond drilling started at Boulder Canyon; geological study of dam sites started by F. L. Ransome, of United States Geological Survey.

([2] XXI 119)

1921: Extensive studies of water supply and designs undertaken. Preliminary report on Problems of Imperial Valley (Fall-Davis report).

1922: Drilling started at Black Canyon dam site. In December, 1922, a board consisting of F. E. Weymouth, F. L. Ransome, L. C. Hill, and A. J. Wiley, inspected and reported on Lees Ferry dam site.

1923: Drilling and geological examinations of Boulder and Black Canyon sites completed; water supply, power, and design studies under way at Denver office.

February, 1924: United States Geological Survey issued preliminary profile on Colorado River below Lees Ferry based on 1923 field surveys. Weymouth report completed.

June, 1924: Supplemental report (sometimes also called volume 9 of Weymouth report) completed.

November, 1928: Report of "Colorado River board."

Congressional hearings from Sixty-seventh to Seventieth Congresses.

Lower Colorado River water and power set-up, George W. Malone, Carson City, Nev.

REVIEW OF THE COLORADO RIVER BOARD'S REPORT

This board was created under authority of the joint resolution approved by Congress, May 29, 1928; and in compliance with this resolution the board was appointed by the Secretary of the Interior and approved by the President to examine and report upon the dam to be constructed under H. R. 5773, the Boulder Dam bill.

This report was rendered to the Secretary of the Interior November 24, 1928, and has been published as H. R. Doc. No. 446, Seventieth Congress, second session. In the following review reference is made to certain pages of this report.

COLORADO RIVER

The board set out in its opening statement that the Colorado River drained an area of about 244,000 square miles and has a total length of about 1,700 miles with a fall of over 7,500 feet in its entire length.

The principal characteristics of its flow are given as the low water during the autumn and winter months with a normal flow of the melting snow, usually beginning late in April reaching its maximum in June and ending by the middle of August. This flow, the report further states, is modified and intensified by torrential floods of short duration which come in general from its southern territories and may occur almost any month of the spring, fall, or winter. Its flood flow offers by far the greatest quantity of water produced by streams and must be impounded in order to be successfully utilized. Floods of 200,000 second-feet are not unusual and larger ones have occurred (p. 2).

ENGINEERING FEASIBILITY

"The engineering feasibility of the proposed dam across the main stream of the Colorado River at Black or Boulder Canyon is basic." There is no further question then, as to the feasibility of these two sites (p. 2).

SELECTION OF SITE

The board then reviews the geology and other details of the two sites and decides that "the board is of the opinion that the Black Canyon site is suitable for the proposed dam and is preferable to that of the Boulder Canyon" (p. 3).

DANGER FROM EARTHQUAKES AND DEFORMATION

The board briefly reviews the history of the region and concludes "that danger from local earthquakes of enough violence to threaten a properly constructed dam in Black Canyon is negligible" (p. 4).

THE DAM AND INCIDENTAL WORKS

"The board is of the opinion that it is feasible from an engineering standpoint to build a dam across the Colorado River that will safely impound water to an elevation of 550 feet above low water. The cost will, however, be greater than that contemplated in the project authorized in H. R. 5773" (p. 4).

The board states in part that the proposed dam would be by far the highest yet constructed and would impound 26,000,000 acre feet of water. In the event of failure it would mean the destruction of several towns and levee system of the Imperial Valley, and probably make impossible the reestablishment of the Colorado River in its normal course. "To avoid such possibilities the proposed dam should be constructed on conservative or ultra-conservative lines." Four reasons are given by the board for the increased cost:

(*a*) Decrease of the allowable stress from 40 tons per square foot, as allowed by the Bureau of Reclamation design, to 30 tons per square foot, thus increasing the amount of material in the dam.

(*b*) An increase in the capacity of the diversion tunnels to 200,000 second-feet from that proposed by the Bureau of Reclamation of 100,000 second-feet (p. 5), thus handling flash floods of larger flow.

(*c*) A permanent spillway utilizing the increased capacity of the diversion tunnels, provided in the revised plans to increase materially the spillway capacity planned in connection with the Bureau of Reclamation design of approximately 110,000 second-feet (p. 5), thus preventing the dam from being overtopped by flash floods.

(*d*) "It is the judgment of the board that it is feasible to make the required excavation for the permanent dam, but it is their opinion that plans and estimates of cost should include provision for the control and handling of a considerable volume of water" (p. 6). This is on account of the expected leakage through cofferdams while excavation is in progress.

All of the above suggestions are in line with the proposed ultra-conservative design, which in view of the unprecedented magnitude of the construction is good engineering practice.

THE POWER PLANT

"While a power house must be fitted to a particular site, and its equipment must be designed and selected for the particular conditions which obtain at such a site, the entire installation will nevertheless be largely standard and offers no particular difficulties." The board is of the opinion that the proposed plans are feasible (p. 6).

THE ALL-AMERICAN CANAL

The bill provides for the construction of a canal connecting the Laguna Dam with the Imperial and Coachella Valleys while the estimate of $31,000,000 by the Bureau of Reclamation applies only to a canal reaching the distribution system of the Imperial Valley. The board reviews the proposed canal (p. 6) and then states: "The board believes that the canal should be lined with concrete through the sand-dune region and should be given a slope sufficient to carry the in-blown sand to a suitable place for deposit and removal." They pronounce the canal feasible with an additional cost.

The following estimates include the provision for maximum stress of 30 tons per square foot; the proposed increase in diversion capacity; the proposed increased spillway capacity for the dam; and the lining with concrete through the sand-dune region of the all-American canal, as proposed with suitable slopes, etc.

The board in its review of the estimates for the proposed structure has reached the conclusion that such estimates should be modified so as to provide as follows:

Dam and reservoir (26,000,000 acre-feet capacity)	$70, 600, 000
1,000,000 horsepower development (installed capacity)	38, 200, 000
The all-American canal (from Laguna Dam to Imperial Valley distribution system)	38, 500, 000
Interest during construction on above (7-year construction period)	17, 700, 000
Total	165, 000, 000

The board further advises "should the canal to Coachella Valley from the Imperial irrigation district be considered a part of the main canal the above estimate would be increased by the sum of $11,000,000.

These estimates are based on a construction period of seven years (p. 7).

ADEQUACY OF THE PROPOSED STRUCTURES

The board briefly reviews the proposed regulations and the flows of the Colorado River and advises that: "A dam of 550 feet above low water, across the Colorado River at Black Canyon, impounding 26,000,000 acre-feet of water, will be adequate, in the opinion of the board, to so regulate the flow of the lower Colorado as to control ordinary floods, to improve the present navigation possibilities, and to store and deliver the available water for reclamation of public lands and for other beneficial uses within the United States."

WATER SUPPLY OF THE COLORADO RIVER

The board reviewed the water supply of the Colorado River at some length (pp. 8 and 9), then concluded:

> An estimate of the excess of the calculated flow at Yuma above the actual flow of the river could be approximately determined only by paralleling the present more exact methods of measurement with the methods formerly used, through two or more seasons of high water flow, and thus determine the error involved. Any estimate without such determination is uncertain. In the opinion of the board the results of the Yuma gaugings are at least 10 per cent too high. Those corrections would reduce the estimate made by the United States Reclamation Bureau of the average annual flow at Laguna Dam, for the period 1902–1922, to about 13,500,000 acre-feet.

The board then refers to the estimate of Mr. Herman Stabler, who was and is at this time, connected with the United States Geological Survey under Mr. George Otis Smith, director, Washington, D. C., as chief of conservation branch. His estimates were made from a long record of gauge heights and the measured flows at Yuma; and were based on the assumption that the Yuma flows were correct. They then state, "Since the board finds that the Yuma gauges for the period 1902–1922 are at least 10 per cent too high, Mr. Stabler's estimate based on these gauges should be correspondingly reduced, thus modifying his estimate for the average flow of the period 1887–1904 of 10,420,000 acre feet is reduced to 9,360,000 acre feet. This estimate, however, is after the flow has been corrected to what it would have been had the irrigation been the same during 1887–1904 as it was the year 1922 which amounted to 1,477,000 acres according to the Weymouth report."

It may be of interest at this time to quote Mr. Herman Stabler's methods, which he designates as method No. 1 and method No. 2, by which he arrives at the following average of the run-off at Yuma from the years 1878 to 1927 (see his letter to Prof. Daniel W. Mead dated October 16, 1928):

> Method No. 1: The daily gauge heights from 1878 to 1922 were plotted to scale. It was found that the annual graph thus prepared normally had two low points, one soon after the beginning of the calendar year and the other late in summer. These points were connected by a line, thus separating the increase in gauge heights due to flood flow from gauge heights due to low-water flow. The areas for each year included between the line of separation thus drawn and the gauge-height graphs were run off by planimeter. The annual planimeter reading was then plotted against the annual run-off for each year of the record from 1902–1922, and a graph of approximate relation developed. From this graph a computed run-off was developed from the planimeter readings for the years 1878 to 1922, inclusive, and I have recently extended this operation to include the years 1923 to 1927.
>
> Method No. 2: By this method the mean monthly gauge heights from 1878 to 1922 were used to compute mean monthly run-off for the same period, and the computations were recently extended to cover the period 1923 to 1927, inclusive. Table No. 1 gives the mean monthly gauge heights of the Colorado River at Yuma. Roughly, the scour at Yuma amounts to 1½ feet to each foot rise in gauge height, that is, the effective depth of channel varies two and one-half times as fast as the change in gauge height. Furthermore, the discharge for the month of November is more nearly uniform than that for any other month in the year. It lies nearly halfway between the flood period of one year and that of the next year, and the channel condition in November may be assumed to have reached a fairly stable state resulting from the preceding flood period and to maintain that state until the early portion of the next flood period when the great annual change in channel condition begins to take place. Having in mind these considerations, the following more or less arbitrary rule for computing effective channel depths was adopted:
>
> (a) Assume channel depth for November as 10.

(*b*) From November to preceding May, to channel depth for any month add (or subtract) two and one-half times the difference in gauge height between the mean monthly stage for that month and the month preceding to find the channel depth for such preceding month.

(*c*) Similarly, from November to subsequent May, add (or subtract) two and one-half times the difference in gauge height between the mean monthly stage for any month and the subsequent month to find the channel depth for a subsequent month.

(*d*) For May, use the mean of values found by (*b*) and (*c*). Following these rules, channel depths for each month from 1878 to 1927, inclusive, were computed.

These channel depths represent as nearly as may be the gauge heights that would have been recorded had the Yuma section been in rock with constant control. By starting afresh each year with November as a fixed datum, the effect is obtained of an annual shift in gauge discharge relation which will, so far as possible, compensate not only for major channel changes due to the annual flood but also for changes of control caused by the building of the dams, river breaks, and the like. The monthly channel depths thus computed were plotted against the published record of monthly run-off from 1902 to 1922, inclusive, and a curve of relation established. From this curve a table for converting channel depths into run-off was prepared. The next step was to compute the monthly run-off from 1878 to date and determine the annual totals.

* * * * * * *

The annual run-off, as computed from methods 1 and 2, their mean and the published record of run-off are compared in Table 7.

TABLE 7.—*Annual run-off at Yuma in millions of acre-feet computed by methods 1 and 2, mean of values computed by the two methods, annual run-off from published records, and differences between computed and published run-off*

Computed run-off				Record run-off	Difference	Computed run-off				Record run-off	Difference
Year	Method No. 1	Method No. 2	Mean			Year	Method No. 1	Method No. 2	Mean		
1878	13	15.4	14.2			1903	15	15.8	15.4	11.3	+4.1
1879	11	11.9	11.4			1904	12	14.2	13.1	10.1	+3.0
1880	15	18.2	16.6			1905	25	20.9	23.0	19.7	+3.3
1881	12	16.3	14.2			1906	19	17.7	18.4	19.5	−1.1
1882	9	12.3	10.6			1907	22	22.6	22.3	25.5	−3.2
1883	15	16.4	16.7			1908	13	12.5	12.8	13.7	−.9
1884	20	21.6	20.8			1909	24	27.2	25.6	26.0	−.4
1885	18	18.0	18.0			1910	12	13.8	12.9	14.3	−1.4
1886	13	16.3	14.6			1911	21	18.6	19.8	17.8	+2.0
1887	12	12.2	12.1			1912	18	18.6	18.3	18.4	−.1
1888	12	11.2	11.6			1913	12	11.7	11.9	11.8	+.1
1889	9	13.0	11.0			1914	18	17.9	18.0	20.7	−2.7
1890	17	18.2	17.6			1915	15	[illegible]	15.1	14.6	+.5
1891	16	15.2	15.6			1916	31	20.7	25.8	23.1	+2.7
1892	16	17.3	16.6			1917	23	20.0	21.5	20.6	+.9
1893	13	15.5	14.2			1918	17	11.5	14.2	13.1	+1.1
1894	12	11.5	11.8			1919	17	10.6	13.8	10.7	+3.1
1895	12	12.2	12.1			1920	20	16.3	18.2	21.4	−3.2
1896	8	11.7	9.8			1921	18	19.0	18.5	19.5	−1.0
1897	11	14.6	12.8			1922	17	17.7	17.4	17.0	+.4
1898	8	12.0	10.0			1923	13	13.6	13.3	17.8	−4.5
1899	14	15.1	14.5			1924	13	11.2	12.1	11.4	+.7
1900	11	12.8	11.9			1925	12	11.6	11.8	12.5	−.7
1901	16	17.8	16.9			1926	12	14.8	13.4	12.2	+1.2
1902	9	13.2	11.1	8.0	+3.1	1927	17	17.0	17.0	17.1	−.1

Quoting further from Mr. Stabler's communication to the engineering board:

The purpose of my study will have been served if it has called attention to the reasonableness of a conclusion that average run-off for 20 years or more prior to 1902 was only about three-quarters of the average run-off of 20 years or more subsequent thereto; that such period should be included in consideration of available water supply in order to obtain the unbiased view afforded by a complete run-off cycle; and, finally, that it is unsafe to base future development on the assumption of an assured run-off at Laguna in excess of 11,000,000 to 12,000,000 acre-feet, with conditions as in 1922.

Mr. Herman Stabler concludes that while the water supply may be somewhat under the estimate of the Bureau of Reclamation, there is sufficient water to irrigate all available lands in the upper basin and still deliver the 7,500,000 acre-feet at Lees Ferry, as contemplated under the "Colorado River compact."

The acreage irrigated in 1922 taken from volume 2, page 10, Weymouth's report, as noted above was 1,477,000 acres, amounting to 2,215,500 acre-feet based on a consumptive use of 1.5 acre-feet for the upper basin, which is no doubt conservative. On this basis, assuming an average run-off at Laguna Dam of 11,000,000 acre-feet, as suggested by Mr. Stabler, and adding thereto the 2,215,500 acre-feet being used at that date, would make his estimate of the flow at Boulder Canyon 13,215,500 acre-feet average over the low period.

In this connection it may be of interest to note the data compiled by E. C. La Rue in Water Supply Paper No. 556.

In this paper the water supply is reviewed in very great detail from pages 101 to 120 including tables of supporting data. Attention is particularly called to Table No. 3, page 108; Table No. 6, page 110; and Table No. 8, page 112.

Table No. 8, page 112, is a summation of Tables 3 and 6 and the last column shows the amount of water available at Lees Ferry with full irrigation development in the upper basin, and is included herewith for reference.

TABLE 8.—*Annual discharge of Colorado River at Lees Ferry, in acre-feet, corrected for past and future irrigation depletion*

Year	Flow as measured (column 6, Table 3)	Correction for past depletion (column 5, Table 3)	Flow corrected for past depletion (column 1 minus column 2)	Correction for future depletion	Flow corrected for past and future depletion (column 3 minus column 4)
	1	2	3	4	5
1895	12, 900, 000	1, 510, 000	11, 390, 000	4, 943, 000	6, 450, 000
1896	12, 800, 000	1, 750, 000	11, 050, 000	4, 942, 000	6, 110, 000
1897	17, 750, 000	1, 690, 000	16, 060, 000	5, 815, 000	10, 200, 000
1898	12, 400, 000	1, 630, 000	10, 770, 000	4, 942, 000	5, 830, 000
1899	20, 300, 000	1, 570, 000	18, 730, 000	5, 815, 000	12, 900, 000
1900	12, 700, 000	1, 510, 000	11, 190, 000	4, 943, 000	6, 250, 000
1901	13, 500, 000	1, 450, 000	12, 050, 000	5, 815, 000	6, 240, 000
1902	8, 850, 000	[1] 1, 040, 000	7, 810, 000	4, 942, 000	2, 870, 000
1903	12, 800, 000	[1] 986, 000	11, 814, 000	4, 943, 000	6, 870, 000
1904	12, 100, 000	[1] 930, 000	11, 170, 000	4, 943, 000	6, 230, 000
1905	13, 600, 000	1, 160, 000	12, 440, 000	5, 815, 000	6, 620, 000
1906	17, 400, 000	1, 090, 000	16, 310, 000	5, 815, 000	10, 500, 000
1907	21, 100, 000	1, 010, 000	20, 090, 000	5, 815, 000	14, 300, 000
1908	11, 100, 000	938, 000	10, 162, 000	4, 943, 000	5, 220, 000
1909	21, 200, 000	862, 000	20, 338, 000	5, 815, 000	14, 500, 000
1910	12, 500, 000	801, 000	11, 699, 000	4, 943, 000	6, 750, 000
1911	14, 700, 000	740, 000	13, 960, 000	5, 815, 000	8, 140, 000
1912	17, 100, 000	679, 000	16, 421, 000	5, 815, 000	10, 600, 000
1913	12, 700, 000	614, 000	12, 086, 000	5, 815, 000	6, 270, 000
1914	18, 900, 000	549, 000	18, 351, 000	5, 815, 000	12, 500, 000
1915	11, 700, 000	469, 000	11, 231, 000	4, 943, 000	6, 290, 000
1916	17, 900, 000	379, 000	17, 521, 000	5, 815, 000	11, 700, 000
1917	20, 500, 000	299, 000	20, 201, 000	5, 815, 000	14, 400, 000
1918	14, 100, 000	239, 000	13, 861, 000	5, 815, 000	8, 050, 000
1919	10, 500, 000	169, 000	10, 331, 000	4, 943, 000	5, 390, 000
1920	19, 200, 000	112, 000	19, 088, 000	5, 815, 000	13, 300, 000
1921	19, 700, 000	56, 000	19, 644, 000	5, 815, 000	13, 800, 000
1922	16, 200, 000	....	16, 200, 000	5, 815, 000	10, 400, 000
Mean	15, 200, 000	....	14, 400, 000	....	8, 880, 000

[1] Reduced 25 per cent because of extremely low run-off.

Development in the upper basin was assumed to be 1,477,000 acres in 1922 in the Weymouth report; Mr. La Rue assumed it to be 1,500,000 acres. The future development of the upper basin is assumed by the Weymouth report to be 2,740,000 acres, which is identical with the figures taken by Mr. La Rue; this makes a total acreage with full development of 4,187,000 acres, which seems to be somewhat in excess of the figures arrived at by subsequent investigations.

The duty of water for all lands in the lower basin where diversion is made at or above Laguna Dam has been established at 3 acre-feet per acre, consumptive use.

The duty of water for all lands in the upper basin has been variously estimated to be from 1.25 to 1.5 acre-feet per acre, consumptive use, and probably will range from 1 to 1.5 acre-feet with the average at least 1.4 acre-feet per acre.

Assuming the duty of water for the lower basin to be 3 acre-feet per acre and the duty for the upper basin 1.5 acre-feet, and the quantity allotted to each 7,500,000 acre-feet per year, the upper basin could bring under cultivation 5,000,000 acres, while the lower basin would be limited to one-half of that amount or 2,500,000 acres. The supply is presumed, however, to be somewhat in excess of the 7,500,000 acre-feet which would increase the lower basin acreage proportionately.

The following table taken from page 10, volume 2, Weymouth report, indicates actual development to the year 1922 and estimated future development.

Summary of irrigation development

DEVELOPMENT WITHIN THE UPPER BASIN

[Acres]

Drainage	Ultimate area	Irrigated, 1922	Additional development		
			Class A	Class B	Class C
Green River in Wyoming	728,000	220,000	202,000	171,000	135,000
White and Yampa Rivers	518,000	123,000	61,000	299,000	30,000
Uinta Basin	356,000	187,000	71,000	69,000	29,000
Colorado River in Colorado	1,478,000	588,000	284,000	318,000	288,000
San Juan Basin	809,000	156,000	91,000	102,000	460,000
Southeast Utah	301,000	171,000	52,000	51,000	27,000
Total	4,187,000	1,447,000	761,000	1,010,000	969,000
Acre-feet per acre			1.38	1.62	1.88
By States:					
Wyoming	737,000	235,000	214,000	173,000	135,000
Colorado	2,260,000	800,000	408,000	688,000	333,000
Utah	723,000	370,000	125,000	137,000	91,000
New Mexico	447,000	42,000	13,000	12,000	380,000

TRANSMOUNTAIN DIVERSIONS

[Acre-feet]

Drainage basin	Ultimate diversion	Diverted in 1922	Additional development		
			Class A	Class B	Class C
Upper Colorado	428,000	20,000	129,000	279,000	
Uinta Basin	117,000	90,000	27,000		
Southeast Utah	9,000	5,000	4,000		
Total	554,000	115,000	160,000	279,000	
By States:					
Colorado	428,000	20,000	129,000	279,000	
Utah	126,000	95,000	31,000		

In the above table, an attempt has been made to classify the projects as to relative feasibility. Obviously such a classification must be very rough. That adopted is as follows:

CLASS A—IMMEDIATE FUTURE DEVELOPMENT

(1) Undeveloped areas of constructed or partially constructed irrigation projects not requiring undue expenditures.

(2) New irrigation projects, concerning which no serious construction difficulties are known, and for which water supply seems ample. (Includes some transmountain diversions.)

(3) Increase in area under small ditches already built or anticipated to be built shortly.

All the above developments are possibly feasible at the present time.

CLASS B—NEAR FUTURE DEVELOPMENT

Developments similar to those of Class A but by reason of relatively higher cost not likely to be carried through in the immediate future.

CLASS C—FAR FUTURE DEVELOPMENT

Developments possibly feasible from the standpoints of construction and water supply, but out of question in the near future by reason of excessive cost.

It is the belief of engineers familiar with conditions in the upper basin States that future irrigation development in this area will be slow, and probably under expectations by those States.

N. C. Grover, chief hydraulic engineer, and Herman Stabler, chief engineer, conservation branch, both of the Geological Survey, of the Department of the Interior, have expressed their opinions very clearly in the matter of water supply in a personal communication to the writer: "That the supply is sufficient for all possible future developments in the upper basin, and still deliver the 75,000,000 acre-feet at Lees Ferry in any 10-year period in the low-water years." Following press release supports the above conclusion.

UPPER-BASIN DEVELOPMENT

The United States Geological Survey has just finished an investigation to determine the possible ultimate development of the States of Wyoming, Colorado, New Mexico, and Utah from the Colorado River and its tributaries.

It has been determined according to a recent "press release" that approximately 1,198,000 acres are now irrigated from the Green and the Colorado Rivers not including 160,000 acres on the San Juan River in New Mexico, with a possible ultimate acreage of 2,997,000 acres on the Green and Colorado Rivers, and of 600,000 acres on the San Juan, making a total ultimate irrigated area of 3,597,000 acres; assuming a consumptive water duty of 1.5 acre-feet per acre, which students of the question agree to be liberal, makes a total consumptive use of water in the upper basin of 5,395,500 acre-feet and, together with an outside estimate of 325,000 acre-feet of possible ultimate transmountain diversions, brings the total possible use to approximately 5,720,000 instead of 7,500,000 acre-feet as contemplated by the Colorado River compact.

Green River

State	Area	Per cent
Wyoming	17,600	39
Colorado	10,700	24
Utah	16,700	37
Total	45,000	100

Colorado River above Green River

State	Area	Per cent
Colorado	22,200	[illegible]
Utah	4,300	[illegible]
Total	26,500	100.0

COMBINED AREA

Wyoming	17,600	24.6
Colorado	32,900	46.0
Utah	21,000	29.4
Total	71,500	100.0

The total mean annual run-off at the junction is about 12,500,000 acre-feet of which 6,800,000 acre-feet flows in the Colorado and 5,730,000 acre-feet in the Green. The reports discuss in detail the extent to which this flow is now being put to use and outline its probable future use. The bare facts are presented.

Irrigation.—Approximately 1,198,000 acres are irrigated at the present time with water from these drainage basins, and it is estimated that this area may ultimately be increased to nearly 2,997,000 acres. The areas irrigated are distributed by States and by major and minor drainage basins as follows:

	Present irrigated area	Additional irrigable area	Ultimate irrigated area
	Acres	*Acres*	*Acres*
State:			
Wyoming	235,000	520,000	755,000
Colorado	667,400	985,000	1,652,400
Utah	295,000	293,400	588,400
Total	1,197,500	1,799,300	2,996,800
Green River	652,500	1,130,300	1,782,800
Colorado River above Green River	545,000	669,000	1,214,000
Total	1,197,500	1,799,300	2,996,800
GREEN RIVER BASIN			
Wyoming:			
Green River and tributaries above Green River, Wyo	140,000	404,000	544,000
Blacks Creek	60,000	47,000	107,000
Hams Fork	12,000	45,000	57,000
Henrys Fork	8,000	12,000	20,000
Little Snake River	15,000	12,000	27,000
Total	235,000	520,000	755,000

	Present irrigated area	Additional irrigable area	Ultimate irrigated area
	Acres	*Acres*	*Acres*
Colorado:			
Green River direct [1]	(1)	(1)	(1)
Small tributaries of Green River	900	900	1,700
Yampa River and tributaries	94,900	255,000	349,900
White River and tributaries	28,900	87,000	115,800
Total	124,500	342,900	467,400
Utah:			
Green River direct	2,000	28,000	30,000
Ashley Creek	27,600	12,400	40,000
Duchesne River and tributaries	147,400	107,600	255,000
White River	----------	44,400	44,400
Price River	24,900	33,000	57,000
San Rafael River	80,000	34,000	114,000
Other tributaries	12,000	8,000	20,000
Total	293,000	267,400	560,000
Total, Green River Basin	652,300	1,130,300	1,782,800
COLORADO RIVER BASIN ABOVE GREEN RIVER			
Colorado:			
Colorado River direct	60,000	74,000	134,000
Minor tributaries to Colorado River	163,000	108,000	271,000
Gunnison River	26,000	56,000	82,000
Tributaries to Gunnison River	244,000	194,000	438,000
Dolores River	17,000	78,000	95,000
Tributaries to Dolores River	33,000	133,000	166,000
Total	543,000	643,000	1,186,000
Utah:			
Minor tributaries to Colorado River	2,000	1,000	3,000
Dolores River	----------	25,000	25,000
Total, Colorado River Basin	545,000	669,000	1,214,000
Grand total	1,197,300	1,799,300	2,996,800

[1] Negligible.

The irrigation of additional lands will result in a future depletion of the flow. The net depletion is estimated to be from 1 to 1½ acre-feet per acre irrigated, or a total amount in acre-feet shown in the following table:

	Green River	Colorado River above Green River	Total
Depletion on basis of 1 acre-foot	1,130,000	669,000	1,799,000
Depletion on basis of 1½ acre-feet	1,700,000	1,003,000	2,703,000

Transmountain diversion.—At the present time there are nine conduits that divert water from the Green River Basin into the Great Salt Lake Basin, claiming about 166,000 acre-feet a year, and six conduits that divert water from the Colorado River above the Green into the Mississippi River drainage basin, with an average annual diversion of 20,400 acre-feet. According to the estimates made by the authors of the reports the possible increased diversion into the Great Salt Lake Basin may amount to 50,000 acre-feet and that into the Mississippi River Basin to 262,000 acre-feet.

Developed power.—Not including all special-use plants such as flour-mills and sawmills, which generate hydroelectric power for use incident to their business, there are 48 hydroelectric power plants in the basin having a total installed capacity of about 49,000 horsepower. These plants are distributed by States and by major and minor basins as follows:

	Number	Installed capacity
Wyoming	1	70
Colorado	41	47,350
Utah	6	1,780
Total	48	49,200
Green River	7	1,850
Colorado River above Green River	41	47,350
Total	48	49,200
Minor tributaries of Green River	7	1,850
Colorado River and minor tributaries	6	20,460
Blue River basin	3	1,900
Eagle River basin	3	524
Roaring Fork basin	4	6,590
Dolores River basin	6	11,890
Gunnison River basin	10	5,508
Minor miscellaneous plants less than 200 horsepower	9	518
Total	41	47,350

Undeveloped power.—The amount of developed power is practically negligible compared with the undeveloped power resources. The reports describe some 90 sites at which it would be possible to develop 169,000 horsepower for 90 per cent of the time, 311,000 horsepower for 50 per cent of the time, or 1,080,000 horsepower with the flow regulated at described reservoir sites. These sites are located as follows by States and by major and minor drainage basins:

The above figures do not include 7,500 horsepower now in use and 10 undeveloped sites capable of producing 280,000 horsepower in New Mexico on the San Juan. The total, then, in the four upper basin States—Wyoming, Colorado, New Mexico, and Utah—is developed 56,700 horsepower, undeveloped 1,360,000 horsepower.

The Colorado River board, after reviewing in some detail existing records of flow (pp. 8–12), in its concluding paragraph on water supply states (p. 12):

> It is estimated that the present flow is depleted by water taken for irrigation in the upper basin by approximately 2,750,000 acre-feet, which amount, if added to the above estimated average flow, would increase it to about 15,000,000 acre-feet. This is the amount apportioned by the seven-States compact for division at Lees Ferry.

MINERAL SALTS IN THE RESERVOIR

After reviewing the records of present conditions the board concludes (p. 12):

> It is the opinion of the board, in view of these controlling conditions, that the actual salt content will not be increased to an injurious amount, even in the beginning, and that, in a comparatively short time, the incoming silt will be so effective in blanketing the salt deposits that the salt content of the river waters will be reduced to about the present amount.

SILTING OF THE RESERVOIR

The board concludes that the efficiency of the reservoir will not be seriously impaired during the first 50 years (p. 13), and estimates that 137,000 acre-feet of silt will be deposited in the proposed reservoir annually. Other estimates have usually been smaller than this, ranging from 88,000 acre feet (A. P. Davis, 1922) to 105,000 acre feet (Weymouth).

It is estimated by other engineers familiar with the situation that well within that period other reservoirs will be constructed above, storing a greater part of silt. Five million acre-feet capacity in Boulder Dam reservoir is allocated to silt control.

RIVER SILT BELOW THE DAM

The board finds that after the construction of the reservoir and it is discharging clear water, that silt will be picked up along a course from that previously deposited, but that this condition will gradually improve (p. 13).

POWER

Quoting from the board's report (p. 14):

> Based on the foregoing estimates of the variations of flow of the Colorado River, it is believed that under present conditions of irrigation a continuous output of 550,000 horsepower, or 1,000,000 horsepower on a 55 per cent load factor, could be maintained even during the years of normal low flow.

They then review the possiblities of future development and its effect and then state:

> A 1,000,000-horsepower hydroelectric plant fully loaded and operating continuously on a 55 per cent load factor, would generate annually 3,600,000,000 kilowatt hours of current. In actual practice this theoretical output might be reduced by approximately 10 per cent.
>
> With the uncertainties of the flow at Boulder Dam it is impossible to estimate closely the average annual output of power which would obtain during a 50-year period.

By referring to the preceding tables of Herman Stabler and E. C. La Rue and their opinions as noted, it will be concluded that with full irrigation development in the upper basin, the 75,000,000 acre-feet can be delivered at Lees Ferry, during any ten-year period.

The above supply equalized at Boulder Canyon is equal to approximately 12,000 second-feet of continuous flow which in turn will generate, with the head available, approximately 550,000 horsepower under ultimate development. For present and near future conditions—say for the next 25 to 60 years—the available water supply will develop 850,000 firm horsepower. See report to Senate Committee on Irrigation and Reclamation, January 20, 1926, by George W. Malone, p. 9. These conditions will obtain until full irrigation development in the upper basin.

Table showing flow required under varying heads to generate 550,000 firm horsepower at 85 per cent efficiency.[1]

Head (feet)	Flow (second-feet)	Head (feet)	Flow (second-feet)
540	10,510	460	12,700
520	11,230	440	13,270
500	11,680	420	13,900
480	12,170	400	14,600

[1] From report of January, 1928, to the Secretary of the Interior by Prof. W. F. Durand, Leland Stanford University.

ECONOMIC FEASIBILITY

The board reviews the economic set-up, mentions the need of an early settlement of the water question with Mexico, and then states (p. 15):

The board believes that the growing demand for power in Southern California when considered on a conservative basis, will be sufficient to absorb the probable power output of the proposed hydroelectric plant.

In the concluding paragraphs of the report the board states (p. 15):

Based on the foregoing and the shortage of power which will occur at low flow, the board is of the opinion that if the Boulder Canyon project is completed and put in operation, carrying as it does the costs of flood protection works and the all-American canal, it will be impossible to meet the operation, maintenance, interest, and a sufficient sinking fund to retire the cost of the project within a 50-year period.

It is obvious that the power which can be generated from Boulder Dam is a valuable resource. If the income from storage can be reasonably increased and the capital investment reduced by the cost of the all-American canal together with a reduction for all or a part of the cost properly chargeable to flood protection, it would be possible to amortize the remaining cost with the income from power.

The writer is of the opinion that the Colorado River board has followed its announced ultra conservative policy both in design and cost.

COST COMPARISON

Comparison Bureau of Reclamation estimates and the modified estimates of the Colorado River board

Item	Bureau of Reclamation	Colorado River board	Per cent
Dam 550 feet high	$41,500,000	$70,600,000	+70
Power plant 1,000,000 installed capacity	31,500,000	38,200,000	+21
All-Americain canal 75 miles long	31,000,000	38,500,000	+24
Interest during construction	21,000,000	17,700,000	−11

The Colorado River board increased the estimates on the dam, power plant, and all-American canal from 21 to 70 per cent, but decreased the interest charges 11 per cent due in part to increased cost of water diversion tunnels to be used during construction, making it possible to work during flood periods, thus decreasing the period of construction from 10 to 7 years.

The board did not consider the transmission lines to the power market. This item has been estimated at $50,000,000 for six 220,000-volt, 3-phase circuits, 300 miles long, inclusive of step-down substations, transformers, condensers, and intermediate condenser substations. This estimate is pronounced liberal by power experts. See the Malone report to the Senate Committee on Irrigation and Reclamation mentioned above.

With a storage dam 550 feet high storing 26,000,000 acre-feet of water, and 1,000,000 installed horsepower, it is estimated that 550,000 firm horsepower at 55 per cent load factor can be delivered.

This would be equal to 3,600,000,000 kilowatt hours per year, and 1 mill per kilowatt hour for that number of kilowatt hours is equal to $3,600,000 per year.

For the estimated cost in mills per kilowatt hour of each item, dam, power plant, transmission lines, and all-American canal under old set-up, see the Malone report mentioned above.

COLORADO RIVER BOARD INCREASED COSTS

Items influencing the Colorado River board to increase the estimate of the Bureau of Reclamation as noted above:

1. Increased spillway capacity.
2. Decreased allowable pressures on foundation from 40 tons to 30 tons per square foot.
3. Increase in size of diversion works.
4. Increase in cost of power plant.
5. Increase in cost of all-American canal.

ECONOMIC SET-UP

Steam power costs at the power market

	Annual charge, per cent	Mills per kilowatt-hour
Return on investment	7.50	
Depreciation	2.25	
Operating expense	1.80	002.19
Stand-by fuel (1.1 barrels per kilowatt):		
$1 per barrel	1.00	
$1.25 per barrel	1.25	
Operating fuel		002.70
$1 per barrel		002.90
$1.25 per barrel		002.50
General expense	.25	
	12.80	002.19, 002.89

Steam-electric power in mills per kilowatt-hour at particular load factor (18,000 British thermal units per kilowatt-hour)

50-YEAR AMORTIZATION PERIOD

	50 per cent	60 per cent	67 per cent
Fuel oil:			
$1 per barrel	5.12	4.80	4.58
$1.25 per barrel	5.56	5.43	5.15

25-YEAR AMORTIZATION PERIOD

	50 per cent	60 per cent	67 per cent
Fuel oil:			
$1 per barrel	4.86	4.56	4.37
$1.25 per barrel	5.42	5.20	4.94

NOTE.—50-year amortization period and Government interest rate is comparable to no amortization payments and 7½ per cent interest.

NOTE.—See economic set-up by Bureau of Reclamation.

The above figures correspond very closely to those submitted to the Secretary of the Interior, by Prof. W. F. Durand, of Leland Stanford University, in his report as "special advisor" to the Secretary, January, 1928, found on pages 379 to 418, hearings before Senate Committee on Reclamation and Irrigation on S. 728 and S. 1274, January 17–21, 1928.

Durand report to Secretary of the Interior, pages 500–501; comparison with Malone report January 1, 1928, page 19:

Fuel economy for steam-electric power plants

[Mills per kilowatt-hour]

Fuel oil	Malone, (page 19) 12,000 British thermal units	Durand, (page 500) 12,000 British thermal units	14,000 British thermal units
$1.00	0.20	0.202	0.236
$1.25	.25	.252	.298
$1.50	....	.302	.356

Comparison between steam power estimates of Dr. W. F. Durand and George W. Malone:

Twenty-five year amortization, 60 per cent load factor

[Mills per kilowatt-hour]

Fuel oil	W. F. Durand		George W. Malone, 12,000 British thermal units
	14,000 British thermal units	12,000 British thermal units	
$1.00	0.515	0.491	0.489
$1.25	.571	.541	.543
$1.50	.628	.591	....

Thirty-five years amortization, 60 per cent load factor

[Mills per kilowatt-hour]

Fuel oil	W. F. Durand		George W. Malone, 12,000 British thermal units
	14,000 British thermal units	12,000 British thermal units	
$1.00	0.494	0.470	0.466
$1.25	.550	.520	.520
$1.50	.607	.570	....

NOTE.—For 12,000 British thermal units examine text top page 502, Durand report.

Mr. Durand prepared tables giving a choice of fixed charges to those who desire to use his estimates and two different fuel economies, one of 12,500 British thermal units per kilowatt-hours yet to be realized and the other of 14,000 British thermal units per kilowatt-hour, readily obtainable in new power plants. By comparing Doctor Durand's table with Malone's results shown in his report to the Senate Committee on Reclamation and Irrigation, January 20, 1928, it will be noted that the fuel economies and the resulting costs based on certain fuel costs are practically identical as shown by the above tables; these results were arrived at entirely independently and presented to the committee about the same date.

Turning then to the table of conclusions, page 21 of Malone's pamphlet:

STEAM POWER

The critical figure of 4.89 mills per kilowatt-hour given for steam power delivered at Los Angeles is based upon $1 per barrel for fuel oil and high economy. If this had been calculated by Doctor Durand's formula the amount would be 4.91 mills per kilowatt-hour, which differs by about 1 per cent (12,000 British thermal units per kilowatt-hour).

The foregoing estimates are made for comparative purposes and based on plant cost of $100 per kilowatt with an added cost of $10 for transmission purposes, making a total cost of $110 per kilowatt of installed horsepower installation.

To new power plants constructed in the power market, under conditions that now obtain, a performance of 13,270 British thermal units, equivalent to 480 kilowatt-hours per barrel of oil may be expected. This item will range from somewhat under 13,000 British thermal units to about 14,000 British thermal units at present.

If power plants can be financed on the basis of a total rate of 7½ per cent annually, such as is obtained by the public utility corporations now operating steam power plants, and which is equivalent to public financing on a 5 per cent basis with 25 years, partial payments, the above estimate of costs will apply.

It has been suggested that a decrease in steam costs might come about through the use of mercury vapor or the use of higher pressures, but it is the opinion of engineers that the increased cost of the mercury vapor in the first case, and the increased cost of construction in the second, will preclude any material reduction.

TRANSMISSION LINES

Six 220,000-volt, 3-phase circuits are proposed to carry the Boulder Canyon power to the power markets; the length of this line has been variously estimated, but the 300 miles which follow closely the line of the Union Pacific Railroad seems to be a conservative estimate. The cost of this line, including step-down substations, transformers, condensers, and intermediate condenser substations, is believed to be conservatively estimated at $50,000,000, including interest, during construction.

Some comment has been made on the amount of depreciation allowed on the transmission lines in this set-up; the amount used here is comparable with similar projects under private management in California.

According to engineers and such internationally recognized transmission experts as Frank G. Baum, of San Francisco, transmission costs may be materially reduced within 10 years, on account of higher voltage lines, etc., so that a smaller number of lines would be required (six circuits are now contemplated) to be constructed as needed.

Estimate of depreciation on transmission line

[Table 34, Bureau of Reclamation Weymouth report]

	Estimated cost per mile	Life	Per cent depreciation	Annual depreciation per mile
		Years	*Per cent*	
Surveying	$125			
Right of way	1,250			
Towers	5,600	50	2	$112
Conductors	5,300	50	2	106
Insulators	1,434	20	5	72
Material booths	325	15	10	32
Total field cost	14,134		2.29	324
Contingencies (10 per cent)	1,412			
Administration and engineering (12½ per cent)	1,744			
Total cost per circuit mile	17,300		2.28	395

Depreciation on 1 line = 395 × 300 = $118,500.
Depreciation on 2 lines = 395 × 600 = 237,000.
Depreciation on 3 lines = 395 × 900 = 355,500.
Depreciation on 4 lines = 395 × 1,200 = 474,000.
Depreciation on 5 lines = 395 × 1,500 = 592,500.
Depreciation on 6 lines = 395 × 1,800 = 711,000.

6 circuits, per mile	$103,800
300 miles	31,140,000

Does not include interest and depreciation during amortization period, and is under the estimate of $50,000,000 including interest and depreciation during amortization period, in about the same ratio as the estimates on the other units, dam, power plant, and all-American canal.

TRANSMISSION 300 MILES TO POWER MARKET

Cost annual operation during amortization period of 35 years on private engineers, estimate of $50,000,000

	Per cent	Cost	Mills
Interest	5	$2,500,000	0.694
Annual payments	1.107	553,500	.1538
Depreciation	1.25	625,000	.1736
Operation and maintenance	1	500,000	.1388
Total	8.35	4,178,000	1.1609

Three billion six hundred million kilowatt-hours, corresponding to 550,000 firm horsepower annual charges of $4,178,000, is equal to 1.16 mills at the switchboard, which on a basis of 12 per cent line losses is equal to 1.32 mills per kilowatt-hour at the southern California power market.

DEPRECIATION

Relative to the depreciation item which is thought to be low by some, as assumed in this report, it is probably not understood.

If the "straight-line" sinking-fund method of depreciation is adopted, it means that for any given life in years of a piece of property of known value, a certain sum is set aside each year so that at the end of that life the total amount will replace the property.

The sinking-fund method of providing for depreciation consists of setting aside a lesser sum, which, invested, at compound interest, would when set aside annually plus the compound interest in the aggregate amount to the life of the property. This method is adopted here and is approved by utility commissions.

Item	Amount	Life	Equivalent straight line
	Per cent	*Years*	*Per cent*
Hydroelectric plants	0.75	28	3.57
Transmission line	1.25	30	3.34
Steam-electric plants	2.26	27½	4.45

COST OF BOULDER DAM POWER AT SWITCHBOARD AND SOUTHERN CALIFORNIA POWER MARKETS

COST OF POWER PER KILOWATT-HOUR AT THE SWITCHBOARD AND IN THE SOUTHERN CALIFORNIA POWER MARKETS ASSUMING A 12 PER CENT TRANSMISSION LOSS

We are advised that the $25,000,000 set aside for flood control, and to be returned from 62½ per cent of the net earnings of the project, does not bear interest. The following table is computed on that basis:

Cost Table No. 1.—*Sinking fund method for the $25,000,000 flood control, straight-line method for remainder*

DAM AND POWER PLANT

At switchboard in mills per kilowatt-hour	At power market (12 per cent line losses), mills per kilowatt-hour	To States of Arizona and Nevada	To Government for special fund	Cost per horsepower-year at switchboard
1.663	1.890	$366,300	....	$10.97
1.8	2.045	551,250	$306,250	11.76
1.9	2.160	686,250	675,000	12.42
2.0	2.273	871,250	900,000	13.06
2.1	2.386	956,250	1,125,000	13.72
2.2	2.500	1,350,250	1,350,000	14.38

The above table of costs takes into account a 9-year absorption period during which time nothing is paid on the $25,000,000 set aside for flood control and the remainder of the cost of the dam and power plant bears interest only, then the $25,000,000 is amortized during the last 41 years in 41 equal annual payments with interest at 4 per cent on the straight-line basis.

Cost of power per kilowatt-hour at the switchboard and in the southern California power markets assuming a 12 per cent line loss.

Assuming for purposes of comparison that the $25,000,000 does bear interest the same as the remainder of the cost of the dam and power plant, the 62½ per cent would equal the amortization payments plus interest on the $25,000,000 in this event.

Cost Table No. 2.—*Straight line basis*

At switchboard	At power market (12 per cent line losses)	To States of Arizona and Nevada	To Government for special fund	Cost per horsepower-year at switchboard
1.990	2.262	$872,800	....	$13.00
2.100	2.386	821,300	$247,500	13.72
2.200	2.500	966,300	472,500	14.38

The above table of costs takes into account a 9-year absorption period, during which time interest only is paid on the total cost of the dam and power plant, then during the remaining 41 years the original cost is amortized in 41 equal annual payments plus interest on a straight-line basis.

	Mills
Transmission line, $50,000,000 for six transmission lines (see p. 61)	1.32
Steam stand-by service for use in connection with Boulder Dam power in southern California power markets is variously estimated from 0.2 to 0.5 mill per kilowatt-hour	.50
	1.82

Under the above assumptions 1.82 mills must be added to the column, power market in Tables 1 and 2 to arrive at the cost of the Boulder Dam power in the southern California power markets, and of course if the transmission cost or steam stand-by estimates were changed, the total costs would be changed by that amount.

For example, then, under Table No. 1, the cost of the power delivered at the switchboard at the dam is 1.8 mills; to use the same power in the southern California markets, it would cost 2.016 mills per kilowatt-hour plus 1.82 mills which would equal 3.836 mills per kilowatt-hour, almost exactly double the price paid if used in the vicinity of the dam.

If the transmission cost can be held to 1.32 mills per kilowatt-hour then, assuming that the steam stand-by cost proves to be 0.5 mill per kilowatt-hour making a total of 1.82 mills per kilowatt-hour in addition to the switchboard cost, then assuming steam-electric power at 4.86 mills per kilowatt-hour (see page 54) the Boulder Dam power would theoretically be worth 3.04 mills per kilowatt-hour at the switchboard, or the difference in cost. It is concluded however, that hydroelectric power properly safeguarded by stand-by service is more valuable than steam power at the same price because of the stability as to cost, the varying price of fuel and other commodities having no effect whatever on the hydroelectric plants.

	Mills
Steam-electric power in southern California market (see p. 54) (estimate of Bureau of Reclamation, under some conditions 5.34 mills per kilowatt-hour)	4.86
Transmission plus steam stand-by costs	1.82
Difference in mills per kilowatt-hour	3.04

Of course any change in the cost of either the transmission line or of the necessary steam stand-by, the cost of steam-electric power remaining constant, must necessarily be reflected directly in the "difference in mills per kilowatt-hour" which is theoretically the amount that the Boulder Dam power is worth at the switchboard under the set-up in the Boulder Dam act, where it is provided that the power is to be sold at a price "that seems justified by competitive conditions at distributing points or competitive centers," and providing readjustment periods to meet changing conditions. (See paragraph (a), section 5, Boulder Canyon project act.)

TABLE No. 3.—*Cost in mills per kilowatt-hour on 3,600,000,000 kilowatt-hours per year*

Steam-electric power in southern California power markets	Cost of transmission line and steam stand-by service	Value of Boulder Dam power at the switchboard, delivered to southern California power markets, assuming 12 per cent line losses
4.80 Malone estimate. (See pp. 55 and 56.) This computed cost is expected to be conservative, and the Bureau of Reclamation costs are probably nearer actual conditions [1]	1.52	3.009
Do	1.62	2.919
Do	1.82	2.741
Do	1.92	2.651
Do	2.00	2.580
Do	2.10	2.491
Do	2.20	2.401
Do	2.30	2.312
Do	2.40	2.223
5.24 Bureau of Reclamation report	1.52	3.330
Do	1.62	3.232
Do	1.82	3.068
Do	1.92	2.969
Do	2.00	2.892
Do	2.10	2.767
Do	2.20	2.678
Do	2.30	2.589
Do	2.40	2.500

[1] Cost of transmission to southern California, estimated from 1.32 to 1.5 mills per kilowatt-hour and steam stand-by power necessary estimated from 0.2 to 0.5 mill per kilowatt-hour.

Table No. 3 is included merely as an aid in comparing costs of Boulder Dam hydroelectric power delivered at the switchboard and into the southern California power markets with the cost of producing steam-electric power in those markets.

There is no doubt but that hydroelectric power properly safeguarded by stand-by service is more valuable than a like amount of steam-electric power, because of its economic stability, the cost is not in any way influenced by the price of fuel, which is the largest single item in the production of power by steam.

It has been suggested that steam-electric power costs will be decreased (see p. 56), but it is the conclusion of outstanding authorities on this subject that any decrease in costs made possible through new or improved methods in producing such power will be more than offset by the increased cost of fuel (see p. 27). (See Professor Durand's report to Senate Committee on Reclamation and Irrigation, January, 1928.)

In any event, contracts will be made, subject to the readjustment periods outlined in paragraph (a) section 5 of the Boulder Dam act, allowing a readjustment of the contract price to whatever change in the production costs that may come about. The first readjustment period is to be made within 15 years, which is approximately 7 years after the power will be ready for delivery.

Bureau of Reclamation power cost—Estimated value of Boulder Canyon hydro-electric energy on basis of cost of competitive steam energy in California power markets

[Estimate by Bureau of Reclamation]

Assumptions:						
Cost of fuel oil per barrel	$0.75	$0.75	$0.75	$0.75	$1.00	$1.00
Cost of steam generating station per kilowatt-hour	$100	$100	$110	$110	$100	$110
Fuel economy, British thermal units, per kilowatt-hour	14,000	14,000	12,000	12,000	14,000	12,000
Fuel economy, kilowatt-hour, per barrel	443	443	517	517	443	517
Fixed charges on steam plant	12%	12%	12%	12%	12%	12%
Load factor	60%	60%	60%	60%	60%	60%
Number of transmission circuits	7	8	7	8	7	7
Production cost of steam energy:						
Fuel cost	1.70	1.70	1.45	1.45	1.45	1.93
Operation	.40	.40	.40	.40	.40	.40
Maintenance	.40	.40	.40	.40	.40	.40
Fixed charges	2.28	2.28	2.51	2.51	2.28	2.51
Total production cost, mills per kilowatt-hour	4.78	4.78	4.75	4.75	5.24	5.24
Cost of transmission of hydroenergy (preliminary)	1.62	1.86	1.62	1.86	1.62	1.82
Cost of auxiliary steam power	.51	.51	.51	.51	.51	.51
Value of Boulder Canyon energy delivered switchboard	2.65	2.41	2.63	2.39	3.21	3.11
Value of Boulder Canyon energy at power plant, based on 12 per cent losses with number of transmission lines as noted at head of column	2.33	2.12	2.31	2.10	2.82	2.74
Value of Boulder Canyon energy of power plant based on 12 per cent losses, with six transmission lines as originally estimated by Bureau of Reclamation, Weymouth Report (see pp. 31–32)	2.54	2.54	2.54	2.52	3.01	3.01
Value based on six transmission lines and 0.25 mill per kilowatt-hour steam stand by instead of 0.51 mill per kilowatt-hour (see p. 28)	2.80	2.80	2.78	2.78	3.27	3.27

COST COMPARISONS—OLD AND NEW SET-UP

[Taken from Congressional Record December 7, 1928]

Mr. PITTMAN. This is what I want to call attention to: There was not any question in the minds of the commission that the Department of the Interior was right in its estimate of revenues to be received from power, because there is no question that a reservoir of that capacity and a dam of that size will provide 3,600,000,000 kilowatt-hours of power.

The total cost of the dam—mind you, the total cost—under the plans of the Department of the Interior, and of the all-American canal, and the power development, together with interest on the entire investment, would have been $125,000,000. They hold that that $125,000,000 could be paid back in less than 25 years from the sale of electric power at three-tenths of a cent per kilowatt-hour. There is no question about that being in the minds of the commission. If it is true that that power alone, at three-tenths of a cent, would pay $125,000,000 in 25 years, why will it not pay for the dam and reservoir, under the commission's report, because that is only $120,000,000?

Let me give the compiled figures. Here is the report of the commission on this proposed dam, which I say is stronger, which has greater spillway capacity. This is the estimate of the commission:

Dam and reservoir (26,000,000 acre-feet capacity), $70,000,000.
One million horsepower development—

That means the power house—

$38,200,000.

Interest during construction of above, $11,682,000.

Total, $120,482,000.

That is less than the $125,000,000 which the Secretary of the Interior estimated could be reimbursed to the Government in 25 years from the sale of power. Now, let us see what the Department of the Interior said that power would pay in 25 years. This is what they said it would pay:

Estimated gross revenues from sale 3,600,000,000 kilowatt-hours power, at three-tenths cent, $10,800,000.

That is the gross receipts annually from the sale of that power.

Storage and delivery of water for irrigation and domestic purposes, $1,500,000.

That includes, mind you, what they might receive from the lands under the all-American canal. That makes a total of $12,300,000.

Estimated fixed annual charges for—

Operation and maintenance, storage, and power, $700,000.

Operation and maintenance all-American canal, $500,000.

Interest on $125,000,000, at 4 per cent, $5,000,000.

Total, $6,200,000.

Estimated annual surplus, $6,100,000, sufficient to pay the entire cost in 25 years.

It will be observed that the allowances he makes for operation and maintenance are extremely liberal. The testimony points to costs being more favorable than thus indicated.

Mind you, as the Senate bill now under consideration eliminates the cost of the all-American canal as a burden upon the revenues received from power, therefore we must adjust the estimates as follows:

Annual receipts from the sale of power, $10,800,000.

Estimated fixed annual charges for operation and maintenance, storage, and power, $700,000.

Interest on the above expenditures—that is, the total amount estimated by the commission for the dam and power house—$2,920,000.

In other words, the annual net receipts on the investment, as provided by the commission, will be $7,180,000. That is the net.

The Secretary has held that $6,200,000 would amortize $125,000,000 in 25 years. Consequently it must be obvious that $7,180,000 will amortize $120,000,000, the estimated cost of dam and reservoir proposed by commission, in 25 years. Those are the figures. Those figures are not questioned by the commission at all, except in one particular.

Mr. NORRIS. Mr. President——

The PRESIDING OFFICER (Mr. Thomas of Idaho in the chair). Does the Senator from Nevada yield to the Senator from Nebraska?

Mr. PITTMAN. I yield.

Mr. NORRIS. I hope the Senator will pardon me. I was listening with great interest until the Senator had reached the point where he was giving the amortization period from the commission's estimate when I was interrupted, and I did not hear what the Senator said after that. Will he be good enough to repeat that last sentence?

Mr. PITTMAN. I will be very glad to repeat it. The Department of the Interior found that the annual revenues from the power alone would be $10,800,000 a year. That is the gross. That figure is not disputed by the commission, except that they throw doubt on it in the way that I will read later. The computation is not questioned.

Leaving out the all-American canal, either receipts from the land or expenditures, the cost annually for operation and maintenance, storage of water, and so forth, is $700,000 a year. The interest on the amount estimated by the Department of the Interior to build the dam and the reservoir, during the period of construction, would be $2,920,000, giving a total annual cost under the estimates of the Department of the Interior, leaving out the all-American canal, of $3,620,000. That would leave an annual profit of $7,180,000. What would that do, according to the estimates of the Department of the Interior? Leaving the all-American canal in, the Department of the Interior says the annual net profits would be only $6,100,000, but taking out the all-American canal the net profits will be $7,180,000. But the Department of the Interior reported that the annual returns of $6,100,000 would amortize the full loan or advance by the Government, the full $125,000,000 which includes the cost of the all-American canal, in 25 years. If $6,100,000 would amortize the total cost of $125,000,000, as estimated by the Department of the Interior, within 25 years, certainly the larger sum of $7,180,000 would pay off in 25 years $120,000,000 estimated by the commission as the total cost of the dam, reservoir, and power development according to their plans.

How do we get the $120,000,000? We get it by taking the estimated cost of the dam as prepared by the commission, which they say is $70,600,000. We take the cost of the power plant estimated by the commission, which they say will be $38,200,000. We compute interest on that amount at 4 per cent during the period of seven years that the commission say will be required for construction, and we find it amounts to $11,682,000. The total cost is $120,482,000. That is the total cost according to the plan of the commission. Of course, we admit that the estimate is enlarged by the commission for the sake of safety. We admit that they have doubled the spillway capacity as a safety factor. We admit that they have increased the cost enormously. But notwithstanding that, they have not increased the cost of the dam and the reservoir and the power house up to the cost of the total project, including the canal, which the Government expected to pay for from power under the House bill. Consequently, there is no doubt about it.

But let me read something else.

Mr. BRATTON. Mr. President, will the Senator yield?

Mr. PITTMAN. I yield to the Senator from New Mexico.

Mr. BRATTON. Neither has the commission questioned the capacity of the project to develop the amount of power to which the Senator has just referred nor the cost of operation, so that by mathematical calculation it is definite that the income and operating expense will be just what the department estimated it to be

Mr. PITTMAN. The Senator is correct except in this way——

Mr. BRATTON. And that by mathematical calculation it is definite that the sum can be amortized within 25 years based upon the figures given by the commission and department.

Mr. OVERMAN. Mr. President, I would like to inquire whether the cost of the transmission lines has been computed and included in the cost of the dam?

Mr. PITTMAN. They have not, because there is no authority in the bill to construct transmission lines.

Mr. OVERMAN. But they have to construct them, do they not?

Mr. PITTMAN. Yes; municipalities, corporations, or others, to get the use of the electricity.

[From Congressional Record December 7, 1928]

Mr. PHIPPS. Mr. President, I do not intend to discuss the measure at length to-day, but I am now in receipt of a communication from the mayor of the city of Denver, in which he transmits to me a memorandum on the subject of the high dam on the lower Colorado River prepared by the special counsel for the city of Denver. I do not consider it necessary to read these communications at length, but I do consider them of importance and therefore request that they be printed in the Record, including the letter from Mayor Stapleton and a copy of my acknowledgment, and the counsel's report.

The PRESIDING OFFICER (Mr. Sackett in the chair). Without objection, it is so ordered.

The documents referred to are as follows:

DENVER, COLO., *December, 1928.*

Hon. LAWRENCE C. PHIPPS,
Senate Office Building, Washington, D. C.

MY DEAR SENATOR: As mayor of the city of Denver, I ask a moment of your time respecting the Boulder or Black Canyon bill of Senator Johnson, being S. 728.

I want to let you know that while, of course, the primary purpose of the proposed high dam is flood and silt control for the benefit of the Imperial Valley and neighboring areas in California, and to some extent for certain of the lowlands of Arizona lying along the river, yet the bill, in solving the flood problem, would serve as a most important step in the solution of the Colorado River controversy. This controversy has been raging for years among the seven Colorado River States. Indeed, unless this bill or an equivalent bill providing for a high dam somewhere on the lower Colorado should be passed there would be no way under the peculiar interstate water law of our part of the country by which with legal certainty the upper States of the Colorado River Basin—Colorado, New Mexico, Wyoming, and Utah—with whose interests the city of Denver is identified, could secure a segregation of part of the water of the river for their future growth and expansion.

There is a rather common impression that the proposed project is of no advantage except to the flood areas above referred to, whereas the bill is needed almost as much, although for reasons different from those of flood control, by the upper States and their cities as well. I am aware that this bill does not follow in all respects the corresponding bill that has passed the House, but undoubtedly the differences would be adjusted in conference committee.

I inclose copy of memorandum filed by the city of Denver with the Colorado River Board showing, as its title indicates, Why a High Dam at Some Point on the Lower Colorado is Needed by the Upper Basin and by the City of Denver.

With thanks for your brief consideration, I am,

Sincerely yours,

BENJ. F. STAPLETON.

DECEMBER 7, 1928.

Hon. BENJAMIN F. STAPLETON,
Mayor, Denver, Colo.

MY DEAR MAYOR STAPLETON: Acknowledgment is made of your recent letter, without date, urging the enactment of S. 728, the bill for the construction of the Boulder Canyon project.

As a member and later chairman of the Senate Committee on Irrigation, I have studied this matter for many years and agree with you that satisfactory legislation for the construction of this dam, which would also bring about the ratification of the Colorado River compact, would be of substantial aid toward securing water from the stream for Colorado and other upper basin States. From the start I have been most anxious adequately to safeguard Colorado's future, as well as present water rights, and have studied the problems involved always with that thought in mind.

I shall take pleasure in calling your indorsement of the proposed legislation to the attention of my colleagues in the Senate, and sincerely trust that a satisfactory bill for this purpose will be enacted during the present session of Congress.

Cordially yours,

LAWRENCE C. PHIPPS.

MEMORANDUM ON WHY A HIGH DAM AT SOME POINT ON THE LOWER COLORADO IS NEEDED BY THE UPPER BASIN AND BY THE CITY OF DENVER

(By L. Ward Bannister, special counsel for city of Denver)

DENVER, COLO., *November 17, 1925.*

COLORADO RIVER ENGINEERING COMMISSION

(Maj. Gen. William L. Sibert, Chairman).

GENTLEMEN:

* * * * *

DENVER'S INTEREST

Colorado's principal source of water supply to serve her future expansion is the Colorado River. Denver does not want to be left to the fate of being the capital city of a State forever limited in its economic development by shortage in water supply. Furthermore, Denver itself has initiated rights for transmountain diversion from the headwaters of the Colorado along several different routes for use of the waters within the city. Denver's interests in the Colorado River are identical with those of the upper States generally.

THE DANGER

The danger to which the upper States, including the city of Denver, are exposed arises from the nature of the law governing interstate streams and from the nature of the present and prospective uses of the water of the river. This combination of law and fact puts in jeopardy the chance of the upper States to increase their present uses of water unless a high dam should be built at some point on the lower Colorado.

THE LAW

The case of Wyoming *v.* Colorado (259 U. S. 419), which is the latest of the decisions of the United States Supreme Court, lays down the rule, with certain modifications which for purposes of a margin of legal safety need not be noticed here, that waters are to be divided between States which maintain the appropriation system of water law, as distinguished from the riparian system, according to seniority of use regardless of State lines. Under this rule the earliest users in the order of their seniority and no matter where situated have the first right to the waters to the extent of the necessities of their respective uses as originally established and the later users get what is left. Whether the latest users get anything at all depends upon whether anything is left after the water is supplied first to the satisfaction of the uses which are older than theirs. Since this rule works regardless of State lines, it would follow that if only the water uses in one State were early enough and the water scarce enough, the other State would go without water in the absence of special remedies to obviate such an unfortunate result. A high dam and the Colorado River compact ratified would constitute such remedies.

THE FACTS

Roughly speaking, about one-third of the waters of the Colorado system have been put to use and the four upper States are using about the same quantity that the three lower States are using. The remaining two-thirds have not been put to use. During the period of low water each year the volume of the water in the river is more than sufficient to take care of the present uses in the different States, and there have been several years lately when it was insufficient; in other words, when the natural low flow was overappropriated.

In the upper States there are no new water projects of great draft upon the river in sight for the near future. There are none of such significance for agricultural purposes among the lower States, except with proposed Government aid. There are power projects, however, proposed for the lower States and to be licensed by the Federal Power Commission sufficient in size to use all of the now unused waters of the Colorado River. Applications for these projects are pending already. If these projects should be licensed by the Federal Power Commission and built, they would be entitled, if the rule of priority regardless of State lines, is to be applied, as contended by the lower States, to have all of the now unused waters of the river go down forever to the lower States to satisfy the requirements of those projects; in which event the upper States could not hold such waters back for use within their own limits, and in consequence the economic development of those States as far as depending upon the Colorado River would be at an end, unless special remedies are to be adopted to circumvent such a disaster. A high dam would be such a remedy.

According to a memorandum issued to me, under date of December 9, 1927, by Engineer E. B. Debler, of the Reclamation Service, it appears that the low flow of the river is exhausted to a degree more serious to the upper States if this memorandum is correct, than generally supposed. The head gate of the Imperial Valley ditch is below Yuma, and the capacity of that ditch is said by Mr. Debler to be 6,500 second-feet, with a water claim therefor of 10,000 second-feet. Yet it also appears that for 32 days in 1915 the flow dropped as low as 2,700 second-feet, and that the average flow for the same period was 4,400 second-feet; that for 24 days in 1919 the flow dropped to as low as 2,300 second-feet, with the average flow for the same period at 4,000 second-feet; that for 73 days, in the summer of 1924, the flow dropped as low as 1,200 second-feet, with the average flow for the same period at 3,300 second-feet; that for 35 days, in the summer of 1926, the flow dropped as low as 2,440, with an average flow for the same period of 4,000 second-feet. When I say that during any of these periods mentioned the flow dropped to a certain minimum I do not mean that this was true for the entire period, but only at some period of time within the period. The average flow for each period as a whole I have given.

The California priorities, including those for the Imperial Valley ditch, are, Mr. Debler informs me, old ones, dating for the most part back to 1900. He tells me that the same thing is true of many of the Arizona priorities. It is said that most of the priorities in the upper basin in point of aggregate of water are more recent. Assuming this situation to be true, it follows that if priorities regardless of State lines were to be strictly applied, the upper States, in default of some special remedy, such as interstate compact and the building of a high dam under act of Congress, would be obliged to allow some of the waters represented even by their existing priorities to go down to satisfy earlier priorities of California and Arizona. Of course, if some of the existing priorities in the upper States would be obliged to surrender water to earlier priorities in California and Arizona, it would be all the more true that such a surrender could be imposed upon priorities in the upper States not yet created but which are sure to come into existence as the upper States continue their development.

As far as present consumptive uses of the waters are concerned, California is more of a rival of the upper States than is Arizona. Under date of December 16, 1927, the same engineer, Mr. E. B. Debler, informs me by a letter that nearly all of the California and Arizona rights out of the main river, so far as volume of water claims is concerned, are older than 1900, and that of the water thus claimed, Arizona has 823,500 acre-feet per annum and California 4,917,000 acre-feet; and that in terms of peak flow per second of time Arizona's claims aggregate 3,688 cubic feet and California's 11,567 cubic feet. Clearly California's claim in terms of acre-feet being over five times that of Arizona, and in terms of second-feet being over three times that of Arizona, it follows that California is many times more dangerous, so far as existing rights in the main stream are concerned, than is Arizona and must be dealt with by upper States.

REMEDIES, INCLUDING THE HIGH DAM

Immense projects are in the offing for the lower States to be built under licenses to be sought from the Federal Power Commission, and with no projects of corresponding magnitude in sight for the upper States in the immediate future, and with the low flow of the river already overappropriated, and with some of the existing water rights of the upper States already in jeopardy because of the contentions which earlier appropriators in the lower States are making for a preference, it follows that the upper States must seek, if they would protect themselves, some remedy which, while affording a fair amount of the water to both groups of States, will not sacrifice the economic future of either group as it might be sacrificed under the rule of priority regardless of State lines without intervention of any kind.

The best remedies are those of interstate agreement, such as the Colorado River compact, and a high dam built under authority of the Congress at some point in the lower States, and with the validity of the compact reinforced as far as the Congress may have power to reinforce it by appropriate provision to that end inserted in the bill authorizing the dam.

The upper States can not get California to ratify the Colorado River compact unless a high dam be provided. Furthermore, if a high dam were built, the existing early irrigation rights in California and Arizona could be satisfied out of the flood flow of the river, leaving the low flow to be retained for use in the upper States.

California argues that, while she would be glad to enter into a compact with the upper States for a division of water between the two groups of States, yet she can't do it with safety without a high dam, for the simple reason that the bulk of her existing priorities are earlier than the bulk of the priorities in the upper States, and therefore preferred, and that she would be sacrificing them by entering into an agreement to divide the waters unless a high dam were provided in order to supply them. The interest, therefore, of the upper States themselves requires that a high dam be built in order that they may obtain California's signature to the interstate agreement, and that the normal flow of the river may be retained more largely in the upper States and the flood flow used more largely in the lower States.

It does not matter to the city of Denver where the high dam is built, whether at Boulder Canyon or Black Canyon or elsewhere, as long as one is built. It does not matter whether the power at the dam is generated by the Government or by private enterprise. It does not matter whether royalties be paid to the States in which the dam is situated or not, although justice to these States would require some provision for income. From the standpoint of the city of Denver all of these questions, while important, are minor compared with the greater question of bringing about a division of the waters between the two groups of States through the building of a high dam and ratification of the Colorado River compact.

There have been proposals of a low dam instead of a high dam. A low dam would afford flood control, it is true, but it would not solve the Colorado River controversy, because it would not provide for the satisfaction of existing water priorities in the lower States in the quantity necessary to induce California to enter into an interstate agreement. Indeed, the upper States would be compelled in their own interest to fight any congressional proposal for a low dam, because as the waters would be released they would be put to additional use in the lower States and additional rights would be claimed in the lower States by reason of this additional use, and the upper States would find themselves without any interstate agreement by which the additional use could be compensated by an increased use to the upper States.

The city of Denver is prepared to accept a project for a high dam, even though the Colorado River compact should not be ratified by more than six States, but hopes that interstate differences may be adjusted, so that all seven States may be included, thus satisfying all States and increasing the certainty of the legality of the division of water between the two groups of States.

I do not know with accuracy just what questions your commission will consider in reaching conclusions. But in behalf of the city I want to get before you the attitude of the city, as maintained by its mayor, the Hon. B. F. Stapleton, toward the proposed Boulder Canyon project, knowing that you will consider any points material to your labors and recognizing fully that all others will be disregarded.

Respectfully,

L. WARD BANNISTER,
Special Counsel for the City of Denver.

Mr. PHIPPS. Mr. President, I do not know of any Senator who has not been convinced of the necessity for the construction of a dam on the lower Colorado River, particularly for the purposes of flood control. The differences that have arisen center about the question of the advisability of making it a high dam, and the arguments pro and con have been under consideration by your Committee on Irrigation and Reclamation for a term of years, including in its studies personal visits to the neighborhood and the site of the proposed dam, and the taking of testimony which now comprises almost a library in itself.

Personally I have found it one of the most interesting, but at the same time the most intricate and difficult questions that I have been called upon to consider since I became a member of the Senate. There are so many ramifications, there are so many different points of view, and even with a bill that is presumably perfected, when we come to reread it we discover some point that has not been properly adjusted and an amendment is proposed to correct that situation, and we find again that that involves additional changes in some other feature of the bill.

I have gone on record heretofore as not only favoring a dam for flood control, but that it should be a dam as high as could be constructed with safety in order that hydroelectric power might be produced there with a view to deriving a revenue that would, at least in part, pay for the cost of the structure and which would at the same time provide waters for irrigation and also for domestic use, need for which in the last two or three years has become more than ever apparent in the cities of the coastal plains.

FLOOD CONTROL

The cost for flood control only has been discussed, and it seems pertinent that some mention be made of it here.

The cost of the dam itself—550 feet high for the storage of 26,000,000 acre-feet—has been increased $29,100,000 by the Colorado River board over the Bureau of Reclamation estimates. Practically all of the hazard in constructing a dam of this type under the existing conditions is encountered in the foundation construction and the first 50 feet in height of the dam.

([1] vol. 4, p. 7)

At least 80 per cent of this increased cost would be in the foundations, spillway capacity, and the increased diversion capacity provided by the board and would apply equally to a low dam for flood control provided, as has been proposed, it be constructed in such manner that it can later be raised to the 550-foot height to fully utilize the site. If this is not done, Nevada would be deprived of her natural resource for the benefit of the public, with no hope of ever fully developing her portion of the river.

Twenty-eight million dollars is the cost estimated by the Bureau of Reclamation for 10,000,000 acre-feet capacity, flood control only; add to that 80 per cent of the increased cost of the 550-foot dam, as added by the board as outlined above, would amount to $28,000,000 and $23,280,000 and would make a total cost of $51,280,000 for flood control only.

Proponents of all plans of river development say that the construction of a high dam at Black Canyon will fit into the full development of the entire lower river. However, the idea is advanced that it would be more economical construction to build an upstream dam first, say at Bridge Canyon, then the floods could be controlled while developing the downstream portion of the river.

This method would cheapen the construction of subsequent dams below, but if it is proposed to return any of the original expenditure Bridge Canyon or any upstream location is not feasible at this time, there being no market within economic transmission distance for the power. (See Hon. Herbert Hoover's statement before the Senate Committee on Irrigation and Reclamation December 10, 1925, pp. 599-605.)

(Senator Oddie, of Nevada, introduced the following statement:)

STATEMENT OF HON. HERBERT HOOVER, SECRETARY OF COMMERCE, WASHINGTON, D. C.

[Taken from Senate committee records on reclamation and irrigation, December 10, 1925, pp. 599 to 605]

Secretary HOOVER. Mr. Chairman, I have the conviction that the committee, due to the many hearings that it has held in the Colorado River Basin and the large knowledge that the members of the committee possess of the problems outside even of that, probably do not wish me to traverse the whole complex of the Colorado River; and I am a little in doubt as to the points upon which I could be of assistance to the committee on.

But I prepared and have here before me a brief note as to one or two questions. I am not at all certain as to whether they are germane to matters on which I possibly can be of service.

I may say that the Colorado River problem does not lie in the lack of enormous resources in water, in arid land, and in power, or of private or public capital to develop it. The difficulties are the sharp conflicts of opinion of the people in the basin on a multitude of questions as to their rights, their interests, and the method of development of the river. And these conflicts have been in course of discussion, to my knowledge, for some 15 years. They have resulted in innumerable conferences, discussions, and appeals to legislation and to the courts.

The first of these conflicts, and the one that overrides all others, is the conflict over water rights between the seven States. The four States in the upper basin have, naturally, opposed any development in the lower basin until such time as they could have assurance of some fixed assurances of their water rights. As the committee is well aware, the application to beneficial use will give priority in water rights as between States, and, as the development of the Colorado River will take place in the lower basin long before any large development in the upper basin, therefore the upper-basin States have justifiably been resolute in their demands for some fixation of the rights before there shall be construction and thus extension of beneficial use down below.

In an attempt to solve this proposal some years ago a compact commission, representing the seven States and Federal Government, was established, and, as you are aware, I acted as the chairman of that commission. Hearings and sessions of the commission extended over a matter of over 18 months, and the commission was composed not only of delegates from each of the States but the most of the sessions were attended by their attorneys general, and a number of the sessions by all but one of the then governors of the States.

After a great deal of discussion and negotiation a compact was arrived at subject to ratification by the State legislatures and by the Congress.

The compact did not attempt to solve any problem on the Colorado River except water rights, and it limited its action to a division of the water between the upper basin and the lower basin. It furthermore limited its action to a division of only a portion of the water of the river adjoining a further apportionment of the water to a considerable number of years in the future to await the character of development.

The compact commission believed that if progress could be obtained that far it would at least take the block off of the development in the lower basin and would reduce all other conflicts to purely local questions, which could be more easily settled with time.

The compact was ratified without reservation by six legislatures, the Arizona Legislature passing the compact with some reservations but approval was refused by the governor.

Subsequently, in order to try and lift the block on development in the lower basin, some of us suggested a 6-State compact, or, rather, a ratification of the compact among six States as being sufficient to satisfy the upper-basin States. Under that proposal the compact was ratified by five States, and California made reservations which the northern States declined to accept. Due to the action of California, that proposal has failed in any practical result, so that at the present time we are still in the midst of the conflict over water rights.

One thing that I have been impressed with in all the discussion that has gone on for nearly three years since the compact was signed is that there has been very little substantial criticism as to the equities of the proposals in the compact. Colorado, Utah, Wyoming, New Mexico, Nevada, and California accepted them in full. The Arizona Legislature ratified the compact with reservations that did not again challenge the equities of the compact seriously. The quarrels over the compact have been due to attempts to force extraneous questions. I believe I can say that the commission arrived at an extraordinary successful document when you consider the tremendous conflict and feeling over this question.

There have recently been conversations between California and Arizona in an attempt to agree upon their differences. A committee, partly appointed by the California Legislature and partly informal, has drawn up a pro forma compact to be signed between California, Arizona, and Nevada.

The main compact provides that the interstate rights between the States in the different basins shall be subsequently settled by further compacts. This action of the folk in the southern basin is entirely in line with the purpose of the main compact, and in their proposed lower-basin compact they, of course, stipulate that it is subject to acceptance of the main Colorado River compact itself.

I am rather hopeful that that negotiation will succeed. They are starting on very sound lines as far as I can observe, and a settlement of that conflict might make it possible to reconvene legislatures and secure early ratification of the compact all along the lines. We would, in case of success of those negotiations, have practically settled what I regard as the most difficult of the conflicts.

The next most important line of conflict is over the character and location of the first works to be erected on the river. I believe the largest group of those who have dealt with the problem, both engineers and business folk, have come to the conclusion that there should be a high dam erected somewhere in the vicinity of Black Canyon. That is known usually as the Boulder Canyon site, but nevertheless it is actually Black Canyon. The dam so erected is proposed to serve the triple purpose of power, flood control, and storage. Perhaps I should state them in a different order—flood control, storage, and power, as power is a by-product of these other works.

There are theoretical engineering reasons why flood control and storage works should be erected farther up the river and why storage works should be erected farther down the river; and I have not any doubt that given another century of development on the river all these things will be done. The problem that we have to consider, however, is what will serve the next generation in the most economical manner, and we must take capital expenditure and power markets into consideration in determining this. I can conceive the development of probably 15 different dams on the Colorado River, the securing of 6,000,000 or 7,000,000 horsepower; but the only place where there is an economic market for power to-day, at least of any consequence, is in southern California, the economical distance for the most of such dams being too remote for that market. No doubt markets will grow in time as to warrant the construction of dams all up and down the river. We have to consider here the problem of financing; that in the erection of a dam—or of any works, for that matter—we must make such recovery as we can on the cost, and therefore we must find an immediate market for power. For that reason it seems to me that logic drives us as near to the power market as possible, and that it therefore takes us down into the lower canyon.

The dam there is recommended by the reclamation engineers, and I believe their latest view is 540 feet in height. This would, I believe, serve the triple purpose of flood control, storage, and power, so far as we can see ahead, for the development of irrigation, domestic water supply, and need of power for a good many years to come.

I do not believe that construction at that point is going to interfere with the systematic development of the Colorado River for storage and power above and below. As I have said, I think the time will come when a storage dam should probably be erected below Boulder Canyon and that storage dams and flood-control dams will be erected far above. Those of you who have looked into the engineering problems involved will recognize that the operation of a single dam for the triple purpose is rather difficult and will not give the maximum power results. For instance, such a dam must be partly empty in anticipation of the spring flood and hence the power possibilities will be much diminished, and beyond this it will be necessary thereafter to lower the head for irrigation purposes. Thus the power production from such a dam will be rather irregular.

But, in any event, I do not believe that we can not now contemplate the expenditure of the several hundreds of millions of dollars necessary to carry out the theoretical plan; we should confine ourselves to what we can afford to spend now, and I do not believe we will destroy the possibilities of the river for systematic development by this course. We must await a settlement of population and their demands to create a need for the future development.

The proposed Black Canyon Dam of 540 feet, as estimated by the reclamation engineers, would cost about $41,000,000 or $42,000,000. The cost of an electrical generation plant to go with it would be about another $33,000,000. And the transmission lines to the power market would be somewhere about $27,000,000 more, or a total of from $110,000,000 to $115,000,000 for dam and equipment. The loss of interest during construction would be $10,000,000 more. The alternative plan of a 606-foot dam would require something like $20,000,000 more.

Now, the 540-foot dam would apparently develop, theoretically at least, about 550,000 primary horsepower and another 450,000 secondary horsepower. No engineer could say at the present moment what the actual power development will be, because none of us know until we have had experience how much the electrical power will need to be made subjective to flood control and irrigation in the manner I have referred to; but in any event these theoretic figures are possibly near enough.

Now, a large part of the power developed will be needed to pump the water for the proposed domestic water supply plan for southern California and both the manufacturers and private power companies will need the surplus power. It seems to me we need some consideration here of making a settled financial plan if we are to expedite this very urgently needed development. The people of southern California have recognized that the folk in the Eastern and Central States will probably not be anxious for the Federal Government to find the whole of the $115,000,000 for this development, and they have already expressed their willingness to make a substantial contribution to it, both from the municipalities and from the private power companies. It seems to me that the Federal Government has a very substantial obligation in this matter. It has been traditional to provide flood control in the protection of our people at the cost of the Federal Government, and we, of course, have the reclamation funds for the development of arid land; so that here is a problem of the proper contribution from municipalities, irrigation districts, private power companies, and the Federal Government.

All this leads me to the belief that somebody ought to be given authority to negotiate a definite financial compact which could be laid before Congress for approval in connection with the construction of these works. It does not seem to me it would take long to do that, and it could possibly be laid on the table here before this session of the Congress expires. I believe that we should do all we can to expedite this matter. It is true that our path would have been smoother if we could have had more success in the ratification of the compact, but so long as we have these great conflicts and differences of view that I have mentioned we must expect difficulties. And in this connection I would remind you that it required, I believe, 10 or 11 years to secure a ratification of the Federal Constitution, and I doubt if there was as much emotion connected with that proposition as there is with water rights between seven States. So we may make progress more speedily than was made by the original thirteen States of this Union.

Now, Mr. Chairman, if there are any further points that I can help the committee on I shall be glad to have them brought to my attention.

The CHAIRMAN (Senator McNary). On that point you have been discussing, do you see any conflict, in the purposes discussed by you in connection with Boulder Canyon, that might prevent private capital from participating in this matter?

Secretary HOOVER. Pardon me, Mr. Chairman, but my attention was distracted and I did not catch your question.

The CHAIRMAN (Senator McNary). You spoke of the different purposes—flood control, irrigation, and power development. Are these functions in which private capital would be interested, or is there a conflict, one with the other?

Secretary HOOVER. Some of them are functions in which private capital would not be interested. In the development of dams outside of Boulder Canyon there is not necessarily any question of Federal finance; the other developments of the river below the upper basin are predominantly power developments and could be carried out by private capital under Government control. You have a problem here of working out that relationship at Boulder Canyon. I think there have been some discussions in southern California as to the possibility of some arrangement between a municipal electrical power establishment and the private power companies distributing in southern California for mutual participation in the Boulder Canyon project. I do not know how far they have got, but in any event it ought to be possible to bring some conclusion out of that, and, through such arrangement, to secure financial support to the Boulder Canyon development. I do not think the Federal Government will ever want to build the electrical power works there, or the transmission lines, and get into the power business. But it is through the power side of the question that the Federal Government can secure a large contribution to the development and hope recovery of its own investment.

The CHAIRMAN (Senator McNary). Is it your opinion that the Government obligation consists only in the matter of erection of a dam for the purpose of flood control?

Secretary HOOVER. No; I think the Government can go further than that. While, of course, you can not very well say our reclamation policy is an obligation, yet it is a sound financial policy, and the proposed dam would be a very large contribution to the reclamation of arid lands. Therefore some contribution on that score would be in order.

The CHAIRMAN (Senator McNary). But, Mr. Secretary, you must bear in mind that there is a special fund for that purpose, under a specific act, which does not come out of the Treasury of the United States but from the resources of the States, while in this case the funds would come under a different plan.

Secretary HOOVER. My suggestion made here was that some sort of authority might be set up to make a plan and to negotiate out the contribution of all these different elements, even including the reclamation fund. I have no detailed plan in mind, but it does seem to me that we are in this position: Here are four or five sources which are willing or should contribute to the work, and we ought to get some sort of definite relationship established to it.

The CHAIRMAN (Senator McNary). Is it in your mind that there is a sufficient demand for electrical power to justify the erection of a dam at this time from that viewpoint alone?

Secretary HOOVER. The probable primary horsepower is something like 550,000. While I can not state precisely, yet it is my belief that the domestic water supply into Los Angeles will absorb about 200,000 horsepower for pumping purposes and which they will need to provide for; that would leave 350,000 horsepower, which I think could be absorbed in that market long before these works could actually be built. This offers a basis also for contribution to cost. I doubt whether there would be a kilowatt of power transmitted for five years if you should start to-morrow on this enormous work of construction. I do not know how far these contributions would go to the total cost. My proposal is that we should find it out.

The CHAIRMAN (Senator McNary). Have you looked into the matter of the domestic supply of water for southern California in regard to whether it should be taken from the Colorado River here or there, whether by lift as mentioned at Black Canyon, or by gravity system some place up the river?

Secretary HOOVER. I am not competent to speak of that. All I know about that matter is what I have read in the newspapers as to statements of various engineers.

The CHAIRMAN (Senator McNary). What sort of suggestion have you to make, or can you detail it a little more to the committee, that a commission should be designated to look into this matter? Do you mean to have it confer with the various States in order to get an allocation of water and power?

Secretary HOOVER. I have not gone into it in detail. My own thought was that we could expedite this whole development, and expedition is what we all want, by having some sort of commission with authority to make a financial plan and who could be helpful in bringing the States together in the matter of the compact.

Such a commission could lay out a financial plan with all the groups involved, and thus have some definite contract—subject, of course to approval by Congress—then you gentlemen would have some finished thing to act upon. It seems to me pretty difficult for Congress to negotiate a thing of that kind, and the administration has no power to do it.

Mr. ODDIE. In this statement Mr. Hoover says very clearly that the primary purpose of this legislation is flood control; and he advocates a high dam, 545 or 550 feet high, primarily for the purpose of flood control. He states that the question of power is incidental to flood control, but he recognized the danger from floods, and he has been a student of this problem for many years. He was appointed chairman of the Colorado River Commission something like eight years ago. He has given a great deal of his time to the study of the matter and has brought his great engineering ability to bear on it. Those of us who admire Mr. Hoover—and I know that we all admire him as a man as well as his great ability—will recognize the strength of his statements on this matter.

I shall not discuss this question any further at this time, Mr. President, because I intend to make some more brief remarks later on when I introduce some technical data prepared by our State engineer. I do hope this legislation will pass promptly, and I feel that Congress will make no mistake in passing it, and that will be doing a most humanitarian as well as necessary act if it passes this bill.

Mr. Oddie subsequently said: Mr. President, I would like permission to make a statement in answer to the statement of the junior Senator from Colorado [Mr. Waterman] regarding the flood menace in the Imperial valley and to have it follow my remarks heretofore made this morning.

As the danger from flood involves the lives of 100,000 American citizens and about $200,000,000 worth of property it becomes particularly important. The dam authorized, with the consequent large storage, will permit of the regulation and stabilization of the river's flow and completely solve the flood danger. Unless prompt action is taken any year may witness a flood of very serious and possible disastrous consequences.

I have obtained certain information on this subject from the report of the committee to the Senate, and I ask now unanimous consent that further statements in regard to this matter may be incorporated in the Record at this point, as they completely answer the statements heretofore made by the junior Senator from Colorado [Mr. Waterman] regarding the danger from floods from the Colorado River.

The PRESIDING OFFICER (Mr. Sackett in the chair). Without objection, it is so ordered.

The statements are as follows:

Mr. F. E. Weymouth, formerly chief engineer of the Reclamation Service, in his 1924 report recommending the project, stated in the plain and conservative language of the engineer, the physical conditions causing the acute flood menace which exists:

"In its present state of partial development, however, the river is a menace no less than it is a benefit. Each spring the snows accumulated on the mountain slopes of the upper basin melt with the advancing season until by the end of May the lower river has become a raging torrent. This flood usually reaches its peak in May or June, after which is ordinarily subsides; the floods have been known to continue into August.

"Annually the river carries past Yuma an average of 200,000,000 tons of silt. When the river is not in flood, this silt burden is largely carried to the gulf, but in times of flood when the river spreads beyond its banks, it drops its load of silt not only at its mouth but wherever along its course the velocity of the water is checked. Especially does this deposition of material occur along and near the banks of its low-water channel. These banks are thus built up by successive floods until they hold the waters to such an elevation that the main current of the stream eventually breaks through and finds a new channel in lower ground.

"In the delta region below Yuma, being less restricted by natural lateral barriers, this tendency finds widest scope. Here the river has built a conical fan-shaped ridge cutting off what formerly was the upper end of the Gulf of California. Along the crest of this flat delta ridge runs the river; one slope toward the south terminates at sea level at the present head of the Gulf of California, the other extending northerly on a much steeper slope reaches a depression 250 feet below sea level at the rim of the Salton Sea. The portion of the ancient gulf thus cut off constitutes the Salton Basin, the irrigated area of which, lying largely below sea level along the northward delta slope, is known as Imperial Valley."

Again referring to temporary means adopted by Imperial irrigation district for flood protection the report proceeds:

"Within a few years at the most the silt deposits will raise the elevation of this latter area to a point where the main current of the floods will again be thrown to the west and north, at which time the assaults of the river on the Volcano Lake Levee will be renewed, with assurance that sooner or later another break into the valley will occur.

"The menace in case of such a break is not limited as at Yuma and above to the loss of crops and improvements and the cutting away of a few or many acres of valuable land, serious as that menace is. Besides all this, the greater danger here is that the levee once breached and the river at flood turned into Salton Sea, the steep gradient of its course will induce the cutting through the soft alluvial soil of a gorge in which the flow may not be checked until a large part of the valley has become submerged beneath the waters of an inland sea." (Hearings on H. R. 2903, 68th Cong., 1st sess., pp. 711, 712.)

It should further be pointed out that, in addition to destroying crops and damaging lands, the Imperial Valley has the decided disadvantage of being below sea level and having no outlet for the water. Ordinarily, the flood waters from any stream finds its way back into the stream as the flood subsides. This is not the case in Imperial Valley. There the flood waters remain in the basin until taken out by the slow process of evaporation.

DANGEROUS SHIFTING CHANNELS

In 1905 the river turned northward from its channel on the crest of the delta and flowed into the Imperial Valley for nearly two years before the break could be closed, thus forming a lake of some 500 square miles known as the Salton Sea. Through heroic efforts on the part of the Southern Pacific Railroad Co., at the request of President Roosevelt, the break was closed in 1907 and the river returned to its channel. The United States then expended approximately $1,000,000 in the building of what is known as the Ockerson Levee to prevent another such disaster as that of 1905. This levee was barely completed, however, when in 1909 the river washed much of it away and turned westward into what is known as Bee River to Volcano Lake, still in Mexican territory, but in a lower depression on the delta. The river flowed on this course for 10 years and was kept there by means of an extensive levee system built by the people of Imperial Valley. By 1919, through its immense silt deposit, the river had filled the bed of Volcano Lake and Bee River to such an extent that it was again flowing on a ridge and the levees could no longer be made to hold it. The Imperial irrigation district then at an expense of approximately $700,000 constructed an artificial channel from Bee River to what is known as Pescadero River and turned the river southerly into a triangular depression between Volcano Lake on the west and the old channel on the east. This is the area referred to by Mr. Weymouth in his report from which quotation is made.

This is the last remaining depression on the delta.

SILT AGGRAVATES FLOOD DANGER

The river has an annual discharge at Yuma of more than 100,000 acre-feet of silt. This silt greatly aggravates the flood menace. No temporary works can be built to hold it. It was the silt deposit that built the deltaic ridge on which the river now flows. It was the silt deposit that filled the Bee River and Volcano Lake, so that the river could no longer be held at that point, and the same silt deposit will quickly fill the depression where the river now flows.

The gradient to the north into Imperial Valley is much greater than that to the south into the gulf, and when the depression is filled there is no means known which, at any cost within reason, can prevent the river from again flowing into the Imperial Valley.

The dam proposed in this bill will catch and hold the silt. Most of the silt finding its way onto the delta is from and above the canyon section. If no other dams were provided on the river, the one proposed in this bill would retain all of the silt finding its may into the reservoir for a period of 300 years and for more than 100 years before its storage capacity and usefulness would be seriously interfered with. As other dams are constructed on the river they will catch and retain the silt, thereby further extending the usefulness of the Boulder Canyon Reservoir.

PAST FLOODS ABOVE IMPERIAL VALLEY

The Colorado River is subject to periods of great floods and great droughts. It has been known to reach a maximum discharge of more than 200,000 cubic feet of water per second and a low flow at the headworks of the Imperial system of 1,250 cubic feet of water per second.

This causes extremely serious flood situations all along the lower river. Floods above Imperial Valley, were they not overshadowed by the exceptional flood danger to Imperial Valley, would attract attention and call for remedial measures. In 1916 the water stood 2 feet deep in the streets of the town of Yuma and threatened its destruction. In 1922 the river inundated a large part of Palo Verde Valley and the water stood several feet deep in the town of Ripley in that valley, destroying much property and otherwise causing a large amount of damage. Other floods have submerged the Parker Valley and also done serious damage to the city of Needles.

The greatest flood danger, however, is to the Imperial Valley, lying far below the river's channel and with no outlet for flood waters once they enter the valley.

PAST FLOODS THREATEN IMPERIAL VALLEY

In 1914 the Volcano Lake Levee was breached and 10,000 cubic feet of water per second flowed through the levee into the Imperial Valley for many days before the levees could be repaired. More serious results were avoided by means of hundreds of men placing bags of earth on top of the levee.

In 1918 the Ockerson Levee, which had been rebuilt by Imperial irrigation district, was breached in two places. The flood water was successfully turned westward to Volcano Lake by other levees, but not until several thousand acres of land had been inundated and the workmen and a Southern Pacific train marooned. In course of two days the men were removed, but the train was held until the flood subsided some three months later.

In 1910, before the river was turned into Pescadero Cut, the levees were again breached and 4,000 acres of land inundated before the opening could be closed. The river was so high and the water-soaked earth so soft that maintenance work could not be carried on by the usual means of dumping rock from trains operated for that purpose. This was found to be the case after a locomotive and cars had been lost in the attempt. Numerous smaller breaks have occurred. In 1925, with only 50,000 second-feet of water, the river turned against the levees and in two different places undermined and destroyed them for distances of several hundred feet. This again occurred in 1926. These smaller breaks are of annual occurrence and serious results have been prevented only by constant vigilance. Telephone communication is maintained throughout the entire length of the levees and numerous watchmen are constantly on patrol. Strings of dump cars are kept loaded with rock and during high water locomotives kept under steam for immediate use.

LEVEE SYSTEM

The Imperial irrigation district has about 78 miles of protective levees in Mexico. The Yuma project has about 30 miles in Arizona and California, built and maintained by the Government, and Palo Verde irrigation district has several miles of similar levees for the protection of Palo Verde Valley. These levees are of necessity built of loose silt upon a foundation of similar material. They are faced with rock, hauled long distances by dump cars upon standard-gauge tracks, maintained on the levees for that purpose. Levees thus constructed afford only partial protection. When the river strikes the levees it is not its overtopping that is so much feared, but the water will quickly eat away the loose material and the levee simply settles down and virtually disappears.

EFFECT OF FLOOD MENACE

Four hundred and sixty thousand acres are now being served with water by the Imperial irrigation district. There is not only the possibility of this land being inundated but there is a constant knowledge that a comparatively small break in the levee system could destroy irrigation works and cut off water for irrigation and domestic purposes. This creates a constant feeling of uncertainty. Property values are less than half of what its income would justify. Capital for full development can not be had, and where money is obtained it is obtained at an excessive rate of interest. The Federal farm-loan banks refuse to lend any money in Imperial Valley because of these conditions.

The happiness of the people, the security of their property, and the proper development of this highly productive area depend largely upon adequate flood control.

UNANIMITY OF VIEW AS TO FLOOD DANGER AND NEED OF QUICK RELIEF

An outstanding feature of the testimony before the committee was the unanimity of view respecting the existence of the flood danger, its seriousness, urgent need for quick action, and that storage up the river was the solution. Engineers like A. P. Davis and F. E. Weymouth, Gen. George Goethals, and William Mulholland joined with responsible executive officials like Mr. Herbert Hoover in voicing this idea. Admittedly and concededly, storage at Boulder Canyon as here authorized will effect the greatest measure of security against the river's floods which may be obtained.

WATER SUPPLY AND IRRIGABLE LAND

Summary of water supply data on Colorado River

[From pages 101 to 123, U. S. Geological Survey Water Supply Paper No. 556, Water Power and Flood Control of Colorado River Below Green River, Utah]

VALUES IN ACRE-FEET PER YEAR

Colorado River at Lees Ferry: Average recorded flow 1911–1923, computed from records of Green, Grand, and San Juan Rivers (Table 2, col. 6, pp. 104–106)	16,100,000
Colorado River at Lees Ferry: 1911–1923 records extended back to 1895 to include dry cycle 1895–1906 (Table 3, col. 6, p. 108)	15,200,000
Reconstructed River at Lees Ferry: This item is variously estimated at from 16,000,000 to 17,000,000 acre-feet and, taking into account prior dry periods, it is estimated at even less than 16,000,000 (deducted from Table 6, cols. 4 and 5, p. 110)	16,600,000
Colorado River at Lees Ferry: Corrected for depletion by irrigation, period 1895 to 1922, one complete cycle (Table 8, col. 3, p. 112)	14,350,000
Estimated present consumption upper Colorado Basin above Lees Ferry (Table 6, col. 4, p. 110)	2,365,000
Estimated future consumption in river flow upper Colorado Basin above Lees Ferry (Table 8, col. 4, p. 112)	5,470,000
Estimated total present and future consumption in upper Colorado River Basin above Lees Ferry (Table 8, col. 4, p. 112)	7,835,000
Future average yearly river flow at Lees Ferry after deduction of combined present and future water consumption by irrigation in upper Colorado River Basin (Table 8, col. 3, p. 112)	8,880,000
Lower Colorado Basin Co. obligation at Lees Ferry (see Colorado River compact)	7,500,000

TABLE 19.—*Drainage basin, area by States (Senate Document 142)*

	Square miles
Wyoming	19,000
Colorado	39,000
New Mexico	23,000
Arizona	103,000
Utah	40,000
Nevada	12,000
California	6,000
Area in United States	242,000
Area in Mexico	2,000
Total	244,000

TABLE 20.—*Drainage basin, area by basins (Senate Document 142)*

	Square miles
Green River	44,000
Upper Colorado (or Grand River)	26,000
San Juan River	26,000
Fremont River	4,600
Paria	1,400
Escalante	1,800
Kanab	2,200
Little Colorado	26,000
Virgin	11,000
Miscellaneous	44,000
Gila	57,000
Total	244,000

DATA TAKEN FROM REPORT TO SENATE COMMITTEE ON RECLAMATION AND IRRIGATION, JANUARY 20, 1928, BY GEORGE W. MALONE

TABLE 10.—*Most feasible projects in California and Arizona*

[Net for United States irrigation use. Required for projects under way and projects not under way, but of most feasible character]

Project	Area		Water		Acre-feet total
	Arizona	California	Arizona	California	
Bullshead	500	....	1,500	....	1,500
Hardyville	2,300	....	6,900	....	6,900
Mohave Valley	24,000	....	72,000	....	72,000
Parker Valley [1]	110,000	....	330,000	....	330,000
Palo Verde Valley	....	79,000	....	237,000	237,000
Yuma	93,000	15,000	396,000	63,750	459,750
Imperial Valley [2]	....	685,000	....	3,014,000	3,014,000
Coachella Valley [3]	....	72,000	....	306,000	306,000
Total	229,800	851,000	806,400	3,620,750	4,427,150

[1] Indian project.
[2] All American with Coachella Valley pumping area and West Side Mesa omitted.
[3] Coachella Valley 72,000 acres includes only gravity lands according to later surveys information furnished by Imperial Irrigation district.

NOTE.—Nevada's gravity lands, 11,000 acres—46,750 acre-feet. Nevada feasible acreage, 15,000 acres—63,750 acre-feet.

Lower basin development: Development on tributaries below Lees Ferry has been assumed as indicated in the Weymouth report of February, 1924. The plan for river regulation below the mouth of Green River has been assumed as indicated on page 796 of the hearings on Senate Resolution 320, Sixty-ninth Congress, first session. At and above Bridge Canyon, Ariz., the arrangement of dams would correspond to that on Plate 3, Water Supply Paper No. 556.

Below Bridge Canyon the following dams would be built:

Dams below Bridge Canyon

Dam	Present river surface	Maximum water surface behind dam
Boulder	645	1,197
Bullshead	507	645
Parker	358	457

TABLE 15.—*Colorado River projects below Boulder Canyon Reservoir*

Project and tract	Average pumping lift	Irrigable area	Acre-feet	Total acre-feet	Arizona		California	
					Irrigable area	Consumptive use	Irrigable area	Consumptive use
	Feet							
Bullshead to Mohave Valley	80	9,000	3.0	27,000	9,000	27,000		
Mohave Valley	None.	25,000	3.0	75,000	24,000	72,000	1,000	3,000
Parker Reservation	None.	104,000	3.0	312,000	104,000	312,000		
Parker-Gila Valley project:								
Parker Valley	None.	12,000	3.0	36,000	12,000	36,000		
Blythe area	None.	50,000	3.0	156,000			60,000	150,000
Palo Verde Mesa	None.	12,000	3.0	36,000			12,000	36,000
Do	90	43,000	3.0	129,000			43,000	129,000
Chucawalla Valley	90	136,000	4.35	592,000			136,000	592,000
Gila Valley	235	632,000	3.0	1,896,000	632,000	1,896,000		
Palo Verde Valley	None.	79,000	3.0	237,000			79,000	237,000
Cibola Valley	None.	16,000	3.0	48,000	16,000	48,000		
Miscellaneous tracts	23	3,000	3.0	9,000	2,000	6,000	1,000	3,000
Yuma project (valley)	None.	64,000	3.0	192,000	48,000	144,000	16,000	48,000
Yuma project (mesa)	72	44,000	3.0	132,000	44,000	132,000		
Imperial irrigation district	None.	515,000	4.35	2,240,000			515,000	2,240,000
All-American canal	None.	211,000	4.35	918,000			211,000	918,000
Do	80	59,000	4.35	257,000			59,000	257,000
City of Los Angeles				1,000,000				1,000,000
Total		2,014,000		8,286,000	891,000	2,673,000	1,123,000	5,613,000

a Nevada lands available for irrigation: Acres—gravity, 11,000; pump, 69,000; total, 80,000. Acre-feet—gravity, 46,750; pump, 293,250; total 340,000.

According to later surveys, by Imperial Valley, additional California lands: West side, 10,000 acres; west mesa, 23,000 acres.

The following tables have been compiled by the writer from reports by the Department of the Interior and data submitted by the engineering departments of the seven States of the Colorado River Basin.

COLORADO RIVER BASIN WATER SUPPLY

Based on long-time mean, covering wet and dry cycles. Recorded flow corrected for depletion by irrigation.

These figures represent approximately the total yearly flow of the Colorado River Basin, unreduced by irrigation consumption; in other words, the run-off of the reconstructed river. Upper and lower basin terms fit definitions of same in Colorado River compact, as drafted at Santa Fe, N. Mex., November, 1922.

TABLE 1.—*Total basin water supply*

Reconstructed river	Values in acre-feet	Per cent
Upper Colorado River Basin	16,600,000	84
Lower Colorado River Basin, less evaporation from the Gila River and Colorado River below Black Canyon, 1,800,000	3,100,000	16
Total	19,700,000	100

TABLE 2.—*Colorado River compact allocations*

Compact November, 1922	Values in acre-feet	Per cent
Upper Colorado River Basin	7,500,000	38
Lower Colorado River Basin	8,500,000	43
Unallocated surplus	3,700,000	19
Total	19,700,000	100

NOTE.—The problem of a reconstructed river is a controversial matter and is included here as a fair average of the various opinions. The unallocated surplus is variously estimated between two and five million acre-feet.

TABLE 3.—*Water supply data*

[Values in acre-feet]

Reconstructed Colorado River at Lees Ferry		16,600,000
Inflow to Colorado River between Lees Ferry and above mouth of Gila River:		
Utah (Kanab, Virgin Rivers)	225,000	
Nevada (Virgin)	75,000	
Arizona (other tributaries)	1,180,000	
	1,480,000	
Evaporation approximately 1,000,000, Black Canyon to Yuma	1,000,000	
		480,000
Reconstructed Gila River:		
New Mexico supply	443,000	
Arizona supply	2,677,000	
	3,120,000	
Evaporation approximately 500,000 on Gila River	500,000	
		2,620,000
Total water resources, Colorado River Basin		19,700,000

TABLE 4.—*Lower Colorado basin water resources*

[Values in acre-feet]

Average yearly water supply:	
Utah (Virgin)	225,000
Nevada (Virgin)	75,000
New Mexico (Gila)	443,000
	743,000
Arizona	3,857,000
Total	4,600,000
Evaporation from Black Canyon to Yuma, including Gila River, approximately 1,500,000	3,100,000

NOTE.—Figures for evaporation estimated for normal flow of both Colorado and Gila Rivers.

TABLE 5.—*Arizona water production, Colorado River Basin*

GILA RIVER SYSTEM

[Average yearly water supply. Values in acre-feet]

Gila River at Kelvin		787,000
Salt River at McDowell		1,470,000
Verde River at McDowell		609,000
Agua Fria River at Glendale		181,000
Hassayampa River		23,000
Consumption above gauging stations		50,000
Total		3,120,000
New Mexico production:		
Gila River at Guthrie, Ariz	244,000	
San Francisco River at Clifton	199,000	
		443,000
Gila system production in Arizona		2,677,000

NOTE.—Above table, No. 5, does not include losses due to development. Available developed supply for use is estimated from 2,400,000 to 2,600,000 acre-feet. (See Table No. 3.)

TABLE 6.—*Summary—Arizona water contribution*

[Average yearly values in acre-feet]

Gila system production		2,677,000
Main Colorado River:		
Little Colorado River	200,000	
Williams River	75,000	
Other tributaries	900,000	
		1,175,000
Total water production in Arizona		3,852,000

NOTE.—No allowance for evaporation in these figures.

With adequate storage on lower Colorado River, such as Boulder Canyon with 26,000,000 storage, supplemented by small reservoir at Bullshead or Parker, water supply available from Colorado River would be fully conserved.

The first draft on this supply will be reservoir evaporation, the following list indicating the most likely arrangement and losses therefrom, giving elevation water surface:

TABLE 8.—*Evaporation amounts in acre-feet annually*

	Acres
Lees Ferry (Glen Canyon) Dam, 3127–3513, average reservoir area	50,000
Power dams, Glen Canyon-Havasu, average reservoir area	20,000
Bridge Canyon, 1207–1773, average reservoir area	15,000
Boulder (Black), 645–1197, average reservoir area	95,000
Bullshead, 502–645, average reservoir area	21,000
Parker, 358–457, average reservoir area	39,000
Total area	240,000

Average loss, in addition to losses occurring under present conditions, 3.5-foot depth.

MEXICAN USES

The above supply contemplates upstream development which will very closely correspond to anticipated flow at Lees Ferry under compact in critical period, but average flow remains sufficient so that Mexican allotment would entirely have to be supplied from this equaled flow. In the absence of Mexican treaty, it is being assumed Mexico will be awarded sufficient water for 200,000 acres, requiring, at 4.25 acre-feet per year, 850,000 acre-feet.

Total supply after full development of upper basin

Mean flow at Lees Ferry	8,880,000
Average gain to Boulder Canyon	1,460,000
River losses below Boulder Canyon	400,000
Evaporation on developed river below Lees Ferry, 240,000 acres at 3.5 depth	840,000
Mexico, 200,000 acres duty, 4.25	850,000
	2,090,000
Total available supply for use in the United States below Lees Ferry	8,250,000

Evaporation over exposed surface at Boulder Canyon approximately 5-foot depth annually.

NOTE.—Above estimate does not include the Gila River. (See Table No. 5, p. 80.)

TABLE 9.—*Consumptive use and duty of water—Arizona and California projects Colorado River*

[Values in acre-feet]

	Gravity		Pumping	
	Above Laguna, consumptive use	Below Laguna; consumptive use; H. G. diversion	H. G. diversion	Net duty on land
S. Doc. No. 142, Problems of Imperial Valley and Vicinity (p. 38)	3.00	4.4	3.8	3.3
Weymouth Report (U. S. B. R. on Colorado River, vol. 3, p. 300), including Chuckawalla		4.0	4.5	3.0
All-American canal, Mead, Schlecht & Grunsky (p. 35)		4.44		3.22
Bulletin 6, Irrigation Requirements of California (p. 184)		4.0	4.44	3.0
Report of Arizona Engineering Commission on Arizona Land Irrigable from the Colorado River		[1] 4.0		3.0
Water Power and Flood Control (W. S. 556)	3.00	4.5	4.5	3.28
Average [2]	3.00	4.35	4.00	3.25

[1] 4.0 acre-feet duty on basis of lined canal and tunnel which would require a somewhat lower duty with unlined canals.
[2] Average as noted is assumed for calculations in this report.

NOTE.—The average duty is obtained as noted for the reason that practically every investigation has developed somewhat different amounts and it is desirable to arrive at some figure to be used, comparable with the various results.

TABLE 12.—*Gains and losses in acre-feet*

[Gains (+), losses (−)]

Year	Lees Ferry to Topock	Topock to Laguna	Lees Ferry to Laguna
1922	+2,627,000	−1,445,000	+1,182,000
1923	+2,040,000	−1,119,000	+921,000
1924	+1,377,000	−1,020,000	+357,000
1925	+400,000	+127,000	+527,000
1926	+300,000	−465,000	−165,000
Average	+1,349,000	−784,000	+565,000

Present loss from Boulder Canyon to Topock estimated at 300,000 acre-feet annually, making flow at Boulder Canyon 1,650,000 acre-feet greater than at Lees Ferry. This gain will be reduced to 1,460,000 acre-feet with future developments on Little Colorado, Virgin River, etc. (See p. 18, vol. 3, Weymouth Report of February, 1924.) This estimate of depletion compares with estimate of 260 second-feet (188,080 acre-feet) by La Rue. (See bottom p. 119, W. S. Paper No. 556.)

The present average annual loss from Boulder Canyon to Laguna Dam is 865,000 acre-feet. Future losses through the Mohave, Parker, and Palo Verde Valleys are accounted for under consumptive irrigation uses, thus making present losses in these localities available for beneficial use. These losses are estimates at 2.5 acre-feet per acre for 200,000 acres, or 500,000 acre-feet annually, leaving a future loss from seepage, undeveloped areas, and undeveloped river channel of roughly 400,000 acre-feet.

TABLE 13.—*Water supply*

	Acre-feet
Mean flow at Lees Ferry, including use and losses above	8, 880, 000
Average gain to Boulder Canyon	1, 460, 000
Total available from Colorado River	10, 340, 000
Reservoir and river losses:	
Reservoir evaporation, average exposed area of reservoirs from Glen Canyon to Parker, inclusive, 240,000 acres.	
Average rate of loss in excess of present losses, 3.5 feet.	
Average annual loss	840, 000
River losses below Boulder Canyon to Laguna Dam, net	400, 000
Total nonbeneficial uses	1, 240, 000
Balance for beneficial uses	9, 100, 000
Mexico estimated 200,000-acre duty, 4.25	850, 000
Total for use in United States	8, 250, 000

NOTE.—The above outline does not take the Gila River into account. (See Table 5.)

TABLE 14.—*Source of Colorado River waters available for lower basin under future conditions*

	Acre-feet
Gain, Lees Ferry to Boulder Canyon	1, 460, 000
Less loss, Boulder Canyon to Laguna Dam	400, 000
Net gain, Lees Ferry to Laguna Dam	1, 060, 000
Contributed by New Mexico (Little Colorado system)	50, 000
Contributed by Utah (Virgin River, Kanab Creek, etc.)	100, 000
Contributed by Nevada	20, 000
	170, 000
Net inflow creditable to Arizona	890, 000
SUMMARY	
Contributed by upper basin	8, 880, 000
Contributed by Utah	100, 000
Contributed by Nevada	20, 000
Contributed by New Mexico	50, 000
Contributed by Arizona	890, 000
Net supply (for reservoir evaporation and beneficial uses)	9, 940, 000
Reservoir losses (largely in Arizona)	840, 000
Mexico,[1] estimated 200,000-acre duty, 4.25	850, 000
Net supply for beneficial use in United States	8, 250, 000

NOTE.—Above supply does not include the Gila River. (See Table 5, p. 80.)

TABLE No. 20.—*Lower basin water supply*

8, 880, 000 acre-feet—mean flow at Lees Ferry under Colorado River compact, assuming full utilization; taken from reconstructed flow at Lees Ferry.

1, 460, 000 acre-feet—average gain to Boulder Canyon, considering gains and losses.

10, 340, 000 acre-feet—mean annual flow into Boulder Dam Reservoir, equal average flow of over 14,300 second-feet.

400, 000 acre-feet—river losses between Boulder Dam and Laguna Dam.

[1] There is some question whether or not the water finally allotted Mexico should all come from the main stream or should be furnished by the entire lower stream system. If the latter should be the case, more water would be available for allocation to the States from the main stream.

840,000 .... acre-feet—evaporation on developed river below Lees Ferry, 240,000 acres exposed area, and assume 3.5 feet depth annual evaporation in addition to present losses.

850,000 .... acre-feet—for Mexico, assuming 200,000 acres with a duty of 4.25 acre-feet per acre.

2,090,000 acre-feet—total to be deducted for reasons noted.

8,250,000 acre-feet—available at Laguna Dam for use in the lower basin States.

2,250,000 acre-feet—Gila River for consumptive use. (This item variously estimated from 2,200,000 to 2,600,000), total estimated flow tributary measurement, no deductions 3,120,000 acre-feet.

1,500,000 acre-feet—from upper basin allocation on basis of latest U. S. G. S. report that they will not be able to use consumptively their 7,500,000 acre-feet allocation, and will be available for lower basin use, "press release" Department of the Interior, February 28, and March 7, 1929, extract from report which is being printed as a public document, see page 48.

12,000,000 acre-feet—for beneficial consumptive use in the lower basin States.

TABLE 16.—*Most feasible acreage*

State	Acres	Acre-feet
California	861,0[illegible]	3,620,750
Arizona	[illegible]	806,400
Nevada	15,[illegible]	63,730
Total	1,096,8[illegible]	4,490,880

TABLE 17.—*Total irrigable acreage*

State	Acres	Acre-feet
California	1,123,000	[1] 5,613,000
Arizona	891,000	2,673,000
Nevada	80,000	340,000
Total	2,094,000	8,626,000

[1] Includes 1,000,000 acre-feet domestic water.

NOTE.—Gila River not included in Table No. 17.

TABLE 18.—*Average discharges of principal tributaries*

[Senate Document No. 142]

	Per cent of total discharge	Discharge in acre-feet	Square miles	Per cent of total area	Acre-feet per square mile
Green River	32	5,710,000	44,000	18	128
Upper Colorado (Grand River)	40	6,940,000	26,000	10	267
San Juan River	14	2,700,000	26,000	10	104
Other areas, except Gila	8	1,360,000	91,000	39	15
Gila	6	1,070,000	57,900	23	19
Total	100	17,780,000	244,000	100	70

NOTE.—For total water supply of lower Colorado River, see tables 5 and 13 and summary.

EVAPORATION

Average water surface evaporation at selected stations on Bureau of Reclamation projects as measured in small pans [1]

Project	Station	Type	Pan	Years of record	Elevation (feet)	Mean annual temperature, °F.	Mean annual wind velocity in miles per hour	Mean evaporation, in inches, during months of— January	February	March	April	May	June	July	August	September	October	November	December	Mean annual evaporation in feet
Carlsbad	Avalon Reservation	Floating	19 inches by 3 feet, square	1911 to 1923	3,188	62.1	......	2.09	3.10	5.33	7.18	7.90	8.41	9.97	9.14	8.31	6.25	3.16	2.47	6.11
Rio Grande	Agricultural College	Land	3 feet cubical [2]	1908 to 1913	[3]3,800	60.3	......	4.65	3.89	6.56	6.90	10.79	10.46	10.63	10.09	7.31	6.41	4.82	3.61	7.71
Do.	Mesilla Park	do.[4]	10 inches by 4 feet, circular	1918 to 1923	3,863	60.9	4.[illegible]	3.06	4.29	7.82	10.08	[illegible]	12.49	12.23	10.09	7.61	6.12	3.56	2.61	7.67
Do.	Elephant Butte	do.[4]	do.	1912 to 1923	4,473	61.1	4.[illegible]	2.52	3.99	6.05	11.05	[illegible]	14.29	12.55	10.59	9.09	7.5[illegible]	4.05	3.02	5.44
Salt River	Roosevelt	do.[4]	do.	1916 to 1923	2,175	67.3	1.75	2.3[illegible]	3.03	5.49	7.88	11.09	13.38	12.52	10.45	8.73	6.14	4.05	2.39	7.26
Yuma	Yuma Citrus	do.[4]	do.	1921 to 1923	191	70.7	3.5[illegible]	[illegible]	6.08	8.71	11.09	14.37	15.90	17.53	14.93	11.65	8.75	5.54	3.9[illegible]	10.23
Do.	Yuma Evaporation	do.[4]	do.	1917 to 1923	137	6[illegible]	1.[illegible]	[illegible]	3.[illegible]	5.52	7.67	8.29	9.09	10.42	[illegible]	7.39	5.[illegible]	3.18	2.46	6.32
Newlands	Fallon	do.	2 feet by 6 feet, circular [2]	1908 to 1923	3,965	5[illegible]	[illegible]	[illegible]	1.75	4.18	6.22	8.25	9.36	10.6[illegible]	[illegible]	6.48	3.[illegible]	1.61	0.76	5.38
Do.	Lake Tahoe	Floating	30 inches by 4 feet, circular	1916 to 1923	6,230	41.5	2.57	1.55	[3]2.50	3.37	3.08	3.78	4.44	5.60	5.91	4.61	3.34	2.87	2.02	3.56
Orland	East Park	do.	do.	1911 to 1923	[3]1,130	58.2	......	1.13	1.60	2.79	4.75	7.28	8.87	10.56	9.55	7.21	4.47	2.39	1.54	5.29
Klamath	Klamath Falls	do.	22 inches by 42 inches, circular	1921 to 1924	4,100	47.7	......	3.07	2.52	1.52	2.85	4.73	6.51	8.35	7.49	6.10	4.32	2.39	[3]1.56	4.38
Umatilla	Cold Springs	do.		1909 to 1913	600	51.6	7.86	1.04	1.12	2.72	5.86	7.04	8.93	12.44	9.40	6.87	3.87	1.73	1.38	5.16
Do.	do.	Land	10 inches by 4 feet, circular	1914 to 1923	623	51.0	7.07	1.13	0.94	3.20	4.21	6.47	7.09	9.13	8.29	5.44	3.29	1.37	0.71	4.33
Do.	Hermiston	do.	2 feet by 6 feet, circular [2]	1912 to 1923	450	51.6	2.93	1.25	0.90	2.21	3.06	5.41	7.27	8.36	6.67	4.47	2.13	0.56	0.27	3.67
Shoshone	Shoshone Dam	do.	10 inches by 4 feet, circular	1913 to 1924	5,390	46.5	......	0.57	1.22	1.82	3.44	4.85	7.46	8.22	7.55	5.43	2.[illegible]	0.59	[3]0.36	3.73
North Platte	Sunflower Camp	do.	do.	1910 to 1917	4,370	46.2	7.9[illegible]	0.92	0.54	2.06	4.15	6.35	7.94	8.21	6.78	5.39	3.11	1.71	[3]0.50	4.02

[1] Abstracted from article entitled "Evaporation on United States Reclamation Projects," by Ivan E. Houk, published in Trans. Am. Soc. C. E., June, 1927, pp. [illegible] to [illegible].
[2] Set in the ground.
[3] Estimated.
[4] Class A, U. S. Weather Bureau installation.

LOWER BASIN POWER DEVELOPMENT

It is estimated that a total of approximately 3,000,000 horsepower can be developed on the lower river below the Grand Canyon under present conditions, at Glen Canyon, Boulder Canyon, Bullshead and Parker reservoir sites; after full irrigation development in the upper basin States this amount would be reduced to approximately 2,800,000 horsepower.

THE ALL-AMERICAN CANAL

The "All-American canal board" appointed pursuant to an agreement with the Imperial irrigation district directors, by the Secretary of the Interior in 1919, included in their report the following recommendations. The members of this board were Elwood Mead, W. W. Schlecht, and C. E. Grunsky.

RECOMMENDATIONS

1. That the all-American canal, or an equivalent high-line canal, from the Laguna Dam into the Imperial Valley be constructed under one of the above-noted methods, or under some other similar procedure for financing the enterprise, and that Congress pass such laws as may be necessary to put into effect any plan that may be agreed upon between the Secretary of the Interior and the Imperial irrigation district.

2. That the connection of the Imperial Canal with the Laguna Dam be made at once.

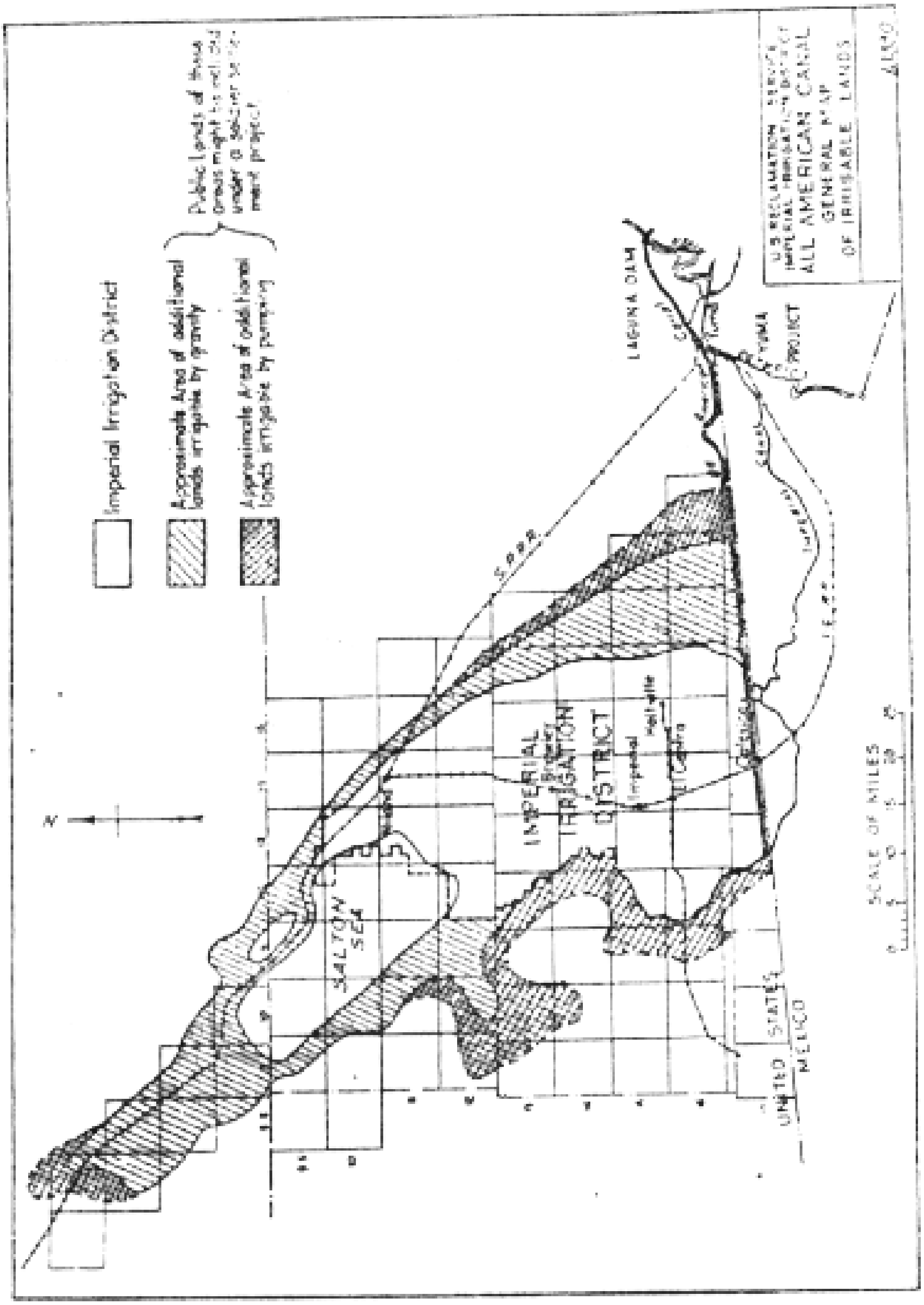
3. That, so far as practicable, the water power of any canal that is constructed be utilized and the apportionment of the cost of installing power plants and of providing the necessary transmission lines should be made on the assumption that the tentative Government plans for the Yuma project would some day be carried out. The Yuma project on this assumption would maintain an interest and would be charged with the proportionate cost of canal capacity for 4,000 second-feet of water to near Araz, and it would be charged for power plant installation in the ratio that 8,500 water horsepower bears to the total water horsepower for which the power installation is to be made.

4. That the development of power with water from an all-American or high-line canal, regardless of the location of power stations, should be charged with such portion of the cost of canal construction down to Araz, and no farther, as is determined by the ratio that one-half of the capacity required for the water used for power bears to the total canal capacity.

5. In case that no other work be undertaken for the joint benefit of the Yuma project and Imperial irrigation district, except the alterations at the Laguna Dam, the enlargement of the Yuma Canal and the extension of this canal to a connection with the head of the present Imperial Canal, then funds for this work should be provided either jointly by the United States for the Yuma project and by the Imperial irrigation district, or by the United States alone subject to repayment of a proper proportionate part of the cost with interest by the Imperial irrigation district, or by the Imperial irrigation district alone, subject to a participation in the power plant and power output,

by the Yuma project upon a repayment to the district of a proportionate part of the construction cost.

6. The power plant installation for construction and other purposes at Pilot Knob should at the outset be for the utilization of



about 3,000 second-feet of water falling 30 feet, and space should be provided for a possible later enlargement of the plant.

7. The United States should undertake the early construction of storage reservoirs on the drainage basin of the Colorado River as part of a comprehensive plan for the betterment of the water-supply

conditions throughout the entire basin of this river. The stored water should be made available for power and irrigation at a fair charge for this service. By storage on a large scale in well-distributed reservoirs the peak of the lower river's flood discharge will be cut down and the menace to the submersible lands along the Colorado River below the Grand Canyon, and in particular to the delta region and the Imperial Valley, will be reduced.

8. Negotiations should at once be entered into, through appropriate channels to bring about an understanding with Mexico, in reference to the control of Colorado River at its high stages on Mexican territory and in reference to the use of the river's water for irrigation in Mexico, and also to permit the United States to construct canals for the irrigation of lands in California across Mexican territory if found desirable to so locate them.

9. That funds be provided for a continuation of the studies relating to the movement of the blow sand on the line of the canal and that these studies be conducted under supervision of the United States Reclamation Service.

Further details can be secured from the report of the "all-American canal board" made to the Secretary of the Interior July 22, 1919.

The map on page 87 is included to show the extent of the proposed canal and the territory served by it.

The length of the proposed canal is approximately 75 miles, not including the branch proposed along the east mesa to Coachella Valley.

The branch to Coachella Valley along the east mesa of Imperial Valley is the portion of the all-American canal included in the pending Senate bill, but not included in the estimated cost of $31,000,000. This estimate raised to $38,000,000 by the engineering board, not including the Coachella portion of the canal.

BOULDER CANYON RESERVOIR

Geology

[From report by F. L. Ransome, geologist, U. S. Geological Survey, 1923[1]]

INTRODUCTION

([1] Vol. 5, 128)

The first geologic examination of the Boulder and Black Canyon Dam-sites by the writer of the present report was made early in 1921. February 1 to 3 were devoted to an examination of Boulder Canyon and on February 4 a trip was made with Engineer Walker R. Young, of the United States Reclamation Service, down the river by boat to the head of Black Canyon, a distance of about 19 miles from the head of Boulder Canyon. February 5 was devoted to the examination of Black Canyon as far down as the lower dam site. A brief preliminary report on this examination was submitted by the United States Geological Survey to the United States Reclamation Service.

([1] Vol. 5, 129)

On November 14, 1922, the writer, with H. A. C. Jenison as assistant, returned to Boulder Canyon, at the request of Director A. P.

[1] Mr. Ransome is now a consulting geologist located at Los Angeles, Calif.

Davis, of the Reclamation Service, and spent 10 days in a further examination of Boulder Canyon and in a reconnaissance of such parts of the Boulder Canyon reservoir site as could be reached from the Reclamation Service camp as a base. He then moved to Black Canyon and made a similar examination of that canyon and of the proposed reservoir site up to the vicinity of old Callville. At this time the reconnaissance was carried down Black Canyon to Jumbo Wash, estimated to be about 15 miles below the head of the canyon. The field work was concluded December 6, 1922. No attempt was made to examine all parts of the reservoir, as this would have required special transportation and camp equipment, would have consumed much time, and would probably have yielded no information of practical value. That part of the reservoir which extends up the Colorado, east of the mouth of the Virgin, lies chiefly in narrow canyons through hard rock and no additional investigation is necessary to support the conclusion that no leakage need be apprehended from this portion of the reservoir.

Subsequently, two days, December 18 and 19, were spent with the board of engineers of the Reclamation Service in a review of conditions at Boulder and Black Canyons, and on December 20, in collaboration with the engineers, a brief report was prepared at Las Vegas, Nev., to Director Davis.

GENERAL REGIONAL GEOLOGY

([1] Vol. 5, 142)

The Muddy Creek formation occupies by far the greater part of the surface within the Boulder Canyon Reservoir site.

Overlying the Greggs breccia and the Muddy Creek formation is a deposit of well-stratified sand and gravel with intercalated flows of basalt. This has been described by Lee,[1] who named it the Temple Bar conglomerate. It is variable in thickness and from Lee's descriptions appears to attain a maximum of over 2,000 feet. He regarded it as probably of early Quaternary age.

([1] Vol. 5, 143)

A still younger deposit of gravels forms bluffs and terraces along the Colorado from the mouth of the Grand Canyon to the Gulf of California. They have been named by Lee [1] the Chemehuevis gravel and were considered by him as of late Quaternary age. Their maximum thickness is given as about 700 feet.

In addition to the intrusive granitic rocks of pre-Cambrian age, such as are exposed in Boulder Canyon and the late Tertiary basalt flows, such as occur in the Muddy Creek formation and Temple Bar conglomerate, the region contains two rather complex masses of predominantly igneous rock of considerable volume and extent. One of these lies just north of Boulder Canyon and stretches westward toward Callville Wash and eastward to the valley of the Virgin; the other occupies many square miles on both sides of the Colorado, in the vicinity of Black Canyon. Information concerning these rocks is too meager to permit of detailed description or to justify the application to them of permanent geologic names. For

[1] Lee, W. T., Geological reconnaissance of a part of western Arizona: U. S. Geological Survey Bulletin 352.

practical convenience of reference in the present report, however, the first of these may be referred to as the Boulder Wash group and the second as the Black Canyon group. The Black Canyon group is the more homogeneous and consists of intrusive masses, flows, breccias, and volcanic sediments that are probably all of Tertiary age. The Boulder Wash group, in addition to volcanic and intrusive rocks, contains some limestone and shale. The volcanic rocks are probably Tertiary but some of the stratified rocks and possibly some of the intrusive rocks may be older than the Tertiary. Detailed study of this interesting region will some day result in the division of the Boulder Wash group into true geologic units.

([1] Vol. 5, 144)

At the base of the Boulder Wash group, on the north side of Boulder Canyon, 1,000 feet or more above the river, is a hard, siliceous yellowish limestone which rests directly upon the pre-Cambrian schist and granite. No fossils have been found in it and its age is unknown. This limestone, which is perhaps from 100 to 200 feet thick, is overlain by several hundred feet of a coarse breccia composed largely of fragments of pre-Cambrian rock. Apparently some lenses of limesetone are interbedded with this breccia. The general dip of the whole is to the north.

([1] Vol. 5, 147)

At least one locality on the west side of Boulder Wash the coarse breccia is overlain by a considerable thickness of calcareous and sandy shales, with some very thin beds of limestone. They appear to dip generally north at about 25° but are disturbed and faulted. Overlying the shale is a thick mass of andesitic breccia with possibly some massive andesite. This, as a whole, also appears to dip to the north, whereas, at the head of Boulder Wash, the sedimentary beds of the Horse Spring formation dip steeply to the south. Between the two is an east-west belt of intrusive rocks, including fine-grained diorites, dioritic porphyries, and perhaps other varieties. These are included in the provisional Boulder Wash group but their relations to the andesite to the south and the Horse Spring formation to the north are as yet obscure. Cursory examination suggested that they may have been intruded along an east-west fault zone. The pressure of a fault appears to be demanded by the manner in which the Horse Spring formation at the head of Boulder Wash dips toward the pre-Cambrian rocks of Boulder Canyon instead of turning upward and lapping over the pre-Cambrian as would be expected of a Tertiary formation. Below the part of Boulder Canyon in which the dam sites are located the rocks of the Boulder Wash group are exposed along the river banks as will be described later.

([1] Vol. 5, 147)

The igneous rocks of the Black Canyon group constitute an extensive mass that lies athwart the course of the Colorado, about 3 miles south of the mouth of Las Vegas Wash, and stretches east and west for 2 or 3 miles on each side of the river. Through this mass the stream has cut the deep gorge of Boulder Canyon and flows wholly within it for about 8 miles, to a point where the walls become less precipitous and pre-Cambrian granitic and schistose rocks emerge from beneath the volcanic group. For about 7 miles farther, down to Jumbo Wash, the river flows mainly through mountains of pre-Cambrian crystalline rocks, but members of the Black Canyon group can be seen on distant summits and in places are low enough to appear at the water's edge. Below Jumbo Wash the canyon was not traversed, but a reconnaissance by Schrader[4] suggests that the Black Canyon volcanic group may be generally continuous with the thick volcanic series that makes up most of the Black Mountains farther south, in the vicinity of Oatman, Ariz.

([1] Vol. 5. 150, 151)

The Black Canyon group is a complex assemblage of lava flows, volcanic breccias, tuffs, volcanic sandstones, and intrusive masses. The lavas are predominantly rather light colored, reddish gray, biotitic rocks of intermediate chemical composition. It is doubtful whether they should be classed as andesites or latites, but inasmuch as accurate classification would require chemical analyses and andesite is the older and better-known term, it will be preferable and sufficiently exact for all practical purposes to refer to them as andesites. Most of the andesites contain considerable glass—that is, the rock solidified before the molten material could crystallize completely—and some flows contain more glass than crystals. Some of the lava flows are crowded with fragments of essentially the same character as the matrix. These, known as flow breccias, probably owe their characteristic structure to the formation of congealed lava crusts that were broken up by the continued movement of the still molten lava, the resulting fragments being enveloped in the liquid portion of the flow. A considerable part of the group consists of breccias of another kind. These are composed chiefly of angular fragments of lava and other rocks of various sizes in a matrix that is also composed of fragmental rock particles. Such rock is the record of explosive volcanic eruptions. The fragments may have accumulated on land or, more probably, in a body of water. Such a breccia, in distinction from a flow breccia, may be called a tuff breccia. Associated with the lava flows and breccias are some relatively thin layers of well-stratified red sandstone and shale, composed of fine andesitic particles. They may be classed as tuffaceous sandstone and tuffaceous shale. Associated with the foregoing rocks and generally underlying them are intrusive rocks which appear to be generally diorites, quartz diorites, or dioritic porphyries. In many places these lower rocks are so altered and decomposed that their exact character is not determinable. In other places the rock is clearly a quartz diorite. All of these rocks are cut by dikes and small irregular masses of basalt.

([1] Vol. 5. 151, 152)

The general form of the entire assemblage of rocks comprising the Black Canyon group is difficult to ascertain and in some respects would remain in doubt even after detailed geologic mapping. It is clear, however, that the rocks are chiefly lava flows and breccia deposits that originally were nearly horizontal. They evidently

[4] Schrader, F. C., Mineral Deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.; U. S. Geol. Survey Bull. 397, Pl. I, 1909.

occupy a basin of which the deepest part is under the present Black Canyon. The shape of this basin and the depth from the river level to the pre-Cambrian crystalline rocks upon which the lavas as a whole rest are not at present determinable. There is some evidence to show that the bottom of the basin subsided after the first eruptions and perhaps continued to sink throughout the period of volcanic activity. Such movement is indicated by the exposure within the canyon walls of layers of volcanic sandstone which now dip at angles up to 65° and have been faulted, whereas the higher flows have generally a much lower dip toward the east-northeast. There is evidence at one locality that the andesite broke through the older rocks in the vicinity of Black Canyon; in other words, that the seat of eruption was local and that the flows and breccias are not the product of outbursts at some unknown distant point. If this is true, it is probable that in some parts of the basin the andesitic lavas extend downward to their point of origin within the earth.

The basaltic dikes and masses that are exposed in the canyon walls belong to a late stage in the eruptive activity and probably extend downward far below the bottom of the basin. They appear to have risen through branching and irregular fissures which cross the general stratification of the flows and breccias.

From the occurrence of pre-Cambrian granitic and schistose rocks both north and south of Black Canyon it is fairly certain that the Black Canyon volcanic group as a whole rests on these rocks. Such a relation is clearly shown on the river about 8 miles below the head of Black Canyon. Here the andesite rests on the pre-Cambrian. It was not practicable to examine the contact closely at this place, but, as seen from the river, it appeared to be fairly close. It is certain that loose gravels or breccias are absent at this point, and if any detrital material intervenes between the lavas and the pre-Cambrian it is not of a character to cause any anxiety as regards possible leakage from a reservoir 8 miles away.

[From report by F. L. Ransome, geologist United States Geological Survey, 1923]

Boulder Canyon Dam

Reservoir Leakage

([1] Vol. 5, 164)

In brief, the water of the proposed Boulder Canyon Reservoir will be confined by mountains of hard rock or by natural dams of softer but not particularly pervious material through which it would have to pass for 20 miles or more before finding an outlet. In other words, there is no point at which escape of water from the reservoir through a relatively thin barrier of pervious material need be feared.

Boulder Canyon Rocks

([1] Vol. 5, 182)

The rocks exposed in the walls of Boulder Canyon, with the possible exception of some dike rocks, are all pre-Cambrian and in a general way may be divided into schist, quartz diorite, and granite. The schist is the older rock and is exposed at the upper entrance to the gorge. It is mainly dark biotitic schist, much crumpled and cut by dikes of pegmatite, aplite, quartz diorite, and fine-grained gray granite in general order of decreasing age.

The schist is succeeded downstream by quartz diorite, which is intrusive into the schist and in a general way underlies it. The quartz diorite is a hard, tough, fine-grained rock of granitic appearance but rather darker in color than typical granite. Like much of the rock in the canyon, it has has undergone some superficial weathering but it is nowhere difficult to collect fresh material. The most conspicuous dark constituent is hornblende in slender black prisms. In some varieties these prisms are an inch or more in length. Black mica (biotite) is also fairly abundant. The light-colored constituents are quártz and feldspar, the feldspar being chiefly calcium-sodium feldspar or plagioclase. The microscope shows that all the constituent minerals are generally fresh.

([1] Vol. 5. 184)

Farther downstream the canyon walls, or at least their lower portions, are composed of a fine-grained gray granite which is intrusive into the quartz diorite. Like the quartz diorite the granite is generally fresh and under the microscope shows a closely interlocking aggregate of orthoclase, plagioclase, quartz, and biotite. The considerable quantity of plagioclase present may justify classification of this rock as a quartz monzonite, but for all practical purposes it is sufficiently exact to refer to it as granite.

[From report by F. L. Ransome, geologist U. S. Geological Survey, 1923]

([1] Vol. 5, 184)

The general distribution of the schist, quartz diorite, and granite in the lower part of the canyon walls is shown on 45–C–88. No attempt was made to map these rocks accurately, as such mapping would serve no immediate useful purpose. It is questionable whether it would be practicable to trace the contacts up the inaccessible parts of the canyon walls. For all purposes connected with dam construction the distinction between the granite and the quartz diorite is unessential. The quartz diorite is probably a slightly tougher rock than the granite and may, therefore, be a little more difficult to drill or break. It will be observed that at line C–1 of the upper dam site (the only site now seriously considered) the north wall is quartz diorite and the south wall granite. Two test tunnels run in the north wall near this line, in 1922, are both in the quartz diorite.

BOULDER CANYON FAULTS

([1] Vol. 5. 185 and 186)

A number of faults—that is, fissures along which the rock on one side has moved relatively to that on the other side—are exposed in the canyon walls. They show some diversity of trend but most of them strike from north to northeast and dip west. The evidence of former movement on these faults is found in the existence of polished and grooved rock surfaces, generally separated by a layer of crushed rock or of triturated rock commonly referred to as gouge.

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None of the faults exposed in the canyon walls shows any indication of present or recent movement. They contain no soft gouge and the crushed material between their walls has been cemented into a rock too hard to be broken out with a pick. This condition, while perhaps not absolutely conclusive, is at least strongly indicative of the absence of recent movements.

SEISMIC DISTURBANCES

([1] Vol. 5, 189)

Careful examination of the region from high points in the vicinity of the canyon failed to show any features in the topography suggestive of recent displacement. The existence of ravines that have been eroded along a fault is not evidence of recent movement; it rather indicates some measure of antiquity.

[From report by F. L. Ransome, geologist, U. S. Geological Survey, 1923]

([1] Vol. 5, 189)

It must be remembered that all through the region west of the Colorado Plateaus faults are numerous, and it would be difficult to find any area of more than a few square miles in Nevada, western Arizona, or southern California where faults are absent. In a geological sense most of these faults are recent but comparatively few of them are known to have been active within historical time. Those, such as the great rift identified with the San Francisco earthquake of 1906, are marked by a characteristic topography that is highly significant of recent activity. The essential conclusion, with reference to dam construction, is that no fault in the vicinity of Boulder Canyon is associated with features such as are recognized as characteristic of [illegible] active since civilized man has inhabited North America.

([1] Vol. 5, 190)

Near the head of Boulder Canyon are three faults. These faults dip to the west and have normal displacement, that is, the west sides have gone down or the east sides have gone up. The throws are moderate—probably not over 200 feet. There is no means, however, of measuring the throw accurately. The nearest of these faults lies 800 feet upstream from the permanent dam. Two of them will be crossed by the proposed 30-foot diversion tunnels, but their presence is not expected to present any engineering difficulties.

Another fault lies about 200 feet downstream from the toe of the proposed dam and erosion along it has produced lateral ravines both north and south of the river.

([1] Vol. 5, 200)

It is probable that any dam constructed in Boulder Canyon will be at the upper or C site, and this is sufficiently distant from the fault zone to insure the safety of the structure should any additional movement take place. Should the Boulder Canyon region again be subjected to deformation by faulting, the major stresses are more likely to find relief along this fault zone than along any of the fractures already existing within the section of the canyon in which the dam sites are located.

FORMATION OF CANYON

([1] Vol. 5, 201)

Boulder Canyon, like many other canyons in the Western States, has been supposed by some who are not geologists and are not appreciative of the erosive power of running water, to have been formed by a fault. As this supposition has been advanced in opposition to the construction of a concrete dam across the canyon[4] it may be well to state that there is no evidence whatever that the gorge was opened by a rending apart of its walls or by erosion along a fault.

[From report by F. L. Ransome, geologist U. S. Geological Survey, 1923]

([1] Vol. 5, 201)

The course of the canyon is more sinuous than would be expected did it follow a single-fault fissure. If it be supposed that each of the comparatively straight sections of the canyon has followed one of a series of intersecting faults, these faults should be visible in the walls at the bends of the river. They do not appear. There is no indication that the rock on one side of the canyon has been displaced with reference to the rock on the other side. On the contrary, dikes, fissures, and other features, provided that they strike in the right directions, can generally be found in their original relative positions on each side of the river. The canyon is wholly the work of running water armed with abundant bowlders, gravel, and sand. Its form indicates that it was cut rapidly in late geologic time.

DURABILITY OF ROCK

([1] Vol. 5, 204)

Notwithstanding the prevalence of jointing the decomposition of the granitic rocks in the walls of the canyon is remarkably slight. This is due partly to the resistant character of the rock itself, partly to the recency of the canyon as a geologic feature, and partly to the closeness of the joints which has not permitted deep penetration of air and surface water. The absence of frost in this locality is, of course, also conducive to the preservation of rock traversed by joints.

Although, of course, massive rock with no joints would be the ideal material on which to construct a dam, few rocks as old as those of Boulder Canyon, particularly in the southwestern United States, are free from joints. The Boulder Canyon granite (including the quartz diorite) is durable, it unquestionably extends for hundreds of feet below the bottom of the river, and the joints are far too tight to permit any flow of water around or under the dam.

BLACK CANYON DAM

RESERVOIR LEAKAGE

([1] Vol. 5, 212)

The same general conditions prevail in the Black Canyon section of the reservoir as in the Boulder Canyon section. Callville Wash, Las Vegas Wash, and Hemenway Wash all rise gradually away from the

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[4] Hearings before the Committee on Irrigation of Arid Lands, House of Representatives, 67th Cong., 4th sess., on H. R. 11449, part 5, p. 210. 1923.

river and head in passes that are so distant from the reservoir and so high above the proposed water surface that overflow through them is impossible. Moreover with the water surface at the highest level proposed, the water would have to pass through many miles of rock to find an outlet. The shortest route of escape through the inclosing rocks would be through the mass between Hemenway Wash and Colorado River, to some point of emergence below the dam site. To accomplish this passage the water would have to pass through at least a mile of rock, partly intrusive dioritic porphyry and partly the volcanic rocks of the Black Canyon group. There is no evidence of the existence of any continuous porous rock member as for example, a layer of conglomerate or loose breccia, through which water could escape by this route.

The possibility of leakage around the dam on the Arizona side of the river, under the gravel-covered slopes that intervene between the Black Canyon volcanics and the pre-Cambrian rocks of the main ridge of the Black Mountains, was also carefully considered. To escape by this general route the water would have to penetrate at least 2 miles of material, mostly solid, impervious rock. As the flows of the Black Canyon group dip generally northeast, away from the dam site, the water would have to find its way not merely between but across these flows and the possibility of escape by this underground route may safely be dismissed.

BLACK CANYON ROCKS

([1] Vol. 5, 220)

They are a series of volcanic flows and tuff-breccias mainly of andesitic composition. There was apparently considerable disturbance during the period of eruption and lower flows and breccia layers were probably tilted and faulted before being covered by younger lava. The walls of the canyon show in many places a rough stratification of the lava flows and breccias in layers 100 feet or more thick. This is shown in the dark canyon walls by slight differences in color and by rather vague lines or zones along which the lava weathers into cavities which give it the appearance of having a coarse, spongy, texture, as seen in the cliffs.

([1] Vol. 5, 221)

It appears that the rock exposed in the walls of Black Canyon from the head of the canyon to a point at least a quarter of a mile below the lower dam site and extending from the river for an unknown height, probably several hundred feet, up the cliffs, is mainly andesitic tuff breccia.

([1] Vol. 5, 222)

It seems necessary to conclude that the tuff breccia and associated sandstone and shale were deposited in a deep basin and that after at least partial consolidation they were faulted and tilted before the andesitic flows buried them. The depth of this basin or the maximum distance from the present river bottom to the bottom of the tuff breccia is not known. Neither is it known on what rock the breccia rests in the deeper part of the basin. As already mentioned, the andesitic rocks rest, at various places, on diorite porphyry. Whether this rock underlies the whole of the tuff breccia or is intrusive into it is not known. It is probable that this diorite porphyry or pre-Cambrian granitic rocks underlie the breccia in the deeper parts of the basin.

FAULTS AND FORMATION OF CANYON

([1] Vol. 5, 223)

As would be expected, a number of faults are exposed in the canyon walls, but as no topographic map of the canyon was available at the time of examination it was not practicable to map these. Some, as has been suggested, were formed during the period of volcanic activity and affect only the tuff breccia and the rocks beneath it. Others dislocate the overlying flows.

None of the faults seen shows evidence of recent movement and none is so situated as to interfere in any way with the maintenance of a high concrete dam at the lower dam site. The following rather interesting evidence was obtained to show that at least one of these faults has long been without movement.

([1] Vol. 5, 224)

At a point on the Arizona side of the canyon, determined by aneroid readings to be about 900 feet above the river, were found potholes and channels worn in the andesite by a stream that once flowed at that level, but which could not possibly flow there with the topography anything like what it is to-day. The potholes are associated with well-rounded hard pebbles up to a foot in diameter. Some are of limestone and must have been brought down from the country east of Boulder Canyon. There appears to be no escape from the conclusion that these potholes and channels were the work of the Colorado River before it cut the present gorge to a depth of over 900 feet below them. Some of the channels cross a fault of which the lithified gouge with nearly horizontal grooving can be seen. There has been no movement on the fault since these channels were cut. The existence of these well-preserved potholes and channels demonstrates (1) that the fault has undergone no movement during a period long enough for the river to cut down over 900 feet through hard rock, (2) that the andesite is capable of retaining a smooth surface through long exposure to the weather, and (3) that the cutting of the gorge, while it probably continued for many centuries, was geologically a comparatively rapid process.

BLACK CANYON DAM SITE AND LEAKAGE AROUND DAM

([1] Vol. 5, 228–231)

The river here is from 250 to 300 feet wide, and the walls rise so steeply that at the 1,100 contour, or about 450 feet above the river, they are only from 600 to 700 feet apart. For a considerable part of their height they are composed of andesite tuff breccia, consisting of angular fragments of andesite and of other fine-grained igneous rocks in a matrix of finer particles, all firmly cemented to a hard rock of generally reddish gray color. Although not separable into distinct beds, the rock exhibits indefinite lines of stratification, emphasized on weathered surfaces by the alignment of irregular pits or cavities which give the rock the superficial appearance of being somewhat porous or spongy. The pits, however, are not original cavities but are due to the disintegration and weathering out of certain fragments in the breccia. In certain spots in the walls the cement of the breccia, which is partly calcite and probably partly oxide of iron, is more readily acted upon by the weather than elsewhere and the breccia disintegrates so as to produce concavities or shallow caves in the cliffs. This action, however, is superficial and the rock back of a very thin surface layer is apparently nearly or quite as hard as elsewhere. The breccia as a whole is a strong, hard, impervious rock and would be excellent material on and against which to construct a dam. There is no deep decomposition and less than 10 feet would have to be removed to secure good anchorage for a concrete structure. The breccia is traversed by some joints, but these are superficially accentuated by weathering. Joints are probably much less abundant than in the granite at Boulder Canyon.

([1] Vol. 5, 232)

When a dam is constructed on granite there is not likely to be much concern about the foundation. There is reasonable certainty that the granite extends downward far beyond any depth that need be considered in planning an engineering structure. When, however, a dam is built on volcanic rock it is necessary not only to consider the character of the rock in sight but to inquire what may be beneath it. Is it possible, for example that a firm massive lava may rest on loose gravel or agglomerate through which water might escape and perhaps in time undermine the foundation of the dam? No one can at present tell what is under the andesite breccia at the lower dam site at Black Canyon, but it is reasonably certain that the breccia itself extends so far below the river bed at this point to insure an adequate foundation for any properly constructed dam. The lines of stratification in the breccia dip upstream at about 50 degrees. The same breccia extends downstream for at least 1,200 feet, with gradually decreasing dip. The average dip can safely be taken at 30 degrees. This would give a thickness of at least 700 feet of breccia below the surface of the river at the dam site. The actual thickness is probably greater than this, as the dip and distance used in the calculation were very conservatively taken. If anywhere beneath the breccia soft or porous deposits occur, these nowhere come to the surface and consequently would not be likely to permit the escape of water held back by the proposed dam. Wherever the base of any member of the Black Canyon volcanic group has been seen no considerable quantity of loose or porous material has been found. About 1,700 feet downstream from the lower dam site an irregular intrusive mass of basalt is exposed on both sides of the river and extends for some hundreds of feet above the water. This mass has presumably come up from great depth and constitutes a natural impervious diaphragm which would prevent free passage of water through a buried porous stratum, did such exist. About a mile below the dam site the breccia disappears and an intrusive dioritic rock forms the lower walls of the canyon. The precise point of change was not recognized in passing up and down the river and the contact between the two rocks is certainly inconspicuous and presumably, therefore, close.

In short, there is no reason to apprehend that water impounded behind a high dam at the lower dam site could escape around or under the dam.

SELECTION OF DAM SITE

BOULDER CANYON

([1] Vol. 5, 26)

Active work of investigating dam sites below the Virgin River began early in 1920. In April of that year Mr. Homer Hamlin, consulting engineer-geologist, of Los Angeles, now deceased, assisted by Edgar T. Wheeler, made a reconnaissance of the river from Virgin River to Yuma, at which time they selected a site in Boulder Canyon about 3,500 feet downstream from its entrance, later designated the A site, as being the most favorable site for the construction of a high dam. In the Hamlin-Wheeler report of July, 1920, it is stated:

> If, however, the site proves unsatisfactory, it may be advisable to try for bed rock in the upper reaches of Black Canyon, some 21 miles below Boulder Canyon dam site. The chances for a dam site here seem just as good as in Boulder Canyon, but the rock is volcanic tuff. It appears to be satisfactory, however, and is very hard and dense.

Diamond-drill operations to test foundation conditions were begun in September, 1920. The first dam site drilled was the A site. A cross section of the river channel was developed by drilling 12 holes.

([1] Vol. 5, 27)

The maximum depth to bed rock below low-water surface in the river was found to be 136 feet. In general, the river channel is filled with fine sand and silt to a depth of about 70 feet, overlying gravel, and bowlders, increasing in size with increased depth. Where it was possible to seat the diamond bit on the rock the holes were carried into the foundation rock in order to ascertain its quality. The diamond drill produces a core, in this case fifteen-sixteenths inch in diameter, which is recovered for examination. The hole determining the maximum depth to rock was continued into the rock for 57 feet to a point 193 feet below low-water surface. Seventy-seven per cent of the core was recovered, which showed the rock to be the fine-grained granite previously described. It is of excellent quality, although considerably jointed.

A fault crosses the river about 120 feet below the line drilled. There has been some slight movement along one of the major west dipping joints, but there is no evidence of either large displacement nor, geologically speaking, recent movement. However, a dam built at the A site would rest on the fault, and although the fault is apparently of no consequence it was thought advisable to locate a site where faulting had not occurred. At site B the amount of concrete required for a dam would be no greater than at the A site. However, examination of the B site disclosed the existence of a well-defined fault fissure there. It appears in the south wall about 15 feet west of the B line and crosses the line obliquely. The fissure contains from 1 to 2 feet of crushed granite cemented to a hard rock. There has probably not been any recent movement, but it would not be advisable to construct a dam on it. The fault could be avoided by moving the dam downstream, but with material increase in concrete yardage. The B site was not drilled.

[1] Vol. 5, 28

The steep canyon walls are unsuited to a railroad or construction plant, and it is believed that construction of a great dam at any considerable distance from the entrance to the canyon would be both difficult and expensive. This in addition to the existence of minor faults at the A and B sites led to the investigation of the C dam site just below the point where the canyon proper begins. Here the upstream heel of the largest concrete dam proposed would rest on a hard dike and the downstream toe would fall at the narrow point in the river channel, where the distance between canyon walls is only about 200 feet. Although the concrete yardage would be greater, it is believed that a dam could be constructed for the same or less cost than at the A site on account of better accessibility.

[1] Vol. 5, 29

On line C–1 a cross section of the river channel was developed by drilling 12 holes, with maximum depth to bed rock, 130 feet. As at the A dam site, the channel is filled with fine sand and silt to a depth of about 70 feet, overlying gravel and heavy bowlders. The holes were carried into the foundation rock to ascertain its quality. The deepest hole penetrated bed rock for a distance of 50.5 feet to a point 180.5 feet below low-water surface; 43.6 per cent of core was recovered, which showed the rock to be the fine-grained granite or quartz diorite, muchly jointed.

It was anticipated that the depth to bed rock, between the points of rock, some 300 feet downstream from line C–1, would be greater than at line C–1 on account of the high velocity of flood water in the constricted area of section, and an attempt was made to outline the channel section by drilling angle holes under the river from the banks on line C–2. One angle hole drilled from the Nevada side was finished. It was 400 feet long and did not run out of rock into the river channel. Two holes were started from the Arizona side. One ran out of rock into the river channel and the other was abandoned as the hole was caving. One of the objects in drilling the angle holes was to determine whether the canyon had been formed by a fault along its axis. As depth to bed rock in the river channel could be ascertained more easily by drilling vertical holes from barges the following season and since a geological examination indicated beyond any doubt that the canyon was not along a fault line, there was no object in continuing the angle hole from the Arizona side.

([1] Vol. 5, 30)

Since preliminary investigations indicated that the C site was more favorable than the A site the entire foundation area of the largest dam proposed was developed at the C site by drilling on lines 200 feet apart up and down stream, on lines under the proposed cofferdams and miscellaneous holes along the shore line to develop rock at tunnel entrances, etc.

It will be interesting to note that proceeding downstream the maximum depth to bedrock increases from 88 feet at line U-400, to 158 feet on line D-200, and 156 feet on line D-400. The shallow depth to rock at line U-400 would prove very advantageous since it could be taken advantage of in construction of the dam. The high rock at this point is explained by the dike previously mentioned which is indicated on drawing 45-C-328 as crossing the river between lines U-200 and U-400. It is composed of a light gray, fine-grained porphyry with small porphyritic crystals of feldspar, quartz, and biotite. It is about 15 feet wide at the water's edge and dips downstream at about 60 degrees.

([1] Vol. 5, 31)

At lines D-200 and D-400 the rock is very much shattered, and in the deepest hole on line D-400 only 14.4 per cent of core was recovered although a double tube core barrel, adapted to use in friable rock, was used. The indications were that between lines D-200 and D-400 there is a zone of crushing, probably secondary to the fault crossing the river just below the dam site. This crushed zone in combination with the restricted width between the projecting points of rock is undoubtedly responsible for the greater depth of scouring.

An interesting feature of the drilling was the development of high bed rock under the proposed upper cofferdam about 1,200 feet upstream from line C-1 with a maximum depth to rock of 34 feet below low-water surface. This discovery led to the immediate consideration of this location as a possible dam site. Locating the dam at this site would simplify the most difficult and expensive feature of construction, that of building and maintaining cofferdams in the Colorado River to reach bed rock at depths developed at other sites. This site, however, is crossed by three plainly marked faults in a direction transverse to the canyon. They are not of recent occurrence and probably are so cemented as to be water tight, but in case of a future earth movement in this locality there would be a possible tendency toward displacement along these old fault planes. This contingency involves an element of risk which more than offsets the advantage gained by building on a shallow foundation and renders this upper site unsuitable for the proposed high dam. A detailed geological examination was made of the site by H. A. C. Jenison, geologist, United States Geological Survey.

([1] Vol. 5, 32)

Upon abandoning the cofferdam site as a possible site for the main dam consideration was given to locating the dam on the comparatively high rock between the cofferdam site and the C site. The dams proposed are of the gravity type built on a curved plan. The topography between the sites is such that a dam placed so that its base would come between the faults mentioned and the dike at the C site would miss the natural abutments in the upper portion. The concrete yardage would be more than at the C site and the Arizona abutment would be poor. The investigations led to the adoption of the C dam site as being the most favorable site for the construction of the proposed high dam in Boulder Canyon. This site was very thoroughly developed for comparison with the best site in Black Canyon, 20 miles downstream.

The total number of holes drilled in Boulder Canyon was 122, 110 of which were put down at the C dam site including those at the cofferdam sites.

[1] Vol. 5, 33

The terms "broken granite," "seamy granite," "crushed granite," etc., found in the drill logs is the result of the drillers attempting to classify the core recovered in detail. The jointing in the granite is responsible for the broken core and a piece of fifteen-sixteenths inch diameter core over 6 or 8 inches long was rare. The core recovered is stored with that obtained at Black Canyon in a stone cellar at the Black Canyon drill camp. No attempt was made to carry the holes on cofferdam line C to rock since the purpose of the drilling was to develop a foundation suitable for the proposed cofferdams and a good bed of bowlders was all that was required. The same was true of cofferdam lines A and B, but here there were no bowlders.

BLACK CANYON

[1] Vol. 5, 38

Two dam sites were investigated in Black Canyon: One about 1400 feet below the entrance, known as the A site, and the other about 1¼ miles below the entrance, known as the D site. Due to the greater width of river channel at the upper site it was anticipated that bed rock would be found at comparatively shallow depths. However, the shallow depth did not materialize, and this, in combination with the character of the rock and the large amount of concrete necessary to build the dam, made the D site preferable.

[1] Vol. 5, 39

The river at the D site is from about 260 to 350 feet wide at low water and the walls rise so steeply that at an elevation 450 feet above the river they are only from 550 to 650 feet apart. For a considerable part of their height the walls are composed of andesite tuff breccia, previously described, overlain by flow breccia.

In the walls the rock shows irregular pits and cavities which give it the superficial appearance of being somewhat porous or spongy. The pits are not original cavities but are due to the disintegration and weathering out of certain fragments in the breccia. The breccia, as a whole, is a strong, hard, massive impervious rock, which would be an excellent material on and against which to construct a dam.

There is no deep decomposition and it is estimated that less than 10 feet would have to be removed to secure good anchorage for a concrete dam. Joints are much less numerous than in the granite at Boulder Canyon.

([1] Vol. 5, 39)

Volcanic rock as a dam foundation is not so generally suitable as granite formation which is deep seated and free from the possibility of being underlain by layers of inferior material, such, for example, as loose gravel through which water might escape and perhaps in time undermine the dam. It is estimated that the breccia at the dam site is at least 700 feet thick below the water surface in the river and perhaps much thicker. If a layer of previous material does exist under the breccia it does not come to the surface and consequently leakage through it would not be likely to occur. About one-fourth mile below the dam site an intrusive mass of basalt has presumably been forced up from great depth to some hundreds of feet above the river level. This mass lies across the canyon, the river having cut through it, and constitutes a natural impervious diaphragm which would prevent free passage of water through a buried porous stratum, did such exist. In short, there is no reason to apprehend that water impounded behind a dam at the lower site in Black Canyon could escape around or under the dam.

([1] Vol. 5, 40, 41)

Diamond drill operations to test foundation conditions were begun in January, 1922. The upper or A site was the first dam site drilled. A cross section of the channel was partially developed by drilling 9 holes on line A, with maximum depth to bed rock below water surface of 90.4 feet. It is likely, however, that the deepest channel was not located. In general, the river channel is filled with fine sand and silt to a depth of from 15 to 20 feet resting on gravel and boulders. Four of the holes were drilled into the bedrock and as at Boulder Canyon, a core fifteen-sixteenths inch in diameter was recovered. In addition to the river holes, a hole was drilled on the Nevada shore above high water to a depth of 250 feet to ascertain the quality of the rock to a considerable depth. In all cases the rock was found to be a spongy flow breccia of light weight and high absorption. The rock contains open seams or cavities, as indicated by the loss of the water pumped into the hole in drilling; soft spots were located; either seams of clay or more probably breccia were crossed; and the percentage of core recovered was low. In short, the rock was not considered suitable for the foundation of a dam of the height proposed and the site was abandoned.

Drilling of the more difficult lower site was undertaken in September, 1922. Due to the fact that the rock is of volcanic origin, usually looked upon as requiring careful investigation before acceptance for a foundation for a high dam, it was desirable to obtain a high core recovery. To accomplish this a core 1⅝ inches in diameter and double-tube core barrels replaced the single-tube type.

([1] Vol. 5, 42)

Although geological examinations indicated that the foundation rock extended to a depth of at least 700 feet below river level; that it does not rest on a layer of material through which water under great pressure might pass; and that if this pervious layer did exist the passage of water would be prevented by a diaphragm of basalt across the canyon below the dam site, it was thought best to test the rock to a considerable depth. A hole was therefore drilled on the Arizona side, opposite the center of the base of the proposed dam, to a depth of 575 feet (557 feet below low-water surface). Eighty-five per cent of the core was recovered. The hole remained in breccia or compact latite or andesite for the entire distance. The rock termed "latite" or "andesite" was encountered several times. It is a smooth, dark red-brown rock, similar to the volcanic breccia but without the angular fragments. Where the change from one rock to the other occurs there is no definite joint. The change is gradual, one merging into the other, and in all probability the two are essentially the same rock with a different distribution of the angular fragments. Three comparatively soft streaks were encountered, one at depth 385 feet, one at 459 feet, and one at 536 feet. The drill water was lost once when the hole had reached a depth of 470 feet, but it is not known whether the water was lost above or below water level in the river. A great deal of trouble was experienced toward the end on account of lack of proper equipment for so deep a hole. It was necessary to "piece out" with smaller drill rods which vibrated badly. There was danger of sticking the diamond bit, and as the additional information to be obtained was of a nature to satisfy curiosity rather than of practical value, the hole was discontinued.

([1] Vol. 5, 43)

The entire area of foundation of the largest dam proposed was developed by drilling on lines 200 feet apart as at Boulder Canyon. In addition, the sites of the proposed cofferdams for diverting the river during construction of the dam were drilled.

As a usual practice all holes at the lower dam site were drilled into bed rock for a distance of 50 feet. The records show that 100 per cent of core was recovered from several holes and that core recovery seldom fell below 90 per cent. The foundation rock was found to be the same andesitic tuff breccia that appears in the canyon walls at the dam site. At times pieces of core 3 and 4 feet long were recovered. In one hole on line D–400 and one on line D–600 compact latite or andesite without angular fragments was encountered, similar to that found in the deep land hole. Briefly, the drilling proved the foundation to be excellent beyond a doubt. The rock is massive, sound, and of a remarkably uniform character.

The maximum depth to rock below low water surface was found to be 110 feet for 400 feet between lines U–200 and D–200, increasing to 123.3 feet at line D–400 and 132.5 feet at line D–600. There is a point just above line U–200 and another near line D–600, where some slight movement has apparently taken place. Although they are considered as of no practical importance the dam has been so placed as to avoid them—thus the downstream toe of the largest dam proposed falls about 50 feet downstream from line D–400 and it is assumed that at this point the maximum depth is 125 feet.

([1] Vol. 5, 44)

In general, the river channel is filled with fine sand and silt to a depth of from 20 to 30 feet overlying gravel and small boulders with the exception that at line D large bowlders, presumably the result of a rock slide from the canyon wall, were encountered. Samples taken at various times show the material below the fine sand to be well graded and suitable for use in concrete. This has a practical value since the material excavated for the foundation may be stored for later use in concrete.

The river has cut a narrow trench down the center of the canyon leaving in most cases almost level benches on either side at an elevation of about 45 feet below low-water surface. These benches are of great practical value in building the dam as discussed under "diversion works" and moreover reduce the height of dam below that indicated by the maximum section designed, over about two-thirds of the width of the canyon. In determining upon the allowable unit stress to be considered in the design of the dam the effect of these benches should not be overlooked.

As at Boulder Canyon, rock was found at the site of the upper cofferdam at comparatively shallow depth, 75 feet at Black Canyon. Consideration was given to moving the dam upstream to take advantage of the higher rock, but the idea was abandoned for the reason that the rock here is spongy, similar to that found at the A dam site, and for the further reason that the yardage of concrete in the dam would be very materially larger than at the D site.

([1] Vol. 5, 45)

The total number of holes drilled in Black Canyon was 51, 41 of which were put down at the lower or D dam site. The holes were located by coordinates, U-200 indicating that the hole is 200 feet upstream from line D which was considered one ordinate, and W-170 indicating that the hole is west of the base line on the Arizona shore 170 feet. The record of cores was kept in more detail than at Boulder Canyon for the reason that the quality of the rock was more in question. The core recovered is stored in a rock cellar at the drill camp on the Nevada side 1 mile upstream from the entrance to Black Canyon.

The datum used at Black Canyon is mean sea level datum.

Foundation Rocks

([1] Vol. 5, 53-55)

The specific gravity, absorption, and compressive strength of the foundation rocks was found by the Bureau of Standards[a] to be as follows:

Dam site	Rock	Specific gravity (average)	Absorption, per cent by weight	Compressive strength (pounds per square inch)
Boulder Canyon C	Diorite	2.768	0.322	Specimen: Dry, 26,510; wet, 23,905
Do	Granite	2.652	292	Specimen: Dry, 22,160; wet, 18,980.
Black Canyon D	Breccia	2.463	2.61	Specimen: Dry, 13,960; wet, 11,060.

The strength was determined by crushing cylindrical specimens 2 inches in diameter by 2¼ inches high. The samples of diorite and granite came from the "dump" of the test tunnels driven in the Nevada abutment at the C dam site in Boulder Canyon and represented rock found 40 or 50 feet from the surface while the breccia came from the excavation of a bench at the D dam site in Black Canyon from which the deep land hole was drilled, within two or three feet of the surface of the canyon wall.

[a] Preliminary report on tests of aggregates for the proposed Boulder Canyon Dam, Colorado River, by U. S. Bureau of Standards, Feb. 11, 1924.

([1] Vol. 5, 403–418)

Accelerated weathering tests [1] by alternate soaking in salt solution and drying indicated that the Black Canyon rocks would probably weather more rapidly than the granite of Boulder Canyon if exposed to freezing and thawing. However, freezing temperatures are rare in the locality of the dam site, in forming to a thickness of possibly one-sixteenth inch a few times each winter on a pail of water in the open.

([1] Vol. 5, 53)

The rocks in both Boulder and Black Canyon are amply qualified for a high dam and while the granitic rocks of Boulder Canyon are superior to the volcanic breccias of Black Canyon so far as mineral composition, strength, and porosity are concerned, these advantages are offset by the better structural conditions at the Black Canyon dam site.

([1] Vol. 5, 54)

The durability of the rocks are fully demonstrated by the narrowness of the canyons and the steepness of the walls. As an example of the durability of Black Canyon rocks, Doctor Ransome in his report cites a case where the Colorado at one time flowed on rock 900 feet above the present elevation of the river, as evidenced by pot holes on the rim of the canyon filled with upcountry gravel. These pot holes demonstrate that the rock is capable of retaining a smooth surface under exposure to the weather through many centuries.

Design of Dam

CHOICE OF DESIGN

([1] Vol. 5, 56)

A large number of preliminary designs and estimates were prepared of dams to impound reservoirs of capacity varying from four to thirty-four million acre-feet the dams ranging in height up to 745 feet from lowest point of foundation to top of parapet. This unprecedented height led to careful consideration of various types of dam to determine which could be built to best fulfill the requirements of safety at a reasonable cost.

Studies made include the earth and rock-fill type of dam, rock fill with concrete face, concrete arch dam, combination multiple arch and gravity dam, concrete gravity dam built straight across the canyons and the same dam built in the form of an arch. Various theories were investigated and trial designs were made according to each for comparison.

No satisfactory solution was found for either a single or multiple arch dam for use at the lower dam site in Black Canyon. The final comparison was therefore made between all-rock-fill dams and concrete dams of the gravity type.

[1] By U. S. Bureau of Standards, see report of Feb. 11, 1924.

ROCK FILL

The river trench is filled with sand, gravel, cobbles, and a few large bowlders. It is essential that a rock-fill dam of the height proposed rest on a foundation that is at least as unyielding as the rock fill of which the dam is built, requiring that all the trench filling down to bed rock under the entire base of the dam be removed before placing the rock fill.

([1] Vol. 5, 57)

The end sought in the design is an impervious face supported by construction varying gradually in flexibility from concrete to loose rock. The face concrete is carried into the foundation and abutment rock to form a cut-off wall. It is proposed to pour the concrete against the rubble masonry with vertical joints about 25 feet apart, the horizontal steel to pass through the joints. The joints will allow for some adjustment in the fill. No satisfactory detail has been worked out for the apparently necessary flexible joint between the rock abutment and the concrete face of the dam. The rubble masonry would be of large rock (6 to 10 tons) laid in Portland cement mortar and chinked with spalls. This, with the concrete face, would result in a comparatively thick water-tight face. Due to the jointing in the masonry it should be somewhat more flexible than the face concrete. The masonry is backed up by an equal thickness of dry rubble of large rock which in turn is supported by the loose rock fill. The downstream slope may be somewhat flatter than is customary. The flatter slope, with berms 100 feet apart vertically, was adopted to insure greater safety. In a rock-fill dam there is a tendency for the rock to "crunch" or roll out from under the load, and it is thought that the berms would guard against this to a certain degree.

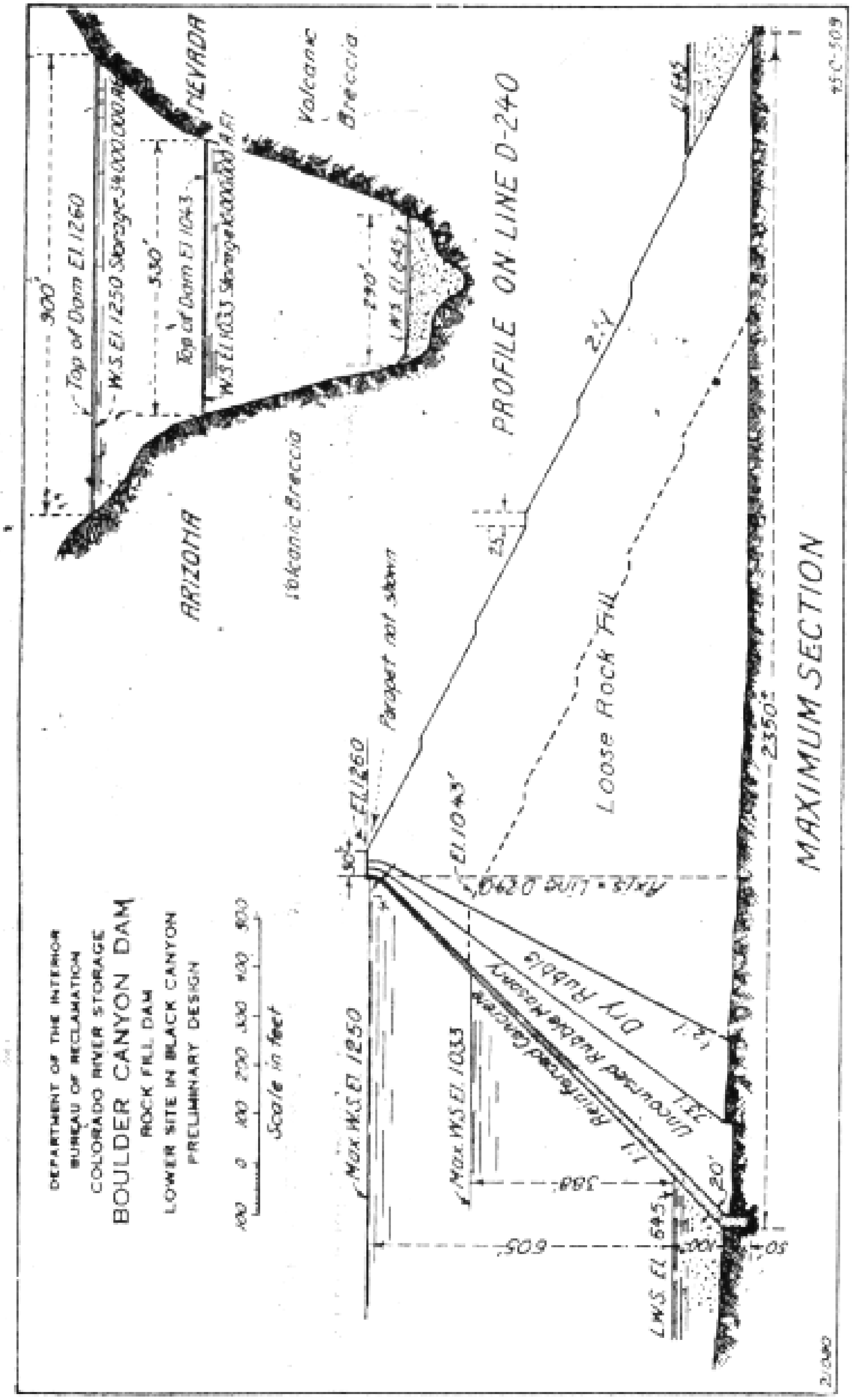
([1] Vol. 5, 58)

In the type of dam proposed all of the rock in the structure is effective at its full weight in resisting the water pressure, which is not true of a dam with core wall in its center. Upon the other hand, a vertical core wall might be less affected by settlement in the fill than concrete laid on the upstream face.

The only accurate measurement of settlement in a rock fill since construction was at Escondido Dam, where a 72-foot fill had settled 4 inches in 19 years. The fill is made of large blocks of hard granite with no fine material, and rests on granite. The upstream face was hand laid for a thickness of 5 feet at top, increasing to 15 feet at base, made tight with timber planking. Loose-rock fill was dumped from trestles and a cableway.

([1] Vol. 5, 59)

It has not been considered necessary to completely fill the interstices in the loose-rock fill at Black Canyon. The rock would be shaken and settled as much as possible by playing jets from hydraulic giants on the fill during the entire rock-placing process. It is thought that this, together with the compacting effected by dropping the rock from cableways, would produce an excellent fill and one which would be comparatively free from excessive settlement.


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE
BOULDER CANYON DAM
ROCK FILL DAM
LOWER SITE IN BLACK CANYON
PRELIMINARY DESIGN
Scale in feet
PROFILE ON LINE D-240
MAXIMUM SECTION
NEVADA
ARIZONA
Volcanic Breccia
Volcanic Breccia
Top of Dam El. 1260
Top of Dam El. 1043
Loose Rock Fill
Dry Rubble
Uncoursed Rubble Masonry
Reinforced Concrete
Parapet not shown
Max. W.S. El. 1250
Max. W.S. El. 1033
L.W.S. El. 645
2350±

([1] Vol. 5, 57)

Consideration was given to filling the river gorge by blasting from the canyon walls, but the idea was abandoned as impractical. There is with such a plan a practical certainty of excessive settlement and a resulting menace to the safety of the dam. With a dam of unprecedented high and large pondage no saving in cost should be attempted at the expense of safety.

([1] Vol. 5, 71)

Since estimates indicate that rock-fill dams for Boulder Canyon Reservoir would be more costly than concrete dams of the type proposed for the same raise in water surface, there appears to be no need of subjecting life and property below the reservoir to a risk which can be avoided by the adoption of the concrete dam proposed, and no further details of the rock-fill dam design are submitted.

SPILLWAY PROVISIONS FOR ROCK-FILL DAM

([1] Vol. 5, 81)

With rock-fill dams no such liberties may be taken with the dam, and spillways of large capacity would need to be provided.

([1] Vol. 5, 82)

For dams with small reservoir capacity the spillway discharge would have to be carried around the abutments in tunnels. For a reservoir of 34,000,000 acre-foot capacity, the dam site offers an excellent opportunity for a safe and, apparently, economical spillway. A layout of the scheme suggested, in the event the largest rock fill were built, is shown on drawing 45–C–438.

Described briefly, the spillway consists of a concrete weir and seven tunnels through the ridge to the east, emptying into an open-cut channel excavated to what is shown as "Spillway Wash." From the end of the open cut the distance down the wash to the river is about seven-eighths mile. The wash enters the river about 1¾ miles below the dam site. Discharge would be controlled by seven 84 by 18 feet steel drum gates mounted on a concrete crest into which they may be lowered. The discharge from each weir gate would be carried through the rock ridge in a 40-foot concrete-lined horseshoe tunnel to the open cut down the side wash to "Spillway Wash." The tunnels would average about 1,550 feet in length. The velocity in the tunnels when carrying 300,000 second-feet of water would be a little over 32 feet per second. The open cut would not be lined with concrete.

([1] Vol. 5, 83)

A geological study of the vicinity by H. A. C. Jenison, geologist, United States Geological Survey, indicates that a large part of the tunnel excavation would be in rock of poor quality, reported as entirely unsuitable for use in concrete by the Bureau of Standards. It is probable that all of the rock could be used in a rock-fill dam, however, since it would make up only a small portion of the total rock required to build the dam.

CONCRETE GRAVITY DAM

GENERAL DESIRABILITY

The unprecedented height of the proposed dam, roughly twice that of any dam heretofore built, necessitates a conservative design. The concrete gravity dam, built of homogeneous material and depending only on its weight to resist the water pressure, rather than uncertain stresses of thick arches, is best suited to this condition. For enhanced safety the dam is to be built in arch form but no dependence is placed on the arching for strength.

DESIGN FORMULAS

([1] Vol. 5, 60)

Careful consideration was given in the design of the concrete gravity dams to Cain's theory versus Bouvier's theory for calculating the stresses in the concrete. Cain's theory solves for maximum pressures perpendicular to the faces of the dam, while Bouvier's theory solves for pressures normal to the resultant of forces.

Investigation of constructed dams by both theories showed the following stresses with a full reservoir:

([1] Vol. 5, 68)

Name of dam	Height in feet	Foundation pressure in tons per square foot			
		No silt back fill		Saturated silt back fill	
		Bouvier	Cain	Bouvier	Cain
Arrowrock	349			31.0	38.4
Ashokan	220			13.3	20.9
Elephant Butte	304			17.6	28.3
Kensico [1]	300			19.0	31.6
Lake Cheesman	227	19.6	22.3		
New Croton	238			18.7	28.9
Roosevelt	280	34.6	34.9		

[1] Ice pressure, 47,000 pounds per linear foot of dam at crest.

PRESSURES ON FOUNDATIONS

The following notes on pressures on foundations of dams designed or in service have been prepared by Mr. F. E. Weymouth, formerly chief engineer, Bureau of Reclamation.

List of pressures on foundations of dams designed or in service

Dam	Type	Material	Height	Pressure in tons
San Gabriel, Calif.[1]	Curved gravity	Concrete	492.5	40.8
Owyhee, Oreg.[1]	do	do	405	44.0
Arrowrock, Idaho	do	Rubble concrete.	351	38.4
Exchequer, Calif.	do	Concrete	325	38.2
Horse Mesa, Ariz.	Constant-angle arch.	do	305	46.8
Roosevelt, Ariz.	Curved gravity	Masonry	280	34.9
Coolidge, Ariz.	Multiple dome	Concrete	250	42.3
Pardee, Calif.[1]	Curved gravity	do	357	40.0
Melones, Calif.	do	do	210	37.8
Calles, Mexico	Constant-angle arch.	do	218	32.0
Bear Valley, Calif.	Arch	Masonry	64	60.1
Stevenson Creek, Calif.	do	Concrete	60	72.5

[1] Under construction.

The designs for the Exchequer, Melones, Pardee, and San Gabriel Dams have been approved by the Federal Power Commission.

The Arrowrock Dam, in Idaho, was completed in 1915, and the reservoir has been filled every year since that date. The list shows that the practice during the past 15 years is to design high dams for pressures of 40 tons or more. None of them have shown any damage from such pressures.

The designs of the Arrowrock, Owyhee, Exchequer, and Coolidge Dams were approved by Mr. A. J. Wiley, recognized by the engineering profession as being the foremost authority on high-dam designs in the world to-day. He has recently returned from India, where he went to advise British engineers on the design of dams over 500 feet high.

The San Gabriel Dam, now under construction near the city of Los Angeles, above a densely populated area, will be the highest dam in the world when finished, 492.5 feet, and requires more concrete than the proposed Boulder Dam.

That dam has been designed with a pressure on the foundation of 40.8 tons. This design was approved by J. B. Lippincott and D. C. Henny, both of them engineers of international as well as national reputation in connection with dam design.

It is true that there has been a progressive increase in recent years in the pressures allowed in the concrete foundations of important structures, but this has not been due to a corresponding reduction in safety requirements. It is due mainly to improvements in quality and strength of concrete made possible by progress in scientific knowledge, and consequent improvements in methods and materials of manufacture. Due to finer grinding, greater uniformity, and other improvements, the quality of cement has gradually improved in the past 20 years. Due to extensive researches by Abrams and others in proportions and methods of mixing, and especially in the quantity of water used, much stronger concrete can be made with given materials than was the practice 10 years ago. Mathematical researches of Cain and others have made computed stresses more certain.

All this progress has been fruitful of results in rendering possible the construction of large works both safer and cheaper than formerly. This accounts for the recent increases in pressures allowed by the most experienced designers of high masonry dams, as shown in the preceding table.

This action is abundantly justified by current tests made during the progress of the work. For example, the concrete placed in the Pardee Dam now under construction shows crushing tests on 8-inch cylinders averaging over 180 tons per square foot.

([1] Vol. 5, 68)

It appears that the limiting stress of 40 tons per square foot is not much in excess of that established by precedent if the dams already built are investigated by the theory adopted for use in designing Boulder Canyon Dam. Although the concrete quantities are materially larger when the dam is designed by Cain's theory (about 15 per cent in case of the largest Boulder Canyon Dam) it is believed that it gives more correct stresses and a section shaped to better withstand the stresses.

The plate just preceding (45–C–479) shows by comparison the dam shapes best adapted to meet the stresses under the Cain and Bouvier theories and also shows the computed stresses under the two theories for the section indicated.

It will be noted that Cain's theory gives stresses much higher than Bouvier's theory, the stress at the toe reaching a maximum of 62.6 tons per square foot by the former theory.

([1] Vol. 5, 61)

The following assumptions are common to all sections designed.

(*a*) Weight of concrete, 150 pounds per cubic foot.

(*b*) Weight of silt, 100 pounds per cubic foot.

(*c*) Horizontal thrust caused by silt equivalent to that produced by a fluid, like water, weighing 80 pounds per cubic foot.

(*d*) Maximum high water surface at top of roadway.

(*e*) Vertical weight of water or silt on sloping faces of dam included in summation of vertical loads.

(*f*) Uplift on joints below low water surface due to full hydrostatic pressure at upstream and downstream faces over two-thirds the area of joint, and on joints above low water surface due to full hydrostatic pressure at upstream face decreasing uniformly to zero at the downstream face over two-thirds area of joint.

(*g*) Horizontal thrust considered as being taken by gravity action alone, no allowance being made for either horizontal or vertical arching.

(*h*) Effect of curvature in reducing the length of section calculated at the downstream face neglected.

(*i*) No tension shall exist at any point.

(*j*) Maximum stress with reservoir filled with water analyzed by Cain's theory, 40 tons per square foot (555 pounds per square inch).

At the time the designs were prepared the Bureau of Standards had not completed the concrete tests on Hemenway gravel, and it was necessary to estimate the weight for design purposes. The weight of 143 pounds per cubic foot will affect a small reduction in the required dam section.

ASSUMPTIONS ON BOULDER CANYON DESIGN

Reference is made to the assumptions appearing on pages 54 and 55. No explanation will be necessary of assumptions A to E, inclusive, the intent of which is clear.

As to assumption F the intent is that pressure at either end of the dam will be that corresponding to the height of the water above that point with water at the top of the dam at the upper end and at the low-water level at the lower end. This pressure has been presumed to be effective over two-thirds of the area, the other one-third of the area distributed uniformly from one end to the other of the dam, which is assumed adequately drained to prevent the formation of pressures over one-third of its area.

With regard to assumption G, the meaning of this is no doubt clear, but further attention on the assumption should be given to the discussion following the explanation of assumption G.

With regard to assumption H, it appears that the stresses were computed by assuming a slice through the dam from front to back face 1 foot in thickness; that is, 1 foot thick between parallel planes through the section of the dam. This amounts to assuming a gravity dam with a straight plan instead of an arched plan and with such a straight plan the pressure of 40 tons per square foot would be attained. In fact, however, the plan of the dam being an arch, the stresses should enter and leave the dam on radial lines with the result that the stresses entering the dam at the upper end over a width of 1 foot or more would be concentrated in the lower end of the dam over a width materially less, the concentration depending on the shortening of the radius. Offsetting this tendency toward increase in stresses there is a shifting of the center of gravity toward the upstream toe by reason of greater thickness at that point. If we now assume that all stresses of the arched dam are carried by gravity only then the maximum stress at the downstream toe, as computed by Mr. B. F. Jakobsen who is associated with Mr. LaRue, at 68.10 tons per square foot at the toe, in a memorandum submitted to the Colorado River Commission of Arizona. Our engineers have made a similar computation and found a stress of 68.3 tons per square foot under the same conditions. It should be borne in mind, however, that this result could only be obtained if arch action were entirely destroyed. It is the belief of the bureau engineers, based upon the results of careful analyses of other dams, that the fears entertained by Mr. Jakobsen regarding the ineffectiveness of arch action are largely without foundation.

The Weymouth design is not considered as final but was selected from experience as representing sufficient yardage for a final design in which the question of stresses could be more fully considered. For this reason it is believed that further discussion of the stresses in the Weymouth section is not warranted, but that the quantity of concrete represented by this section is adequate for a design which will meet all reasonable requirements in the final design.

([1] Vol. 5, 64)

With reference to assumption (*f*), although uplift is recognized in the design, precaution against its occurrence is taken by an extensive system of foundation grouting and drainage of both the foundation and the dam itself, with resulting increase in dam strength.

With reference to assumption (*h*), although investigations indicate that the stress at the toe, reservoir full, is materially increased by this reduction of length if the dam is considered as resisting the pressure by gravity action alone, it is probable that the arch form adds security in even greater proportion since the stress can not exist without first developing both horizontal and vertical arch action.

In the event silt accumulates in the reservoir to the top of the dam (an event quite unlikely by reason of upstream storage development), the foundation pressure will be increased materially over that produced by water alone. The resultant of pressures, however, will remain within the middle third of the base at all heights and the sliding coefficient will be less than that required to satisfy uplift assumptions.

Silt and uplifts are not assumed to act at the same time.

In the design of the dam a section 1 foot long was assumed, for the highest portion of the dam.

RESULTING STRESSES

The stresses for the adopted dam section for the reservoir of 34,000,000 acre-feet capacity are shown on the print opposite (45–C–480). For this and other dams the computed stresses are as follows:

([1] Vol. 5, 65–69)

	Reservoir capacity in acre-feet	Maximum height of dam to roadway in feet	Pressures expressed in tons per square foot by Cains's theory		
			No uplift or silt	With uplift reservoir full	With silt to top of dam
Maximum pressure U. S. face	34,000,000	740	41.3	8.6	19.2
Maximum pressure D. S. face	34,000,000	740	39.7	39.6	45.6
Maximum sliding factor	34,000,000	740	.51	.71	.64
Maximum pressure U. S. face	20,000,000	640	40.4	3.1	9.1
Maximum pressure D. S. face	20,000,000	640	39.7	39.7	49.4
Maximum sliding factor	20,000,000	640	.52	.72	.67
Maximum pressure U. S. face	10,000,000	523	35.5	......	......
Maximum pressure D. S. face	10,000,000	523	34.9	35.0	41.1
Maximum sliding factor	10,000,000	523	.51	.69	.61

The section chosen for investigation is the maximum that could exist at the lower dam site in Black Canyon assuming that bed rock in the narrow trench is level.

([1] Vol. 5, 66)

As a matter of fact, at the upstream heel of the dam the rock is 14 feet higher than at the downstream toe.

Over the greater part of the foundation area the rock is at about elevation 600, 80 feet above the lowest point of rock at the downstream toe of the dam. Thus, there is only a very small portion of the dam that is as high as assumed and if the foundation were assumed as being at elevation 600 the maximum designed stress for the highest dam would not be in excess of about 36.7 tons at the downstream side and it is believed that this stress could be reduced to 35 tons without adding concrete by changing the shape of the downstream face slightly. Certainly, the loads would be distributed to the side benches in the river channel in such a way as to relieve the higher stresses at the toe at the deepest point in the narrow trench. Furthermore, with additional work on the design than is warranted in the preliminary design, the stress could undoubtedly be made to increase uniformly toward the bottom rather than as shown on the stress diagram. The comparatively high stress at the upstream heel with reservoir empty is not of much importance since the reservoir can never be empty—at least not below river level and probably not below the lower set of permanent outlets.

The stresses due to silt are higher than those due to water alone. However, the assumption that the reservoir will at some time be filled to the top with silt is rather extreme and it is questionable if the silt deposit will not relieve the pressures rather than increase them. Authorities do not agree upon this point and experiments are not conclusive.

([1] Vol. 5, 67)

As indicated on the stress diagram a study was made of the effect of varying the top width of the dam. Reducing the width from 50 to 25 feet did not result in appreciable saving in concrete and for a dam of the size proposed the wider top is believed to be more in keeping with other dimensions.

([1] Vol. 5, 72)

A design and estimate was prepared of a dam at the lower dam site in Black Canyon to develop a maximum pressure of 30 tons per square foot by Cain's theory. The concrete required to build such a dam would be about 25 per cent in excess of that for a pressure of 40 tons per square foot, and the total estimated cost about 12 per cent more. It might be possible to reduce the pressures and the cost of the dam through the use of some sort of hollow or perforated construction instead of following the usual practice in designing gravity dams, but it is questionable if any " freak design " would be approved where the integrity of the structure is of such great importance.

DESIGNS

A preliminary design of a concrete gravity dam to store 26,000,000 acre-feet is shown on 45-D-558. Preliminary designs of concrete gravity dams and estimates for reservoirs of 34,000,000, 20,000,000, and 10,000,000 acre-feet were also made.

In all cases the estimates assume that it will be necessary to remove foundation and abutment rock to a depth of 10 feet to secure absolutely round rock. It is proposed that each dam be built on a curve to best fit the dam site. The radius of curvature is indicated on the designs.

The proposed layout at the dam site is shown on 45-C-456. If the power house were moved upstream to shorten the pressure tunnels its cost would be materially increased, and it would be located at the base of the very steep canyon wall where rocks falling from above might damage the machinery as well as the building. It was also found that the saving in cost of the tunnels by moving the dam downstream did not offset the increased cost of the dam due to its greater volume.

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OUTLET WORKS

([1] Vol. 5, 74)

Balanced 72-inch needle valves were adopted because—

First. They are particularly adapted to working under high heads.

Second. The discharge is into open air, which avoids difficulties arising through the creation of vacuum around the contracted jet.

Third. The energy of the jet is destroyed in the river channel where no damage can result.

Fourth. Regardless of the stage of water in the reservoir the valves are under observation and may be repaired or replaced at any time.

The valve conduits are to be lined with semisteel to prevent the water in the conduits from exerting uplift within the dam to transmit the compressive forces in the dam and to resist the wear and tear of silt which will in time be carried through the dam.

([1] Vol. 5, 75)

Each conduit is provided with a 5 by 9 foot hydraulic-operated emergency slide gate near the upstream end operated from a gallery in the dam.

Trash racks have been provided on the upstream face of the dam with provision for mechanical raking.

The trash rack piers contain two grooves to guide bulkheads to position in case it becomes necessary to do some repair work in the conduit upstream from the emergency gate before the water in the reservoir is drawn down. A traveling crane on top of the dam will handle needle valves, trash racks, and bulkheads.

The maximum irrigation demand is assumed as 30,000 second-feet. Capacity curves, velocity curves, and working heads are shown upon the drawings. In case of the dam to store 20,000,000 acre-feet, the outlet works will operate as follows:

([1] Vol. 5, 77)

(*a*) The lower set of valves begin discharging with 2,000,000 acre-feet in the reservoir.

(*b*) With 5,700,000 acre-feet in the reservoir the discharge is 30,000 second-feet.

(*c*) The upper set begins discharging at the time the lower set is carrying 26,000 second-feet.

(*d*) The upper set with full reservoir will discharge 38,000 second-feet under a head of 200 feet.

(*e*) Both sets will discharge 85,000 second-feet with water surface standing at top of parapets. Maximum head 315 feet.

In the estimates it has been assumed that all needle valves for any one dam are of the same design, although the heads on the two tiers are different in order that they may be interchangeable in an emergency.

The only excuse for operating valves in the higher dam under heads greater than 275 feet would be:

(*a*) It might be desired to discharge the 40,000 second-feet flood-control water before the water surface in the reservoir reached the bottom of the 5,000,000 acre-foot flood-control storage reserve, in which case the lower set would be required to operate under a head of 365 feet. With water surface above this level the upper valves alone would pass the 40,000 second-feet.

(*b*) At very long intervals of time it might be necessary to operate the lower set of valves under heads as great as 415 feet to prevent water overtopping the parapets on the dam. Even this head is not considered excessive for emergency use during a short period.

([1] Vol. 5, 79)

The outlets at river level are not a part of the permanent outlet works as they are to be "plugged" when their usefulness has ceased. Their function is to carry the low-water flow of the river during the time the diversion tunnels are being closed and until the water surface in the reservoir is raised to the lower set of valves.

In the event a power house is built as a part of the development a large part of the irrigation requirement, and at times all of it, would pass through the power house thus relieving the outlet works. With the outlets provided it is possible that overtopping may occur at very long intervals—perhaps once in 500 years if it is attempted to control the flood to 40,000 second-feet. Overtopping could be prevented by opening the gates to discharge at the rate of about 80,000 second-feet at a time when it becomes evident that overtopping would otherwise occur.

SPILLWAY

([1] Vol. 5, 80)

Studies of various types of spillways were made. In one the discharge was carried downward into the tunnels used for diverting the river during construction of the dam. In another the discharge was carried at high velocity in large tunnels through the point of rock on the Arizona side and dropped over the cliff downstream from the dam. In another the discharge was carried at comparatively slow velocity through the ridge east of the dam site and dropped into a wash, entering the river about 1½ miles by river below the dam site.

In the case of the concrete dams the plan of carrying the abnormal floods occurring at very long intervals over the dam was adopted as being both the most economical and the safest manner in which to handle the discharge. As indicated on one of the stress diagrams the dams have been designed to pass water over the central portion with water surface in the reservoir standing 21 feet above the roadway with the resultant of forces falling within the middle third of the critical joint.

To keep the possible overflow from striking the abutments of the dam the latter has been raised at each end 25 feet above the roadway.

The flow will be at right angles to the crest toward the center of curvature. Any overtopping would be of short duration and the only damage anticipated would be the possible breaking off of the parapets. This, however, might result in a sudden increase in flow downstream.

Construction Plan

DIVERSION WORKS

([1] Vol. 5, 84)

(See drawing 45–C–456.) In designing the proposed diversion works the flow of the Colorado River at Yuma between the years 1902 and 1923 was used as a basis for calculating probable discharges at Boulder or Black Canyon.

The relative peak discharge at points widely separated on the river depends upon the magnitude and duration of the flood. Large floods build up more gradually and are "ironed out" by the effect of channel storage proportionally less than are the "flashy floods" originating in streams like the San Juan, Little Colorado and Virgin. The impending danger of losing cofferdams will be due to the flashy floods which are apt to occur at any time during the working season.

([1] Vol. 5, 85)

As an example of the absorbing power of the river channel the flood of October, 1911, is cited. The discharge at Yuma suddenly rose from 8,000 to 60,000 second-feet, 2,000 second-feet of which came from the Gila and the remainder principally from the San Juan and Dolores Rivers. At Ship Rock, N. Mex. (about 325 miles above Lees Ferry), the discharge of the San Juan River was estimated to be 150,000 second-feet. (Water supply Paper No. 309, p. 246.) Assuming that the San Juan and Dolores peaks did not coincide this peak discharge of 150,000 second-feet diminished to 58,000 second-feet at Yuma or at the average rate of about 100 second-feet per mile. Upon this basis the discharge at Lees Ferry is assumed to have been about 117,000 second-feet and at Boulder Canyon about 90,000 second-feet.

([1] Vol. 5, 86)

Drawing 45–C–393 shows the working periods permitted by the river when discharging 25,000, 35,000, 50,000, and 75,000 second-feet, assuming that these discharges represent the capacity of the temporary diversion works. The discharges exceeded 75,000 second-feet a total of nine times in the 19 seasons after work would probably have been started. The flood of September, 1923, which is estimated to have been close to 100,000 second-feet at Boulder Canyon, would also have overtopped the cofferdams. Only four of these overtoppings would have been serious, since in other instances work would not have been far advanced. The serious floods would have occurred as follows:

October, 1911, estimated peak, 82,000; work advanced 2½ months.
March, 1916, estimated peak, 88,000; work advanced 8½ months.
February, 1920, estimated peak, 96,000; work advanced 7¾ months.
September, 1923, estimated peak, 100,000; work advanced 2 months.

In the season 1909–10 conditions were extremely severe, and even with diversion works of 75,000 second-feet capacity only 7½ months would have been available for completing the season's work.

The appreciably longer working season and lessened danger from overtopping justifies the construction of temporary diversion works having a capacity of 100,000 second-feet since the loss of a cofferdam after the work was well under way would undoubtedly defer the completion of the storage dam at least a year.

([1] Vol. 5, 87)

Temporary diversion of 100,000 second-feet is accomplished by means of three concrete-lined tunnels at 130-foot centers on the Nevada side of the river, and rock-earth fill cofferdams, the tunnels to be later used for power development.

Estimates of tunnels of varying size and the necessary cofferdams for each size indicated that a combination utilizing 33-foot diameter tunnels was the most economical, but since tunnels 35 feet in diameter were best suited to the requirements of power development this size was adopted at very little greater cost. The largest tunnels justified by other conditions are desirable to effectively pass the large quantities of drift and débris carried by the Colorado River. That portion of the tunnels used later for power purposes is lined with 1:2:4 concrete with an average thickness of 30 inches. It is proposed to grout between the concrete and rock under a pressure slightly in excess of the pressure to which the tunnels will be subjected in operation as penstocks.

The report of the Colorado River board recommended diversion tunnels with a capacity of 200,000 second-feet instead of 100,000 second-feet as recommended by the Bureau of Reclamation, therefore the excavation and concrete required for this unit of the project would be practically twice that mentioned above for this item.

([1] Vol. 5, 88)

The portions of the tunnels not used as penstocks are lined with 1:2½:5 concrete having an average thickness of 18 inches, the least thought to be practicable. High rock points would be permitted to extend to within 6 inches of the face of the concrete.

Although horseshoe tunnels would be more easily dug, on account of the flatter bottom, circular tunnels were adopted for the reason that they are better adapted to distributing uniformly the great pressures to which they will be subjected under full reservoir head.

([1] Vol. 5, 90)

It is proposed to drive and line all tunnels complete before the rock-fill cofferdams are started. All tunnels may be driven simultaneously from both ends, the muck being removed through "muck tunnels" at each end, constructed on a grade of about 5 per cent from the invert of the large tunnels to a point above high water. The muck tunnels, crossing all diversion tunnels below low-water surface in the river and with exits above high water, would permit the driving of the diversion tunnels regardless of the stage of the river. The inlet and outlet ends of the diversion tunnels will have to be completed behind cofferdams during low water.

It is proposed to use rock-fill cofferdams to turn the river, as they appear to be the most practicable type for the situation, having been successfully used at other points on the river and exclusively in recent years in closing breaks on the lower river.

Test holes were put down on the sites of the temporary cofferdams, the location of the lines drilled being based upon the assumption that a percolation factor of 6 would be sufficient for the gravelly material in the river bed below the fine sand. The results of the investigations are shown in the drilling logs, lines U940 and D1000.

In order to insure the safety of the rock fill cofferdams, they must rest upon a better foundation than is offered by the sand and silt in the river bed. It is believed that great floods scour out the channel filling clear to bedrock while ordinary floods probably scour out the sand and silt down to the more stable gravel and bowlders.

([1] Vol. 5, 91)

It is proposed to start dumping large rock obtained from the canyon walls at the cofferdam sites from cableways spanning the site as soon as the flood begins to recede in July, the diversion tunnels having been completed before the spring flood. It is assumed that at this time the river channel will be scoured out to at least elevation 620, perhaps deeper under the lower cofferdam. The first rocks dropped would be as large as it is practicable to handle. Some of these rocks would be carried downstream beyond the limits of the cofferdam section, but at some stage a part of them would begin to "hang" within the section. At this point smaller rock would be dropped simultaneously which would be caught by the larger rocks and held in the interstices. As the flood receded more rocks would stay in place. The estimates assume that 25 per cent of the rock dropped will be carried away. During the rock placing process the diversion tunnels would be discharging at full capacity, and to reduce the head on the cofferdams these would be built simultaneously, the lower one being kept half as high as the upper one.

([1] Vol. 5, 92)

Due to the velocity of the overflowing water, the lower side of the rock fill may take a slope as flat as 1 on 4 or 5 and by the time the rock fill is raised sufficiently high to turn the entire flow through the tunnels, a blanket of sand and silt will, no doubt, have deposited on the upper slope to approximately normal river bed level. Experiments at Boulder Canyon have demonstrated this material to be very tight is undisturbed. Above the top of the sand, and to the top of the rock fill, an earth blanket will be placed on the water side, material for which may be obtained in Hemenway Wash.

For additional safety the channel excavation for the main dam not suitable for making concrete may be dumped on the water side of the cofferdams.

The arguments in favor of using rock-fill cofferdams constructed as proposed, are as follows:

([1] Vol. 5, 92)

(*a*) The process and necessary equipment is not complicated.

(*b*) If the fill is placed during the recession of the flood, the rock will be deposited on a bottom as established by the flood which is unquestionably much more stable than the normal river bed at low water.

([1] Vol. 5, 92)

(*c*) A fill built as here planned will effect a saving of time of approximately two months for other work since if built from trestles, or if a type is built requiring caissons, piles, cribs, etc., construction could not be undertaken until about the 1st of September or until the return of low water in the river.

(*d*) The rock-fill type placed by cableways is particularly adapted to fighting floods. Any type requiring the building of trestles across the river would be in imminent danger of being destroyed by the flash floods which may occur at any time. Loss of a cofferdam during its construction might result in a year's delay in completing the main dam.

([1] Vol. 5, 93)

(*e*) If the rock fill were built at low water stage, its foundation would be such that a blowout of the sand on which it rested would be apt to occur under the head to which it would be subjected.

(*f*) With the cableways left in place over the crest of the cofferdam it could be raised rapidly if endangered by flood and if the rock fill is partially or entirely lost, it could be replaced without having to wait to rebuild trestles, drive piles, etc.

Behind the temporary cofferdams it is proposed to build portions of the upstream and downstream faces of the dam to the height necessary to permanently divert the river. The work to be accomplished in bringing the whole dam up to the elevation of the river would be entirely too great to be accomplished between seasonal floods. With the river permanently diverted, excavation of the foundation and pouring of the concrete between the permanent cofferdams could proceed without undue haste.

([1] Vol. 5, 94)

Permanent cofferdams to force 200,000 second-feet through the diversion tunnels were given consideration but the design was not considered practicable and, moreover, a flood of that proportion has only occurred once in the 20 years of record—in 1921—when the discharge at Yuma was about 185,000 second-feet, estimated to have been about 200,000 second-feet at Boulder Canyon.[a] The design proposed for adoption is shown on 45–C–456. For the permanent cofferdams the diversion capacity is calculated to be 135,000 second-feet in case of the long tunnels discharging below the power house and 154,000 second-feet if the shorter tunnels are used—sufficient to pass ordinary floods. The cofferdams might be overstopped in a high year, but no damage could result beyond filling the hole with sand, or possibly sand and gravel.

By reference to the drilling data, it will be noted that under the proposed upper permanent cofferdam a bench at elevation 600 (45 feet below low-water surface) flanks the deep river trench on both sides. It is proposed to first build a portion of the gravity section at the upstream side of the dam on each bench, leaving a gap about

[a] In 1920 the discharge at Boulder Canyon was also about 200,000 second-feet. Maximum 1921–1928 approximately 125,000 second-feet.

160 feet wide over the deep trench. The rock excavation on the benches would be under way while the loose material in the deep trench was being excavated and the pouring of concrete would be started at the earliest possible moment.

([1] Vol. 5, 95)

In order to reduce the immediately needed excavation and concrete quantities across the deep trench to a minimum, a thin arch with short radius has been designed for the cofferdam. The gravity sections have sufficient section to keep the tangential thrust of the arch well within the section. Both the gravity and arch sections would be stepped and dovetailed on the down-stream side and steel bars, or rails, would be left projecting to secure a good bond with the concrete to be later added.

([1] Vol. 5, 96)

The lower permanent cofferdam is designed as a gravity dam to take water pressure from either side. Its construction would be carried on simultaneously with that of the upper cofferdam. The problem here is less difficult and there is less concrete to be placed. There is a possibility that the lower permanent cofferdam may not be needed, depending on conditions found when the dam site is unwatered. If the leakage through the rock-fill cofferdam and the underlying gravel and bowlders can be handled at a reasonable expense and it appears feasible to complete the permanent upper cofferdam on schedule, then the temporary lower rock fill could be raised to the necessary elevation to avoid overtopping by the spring flood, and the permanent cofferdam dispensed with. On the other hand, if the permanent upper cofferdam can only be completed to river grade, or a little above, it would be better to build the permanent lower cofferdam than to take a chance of losing the lower rock-fill dam during the flood. Since the additional expense of building the permanent lower cofferdam is small, it is probable that it should be built. The only objection to it is the fact that it introduces what may be considered a line of weakness in the completed dam where the stresses are high. However, in the design, an effort has been made to minimize this fault by making the general direction of the joint normal to the direction of pressures. The upstream face would be dovetailed and steel "spuds" would be left projecting as in case of the upper dam.

The critical time in the construction period is that during which the permanent cofferdams are being built. It will, in an ordinary season, be necessary, in about eight or nine months' time, to build the rock-fill cofferdams, excavate the river channel filling and rock under the cofferdams, and place the concrete to at least low-water surface. The cut-off trench in the foundation has been placed just downstream from the permanent upper cofferdam as a timesaver, as with the trench at the upstream heel of the dam, construction of the permanent cofferdam would be delayed awaiting completion of the trench excavation.

([1] Vol. 5, 97)

When it is desired to begin storing water in the reservoir the diversion tunnels will be plugged near the reservoir end with concrete and the river discharge carried by the conduits through the concrete dams at about river grade. After the tunnel plugs have been placed the lower tier of outlets without gates will be plugged with concrete behind a ball to be placed at the upstream end and a low cofferdam built on the dam at the lower end, the water in the meantime being controlled by the outlets provided with gates. After water level reaches the higher valves the conduits at river level are to be permanently plugged with concrete.

Construction Railroad

TO BOULDER CANYON

([1] Vol. 5, 99)

Boulder Canyon may be reached by three railroad routes, each of which is considered feasible.

(*a*) From Dyke, on the Los Angeles & Salt Lake Railroad, 13 miles northeast of Las Vegas, Nev., distance about 40 miles.

(*b*) From Overton, Nev., on Los Angeles and Salt Lake Railroad, distance about 42 miles.

(*c*) From Mineral, Ariz., on the Santa Fe Railroad, distance about 62 miles.

In March, 1921, Mr. J. P. Mack, of the Union Pacific system, made a reconnaissance of the routes from Dyke and Overton to the upper end of Boulder Canyon.

A line from Overton to the dam site would require comparatively heavy construction with grades southbound of about 2 per cent and northbound 4 per cent and with maximum curvature of about 14°. About 6 miles from the river is the last divide, at elevation 2,200, from which the fall is very rapid to river. The cost of this line is estimated at $1,750,000.

In 1921, Mr. Woodbury Howe, locating engineer for the Atchison, Topeka & Santa Fe Railroad, made a reconnaissance of a route from Mineral, Ariz., to the upper end of Boulder Canyon which indicated that a railroad from the south would be feasible with a 2 per cent grade. The cost is estimated at $1,675,000.

TO BLACK CANYON

([1] Vol. 5, 102)

Black Canyon may be reached by two railroad routes, either of which is considered feasible.

(*a*) From Las Vegas, Nev., on the main line of the Los Angeles & Salt Lake Railroad (Union Pacific system). Distance about 30 miles.

(*b*) From Searchlight, Nev., the end of a branch of the Atchison, Topeka & Santa Fe Railroad, which leaves the main line at Goffs, Calif.; distance about 48 miles.

(Note.—Santa Fe branch line from Goffs to Searchlight has been dismantled since the Weymouth report was written.)

The alternate locations are shown on drawing 45–C–450.

The only suitable site at the dam site for the construction camp, machine shops, railroad terminals, etc., is above the flow line of the reservoir at the west end of the dam, on the Nevada side of the river.

There is only one feasible route to the dam site for a railroad through the rough hills adjacent to the river so no matter whether the railroad is built from Las Vegas or Searchlight, the last 3½ or 4 miles will be over the same route.

A railroad from Las Vegas could reach the dam site by either of two routes—one down Las Vegas Wash and along the foothills above elevation 1,250, distance about 40 miles; and the other over what is known as Railroad Pass, distance about 30 miles. While the latter is the shorter the grades would be heavier.

([1] Vol. 5, 104)

The last 3½ miles through the hills from Hemenway Wash to the dam site will require heavy construction, and considerable additional expense will be needed to secure a complete terminal at or near the dam site. The cost of this terminal will depend largely upon where concrete aggregate for the construction of the dam is obtained. If the aggregate is hauled over the railroad, more railroad facilities will, of course, be required than if crushed rock is used from the cliffs at the dam site. A deposit of sand and gravel has been developed in Hemenway Wash at the point where the railroad enters the hills. The deposit contains sufficient material for the construction of the dam, and appurtenant structures and will undoubtedly be used, since preliminary tests have shown it to be suitable, and since its use will prove more economical than crushed aggregate.

In order to ascertain the feasibility and cost of a railroad from the gravel pit to the dam site, a preliminary location survey was made by the Bureau of Reclamation. The resulting alignment and profile is shown on drawing 45–C–415.

([1] Vol. 5, 105)

A level piece of ground about 1 mile from the dam site has been utilized for a terminal or switch yard, where provision is made for handling the heavy traffic which would result from hauling concrete aggregate in addition to other freight. From the gravel pit to the switch yards the grade is down hill with the exception of a short piece of track near the gravel pit which has a grade against loaded trains of 2.02 per cent. One 800-foot tunnel is required. More difficult country is encountered from the switch yard to the dam site. Here the line is on a down grade except along the cliffs at the dam site, where, for safety, the track is made level. The maximum grade is 5.63 per cent, which may make the use of geared locomotives below the switch yards necessary. At the bottom of this heavy grade a "cradle track" is provided for stopping runaway cars. At the dam site a loop track is shown which would simplify the operation of gravel trains over the concrete mixing plant. The construction of this loop requires a 350-foot tunnel, and the expense might not be warranted since trains could be backed out with little inconvenience.

The estimated cost of the railroad, including terminals, spurs, and necessary track, upon the assumption that concrete aggregate will be hauled to the dam site from the gravel pit in Hemenway Wash is included with the estimated cost of Boulder Canyon Reservoir. The estimates assume a standard-gauge railroad using 85-pound steel.

Although no reconnaissance of a railroad from Las Vegas to the dam site was made, it is believed that the cost would be about the same as that for a line from Searchlight.

The distances from San Bernardino, Calif., to the dam site via Las Vegas would be 301 miles.

CONSTRUCTION PLAN

([1] Vol. 5, 107)

It is assumed that all construction machinery at the dam site will be electrically operated. Due to the magnitude of the work it is assumed that the construction railroad to the dam site and the plant for furnishing power will be built before work at the dam site is undertaken, the latter either at Las Vegas or the dam site, depending upon whether it would be more economical to transport fuel or transmit power. During the construction of the railroad and power plant a construction camp would be built at the dam site, including housing facilities, shops, water supply, etc.

After making detailed studies of various construction plants it appears that a cableway plant is best adapted for use at the proposed dam site. The cableways would span the canyon in positions to handle both the excavation and concrete. Cableways used to build the rock-fill cofferdams would, after their completion, be moved to new positions over the main dam. Nine cableways are proposed, each capable of handling a 12-ton rock or five cubic yards of concrete each trip.

([1] Vol. 5, 108, 109)

The first work to be done is the driving of the three diversion tunnels, involving about 15,500 linear feet of 38 to 40 feet diameter tunnel and lining them with concrete. Electric shovels and muck trains would probably be used, the shovels digging themselves in at both ends of each tunnel through the muck tunnel described under the heading "Diversion works," with its portal above high-water surface. The large tunnels would not be "blown through" at either end until the concrete lining had been completed, since otherwise work could not be carried on during high water. Excavation would be started during low water so that the six shovels could be taken to the tunnel portals on barges. To get the shovels from the railroad at elevation 1,375 to the barges, cableways Nos. 1 and 2 would be used. These two cableways and the railroad trestle under them would be the first equipment installed at the dam site. The longest tunnel has a length of 5,700 feet. If it is assumed that work would be carried three shifts per day for six days a week, with an average daily progress of 15 linear feet, it would require about 15 months to complete the excavation. Concrete lining would follow the excavation closely. Therefore if work were started in December it should be completed by the middle of the second March, prior to the beginning of the spring flood. Upon completion of the diversion tunnels the shovels would be moved to the rock quarries to furnish rock for the temporary cofferdams.

During construction of the diversion tunnels the camp would have been completed; three cableways would have been erected over each rock-fill cofferdam; cableway No. 9 would have been erected over the lower permanent cofferdam; and the quarries above the rock-fill cofferdams would have been opened up. Diversion capacity has been enlarged from 100,000 to 200,000 second-feet, in accordance with special engineering board's report.

([1] Vol. 5, 110)

As stated under "Diversion works," the rock-fill cofferdams would be started as soon as the flood began to recede, probably in July. The upper cofferdam is much the larger and would take the longer time in building, requiring 620,000 cubic yards of loose rock, including the 25 per cent assumed to be swept away. The material will be handled in 8 by 2½ foot steel skips, the loaded skips weighing from 8 to 8½ tons. The skips would be filled by the electric shovels, with some hand work, and taken to the cableways on flat cars. The skips would be dumped automatically without lowering down into the canyon, permitting high speed and large output. The quarry equipment to maintain the pace set by the cableways would have to be efficient. Work would be carried on three shifts per day without interruption, at least until the river had been turned. The crest of the fill would be kept level in order to avoid a concentrated flow at any one point. Allowing 30 seconds for "hooking" each successive skip, each cableway should average 30 trips per hour. On similar work these skips averaged 4.3 cubic yards of loose material per load. Assuming this as a basis of computations each cableway would handle 129 yards per hour or 3,100 yards per day. Three cableways would place about 9,000 yards per day, and it would require 69 days to complete the cofferdam or conservatively three months. By the middle of October therefore the rock fill should be completed. The fill would be made water-tight by placing sand and gravel from Hemenway Wash on the upstream face.

The river should be turned at least by the middle of September, at which time the fill then in place could be made water-tight so that unwatering of the dam site could be started. The lower cofferdam would have been completed and cableways Nos. 7 and 8 moved to positions 7B and 8B over the lower permanent cofferdam. As soon as the site was unwatered, excavation of the river bed would be started at both permanent cofferdams—probably about October 1.

([1] Vol. 5, 111)

The loose excavation for the lower permanent cofferdam is the greater and amounts to 343,000 cubic yards. However, the time element is more important in case of the upper permanent cofferdam where there are 188,000 cubic yards to be removed. By October 1, cableway No. 3 could have been moved to position 3B leaving No. 4A and 5A to finish the upper rock fill cofferdam. There would thus be three cableways commanding each permanent cofferdam site.

Electric shovels or dragline excavators would be used in the hole to load the same skips that were used in building the rock-fill cofferdams. The skips would average 4.3 yards per trip. Allowing 30 seconds for "hooking," each cableway could make 13 trips per hour, lifting out of the hole and dumping into a "dirt trap" at the top of the canyon. Work would be carried on continuously for 24 hours a day. Each cableway would handle 56 yards per hour or 1,340 yards per day, and three cableways would handle 4,000 yards per day. At this rate the excavation would require 47 days or conservatively 2 months. By December 1, therefore, the excavation of loose material at the upper site should be finished. Work of preparing the foundation would take another month and it would be the 1st of January before concreting could be started. Excavated material suitable for use, in concrete would be stored in the spillway basin under cableways Nos. 1, 2, and 3B.

([1] Vol. 5, 112)

There are 150,000 yards of concrete in the upper permanent cofferdam and 85,000 in the lower. By December 1, the concrete mixing plant would have been completed and the gravel pit in Hemenway Wash would have been opened up, the shovels used in the diversion tunnels, quarries, and dam excavations having been moved to the gravel pit. Concrete buckets would be of the bottom-dumping type with capacity of 5 cubic yards per trip. It is assumed that concrete would be placed on two shifts per day only, the third shift being devoted to cleaning up and keeping the job going. Each cableway could make 13 trips per hour allowing 30 seconds for hooking skips. Each cableway could place 65 yards per hour or about 1,000 yards per day. One cableway would be reserved for general service, leaving two outfits to place 2,000 yards per day. If this rate could be maintained it would require 75 days, or until March 15, to finish the work. If concrete were placed at half the rate assumed, the cofferdam could still be finished by the end of May in time to turn the seasonal flood which does not usually occur until late in June.

One of the characteristics of the Colorado is its tendency toward flashy floods of comparatively small volume. Although of small volume and short duration they cause a great deal of anxiety and would be a source of great danger. The river may rise from 10 to 15 feet in a few hours' time at most any time during the working season. During such a time the temporary rock-fill cofferdams would be in danger and in order to be in a position to combat the flood two cableways would be left in position over the upper rock fill and one over the lower fill until the permanent cofferdams have been completed. After that they would be moved to their new positions over the main dam.

([1] Vol. 5, 113)

It appears that the work of diverting the river can be accomplished in the time available and certainly the permanent cofferdams could be at least be brought up to river level from where they could be completed after high water without rebuilding temporary cofferdams. From the time construction of the railway is started until the permament cofferdams are finished will be at least 30 months, allowing 3 months to build the railroad.

Any diversion scheme which does not contemplate building the permanent cofferdams in one low-water period will be a very expensive one, since it will involve the partial or total loss of both temporary cofferdams and their replacement, and the excavation of the river-bed material at the dam site for the second time—at least down to the uncompleted structure. While the monetary loss would not be especially serious, the loss of time, necessary shutdown, and demoralization of the organization would have a serious effect upon the work.

With the permanent cofferdams successfully completed the construction of the dam would be a comparatively easy matter and would resolve itself, more or less, into the development of a plant to put concrete into the dam at the greatest practicable speed and at the least possible cost compatible with good quality.

([1] Vol. 5, 114)

Excavation of the remaining loose material between the finished cofferdams and work of preparing the foundation rock would be taken up immediately. By the time this work was done the heat of the summer would slow up operations and concreting on a large scale would not be started until about September 1, three years after beginning construction of the railroad.

The volume of concrete in the dam, exclusive of that in appurtenant structures, is estimated to be 3,560,000 cubic yards. Assuming 250 working days per season and an average daily rate of progress of 3,500 cubic yards, it would require four years to place the concrete. As the dam is raised the area over which concrete can be placed becomes less, so that in order to maintain the average rate of progress it may be necessary to place concrete in the lower portion of the dam at twice the average rate. Work would be carried on for three shifts per day, but one shift would necessarily be devoted to repairing equipment and getting the work cleaned up in order that concreting on the other two shifts may not be delayed.

([1] Vol. 5, 115)

The maximum rate at which concrete would be placed is estimated to be 3,500 cubic yards per shift of 8 hours, which amounts to 438 yards per hour and, considering loads of 5 yards, the requirements of cableway service are 87½ trips per hour. The cableways proposed are capable of making 13 trips per hour each, carrying concrete the average distance and lowering to the average depth of the lower two-thirds of the concrete in the dam. Thus it will require seven cableways to do the work. However, nine cableways are proposed, partly on account of advantageous spacing of cableways over the work and partly on account of the fact that some of these cableways will be used for handling forms and miscellaneous material.

If the average rate of progress could be maintained, the dam would be completed about seven years from the time work is started on the construction railroad.

The plant proposed for building the dam is very simple and is one which should perform the work at a minimum cost. It is proposed to locate the mixing plant on the rim of the canyon in a position to be under the cableways but above the top of the completed dam so that the concrete may be handled by gravity. The mixing plant would be designed to produce 3,500 cubic yards per 8-hour shift or at the rate of 7.3 cubic yards per minute. If 2½-yard mixers were adopted it would require a battery of five mixers with probably a spare mixer to insure the availability of five at all times. The mixer would be set under the material bins and would dump into hoppers holding at least two batches. The cableway skips would be carried to the mixing plant on flat cars running on tracks under all the cableways.

([1] Vol. 5, 116)

The cement, sand, gravel, and cobbles would be brought in on the railroad built over the material bins and dumped directly into the bins. For each yard of concrete 1.44 cubic yards of material exclusive of cement are required, or for the construction of the dam 5,130,000 cubic yards. If 30-yard dump cars are used it will require 171,000 carloads of material from the gravel pit 3½ miles away. Trains will be operated three shifts per day so that when runs of 7,000 yards per day are being made at the dam 336 carloads of material will be required at the rate of 14 cars per hour continuously. In operation a 7-car train would probably be brought from the switching yards to the mixing plant every half hour.

Two reciprocating locomotives with one spare could probably handle the trains between the gravel pit and the switching yard. Three geared engines with a spare could handle the cars from the switching yard to the mixing plant. Two switch engines would be required in the yards. A large number of gravel cars would be required not only to insure flexibility in operation but to provide live storage in cars in the switching yards where they could be drawn upon in case of an accident on the railroad.

([1] Vol. 5, 117)

The screening plant for separating the coarse aggregate from the fine would be located at the gravel pit in Hemenway Wash. It would be designed to deliver at the rate of 420 cubic yards of separated aggregate per hour continuously. Some of the electric shovels used at the dam site early in the construction period would be used in the gravel pit.

Construction Materials

CEMENT

([1] Vol. 5, 49)

The estimated cement requirement is 4,000,000 barrels for a reservoir of 34,000,000 acre-feet capacity and proportionately less for smaller reservoirs. The southern California and Utah mills are very favorably located with respect to distance and rail connections to the dam site and their combined daily capacity is about 20,000 barrels, or 6,000,000 barrels annually for 300 working days per year. This is 50 per cent in excess of the total cement requirements for the dam if built in a single year.

CONCRETE AGGREGATE

The sand found along the river banks and in the upper portion of the river bed with predominating grain diameters of 0.001 to 0.005 inch is too fine for general use in concrete other than to supply a possible deficiency of "fines" in a natural or crushed sand. This sand contains very little organic matter, being finely broken and worn rock fragments of great variety with quartz predominating. The coarser sand and gravel found in the lower portion of the river bed are suitable for concrete, and it is proposed to store such material from the excavation for the dam at Black Canyon to be later used for concrete.

Concrete aggregate could be made by crushing the granitic rocks of Boulder Canyon or the glassy lavas at Black Canyon. The "latite" at Black Canyon is very brittle and could readily be made into sand and gravel, but the process would be comparatively expensive.

([1] Vol. 5, 50)

No large deposits of clean sand and gravel were located in the immediate vicinity of any of the dam sites. The cleanest deposits are found in Callville Wash., but these are not favorably located with respect to the dam sites. In Hemenway Wash are very large deposits of sand and rather angular gravel containing considerable fine material. The most promising deposit lies about 3½ miles from the adopted dam site in Black Canyon on the route of the proposed construction railroad to the dam site. Test pits developed more than sufficient material for the largest dam under consideration. An examination of this pit was made by H. A. C. Jenison.[7]

([1] Vol. 5, 51)

Samples, ranging in weight from 150 pounds to 1,000 pounds, of various materials in the vicinity of the dam sites which in the field appeared to be suitable for concrete aggregate were tested by the Bureau of Standards, with results thereof contained in the report of February 11, 1924.[8]

([1] Vol. 5, 52, 432, 433)

The tests show that the Hemenway sand and gravel, although apparently dirty and forbidding in appearance, is the most suitable of any of the materials submitted for test as to concrete strength, workability, and durability. Crushing tests of concrete made from the unwashed material, just as it is found in the pit, gave nearly the same strength as washed material, and better workability. Twenty-eight day tests of concrete cylinders of this material showed average strength of over 1,500 pounds per square inch for the more suitable mixtures, comparing favorably with concrete concurrently made with proven gravels from the Washington vicinity. The weight of

[7] Report on Hemenway Wash gravel deposits by H. A. C. Jenison, geologist, United States Geological Survey, Oct. 3, 1923.

[8] Preliminary report on tests of aggregates for the proposed Boulder Canyon Dam, by U. S. Bureau of Standards, Feb. 11, 1924.

Hemenway gravel concrete averaged 143 pounds per cubic foot against 146 pounds for the Washington gravel. With extended research to determine the best proportioning and preparation of Hemenway gravels concrete of the highest quality can be expected. It appears that washing may not be found necessary and that screening may be limited to a simple separation of the course aggregates from the fine. There was some doubt about the dirty films on the gravel, but microscopic examination showed these to be calcium carbonate and iron oxide, both stable minerals, and dispelled suspicion.[a]

([1] Vol. 5, 52, 53)

A lightweight concrete without sacrifice of strength would be desirable in that its use would result in a smaller dam section and therefore a less cost, provided the lightweight concrete could be produced cheaply. A possibility in this direction lies in the use of crushed latite which is to be found at the adopted dam site in Black Canyon in a very advantageous position to be quarried cheaply. It is brittle and could be crushed readily. Its apparent specific gravity is about 2.27 and the weight per cubic foot of concrete resulting from its use was found to be 131 pounds against about 143 pounds for the Hemenway gravel. The crushed aggregate is sharp, and when used alone, results in a harsh mix of poor workability. The substitution of fine river sand for 25 per cent of the crushed sand improved both the strength and workability of the concrete. It is believed, however, that the saving in concrete with the lightweight latite would be more than offset by the additional cost crushing aggregate in comparison with Hemenway gravels.

Unit Costs

PORTLAND CEMENT

([1] Vol. 5, 118)

In July, 1923, letters were written to several large manufacturers of cement requesting quotations on cement shipped in bulk in very large quantities to be used for estimating purposes. The following quotations were received:

	Per barrel
Monolith Portland Cement Co., Monolith, Calif	$2.50
Colton Portland Cement Co., Colton, Calif	2.30
Cash, 10 days	2.25
Ogden Portland Cement Co., Ogden, Utah	2.10
Southwestern Portland Cement Co., Victorville, Calif	2.00
Riverside Portland Cement Co., Riverside, Calif	2.00
Colorado Portland Cement Co., Portland, Colo	2.00
Cash, 10 days	1.90

[a] Letter by Geologist E. F. Burchard, of U. S. Geological Survey, to Mr. J. C. Pearson, of the Bureau of Standards, Feb. 15, 1924.

Freight rates as of November 24, 1923, are as follows:

	Per hundred-weight
From Riverside or Colton, Calif., to Las Vegas, Nev	$0.305
From Ogden, Utah, to Las Vegas, Nev	.36
From Riverside, Calif., to Searchlight, Nev	.31

	Per barrel
From Riverside, Calif., to Searchlight, Nev., assuming that Santa Fe will grant a rate over the branch line to Searchlight as favorable as that now in force on the main line	$0.2325
Assume cost of cement at mill	2.00
Freight, Riverside to Searchlight, 380 pounds at 23¼ per hundredweight	.88
Freight, Searchlight to dam site, 48 miles, at 1¼¢ per ton-mile	.14
Storage and rehandling at mixing plant	.10
Total estimated cost in bins at mixing plant	3.12

Say $3.10 per barrel.

ROCK IN TEMPORARY ROCK-FILL COFFERDAMS

([1] Vol. 5, 119)

Source of material, rock in the canyon walls at the cofferdam sites.

Quarrying and loading into skips on cars:	Per cubic yard
Drilling and blasting	$0.45
Mucking, including derricks, steam shovel, and hand	.70
Power	.05
Repairs and supplies	.10
Plant depreciation	.20
Total by solid measurement	1.50

([1] Vol. 5, 119)

It is assumed that 1 cubic yard of solid rock will build 1½ cubic yards of rock fill dropped from cableways (33⅓ per cent voids).

	Per cubic yard
The resulting quarrying cost of rock measures in the fill is	$1.00
Hauling to cableways	.15
Placing by cableways	.15
Total estimated cost in dam	1.30

GRAVEL AND COBBLES FOR CONCRETE

Source of material, gravel deposit in Hemenway Wash, 3½ miles from the dam site.

	Per cubic yard
Steam shovel operation	$0.15
Hauling to screening plant	.15
Operation of screening plant [38]	.35
Plant depreciation	.15
Hauling to mixing plant	.10
Total estimated cost in bins at mixing plant	.90

[38] The material will probably require some sorting and washing.

CRUSHED GRAVEL

([1] Vol. 5, 120)

Assuming that upon further investigation the Hemenway gravel is found to be unsuitable for use in concrete and that the rock at the dam site will be used—

	Per cubic yard
Quarrying and loading at $1.50 per cubic yard, solid—40 per cent voids in concrete	$0.90
Hauling to crushing plant	.15
Operation of crushing plant	.25
Plant depreciation	.15
Transporting to mixing plant	.15
Total estimated cost in bins at mixing plant	1.60

CRUSHED COBBLES

Assuming that Hemenway gravel pit yields unsuitable material and that rock at the dam site will be used—

	Per cubic yard
Quarrying and loading at $1.50 per cubic yard, solid—50 per cent voids crushed	$0.75
Hauling to crushing plant	.15
Operation of crushing plant	.20
Plant depreciation	.15
Transporting to mixing plant	.15
Total estimated cost in bins at mixing plant	1.40

SAND

([1] Vol. 5, 121)

Assuming 50 per cent natural sand mixed with 50 per cent crushed sand.

	Per cubic yard
Natural sand same as gravel	$0.90
Crushed sand:	
Quarrying and loading rock at $1.50 per cubic yard, solid—35 per cent voids crushed	.97
Hauling to crushing plant	.15
Operation of crushing plant—	
Crushing	.25
Rolling	.40
Plant depreciation	.20
Transporting to mixing plant	.15
Total crushed sand	2.12
Total estimated cost of mixed sand in bins at mixing plant	1.50

CRUSHED SAND

Assuming that no suitable natural sand can be found and that the rock at the dam site will be used—

Cost same as above crushed sand, say, $2.10 per cubic yard.

NOTE.—The estimates of cost were prepared prior to receiving the report from the Bureau of Standards, which indicates that the material from Hemenway Wash is satisfactory. The unit cost of sand used in the estimates is therefore too high. The sand would cost no more than the gravel which is estimated at $0.90 per cubic yard.

MIXING AND PLACING CONCRETE IN BODY OF DAM

([1] Vol. 5, 122)

		Per cubic yard
Mixing:		
Operation		$0.10
Power		.05
Repairs		.08
Water		.02
Plant depreciation		.15
Total		.40
Cableway haul:		
Operation		.12
Power		.05
Repairs		.05
Plant depreciation		.18
Total		.40
Placing on dam:		
Cleaning and placing	$0.30	
Pumping and lighting	.10	
Miscellaneous	.05	
Total		.45
Total estimated cost		1.25

Colorado River Storage, Boulder Canyon Reservoir, Lower Site (Black Canyon), Curved Gravity Type

([1] Vol. 5, 441)

With reference to the following estimates it will be noted that the cost of a dam 550 feet high, with a reservoir capacity of 26,000,000 acre-feet, was increased from $41,500,000 to $70,600,000 by the special engineering board.

Three items entered into the increased cost of the dam, viz:

(*a*) Increased spillway capacity over top of dam.

(*b*) Decreased allowable pressures on foundation from 40 tons to 30 tons per square foot.

(*c*) Increase in size of diversion works.

It is not assumed, however, that the board varied the unit costs materially.

Maximum pressure, 40 tons per square foot, by Cain's theory; 20,000,000 acre-feet flood control, power, and irrigation reservoir.

The following estimates on the various dams are taken from the original Bureau of Reclamation estimates and must be increased as indicated above; they are included here for the purpose of indicating the work to be done.

DIVERSION TUNNEL DISCHARGE BELOW POWER HOUSE

Top of parapet: Elevation, 1,165 feet.
Top of dam: Elevation, 1,160 feet.
Maximum normal water surface: Elevation, 1,150 feet.
Water surface of river: Elevation, 645 feet.
Raise in water surface: 505 feet.
Radius of axis: 760 feet.

Preliminary estimate

[To be increased according to the Colorado River board report. (See page 53)]

Item	Quantity	Unit cost	Total cost
DIVERSION WORKS			
Temporary diversion, 100,000 second-feet; permanent diversion, 135,000 second-feet. Diversion tunnels, 3 35-foot circular tunnels 15,100 feet long:			
Excavation—			
Class I and II, at portals	10,000 cubic yards	$1.00	$10,000.00
Class III, 9,600 linear feet chargeable to power, 30-inch lining.	495,000 cubic yards	6.00	2,970,000.00
Class III, 5,500 linear feet chargeable to diversion, 18-inch lining.	232,000 cubic yards	6.00	1,392,000.00
Class III, muck tunnels	5,200 cubic yards	8.50	44,200.00
Class III, removing tunnel lining for plugs, 900 linear feet.	5,800 cubic yards	8.00	46,400.00
Total, excavation			4,462,600.00
Cofferdam at tunnel entrance	900 linear feet	425.00	382,500.00
Concrete—			
Tunnel lining, 30-inch, 1:2:4 mix—Chargeable to power—			
Cement	225,000 barrels	3.10	697,500.00
Sand	63,000 cubic yards	1.50	94,500.00
Gravel	126,000 cubic yards	.90	113,400.00
Forms	150,000 cubic yards	2.75	412,500.00
Mixing and placing	do	3.25	487,500.00
Miscellaneous	do	1.00	150,000.00
Total			1,955,400.00
Concrete in place	150,000 cubic yards	13.00	1,950,000.00

([1] Vol. 5, p. 442)

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels

Item	Quantity	Unit cost	Total cost	Summary
Tunnel lining, 18 inches, 1: 2½ : 5 mix, chargeable to diversion:				
Cement	43,400 barrels	$3.10	$134,540.00	
Sand	15,400 cubic yards	1.50	23,100.00	
Gravel	30,500 cubic yards	.90	27,450.00	
Forms	35,000 cubic yards	2.75	96,250.00	
Mixing and placing	do	3.25	113,750.00	
Miscellaneous	do	1.00	35,000.00	
Total			430,090.00	
Concrete in place	35,000 cubic yards	12.25	428,750.00	
Tunnel plugs, 1: 2½ : 5 : 2½ mix:				
Cement	38,900 barrels	3.10	120,590.00	
Sand	13,600 cubic yards	1.50	20,400.00	
Gravel	27,200 cubic yards	.90	24,480.00	
Cobbles	13,600 cubic yards	.90	12,240.00	
Bulkheads	37,800 cubic yards	.75	28,350.00	
Mixing and placing	do	2.00	75,600.00	
Miscellaneous	do	.75	28,350.00	
Total			310,010.00	
Concrete in place	37,800 cubic yards	8.25	311,850.00	
Grouting plugs (6)	900 linear feet	16.00	14,400.00	
Grouting tunnel lining chargeable to power.	9,600 linear feet	16.00	153,600.00	
Closing tunnel portals (lump sum)			35,000.00	
Total, diversion tunnels				$7,738,700.00
Upper temporary cofferdam:				
Rock fill, 25 per cent waste	620,000 cubic yards	1.30	806,000.00	
Earth mattress	128,000 cubic yards	1.00	128,000.00	
Total, upper cofferdam				934,000.00

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
Lower temporary cofferdam:				
Rock fill, 25 per cent waste	137,000 cubic yards	$1.30	$178, 100. 00	
Earth mattress	36,000 cubic yards	1.00	36, 000. 00	
Total, lower cofferdam				$214, 100. 00
Upper permanent cofferdam, excavation:				
Class I, sand and silt	114,000 cubic yards	.50	57, 000. 00	
Class II, gravel and bowlders, including talus.	74,000 cubic yards	2.00	148, 000. 00	
Class III, below elevation 645	16,600 cubic yards	5.00	83, 000. 00	
Class III, above elevation 645	7,500 cubic yards	2.50	18, 750. 00	
Total, excavation			306, 750. 00	
Grouting and drainage:				
Drilling 3-inch grout holes	3,200 linear feet	3.00	9, 600. 00	
Drilling 3-inch drain holes	1,400 linear feet	3.00	4, 200. 00	
Grouting (87 holes)		100.00	8, 700. 00	
Miscellaneous drilling and grouting (lump sum).			5, 000. 00	
Total, grouting and drainage			27, 500. 00	
Concrete:				
Gravity sections, 1:2½:5:2½ mix—				
Cement	113,000 barrels	3.10	350, 300. 00	
Sand	39,600 cubic yards	1.50	59, 400. 00	
Gravel	79,200 cubic yards	.90	71, 280. 00	
Cobbles	39,600 cubic yards	.90	35, 640. 00	
Forms	110,000 cubic yards	1.00	110, 000. 00	
Mixing and placing	do	1.50	165, 000. 00	
Miscellaneous	do	.75	82, 500. 00	
Total			874, 120. 00	
Concrete in place	110,000 cubic yards	8.00	880, 000. 00	
Arch section, 1:2½:5:2½ mix—				
Cement	41,200 barrels	3.10	127, 720. 00	
Sand	14,400 cubic yards	1.50	21, 600. 00	
Gravel	28,800 cubic yards	.90	25, 920. 00	
Cobbles	14,400 cubic yards	.90	12, 960. 00	
Reinforced steel	191,000 pounds	.06	11, 460. 00	
Forms	40,000 cubic yards	3.00	120, 000. 00	
Mixing and placing	do	1.75	70, 000. 00	
Miscellaneous	do	1.00	40, 000. 00	
Total			429, 660. 00	
Concrete in place	40,000 cubic yards	10.75	430, 000. 00	
Total, upper cofferdam				1, 644, 250. 00
Lower permanent cofferdam:				
Excavation—				
Class I, sand and silt	243,000 cubic yards	.50	121, 500. 00	
Class II, gravel and bowlders including talus.	100,000 cubic yards	2.00	200, 000. 00	
Class III, below elevation 645.	25,400 cubic yards	5.00	127, 000. 00	
Class III, above elevation 645.	600 cubic yards	2.50	1, 500. 00	
Total, excavation			450, 000. 00	
Grouting and drainage: Miscellaneous grouting.			5, 000. 00	
Concrete, 1:2½:5:2½ mix:				
Cement	87,500 barrels	3.10	271, 250. 00	
Sand	30,600 cubic yards	1.50	45, 900. 00	
Gravel	61,200 cubic yards	.90	55, 080. 00	
Cobbles	30,600 cubic yards	.90	27, 540. 00	
Forms	85,000 cubic yards	1.00	85, 000. 00	
Mixing and placing	do	1.50	127, 500. 00	
Miscellaneous	do	.75	63, 750. 00	
Total			676, 020. 00	
Concrete in place	85,000 cubic yards	8.00	680, 000. 00	
Total, lower cofferdam				1, 135, 000. 00
Pumping (lump sum)				100, 000. 00
Gross total, diversion works				11, 786, 050. 00

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
Credit, chargeable to dam:				
Upper permanent cofferdam—				
Excavation, all			$306,750.00	
Grouting and drainage, all			27,500.00	
Concrete, all except excess over cost in dam.	150,000 cubic yards	$7.00	1,050,000.00	
Total, upper cofferdam			1,384,250.00	
Lower permanent cofferdam—				
Excavation, all			450,000.00	
Grouting and drainage, all			5,000.00	
Concrete, all except excess over cost in dam.	85,000 cubic yards	7.00	595,000.00	
Total, lower cofferdam			1,050,000.00	
Total, chargeable to dam				$2,434,250.00
Credit, chargeable to power:				
Diversion tunnels—				
Excavation, Class III, 9,600 linear feet.	495,000 cubic yards	6.00	2,970,000.00	
Concrete, tunnel lining, 30-inch, 9,600 linear feet.	150,000 cubic yards	13.00	1,950,000.00	
Grouting tunnel lining	9,600 linear feet	16.00	153,600.00	
Total, chargeable to power				5,073,600.00
Total credit				7,507,850.00
Total diversion works				4,258,200.90
([1] Vol. 5, p. 462)				
Dam:				
Excavation—				
Class I, sand and silt	539,000 cubic yards	.50	269,500.00	
Class II, gravel and bowlders.	187,000 cubic yards	2.00	374,000.00	
Class III, dam base (below elevation 645).	95,000 cubic yards	5.00	475,000.00	
Class III, dam abutments	78,000 cubic yards	2.50	195,000.00	
Class III, cut-off trench	29,300 cubic yards	5.00	146,500.00	
Total, excavation				1,460,000.00
([1] Vol. 5, p. 463)				
Grouting and drainage foundation:				
Drilling 3-inch grout holes	9,100 linear feet	3.00	27,300.00	
Drilling 3-inch drain holes	4,100 linear feet	3.00	12,300.00	
Grouting	330 holes	100.00	33,000.00	
Miscellaneous drilling and grouting (lump sum).			20,000.00	
Dam:				
Gate valves, 2 36-inch at 5,000 pounds.	10,000 pounds	.25	2,500.00	
Pumps, 2 at 1,600 pounds	3,200 pounds	.25	800.00	
Drain covers	4,600 pounds	.10	460.00	
Freight	17,800 pounds	.01	178.00	
Installation	do	.02	356.00	
Total grouting and drainage				96,894.00
Concrete:				
Dam, 1:2¼:5:2¼ mix—				
Cement	2,370,000 barrels	3.10	7,347,000.00	
Sand	828,000 cubic yards	1.50	1,242,000.00	
Gravel	1,660,000 cubic yards	.90	1,494,000.00	
Cobbles	828,000 cubic yards	.90	745,200.00	
Forms	2,300,000 cubic yards	.25	575,000.00	
Mixing and placing	do	1.25	2,875,000.00	
Miscellaneous	do	.75	1,725,000.00	
Total			16,003,200.00	
Concrete in place	2,300,000 cubic yards	7.00		16,100,000.00
Parapets, 1:2¼:5 mix:				
Overflow section—				
Cement	925 barrels	3.10	2,868.00	
Sand	330 cubic yards	1.50	495.00	
Gravel	650 cubic yards	.90	585.00	
Forms	745 cubic yards	10.00	7,450.00	
Mixing and placing	do	5.00	3,725.00	
Miscellaneous	do	3.00	2,235.00	
			17,358.00	
Concrete in place	do	23.25		17,321.00

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
([1] Vol. 5, p. 463)				
Lighting:				
Lamps and pedestals	5 units	$500.00	$2,500.00	
Wiring and small fixtures in galleries and on top.	Lump sum		7,000.00	
Total lighting				$9,500.00
Total dam				17,683,715.00
([1] Vol. 5, p. 464)				
Outlet works:				
Trash racks for permanent outlets—				
Concrete piers, 1:2½:5 mix, 1 cubic yard per linear foot—				
Cement	12,800 barrels	3.10	39,680.00	
Sand	4,540 cubic yards	1.50	6,810.00	
Gravel	8,960 cubic yards	.90	8,064.00	
Reinforced steel, 120 pounds per cubic yard.	1,240,000 pounds	.06	74,400.00	
Forms	10,300 cubic yards	10.00	103,000.00	
Mixing and placing	do	6.00	61,800.00	
Miscellaneous	do	2.00	20,600.00	
Total			314,354.00	
Concrete in place	do	30.50	314,150.00	
Concrete balcony, elevation 1160, 1:2½:5 mix—				
Cement	378 barrels	3.10	1,172.00	
Sand	134 cubic yards	1.50	201.00	
Gravel	265 cubic yards	.90	239.00	
Reinforced steel, 100 pounds per cubic yard.	30,500 pounds	.06	1,830.00	
Forms	305 cubic yards	15.00	4,575.00	
Mixing and placing	do	5.00	1,525.00	
Miscellaneous	do	2.00	610.00	
Total			10,152.00	
Concrete in place	305 cubic yards	33.25	10,141.00	
Concrete platforms, elevation 944 and elevation 844, 1:2½:5 mix—				
Cement	660 barrels	3.10	2,046.00	
Sand	235 cubic yards	1.50	353.00	
Gravel	460 cubic yards	.90	414.00	
Reinforced steel, 100 pounds per cubic yard.	53,000 pounds	.06	3,180.00	
Forms	530 cubic yards	12.00	6,360.00	
Mixing and placing	do	5.00	2,650.00	
Miscellaneous	do	2.00	1,060.00	
Total			16,063.00	
Concrete in place	530 cubic yards	30.25	16,032.00	
Guniting beams	962 beams	9.25	8,899.00	
Trash rack metal—				
Beams, 962, at 40 pounds per linear foot.	462,000 pounds	.06	27,720.00	
Rails, 962, at 10 pounds per linear foot.	99,100 pounds	.06	5,946.00	
([1] vol. 5, p. 465)				
Grooves, 38,500 feet 7 inches by 16.4 pounds ship channel.	632,000 pounds	.06	37,920.00	
Grills	2,160,000 pounds	.06	129,600.00	
Anchor bolts	21,500 pounds	.08	1,724.00	
Cover plates and accessories, large.	62,000 pounds	.08	4,960.00	
Cover plates and accessories, small.	16,000 pounds	.08	1,280.00	
Freight	3,452,700 pounds	.01	34,527.00	
Installation	do	.02	69,054.00	
Railing, 2½-inch pipe in place	1,130 linear feet	.50	565.00	
Fittings, 1 per 10 linear feet	113	.50	57.00	
Total trash rack metal			313,357.00	
Total trash rack for permanent outlets.				664,077.00

Boulder Canyon Dam, 40 tons, 80,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
Trash rack for sluices same as for 34,000,000 acre-feet dam.				$184,218.00
Permanent outlet conduits:				
Semisteel lining, 5,625 linear feet	11,800,000 pounds	$0.09	$1,062,000.00	
Bolts	12,000 pounds	.08	960.00	
Freight	11,812,000 pounds	.0075	88,590.00	
Installation	do	.015	177,180.00	
Grouting behind lining	5,625 linear feet	5.00	28,125.00	
Total permanent outlet conduits.				1,336,855.00
Sluice outlet conduits same as for 34,000,000 acre-feet dam.				85,413.00
Permanent outlet control:				
Slide gates (30), 5 by 9 feet	2,100,000 pounds	.25	525,000.00	
Pressure pump system in place	2 units	14,000.00	28,000.00	
Needle valves (30), 72 inches	4,500,000 pounds	.24	1,080,000.00	
Freight	6,600,000 pounds	.01	66,000.00	
Installation	do	.02	132,000.00	
Total permanent outlet control				1,831,000.00
Sluice gates, same as 34,000,000 acre-feet dam.				130,940.00
Closing sluiceways:				
Lower tier—				
Closing entrance (lump sum)			100.00	
Preparing surface	3,400 linear feet	4.00	13,600.00	
Concrete spheres, same as 34,000,000 acre-feet dam.			1,511.00	
Concrete for plugs, 1:2¼:5 mix—				
Cement	4,410 barrels	3.10	13,671.00	
Sand	1,570 cubic yards	1.50	2,355.00	
Gravel	3,100 cubic yards	.90	2,790.00	
Bulkheads	3,560 cubic yards	1.00	3,560.00	
Mixing and placing	do	10.00	35,600.00	
Miscellaneous	do	.50	1,780.00	
Total			59,756.00	
Concrete in place	3,560 cubic yards	16.75	59,630.00	
Pressure grouting	3,400 linear feet	5.00	17,000.00	
Upper tier—				
Preparing surface	2,800 linear feet	4.00	11,200.00	
Concrete for plugs, 1:2¼:5 mix—				
Cement	3,650 barrels	3.10	11,315.00	
Sand	1,290 cubic yards	1.50	1,935.00	
Gravel	2,560 cubic yards	.90	2,304.00	
Bulkheads	2,940 cubic yards	1.00	2,940.00	
Mixing and placing	do	10.00	29,400.00	
Miscellaneous	do	.50	1,470.00	
Total			49,364.00	
Concrete in place	2,940 cubic yards	16.74	49,246.00	
Pressure grouting	2,800 linear feet	5.00	14,000.00	
Total, closing sluiceways				166,286.00
Track and crane:				
Track, 745 linear feet, at 50 pounds	37,300 pounds	.032	1,194.00	
Accessories	1,150 pounds	.08	92.00	
Locomotive crane	200,000 pounds	.20	40,000.00	
Freight	238,450 pounds	.01	2,385.00	
Installation	do	.02	4,769.00	
Total, track and crane				48,440.00
Elevators, inclined, f. o. b. factory, 2 at 25,000 pounds	50,000 pounds	1.00	50,000.00	
Freight	do	.01	500.00	
Installation	do	.02	1,000.00	
Total, elevators				51,500.00
Total, outlet works				4,818,729.00

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
Spillway:				
Concrete—				
Parapets, abutment sections to keep overflow from side walls, 1:2¾:5 mix—				
Cement	2,480 barrels	$3.10	$7,688.00	
Sand	880 cubic yards	1.50	1,320.00	
Gravel	1,740 cubic yards	.90	1,566.00	
Reinforcing steel, 25 pounds per cubic yard.	50,000 pounds	.06	3,000.00	
Forms	2,000 cubic yards	10.00	20,000.00	
Mixing and placing	do	5.00	10,000.00	
Miscellaneous	do	3.00	6,000.00	
Total			49,574.00	
Concrete in place	2,000 cubic yards	24.75		$49,500.00
Elevator towers and shafts, 1:2¾:5 mix—				
Cement	3,350 barrels	3.10	10,385.00	
Sand	1,190 cubic yards	1.50	1,785.00	
Gravel	2,350 cubic yards	.90	2,115.00	
Reinforcing steel, 80 pounds per cubic yard.	216,000 pounds	.06	12,960.00	
Forms	2,700 cubic yards	20.00	54,000.00	
Mixing and placing	do	6.00	16,200.00	
Miscellaneous	do	4.00	10,800.00	
Total			108,245.00	
Concrete in place	2,700 cubic yards	40.00		108,000.00
Roadway in abutment section, 1:2¾:5:2¾ mix—				
Cement	885 barrels	3.10	2,744.00	
Sand	310 cubic yards	1.50	465.00	
Gravel	620 cubic yards	.90	558.00	
Cobbles	310 cubic yards	.90	279.00	
Forms	860 cubic yards	.50	430.00	
Mixing and placing	do	2.00	1,720.00	
Miscellaneous	do	1.00	860.00	
Total			7,056.00	
Concrete in place	860 cubic yards	8.25		7,095.00
Eagles and bases	2 sets	10,000		20,000.00
([1] vol. 5, p. 468)				
Roadway, tunnel excavation (lump sum).				10,000.00
Railing—				
2¾-inch brass pipe	100 linear feet	1.00	100.00	
Fittings (1 per 5 linear feet)	20	1.00	20.00	
Railing place				120.00
Total, spillway				194,715.00
([1] vol. 5, p. 450)				
Construction, railroad: Standard gauge railroad from Searchlight, Nev., end of Atchison, Topeka & Santa Fe branch to the lower dam site in Black Canyon.				
([1] vol. 5, p. 451)				
Main line from Searchlight to proposed gravel pit in Hemenway wash, as estimated by Woodbury Howe, locating engineer, Santa Fe system, reconnaissance made in April, 1923:				
Approximate	40 miles	22,500.00	900,000.00	
Do	4.5 miles	40,000.00	180,000.00	
Total, Searchlight to gravel pit	44.5 miles			1,080,000.00

Boulder Canyon Dam, 40 tons, 20,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
Main line from gravel pit to dam site, station 0 to 197-50, drawing 45-C-415:				
Grading and surfacing—				
Class I	58,000 cubic yards	$0.30	$17,400.00	
Class II	14,400 cubic yards	1.00	14,400.00	
Class III	53,000 cubic yards	2.00	106,000.00	
Total				$137,800.00
Track materials—				
85-pound rail	499.7 gross tons	72.00	35,978.00	
Angle bars	579.1 hundredweight	4.00	2,316.00	
Track bolts	56.6 hundredweight	5.50	311.00	
Track spikes	232.1 hundredweight	4.25	986.00	
Ties, untreated fir, 7 by 9 inches by 8½ feet.	9,876	1.60	15,802.00	
Tie plates	67.3 tons	52.00	3,500.00	
Track laying	3.74 miles	500.00	1,870.00	
				60,763.00
Tunnel station 100-50 to 108-50, Class III	11,700 cubic yards	6.50		76,050.00
Framed trestles—				
Excavation	1,000 cubic yards	5.00	5,000.00	
Concrete	700 cubic yards	10.00	7,000.00	
Lumber	1,300 M board measure	45.00	58,500.00	
Hardware	700 hundredweight	5.00	3,500.00	
Erecting	1,300 M board measure	45.00	58,500.00	
Total				132,500.00
Culverts, 12 to 48 inches corrugated iron pipe (lump sum).				6,000.00
Ballast	2 miles	3,500.00		7,000.00
Section gang quarters—				
Section foreman's house	1	1,200.00		
Bunk house	1	2,000.00		
Oil house	1		250.00	
Toolhouse	1		250.00	
Loading platform	1		100.00	
Total				3,800.00
Telephone line	3.74 miles	600.00		2,244.00
([1] vol. 5, p. 452)				
Right of way (lump sum)				10,000.00
Total, gravel pit to dam site	3.74 miles			436,157.00
Total estimated field cost of main line.	48 miles			1,516,157.00
Switch yard:				
Grading and surfacing—				
Class I	18,000 cubic yards	0.30	5,400.00	
Class II	do	1.00	18,000.00	
Class III	12,000 cubic yards	2.00	24,000.00	
Total				47,400.00
Track materials—				
85-pound rail	619 gross tons	72.00	44,568.00	
Angle bars	717 hundredweight	4.00	2,868.00	
Track bolts	70 hundredweight	5.50	385.00	
Track spikes	287 hundredweight	4.25	1,220.00	
Ties—untreated fir, 7 by 9 inches by 8½ feet.	12,200	1.60	19,520.00	
Track laying	4.63 miles	5.00	2,315.00	
			70,876.00	
Track in place	4.63 miles	15,300.00		70,839.00
Frogs and switches	27 sets	400.00		10,800.00
Ballast	2 miles	3,500.00		7,000.00
Drainage (lump sum)				6,000.00
Roundhouse and equipment (lump sum).				25,000.00
Coal chute (lump sum)				15,000.00
Yard office (lump sum)				1,200.00
Total estimated field cost of switch yard.				183,239.00
Loop track station 197-50 to 225:				
Grading, Class III	9,000 cubic yards	2.00		18,000.00
Tunnel excavation, Class III	11,000 cubic yards	6.50		71,500.00
Track materials in place	0.521 mile	15,300.00		7,971.00
Culverts (lump sum)				800.00
Total estimated field cost of loop track.				98,271.00

Boulder Canyon Dam, 40 tons, 30,000,000 acre-feet, long diversion tunnels—Contd.

Item	Quantity	Unit cost	Total cost	Summary
([1], vol. 5, p. 453)				
Derail—Spur—P. S. station 176-25:				
Grading—				
Class I	14,000 cubic yards	$0.30	$4,200.00	
Class III	3,000 cubic yards	2.00	6,000.00	
Total				$10,200.00
Track materials	0.161 mile	15,300.00		2,463.00
Culvert (lump sum)				500.00
Frogs and switches	1 set			400.00
Total estimated field cost of cradle spur.				13,563.00
Sidetrack at mixing plant—P. S. 177-50 to 186-50:				
Grading: Class III	6,000 cubic yards	2.00		12,000.00
Track materials in place	0.171 mile	15,300.00		2,616.00
Frogs and switches	2 sets	400.00		800.00
Total estimated field cost sidetrack.				15,416.00
Power-house spur—P. S. station 172-20:				
Grading (lump sum)				10,000.00
Track materials in place	0.246 mile	15,300.00		3,764.00
Frogs and switches	1 set			400.00
Total estimated field cost power-house spur.				14,164.00
Total estimated field cost construction—railroad.				1,840,810.00
([1]) Vol. 5, pp. 458-460)				
Railroad—Same as for 34,000,000 acre-feet dam				1,840,810.00
Construction camp				500,000.00
Permanent improvements: Grounds, operators' quarters, water supply, etc.				60,000.00
Right of way—Reservoir				250,000.00
Total estimated field cost				29,306,169.00
Administration, engineering and construction, 22½ per cent				6,593,888.00
Total estimated cost:				
Exclusive of power development and interest during construction				35,900,057.00
Roughly				36,000,000.00

ALTERNATIVE ESTIMATE

If it is found necessary to crush concrete aggregate the unit prices analyzed in the descriptive notes for crushed sand, gravel, and cobbles will alter the cost as shown below:

Diversion works	$4,331,550
Dam	19,409,460
Outlet works	4,540,356
Spillway	200,000
Railroad	1,840,810
Construction camp	500,000
Permanent improvements	60,000
Right of way	250,000
Total estimated field cost	31,132,236
Administration, engineering and construction, 22½ per cent	7,004,753
Total estimated cost:	
Exclusive of power development and interest during construction	38,136,989
Roughly	38,000,000

Boulder Canyon Reservoir, Black Canyon Dam Site

([1] vol. 5, pp. 441–454)

[Capacity 34,000,000 acre-feet. Maximum water surface, elevation 1,250 feet. Diversion tunnels discharging below power house]

Preliminary estimate

[To be increased according to Colorado River board report. (See page 53)]

Item	Cost
Diversion works, same as for 20,000,000 acre-foot reservoir	$4,258,200
Foundation, excavation, total 1,112,000 cubic yards	1,840,500
Grouting and drainage	118,434
Concrete in body of dam, 3,560,000 cubic yards, at $7	24,920,000
Parapets, lighting, rimming roadway at abutments, railing, and extra concrete on abutments	184,415
Outlet conduits	2,097,556
Outlet works, trash racks	1,304,159
Valves and gates	2,082,140
Closing sluiceways	358,931
Track, crane, and elevators	250,193
Construction railroad as per 20,000,000 acre-foot reservoir	1,840,810
Construction camp	500,000
Permanent improvements	60,000
Right of way	500,000
Field cost	40,345,358
Administration, engineering, and contingencies, 22½ per cent	9,077,706
Total, exclusive of interest during construction	49,423,064
Roughly	49,500,000

([1] Vol. 5, pp. 474–482)

Boulder Canyon Reservoir, Black Canyon Dam Site

[Capacity, 10,000,000 acre-feet; maximum water surface, elevation 1,033 feet. Diversion tunnels discharging above power-house site]

Item	Cost
Diversion works, total tunnel length, 10,500 feet	$5,516,700
Foundation excavation, total 800,000 cubic yards	1,198,500
Grouting and drainage	71,594
Concrete in body of dam, 1,320,000 cubic yards	9,240,000
Parapets, lighting, roadway, etc	51,881
Outlet conduits	1,511,284
Trash racks	571,480
Valves and gates	1,905,696
Track, crane, and elevators	258,937
Construction railroad	1,826,646
Construction camp	500,000
Permanent improvements	75,000
Right of way	200,000
Total field cost	22,955,698
Administration, engineering, and contingencies, 22½ per cent	5,165,032
Total estimated cost	28,120,730
Roughly	28,000,000

RIGHT OF WAY

([1] Vol. 5, pp. 528, 529, 530)

[From report by H. L. Baldwin, engineer, United States Geological Survey, 1919]

If the reservoir is constructed to a height of 1,250 feet, the town of Overton would be at the upper end thereof and not injuriously affected thereby.

About 6½ miles of the Los Angeles & Salt Lake Railroad below Overton would be submerged, as would also the villages of Kaolin and St. Thomas situated thereon.

Assisted by a resident whose interests are not particularly involved, I made an estimate of the total value of all improvements, houses, fences, ditches, irrigable lands, etc., in the valleys above junction of Muddy Creek and Virgin River, itemizing each article, and I place the total value thereof at a little less than $450,000. This covers the villages of Kaolin and St. Thomas above mentioned, but does not cover the value of railway property, which consists of roadbed alone and no buildings. The irrigated land can not be valued at much, if any, exceeding $125 per acre.

The crops raised are wheat, alfalfa, a few grapes for raisins, cantaloupes, and some garden produce.

None of these seem profitable and the community, Mormon with three exceptions, is far from being a thrifty, enterprising, or successful one. In the Virgin Valley are two ranches with very little in the way of improvements, and both located near St. Thomas. There is considerable land below St. Thomas that would likely subirrigate from the underground flow of the Virgin, but nothing has been done to attempt to use it.

A canal, heading near the crossing of the Virgin River east of St. Thomas and some 10 miles in length, was constructed four or five years ago to irrigate the irrigable areas of sections 10, 15, 16, 21, and 22 of township 18 south, range 68 east, less than 1,000 acres in extent, but through bad management was never completed, and the present value of the improvements is practically nil.

The only remaining improvement is the house on the placer claim of Harry Armitage, not over a couple hundred dollars value, and Bonelli's well-built stone house at the mouth of the Virgin River, probable value not to exceed $2,000.

For a reservoir of a capacity of 26,000,000 acre-feet with dam at Black Canyon, the maximum high water would be at elevation 1,197 feet, which would pass through the lower section of Kaolin. The total population of the area to be submerged is less than 100. The value of the submerged land and improvements, including the railroad branch, but excluding mining values, is estimated at $300,000.

A mineral valuation survey commenced in 1922 was not completed.

SALT DEPOSITS

([1] Vol. 5, p. 237)

[From report by F. L. Ransome, geologist, United States Geological Survey, 1923]

The known salt deposits of the Virgin Valley occur in the lower part of the Muddy Creek formation at a number of places between St. Thomas and the mouth of the Virgin. Apparently they are all at about the same stratigraphic horizon. Some of the salt is very pure and is coarsely crystalline, but a large part of it is brown and contains considerable fine silty material. In places the salt appears to grade horizontally into silt and this suggests that the known outcrops are not parts of a continuous salt bed but are lenticular masses in a bed or series of beds that is preponderantly silt.

([1] Vol. 5, p. 253)

It is clear that in the Muddy Creek formation of the Virgin Valley there are extensive deposits of rock salt. The quantity of salt contained in these deposits can not be estimated at present but probably amounts to over 25,000,000 tons. The greater part of this salt will probably be submerged beneath the water of the proposed reservoir. Some salt will undoubtedly go into solution but it is not believed that this will be sufficient to make the water appreciably saline. Much of the salt is so deeply buried that solution must necessarily be very slow. The actual salt outcrops are in bluffs where the effect of solution will be to undermine the insoluble overburden. This material will in time settle down over the salt and cover the exposed edges of the deposit, after which solution will be extremely slow. Although the quantity of salt is large the surface of salt actually exposed to rapid solution is a negligible part of the entire reservoir area.

MINES

([1] Vol. 5, pp. 527–528)

[From report by H. L. Baldwin, engineer, United States Geological Survey, 1919]

Rock salt occurs at several places in the Virgin Valley, notably at:

(1) The Bonelli mine in section 4, township 20 south, range 68 east, which has apparently not been much worked;

(2) Black salt mines in section 16, township 19 south, range 68 east, the extent of the working being several drifts, none of which exceed 25 feet in length, run into the deposit;

(3) Calico salt mines in sections 31 and 32, township 18 south, range 68 east, show evidence of considerable prospecting but very little salt has apparently been mined, although the size of the deposit is large;

([1] Vol. 5, p. 528)

[From report by H. L. Baldwin, engineer, United States Geological Survey, 1919

(4) The "salt mine" in section 34, township 17 south, range 68 east. This mine is worked considerably and the rock salt hauled by wagon to the railroad at St. Thomas 5½ miles distant where it is worth $7 per ton. This mine was recently sold for a price supposed to be about $50,000. Some salt has also been removed from section 27 in this township." No other mines or prospects of any kind are known which could be affected by the construction of the reservoir.

MINERAL DEPOSITS

METALLIFEROUS DEPOSITS

([1] vol. 5, p. 237)

[From report by F. L. Ransome, geologist, United States Geological Survey, 1923]

The character of the country which would be submerged by either of the proposed dams is not suggestive of rich or varied mineral resources. Some indications of metalliferous deposits in place may possibly exist in some of the canyon portions of the reservoir, but none was seen in the part of the area examined in 1921 and 1922. Placer gold has been reported in some of the gravel deposits near the river. Rock salt and gypsum occur in large quantity in the reservoir above Boulder Canyon, and some indefinite reports have been received of the occurrence of alum somewhere within the proposed reservoir site.

GOLD PLACERS

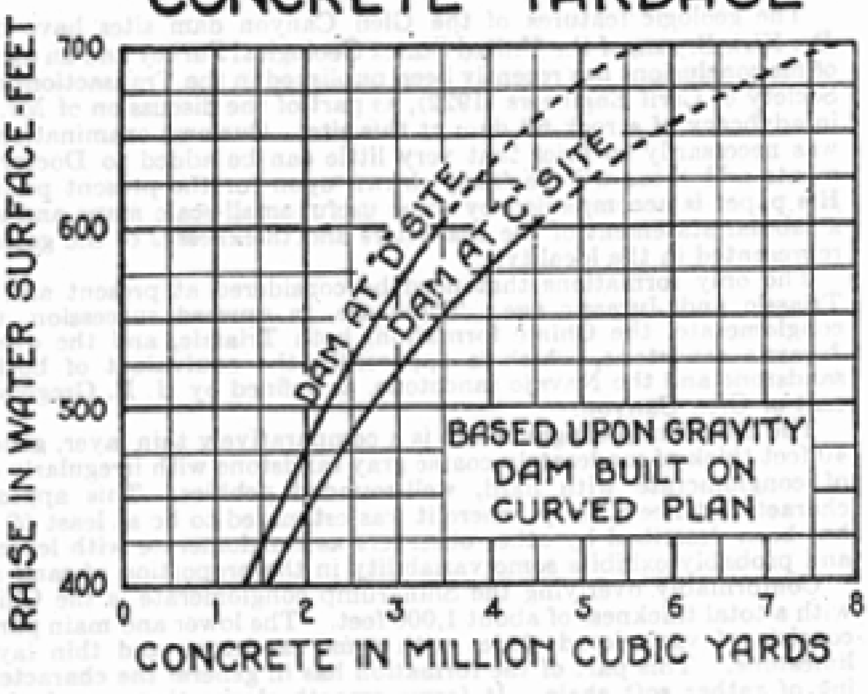
([1] vol. 5, pp. 254–255)

Claims have been made that certain gravels in the Black Canyon reservoir are gold bearing, particularly those which underlie a flat of about half a square mile in area, situated on the north bank of the Colorado, about 1½ miles east of the mouth of Las Vegas wash. In 1921 some churn drilling was done here by Stetson, Gillette, and others. The operations were conducted from what is known as Black's camp and were in charge of Mr. Fred Hess, with headquarters in Las Vegas. One drill was in operation. Gold was reported to occur from a depth of 20 feet down, no bed rock having been reached. No definite information was obtained concerning the character of the material passed through, or the tenor of the gravels. At the time of visit in 1922, the camp was being maintained but no drilling was in progress. The general impression gained was that the exploitation was perfunctory and that no lively expectation was entertained of actual mining.

If it is maintained that these gravels contain enough gold to be of economic value it will probably be necessary to test them by drilling or shaft sinking. No reliance can be safely placed on the statements or records of those now holding the ground.

148 ?
149 ?
GRAPHIC

CONCRETE YARDAGE



RESERVOIR CAPACITY

RAISE in W.S.	STORAGE in ACRE-FEET		
	Dam at "D" Site	Dam at "C" Site	Excess at "D" Site
405'	11,300,000	10,650,000	650,000
505'	20,500,000*	19,500,000	1,000,000
605'	34,000,000	33,000,000	1,000,000

"C" SITE = UPPER SITE IN BOULDER CANYON
"D" SITE = LOWER SITE IN BLACK CANYON

* Referred to elsewhere as 20,000,000 a.f. reservoir

COLORADO RIVER STORAGE
BOULDER CANYON RESERVOIR
COMPARISON OF DAMS at "C" SITE and "D" SITE
DEC. 15. 1923.
BASED ON PRELIMINARY ESTIMATE

27/67 | 45-C-420

GLEN CANYON RESERVOIR

[From Board Report by F. E. Weymouth, F. L. Ransome, Louis C. Hill and A. V. Wiley; dated December 20, 1922]

GEOLOGIC FEATURES

The geologic features of the Glen Canyon dam sites have been studied by Dr. Kirk Bryan, of the United States Geological Survey and an excellent summary of his conclusions has recently been published in the Transactions of the American Society of Civil Engineers (1922), as part of the discussion of Mr. LaRue's paper in advocacy of a rock-fill dam at this site. Our own examination of the geology was necessarily so brief that very little can be added to Doctor Bryan's statements and these will be freely drawn upon for the present preliminary report. His paper is accompanied by some useful small-scale maps and sections and by a tabular statement of the characters and thicknesses of the geologic formations represented in the locality.

The only formations that need be considered at present are those of upper Triassic and Jurassic age. These are, in upward succession, the Shinarump conglomerate, the Chinle formation, both Triassic, and the overlying massive Jurassic sandstone, which is apparently the equivalent of both the Wingate sandstone and the Navajo sandstone, as defined by H. E. Gregory, to the southeast of Glen Canyon.

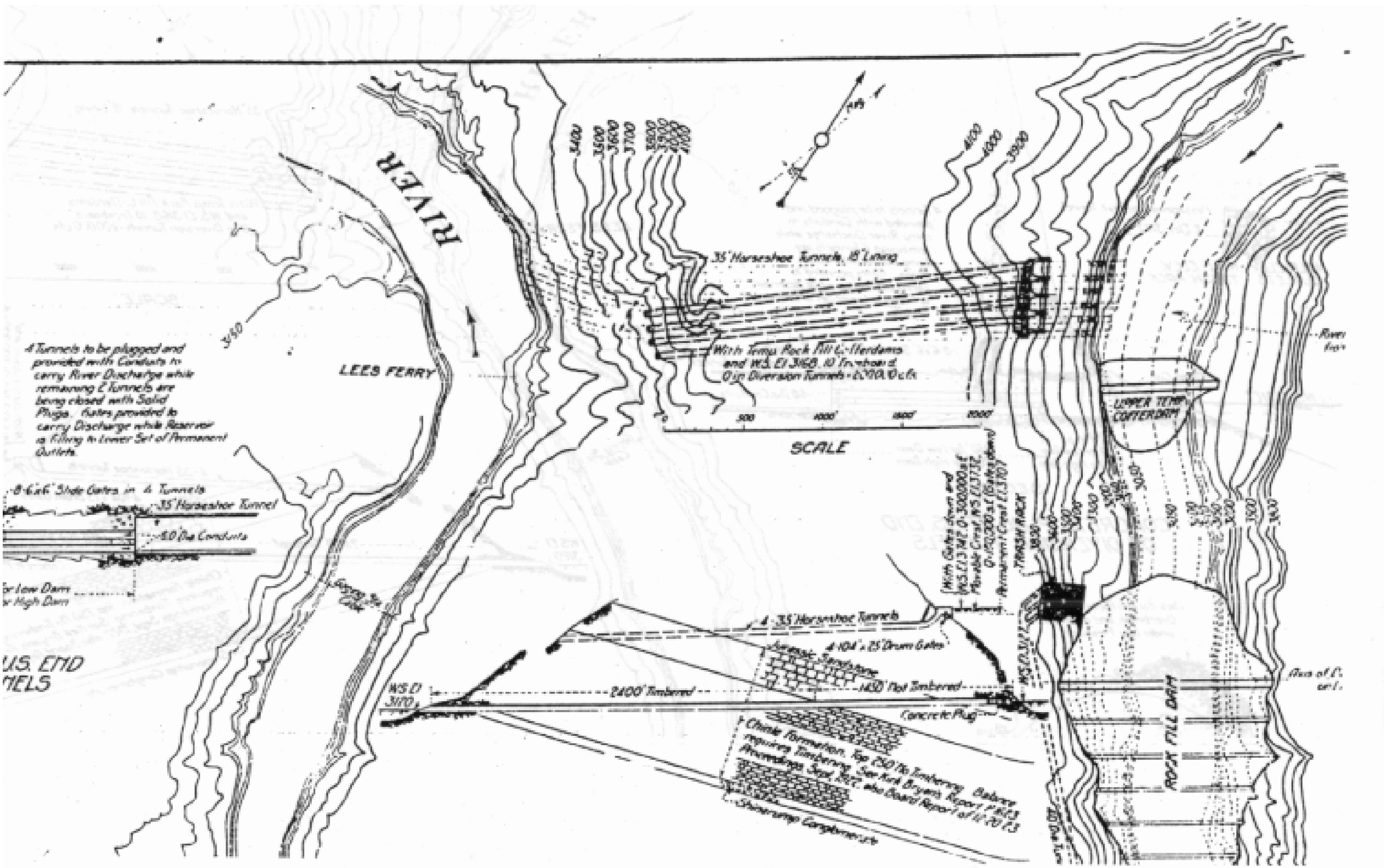
The Shinarump conglomerate is a comparatively thin layer, generally less than 40 feet thick of moderately coarse gray sandstone with irregularly disposed lenses of conglomerate with hard, well-rounded pebbles. This appeared to be its character at Lee's Ferry, where it was estimated to be at least 50 feet thick. It has been described by other observers as conglomerate with lenses of sandstone and probably exhibits some variability in the proportion of sand and pebbles.

Conformably overlying the Shinarump conglomerate is the Chinle formation, with a total thickness of about 1,000 feet. The lower and main part of the Chinle consists of varicolored shales with some sandstone and thin layers of impure limestone. This part of the formation has in general the characteristic weathering of rather soft shale. It forms smooth slopes that are cloaked with finely disintegrated crumbling material much of which has the appearance of a loose sterile soil. The upper 200 to 300 feet of the Chinle formation is so distinctly different from the lower part as to raise the question why it was not given a distinctive name. It consists of rather light brick-red sandstones and shales in alternate layers. Sandstone predominates over shale and some of the beds are apparently 6 feet or more in thickness. This part of the Chinle is much more resistant than the lower part and generally appears as a slightly stept cliff at the base of the Jurassic sandstone. Some of the thicker beds might be used as building stone.

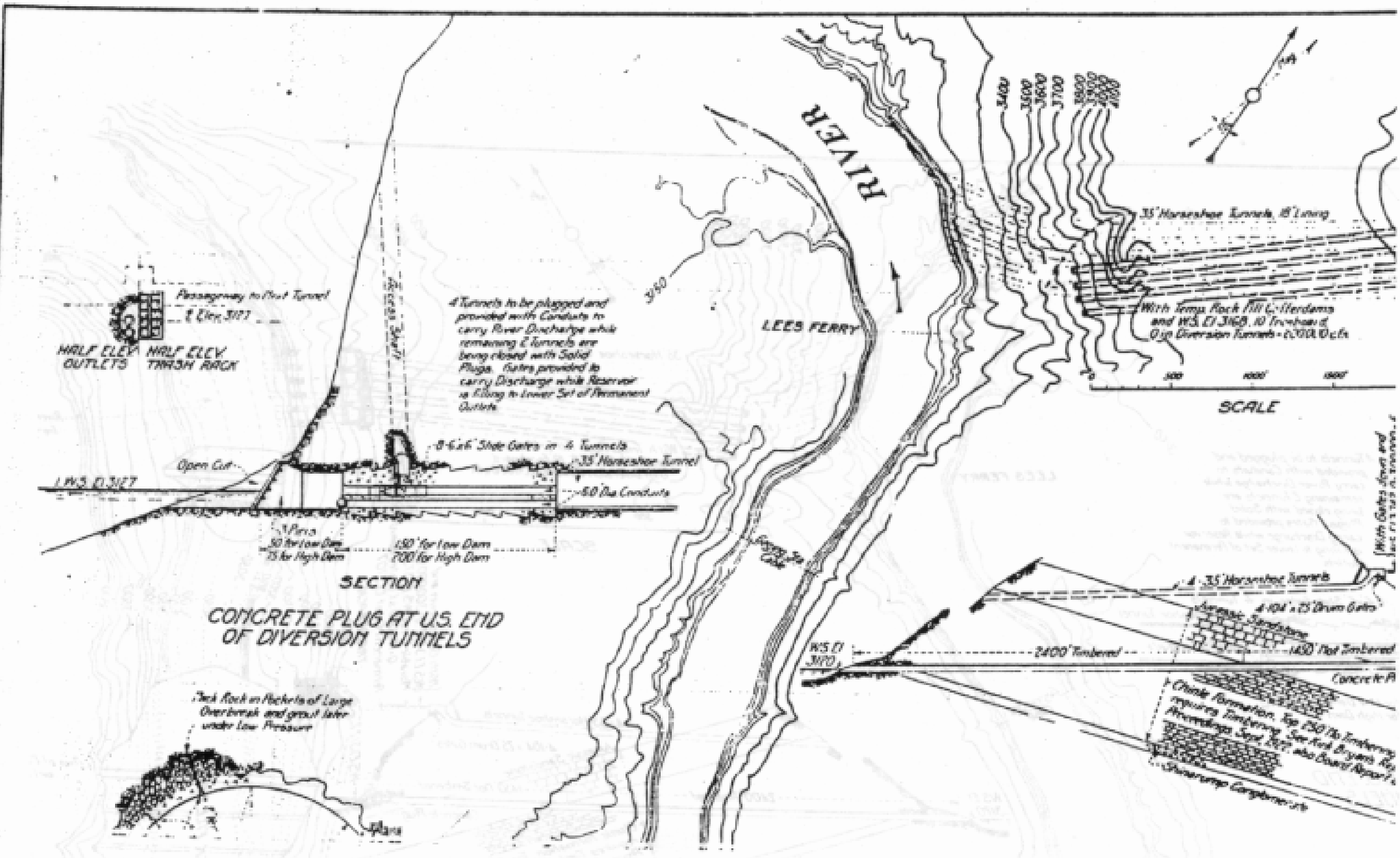
The Jurassic sandstone, the rock actually exposed at the dam sites, has been estimated by Doctor Bryan to be from 1,100 to 1,200 feet thick. It is extraordinarily massive as seen in cliff faces, the inclined crossbedding being as a rule more conspicuous than the true bedding. It contains a few thin lenticular layers of impure cherty limestone, usually not over a foot or two thick.

The country for hundreds of miles around Lee's Ferry has the general character of a plateau underlain by the beds just described in a nearly horizontal attitude. There is a regional northerly dip of probably from 1 to 4 degrees. Extending north and south through Lees Ferry, and continuing for over 40 miles south of the Colorado along the line of the Echo Cliffs, is one of the great monoclinal folds described by the early geological explorers. Along this line the beds, as they are followed westward, turn sharply upward and then resume, at a level about 1,000 feet or more higher, a horizontal attitude west of the fold or flexure. In consequence of this steplike fold, the beds at Lees Ferry show a dip of 10 degrees or more to the east, or toward the lower of the two dam sites, which is about 2,000 feet east-northeast of the ferry, separated by a high sandstone ridge, around which the river loops to the south before it reaches the mouth of the Paria.

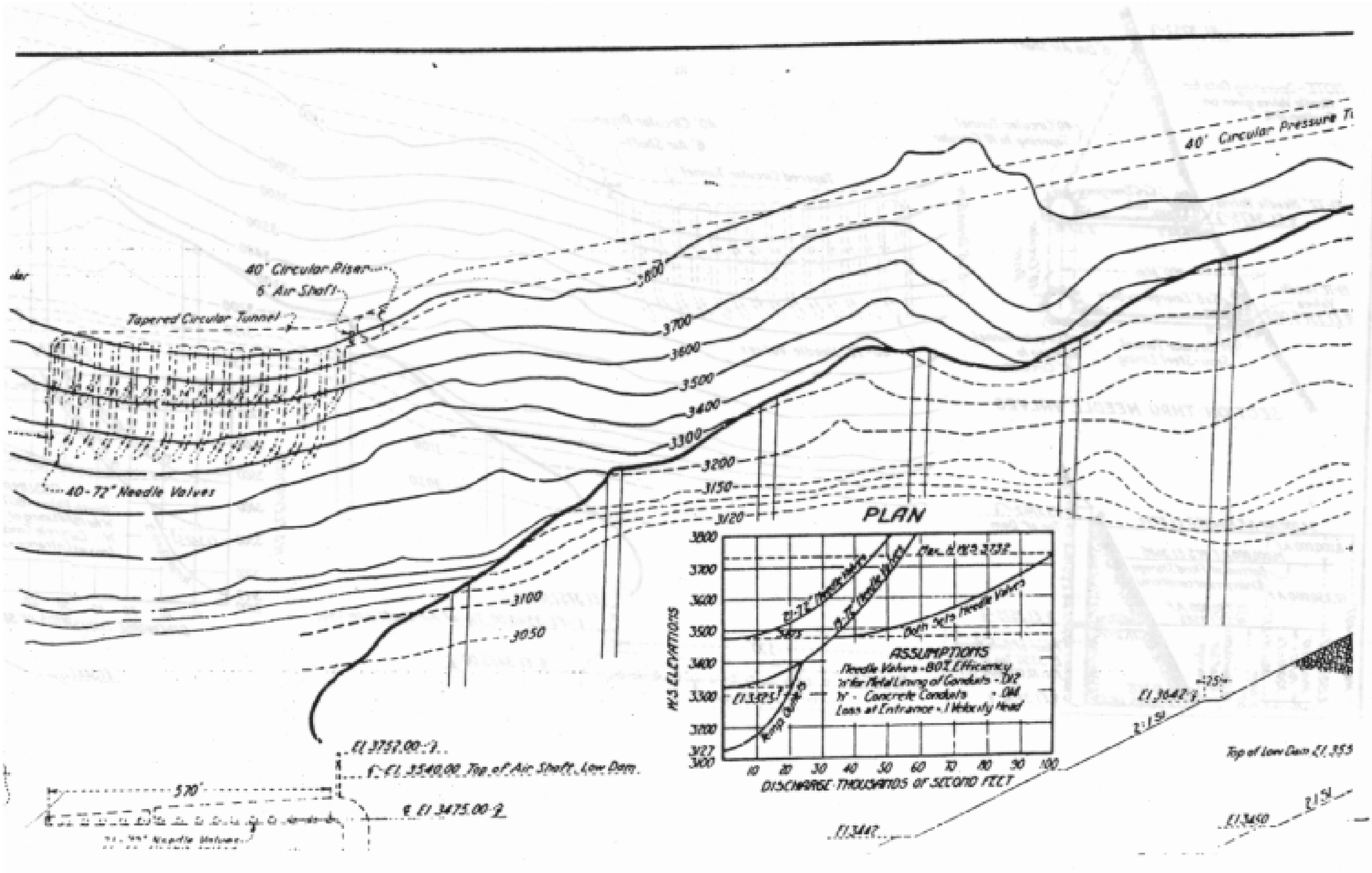
In approaching the dam site by river from Lees Ferry, the route for about half a mile is south and follows approximately the strike of the beds. The rocks exposed along the water's edge along this stretch are the upper red sandstones and shales of the Chinle formation. A sharp bend to the east takes the visitor for nearly a mile across the strike of the beds and about 1,000 feet from the eastern end of this stretch, the Chinle formation disappears below the river level, and the canyon walls consist entirely of the massive Jurassic sandstone. Upstream from this second bend the river is a straight stretch of the canyon which

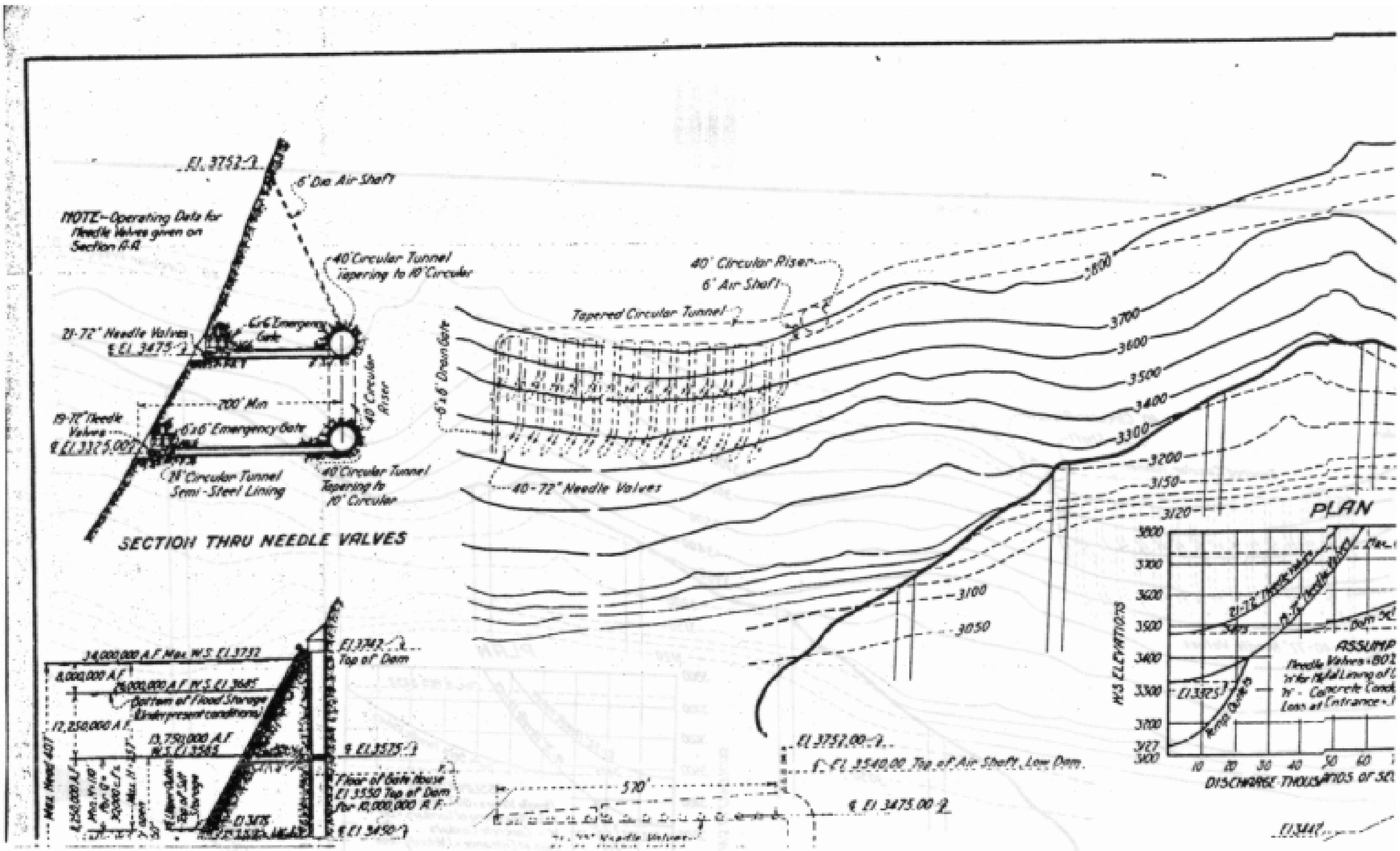


RIVER
LEES FERRY
4 Tunnels to be plugged and provided with Conduits to carry River Discharge while remaining 2 Tunnels are being closed with Solid Plugs. Gates provided to carry Discharge while Reservoir is Filling to Lower Set of Permanent Outlets.
35' Horseshoe Tunnels, 18" Lining
With Temp. Rock Fill Cofferdams and W.S. El 3168.10 Timbered, Q in Diversion Tunnels = 200,110 c.f.s.
SCALE
UPPER TEMP. COFFERDAM
TRASH RACK
ROCK FILL DAM
4-35' Horseshoe Tunnels
4-10'4" x 25' Drum Gates
Jurassic Sandstone
2400' Timbered
1400' Not Timbered
Concrete Plug
W.S. El. 3170
Shinarump Conglomerate
Permanent Crest El. 3707
U.S. END
NELS
for Low Dam
for High Dam
35' Horseshoe Tunnel
6.0' Dia. Conduits



Passageway to Next Tunnel
℄ Elev. 3177
HALF ELEV. OUTLETS
HALF ELEV. TRASH RACK
Access Shaft
4 Tunnels to be plugged and provided with Conduits to carry River Discharge while remaining 2 Tunnels are being closed with Solid Plugs. Gates provided to carry Discharge while Reservoir is Filling to Lower Set of Permanent Outlets
8-6'x6' Slide Gates in 4 Tunnels
35' Horseshoe Tunnel
Open Cut
L.W.S. El. 3127
6.0' Dia. Conduits
50' for Low Dam
75' for High Dam
150' for Low Dam
700' for High Dam
SECTION
CONCRETE PLUG AT U.S. END OF DIVERSION TUNNELS
Pack Rock in Pockets of Large Overbreak and grout later under Low Pressure
3150
LEES FERRY
RIVER
3400
3500
3600
3700
3800
35' Horseshoe Tunnels, 18" Lining
With Temp. Rock Fill Cofferdams and W.S. El. 3168, 10 Timbered, 0 in Diversion Tunnels
SCALE
0
500
1000
1500
W.S. El. 3170
2400' Timbered
1430' Not Timbered
4-35' Horseshoe Tunnels
4-104' x 25' Drum Gates
Concrete
Chinle Formation. Top 250' No Timbering required. Timbering. See Kirk Bryan's Rep. Proceedings Sept. 1927, also Board Report.
Shinarump Conglomerate


40' Circular Pressure T
40' Circular Riser
6' Air Shaft
Tapered Circular Tunnel
40-72" Needle Valves
3800
3700
3600
3500
3400
3300
3200
3150
3120
3100
3050
PLAN
H.S. ELEVATIONS
DISCHARGE THOUSANDS OF SECOND FEET
Both Sets Needle Valves
ASSUMPTIONS
Needle Valves - 80% Efficiency
Loss at Entrance - .1 Velocity Head
El. 3752.00
El. 3540.00 Top of Air Shaft, Low Dam
El. 3475.00
570'
Top of Low Dam El. 3??
El. 3442
El. 3450



El. 3752
6' Dia Air Shaft
NOTE—Operating Data for Needle Valves given on Section A-A
40' Circular Tunnel tapering to 10' Circular
21-72" Needle Valves
El. 3475
6x6' Emergency Gate
200' Min
40' Circular Riser
19-72" Needle Valves
El. 3325.00
6x6' Emergency Gate
38' Circular Tunnel Semi-Steel Lining
40' Circular Tunnel Tapering to 10' Circular
SECTION THRU NEEDLE VALVES
40' Circular Riser
6' Air Shaft
Tapered Circular Tunnel
6'x6' Drain Gate
40-72" Needle Valves
3800
3700
3600
3500
3400
3300
3200
3150
3120
3100
3050
PLAN
34,000,000 A.F. Max. W.S. El. 3732
8,000,000 A.F.
26,000,000 A.F. W.S. El. 3685
Bottom of Flood Storage (Under present conditions)
12,250,000 A.F.
13,750,000 A.F. W.S. El. 3565
Max. Head 407'
El. 3742 Top of Dam
El. 3525
Floor of Gate House El. 3550 Top of Dam for 10,000,000 A.F.
El. 3450
El. 3752.00
El. 3540.00 Top of Air Shaft, Low Dam.
570'
El. 3475.00
W.S. ELEVATIONS
DISCHARGE THOUSANDS OF SEC
ASSUMP
El. 3325

extends northwest for over a mile and one-half. The lower dam site is in this section, about ¾ of a mile above the bend. The lower end of this straight stretch is probably from 1,500 to 2,000 feet east of the visible upward tilt of the beds along the east flank of the monoclinal fold; the north end of the stretch, lying farther west, shows the beds just turning up into the fold. To one going upstream toward the dam site the bedding planes in the Jurassic sandstone have an apparent dip of about 4 degrees upstream, or to the northwest.

It was impossible in the short time available to determine the probable depth below water surface to the top of the Chinle. It was roughly estimated at about 250 feet. A drill hole put down by the Southern California Edison Co., at the base of the east wall to a depth of about 200 feet below the water surface is clearly all in the Jurassic sandstone, as shown by the core.

The Jurassic sandstone has been fully described by Gregory, Bryan, and others. It is a fine-grained, very uniform quartzose sandstone which appears to owe its reddish tint to the superficial redness of certain individual grains. The grains are imperfectly cemented and the whole resembles in hardness the type of soft brick known to the trade as salmon brick. It crumbles under shock, such as that of ordinary blasting, and small fragments can be crushed to sand between the fingers. Notwithstanding its softness the rock stands remarkably well in the canyon walls, forming large smooth cliffs that rise for 1,000 feet or more above the river and which in places are within 5° of being vertical. A conspicuous feature of these walls is the presence of a series of nearly vertical fractures or joints which strike approximately east and west. These joints are not everywhere present but occur in groups, comprising many joints from a few inches to a few feet apart. At such places the sandstone is divided into great, vertical, closely fitting slices. The joints themselves are very close and appear to be as a rule cemented by films of calcite. Under the action of weather however, the joints form zones of relative weakness and where they occur there is a tendency for the rocks to fall off in blocks and for the canyon walls to lose some of their sheer smoothness. One such zone of joining crosses obliquely the line along which drilling is now in progress and constitutes a possible weakness in the abutments. Another section of the canyon, a few hundred yards downstream from the present drill line, offers better abutments with apparently no greater distance between them but the top of the Chinle (the red sandstone and shale) is probably a few feet nearer the bottom of the river than it is farther north. The upper beds of the Chinle, however, to a thickness of 200 feet or more, would probably be safe material upon which to base a dam.

The upper dam site is situated about 5 miles upstream from the lower site just south of a point where the canyon turns sharply to the east. The walls are of the same sandstone as those of the lower site but the depth to the top of the Chinle formation is probably slightly greater. The abutments here are particularly smooth and massive.

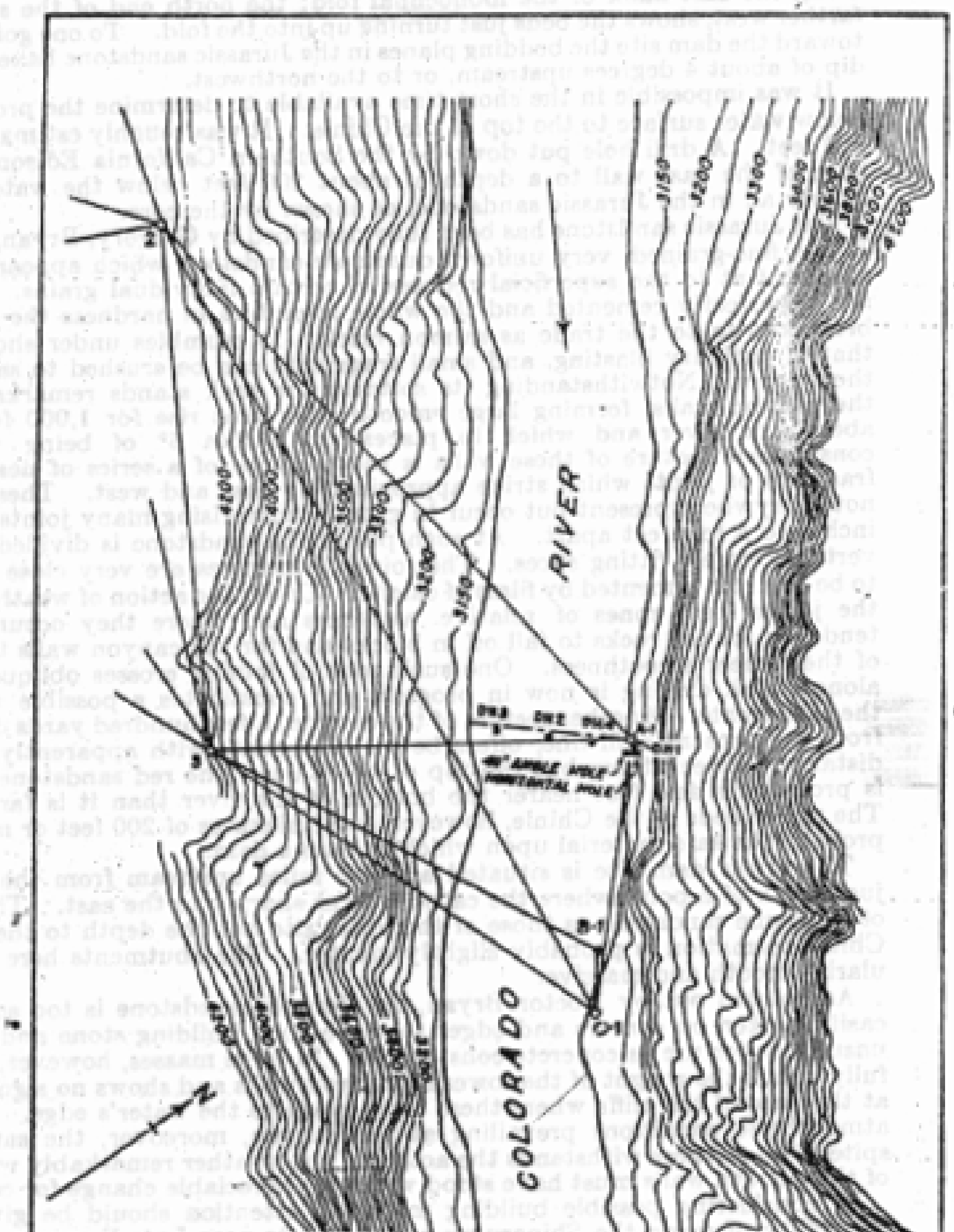
As pointed out by Doctor Bryan, the Jurassic sandstone is too soft and too easily broken on corners and edges to make good building stone and is entirely unsuitable for use as concrete constituent. In large masses, however, it successfully resists the weight of the towering canyon walls and shows no signs of failure at the base of the cliffs where these come down to the water's edge. Under the atmospheric conditions prevailing at the canyon, moreover, the sandstone in spite of its softness withstands the action of the weather remarkably well. Some of the smooth walls must have stood without appreciable change for centuries.

In considering possible building materials attention should be given to the possibility of using the Shinarump conglomerate near Lees Ferry as a source of sand and gravel. The nearest rock suitable for crushing and use in concrete is probably the cherty Kaibab limestone which is exposed over a large area a mile or two west of Lees Ferry and forms the walls of Marble Canyon. Considerable gravel of recent geologic age occurs at the mouth of the Paria, just below Lees Ferry, but it is doubtful whether the quantity would be sufficient for the construction of a dam of the size proposed.

DAM SITES

Two dam sites have been investigated, one four miles and the other about 9 miles above Lees Ferry. Mr. LaRue's paper[1] indicates that the lower site is preferable and the Reclamation Bureau Board of

[1] Tentative plan for the construction of a 780-foot rock-fill dam on the Colorado River at Lees Ferry Ariz., by E. C. LaRue. Trans. A. S. C. E., vol. 58, p. 200.


COLORADO RIVER
COLORADO RIVER BASIN
LEES FERRY DAMSITE
LOCATION OF
CORE DRILLING 1922
SCALE IN FEET
0 100 500 1000
Topography taken from U. S. G. S. lithograph map, showing LEES FERRY DAM SITE.
Triangulation from Field Book 2250 Page 27
March 1923
21169

Engineers favors the same site. Both sites are located near the upper end of long horseshoe bends in the river which may be taken advantage of in river diversion during construction and in passing spillway water.

DRILLING AT DAM SITE

Southern California Edison Co., of Los Angeles, Calif., made investigations of foundation conditions at the dam site by means of a core drill in November and December, 1922, and in January, 1923. The dam site is located about 4 miles upstream from Lees Ferry on the north side of the "Horseshoe" curve which the Colorado River makes in approaching Lees Ferry. The line on which the drilling was done is within the area which had tentatively been selected as the appropriate location for a dam at the lower end of Glen Canyon. Six holes were drilled as shown upon the accompanying drawing.

The first hole drilled (No. 1) was put down vertically on the left bank of the river to a depth of 221 feet for the purpose of obtaining a cross section of the formation at this location where the strata are reasonably nearly level, although quite close to the beginning of a monocline, which shows very decidedly at Lees Ferry. The entire hole was in solid rock and for most of the distance a core was obtained and preserved. The next three holes (Nos. 2, 3, and 4) were drilled vertically from a barge anchored in the river. The holes penetrated the channel filling and were, in each instance, carried into the solid sandstone bedrock for a considerable distance. The horizontal distances between vertical holes are as follows:

Between No. 1 and No. 4 .... 121 feet.
Between No. 4 and No. 2 .... 146 feet.
Between No. 2 and No. 3 .... 157 feet.

In order to develop the character of the rock for some distance under the exposed surface two holes (Nos. 5 and 6) were drilled on the left bank of the river near hole No. 1. Hole No. 5 was drilled horizontally for a distance of 69 feet. Hole No. 6 was drilled at an angle of 40 degrees to the horizontal for a distance of 52 feet.

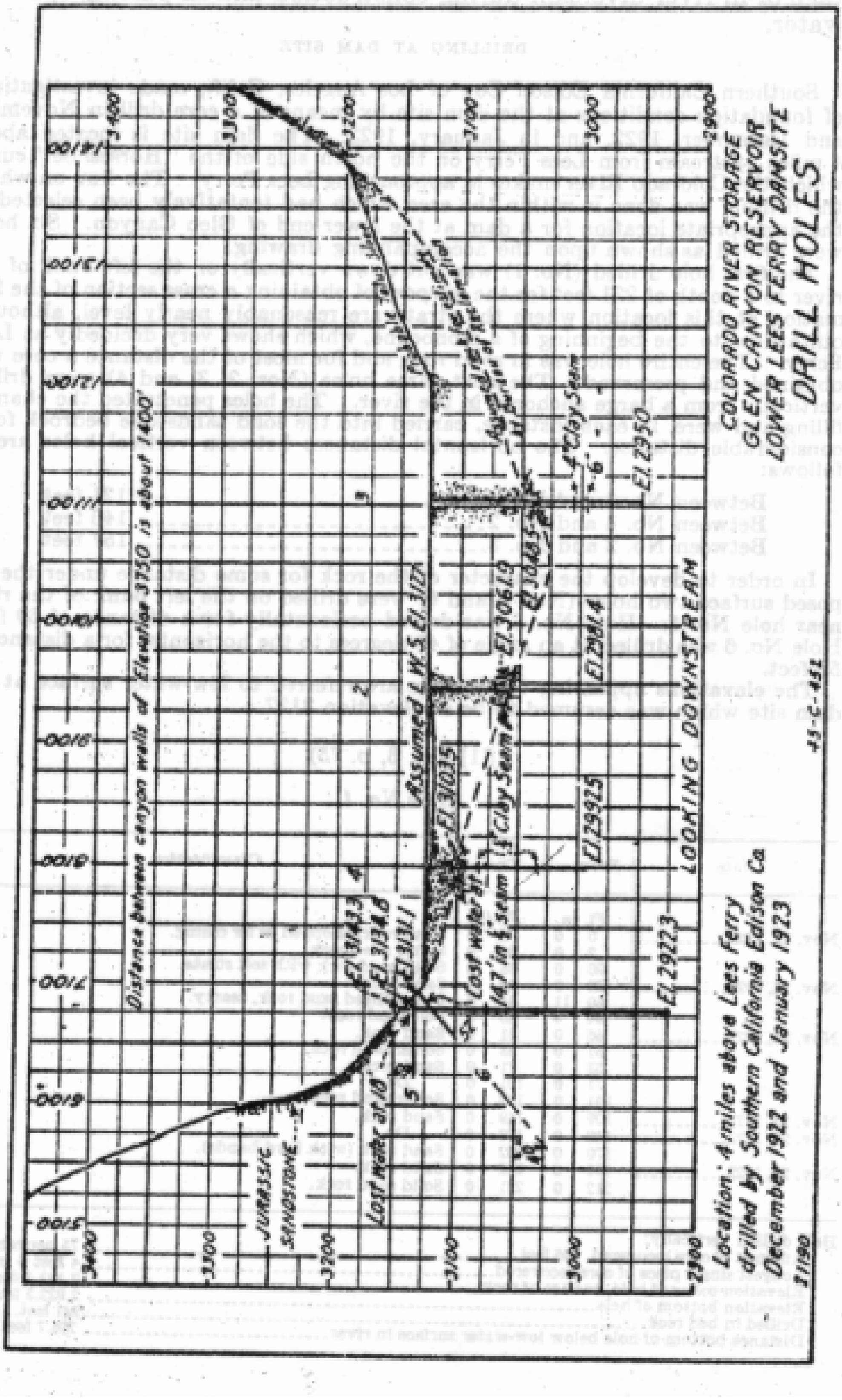
The elevations appearing on the logs are referred to low-water surface at the dam site which was assumed to be at elevation 3127.

([1] Vol. 6, p. 75)

Hole No. 1

Date	From— Ft.	From— in.	To— Ft.	To— in.	Classification
Nov. 23, 1922	0	0	2	0	Sand rock, chopped in for casing.
	2	0	20	0	Softer sand rock.
	20	0	38	0	Solid sand rock with soft strata.
Nov. 24, 1922	38	0	40	11	Sand rock.
	40	11	44	6	Crystallized sand rock, seamy.
	44	6	46	0	Soft sand rock.
Nov. 25, 1922	46	0	51	0	Sand rock.
	51	0	53	0	Softer sand rock.
	53	0	71	0	Sand rock.
	71	0	101	0	Do.
	101	0	109	0	Softer sand rock.
Nov. 26, 1922	109	0	149	0	Sand rock.
Nov. 27, 1922	149	0	170	0	Do.
	170	0	192	0	Sand rock (with hard bands).
Nov. 28, 1922	192	0	212	0	Sand rock.
	212	0	221	0	Solid sand rock.

Hole drilled vertically:
- Amount of core recovered, 166 feet .... 75 per cent.
- Longest single piece of core recovered .... 4 feet 5 inches.
- Elevation collar of hole, surface of rock .... 3,143.3 feet.
- Elevation bottom of hole .... 2,922.3 feet.
- Drilled in bed rock .... 221 feet.
- Distance bottom of hole below low-water surface in river .... 204.7 feet.


COLORADO RIVER STORAGE
GLEN CANYON RESERVOIR
LOWER LEES FERRY DAMSITE
DRILL HOLES
Location; 4 miles above Lees Ferry
drilled by Southern California Edison Co.
December 1922 and January 1923
LOOKING DOWNSTREAM
Distance between canyon walls at Elevation 3750 is about 1400'
JURASSIC SANDSTONE
Assumed L.W.S. El. 3103
Clay Seam
El. 2950
El. 2922.3
El. 2992.5
45-C-451

([1] Vol. 6, p. 76)

Hole No. 2

Date	From—		To—		Classification	Core
	Ft.	*in.*	*Ft.*	*in.*		
Dec. 12, 1922	0	0	2	6	Space top of barge to water	None.
	2	6	7	10	Surface of water to river bed	Do.
	7	10	29	0	Sand	Do.
Dec. 13, 1922	29	0	33	0	do	Do.
	33	0	34	0	Bowlder	Do.
	34	0	52	0	Sand	Do.
Dec. 14, 1922	52	0	57	0	do	Do.
	57	0	62	0	Sand and gravel	Do.
Dec. 15, 1922	62	0	69	6	Sand gravel	Do.
	69	6	72	0	Sand rock	Do.
Dec. 16, 1922	72	0	83	0	do	Maximum core, 5 inches.
	83	0	99	0	Solid sand rock	Maximum core, 1 foot 5 inches.
Dec. 17, 1922	99	0	139	0	Sand rock	Maximum core, 2 feet 6 inches.
	139	0	150	0	do	Maximum core, 1 foot 7 inches.

Hole drilled vertically:
- Amount of core recovered, 61 feet — 75.8 per cent.
- Longest single piece of core recovered — 2 feet 6 inches.
- Elevation collar of hole, top of casing — 3,131.4 feet.
- Elevation surface of bed rock — 3,061.9 feet.
- Elevation bottom of hole — 2,981.4 feet.
- Drilled in bed rock — 80.5 feet.
- Distance, low water surface to bed rock — 65 feet.

([1] Vol. 6, p. 78)

Hole No. 3

Date	From—		To—		Classification	Core
	Ft.	*in.*	*Ft.*	*in.*		
Dec. 22, 1922	0	0	5	0	Space from top of barge to river bed	None.
	5	0	20	6	Sand	Do.
Dec. 23, 1922	20	0	23	6	Sand rock bowlder	Do.
	23	6	30	0	Sand and gravel	Do.
	30	0	42	0	do	Do.
Dec. 24, 1922	42	0	53	0	do	Do.
	32	0	50	0	Drove 3-inch pipe material given in reports of 23d and 24th.	Do.
Dec. 25, 1922	53	0	56	0	Sand, small bowlders, and gravel	Do.
	56	0	59	0	Sand rock bowlder	Do.
	59	0	65	0	Sand, small bowlders, and gravel	Do.
	65	0	77	0	Sand and gravel	Do.
Dec. 26, 1922	77	0	82	6	do	
	82	6	99	0	Solid sand rock	Maximum core, 2 feet.
	99	0	130	8	Sand rock	Maximum core, 2 feet 3 inches.
	130	8	131	0	Clay seam	
	131	0	136	0	Sand rock	
Dec. 27, 1922	136	0	137	0	Solid sand rock	
	137	0	137	6	Clay	
	137	6	149	0	Solid sand rock	Maximum core, 8 feet 9 inches.
	149	0	181	0	Sand rock	Maximum core, 2 feet.

Hole drilled vertically:
- Amount of core recovered, 92 feet — 93.4 per cent.
- Longest single piece of core recovered — 8 feet 9 inches.
- Elevation collar of hole, top of casing — 3,131 feet.
- Elevation surface of bed rock — 3,048.5 feet.
- Elevation bottom of hole — 2,950 feet.
- Drilled in bed rock — 98.5 feet.
- Distance, low water surface to bed rock — 78.5 feet.

([1] Vol. 6, p. 78)

Hole No. 4

Date	From—		To—		Classification	Core
	Ft.	In.	Ft.	In.		
Dec. 30, 1922	0	0	2	5	Collar of hole to water	None.
	2	8	8	8	Water	Do.
	8	8	20	0	Sand	Do.
	20	0	27	0	Sand and gravel	Do.
	27	0	28	0	do	Maximum core, 8 inches.
Dec. 31, 1922	28	0	39	0	Soft sand rock	Maximum core, 1 foot 6 inches.
	39	0	54	0	Sand rock, ½-inch clay seam at 44 feet to 44 feet ½ inch.	Do.
Jan. 1, 1923	54	0	98	0	Sand rock, ½-inch clay seam at 98 feet.	Maximum core, 1 foot 7 inches.
	98	0	130	0	Sand rock	Maximum core, 1 foot 3 inches.

Hole drilled vertically:
- Amount of core recovered, 92 feet .... 83.9 per cent.
- Longest single piece of core recovered .... 1 foot 7 inches.
- Elevation collar of hole, top of casing .... 3,131.5 feet.
- Elevation surface of bed rock .... 3,103.5 feet.
- Elevation bottom of hole .... 2,992.5 feet.
- Drilled in bedrock .... 111 feet.
- Distance, low-water surface to bedrock .... 23.5 feet.

([1] Vol. 6, p. 79)

Hole No. 5

Date	From—	To—	Classification	Core
Jan. 4, 1923.	Feet	Feet		
Day shift	0	33	Sand rock	Maximum core, 6 feet 8 inches.
Night shift	33	69	Solid sand rock	Do.

Hole drilled horizontally:
- Lost water at 18 feet.
- Amount of core recovered, 66 feet .... 95.7 per cent.
- Longest single piece of core recovered .... 6 feet 8 inches.
- Elevation collar of hole .... 3,134.5 feet.
- Drilled in bed rock .... 69 feet.
- Distance, collar of hole above low-water surface in river .... 7.8 feet.

([1] Vol. 6, p. 80)

Hole No. 6

Date	From—		To—		Classification
	Ft.	In.	Ft.	In.	
Jan. 5, 1923	0	0	20	0	Soft sand rock.
	20	0	40	0	Sand rock.
	40	0	49	6	Soft sand rock.
	49	6	52	0	Crystallized sand rock.

Hole drilled downward at an angle of 40° with the horizontal:
- One-half inch seam encountered at 14 feet 7 inches; lost water.
- Amount of core recovered, 27 feet .... 51.9 per cent
- Longest single piece of core recovered .... Not stated.
- Elevation collar of hole .... 3,131.1 feet.
- Drilled in bed rock .... 52 feet.
- Distance, collar of hole above low-water surface in river .... 4.1 feet.

([1] Vol. 6, p. 2)

Three of the holes drilled were in the river channel to develop the depth to bedrock and character of rock under the dam. It will be noted that the deepest of these holes located bedrock 79 feet below low-water surface. However, there is no assurance that the deepest channel was located since the holes are 140 and 157 feet apart. The estimates assume maximum depth to rock 100 feet, the same as originally assumed by Mr. LaRue. The drilling records show, further, that the river channel is filled with river sand and gravel with very few boulders and that clay-filled seams from one half inch to 6 inches thick exist in the bedrock. The geologists did not report the existence of seams of clay in the sandstone above water surface, and it is probable that the drillers interpreted the cuttings from very soft layers of sandstone as clay.

STRENGTH OF ROCKS

LABORATORY CERTIFICATE SMITH-EMERY COMPANY

([1] Vol. 6 p. 81)

Chemical Engineers and Chemists,
Metallurgical and Testing Engineers,
245 South Los Angeles St.,
Los Angeles, January 12, 1923.

Laboratory
No. 45499-500
Sample: Core Samples
Received: 12-27-1922
Submitted by:
Southern California Edison Co. Marked: Colorado (Order No. E 74718)
Edison Building,
Los Angeles, Calif.

Mr. DOOLITTLE:

COMPRESSION TESTS

Marked: 88 feet.[1]
Cylinders 1.11″ dia. x 2.12″ high, area .9677 sq. in.
No. 1 .... 2,500 lbs.
No. 2 .... 2,050 lbs.
No. 3 .... 1,900 lbs.

Average .... 2,150 lbs. = 2,220 lbs. per sq. in.

Marked: 210 feet[1]
Cylinders 1.12″ dia. x 2.25″ high, area .9852 sq. in.
Hole No. 1.
No. 1 .... 12,600 lbs.
No. 2 .... 12,200 lbs.
No. 3 .... 13,300 lbs.

Average .... 12,700 lbs. = 12,900 lbs. per sq. in.

Cylinders 1.11″ dia. x 2.25″ high, area .9677 sq. in.
No. 4 .... 15,100 lbs.
No. 5 .... 8,300 lbs.
No. 6 .... 7,900 lbs.

Average .... 10,433 lbs. = 10,480 lbs. per sq. in.

Respectfully submitted.

SMITH-EMERY CO.
Inspecting and Testing Engineers.

([1] Vol. 6, p. 19)

In regard to the suitability of the Jurassic sandstone as abutments for an exceedingly high dam a statement of Mr. Bryan's should not be overlooked. In speaking of tunnels through the rock he says:[2]

However, unless the velocities in the tunnel are low, a concrete lining will be necessary to prevent wear. It seems likely also that there will be losses to the

[1] The samples tested were cylinders obtained at depths of 88 feet and 210 feet, respectively, in hole No. 1
[2] Proceedings, A. S. C. E., September, 1922.

adjacent porous sandstone if the water in the tunnel is under great pressure and that this water percolating through the sandstone may eventually find or work out channels large enough to produce serious losses from the tunnel and direct the water toward inconvenient places.

In another place he states that the cementing material of the sandstone is calcium carbonate. What is true of pressure tunnels would be true of the reservoir itself. It is possible that by reason of the solubility of the calcium carbonate any crevice in the rock might become enlarged and in time produce the channels referred to in connection with pressure tunnels. If these channels should develop in the abutments of the dam or in its foundation, serious results would follow.

([1] Vol. 6, pp. 26–27)

Concrete Dam

DESIGN

The principles of design used for the Boulder Canyon Dam have also been employed for the Glen Canyon Dam. Owing to the inferior quality of the rocks at the dam site, an effort was made to design a dam of the least obtainable pressures with results as follows:

Pressure in tons per square foot

	No uplift or silt	Full reservoir with uplift	With silt to top of dam
RESERVOIR CAPACITY 34,000,000 ACRE-FEET			
Maximum pressure upstream face	30.9	15.4	36.1
Maximum pressure downstream face	30.9	31.0	36.6
Maximum required sliding factor	.49	.63	.62
RESERVOIR CAPACITY 10,000,000 ACRE-FEET			
Maximum pressure upstream face	22.9	11.5	25.4
Maximum pressure downstream face	22.7	22.9	23.6
Maximum required sliding factor	.43	.58	.54

The section and pressure diagram for the larger dam are shown on drawing 45-C-457.

With reference to allowable foundation pressures Mr. Wiley states in paragraph 29 of his letter of November 27, 1923:

It does not seem feasible to build any type of masonry dam of the necessary height for effective storage on the soft sandstone at Glen Canyon, at least no type or height requiring maximum pressures of more than 20 tons per square foot should be used.

([1] Vol. 6 p. 28)

From the studies which have been made it appears that if the above condition is fulfilled it is not feasible to build a gravity dam at the Lees Ferry site for a reservoir capacity of 10,000,000 acre-feet or more unless it would be possible to reduce the pressures through the use of some sort of hollow or perforated construction instead of following the usual practice in designing gravity dams. It is questionable, however, if any "freak design" would be approved for a dam of such unprecedented height and where the integrity of the dam is of such great importance.

In all cases the estimates assume that it will be necessary to remove foundation and abutment rock to a depth of 20 feet to insure a sound foundation.

As indicated by the stress diagrams each section has been investigated with water passing over the top and found to satisfy all assumed conditions with a depth of 21 feet on the roadway. A greater depth could probably pass over with safety. The estimates submitted are for dams with the minimum pressures obtainable as above indicated.

([1] Vol. 6, pp. 3–4)

It is believed that the foundation rock is capable of safely carrying the pressure of 22½ tons per square foot but no more. It therefore follows that construction of the higher concrete dam would not receive the approval of the engineering department of the Bureau of Reclamation.

The concrete dams have been designed to pass rare floods of exceptional discharge over the top. This plan materially increases the nominal storage capacity of the reservoir and particularly the flood-control reserve.

A departure from the Boulder Canyon design is found in the apron at the lower toe of the dam, which is here considered necessary by reason of the comparatively soft foundation stone.

([1] Vol. 6, p. 34)

OUTLET WORKS

The plan is the same as used for the Boulder Canyon Dam, 7½-foot conduits lined with 1½-inch steel passing through the dam and discharging through 72-inch needle valves at the lower face of the dam. Each conduit is provided with a 5 by 9 foot hydraulic operated emergency gate at the upper end. Trash racks are provided at the upstream face and arranged for mechanical raking.

([1] Vol. 6, p. 36)

The maximum irrigation demand is assumed as 30,000 second-feet. Capacity curves, velocity tables, and working heads are shown upon the drawings. It will be noted, in case of the concrete dam for the 34,000,000 acre-foot reservoir, that—

(*a*) The lower set of valves begin discharging with 1,500,000 acre-feet in the reservoir.

(*b*) With 5,000,000 acre-feet in the reservoir (W. S. at top of silt storage) the discharge is 29,000 second-feet.

(*c*) The upper set begin discharging at the time the lower set are carrying 32,000 second-feet.

(*d*) The upper set with full reservoir will discharge 47,000 second-feet under a head of 257 feet.

(*e*) Both sets with full reservoir will discharge 100,000 second-feet with maximum head 407 feet.

([1] Vol. 6, pp. 36–37)

In the estimates it is assumed that all needle valves for any one dam are of the same design, although the head on the two tiers is different, in order that they may be interchangeable. In an emergency a valve from the upper tier might replace one in the lower tier while the latter was being repaired.

([1] Vol. 6, pp. 40–51)

CONSTRUCTION PLAN

The plan of cofferdams and diversion tunnels is the same as outlined for Boulder Canyon Reservoir except that tunnels do not by-pass the dam site but instead pass through the neck of the horseshoe bend made by the river and return water to the river near Lees Ferry. Three 35-foot tunnels with 18-inch concrete lining and 3,500 feet long are contemplated. The sequence of construction is also as outlined for Boulder Canyon Reservoir.

([1] Vol. 6, p. 20)

CONCRETE AGGREGATE

The sand as found along the river and in the upper portion of the channel filling is too fine for use in concrete other than to supply possible deficiency in "fines" in a natural or crushed sand. The coarser sand found in the lower portion of the channel may be found suitable.

The Jurassic sandstone is said to be entirely unsuitable for use in concrete either as sand, gravel, or plums. It therefore becomes necessary to go elsewhere than the dam site to obtain concrete materials.

The Geological Survey made an examination of samples of sandstone taken from the canyon walls by a board of engineers in December, 1922, and in report of October 6, 1923, it is stated:

([1] Vol. 6, p. 21)

The sandstone Nos. 48915, 48916, and 48917 are apparently of no value on account of their lack of cementing material and high porosity.

Glen Canyon sandstone: Light red, fine grained, porous, soft sandstone. There is very little cementing material and consequently little coherence. Some soft, clayey cementing material may have been lost during grinding of the thin section for microscopic study. The presence of such material is very objectionable. Traces of calcite and of kaolinized material are present. It will probably not weather well if continually saturated with water, chiefly on account of lack of cementing material and partly on account of the possible presence of a deleterious mineral, leverrierite.

Considerable gravel occurs at the mouth of Paria River, immediately below Lees Ferry, but it is doubtful if in sufficient quantity for the construction of a large dam. It probably could be used in the preliminary work of lining diversion tunnels, etc., if found to be suitable.

Crushed rock may be obtained from either of two sources: (*a*) The Shinarump conglomerate, which occurs in the vicinity of Lees Ferry and along the east side of Paria River in a layer about 40 feet thick of moderately coarse gray sandstone with lenses of conglomerate with hard, well rounded, silicious pebbles; (*b*) the cherty Kaibab limestone, which occurs in large quantities about 2 miles downstream from Lees Ferry. The formation is about 250 feet thick and it is said that there are numerous places where quarrying can be done economically.

([1] Vol. 6, p. 23)

In the accompanying estimates it has been assumed that sand and gravel for concrete used in the diversion works may be obtained from the gravel bars at the mouth of the Paria. Concrete materials going into the main dam, whether concrete or rock fill, and into the spillway for the rockfill dams are assumed to be manufactured from the Kaibab limestone. It is probable that the conglomerate could be converted to gravel and sand more economically. Upon the other hand it is located at the elevation of the river, while the limestone quarries could be at a higher elevation, resulting in a more economical delivery to the mixers at the top of the dam. It is believed that material may be obtained from either source at about the same cost "in concrete," and it will undoubtedly be desirable to mix the product from the two sources.

RAILROAD TO LEES FERRY

([1] Vol. 6, p. 52)

There are two possible railroad connections for a railroad to Lees Ferry: (*a*) From Cedar City, Utah, the end of a branch line of the Union Pacific leaving the main line (Los Angeles & Salt Lake Railroad) at Lund, Utah; (*b*) from Flagstaff or Bellmont on the Atchison, Topeka & Santa Fe Railroad.

The distance is apparently about the same, but as the country to the south seems to be less difficult the latter connection has been assumed in the estimate.

([1] Vol. 6, p. 53)

The proposed location, in a general way, follows the wagon road to Lees Ferry, 138 miles from Flagstaff or 133 miles from Bellmont. On the Flagstaff quadrangle sheet there is shown a railroad from Bellmont to Wild Bill's Ranch, 5 miles north. The suitability of this road for use as a portion of the road to Lees Ferry is not known. No location surveys have been made, as far as known. Distances and grades used in the estimates were obtained by scaling on the topographic sheets which are shown to a scale of about one-fourth inch to the mile. It should be recognized that the estimates are based upon very meager data, and that an actual survey would undoubtedly lead to the adoption of a different alignment and result in an estimated cost varying considerably from that shown.

The estimates assume a standard-gage railroad built on a maximum grade of 3 per cent with 85-pound steel laid on 7 inch by 9 inch by 8½ feet green fir ties, without ballast except where the track is laid on solid rock.

([1] Vol. 6, p. 54)

Although not essential, it would be desirable to deliver materials for the dam at the elevation of its crest. An inspection of the topographic map and of pictures indicates that the construction of a railroad along the river from Lees Ferry to the dam site would be impracticable. Two schemes were considered by which material could be delivered at the dam site above reservoir level. In the first it was assumed that the railroad would extend up the south (east) side of the river at Lees Ferry at about elevation 4,000 feet to a point opposite the quarry track tunnel which will be discussed later. Material would be transferred across the river to cars on the quarry track by cableways of large capacity, but the necessary span would be about 4,000 feet, which is impracticable. In the second scheme it was assumed that it would be possible to construct 8 miles of track from about mile 125 to mile 15 on the quarry track, crossing the Colorado River just below the mouth of the Paria River. This plan is considered the better for the reason that material and equipment could be delivered at the dam site without transfer. Its feasibility depends upon a practicable crossing of the river. In regard to this point it seems to be Mr. LaRue's opinion that near Lees Ferry bed rock extends across the channel at the surface, which, if true, would simplify the construction of a railroad bridge. In either case the cost would be about the same, since the cost of the bridge would be offset partially by the cable installation. The required length of track is practically the same in either case.

RAILROAD FROM DAM SITE TO ROCK QUARRY

([1] Vol. 6, p. 55)

The estimates are based upon the assumption that rock for the manufacture of concrete aggregate or for the rock fill dams will be obtained at the head of Marble Canyon. On account of the large amount of material to be hauled it is proposed to build a double track, standard-gauge railroad from the dam site to the rock quarries.

Beginning at a point 1,000 feet downstream from the axis of the dam the line is built along the south (west) side of Glen Canyon at the elevation of the top of dam, for about one-half mile. Continuing thence at a -1 per cent grade through a tunnel 1,750 feet in length and along the north side of Paria Canyon to mile 9½, where the Paria is crossed at about elevation 3,270. From the Paria crossing the line runs on a nearly level grade to the assumed limestone quarries at mile 18½. If it is desired to reach the gravel beds at the mouth of the Paria a line could be built down the west bank of that stream.

RIGHT OF WAY

([1] Vol. 6, p. 56)

There is no definite information relative to right-of-way matters. It is believed that the reservoir occupies a portion of the Colorado and San Juan Rivers which is practically uninhabited. A nominal sum, however, has been allowed in the estimates to adjust claims which no doubt will be presented.

([1] Vol. 6, p. 57)

UNIT COSTS

CEMENT

Cost at mill (Riverside, Calif.)	per barrel	$2.00
Freight to Bellemont	do	.84
Freight, Bellemont to dam (1½ cents ton-mile)	do	.38
Handling	do	.13
		3.35

ROCK IN TEMPORARY ROCK-FILL COFFERDAMS

Source of material—Sandstone of the canyon walls at dam site

Quarrying and loading rock into skips on cars:	
Drilling and blasting ..... per cubic yard..	$0.45
Mucking, including derricks, steam shovel, and hand ..... do....	.70
Power ..... do....	.05
Repairs and supplies ..... do....	.10
Plant depreciation ..... do....	.20
Total, by solid measurements ..... do....	1.50

([1] Vol. 6, p. 58)

Rock is soft sandstone, which it is assumed will break up and pack very tightly when dropped from cableways. If swell in the completed fill is assumed as 35 per cent (26 per cent voids) the resulting quarrying cost of rock measured in the fill is ..... per cubic yard..	$1.10
Hauling to cableways ..... do....	.15
Placing by cableways ..... do....	.15
Total estimated cost in the dam ..... do....	1.40

([1] Vol. 6, pp. 60–64)

GRAVEL AND COBBLES FOR CONCRETE IN DIVERSION WORKS

Source of material—Gravel beds at mouth of Paria River

Steam-shovel operations ..... per cubic yard..	$0.15
Hauling to screening plant ..... do....	.15
Operation screening plant ..... do....	.25
Plant depreciation ..... do....	.15
Hauling to mixing plant at river grade ..... do....	.20
Total estimated cost in bins at auxiliary plant ..... do....	.90

SAND FOR CONCRETE IN DIVERSION WORKS

Assuming 50 per cent natural sand mixed with 50 per cent crushed conglomerate.

Source of material—Gravel beds and rock at mouth of Paria River

Natural sand same as gravel ..... per cubic yard..	$0.90
Crushed conglomerate:	
Quarrying and loading rock at $1.50 per cubic yard solid, 35 per cent voids ..... per cubic yard..	.97
Hauling to crushing plant ..... do....	.15
Operation crushing plant, crushing ..... do....	.25
Rolling ..... do....	.40
Depreciation ..... do....	.20
Hauling to mixing plant ..... do....	.20
Total crushed sand ..... do....	2.17
Total estimated cost mixed sand in bins at auxiliary mixing plant ..do....	1.55

CRUSHED GRAVEL FOR CONCRETE IN STRUCTURES OTHER THAN DIVERSION WORKS

Source of material—Limestone in Marble Canyon or conglomerate east side of Paria River

Quarrying and loading rock at $1.50 per cubic yard solid, 40 per cent voids in concrete ..... per cubic yard..	$0.90
Hauling to crushing plant ..... do....	.15
Operation crushing plant ..... do....	.25
Plant depreciation ..... do....	.15
Hauling to mixing plant, 19 miles at 1 cent per ton-mile, 2,700 pounds per cubic yard ..... per cubic yard..	.25
Total estimated cost of gravel in bins at mixing plant ..... do....	1.70

CRUSHED COBBLES FOR CONCRETE IN ALL STRUCTURES OTHER THAN DIVERSION WORKS

Source of material—Limestone in Marble Canyon or conglomerate east side of Paria River

Quarrying and loading rock at $1.50 per cubic yard solid, 50 per cent voids per cubic yard	$0.75
Hauling to crushing plant do	.15
Operation crushing plant do	.20
Plant depreciation do	.15
Hauling to mixing plant, 19 miles at 1 cent per ton-mile, 2,100 pounds per cubic yard per cubic yard	.20
Total estimated cost of crushed cobbles in bins at mixing plant per cubic yard	1.45

CRUSHED SAND FOR CONCRETE IN ALL STRUCTURES OTHER THAN DIVERSION WORKS

Source of material—Limestone in Marble Canyon or conglomerate east side of Paria River

Quarrying and loading rock at $1.50 per cubic yard solid, 35 per cent voids per cubic yard	$0.97
Hauling to crushing plant do	.15
Operation crushing plant:	
Crushing do	.25
Rolling do	.40
Depreciation do	.20
Hauling to mixing plant, 19 miles at 1 cent per ton-mile, 3,000 pounds per cubic yard per cubic yard	.28
Total estimated cost of crushed sand in bins at mixing plant per cubic yard	2.25

MIXING AND PLACING CONCRETE

Mixing:		
Operation per cubic yard		$0.10
Power do		.05
Repairs do		.08
Water do		.02
Depreciation do		.15
Total do		.40
Cableway haul:		
Operation do		.12
Power do		.05
Repairs do		.05
Depreciation do		.18
Total do		.40
Placing on dam:		
Cleaning and placing do	.30	
Pumping and lighting do	.10	
Miscellaneous do	.05	
Total per cubic yard		.45
Total estimated cost do		1.25

CONCRETE DATA

([1] Vol. 6, pp. 65–66)

In the estimates for the concrete dams it is assumed that plums will be added in the form of comparatively large cobbles put through the mixers. It is probable that the equipment will be large and that the cobbles will range in size from 6 to 12 inches. The following table is the basis upon which the quantities have been calculated:

Material	Parts cubic feet	Voids		Solids, cubic feet	Swell, cubic feet	Volume, cubic feet	Specific gravity	Weight		Quantity, per cubic yard, concrete
		Per cent	Cubic feet					Per cubic foot	Total	
										Barrels
Cement	1					1.00			100	1.63
										Cubic yards
Sand	2½	33⅓	0.83	1.67	0.17	2.67	2.65	165	275	0.35
Gravel	5	[1] 40	2.00	3.00	.67	4.67	2.65	165	495	.72
Cobbles	2½	50	1.25	1.25	4.42	6.92	2.65	165	206	.35
Total						6.92		[2] 155	1,076	

[1] Crushed gravel loose will probably contain 45 per cent voids. Assumed reduced to 40 per cent by shaking and ramming during placing of concrete.

[2] Actual weight will probably be about 95 per cent of computed weight or 147 pounds per cubic foot. In the design the weight is assumed as 150 pounds.

Colorado River Storage, Lees Ferry Dam—Lower Site, Curved Gravity Type With Apron

([1] Vol. 6, pp. 87–97, 120–123. Feb. 1, 1924)

Maximum pressure 30 tons per square foot by Cain's Theory: 34,000,000 acre-feet flood control and irrigation reservoir:

Top of parapet, elevation, 3,747 feet. Raise in W. S. 605 feet.

Top of dam elevation, 3,742 feet. Radius of axis, 1,100 feet.

Normal W. S. elevation, 3,732 feet. Outlet capacity W. S. elevation 3,732: 100,000 second-feet.

Preliminary estimate based on meager data

[Probably to be increased in accordance with report on Black Canyon Dam. (See p. 53.)]

Item	Quantity	Unit cost	Item cost	Feature cost
Diversion works: [1]				
Excavation—				
Class I and II at portals	10,000 cubic yards	$1.00	$10,000.00	
Class III. Main tunnels	472,000 cubic yards	6.00	2,832,000.00	
Class III. Muck tunnels	5,200 cubic yards	8.50	44,200.00	
Class III. Subsequent removal of tunnel lining to place closing plugs	3,000 cubic yards	8.00	24,000.00	
Timbering (7,200 linear feet)	3,580 M board measure	96.00	343,680.00	
Cofferdam at tunnel entrance	900 linear feet	425.00	382,500.00	
Concrete tunnel lining 18 inches (1:2½:5 mix)	73,900 cubic yards	12.50	923,750.00	
Tunnel plugs (1:2½:5:2½ mix)	20,000 cubic yards	9.50	190,000.00	
Grouting plugs, 3	450 linear feet	16.00	7,200.00	
Closing tunnel portals			[2] 25,000.00	
Upper temporary cofferdam—				
Rock fill (25 per cent waste)	500,000 cubic yards	1.40	700,000.00	
Earth mattress	39,000 cubic yards	1.00	39,000.00	

[1] Temporary diversion 100,000 second feet; permanent diversion 150,000 second feet; diversion tunnels, 3 25-foot horseshoe tunnels 2,700 feet long.

[2] Lump sum.

Preliminary estimate based on meager data—Continued

Item	Quantity	Unit cost	Item cost	Feature cost
Diversion works—Continued.				
Lower temporary cofferdam—				
Rock fill (35 per cent waste)	220,000 cubic yards	$1.40	$308,000.00	
Earth mattress	20,000 cubic yards	1.00	20,000.00	
Permanent cofferdam—Excavation included with dam.				
Concrete in permanent cofferdams, excess of cost over cost of concrete in balance of dam.	496,000 cubic yards	.75	372,000.00	
Pumping			[1] 100,000.00	
Total—Diversion works				$6,456,530.00
Dam:				
Excavation—				
Class I. Sand and silt—dam	809,000 cubic yards	.50	404,500.00	
Class I. Sand and silt—apron	135,000 cubic yards	.50	67,500.00	
Class II. Gravel and bowlders—dam.	710,000 cubic yards	2.00	1,420,000.00	
Class II. Gravel and bowlders—apron.	120,000 cubic yards	2.00	240,000.00	
Class III. Dam base (below elevation 3127).	411,000 cubic yards	5.00	2,055,000.00	
Class III. Apron	44,800 cubic yards	5.00	224,000.00	
Class III. Dam abutments	424,000 cubic yards	2.50	1,060,000.00	
Class III. Cut-off trench	38,700 cubic yards	5.00	193,500.00	
Total excavation			5,664,500.00	
Grouting and drainage foundation—				
Drilling 3-inch grout holes	17,200 linear feet	3.00	51,600.00	
Drilling 3-inch drain holes	7,700 linear feet	3.00	23,100.00	
Grouting	460 holes	100.00	46,000.00	
Miscellaneous drilling and grouting.			[1] 25,000.00	
Gate valves (36 inch), 2, at 5,000 pounds.	10,000 pounds	.25	2,500.00	
Pumps, 2, at 1,600 pounds	3,200 pounds	.25	800.00	
Drain covers	5,400 pounds	.10	540.00	
Freight	18,600 pounds	.014	260.00	
Installation	18,600 pounds	.02	372.00	
Total grouting and drainage			150,172.00	
Concrete in dam (1:2¼:5:2¼ mix)	8,560,000 cubic yards	8.25	70,620,000.00	
Apron (1:2¼:5:2¼ mix)	178,000 cubic yards	9.25	1,646,500.00	
Parapets (1:2¼:5 mix), 1,483 linear feet, concrete in place.	925 cubic yards	24.75	22,894.00	
Lighting—				
Lamps and pedestals	6	500.00	3,000.00	
Wiring and small fixtures in galleries on top.			[1] 10,000.00	
Total dam				78,117,066.00
Outlet works:				
Trash racks for permanent outlets—Concrete piers (1:2¼:5 mix).	25,100 cubic yards	31.75	796,925.00	
Concrete balcony, elevation 3,742 (1:2¼:5 mix).	460 cubic yards	34.50	15,870.00	
Concrete platforms, elevation 3,460 and 3,312 (1:2¼:5 mix).	612 cubic yards	31.50	19,278.00	
Guniting beams	2,200 beams	9.25	20,350.00	
Trash rack metal—Beams, 2,200 at 40 pounds per linear foot.	1,190,000 pounds	.06	71,400.00	
Rails, 2,200 at 10 pounds per linear foot.	220,000 pounds	.06	13,200.00	
Grooves, 88,000 feet of 7 inches by 16.4 pounds ship channels.	1,440,000 pounds	.06	86,400.00	
Grills, 22,000 linear feet at 224 pounds.	4,940,000 pounds	.06	296,400.00	
Anchor bolts	39,500 pounds	.08	3,160.00	
Cover plates and accessories	102,400 pounds	.08	8,192.00	
Freight and installation	7,931,900 pounds	.034	269,681.00	
Railing—				
2½-inch pipe in place	1,520 linear feet	.50	760.00	
Fittings (1 per 10 linear feet)	152 fittings	.50	76.00	
Total, trash racks for permanent outlets.			1,601,696.00	

[1] Lump sum.

Preliminary estimate based on meager data—Continued

Item	Quantity	Unit Cost	Item cost	Feature cost
Outlet works—Continued.				
Trash racks for sluices—Concrete piers (1:2¼:5 mix).	4,240 cubic yards	$34.25	[illegible]	
Concrete platforms, elevation 3,102 (1:2¼:5 mix), same as 22.5-ton dam.	144 cubic yards	32.75	4,716.00	
Guniting beams	160 beams	9.25	1,480.00	
Trash rack metal—				
Beams, 160 at 40 pounds per linear foot.	88,000 pounds	.06	5,280.00	
Rails, 160 at 10 pounds per linear foot.	16,300 pounds	.06	978.00	
Grooves, 6,400 feet at 7 inches by 16.4 pounds ship channels.	105,000 pounds	.06	6,300.00	
Grills, 1,600 linear feet at 224 pounds.	358,000 pounds	.06	21,480.00	
Anchor bolts	2,660 pounds	.08	213.00	
Freight and installation	569,950 pounds	.034	19,378.00	
Total, trash racks for sluices.			165,070.00	
Permanent outlet conduits—				
Semisteel lining, 10,600 linear feet in place.	22,300,000 pounds	.115	2,564,535.00	
Bolts	22,300 pounds	.08	1,784.00	
Grouting behind lining	10,600 linear feet	5.00	53,000.00	
Total			2,619,842.00	
Sluice outlet conduits—				
Semisteel lining, 1,440 linear feet in place.	2,420,000 pounds	.115	278,290.00	
Bolts	2,400 pounds	.08	192.00	
Grouting behind lining	1,440 linear feet	5.00	7,200.00	
Total			285,682.00	
Permanent outlet control—				
Slide gates (17), 5 by 9 feet at 65,000 pounds.	1,110,000 pounds	.25	277,500.00	
Slide gates (16), 5 by 9 feet at 70,000 pounds.	1,120,000 pounds	.25	280,000.00	
Pressure pump system in place.	2 units	14,000.00	28,000.00	
Needle valves (33), 72 inches.	4,950,000 pounds	.24	1,188,000.00	
Freight and installation	7,180,000 pounds	.034	244,120.00	
Total			2,017,620.00	
Sluice gates—				
Slide gates (8), 6 by 6 feet at 60,000 pounds.	480,000 pounds	.25	120,000.00	
Pressure pump system in place.	1 unit	5,500.00	5,500.00	
Freight and installation	480,000 pounds	.034	16,320.00	
Total, sluice gates			141,820.00	
Closing sluiceways—				
Lower tier—				
Closing entrance	Lump sum		100.00	
Preparing surface	6,400 linear feet	4.00	25,600.00	
Concrete in spheres (8), 7.5 feet diameter (1:2¼:5 mix; same as 22.5 ton dam.	65 cubic yards	24.75	1,609.00	
Concrete for plugs (1:2¼:5 mix).	6,720 cubic yards	18.25	122,640.00	
Pressure grouting	6,400 linear feet	5.00	32,000.00	
Upper tier—				
Preparing surface	5,120 linear feet	4.00	20,480.00	
Concrete for plugs (1:2¼:5 mix).	5,370 cubic yards	18.25	98,002.00	
Pressure grouting	5,120 linear feet	5.00	25,600.00	
Total, closing sluiceways			325,031.00	

Preliminary estimate based on meager data—Continued

Item	Quantity	Unit cost	Item cost	Feature cost
Outlet works—Continued.				
Track and crane—				
Track, 1,460 linear feet, at 50 pounds.	73,000 pounds	$0.032	$2,336.00	
Accessories	2,180 pounds	.08	174.00	
Locomotive crane	200,000 pounds	.20	40,000.00	
Freight and installation	275,180 pounds	.034	9,357.00	
Total, track and crane			51,867.00	
Elevator—				
F. o. b. factory, 3 at 20,000 pounds.	60,000 pounds	1.00	60,000.00	
Freight and installation	do	.034	2,040.00	
Total, elevators			62,040.00	
Total, outlet works				$7,271,638.00
Spillway:				
Concrete—				
Parapets, abutment sections to keep overflow from sidewalls (1:2¼:5 mix).	8,200 cubic yards	26.00	213,200.00	
Elevator towers and shafts (1:2¼:5 mix).	2,700 cubic yards	41.50	112,050.00	
Roadway in abutment sections (1:2¼:5:2¼ mix).	3,000 cubic yards	9.50	28,500.00	
Eagles and bases	2 sets	10,000	20,000.00	
Railing			120.00	
Total spillway				373,870.00
Railroad—Bellmont to Lees' Ferry, 133 miles standard gauge:				
Grading and surfacing—				
Level country	46 miles	15,000.00	690,000.00	
Average country	62 miles	35,000.00	2,170,000.00	
Rough country	25 miles	58,000.00	1,450,000.00	
Track, main line—				
Rail, 85-foot	17,770 gross tons	72.00	1,279,440.00	
Angle bars	20,590 hundredweight	4.00	82,360.00	
Track bolts	2,011 hundredweight	5.50	11,060.00	
Spikes	8,250 hundredweight	4.25	35,062.00	
Ties, 7 by 9 inches by 8 feet 6 inches, untreated.	351,100 each	1.60	561,760.00	
Tracklaying	133 miles	500.00	66,500.00	
Total track, without ballast.	do	15,300.00	2,034,900.00	
Ballast and ballasting	20 miles	3,500.00	70,000.00	
Subterminal at Little Colorado River, water and coaling stations.	1		20,000.00	
Sidetracks, including switches.	2 miles	31,500.00	63,000.00	
Buildings	5		6,700.00	
Other main-line stations—				
Sidetracks and station buildings.	11 units	35,400.00	389,400.00	
Terminal yards	2 units	70,000.00	140,000.00	
Bridges and culverts—				
Little Colorado River, 400 feet, steel.			127,000.00	
Other bridges and culverts	133 miles	3,000.00	399,000.00	
Telegraph line	do	600.00	79,800.00	
Right of way through 20 miles improved land, including fencing railroad from rock quarry to dam, 18.5 miles standard gauge, double track.	20 miles	7.50	15,000.00	
Railroad dam to quarry	18.5 miles			
Grading and surfacing—				
3 miles solid rock	340,000 cubic yards	1.25	425,000.00	
Average country	8.5 miles	50,000.00	425,000.00	
Rough country	7 miles	85,000.00	595,000.00	
Tunnel, 29 by 22 feet 5 inches, 1,750 feet long—				
Excavation	45,000 cubic yards	6.00	270,000.00	
Timbering	1,750 linear feet	40.00	70,000.00	
Rail, fittings, ties, and track laying, double track.	15.5 miles	32,500.00	503,750.00	

Preliminary estimate based on meager data—Continued

Item	Quantity	Unit cost	Item cost	Feature cost
Rail, fittings, ties, tracklaying, ballasting, double track.	3 miles	$37,700.00	$113,100.00	
Bridges and culverts—				
Paria Canyon trestle			15,000.00	
Small structures	18.5 miles	3,000.00	55,500.00	
Telephone line	do	600.00	11,100.00	
Terminal yard			70,000.00	
Roundhouse, coal chute, etc			40,000.00	
Sidings, station, buildings, etc			70,800.00	
				$10,319,050.00
Construction camp				500,000.00
Permanent improvements:				
Operators quarters			60,000.00	
Power plant for local use			15,000.00	
				75,000.00
Right of way, reservoir				300,000.00
Total field cost				102,413,154.00
Administration, engineering, and contingencies, 22¼ per cent.				23,267,960.00
Total estimated cost exclusive of interest during construction.				126,681,114.00
Roughly				126,500,000.00

ROCK-FILL DAM

DESIGN

([1] Vol. 6, p. 28)

The river trench is filled with sand and gravel with very few bowlders. It is essential that a rock-fill dam of the height proposed must rest on a foundation that is at least as unyielding as the rock fill of which the dam is built. It has, therefore, been assumed that all the trench filling down to bedrock under the entire base of the dam will be excavated before placing the rock fill.

The following is quoted from Mr. Wiley's letter of November 27, 1923:

([1] Vol. 6, p. 30)

It seems reasonable to assume that some type of rock-fill dam can be built at Glen Canyon of any necessary height or up to 30,000,000 acre-feet capacity. Such a dam should be founded entirely on bedrock, should be built of some better material than the local sandstone, such as the limestone from Marble Canyon, and should have a concrete face, there being no local material available either for a puddle core or puddle face.

([1] Vol. 6, p. 31)

The design of the section adopted for estimating the cost of rock-fill dams for both the 10,000,000 and 34,000,000 acre-feet reservoirs is shown in drawings 45–C–475 and 45–C–488. It will be noted that the smaller structure is so built that it may be raised if found to be desirable at a later date. The end sought in the design is to provide an impervious face supported by construction varying gradually in flexibility from concrete to loose rock. The concrete face is on a 1:1 slope, varies in thickness from 20 feet at the bottom to 4 feet at the top, and is to be reinforced with 1¼-inch square bars at 12-inch centers horizontally and 1-inch bars at 24-inch centers vertically embedded 12 inches from the water face. It is proposed to pour the concrete against the rubble masonry with vertical joints about 25 feet apart, the horizontal steel to pass through the joints. The joints will allow for some adjustment in the fill. No satisfactory detail has been worked out for the apparently necessary flexible joint between the rock abutment and the concrete face of the dam. The rubble masonry is to be of large rock (6 to 10 tons) laid in Portland cement mortar and chinked with spalls. This, with the concrete face, produces a comparatively thick water-tight face. Due to the jointing in the masonry it should be somewhat more flexible than the face concrete. The masonry is backed up by an equal thickness of dry rubble of large rock, which in turn is supported by the loose rock fill. The downstream slope is somewhat flatter than is customary. The flatter slope, with berms 100 feet apart vertically, was adopted to insure greater safety. In a rock-fill dam there is a tendency for the rock to "crunch" or roll out from under the load and it is thought that the berms will guard against this to a certain degree.

In the type of dam proposed all of the rock in the structure is effective at its full weight in resisting the water pressure which would not be true of a dam with a center core wall. Upon the other hand, a vertical core wall might be less effected by settlement in the fill than concrete laid on the upstream face.

([1] Vol. 6, p. 32)

It has not been considered necessary to completely fill the interstices in the loose rock fill at Lees Ferry. The procedure would be expensive as there is apparently no suitable material to be found in its natural state in the vicinity of the dam site, and crushing would have to be resorted to.

([1] Vol. 6, p. 33)

It is proposed to shake and settle the loose rock as much as possible by playing jets from hydraulic giants on the fill during the entire time rock is being placed. It is thought that this, together with the compacting affected by dropping the rock from cableways, will produce an excellent fill and one which will be comparatively free from excessive settlement.

MATERIAL FOR ROCK FILL

([1] Vol. 6, p. 22)

The Jurassic sandstone at the dam site is too soft to make a good building stone. The nearest suitable rock is the Kaibab limestone below Lees Ferry.

([1] Vol. 6, p. 29)

According to Mr. Bryan, the only source of material in the vicinity of the dam site for filling the interstices of a rock fill (and the same is assumed to be true of the earth portion of an earth-rock fill dam) is the Moenkopi formation (sandy shale with gypsum), the base of the Chinle formation (shales), and the landslide material south of Lees Ferry. All would have to be crushed and graded. The first two contain soluble salts. The latter is probably the most suitable as it is Mr. Bryan's opinion that, after crushing, a mixture of disintegrated shale and leached sandstone would result having a texture similar to loam. Its use would prove expensive and, lacking experimental data, there is no assurance that it is suitable. For this reason a type of rock-fill dam has been adopted in the estimates which is constructed entirely of rock and concrete.

In large masses the sandstone of the canyon walls in its natural state resists great loads. However, as pointed out by Mr. Bryan, in a rock fill some of the blocks will be forced to bear very heavy loads while resting on a point rather than on a flat surface. Such rocks would undoubtedly be crushed. Moreover, a stated by Doctor Ransome in board report of December 20, 1922, it is believed that the disintegration of the soft sandstone in the fill would result in a settlement greater in proportion than ordinarily occurs in rock fill dams.

In the accompanying estimates, it has been assumed that sand and gravel for concrete used in the diversion works may be obtained from the gravel bars at the mouth of the Paria. Concrete materials going into the main dam, whether concrete or rock fill, and into the spillway for the rock-fill dams are assumed to be manufactured from the Kaibab limestone.

OUTLET WORKS

([1] Vol. 6, p. 35)

Waters would be conveyed around one end of the dam by means of a 40-foot diameter pressure tunnel lined with reinforced concrete and supplied by three vertical intake tunnels, each fitted with three large cylinder gates at varying levels, and these in turn supplied by horizontal intake tunnels leading into the canyon wall from a trash rack structure extending the full depth of anticipated reservoir operation. Water would be conveyed from the pressure conduit to 72-inch needle valves on the face of the cliff through 7½-foot diameter, steel-lined conduits.

While a shorter conduit tunnel could be obtained by piercing the "neck" of rock at the base of the loop of the river, such a plan would involve placing the tunnel and valves in the Chinle formation which would not be desirable.

SPILLWAY

([1] Vol. 6, pp. 40–41)

Each of four drum gates each 104 feet long by 25 feet high will discharge into a 35 concrete-lined tunnel 2,325 feet long passing through the neck at the base of the river bend. When raised the gates would have a crest 10 feet below top of dam and at the top of flood-control storage. Their capacity would be 180,000 second-feet with water 10 feet below top of dam and 300,000 second-feet with water at the top of the dam. While it would be feasible to connect the gates with the diversion tunnels and so avoid much new tunnel construction for spillway purposes, such a plan has been discarded owing to high tunnel velocities that would result.

CONSTRUCTION PLAN

([1] Vol. 6, p. 45)

In constructing a rock-fill dam, no chances of overtopping may deliberately be taken as with a concrete dam, and the diversion works have therefore been planned for a capacity of 200,000 second-feet by means of six concrete-lined 35-foot diameter tunnels, each 3,850 feet long, passing through the "neck" of the river bend. The cofferdams would be built as for the concrete dam except that a lighter cofferdam would be provided below the main dam.

([1] Vol. 6, p. 51)

In case of the rock-fill dams the procedure of plugging the diversion tunnels would be about the same as in case of the concrete dams except that the conduits would be built in the tunnel plugs themselves. In this case six tunnels are proposed. In low-water season four of them would be plugged, leaving both the conduits to be closed by means of a ball and these controlled by gates through the plugs. The remaining two diversion tunnels would be plugged while the discharge was carried by the conduits provided.

([1] Vol. 6, pp. 55, 56)

RAILROADS

The provisions are the same as for the concrete dam. In the case of the rock-fill dams it might be possible to utilize the spillway tunnels as railroad tunnels during construction. However, consideration of this plan leads to the adoption of a separate railroad tunnel. The spillway tunnels are depressed to create high velocities and are too low for use by the railroad. It is considered advisable to keep the railroad tunnel above the elevation of water surface in the reservoir in order that the dam may be accessible at all times, especially in emergency when it might be desirable to add rock to the structure in large quantities.

UNIT COSTS

([1] Vol. 6, p. 58)

ROCK IN LOOSE-ROCK PORTION OF MAIN ROCK-FILL DAMS

	Per cubic yard
Source of material—Limestone in Marble Canyon.	
Quarrying and loading into skips on cars:	
Same as that to obtain rock for temporary cofferdams	$1.50
It is assumed that 1 cubic yard solid rock will build 1½ cubic yards of rock fill dropped from cableways (33⅓ per cent voids). The resulting quarrying cost of rock measured in the fill is	1.00
Hauling to dam site 19 miles, at 1 cent per ton-mile, 3,000 pounds per cubic yard	.28
Placing by cableway	.15
Compacting by jets and miscellaneous	.10
Total estimated cost in the dam	1.53
Say	1.50

([1] Vol. 6, p. 59)

ROCK IN DRY-RUBBLE PORTION OF ROCK-FILL DAMS

Source of material—Limestone in Marble Canyon.	
Quarrying and loading onto cars:	
Large rock assumed at same price as smaller rock going into loose-rock fill since getting out 1 class of rock will require handling the other. Increased handling offset by less shooting	$1.50
It is assumed that by careful spalling voids can be reduced to 20 per cent. 1 cubic yard of rock in solid will therefore build 1¼ cubic yards rubble. The resulting quarrying cost of rock in the wall	1.20
Hauling 19 miles, at 1 cent per ton-mile, 3,600 pounds per cubic yard	.35
Transporting rock to work by cableway	.65
Placing—300 cubic yards per shift per derrick:	
Derrick operation—labor	1.25
Power	.05
Repairs and supplies	.15
Cableway service moving derricks, etc	.10
Plant depreciation	.30
Miscellaneous	.15
Total estimated cost in the dam	4.20

RUBBLE MASONRY PORTION OF ROCK-FILL DAM

([1] Vol. 6, p. 60)

Source of material—Limestone in Marble Canyon.	
Quarrying and loading:	
Same as for dry rubble	$1.50
It is assumed that the masonry will consist of 65 per cent rock and 35 per cent of 1:3½ mortar. Then 1 cubic yard of rock in the solid will build 1.54 cubic yards of dam. The resulting quarrying cost of rock in the dam	.97
Hauling 19 miles, at 1 cent per ton-mile, 3,000 pounds per cubic yard	.28
Transporting rock to work by cableway	.65
Placing—same as dry rubble	2.00
Total rock measured on dam	3.90
Mortar—1:3½ mix:	
0.35 cubic yard per yard of masonry—	
Cement 1.8 by 0.35 by 3.35	2.11
Sand 0.87 by 0.35 by 2.25	.69
Mixing and placing, including plant	1.25
Total mortar measured on dam	4.05
Total estimated cost masonry in dam	7.95
Say	8.00

Colorado River Storage

LEES FERRY DAM—LOWER SITE—ROCK-FILL TYPE

([1] Vol. 6, pp. 127–135)

[34,000,000 acre-feet flood control and irrigation reservoir]

Top of parapet elevation, 3,747 feet.
Top of dam elevation, 3,742 feet.
Normal water surface elevation, 3,732 feet.
Raise in water surface, 605 feet.

Outlet capacity, water surface elevation, 3,732 feet; 100,000 second-feet.
Spillway capacity, water surface elevation, 3,742 feet; 300,000 second-feet.

Preliminary estimate

[Probably to be increased in accordance with Colorado River board report. (See p. 53.)]

[Based upon meager data]

Item	Quantity	Unit cost	Item cost	Feature cost
Diversion works—200,000 second-feet: 6 25-foot lined horseshoe tunnels each 2,850 feet long:				
Portal excavation	25,000 cubic yards	$1.00	$25,000.00	
Main tunnel, excavation	1,023,000 cubic yards	6.00	6,138,000.00	
Muck tunnel, excavation	5,200 cubic yards	8.50	44,200.00	
Tunnel plug, excavation	6,000 cubic yards	8.00	48,000.00	
Timbering, 14,400 linear feet	7,120 M board measure	98.00	697,760.00	
Cofferdam at tunnel entrance	1,400 linear feet	425.00	595,000.00	
Tunnel lining concrete	154,000 cubic yards	12.50	1,925,000.00	
Tunnel plugs	37,500 cubic yards	9.50	356,250.00	
Grouting plugs	900 linear feet	16.00	14,400.00	
Closing tunnel portals			50,000.00	
			9,829,210.00	
Temporary cofferdams—				
Rock fill	720,000 cubic yards	1.40	1,008,000.00	
Earth mattress	59,000 cubic yards	1.00	59,000.00	
Pumping			100,000.00	
Total for diversion works				$10,996,210.00
Dam:				
Sand and silt excavation	1,400,000 cubic yards	.50	700,000.00	
Gravel and bowlders	1,130,000 cubic yards	2.00	2,260,000.00	
Rock above river level	159,000 cubic yards	2.50	397,500.00	
Rock below river level	130,000 cubic yards	5.00	650,000.00	
Total excavation			4,007,500.00	
Concrete face 1:2¼:5:2¼ mix, 6.62 pounds reinforcing per square foot	460,000 cubic yards	9.75	4,485,000.00	
Parapet concrete	685 cubic yards	28.25	19,351.00	
Rubble masonry backing, 65 per cent rock, 35 per cent mortar	2,220,000 cubic yards	8.00	17,760,000.00	
Dry rubble back	1,880,000 cubic yards	4.20	7,896,000.00	
Loose rock fill	18,400,000 cubic yards	1.50	27,600,000.00	
Lighting			5,000.00	
Total, dam				61,772,851.00
Outlet works:				
Towers—				
Excavation, open cut	21,600 cubic yards	1.50	32,400.00	
Excavations, shafts and tunnels	47,800 cubic yards	8.50	406,300.00	
Concrete—				
Shaft lining, plain	5,500 cubic yards	14.50	79,750.00	
Gate chamber, plain	1,600 cubic yards	14.50	23,200.00	
Columns, reinforced	400 cubic yards	32.50	13,000.00	
Inlet tunnels, plain	7,050 cubic yards	14.50	102,225.00	
Piers, reinforced	4,000 cubic yards	19.50	78,000.00	
Trash-rack piers, reinforced	8,700 cubic yards	31.75	276,225.00	
Trash-rack balcony, reinforced	160 cubic yards	34.50	5,520.00	
Gate houses, reinforced	1,000 cubic yards	31.50	31,500.00	
Pressure grouting	2,400 linear feet	11.00	26,400.00	
Gate-house fittings			1,000.00	
Guniting beams	816 each	9.25	7,548.00	
Trash-rack metal, in place (average)	2,899,200 pounds	.095	274,024.00	
Cylinder gates (average)	3,860,500 pounds	.236	913,913.00	
Track and crane (average)	211,635 pounds	.225	47,583.00	
Total, towers				2,318,590.00
Tunnel—				
Excavation, open cut	70,000 cubic yards	1.50	105,000.00	
Excavation, air shaft and galleries	26,600 cubic yards	8.50	226,100.00	
Excavation, tunnel	211,000 cubic yards	6.00	1,266,000.00	
Tunnel lining concrete	38,200 cubic yards	14.25	544,350.00	
Air-shaft and gallery lining	23,100 cubic yards	20.50	473,550.00	
Pressure grouting in tunnel	4,190 linear feet	18.50	77,515.00	
Pressure grouting shaft and galleries	8,220 linear feet	5.00	41,100.00	
Needle valves, in place	6,000,000 pounds	.27	1,620,000.00	
Semisteel lining	16,800,000 pounds	.12	2,016,000.00	
Pressure-pump system in place	2 units	14,000.00	28,000.00	
Drain gate, 6 by 6 feet	60,000 pounds	.28	16,800.00	
Semisteel lining to gate	420,000 pounds	.12	50,400.00	
Total, tunnel				6,464,815.00

Preliminary estimate—Continued

[Based upon meager data]

Item	Quantity	Unit cost	Item cost	Feature cost
Temporary outlets:				
Excavation, open cut	2,700 cubic yards	$1.50	$4,050.00	
Excavation, shaft and gallery	2,520 cubic yards	8.50	21,420.00	
Concrete, trash-rack piers, reinforced	2,100 cubic yards	24.25	50,925.00	
Steel lining in conduits	739,740 pounds	.115	85,062.00	
Grouting behind lining	440 linear feet	5.00	2,200.00	
6 by 6 feet slide gates	448,000 pounds	.284	127,232.00	
Pressure-pump system			5,500.00	
Trash-rack metal	315,000 pounds	.093	29,650.00	
Total temporary outlets				$326,029.00
Closing temporary outlets—				
Concrete plugs	4,780 cubic yards	18.25	87,2[illegible]	
Pressure grouting	3,250 linear feet	5.00	16,2[illegible]	
Preparing surface	2,800 linear feet	4.00	11,200.00	
Miscellaneous			1,709.00	
Total				116,394.00
Grand total outlet works				9,225,828.00
Spillway:				
Excavation, open cut	121,000 cubic yards	1.50	181,500.00	
Excavation, shafts	920 cubic yards	15.00	13,800.00	
Excavation, tunnels	411,000 cubic yards	6.00	2,466,000.00	
Concrete—				
In crests, light reinforced	7,900 cubic yards	14.25	112,575.00	
Piers, walls, etc., reinforced	10,400 cubic yards	21.75	226,200.00	
Transitions, reinforced	3,370 cubic yards	20.50	69,085.00	
Tunnel lining, plain	63,000 cubic yards	13.50	850,500.00	
Vents and drains	260 cubic yards	17.75	4,615.00	
Parapets	275 cubic yards	28.25	7,769.00	
Grouting tunnels	9,260 linear feet	8.00	74,080.00	
Back fill	5,000 cubic yards	.50	2,500.00	
Movable crests, in place	5,193,000 pounds	.14	706,200.00	
Valves and hoists	4 units	6,685	26,740.00	
4-foot pipe and fittings	209,437 pounds	.012	25,253.00	
Miscellaneous metal	85,774 pounds	.014	12,147.00	
Total, spillway				4,77[illegible],915.00
Railroad as for masonry dam				10,319,050.00
Construction camp				500,000.00
Permanent improvements:				
Quarters for attendants			60,000.00	
Power plant for local use			15,000.00	
				75,000.00
Right of way				300,000.00
Total field cost				[illegible],977,895.00
Administration, engineering, and contingencies, 22½ per cent.				[illegible],042,776.00
Total estimated cost exclusive of interest during construction.				[illegible],920,671.00
Roughly				[illegible],000,000.00

([1] Vol. 6, pp. 10–13)

Colorado River storage—Glen Canyon Reservoir—Concrete dams—Summary of preliminary estimates

[Comparative cost of reservoirs impounded by dams with various limiting foundation pressures at the lower Lees Ferry dam site. Nonoverflow gravity dams built on a curved plan. In estimates B and C the dam has been designed to produce the minimum possible foundation pressure for a dam of the given height. It is not believed that the foundation is good for more than 20 tons per square foot. Estimates based upon meager data.]

	A	B	C
Raise in water surface ... feet	413	413	605
Elevation, top of flood storage ... do	3,540	3,540	3,732
Limiting foundation pressure ... tons	30	22½	30
Total storage ... acre-feet	10,000,000	10,000,000	34,000,000
Diversion works (rock-fill cofferdams and three 35-foot horseshoe tunnels discharging (A and B) below cofferdams and (C) through neck of horseshoe bend in river (Q=100,000 second-feet))	$6,076,000	$6,125,000	$6,457,000
Dam (including excavation, concrete, grouting, draining, and lighting)	30,400,000	40,134,000	78,117,000

Colorado River storage—Glen Canyon Reservoir—Concrete dams—Summary of preliminary estimates

	A	B	C
Outlet works (metal-lined conduits through dam, discharge controlled by 27 (A and B) and 23 (C) 72-inch needle valves on downstream face)	$4,702,000	$5,453,000	$7,272,000
Spillway (extra to raise dam at abutments to allow abnormal floods to pass over dam)	292,000	292,000	374,000
Railroad (including 133 miles from Bellmont, near Flagstaff, to Lees Ferry, switching yards and spurs)	7,655,000	7,655,000	7,655,000
Construction railroad (from limestone quarries at head Marble Canyon to dam site, 18½ miles of double-track line)	2,664,000	2,664,000	2,664,000
Construction camp	500,000	500,000	500,000
Permanent improvements (grounds, operators' quarters, water supply, power plant for lighting and operating mechanism, etc.)	75,000	75,000	75,000
Right of way	200,000	200,000	300,000
Total estimated field cost	52,562,000	63,088,000	103,413,000
Administration, engineering, and contingencies, 22½ per cent	11,827,000	14,195,000	23,268,000
Total estimated cost (exclusive of interest during construction)	64,389,000	77,283,000	126,681,000
Roughly	64,500,000	77,500,000	126,500,000

The above estimates of the dams include a concrete apron or "bucket" at the downstream toe for the protection of the soft sandstone against possible flow over the top of the dam. On drawing 45–C–423 the apron is not shown, for the reason that it is not included in the design of the dam section as either producing or taking loads.

Colorado River storage—Glen Canyon Reservoir—Rock-fill dams—Summary of preliminary estimates

[Probably to be increased in accordance with Colorado River Board report. (See p. 53.)]

[Comparative cost of reservoirs impounded by dams at the lower Lees Ferry dam site, the smaller dam being so built that it can be raised later if found desirable. Estimmges based upon meager data. For comparison with concrete gravity dams of same height refer to estimates A, B, and C under Concrete Dams]

	A	B
Raise in water surface ... feet	413	605
Elevation, top of flood storage ... do	3,540	3,732
Total storage ... acre-feet	10,000,000	34,000,000
Diversion works (rock-fill cofferdams and six 35-foot horseshoe tunnels discharging through neck of horseshoe bend in river (Q=200,000 second-feet))	$10,996,000	$10,996,000
Dam (including excavation, loose-rock fill, dry rubble, rubble masonry, concrete, and lighting)	41,110,000	61,773,000
Outlet works (40-foot horseshoe pressure tunnel in rock around 1 abutment; entrance controlled by emergency cylinder gates; outlet controlled by forty 72-inch needle valves along canyon wall downstream from toe of dam)	8,406,000	9,226,000
Spillway (4 movable drum gates on concrete weir discharging into tunnels through neck of horseshoe bend in river to Lee Ferry (Q=300,000 second-feet))	5,404,000	4,779,000
Railroad (including 133 miles from Bellmont, near Flatstaff to Lee Ferry, switching yards, and spurs)	7,655,000	7,655,000
Construction railroad (from limestone quarries at head of Marble Canyon to dam site, 18½ miles of double-track line)	2,664,000	2,664,000
Construction camp	500,000	500,000
Permanent improvements (grounds, operators' quarters, water supply, power plant for lighting and operating mechanism, etc.)	75,000	75,000
Right of way	200,000	300,000
Total estimated field cost	77,011,000	97,968,000
Administration, engineering, and contingencies, 22½ per cent	17,327,000	22,043,000
Total estimated cost (exclusive of interest during construction)	94,338,000	120,011,000
Roughly	94,500,000	120,000,000

Marble Canyon Reservoir Site

A suggestion has been made that a dam be constructed in Marble Gorge rather than at Lees Ferry in order to take advantage of the narrower section. The following is quoted from Water Supply Paper No. 556, pages 52–53.

> The so-called bridge site is in Marble Gorge, 4½ miles below Paria River. Here the depth of the canyon is 400 feet and the distance between the walls at the top is but little more than 600 feet. The site is easily accessible from both sides of the river, and the conditions are favorable for the construction of a highway bridge at this point. (See p. 22.)
>
> In July, 1923, the writer made a thorough study of this locality to determine its suitability as a site for a storage dam to utilize the Glen Canyon Basin. For this purpose the water should be raised to an elevation of 3,513 feet above sea level. It was found that the walls at the bridge site are of sufficient height to permit the construction of such a dam. However, examination of the rock formations in the canyon with R. C. Moore, geologist, showed that the canyon walls at the bridge site include practically all of the Kaibab limestone and Coconino sandstone. It follows, therefore, that the river has cut through these formations and that its bed is now in the soft Hermit shale, which underlies the Coconino sandstone. The Hermit shale consists of soft red shale and thin-bedded sandstone and is unsuitable for the foundation of a high dam. In Plate XXIII is a map of the site and a cross section showing the rock structure. Further information regarding the geology of this part of Marble Gorge will be found in Appendix B (p. 134). As shown by the topographic map of the bridge site, it would not be possible to build a dam farther upstream, because the walls are too low to support a dam of the required height. About 2 miles above the bridge site the foundation may be favorable, but the walls are low, and a dam of the maximum practicable height would create a storage capacity of less than 4,000,000 acre-feet and would not permit full utilization of the Glen Canyon Reservoir site.

Comments on Marble Canyon Dam for Glen Canyon Reservoir

(Pp. 455–464 of Hearings on S. 728 and S. 1274, January 17, 18, 1928)

GEOLOGY

It will be noted that Ransome is not quoted as saying that the site is favorable for a high dam.

UTILIZATION OF RESERVOIR

A capacity of 11,000,000 acre-feet is proposed for "flood control, irrigation, or power development, or the dam may serve all three needs." The capacity indicated is barely sufficient for flood-control purposes and can, therefore, give only minor benefit for irrigation and power. Its capacity is so small that silt will rapidly reduce its serviceability. A flood like that of 1884 can not be controlled to 40,000 second-feet with a capacity of 11,000,000 acre-feet; and with the small valve capacity proposed by LaRue, high overflow discharges are inevitable with the structure outlined.

UNIT PRICES

The estimate by LaRue is based on a truck haul of 125 miles. Assuming that the trucking contractor will have to do very little toward road construction, it may be found possible to get such hauling done for 15 cents per ton-mile. Cement haul would then cost as follows:

Cost per ton for 125 miles	$18.75
Cost per barrel (380 pounds) for 125 miles	3.56

Cement at the dam would then cost as follows:

Cement at mill (see p. 158)	$2.00
Freight to Bellemont or Flagstaff (see p. 158)	.84
Truck haul as above	3.56
Handling	.10
Cost per barrel on job	6.50

With arch design as contemplated concrete in body of dam will require fully 1.25 barrels of cement per yard of concrete.

LaRue-Jakobsen estimate shows a cost of $9,553,000 for 1,370,000 cubic yards of concrete (see pp. 462–463 of the hearings on S. 728 and S. 1274) or $7 per cubic yard. The cost of cement alone would be $1\frac{1}{4} \times \$6.50$, or $8.12 per cubic yard of concrete.

Similar deficiencies are apparent in other items.

The following is a comparison with costs for a dam of about equal storage capacity at Boulder Canyon (Black Canyon site), to be increased in accordance with Colorado River Board report on Black Canyon. (See p. 53.)

	Marble Canyon, by LaRue	Boulder Canyon, for flood control only
Storage capacity	11,000,000	10,000,000
Raise in water ... feet	452	386
Concrete in dam	1,370,000	1,320,000
COSTS		
Diversion		$5,516,700
Foundation excavation	$3,440,000	
Spillway excavation		1,198,500
Concrete, in dam, including construction railroad or highway	[1] 10,533,000	[1] 11,118,527
Valves and spillway	1,314,000	3,988,400
Pressure grouting, right of way, etc	285,000	553,531
Camps, engineering, contingencies	2,186,000	5,740,032
Total, exclusive of interest	17,728,000	28,120,730

[1] 35-mile haul for Boulder Canyon, 125 miles for Marble Canyon.

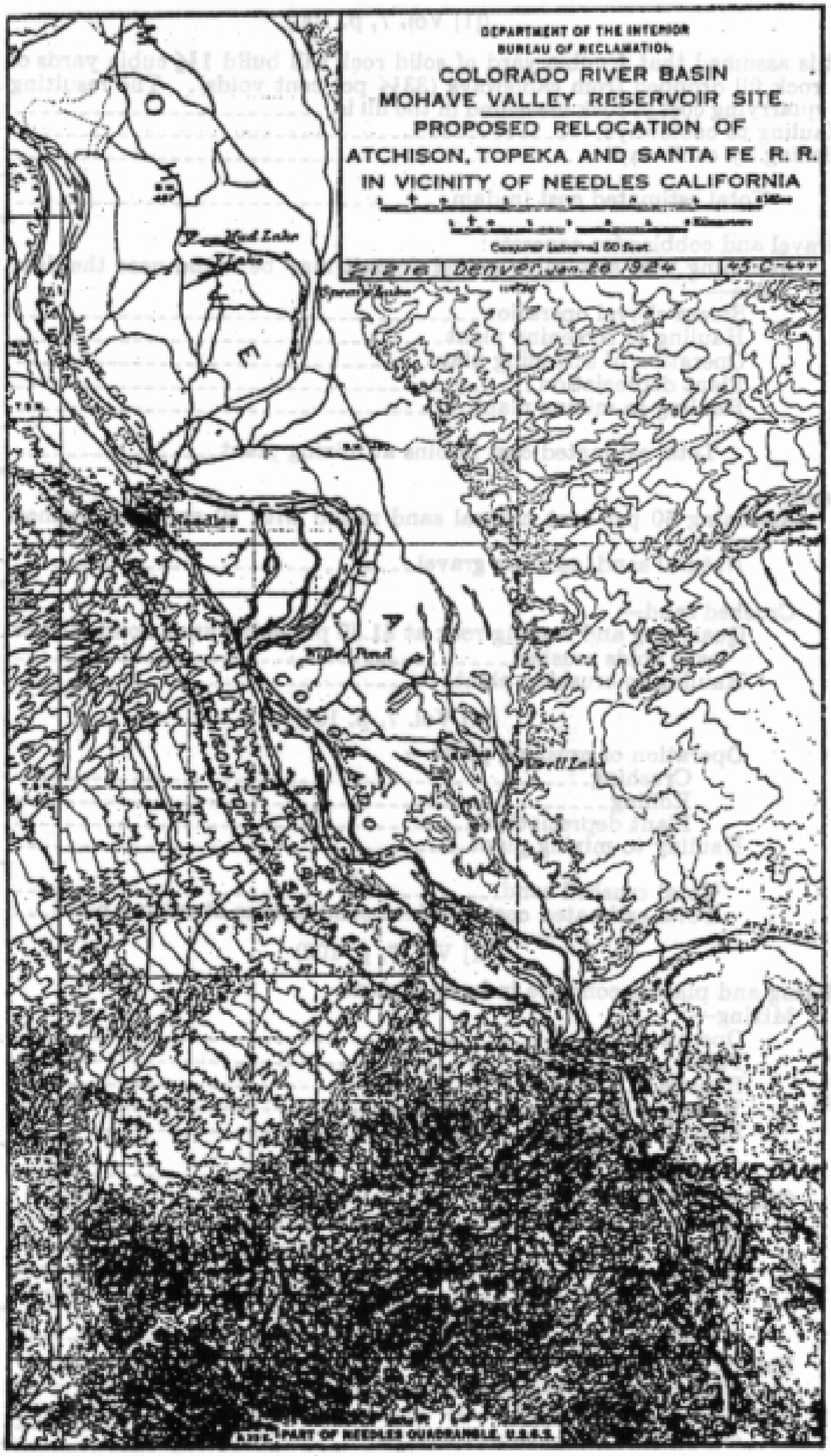
In view of the fact that concrete yardages for the two dams are almost identical; the fact that bed rock depths should be less at the site of Boulder Canyon than at Marble Gorge site by reason of the harder rocks at the former, and the much greater distance from existing rail connections, it would appear that the estimate for Marble Gorge was gotten up very hastily.

Mohave Valley Reservoir—Topock Dam

LOCATION

([1] Vol. 7, p. 89)

Mohave Valley Reservoir site is located on the Colorado River in Arizona, California, and Nevada, with dam site in Mohave Canyon about 2½ miles below the Topock crossing of the Santa Fe Railroad. The dam site is about 120 miles by river below that proposed for Boulder Canyon Reservoir and 200 miles above Yuma. A reservoir


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN
MOHAVE VALLEY RESERVOIR SITE
PROPOSED RELOCATION OF
ATCHISON, TOPEKA AND SANTA FE R.R.
IN VICINITY OF NEEDLES CALIFORNIA
Needles
PART OF NEEDLES QUADRANGLE, U.S.G.S.

([1] Vol. 7, p. 100)

It is assumed that 1 cubic yard of solid rock will build 1½ cubic yards of rock fill dropped from cableways (33⅓ per cent voids). The resulting quarrying cost of rock measured in the fill is	$1.00
Hauling to cableways	.15
Placing by cableways	.15
Total estimated cost in dam	1.30
Gravel and cobbles for concrete:	
Assuming that a suitable gravel deposit may be found near the dam site—	
Steam-shovel operation	.15
Hauling to screening plant	.15
Operation of screening plant	.25
Plant depreciation	.15
Hauling to mixing plant	.20
Total estimated cost in bins at mixing plant	.90
Sand:	
Assuming 50 per cent natural sand mixed with 50 per cent crushed sand—	
Natural sand, same as gravel	.90
Crushed sand—	
Quarrying and loading rock at $1.50 per cubic yard, solid, 35 per cent voids crushed	.97
Hauling to crushing plant	.15

([1] Vol. 7, p. 101)

Operation of crushing plant—	
Crushing	$0.25
Rolling	.40
Plant depreciation	.20
Hauling to mixing plant	.15
Total crushed sand	2.12
Total estimated cost of mixed sand in bins at mixing plant	1.50

([1] Vol. 7, p. 102)

Mixing and placing concrete in body of dam:	
Mixing—	
Operation	$0.15
Power	.05
Repairs	.08
Water	.02
Plant depreciation	.20
Total	.50
Cableway haul—	
Operation	.15
Power	.05
Repairs	.05
Plant depreciation	.25
Total	.50
Placing on dam—	
Cleaning and placing	.30
Pumping and lighting	.10
Miscellaneous	.10
Total	.50
Total estimated cost	1.50

■ Higher unit cost than used in estimates for much larger dams farther upstream.

CONCRETE DATA

([1] Vol. 7, p. 103)

In the estimate for the dam it is assumed that plums will be added in the form of comparatively large cobbles put through the mixers. The materials going into the concrete are assumed as follows:

Ingredient	Parts	Amount per cubic yard concrete
Cement	1	1.03 barrels per cubic yard.
Sand	2¼	0.36 cubic yard.
Gravel	5	0.72 cubic yard.
Cobbles	2¼	0.36 cubic yard.

([1] Vol. 7, p. 113)

Colorado River Storage, Mohave Valley Reservoir—Gravity Overflow Dam—Mohave Canyon Dam Site No. 2

[10,000,000 acre-feet flood-control reservoir]

Top of parapet, elevation 621 feet.
Top of dam, elevation 616 feet.
Top of spillway crest, elevation 585 feet.
Raise in water surface, 160 feet.

Outlet capacity, water surface, elevation 585 feet; 80,000 second-feet.
Spillway capacity, water surface, elevation 604 feet; 120,000 second-feet.

Preliminary estimate

[Probably to be increased in accordance with Colorado River board report on Black Canyon. (See page 53)]

Item	Quantity	Unit cost	Total cost	Summary
Diversion works:[1]				
Excavation—				
Classes I and II. At portals	10,000 cubic yards	$1.00	$10,000.00	
Class III. Main tunnels	460,000 cubic yards	6.00	2,760,000.00	
Class III. Muck tunnels	5,200 cubic yards	8.50	44,200.00	
Class III. Removing tunnel lining for plugs	2,300 cubic yards	8.00	18,400.00	
Total excavation			2,832,600.00	
Cofferdam at tunnel entrance	900 linear feet	425.00	382,500.00	
Concrete—				
Tunnel lining, 18 inches (1 : 2¼ : 5 mix)—				
Cement	77,400 barrels	2.90	224,460.00	
Sand	27,500 cubic yards	1.50	41,250.00	
Gravel	54,300 cubic yards	.90	48,870.00	
Forms	62,400 cubic yards	2.75	171,600.00	
Mixing and placing	do	3.25	202,800.00	
Miscellaneous	do	1.00	62,400.00	
Concrete in place			751,380.00	
	62,400 cubic yards	12.00	748,800.00	
Tunnel plugs (1 : 2¼ : 5 : 2¼ mix)—				
Cement	17,500 barrels	2.90	50,750.00	
Sand	6,120 cubic yards	1.50	9,180.00	
Gravel	12,200 cubic yards	.90	10,980.00	
Cobbles	6,120 cubic yards	.90	5,508.00	
Forms	17,000 cubic yards	.75	12,750.00	
Mixing and placing	do	2.00	34,000.00	
Miscellaneous	do	.75	12,750.00	
			135,918.00	
Concrete in place	do	8.00	136,000.00	
Grouting plugs, 3	300 linear feet	18.50	5,550.00	
Closing tunnel portals	Lump sum		25,000.00	
Total, diversion tunnels				$4,140,450.00

[1] Temporary diversion, 100,000 second-feet. Diversion tunnels, three 40-foot horseshoe tunnels, 3,700 feet long.

Preliminary estimate—Continued

Item	Quantity	Unit cost	Item cost	Summary
Outlet works:				
Trash rack for permanent outlets—				
Concrete piers, 1:2¼:5, reinforced, mix, 1 cubic yard per linear foot.	3,440 cubic yards	$30.25	$104,060.00	
Concrete balcony, elevation 385 feet, 1:2¼:5 mix, reinforced.	235 cubic yards	33.00	7,755.00	
Concrete platform, elevation 419 feet, 1:2¼:5 mix, reinforced.	300 cubic yards	30.00	9,000.00	
Guniting beams	320 beams	9.25	2,960.00	
Trash rack metal—				
Beams, 320 at 40 pounds per linear foot.	154,000 pounds	.06	9,240.00	
Rails, 320 at 10 pounds per linear foot.	33,000 pounds	.06	1,980.00	
Grooves, 12,800 linear feet of 7-inch 164-pound ship channels.	210,000 pounds	.06	12,600.00	
Grills	717,000 pounds	.06	43,020.00	
Anchor bolts	7,170 pounds	.08	574.00	
Cover plates and accessories, large.	32,800 pounds	.08	2,624.00	
Cover plates and accessories, small.	9,000 pounds	.08	720.00	
Freight	1,162,970 pounds	.0053	6,164.00	
Installation	1,162,970 pounds	.02	23,259.00	
Total, trash rack metal			100,181.00	
Total, trash rack for permanent outlets.				$223,956.00
Permanent outlet conduits—				
Semisteel lining, 3,000 linear feet.	6,720,000 pounds	.09	604,800.00	
Bolts	6,700 pounds	.08	536.00	
Freight	6,726,700 pounds	.0053	35,652.00	
Installation	6,726,700 pounds	.015	100,900.00	
Grouting behind lining	3,000 linear feet	5.00	15,000.00	
Total, permanent outlet conduits.				756,888.00
Permanent outlet control—				
Slide gates (20), 6 by 9 feet	1,400,000 pounds	.25	350,000.00	
Pressure pump system in place	1 unit	14,000	14,000.00	
Freight	1,400,000 pounds	.0053	7,420.00	
Installation	1,400,000 pounds	.02	28,000.00	
Total, permanent outlet control.				399,420.00
Track and crane—				
Track, 270 linear feet, at 50 pounds	13,500 pounds	.032	432.00	
Accessories	402 pounds	.08	32.00	
Crane	Lump sum		25,000.00	
Freight	13,902 pounds	.0053	74.00	
Installation	13,902 pounds	.02	278.00	
Total, track and crane				25,816.00
Total, outlet works				1,406,080.00
Spillway:				
Concrete piers for railroad and highway bridges (1:2¾:5 mix).	2,200 cubic yards	15.75		34,650.00
Pier noses—				
Castings	14,000 pounds	.10	1,400.00	
Anchor bolts	250 pounds	.08	20.00	
Freight	14,250 pounds	.0053	76.00	
Installation	do	.02	285.00	
Total, pier noses				1,781.00
Highway bridge, superstructure of four 118-foot spans in place.	500,000 pounds	.085		42,500.00
Total, spillway				78,931.00
Construction camp	Lump sum			150,000.00
Permanent improvements	do			35,000.00

Preliminary estimate—Continued

Item	Quantity	Unit cost	Total cost	Summary
Right of way, reservoir:				
Purchase of land	Lump sum		$2,500,000.00	
Moving town of Needles	do		1,500,000.00	
Moving Fort Mohave	do		75,000.00	
Total, right of way				$4,075,000.00
Total estimated field cost				14,074,755.00
Administration, engineering, and contingencies, 22½ per cent.				3,166,820.00
Total estimated cost of reservoir, exclusive of interest during construction and cost of reconstruction of railroad and highway.				17,241,575.00
Reconstruction of railroad:				
Grading, tunnels, and bridging	Lump sum		3,000,000.00	
Tracks, signals, etc	do		1,300,000.00	
Terminals at Needles—				
Yard tracks	do		1,000,000.00	
Depot, shops, icing facilities, etc			1,700,000.00	
Capitalization of increased length of line.	Lump sum		1,500,000.00	
Total railroad				8,500,000.00
Reconstruction of highway, exclusive of bridge on dam.	Lump sum			200,000.00
Total estimated cost—				
Exclusive of interest during construction.				25,941,575.00
Roughly				26,000,000.00

([1] Vol. 7, pp. 105, 106)

Colorado River Storage, Mohave Valley Reservoir—Concrete Dams

SUMMARY OF PRELIMINARY ESTIMATES

[Probably to be increased in accordance with the Colorado River Board report on Black Canyon (see p. 53)]

[Based upon very meager data]

Comparative estimated cost of flood-control reservoirs impounded by dams of different heights in Mohave Canyon 2½ miles below the railroad bridge at Topock, Ariz.

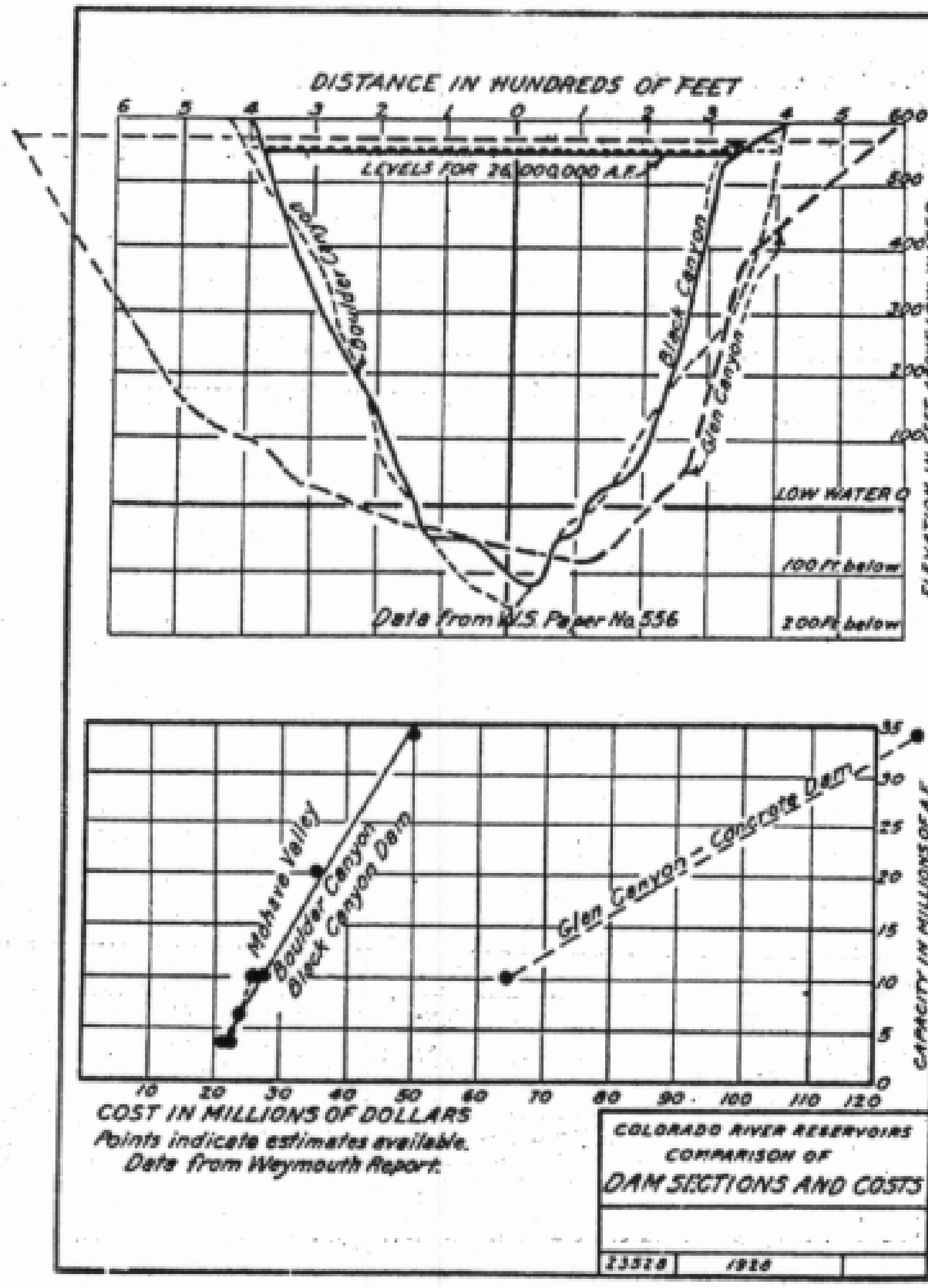
Overflow gravity dams built on a straight plan

	A	B	C
Raise in water surface ... feet	100	125	160
Elevation top of flood storage ... do	525	550	585
Storage in acre-feet	4,000,000	6,000,000	10,000,000
Diversion works: Rock-fill cofferdams and three 40-foot horseshoe tunnels with Q=100,000	$4,733,000	$4,733,000	$4,733,000
Dam: Including excavation, concrete, grouting, draining, and lighting	1,796,000	2,341,000	3,261,000
Dike: At Topock across low ground on Arizona side		74,000	336,000
Outlet works: Metal lined conduits through dam; discharge controlled by (A) twenty 6 by 11 foot slide gates, (B) twenty 6 by 10 foot slide gates, and (C) twenty 6 by 9 foot slide gates	1,244,000	1,327,000	1,406,000
Spillway: Includes bridge piers on spillway section and steel for highway bridge	79,000	79,000	79,000
Construction camp	150,000	150,000	150,000
Permanent improvements: Grounds, operators' quarters, water supply, etc	35,000	35,000	35,000
Right of way	3,575,000	3,825,000	4,075,000
Total estimated field cost	11,612,000	12,564,000	14,075,000
Administering, engineering, and contracting, 22½ per cent	2,612,000	2,827,000	3,167,000
Total estimated cost of reservoir, exclusive of interest during construction and cost of reconstruction of railroad and highway	14,224,000	15,391,000	17,242,000
Reconstruction of railroad, including grading, tunnels, bridging, track, signals, terminals, and capitalization of increased length of line	8,150,000	8,300,000	8,500,000
Reconstruction of highway	100,000	150,000	200,000
Total estimated cost, exclusive of interest during construction	22,474,000	23,841,000	25,942,000
Roughly	22,500,000	24,000,000	26,000,000

([1] Vol. 9, pp. 1–7)

CHIEF ENGINEER,
COMMISSIONER,
Colorado River Storage:

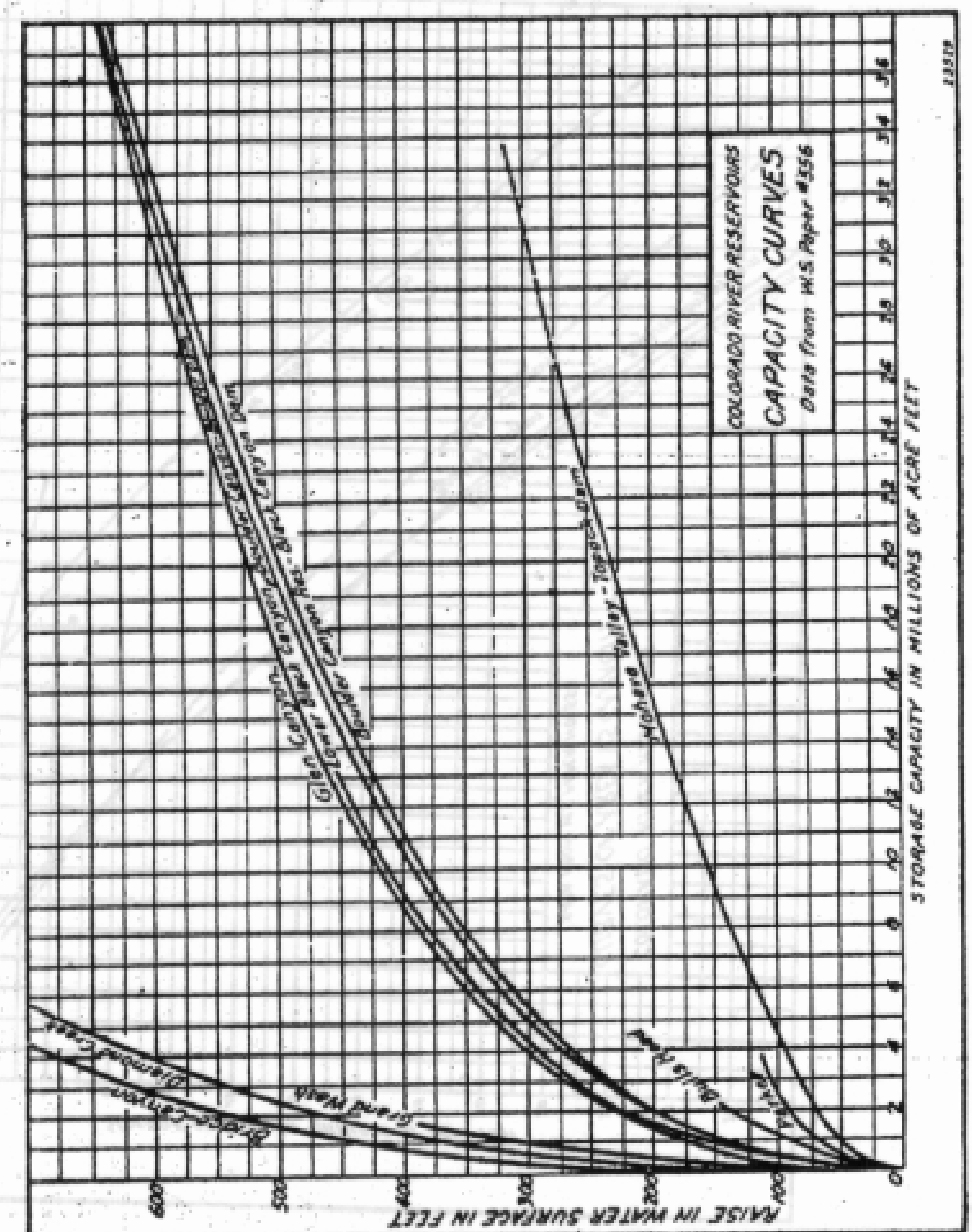
1. Investigations of the Colorado River Basin were started in 1904 by the Reclamation Service with the view of augmenting the water supply for irrigation in the lower valley and to provide control of the ever-present flood menace in the



delta region. Prolonged investigation of the upper basin indicated lack of requisite storage at reasonable cost for the accomplishment of the desired ends, hence investigations of storage sites in the lower river were taken up. After a preliminary study of the problem and a reconnaissance of the river below the mouth of the Virgin, work was concentrated on the better dam sites in Boulder and Black Canyons in 1919 and thereafter.

2. The primary object was the control of the river for irrigation and flood-control purposes. With the progress of these investigations, the large amount

of power that could be developed without interfering with the primary use of the reservoir for irrigation and flood control was soon realized. It was soon found that it would be possible to develop power at the dam sites considered and that this power could be sold at a price sufficient to repay the entire construction costs. In all these studies the power problem was considered only as incidental to irrigation and flood control. Studies were largely concentrated at the Boulder Canyon Reservoir site and it was found that requisite storage could be obtained there at

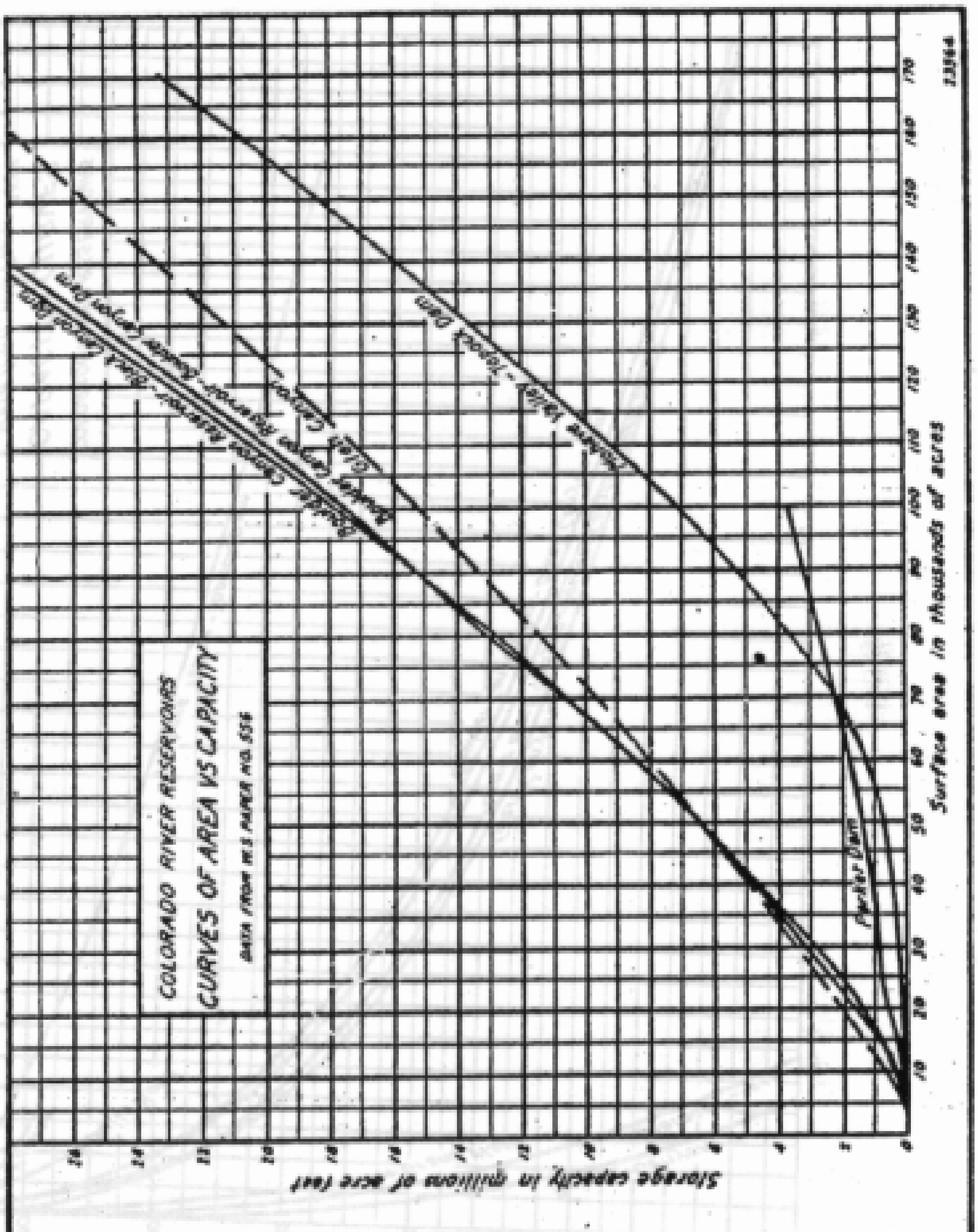


the lowest cost and that this development could be made without interfering with other development on the river.

3. A preliminary report on this subject was made under the heading "Problems of the Imperial Valley and vicinity" in 1922, by the then Director of the Reclamation Service, Mr. A. P. Davis. Studies of the problem continued after that report was completed and the results were embodied in a voluminous report, containing nearly 2,000 typewritten pages, submitted by me in February, 1924,

to the Secretary of the Interior, under the heading, "Report on the problems of the Colorado River Basin." When this report was written the data available on dam sites above Boulder Canyon was practically limited to the Glenn Canyon and Diamond Creek sites.

4. The United States Geological Survey in 1923, made some topographic surveys and a general geological examination of the Colorado River gorge from Lees Ferry to Las Vegas wash, the latter being between the Boulder and Black



Canyon Dam sites, which were investigated by the Bureau of Reclamation for the Boulder Canyon Reservoir site. A few days prior to the completion of my report in February, the Geological Survey furnished an approximate elevation of some of the dam sites below Diamond Creek. Brief studies were therefore made in the time remaining which led to an alternative plan being submitted limiting the height of Boulder Canyon Dam to the level of Bridge Canyon Dam site. It was pointed out that the success of this plan would depend upon the feasibility of the Bridge Canyon site for a high dam and power plant.

5. Since the rendition of the above-mentioned report, I have received from the Geological Survey a preliminary profile of the Colorado River through the stretch investigated in 1923, and also topography of the principal dam sites noted by the survey party below Grand Canyon National Park. These data, in addition to data obtained from investigations by the Bureau of Reclamation, have made it possible to extend previous studies and to determine the best plan for the development of the lower river, having in mind at all times the paramount interest of irrigation and flood control. Some of the results of these studies are embodied in this paper. The section of the river through the park has been neglected by reason of public aversion to development thereof. The section above the park is so distant from large power markets that its development will only be undertaken after the entire power possibilities below the park have been fully utilized.

6. The more important factors involved in the proper development of the entire section below the park are in the order of this importance:

(a) Adequate storage capacity for irrigation and flood control with a minimum of evaporation loss.

(b) Construction cost.

(c) Maximum power output with maximum flexibility.

(d) Minimum destruction of developed and undeveloped property.

ADEQUATE STORAGE CAPACITY FOR IRRIGATION AND FLOOD CONTROL

7. This factor is by far the most important, as the use of water for irrigation must be made superior to use of water for power in the Colorado River Basin. The object of the development should be, first of all, the protection of present irrigated lands from the ever-present dangers of inundation and water shortage, and thereafter the provision of adequate storage capacity to permit the utmost development of the water resources of the Colorado River Basin. Other waters can not be substituted for irrigation of lands in the Colorado River Basin. On the other hand, power can be provided from other sources.

8. Under present conditions less than 1,000,000 acre-feet of active storage is required to insure an adequate irrigation supply for the lower Colorado areas. With further development throughout the Colorado River Basin, this amount will soon increase rapidly. In my report of February, 1924, it was estimated that 25,000,000 acre-feet would ultimately be required for this purpose alone if upstream developments did not create material hold-over storage. Undoubtedly considerable storage of this type will in time be provided by upstream irrigation and power developments. It is believed, however, that 15,000,000 acre-feet of storage will be required for this purpose on the lower river.

9. Present silt inflow at Boulder Canyon is estimated at 80,000 acre-feet annually and will gradually decrease as upstream reservoirs are constructed. To prevent encroachment by silt on storage needed for irrigation purposes for a long period of years an additional capacity of 5,000,000 acre-feet is needed.

10. Floods should be controlled to a discharge of not over 40,000 second-feet at Yuma, as discharges of over 50,000 second-feet are difficult of control and seriously endanger present levees. The uncertainties attending any change in the regimen of a stream like the Colorado River dictate that ample provision should be made to meet such uncertainties. Under present conditions such control will require 8,000,000 acre-feet of storage. This amount will decrease to 5,000,000 acre-feet with considerable upstream development.

11. From the above it will be seen that a total capacity of 25,000,000 acre-feet should be provided to meet future conditions. That such a capacity is not needed to care for irrigation, flood control, and silting for the immediate future is apparent. The provision of this or even a greater amount at the present time is not an economic blunder, however, as the full control of present flow for the prevention of waste and therefore the maximum power output, requires over 30,000,000 acre-feet of storage.

12. The location of this storage is also an important factor. From the standpoint of flood control and avoidance of irrigation waste, storage should be as near the point of use as possible. To hold down evaporation losses, the reservoir should be deep and located in the canyon section.

CONSTRUCTION COST

13. Even with the cost of the dams added to the power feature, power can be developed more cheaply at Boulder Canyon for the power market available

than at any other point on the Colorado River. Modification of pla[illegible] for purely storage development for the purpose of power development must [illegible] made at minimum cost per unit of power in order that the additional investm[illegible]nt may be justified and the burden on the power users reduced to a minimum. All of the more recent studies have indicated that the cost of storage for irr[illegible]gation and flood control should be saddled on the power development.

POWER OUTPUT

14. While adequate provision must be made for irrigation and flood control, any accepted plan must offer no avoidable interference with the maximum possible power development. Maximum power output is desirable as the presence of a market in the near future for all power that may be developed below the park is generally conceded. As power is the product of head and water, it follows that the maximum possible output would be obtained with stream control at the head of a section and utilization of the entire head bel[illegible]w. As no feasible storage possibilities with sufficient capacity exist above Bou[illegible]r Canyon reservoir site, it follows that any adopted plan must be a compromise between a sacrifice of operating head and of storage capacity to obtain a maximum product.

15. A considerable portion of the energy used in southern California at the present time is devoted to irrigation pumping, which varies greatly from year to year as stream flow varies. No doubt such pumping will continue to take a considerable part of all power marketed there. Some of the power systems with which the Colorado River development would be interconnected are less fortunate in storage possibilities. The best use of Colorado River power is possible only with a large storage reserve at strategic points which will permit a flexible power output.

DESTRUCTION OF PROPERTY VALUES

16. The Mohave Valley Reservoir, if developed to elevation 600, as proposed by Colonel Kelley, would require the reconstruction of about 23 miles of double-track main line railroad of the Santa Fe with an increase of about 3 miles in length of line. The city of Needles, with a population of over 2,500, would have to be moved to a new site, together with extensive terminal facilities of the railroad company. Irrigable land to the extent of 40,000 acres would be submerged. Much of this land is Indian reservation, and a school would also have to be moved. Parker Valley Dam, if developed to elevation 425, would not destroy any property of value. Developed to elevation 458, the lower part of Mohave Valley would be submerged to the extent of possibly 10,000 acres.

FIELD DATA AVAILABLE FOR DESIGNING WORK

17. *Diamond Creek Dam site.*—Topography and drilling data were obtained from J. B. Girand, applicant before the Federal Power Commission for this site.

18. *Bridge Canyon, Spencer Canyon, and Devil's Slide Dam sites.*—Topography at dam sites was obtained in 1923, by the United States Geological Survey, but in most cases in insufficient amount to cover sites for dam and power house. No data are available on foundations. Estimates of cost are based on assumed depths to rock of 60, 90, and 120 feet, the middle depth being used for general comparison of plans. Accessibility of sites has been assumed without actual knowledge in regard thereto.

19. *Boulder Canyon Reservoir site.*—Detailed topography of reservoir area and dam sites has been obtained. Surveys made for connecting railroads indicate a readily accessible site. The two most favorable dam sites indicated by detailed geological investigations have been thoroughly drilled. Concrete materials have been located and subjected to practical tests for suitability for concrete with gratifying results. This work was carried on from 1918 to 1923.

20. *Bullshead Reservoir site.*—Topography for this site was obtained in 1902 and 1903. This site was diamond drilled in 1903 by the Reclamation Service and is reported in the second annual report of that service.

21. *Mohave Valley Reservoir site.*—General topography of the reservoir site was made in 1902 and 1903. Topography of the dam site was made by the United States Geological Survey in 1923. No drilling has been done. Estimates of depth to rock are based on conditions encountered at the railroad bridge a few miles above and at dam sites tested at other points on the Colorado

River. The cost of necessary changes in railroad trackage and facilities is from information furnished by the railroad company.

22. *Parker Dam site.*—General topography was taken in 1902 and 1903. Additional topography was furnished by Fred Noetzli of Los Angeles, Calif. The site has not been tested for foundations.

DESIGNS AND ESTIMATES

23. Designs and estimates for the dam for the Boulder Canyon Reservoir site have been worked out in great detail for various heights of dam and are based on complete field data.

24. Data for the Diamond Creek, Bullshead and Parker sites are in such shape that the designs and estimates can be considered a little better than preliminary.

25. The foundation conditions and right-of-way difficulties at Mohave Valley site are very uncertain. There are so many uncertainties connected with the cost of development of this site that any estimates made with available data may be very misleading. The site should not under any circumstances be developed.

26. The Bridge Canyon, Spencer Canyon, and Devil's Slide sites have incomplete topography from which estimates can be made.

DEVELOPMENT PLANS

27. While an infinite number of plans for the development of the Grand Canyon-Parker section may be advanced on the basis of known and assumed dam sites, it is believed the plans presented on Exhibit B (45-D-537) cover all of the more favorable plans.

28. In making comparison of the various plans along the lines of their most important features, two conditions of water supply have been assumed, namely, present water supply without upstream control and possible future water supply with stream flow fully equated. Neither condition will ever be fully experienced. By the time the entire river section below the park can be put to power use, much irrigation and power development may take place above. Full control of the river by upstream storage is infeasible. Actual conditions will gradually leave the status of "present" conditions and approach that of full upstream development.

29. Evaporation from reservoirs is based on an estimated loss of 5 feet per year over the average exposed area in each case. This value may be considered an average. Actual losses will be higher in the lower desert region below Boulder Canyon than in the canyon section proper.

30. Exhibit C (45-D-538) shows summaries of the more important features of the various plans.

31. Plan A, exclusive of the Parker Dam, was first suggested by me in my February, 1924, report to the Secretary of the Interior. That plan, with the Parker Dam included, presents, in my opinion, the best scheme of development for the lower river as a whole. The outstanding advantage of Plan A is that it supplies the needed storage capacity at a minimum evaporation loss. This plan provides superior flood control by reason of control of Williams River and it entails a minimum destruction of irrigable areas. The cost of construction is the lowest, both under present and future conditions. With but partial stream control by upstream reservoirs, such as will actually be realized, the power output of the plans with small storage capacity would suffer far more severely than this plan. The cost of the Parker Dam is included in the total cost of this plan. It would provide a much needed diversion for the Parker Valley and for contemplated irrigation of higher lying lands below.

Colorado River Storage, Supplementary Report

([1] Vol. 9, p. 33)

Summary of estimates of cost of dams

Probably to be increased in accordance with the Colorado River Board report on Black Canyon (see p. 53)]

Site	Assumed low-water surface elevation	Normal water surface elevation	Assumed maximum depth to bedrock	Total estimated cost: With pit aggregate	Total estimated cost: With crushed aggregate
			Feet		
Diamond Creek	1,335	1,770		$34,000,000	[1] $27,500,000
Bridge Canyon	1,215	1,770	120	31,000,000	33,500,000
Do	1,215	1,770	90	30,000,000	32,500,000
Do	1,215	1,770	60	28,500,000	31,500,000
Spencer Canyon	1,115	1,320	120	13,500,000	14,000,000
Do	1,115	1,320	90	13,000,000	13,500,000
Do	1,115	1,320	60	12,000,000	13,500,000
Devil's Slide	1,035	1,320	120	18,500,000	19,500,000
Do	1,035	1,320	90	17,500,000	18,500,000
Do	1,035	1,320	60	17,500,000	18,000,000
Boulder Canyon (Black Canyon dam site)	645.5	1,250		[1] 49,500,000	[1] 53,000,000
Do	645.5	1,200		[2] 40,500,000	
Do	645.5	1,100		[2] 31,500,000	
Do	645.5	1,020		[2] 27,000,000	
Bullhead	495	[3] 645		[2] 14,000,000	
Mohave Valley	425	600		25,500,000	
Parker	358	451		9,000,000	
Do	358	423		7,000,000	

[1] From estimates in February, 1924, report.
[2] From cost curve, p. 484, vol. 5, of February, 1924, report.
[3] Corrected for mean sea-level datum.

Estimates for pit aggregate and 90-foot depth to bedrock used in summaries.

Bridge Canyon Dam Site

([1] Vol. 9, pp. 35–36)

Topography at the dam site is based on recent work by the Geological Survey. Bedrock conditions in the river channel are not known and maximum depths below low-water surface of 120, 90, and 60 feet are provided for by continuing the slopes of the canyon walls to the corresponding elevations.

It is planned to raise the water surface 555 feet, making the top of dam elevation, 1,780.

Assuming bedrock 120 feet below low-water surface, the maximum height of dam is 685 feet. The section was approximated with sufficient accuracy from those at Boulder Canyon for 20,000,000 and 34,000,000 acre-feet reservoirs, having maximum heights of 626 feet and 726 feet, respectively. It is assumed that rock must be removed to a depth of 10 feet over the base and abutments to reach solid foundation and that the gravel and bowlders are covered with 20 feet of sand and silt. Drainage and grouting details in the dam and foundation follow the scheme shown on earlier drawings.

The diversion works have a capacity of 100,000 second-feet. The diversion tunnels will subsequently serve as penstocks and are made circular, of a length greater than that required for diversion purposes only.

A spillway is provided on the dam similar in all respects to that at Diamond Creek.

Temporary outlets similar to those at Diamond Creek are provided. There are no permanent outlets, the natural flow of the river being carried through the power house or over the spillway.

Information concerning concrete materials is lacking, and the estimates have been prepared for pit and crushed aggregate, following the practice at Diamond Creek. It is assumed that the total length of construction railroad and the cost per mile will be the same as at Diamond Creek, and what has been said of right of way at the latter site is applicable to Bridge Canyon. Unit costs are the same throughout for the two sites.

Colorado River Storage—Bridge Canyon Dam

CURVED GRAVITY TYPE—DEVELOPMENT TO ELEVATION 1,770 FEET

([1] Vol. 9, pp. 46–55)

Top of parapet elevation, 1,785 feet.
Top of dam elevation, 1,780 feet.
Normal water surface elevation, 1,770 feet.
Raise in water surface, 555 feet.
Radius of axis, 700 feet.
Bed rock assumed 120 feet below low water surface.

Preliminary estimate based upon meager data

[Probably to be increased in accordance with Colorado River Board report on Black Canyon (see p. 53)]

Item	Quantity	Unit cost	Item cost	Feature cost
Diversion works (100,000 surface feet):				
(3 35-foot tunnels, 3,700 feet long)—				
Portal excavation	10,000 cubic yards	$1.00	$10,000	
Main tunnels excavation	467,000 cubic yards	6.00	2,802,000	
Muck tunnels excavation	5,200 cubic yards	8.50	44,200	
Cofferdam of tunnel entrance	900 linear feet	425.00	382,500	
Tunnel lining	71,000 cubic yards	12.00	852,000	
Tunnel plugs, excavation	2,000 cubic yards	8.00	16,000	
Tunnel plugs, concrete	13,400 cubic yards	8.00	107,200	
Tunnel plugs, grouting	300 linear feet	16.00	4,800	
Closing portals			35,000	
Rock fill in main cofferdams	765,000 cubic yards	1.30	994,500	
Earth in main cofferdams	98,000 cubic yards	1.00	98,000	
Pumping			100,000	
Trash racks for sluices (details not here copied).			41,284	
Closing sluiceways, concrete	8,640 cubic yards	16.50	142,560	
Closing sluiceways, other items (details not copied).			38,273	
Total for diversion				$5,668,317
Dam:				
Foundation excavation, all classes	679,300 cubic yards	2.11	1,431,500	
Grouting and drain holes in foundation	72,000 linear feet		83,000	
7 36-inch gate valves, in place			4,294	
Concrete in body of dam	2,290,000 cubic yards	6.75	15,457,500	
Concrete in parapets	320 cubic yards	23.00	7,360	
Lighting			5,700	
Total, dam				16,989,354
Spillway:				
Concrete	2,800 cubic yards	19.25	53,900	
Gates in place	8,193,000 pounds		685,200	
Piping, valves, and hoists			50,473	
Trash racks and miscellaneous metal			10,567	
Total spillway				800,140
Construction railroad:				
From Peach Spring on A., T. & S. F. R. R. (Inc.), yards and equipment.	21 miles	50,000		1,050,000
Construction camp				600,000
Permanent improvements				60,000
Right of way				50,000
Total field cost				25,115,811
Administration, engineering, and contingencies, 22½ per cent.				5,651,057
Total without interest during construction.				30,766,868

Preliminary estimate based upon meager data—Continued

Item	Quantity	Unit cost	Item cost	Feature cost
Roughly				$31,000,000
Revised total with bedrock at depth of 90 feet.				30,300,000
Revised total with bedrock at depth of 60 feet.				28,300,000
Increase in cost if concrete gravel is not found available, requiring crushed aggregate.				2,500,000

PARKER DAM SITE

([1] Vol. 9, pp. 42–43)

Topography at the dam site is based on a map furnished by Fred A. Noetzli, which was prepared from a survey made under the supervision of H. E. Linden, formerly of Beckman & Linden Engineering Corporation.

It is planned to raise the water surface 67 feet, making the top of dam at elevation 468 to provide a flood-storage capacity above the diversion level.* Under these conditions the maximum raise in water surface will be 100 feet. Sections of the dam are shown on Exhibit 45–C–527.

Assuming river bed at elevation 348, the height of dam will be 120 feet. It is planned to build the dam on the soft material in the river channel with a wide base to reduce unit pressures and an earth blanket is provided on the assumption that safety will be secured with a percolation factor of 15.

The diversion works have a capacity of 40,000 second-feet, assuming that a flood-control dam would previously be constructed upstream, which, however, will not control Williams Creek.

The plan of the high dam is to utilize the downstream part of the diversion tunnels for the spillway, connecting them with the spillway crest by means of inclined tunnels.

The spillway is provided with three drum gates of the size adopted for Diamond Creek and other sites.

Outlet works are provided having a capacity of 40,000 second-feet with water surface at elevation 425.

It is assumed that the cost per mile of the construction railroad will be the same as at Diamond Creek and the distance from Parker on the Atchison, Topeka & Santa Fe Railroad is about 5 miles.

The cost of right of way is based on an estimate of 5,000 acres of irrigable land and 17,500 acres of nonirrigable land to be submerged by the reservoir. The cost per acre was assumed to be the same as for the Mohave Reservoir, viz., $50 and $10, respectively.

* Capacity indicated for flood storage purposes may in the alternative be used for regulation purposes if so needed in case Bullshead Reservoir is not built. The interests using Parker Dam for diversion or power purposes should be willing to dedicate the upper portion of the dam for this purpose in return for the use of Boulder Canyon storage.

([1] Vol. 9, pp. 79–85)

Colorado River storage—Parker Dam earth-fill type

[Development to elevation 451]

Top of parapet	Elevation 472	Raise in water surface to normal water surface, feet	67
Top of dam	Elevation 468	Outlet capacity, water surface elevation 423 surface feet	40,000
Normal water surface	Elevation 423		
Top of flood storage	Elevation 451	Spillway capacity, water surface elevation 458 surface feet	200,000

Preliminary estimate

[Based upon meager data]

Item	Quantity	Unit cost	Item cost	Feature cost
Diversion works (40,000 second-feet capacity, two 38-foot tunnels):				
Excavation for tunnel approaches	700,000 cubic yards	$0.64	$450,000.00	
Excavation for tunnels	200,000 cubic yards	6.00	1,200,000.00	
Tunnel lining	28,700 cubic yards	12.25	351,575.00	
Tunnel plug excavation	700 cubic yards	8.00	5,600.00	
Tunnel plug concrete	4,900 cubic yards	9.00	44,100.00	
Tunnel plug grouting	100 linear feet	16.00	1,600.00	
Cofferdam fill	330,000 cubic yards	1.28	410,300.00	
Pumping			50,000.00	
Total diversion				$2,513,175.00
Dam:				
Excavation, all classes	31,700 cubic yards	.908	30,000.00	
Embankment—				
Earth	1,749,000 cubic yards	.65	1,136,850.00	
Gravel	250,000 cubic yards	1.25	312,500.00	
Loose rock (placing only)	50,000 cubic yards	1.00	50,000.00	
Riprap	32,000 cubic yards	2.50	80,000.00	
Cut-off walls, concrete, reinforced	1,050 cubic yards	18.50	19,425.00	
Parapets, concrete	630 cubic yards	21.25	13,388.00	
Total dam				1,642,163.00
Outlet works:				
Excavation, open cut	100,000 cubic yards	1.00	100,000.00	
Tunnel excavation	70,000 cubic yards	6.00	420,000.00	
Cylinder gate shaft excavation	3,500 cubic yards	8.50	29,750.00	
Tunnel lining	9,200 cubic yards	12.25	112,700.00	
Cylinder gate shaft lining	800 cubic yards	18.75	15,000.00	
Grouting	200 linear feet	11.00	2,200.00	
Gate tower concrete reinforced	4,800 cubic yards	23.50	112,800.00	
Gunite			2,888.00	
Gate houses			13,181.00	
Cylinder gates and machinery	1,218,500 pounds	.24	295,172.00	
Trash racks	1,175,000 pounds	.101	118,960.00	
Railing			1,227.00	
Bridge			10,640.00	
Total outlet works				1,235,516.00
Spillway:				
Excavation—				
Open cut	108,000 cubic yards	1.42	154,000.00	
Tunnel	25,000 cubic yards	6.00	150,000.00	
Air shafts	400 cubic yards	15.00	6,000.00	
Concrete, spillway crest, reinforced	4,000 cubic yards	13.00	52,000.00	
Piers, walls, etc., reinforced	3,700 cubic yards	21.50	79,550.00	
Concrete, plain in crest and piers	800 cubic yards	10.75	8,600.00	
Transitions walls and roof, reinforced.	3,000 cubic yards	20.25	60,750.00	
Transition floor and walls, reinforced.	5,000 cubic yards	12.75	63,750.00	
Tunnel lining	1,700 cubic yards	12.25	20,825.00	
Portal lining	do	11.25	19,125.00	
Air-shaft lining	100 cubic yards	16.50	1,650.00	
Valves, pumps, and hoists	126,000 pounds	.23	28,980.00	
Movable crest gates	3,902,250 pounds	.14	514,801.00	
Miscellaneous metal work	329,300 pounds	.14	43,148.00	
Total spillway				1,206,679.00
Road improvements	5 miles	2,000.00		10,000.00
Construction railroad	do	50,000.00		250,000.00
Construction camp				150,000.00

Preliminary estimate—Continued

Item	Quantity	Unit cost	Item cost	Feature cost
Spillway—Continued.				
Permanent improvements				$25,000.00
Right of way				426,050.00
Total field cost				7,456,733.00
Administration, engineering, and contengencies, 22½ per cent.				1,677,763.00
Total cost, exclusive of interest during construction and of power plant.				9,134,496.00
Roughly				9,000,000.00

Bullshead Reservoir

DAM SITES

([1] Vol. 7, pp. 49–50)

Three sites have received consideration, located, respectively, 1,300, 3,300, and 6,300 feet below Bullshead Rock, shown on drawing 45–C–166. Both the Lee[1] and Hamlin-Wheeler[2] reports held that the Colorado River has shifted its course in this vicinity, with its former course entering the map to the east of Bullshead Rock, thence across the present channel just below dam site 1, and passing out near the N arrow to the left.

The results of drilling for rock, in each case found to be granite, is shown on drawings 45–C–149, 45–C–186, and 45–C–212. The Lee report suggests the possibility of shallower depths to rock above Bullshead Rock, but no physical data for such a site are now available.

NOTE.—The farthest possible dam site downstream should be chosen to develop as nearly as possible the river fall and storage possibilities between Black Canyon and Needles Valley.

([1] Vol. 7, p. 51)

Dam site No. 1 has been adopted for the purpose of estimating, for the following reasons:

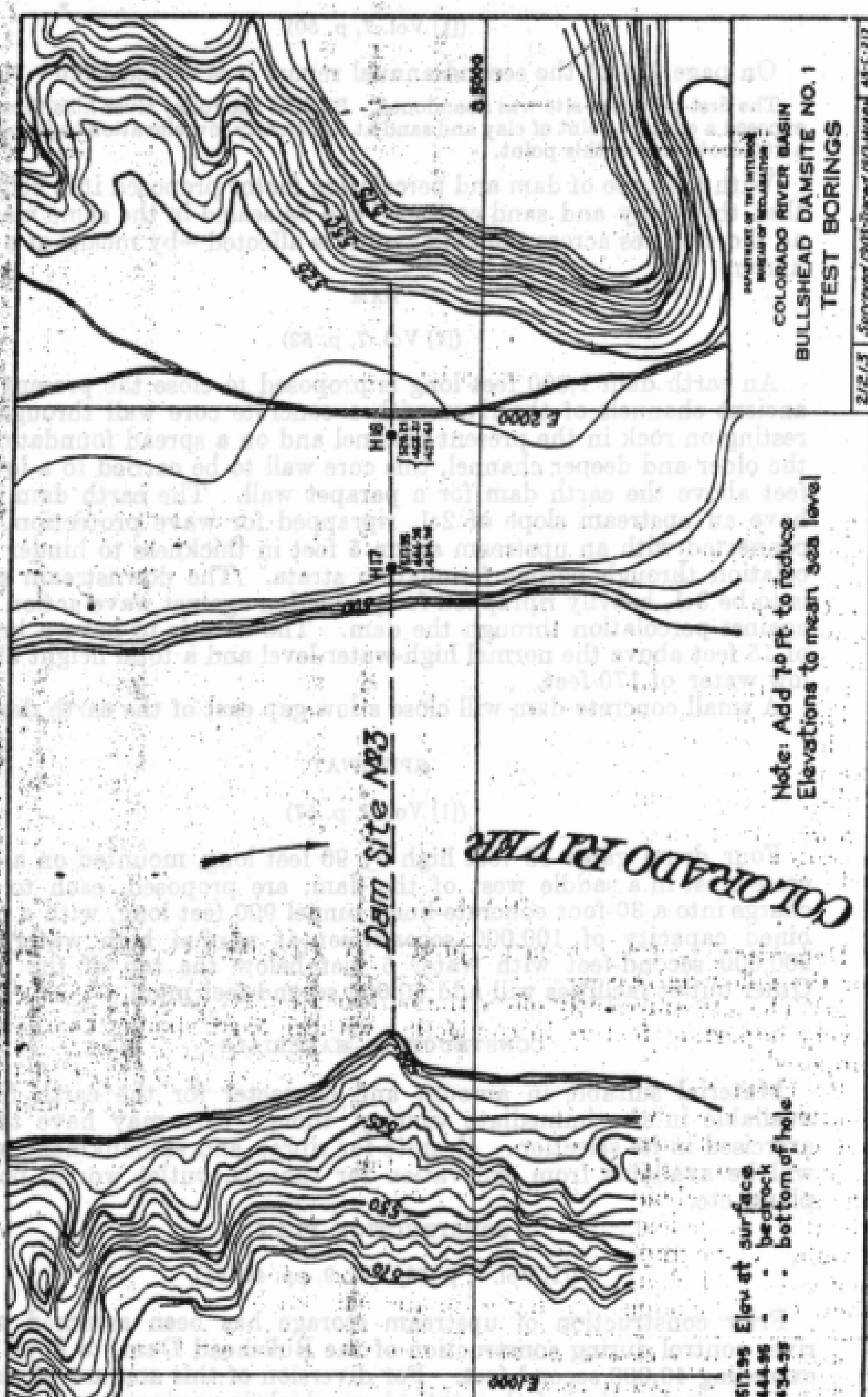
(*a*) The site apparently offers the best location for a safe spillway, a very important feature in connection with an earth dam, which is proposed.

(*b*) From the limited topography available it appears that the abutments are lower at the other sites, and a dam built there would not create sufficient storage.

(*c*) A dam at site No. 1 closes both the old and new channels with one structure about 1,800 feet long on top. At site No. 2 a dam of about the same length would be required to close the present channel. Available topography does not permit of determination of the distance across the old channel. The topography at site No. 3 also does not show the old channel, so that estimates can not be made.

[1] Report on Geological Reconnaissance Survey of Lower Colorado River from Bullshead to Yuma, October, 1902–June, 1903.

[2] Report on Reconnaissance of Colorado River from Virgin River to Yuma, by Homer Hamlin and Edgar T. Wheeler, July, 1920.


COLORADO RIVER BASIN
BULLSHEAD DAMSITE NO. 1
TEST BORINGS
Note: Add 7.9 Ft to reduce
Elevations to mean sea level
Dam Site No. 3
COLORADO RIVER
Elev at surface
bedrock
bottom of hole
511.95
444.95
434.95
N

([1] Vol. 7, p. 50)

On page 134 of the second annual report it is stated that—

The first proposed site was abandoned. Back of the rocky river hills there was exposed a contact point of clay and sand at sufficiently low elevation to jeopardize a 100-foot dam at this point.

With the type of dam and percolation factor proposed it is believed that the "clay and sand contact" can be sealed in the same manner as the closures across the old channel is affected—by means of a rear apron.

DAM

([1] Vol. 7, p. 52)

An earth dam 1,600 feet long is proposed to close the present and ancient channels of the river with a concrete core wall throughout, resting on rock in the present channel and on a spread foundation in the older and deeper channel, this core wall to be carried to a level 4 feet above the earth dam for a parapet wall. The earth dam is to have an upstream slope of 2:1, riprapped for wave protection, and connected with an upstream apron 5 feet in thickness to hinder percolation through porous foundation strata. The downstream slope is to be 3:1, heavily riprapped for protection against wave action and against percolation through the dam. The dam is to have a height of 15 feet above the normal high-water level and a total height above low water of 170 feet.

A small concrete dam will close a low gap east of the earth dam.

SPILLWAY

([1] Vol. 7, p. 57)

Four drum gates 18 feet high by 96 feet long, mounted on a concrete crest in a saddle west of the dam, are proposed, each to discharge into a 30-foot concrete-lined tunnel 900 feet long, with a combined capacity of 100,000 second-feet at normal high water and 200,000 second-feet with water 5 feet below the top of the dam. Other outlet facilities will add 50,000 second-feet more.

CONSTRUCTION MATERIALS

Material suitable in amount and character for the earth fill is available in the immediate vicinity, though care may have to be exercised in its selection. Granite for riprap and embankment work will be available from excavation for tunnels, outlet works, power plant, etc.

CONSTRUCTION PLAN

([1] Vol. 7, p. 58; Vol. 9, pp. 40, 91)

Prior construction of upstream storage has been assumed with river control during construction of the Bullshead Dam, to flows not exceeding 40,000 second-feet. For diversion of this amount of water during construction of the earth dam which is proposed to be made "in the dry," two 35-foot-diameter concrete-lined tunnels are to be provided between the dam and the spillway, emptying into the lower spillway basin, with stream flow to be diverted thereto by means of a rock-fill cofferdam at the upper end and by the lower toe of the dam at the lower end. Upon completion of the dam, the lower ends of the tunnels would be fitted with two 18-foot needle valves, each to permit by-passing irrigation water and for sluicing purposes, while steel penstocks from the tunnels would carry water to the power house. The upper ends of the tunnels would be plugged, and immediately back of the plugs intake towers would be added to provide the primary control of water released for power and irrigation purposes.

RIGHT OF WAY

([1] Vol. 7, p. 60)

In the letter of November 6, 1920, the Yuma project manager states:

The land in the Bullshead Reservoir site was withdrawn in 1903. It is not believed there is any private land in the site. There are a few squatters in the Cottonwood Island district with some irrigation improvement, consisting of some small pumping plants and small ditches and a few hundred acres under cultivation. The value of these improvements is estimated at $15,000.

There are several mining claims, some with mills constructed and with other improvements in the reservoir site. It is not known what the value of these claims is.

It is believed that the item of contingencies may be assumed to include purchase of property of unknown value.

ACCESSIBILITY

([1] Vol. 7, p. 60)

While a railroad connection could be provided without difficulty, truck haul will probably be found the more economical on account of the limited amount of material to be transported.

([1] Vol. 7, pp. 60–61)

Unit costs:	
Portland cement—	
Assume cost at mill (bulk) .... per barrel..	$2.00
Freight from Colton, Calif., to Union Station as of Jan. 8, 1924, 380 pounds, at $0.2366 per hundredweight .... per barrel..	.90
Freight by truck from Union Station to dam site at $0.25 per ton-mile .... per barrel..	1.25
Storage and handling .... do....	.15
Total estimated cost at dam site .... do....	4.30
Sand for concrete—	
Assumed same as used in Boulder Canyon estimate..per cu. yd..	1.50
Gravel for concrete—	
Assumed same as used in Boulder Canyon estimate .... do....	.90
Cobbles for concrete—	
Assumed same as used in Boulder Canyon estimate .... do....	.90
Earth in embankment .... do....	.65

COST ESTIMATE

Bullshead development with installation of 400,000 horsepower.
Raise in water surface 143 feet.

[All items include 22½ per cent of field cost for overhead, engineering, and contingencies]

Dam	$3, 648, 662
Intake towers, tunnels, and valves	5, 844, 500
Diversion, other than included in dam	1, 451, 625
Spillway	2, 742, 775
Penstocks, powerhouse and contents	15, 172, 300
Switching station	2, 561, 110
Right of way, construction camp, etc	357, 700
Total	31, 778, 672
Called in report	31, 500, 000

Above data from volume 7, pages 47 and 74, and volume 9, pages 258–263.

SEQUENCE OF DEVELOPMENT BELOW GRAND CANYON NATIONAL PARK

Boulder Canyon Reservoir is, of course, the first to be built for the reason that it alone is capable of providing the necessary capacity for flood control and at the same time an adequate power output to permit repayment of the cost of the reservoir, dam, and power plant from power revenues alone.

For a long term of years, possibly as high as 25 to 40, after the construction of Boulder Canyon Reservoir the slow development of the upper basin will leave a water supply for the Boulder Canyon Reservoir such that a full power output may be had and additional water may at times be released when needed for irrigation purposes in excess of power demand for an irrigation development on the lower Colorado River at least double the present area. For this length of time there would then be no need or necessity for a reregulating reservoir on account of the usual lack of coordination between power and irrigation requirements.

Undoubtedly the growing power market in California will necessitate additional power plants on the Colorado River long before the end of the so-called 25 to 40 year period above described, and the location of the power plants will be governed solely by the relative cost of power development.

Bridge Canyon Dam appears to be the most attractive of the sites, in that it is believed to have a shallow depth to bedrock and a very high head, namely, 555 feet, can be obtained with a moderate amount of concrete. The dam site is only about 35 miles from a railroad. While this power dam would have only a small amount of regulating storage and its yearly load factor is therefore likely to be moderately low, pending the construction of reservoirs upstream, the combined load factor of Boulder Canyon and Bridge Canyon can be made to fit the market and yet develop a very large part of the flood period power at Bridge Canyon since the Boulder Canyon plant could be run at a higher load factor at times when the stream flow at Bridge Canyon would permit only a low load factor at that point.

The best plan of development below Boulder Canyon contemplates a dam at Bullshead to utilize the entire river drop down to the Needles Valley and a dam at Parker to utilize the entire drop between Needles and Parker Valleys, leaving the greater part of the Mohave Valley between the Bullshead Dam and the backwater of the Parker

Dam for future development. Either dam can be constructed to provide reregulation of Boulder Canyon outflow if desirable, and in addition provide a material power output.

The development of the Colorado River Indian Reservation, also called the Parker Valley, containing 110,000 irrigable acres, requires the construction of a diversion dam, in order to provide a gravity supply and for this purpose the Parker Dam is admirably suited. In addition, the Parker Dam may be used to provide a high level diversion for supply to be carried to Los Angeles; to provide the highest feasible diversion for the Parker-Gila Valley project; and to provide the highest feasible diversion for the development of California lands lying above the elevation of Palo Verde Valley, including the Palo Verde mesa, the Chucawalla Valley, and an area around Blythe estimated by LaRue in the Arizona Engineering Commission report, at 50,000 acres. The Parker Dam would at the same time be able to create a considerable power output by reason of water that would be by-passed for use in the Parker Valley and for diversion by the Yuma project and the Imperial Valley. For reregulation purposes it would be necessary to reserve something like 25 feet of the upper portion of the storage behind the Parker Dam, if reregulation were to be obtained at this point entirely.

The better plan is to provide a part of the requisite reregulation capacity at the Parker Dam and a part at the Bullshead Dam. By this method the high level diversion advantages of the Parker Dam would not be materially encroached upon while the average head maintained at Bullshead would be a near maximum.

In view of the manifold purposes which the Parker Dam would serve and the probability that the cost per kilowatt of power would be no greater at Parker Dam than at Bullshead, it would appear very likely that the Parker Dam would be built first and if the present estimates of the growth of power load in California are approximately correct, the construction of the Parker Dam can be contemplated within 18 to 20 years after completion of the Boulder Canyon Dam. The amount of power available at Parker is 190,000 horsepower and would be fully absorbed by the California market in two to three years, making it appear probable that the Bullshead Dam would be started approximately 20 years after the completion of the Boulder Canyon Dam.

The Bullshead Dam has a power capacity, with present water-supply conditions, of 405,000 horsepower (see p. 219). In both instances the power capacity given is based on a 55 per cent load factor.

Should the advantages to be realized from the Parker Dam prove to be fully as great as herein outlined, it is quite possible that its construction will not be delayed until there is a demand for its power output but that it would in fact be constructed very shortly after the completion of the Boulder Canyon Dam and in any event ahead of the Bridge Canyon Dam.

Summarizing, then, it appears that the most likely sequence of development below the Grand Canyon National Park would be as follows:

1. Boulder Canyon Dam.
2. Parker Dam.
3. Bridge Canyon Dam.
4. Bullshead Dam.

The next construction after the above four dams on the Colorado River is anticipated to be a storage dam at either Lees Ferry or Dark Canyon, Dark Canyon being just above the backwater of Lees Ferry site. It is not expected that a power plant would be provided at such a reservoir, the purpose of its construction being to provide a better distribution of the water supply for the Bridge Canyon Dam, thereby increasing its power output and to relieve the Boulder Canyon Dam of a portion of its flood control reserve, thereby permitting a higher average head and an increased power output.

It also appears likely that public opinion will by that time permit the construction of power dams in the Grand Canyon National Park, which dams would receive much benefit from the river regulation at Lees Ferry.

Boulder Canyon versus Mohave Valley

FLOOD CONTROL

The time for travel of Colorado River waters from Boulder Canyon Reservoir to the Imperial Valley is roughly one day more than from Mohave Valley Reservoir, and the latter thus permits a slightly better control in time of need for reduction in stream flow. The anticipated construction of the Parker diversion dam will eliminate this advantage. The intervening area between the reservoirs is not productive of appreciable run-off.

SILT CONTROL

If adequate capacity is provided at Mohave Valley Reservoir, the reservoirs are on an equal plane in this respect.

IRRIGATION STORAGE

With equal capacities, the Mohave Valley Reservoir would have a slight advantage by reason of lesser distance, but this advantage would be lost with the anticipated construction of the Parker diversion dam.

RESERVOIR EVAPORATION LOSSES

The surface area for the Mohave Valley Reservoir would be fully 40 per cent larger than for Boulder Canyon Reservoir for equal storage capacities of large amount. The lower altitude, higher temperatures, and greater exposure to winds at Mohave Valley produce, in addition, a larger rate of loss, so that the reservoir loss as a whole, for equal capacity, will be from 50 to 75 per cent greater for the Mohave Valley Reservoir than for the Boulder Canyon Reservoir, a factor of much importance in the ultimate utilization of the water resources of the Colorado River Basin.

ENGINEERING FEASIBILITY

Neither site presents problems especially difficult of solution but great (at present unknown) depths to rock at the Topock Dam site may necessitate the construction of a type of dam other than that of the concrete gravity type assumed in the construction estimates, with an increase in costs.

POWER PRODUCTION

The raise in water level for equal reservoir capacities at the Topock Dam is slightly less than half that at Black Canyon Dam with correspondingly less power output since the amount of water available for use will be the same at both sites. The future construction of the Parker Dam which is needed for irrigation diversion will reduce the power head at Topock Dam to some extent.

POWER MARKET

The principal market for power from both dam sites is southern California with the distance to the market from the two points roughly equal, the Mohave Valley distance being slightly less. Both are within transmission distances now considered feasible.

COST

For reservoirs of small capacity, comparative estimates show practically equal costs and from very rough estimates the same appears to be true for larger capacities although this can not be fully verified with the present lack of data on Topock Dam site, particularly as to foundation conditions.

FINANCIAL FEASIBILITY

The greatly reduced annual power income of the Mohave Valley reservoir in comparison with that anticipated for Boulder Canyon Reservoir will be insufficient to finance construction of the Mohave Valley Reservoir with plans now under consideration for financing Boulder Canyon Reservoir.

Comparison of Reservoirs

BOULDER CANYON VERSUS LEES FERRY

The comparisons are based on the construction of a dam in Black Canyon for the Boulder Canyon Reservoir and at the lower Lees Ferry site for the Glen Canyon Reservoir.

FLOOD CONTROL

The time for travel of water in the Colorado River is almost twice as long from Lees Ferry to the Imperial Valley as from Boulder Canyon. When waters are being released for flood control purposes and the occasion arises to reduce such flow past the Imperial Valley by reason of needed repairs to the levee system or anticipated floods on Gila River, response of the river will not be as prompt with Glen Canyon Reservoir as with Boulder Canyon Reservoir. Between Glen and Boulder Canyons there is a drainage area of 56,000 square miles drained principally by the Little Colorado and Virgin Rivers. Floods of considerable magnitude may originate in this area. With the construction of additional dams between Lees Ferry and Parker for power purposes, this advantage will gradually be lost.

SILT CONTROL

Material reduction, approaching stoppage, of the silt flow through the Lower Colorado River is necessary to reduce the operating costs for the irrigation systems and to minimize the upbuilding of the Colorado River delta. Unless accomplished, large quantities of Colorado River water must be wasted past the intakes at Laguna Dam and Imperial heading to carry silt onward toward the Gulf of California. Much silt is contributed by the area between the two reservoirs, particularly by the washes entering Colorado River in the Grand Canyon region all of which have very steep gradients through the readily eroded sedimentary formations. The power dams which would be constructed below Lees Ferry in the event Boulder Canyon is not constructed, would offset the advantages of Boulder Canyon, but plans so far advanced for such dams contemplated capacities which would be lost by silting in a relatively short time unless Mohave Valley Reservoir were built to large capacity.

IRRIGATION STORAGE

Boulder Canyon being nearer to the irrigated area and controlling a larger portion of the total run-off would be more effective. This advantage would be largely lost with the construction of power dams below Lees Ferry.

RESERVOIR EVAPORATION LOSSES

For storage capacities of 6,000,000 acre-feet or more, the surface area of the Glen Canyon Reservoir is larger than for Boulder Canyon Reservoir, but on account of the lesser evaporation rate for the Glen Canyon Reservoir, the average annual loss would be approximately equal.

ENGINEERING FEASIBILITY

Boulder Canyon Reservoir is feasible in that a safe dam can be constructed in accordance with recognized engineering principles on the sound rocks found at the dam site. A concrete dam for the Glen Canyon Reservoir necessitates foundation pressure, not considered entirely safe and the inclosing rock structure presents grave possibilities of destructive percolation losses.

POWER PRODUCTION

For equal capacities the power heads are roughly equal but the flow at Boulder Canyon is nearly 10 per cent larger, making the power production proportionately larger. The Glen Canyon Reservoir would materially increase power production of all sites between the two reservoirs but this advantage will largely be lost as reservoirs are constructed in the upper basin for power and irrigation purposes.

POWER MARKET

Boulder Canyon lies within recognized limits for transmission of power to the most promising, and at present only, market available. Glen Canyon is over 500 miles or roughly twice as far from the same market, a distance not now considered a practicable transmission-line distance.

COST

For equal storage capacities, Glen Canyon Reservoir will cost more than twice as much as Boulder Canyon Reservoir.

FINANCIAL FEASIBILITY

The margin of sale price over cost for the Boulder Canyon power is inadequate to finance the additional cost of the Glen Canyon development over that of the Boulder Canyon development if the present proposed plan of finance is followed.

POWER

Load and output of large power companies in Southern California

PEAK LOAD IN KILOWATTS

Year	Southern California Edison Co.	City of Los Angeles Bureau of Power and light	Southern Sierras Power Co.	Los Angeles Gas and Electric Corporation	San Diego Consolidated Gas and Electric Co.
1921	238, 480	51, 900	45, 700	------------	------------
1922	259, 160	75, 275	36, 200	------------	------------
1923	312, 600	98, 945	40, 100	43, 500	------------
1924	330, 660	101, 162	40, 500	69, 000	------------
1925	395, 900	109, 850	49, 900	58, 300	27, 300
1926	422, 700	121, 700	50, 200	68, 200	31, 900
1927	448, 900	133, 300	57, 600	74, 000	------------

YEARLY OUTPUT IN MILLIONS OF KILOWATT-HOURS

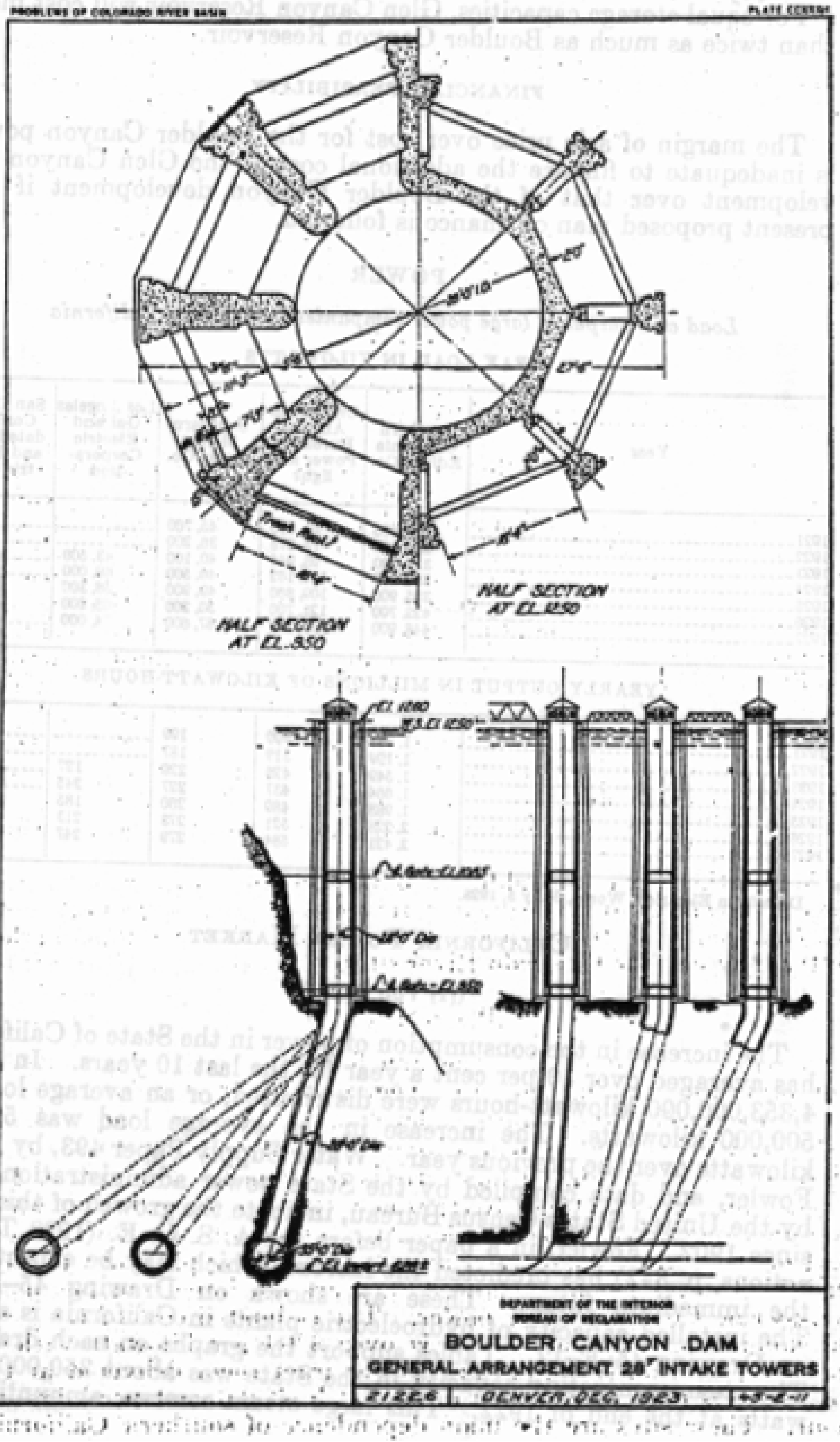
Year	Southern California Edison Co.	City of Los Angeles Bureau of Power and light	Southern Sierras Power Co.	Los Angeles Gas and Electric Corporation	San Diego Consolidated Gas and Electric Co.
1921	1, 225	300	199	------------	------------
1922	1, 159	319	187	------------	------------
1923	1, 349	426	220	127	------------
1924	1, 664	437	227	245	------------
1925	1, 983	480	260	185	118
1926	2, 228	521	273	213	123
1927	2, 421	584	279	247	127

Data from Electrical World, May 5, 1928.

California Power Market

([1] Vol. 8, p. 9)

The increase in the consumption of power in the State of California has averaged over 10 per cent a year for the last 10 years. In 1922, 4,353,000,000 kilowatt-hours were distributed, or an average load of 500,000 kilowatts. The increase in the average load was 50,000 kilowatts over the previous year. Water Supply Paper 493, by F. H. Fowler, and data compiled by the State power administration, and by the United States Census Bureau, indicate the growth of this load since 1902. Fowler, in a paper before the A. S. C. E. (1923 Transactions, p. 842) has predicted the increase which may be expected in the immediate future. These are shown on Drawing 45–E–13. The installed capacity of hydroelectric plants in California is shown on Drawing 45–E–12. Tables support the graphs on each drawing. The steam-generating capacity in the State was about 350,000 kilowatts at the end of 1922. This large steam reserve, amounting to


PROBLEMS OF COLORADO RIVER BASIN
HALF SECTION AT EL. 850
HALF SECTION AT EL. 1050
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON DAM
GENERAL ARRANGEMENT 28' INTAKE TOWERS
21226
DENVER, DEC. 1923
45-2-11

38 per cent of the installed hydroelectric generating capacity, was in part necessary to provide against lack of water power, and the ratio of steam to hydropower capacity can be reduced by providing storage reservoirs for the hydroelectric plants.

The power at Boulder Canyon would be firm power, available 24 hours a day, year in and year out. Moreover, daily, weekly, and monthly peaks could be carried without waste of water, so long as the average draft does not exceed the value assumed in the water studies. In this respect Boulder Canyon power is at least as reliable as steam power and probably more reliable, considering the risk of fuel supply in steam plants and the greater ease of picking up large, unexpected loads with the hydraulic plant.

([1] Vol. 8, p. 10)

Compared with hydraulic developments in California, even when such developments are provided with adequate storage, Boulder Canyon power has the great advantage of having an immense reservoir at the plant available for instantaneous use, while in the California developments the storage reservoirs would be, in many cases, several miles distant, and additional water could be supplied only after some hours' notice of the requirement. Considering the reliability of the water supply at Boulder Canyon, the generating capacity required to handle a given average load would be less than in the California plants. Generating capacity of about 200 per cent of the average load will probably be required under the most favorable conditions. The average load in 1932, when power from Boulder Canyon is estimated to be available, will probably exceed 1,250,000 kilowatts. This means generating capacity of perhaps 2,500,000 kilowatts. It appears therefore that additional capacity to the extent of 1,500,000 kilowatts will be needed by 1932, and the installed capacity will need to be increasing at the rate of 200,000 kilowatts annually at that time.

The northern part of California is well supplied with water-power sites, and on account of the greater transmission distance from Boulder Canyon, many of these sites can undoubtedly serve this market better than can the Colorado River sites.

([1] Vol. 8, p. 11)

On Big Creek (including the San Joaquin River) the Southern California-Edison Co. has sites aggregating 900,000 kilowatts of which about 200,000 kilowatts is developed. The San Joaquin Light & Power Co. has sites on Kings River aggregating 200,000 to 300,000 kilowatts of which 80,000 kilowatts is developed. The city of Los Angeles has sites on Owens River which will develop 90,000 kilowatts and on Kings River 150.000 kilowatts. Other sites in the southern part of the State are mostly of uncertain water supply and will have such high development costs that they are not important factors in considering Colorado River power. The estimated cost of the large developments mentioned above is over $200 per kilowatt without including transmission lines and power from them delivered at the load centers may be expected to cost at least 0.6 cent per kilowatt-hour. These sites are the main dependence of southern California,

and development must proceed at a rapid rate to keep pace with the growing demand. The best sites will have to be developed before power can possibly be delivered from Colorado River. Should a large block of power be brought in from the latter source, it might release a certain amount of power from the San Joaquin, Big Creek, and other sites which could then be sent north, but in dealing with the immediate problem it seems best to consider only the southern part of California as a prospective market.

([1] Vol. 8, p. 12)

In the southern part of California 2,184,000,000 kilowatt-hours were distributed in 1922, or an average load of 250,000 kilowatts. By 1932 the average load may be expected to reach 800,000 kilowatts, requiring a generating capacity of probably 1,600,000 kilowatts. At that date the annual increase will approximate 75,000 kilowatts, requiring new installation at the rate of 150,000 kilowatts a year. The installed hydroelectric capacity was 400,000 kilowatts in 1922 and the steam-electric capacity was 225,000 kilowatts. By 1932 nearly 1,000,000 kilowatts of new generating capacity will be required.

Boulder Canyon Power Plant

Cost estimate Boulder Canyon power plant—installation, 1,200,000 horsepower

[To be increased in accordance with the Colorado River Board report on Black Canyon (see p. 48)]

[Data from vol. 8, pp. 51, 54, 55, 57, 59, 69, 72, 73, 74, 75]

Colorado River Board raises this estimate 20 per cent for installed capacity of 1,000,000 horsepower.

	Quantity	Unit cost	Item cost	Feature cost
Intake towers, 3 to 28 feet diameter:				
Excavation, rock	66,300 cubic yards	$1.50	$99,500.00	
Concrete columns, base, top, and beams.	11,040 cubic yards	25.00	276,000.00	
Inside lining, concrete	16,800 cubic yards	20.00	336,000.00	
Concrete in gate house, etc	180 cubic yards	40.00	7,200.00	
Gate house	3 each	800.00	2,400.00	
Pipe railing and lamp posts			2,700.00	
Trash racks	3,984,000 pounds	.08	318,700.00	
Cylinder gates, cast iron	2,082,000 pounds	.20	416,400.00	
Bronze lining	48,000 pounds	.50	24,000.00	
Connecting bridges	3		17,400.00	
Concrete bridge			6,100.00	
Hoists and motors	110,000 pounds	.33	36,300.00	
Gears, couplings and guides, etc.	184,000 pounds	.22	40,500.00	
Crane (one-half of cost)	100,000 pounds	.20	20,000.00	
Rake and hoist			3,000.00	$1,606,200.00
Diversion tunnels (part chargeable to power, balance included with cost of dam):				
Excavation	495,000 cubic yards	6.00	2,970,000.00	
Concrete lining, 30 inches	150,000 cubic yards	13.00	1,950,000.00	
Pressure grouting	9,600 linear feet	16.00	153,600.00	
Downtake tunnels from towers, 28 feet:				
Excavation	39,200 cubic yards	12.00	470,400.00	
Concrete lining, 30 inches	11,100 cubic yards	13.00	144,300.00	
Pressure grouting	1,130 linear feet	13.00	14,700.00	5,703,000.00
Penstocks, 12 units:				
Excavation, rock	25,850 cubic yards	10.00	258,500.00	
Concrete plugs (at lower end of tunnels).	5,100 cubic yards	8.00	40,800.00	
Concrete piers	271 each	13.00	3,520.00	
Steel pipe	3,850 tons	300.00	1,155,000.00	1,458,200.00
Total (approximate)				

Cost estimate Boulder Canyon power plant—installation, 1,200,090 horsepower—Con.

	Quantity	Unit cost	Item cost	Feature cost
Generating station building:				
Tailrace excavation	33,800 cubic yards	$2.50	$84,500.00	
Station excavation	123,730 cubic yards	1.50	185,600.00	
Mass concrete in substructure	37,400 cubic yards	12.00	448,800.00	
Reinforced walls, etc., in substructure.	7,700 cubic yards	18.00	138,600.00	
Reinforced slabs, etc., in substructure.	5,000 cubic yards	30.00	150,000.00	
Reinforced walls, etc., in superstructure.	5,230 cubic yards	35.00	183,000.00	
Reinforced slabs, etc., in superstructure.	1,750 cubic yards	40.00	70,000.00	
Thin walls, metal lath, and plaster.	96,400 surface feet	.35	33,700.00	
Steel rails	150,000 pounds	.05	7,500.00	
Structural steel and floor plates	2,572,000 pounds	.08	205,800.00	
Pipe railings	15,560 pounds	.15	23,300.00	
Temporary end walls	56,000 pounds	.12	6,700.00	
Steel rolling doors	19,130 surface feet	2.00	38,300.00	
Steel swing doors	1,342 surface feet	1.50	2,000.00	
Windows, steel sash	28,900 surface feet	1.50	43,400.00	
Roofing	93,650 surface feet	.25	23,400.00	
Piping, plumbing, hardware, lighting, fixtures, woodwork, and painting, lump sum.			54,000.00	
Finishing walls	78,000 surface feet	.10	7,900.00	
Finishing floors	35,600 surface feet	.20	7,100.00	
Miscellaneous labor and material.			22,500.00	
Total building			1,977,100.00	
Hydraulic equipment:				
Turbines and governors, 12	12 units	275,000.00	3,300,000.00	
11 by 10 feet balanced valves	do	125,000.00	1,500,000.00	
Freight and erection	15,720,000 pounds	.025	393,000.00	
Cranes and tools, including freight and erection.	750,000 pounds	.33	248,000.00	
Electrical equipment:				
Generators and exciters, 12	12 units	500,000.00	6,000,000.00	
Humidifiers	do	6,500.00	78,000.00	
15-kilovolt O-C breakers	12	7,500.00	90,000.00	
15-kilovolt disc. switches	108	275.00	29,700.00	
27,000 kilovolt ampere transformers.	36	51,500.00	1,854,000.00	
200 kilovolt ampere transformers.	3	800.00	2,400.00	
100 kilovolt ampere transformers.	6	600.00	3,600.00	
2,300 volt O-C breakers	34	250.00	8,500.00	
2,300 volt disc. switches	190	20.00	3,800.00	
Voltage regulators	12	1,000.00	12,000.00	
Switchboard	12	5,000.00	60,000.00	
Installation transformers			17,100.00	
15 kilovolt generator leads	12	1,400.00	16,800.00	
15 kilovolt bus supports	900	16.00	14,400.00	
Station wiring			60,000.00	
Conduit system			30,000.00	
Cooling water system			9,500.00	
Transformer oil system			28,000.00	
Lubricating oil system			11,000.00	
Storage batteries and charging sets.			3,000.00	
Telephone equipment			5,000.00	
Miscellaneous equipment			31,200.00	
Freight and erection			1,038,600.00	
Total station equipment			14,848,200.00	
Total generating station				$16,825,300.00
Incline railroad:				
Excavation	4,500 cubic yards	2.00	9,000.00	
Track, fastenings, ties, etc			1,116.00	
Car, hoist, hoist house, and cable.			4,750.00	
Freight and installation			9,000.00	
				23,871.00

Cost estimate Boulder Canyon power plant—installation, 1,200,000 horsepower—Con.

	Quantity	Unit cost	Item cost	Feature cost
Power lines to substation:				
Excavation and backfill			$3,900.00	
Concrete			8,100.00	
Steel towers			72,000.00	
Conductors and insulators			60,000.00	
Freight installation, miscellaneous.			27,000.00	
				$180,000.00
Elevator				30,000.00
Operators quarters				100,000.00
Improvements to grounds				20,000.00
Total field cost				25,958,571.00
Engineering, overhead and contingencies, 22½ per cent.				5,840,678.00
Total				31,799,249.00
Roughly				32,000,000.00

Power (Cost Comparison)

The Bureau of Reclamation estimates that 1,200,000 horsepower installed capacity will cost $32,000,000.

The engineering board rendering its report to the Secretary of the Interior November 24, 1928, raises that estimate approximately 20 per cent for an installed capacity of 1,000,000 horsepower, making the total cost of the proposed plant for the 26,000,000 acre-foot reservoir $38,500,000.

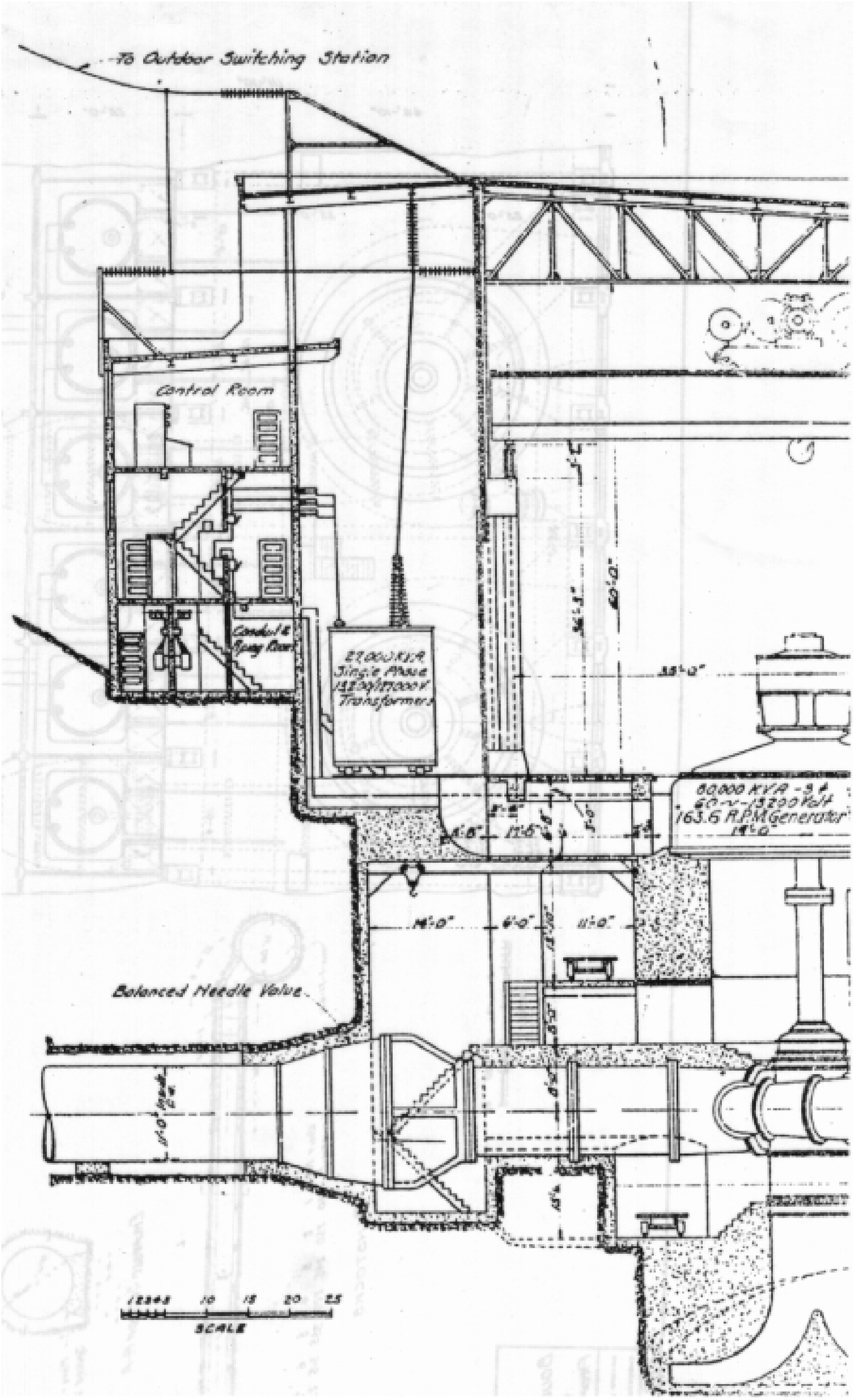
The detail costs then may be taken for estimating purposes as listed, adding the proposed 20 per cent, although all items will not be effected in the same ratio.

Extra power can be developed beyond the 1,000,000 proposed installation capacity, during the period of upper basin irrigation development, which time is variously estimated from 50 to 150 years for full development. This extra installation is estimated to be economically feasible and will no doubt be brought about, the equalized flow will be nearer 20,000 second-feet than the required 10,000 or 12,000 second-feet for the first 40 or 50 years.

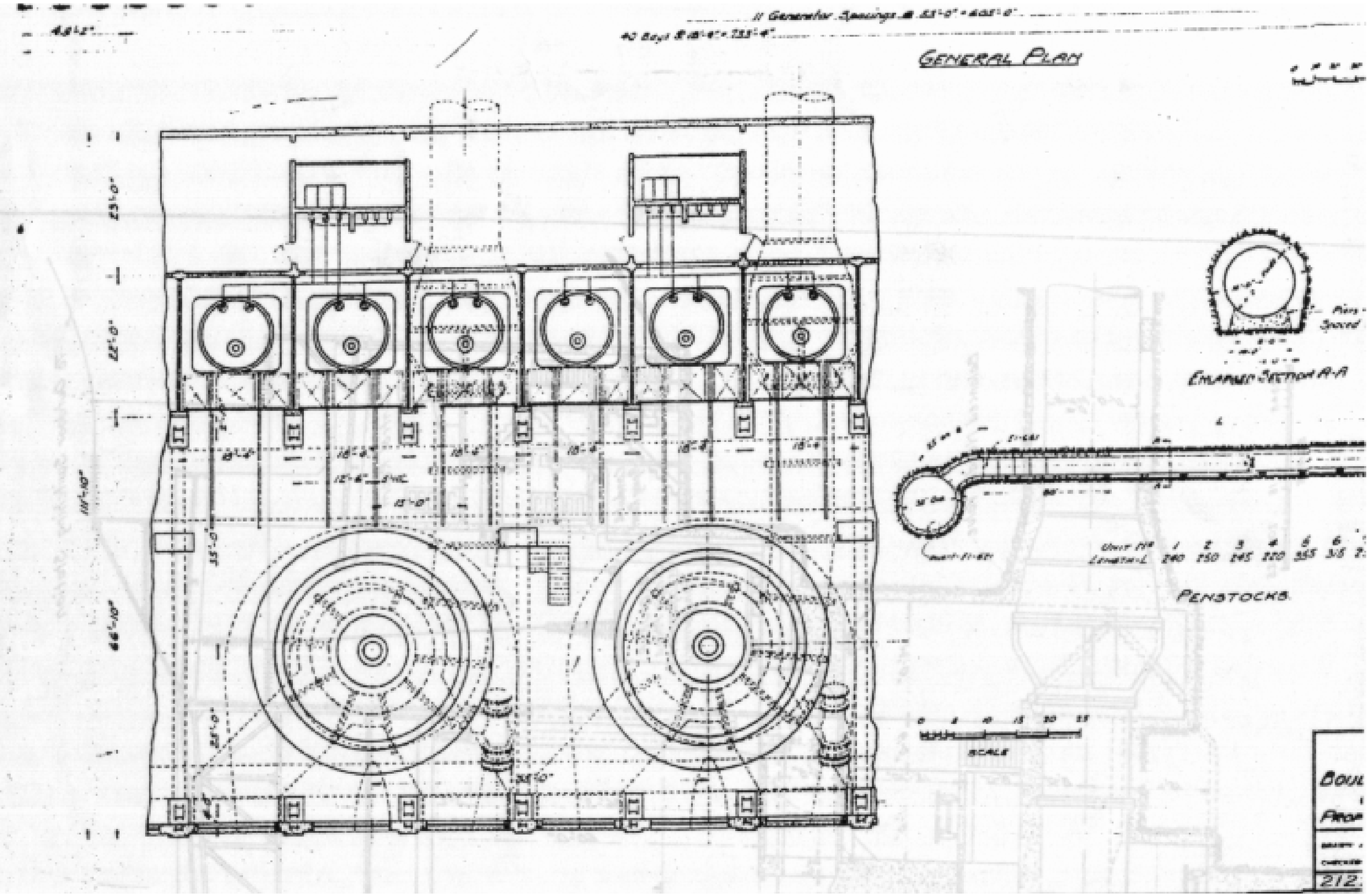
For the above period of time the plants may be operated upon a load factor of from 75 to 85 per cent, which would mean 750,000 to 850,000 firm horsepower would be available instead of the 550,000 firm horsepower after full irrigation development in the entire Colorado River Basin.

It is, of course, impossible in a report such as this to give the details in relation to every item mentioned, but in each case reference is made to the source of the informaton so that the supporting data is readily obtainable.

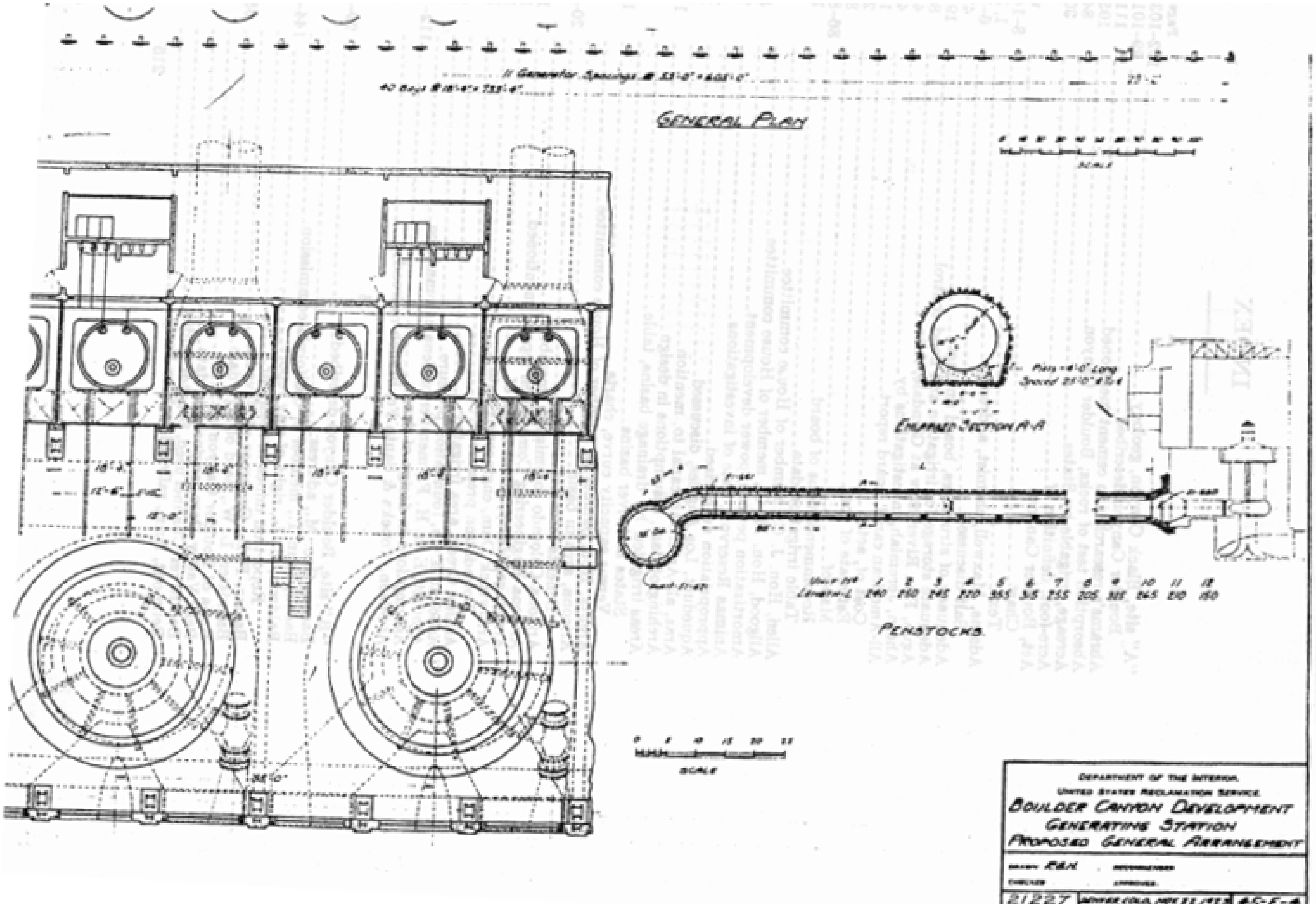
Geo. W. Malone.
State Engineer for Nevada,
Secretary Colorado River Commission.



To Outdoor Switching Station
Control Room
27,000 KVA
Single Phase
Transformers
80,000 KVA
163.6 R.P.M. Generator
Balanced Needle Valve
1 2 3 4 5 10 15 20 25
SCALE



11 Generator Spacings @ 55'-0" = 605'-0"
40 Bays @ 18'-4" = 733'-4"
GENERAL PLAN
111'-10"
66'-10"
22'-0"
23'-0"
ENLARGED SECTION A-A
Unit No 1 2 3 4 5 6
Length-L 240 250 245 220 355 315
PENSTOCKS
SCALE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SCALE
ENLARGED SECTION A-A
PENSTOCKS
Unit No. 1 2 3 4 5 6 7 8 9 10 11 12
Length-L 240 260 245 220 355 315 255 205 325 265 210 150
SCALE
DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
BOULDER CANYON DEVELOPMENT
GENERATING STATION
PROPOSED GENERAL ARRANGEMENT
21227
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