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DEPARTMENT OF THE INTERIOR

UNITED STATES RECLAMATION SERVICE

REPORT ON

PROBLEMS OF IMPERIAL VALLEY AND VICINITY

Required by

Act of Congress approved May 18, 1920

41 Stat., 600

(Public No. 208 - 66th Congress)

February, 1922.

NOTE: This report is based upon extended engineering studies, surveys and estimates, and statistical data on file with the Reclamation Service. This material, portions of which formed appendices to the original report as submitted to Congress, is not included here.

U.S. Bureau of Reclamation

DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE

Washington, D. C., Feb. 4, 1922.

The Secretary

of the Interior.

Sir:

Transmitted herewith is "Report on the Problems of the Lower Colorado Basin," required by the Act of Congress approved May 18, 1920, entitled "An Act to provide for an examination and report on the condition and possible irrigation development of the Imperial Valley in California" (41 Stat., 600).

This report supersedes the preliminary report transmitted to you on November 27, 1920, in which it was stated that further report would be made.

The study of the Colorado River Basin from the standpoint of its use in irrigation and otherwise may be said to have begun by the establishment of stations for the measurement of stream discharge in various parts of the basin in 1894 and 1895 by the U. S. Geological Survey. One of these stations was established at Yuma, Arizona, to intercept and measure the discharge of the entire stream, there being no tributaries below this point. It was found that gage height readings had been kept for a considerable period by the Southern Pacific Railroad Company at Yuma and these were utilized so far as possible, but the shifting nature of the channel made their use of doubtful value, and also to a considerable extent vitiated the records kept at Yuma by the Geological Survey for the first few years.

After the passage of the Reclamation Act in 1902 the Reclamation Service took up the systematic study of the lower river, provided for more frequent and systematic gagings at Yuma and other points, and made a topographic survey of the lower valleys of the Colorado River from Bull's Head to the Mexican boundary. The investigations were continued, particularly as regards stream measurements and the survey of reservoir sites and borings at the necessary dams. In the stream measurement work substantial cooperation was extended by the Geological Survey and the results were assembled in the publications of that bureau from time to time.

A more intensive study of the entire basin was inaugurated in 1914 by a special allotment of $50,000 for this purpose, supplemented by annual allotments in subsequent years, and this work was finally assembled in three large volumes of manuscript by Mr. John T. Whistler. It included a reconnaissance of practically all of the proposed reservoir sites and irrigation projects in the basin above the Arizona line and the compilation of all existing data including the water filings and water rights throughout the basin. The study did not stop with the rendition of Mr. Whistler's report, but was transferred to the lower basin where the topographic survey of the basin was continued up the river from Bull's Head and a detailed survey made of the proposed reservoir site at and above Boulder Canyon.

This report has drawn freely upon all previous investigations so far as necessary and applicable to the solution of the problems of the lower valley, as required in the act authorizing the report.

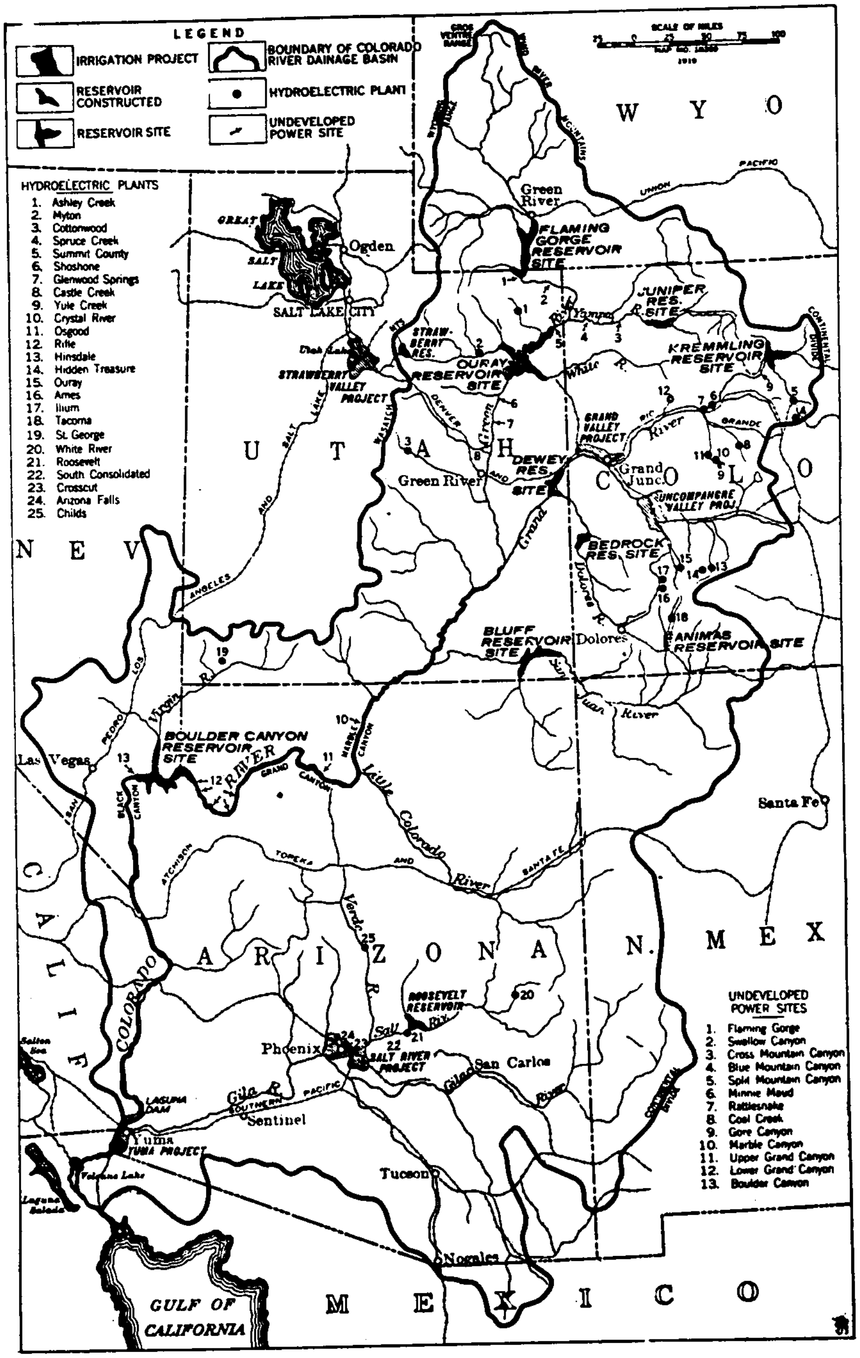
The investigations for this report have been under the direction of Mr. F. E. Weymouth, the Chief Engineer of this Service, and the detailed studies very largely are the work of Mr. Harold Conkling. Acknowledgements are also due to Mr. C. A. Bissell, Engineer, who has made supplemental studies and assisted in arranging and editing the report.

Respectfully,

(Signed) A. P. Davis,

Director.

Enc. 10972.



COLORADO RIVER BASIN

HYDRAULIC PROBLEMS OF THE COLORADO RIVER.

The control of the floods, and development of the resources of the Colorado River, are peculiarly national problems for several good reasons:

1. The Colorado River is international.

2. The stream and many of its tributaries are interstate.

3. It is a navigable river.

4. Its waters may be made to serve large areas of public lands naturally desert in character.

5. Its problems are of such magnitude as to be beyond the reach of other than national solution.

That these problems are national in character, scope and magnitude, was recognized by the Act of Congress approved May 18, 1920, entitled, "An Act to provide for an examination and report on the condition and possible irrigation development of the Imperial Valley in California," which forms the authority for this report.

A broad consideration of the various problems of the Imperial Valley and of the lands "which can be irrigated at a reasonable cost from known sources of water supply by diversion of water from the Colorado River at Laguna Dam," as required by the act under which this report is made, involves a comprehensive study of the entire Colorado Basin, which the law recognized in Section 3, where report was required upon "the effect on the irrigation development of the other sections or localities * * * *."

This report will therefore include a general review of the conditions and water resources of the entire Colorado Basin.

To make the report complete, data were required on five principal lines:

1. Quantity and regularity of water supply for irrigation.

2. Protection from the floods of Colorado River.

3. Storage facilities available.

4. Available land for irrigation.

5. Canal systems required to serve these lands.

The water supply of the Colorado Basin has been measured at various points for many years, and a large number of gaging stations in different parts of the basin have been maintained for varying periods. The measurements have mostly been made by the Geological Survey, but some of them have been conducted by the Reclamation Service, and some by the interested States. So far as available and pertinent they are condensed in this report, and are an essential part thereof.

PHYSIOGRAPHIC FEATURES.

The Colorado River is formed by the junction of the Grand* and Green rivers in southeastern Utah. The Grand, which by reason of its volume may be considered the upper continuation of the main stream and is also in an approximate alignment therewith, rises in northeastern Colorado and has a length above its junction of about 450 miles. Its principal tributaries are Frazer, Blue, Eagle, Williams, and Roaring Forks and the Gunnison River.

The Green is the longest branch, rises in the Wind River mountains of Wyoming, flows in a southerly direction into Utah and then turns eastward flowing into Colorado and back into Utah, and has a length of about 700 miles from its source to its mouth at the junction with the Grand. Its principal tributaries are Blacks Fork, Henrys Fork, Yampa, Ashley Creek, Duchesne River, White River, Minnie Maud Creek, Price River and San Rafael River.

The length of the Colorado from the junction of the Green and the Grand to the Gulf of California is about 1050 miles, thus making, with the continuation of the

(*Foot note). Recent action of the United States and of Colorado and Utah has changed the name from "Grand" to "Colorado."

Green, 1750 miles total length. Below the junction with the Green, it flows southwesterly into Arizona across the northwest corner of that State, then turning south, forms the boundary between Arizona on the east and Nevada, California, and Mexico on the west, reaching the Gulf of California about 120 miles below Yuma.

The drainage area of the Colorado River is 244,000 square miles, distributed as shown in the following table:

AVERAGE DISCHARGES.

	Per cent of total discharge	Discharge in Acre-feet	Square miles	Per cent of total Sq.Mi.	A. F. per Sq.Mi.
Green River	32	5,510,000	44,000	18	125
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	1,530,000	31,000	39	16
Gila	6	1,070,000	57,000	23	19
Total	100	17,550,000	244,000	100	70

The water supply from the various branches is also shown in this table and is by no means in proportion to the area drained, the discrepancy being due to the wide diversity of climatic and topographic conditions.

The rim of the basin whence the streams take their sources is composed largely of high mountain ranges. On the north and east the Wind River Mountains and the ranges of the Continental Divide are the highest and furnish the greatest water supply.

This is especially true of the Rocky Mountains in north central Colorado, and for this reason the run-off from that region is far greater in proportion to area than that of any other part of the basin.

The lower third of the basin is composed mainly of hot, arid plains of low altitude, broken here and there by occasional short mountain groups or ranges reaching elevations of 3,000 to 5,000 feet. The central portion of the basin is a high plateau through which the streams have cut narrow canyons often of great depth. Every tributary through this region is in canyon, so that much of the central and upper part of the basin is traversed by deep gorges and is exceedingly rough. At its mouth the river has built up a great delta from the materials eroded in the canyons described, and has by this means encroached upon the Gulf of California at its mouth and finally cut off the upper end of this gulf entirely. The isolated portion forming a deep depression below sea level, is known as the Salton Basin and includes the Imperial Valley of great extent and remarkable fertility, with a saline lake in the bottom, known as Salton Sea.

The area of the drainage basin of the Colorado River of approximately 244,000 square miles, is divided among the political divisions as follows:

AREA DRAINAGE BASIN

	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

Some of the areas in Arizona and California are very indefinite, owing to the absence of definite topographic divides and the contributions of water from California and Mexico are negligible. The volume of contributory water from the different States, while not separately measured, is in the following order -- Colorado, Utah, Wyoming, Arizona, New Mexico, Nevada, Mexico, California.

The various branches of the Colorado drain the following areas:

	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
	244,000

	Square miles
Area including San Juan and all above	108,000
Above Boulder Canyon, and below mouth of San Juan	53,000
Below Boulder Canyon, and above Gila	24,000
Gila River Basin	57,000
	242,000

SILT DEPOSIT DATA.

The Colorado River and most of its tributaries have been for many centuries, and still are, eroding their beds and banks and carrying large quantities of sediment, a part of which are deposited on the alluvial valleys during periods of overflow, and part reaches the Gulf of California where it is continually extending and enlarging its delta.

Observations of silt carried have been taken periodically at Yuma just below the mouth of the Gila River for a long series of years and show an average annual amount by volume of 113,000 acre-feet, on the assumption that 85 pounds of dry matter is equivalent to a cubic foot of solid. Most of the time, the Gila River is nearly dry and the little water it discharges is clear. The observations at Yuma therefore indicate the silt traveling at that time in the Colorado above the Gila, and by difference at other times, the quantity discharged by the Gila during its relatively short high water periods. Observations on the Gila have also been taken at the Buttes above Florence and at San Carlos. A few observations have also been taken on the San Juan, the Green and the Grand, but these are too few to be conclusive and any statement concerning these streams must be considered as a very rough estimate. The following table shows the estimates on which this report is based.

	Annual water A. F.	Annual silt A. F.	Per cent silt
Colorado at Yuma	17,740,000	113,000	0.85
Gila	1,070,000	15,000	1.40
San Juan	2,700,000	29,000	1.07
Green	5,510,000	30,000	0.54
Grand	6,940,000	20,000	0.29
Other tributaries	1,560,000	19,000	1.22

The silt content of the Colorado, with the Gila not in flood, has averaged about .5 of 1 per cent and this is fairly representative of the silt conditions at Boulder Canyon reservoir. The discharge at Boulder Canyon is estimated at 17,500,000 acre-feet annually. On this basis, the average annual silt discharge is about 88,000 acre-feet per annum.

The development of the best reservoir sites on the main branches of the Colorado River, if used for irrigation in the lower basin would affect the conditions of power development in their basins below, because the water would be regulated in accordance with the needs of irrigation rather than of power. The power possibilities which would be affected thereby are shown in the following table, which is expressed in horsepower, continuous output, 88% efficiency at the turbines.

	Present	After irrigation develops above
Green River Basin:		
Yampa, below Juniper reservoir	289,000	244,000
White, below Rangeley	24,000	16,000
Main Stem, below Flaming Gorge reservoir	1,080,000	729,000
Total -- Green River Basin	1,393,000	989,000
Grand River Basin, below Dewey reservoir	210,000	210,000
Colorado, above Grand Canyon Park	6,510,000	4,810,000
Total	8,113,000	6,009,000
In round figures	8,000,000	6,000,000

The above power developments would be further diminished by evaporation from the reservoirs built for power which would depend largely upon the plan of development.

Urgency of Relief.

In the valleys of the Lower Colorado, and especially the Imperial Valley, storage is needed for the extension of irrigation and for safety against drouth of the areas already irrigated when the cycle of low years rolls around.

The need is also vital for protection from floods of the Colorado which threaten the levees along the river valley and which are a constant menace to the Imperial Valley, threatening a repetition of the experience of 1906. Both of these problems are urgent and vital.

The years 1902, 1903, 1915, and 1919 were years of low water flow, the first two being shortly after the beginning of irrigation in the lower valleys and when the area irrigated was so small that no shortage occurred. In the year 1915 irrigation had proceeded to a substantial degree.

The records of the Imperial Irrigation system show that for a considerable period in 1915 the waters of the Colorado River were all, or practically all, diverted at the intake of that canal and applied in irrigation of Imperial Valley, with the result that an actual shortage existed there part of the time. The shortage was not severe nor disastrous but it had a value as indicating the actual state of the water supply in relation to use. The shortage would have been still greater had a period as low as that of 1902 and 1903 occurred at that time. This relation appears in the following table showing the annual discharge of the Colorado River at the Laguna Dam. It will be noted that 1915, when the first shortage occurred, was by no means the lowest year of record. A shortage also accurred in 1919 and the years 1902, 1903, and 1904 all show a less discharge than 1915.

Table No. 10

DISCHARGE OF COLORADO AT LAGUNA DAM - ACRE-FEET

Year	A.F.	Per cent of mean
1899	21,700,000	132
1900	16,800,000	102
1901	15,200,000	93
1902	9,110,000	56
1903	11,300,000	69
1904	9,890,000	60
1905	16,000,000	98
1906	17,700,000	108
1907	24,800,000	151
1908	12,600,000	77
1909	25,400,000	155
1910	14,200,000	87
1911	17,600,000	107
1912	18,200,000	111
1913	11,800,000	72
1914	20,200,000	123
1915	12,900,000	79
1916	18,900,000	115
1917	20,000,000	122
1918	13,100,000	80
1919	11,000,000	67
1920	21,100,000	129
Mean	16,400,000	

Since 1915 there has been considerable improvement in the application of water in the Imperial Valley but recent experience shows that storage is needed to supplement the low water flow before any large irrigable areas can be added.

Since 1915 Imperial Valley has increased its irrigated area over 60,000 acres in the United States and about 150,000 acres in Mexico. The Imperial Irrigation District contains more than 100,000 acres of irrigable land not yet irrigated and the same valley in Mexico can increase over 40,000 acres and is in a physical position to take the necessary water from the Imperial Canal before it reaches the California line.

The Yuma project is increasing its irrigated area and has a recognized right to extend up to a limit of 120,000 acres.

The Palo Verde Valley has increased its irrigated area since 1915 by about 15,000 acres and is in physical position to increase this area up to 78,000 acres.

Two government projects in Colorado taking water from the Colorado River drainage have increased their acreage since 1915 about 30,000 acres and have established rights by which these can be further increased by over 50,000 acres. In addition to the above, irrigation uses are increasing in the Uintah and Spanish Fork basins in Utah and at numerous other points in the upper Colorado Basin, most of which are small in amount but which aggregate a considerable acreage and will reduce the water supply of the lower basin to a substantial degree. These may be taken as offsetting the improvements in duty of water in the Imperial Valley.

Assembling the more important of the known data, we have the following table showing increase over 1915;

Project	Irrigated 1915	1920	Ultimate
Imperial District	336,000	415,000	515,000
Mexico	40,000	190,000	(?)
Yuma	28,000	54,000	120,000
Palo Verde	20,000	35,000	78,000
Grand Valley Project	----	15,000	53,000
Uncompahgre project	50,000	70,000	110,000
Total	474,000	777,000	---

This table indicates that the increased irrigation in the Basin in 1920 over 1915 is about 300,000 acres and that the desired expansion in the Imperial Irrigation District and incontestible or unpreventable expansion in other regions will bring this acreage up to 877,000 acres, or about 400,000 acres more than in 1915, besides the various increases in the Upper Basin.

In addition to this, there are large areas in the Colorado River Reservation, the Mohave Valley, and at some other points where development has been undertaken, or is likely to be undertaken in the near future, which should be taken into account.

The above data are certainly convincing that no large area, such as the East Mesa lands and Coachella Valley can be added to the irrigated acreage without certainty of water shortage, or if so added would constitute a serious menace to the water supply of the present irrigated lands in the Imperial and Yuma valleys unless a large amount of storage be provided.

For full development of all the lands that can be reached by gravity and reasonable pumping lifts on the Lower Colorado River, large storage capacity will be required, estimated at about 11,000,000 acre-feet, if provided by a reservoir below the Grand Canyon in the Colorado. If storage is provided above the Canyon, this must be increased by at least 2,000,000 acre-feet on account of the unavoidable losses due to the impossibility of regulating the flow in exact accordance with the needs of irrigation from a reservoir so far distant, and for other reasons. This capacity can be somewhat reduced if the acreage be reduced by cutting off the more doubtful and less desirable acres which have been included.

To remove the menace of flood from the Colorado River will require a much larger storage capacity than that above given.

Owing to the gradual upbuilding of its deltaic bed and banks, the flood menace from the Colorado River is an increasing and ever-recurring problem of great importance.

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

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

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

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

The floods divide themselves naturally into two general classes - those from the Colorado River, which drains large areas in Wyoming, Colorado, New Mexico, Utah and Arizona, and those from the Gila, which lies mostly in Arizona and partly in New Mexico and Mexico. While the area drained is much larger for the Colorado than for the Gila and the water supply vastly greater, the habits of flow are such that the Gila River, owing to its flashy character, sometimes furnishes flood waves at its mouth near Yuma almost as large as the maximum discharge of the Colorado at the same point. These floods from the Gila, however, are infrequent and of relatively short duration. While their sudden character and erratic occurrences make them peculiarly menancing to the levees or other property on the banks of the river, they do not present so great a menace to the Imperial Valley on account of their short duration and relatively small volume. The Colorado River rises gradually, carries a large volume of water for several weeks, and declines gradually. Should it break into the Imperial Valley at time of flood, the long duration of high water would cause great erosion and render its control exceedingly difficult. This is the experience actually obtained when this occurred. The Gila, on the other hand, might break into the Imperial Valley but the relatively short duration would not furnish nearly so much water to the Salton Sea, and consequently not incur the danger of Submerging the entire valley. The quick decline would make its control comparatively easy. The great floods of the Gila occur in winter, while those of the Colorado occur in summer. So far as known, they never have coincided; but if this ever should occur, it would greatly increase the menace.

A reservoir site of 2,200,000 acre-feet capacity has been investigated near Sentinel, on the Lower Gila, which, if built and maintained, would practically eliminate the menace from the floods of the Gila, but the investigations show such poor conditions for foundation and abutments that the feasibility of this reservoir is subject to doubt.

The control of the Colorado River proper is, for the reasons above stated, the main element involved, and this has been investigated extensively.

Possible reservoir sites have been found on the Grand and the Green rivers, which, if constructed and operated for the purpose of flood protection, would greatly reduce the volume of the floods, for though the areas intercepted by each are small compared with the total area of the Colorado River Basin, they drain mountains with high precipitation that furnish a relatively large volume of water. A reservoir site also exists on the San Juan River, which is the next tributary of importance, but the feasibility of this has not been established.

Of the total area drained by the Colorado River, 244,000 square miles, 96,000 is drained by the Grand, the Green, and the San Juan, which, though draining less than two-fifths of the total area, furnish approximately 84 per cent of the total water supply. There is still, however, nearly 100,000 square miles below these rivers, exclusive of the Gila, which would be uncontrolled by such reservoirs. These areas, though furnishing a relatively small quantity of water, owing to their aridity, are yet of such extent and declivity that they furnish occasional floods of magnitude from direct precipitation, due to which their control is important from the standpoint of the flood menace.

In the study of this problem, it has been demonstrated that for several reasons it is desirable to have a reservoir below the Grand Canyon of the Colorado, which will intercept most of the drainage of the Colorado River, and therefore, be a more complete solution of the flood control problem. This method of control is still more vital for other reasons.

The large areas of very fertile and valuable lands now developed and being rapidly developed, require immediate relief by extension of storage for irrigation, and if such storage is constructed in the upper basin, it will of course be operated in conformity with the requirements of irrigation in the lower valley as nearly as this can be predicted, but a large percentage of the water will be lost owing to the great distance and the impossibility of predicting the exact requirements a month or more ahead. In order to provide against embarrassing shortage, it will be necessary to turn out at all times sufficient water to provide for the most extreme conditions that may occur, but which seldom do occur, and this will mean that nearly all the time a large amount of water will be flowing to waste. A large part of this waste can be obviated by an adequate reservoir on the lower river.

In addition to the above waste, any water supply appropriated above for use in the lower valley would not be available for irrigation in the upper valley. The most feasible sites occur at points where this would be an objection to such use, because it would leave in an arid state lands that might otherwise be irrigated in the upper basin. Such a result would be a distinct waste of resources, as investigations show that there is a sufficient quantity of water to furnish an adequate supply to all of the lands in the basin that can be feasibly reached by gravity or reasonable pumping lifts. There will, of course, be local exceptions to this where the areas can be reached only by tributaries in which the local supply is insufficient, but this is aside from the main question.

In addition to the above waste, the regulation of waters from the upper river in accordance with irrigation needs in the lower valley would be distinctly out of harmony with the best use of these waters for power in the canyon regions where the power resources predominate.

In the upper and lower regions of the Colorado Basin irrigation interests should and must predominate, although power resources are very important. In the middle or canyon region of the basin, power resources predominate and irrigation interests are small. In general, where irrigation interests are practicable, they should be given preference over power interests and this rule requires storage of water in Boulder Canyon, or below, for the use of the lower valleys.

The States in the upper basin are therefore vitally interested in seeing that such development takes place before the natural resources are depleted by storage above for use in the lower valleys.

Likewise the States containing the lower valleys are interested in having storage in the lower basin on account of the economies thereby obtained and the greater convenience and ease of control of a reservoir near the point of use. Incidentally it will have large power resources which are important in the development of the resources of the Southwest.

Recognizing the importance of developing the Colorado Basin on broad lines in such a way as to realize the greatest benefits therefrom, the States of the Colorado River Basin have taken steps to organize a commission upon which each of the seven States interested will be represented and on which it is contemplated the United States will also be represented in order to work out and recommend to their respective States and Congress such action as will bring about the best use of the water resources of this great river system, the largest and most important river system lying entirely within the arid region.

Fortunately, the investigations at Boulder Canyon have shown the feasibility of a high dam at that point which, if built, would furnish storage as shown in the following tables:

Capacity Table - Boulder Canyon Reservoir.

(Computed from original planetable sheets; scale, 2" equals 1 mile)

Contour elevations	Area Acres	Capacity A. F.	Contour elevations	Area Acres	Capacity A.F.
700	--	----	1,050	53,160	7,130,500
750	2,350	58,750	1,100	67,740	10,155,000
800	7,950	316,250	1,150	84,110	13,949,250
850	15,260	846,500	1,200	105,100	18,679,500
900	21,620	1,818,500	1,250	127,660	24,498,500
950	29,160	3,088,000	1,260	131,000	26,000,000
1,000	39,690	4,609,250	1,280	142,000	28,600,000
			1,300	152,000	31,600,000

NOTE: The canyon walls extend up to above the 2,000-foot contour, or about 700 feet higher than the last one for which capacity is calculated.

Progress of Investigations.

The preliminary report on the problems of Imperial Valley and vicinity, published in January, 1921, described the progress of investigations up to that date, and these have been continued up to the preparation of this report.

Soil surveys under the direction of Prof. Charles F. Shaw have been prosecuted and land classification based upon this examination has been made and shown upon maps. These subjects are treated in this report on subsequent pages.

Borings have been prosecuted at the proposed dam site in Boulder Canyon and the cross section of the canyon has been fairly well worked out. A large amount of additional borings is, however, necessary to develop the entire foundation of the proposed dam and this will probably modify its location. Similar information is also necessary for the cofferdam which must precede the main construction, and must be, for temporary work, of a rather substantial character. Results of the borings are shown in the accompanying diagrams and indicate the maximum depth to bedrock of about 135 feet below low water. level. This is regarded as feasible, although the foundation work will of course be difficult and expensive in view of the great volume of the river when in freshet.

Various studies have been made on the basis of the information available and these studies indicate the cost of a dam with flow line at 1230 feet, to be about $45,000,000. This would have a storage capacity of about 21,000,000 acre feet. Increased height of dam to provide greater storage can be provided at an additional cost of about one dollar per acre foot, for the next 10,000,000 acre feet. A capacity of 31,000,000 acre feet would require a flow line at about 1296 feet above sea level.

These figures include preliminary work and the completion of the dam in shape to serve for storage purposes and upon which to install power plants, but do not include any other cost of power development or transmission.

A reconnaissance has been made for two possible railroad lines - one approaching from the west and joining the Salt Lake and Los Angeles Railroad near Las Vegas; the other approaching from the north, being a continuation of the branch which runs from Moapa to St. Thomas. A reconnaissance should be made also with a possible connection with the Santa Fe system to the south, with a comparison of the cost and results.

The High Line Canal.

The construction of a high line canal connecting Laguna Dam with Imperial Valley was investigated and reported upon by a board representing the State of California, Imperial Irrigation District and the United States under date of July 22, 1919, and was published under the title "Report of the All-American Canal Board. A canal located entirely within the United States from the Colorado River at Laguna Dam into the Imperial Valley, California." Reference is made to that report for the details of such a plan, and its unit estimates of cost are accepted for the purposes of this report. It is necessary, however, to modify acreages and other details in view of the information recently collected. The agricultural lands that it would serve in addition to Imperial Irrigation District are given in the following table:

	Irrigable lands (Acres)	Doubtful lands (Acres)	Total (Acres)
East Mesa	160,000	10,000	170,000
Dos Palmas tract	5,000	2,000	7,000
Coachella Valley	72,000	63,000	135,000
West Mesa	33,000	87,000	120,000
	270,000	162,000	432,000

The above table includes only lands which require the construction of the High Line Canal to reach them. In addition to this the Imperial Irrigation District is heavily interested in having a high line built for the reasons stated in the board report above referred to. The construction of a high line canal is provided for in a contract with the United States dated October 23, 1918. In addition to this the District is pledged to connection with the Laguna Dam by contract with the Yuma County Water Users' Association in order to terminate the dangerous practice of maintaining a diversion dam at Hanlon Heading. This connection should be made at the earliest possible date in accordance with the existing understandings and contracts. The distribution of the cost of the high line canal would be according to the following table:

Cost of High Line Canal.

To connect with dam	$1,843,000
Canal	28,930,000
	30,773,000

Division of Costs of Canal.

Yuma project by contract	980,000
Remainder for Imperial Valley	29,793,000

Divided as follows by acreage benefited:

Imperial district	515,000 acres	18,826,000
Extensions in U.S.	270,000 "	9,870,000
" " Mexico	30,000 "	1,097,000
	815,000 "	29,793,000

Cost per acre Imperial Valley - $36.55

Division of Costs of Power Installation Along Canal.

Plant No. 1	$1,380,000
" " "	1,927,000
	$3,307,000

Divided as follows:

Yuma project	$528,000	
Imperial District	2,051,000	
Pumping	728,000	$3,307,000

Pumping is divided as follows:

	New lands acres	Average per acre	Total
United States	270,000	2.21	$596,000
Mexico	30,000	4.40	132,000
			728,000

Division of costs of distribution system including pumps.

United States	270,000	$53.57	14,461,000
Mexico	30,000	21.67	650,000
			15,111,000

Summary of Distribution of Costs
Imperial Valley
Cost per acre

	High Line Canal	Power	Distribution system	Total
Imperial District	36.55	3.98		40.53
Extensions:				
United States	36.55	2.21	53.57	92.33
Mexico	36.55	4.40	21.67	62.62

Allocation of costs to classes of lands in Imperial Extensions.

Private	Entered	Public	Indian	California	So.P.R.R.	Total
$1,339,000	$1,420,000	$15,400,000	$1,062,000	$1,348,000	$4,359,000	$24,927,000
						1,879,000
						26,806,000

Imperial Valley Extension
Irrigable area - acres.

Imperial Valley Extension	Private	Entered	Public	Indian	State Calif.	So.P.R.R.	Total
East Side Mesa	1,200	1,200	148,100		8,300	1,200	160,000
Los Palmos	200	1,400	700		300	2,400	5,000
Coachella Val.	12,100	3,400	3,800	11,400	4,400	36,900	72,000
West Side	10,000	9,300	14,300	100	1,500	6,700	33,000
U.S. lands	14,500	15,300	166,900	11,500	14,600	47,200	270,000
Mexican lands							30,000

Flood protection and irrigation storage benefits.

The distribution of benefits from water storage is perhaps the most complicated and difficult to determine, and involves questions of law which it is neither possible nor desirable to determine at the present time.

The Yuma project of the United States Reclamation Service claims an early valid right to the diversion of water, based upon an act of Congress (33 Stat., 224) authorizing the diversion of water for the Yuma project and including Indian lands. The Imperial Irrigation District, on behalf of the lands within its boundaries, claims a right based upon filings under California laws. Similar claims are asserted by the Palo Verde Irrigation District and some other tracts in the Colorado Valley, and which of these is to get preference is a matter of dispute depending perhaps in part upon various questions of fact which will require careful determination. The claim is asserted on behalf of the Indians of the Colorado River Indian Reservation to sufficient water for their lands, irrespective of prior appropriations.

These claims in the aggregate are conflicting, but it is neither necessary nor desirable that they be now determined, nor is this possible in time for this report.

A similar difficulty arises in allocating the benefits for flood protection although in a broad sense the older lands having the best water rights are those most in need of flood protection.

Power Development.

The development of power at the Boulder Canyon reservoir is a by-product, which does not in all respects conform to the requirements of irrigation but can be made to conform thereto with some adjustments. The extremely arid and semi-tropic character of the lands in the Lower Colorado Basin makes it necessary to irrigate throughout the year and the irrigation requirements therefor conform more nearly to the requirements for power than do those in northern latitudes.

It is estimated that the feasible irrigation projects in the lower Basin, which would divert water from the main stream, comprise 2,020,000 acres, of which about 60% is in the United States and 40% in Mexico. The full development of the proposed projects in the Upper Basin will subtract substantially from the total water supply, but there will still be left ample water to irrigate all the lands of the Lower Basin if it is conserved and regulated in a storage reservoir of ample capacity. The water can be used for power as drawn from the reservoir and the amount of power that can be developed with different amounts of storage capacity and with different assumptions of irrigated land below is shown by the diagram in figure 2. It shows that with 1,505,000 acres of land in the Lower Basin irrigated and with a total storage capacity of 31,400,000 acre feet of which the lower 5,000,000 is reserved for silt storage and the upper 5,000,000 is reserved for flood control, it is possible to develop over 700,000 firm horsepower. With the entire 2,020,000 acres of irrigable land developed in the lower basin the possibilities are still 600,000 firm horsepower, and besides this there is a large amount of secondary power which is not constant but will be of considerable value.

All this is on the assumption that the total area of irrigable land in the upper basin is irrigated, namely about 4,000,000 acres, of which about 3/8 is now under ditch. The development of the upper basin will doubtless proceed steadily but it will be a long time before the full development is reached, and the water later to be consumed by future irrigation will be available for power at Boulder Canyon until that development is realized. This will greatly increase the figures shown above for a long time to come, and, in the meantime, any regulation of the river above for any purpose will also tend to increase them.

The great value of this power and the wide demand for it, together with its magnitude, indicate that the power privileges of the Boulder Canyon reservoir can be made to bear the entire cost of the dam.

The markets for power are numerous and various in this part of the country, consisting in general of the mining interests in Arizona and Nevada, the pumping requirements in the Colorado River Valley, and the needs of the municipalities of Arizona and southern California for municipal and commercial uses. Possible municipal customers of importance are Prescott, San Diego, Riverside and Los Angeles.

The last named city has indicated a desire to share in this development as shown by the letter dated December 16, 1920, on page 203. This city has already developed considerable power on the Los Angeles aqueduct, and owns a system for distributing electric current within the city limits. The demands, present and prospective, are far beyond the capacity of the city to supply with the present facilities, and this is considered the most effective and extensive of all of the power demands.

It is desirable of course to extend to all customers who desire to share in this development the same privileges. The use of the name of the city of Los Angeles is merely typical of such cities as may eventually elect to share in this development. Others may later apply and should have equal privileges.

Status of Lands in Lower Colorado Basin in the United States.

	Irrigable area						
	Private	Entered	Public	Indian	State	So.Pac. R.R.	Total
Cottonwood Island			4,000				4,000
Mohave Valley	12,800		1,600	12,600			27,000
Chemehuevis Valley			1,500	2,500			4,000
Parker Project				110,000			110,000
Palo Verde Valley	72,000	6,000					78,000
Palo Verde Mesa	3,500	12,400	800		1,300		18,000
Chucawalla Valley	500	32,500	8,500		2,500		44,000
Cibola Valley	6,900	2,500	4,800		1,800		16,000
Isolated Tracts	2,900		1,100				4,000
Yuma project	62,000	19,000	38,200	9,000	1,800		130,000
Imperial District	515,000						515,000
Imperial Valley Extensions:							
East Side Mesa	1,200	1,200	148,100		8,300	1,200	160,000
Dos Palmas	200	1,400	700		300	2,400	5,000
Coachella Valley	12,100	3,400	3,800	11,400	4,400	36,900	72,000
West Side	1,000	9,300	14,300	100	1,600	6,700	33,000
Total in U. S.	690,000	87,700	227,400	145,600	22,000	47,200	1,220,000

Construction Methods.

Borings made in 1903 and 1904 on the lower river showed that at Bulls Head, Williams Fork, Picacho, and other points tested, the subterranean channel of the river had been eroded to a great depth, so that the foundation of dams at any of these points on bed rock was considered infeasible. In view of this fact and of the silt problem, some engineers were led to conclude that storage at any point in the lower basin of the Colorado River was not feasible. Further consideration, however, led to the evolution of a plan for building a high dam without excavating the river to bed rock, which, owing to the peculiar topography of Boulder Canyon seemed to be at least worthy of consideration. At this point the canyon is about 300 feet wide at the river level, and cliffs of massive granite reach upward nearly vertical to a height of over 2,000 feet above the river. Plans were evolved for a loose rock dam at this point constructed by the following method:

It is proposed to pierce the cliffs with large tunnels on each side of the dam site a short distance above the low level of the river at medium stages in order that the river might be diverted through these tunnels at moderate stages if desired. These tunnels were to be equipped with controlling works. For a dam say 600 feet above the river level it was proposed to provide slopes for a rock fill dam of three to one on each side when counted from bed tock to summit with a top width of 30 feet. This would mean that the thickness of the dam up and down stream at the river bed would be 3630 feet, or nearly three-quarters of a mile. The cliffs were to be pierced with small tunnels parallel to the river at numerous points well above and outside the lines of the dam in order later to blow the rock from these tunnels into the river for forming a loose rock dam. At a point just above where the upstream slope of the dam would intersect bed rock a tunnel on each side of the river was to be filled with powder and exploded, throwing the rock into the river bed in such manner as to form a coffer dam and divert the river into the diversion tunnels. This coffer dam was to be faced with smaller rock in order to serve its purpose and then the river turned over the coffer dam, which it would proceed to destroy by scouring the bed of the river at the lower toe and rolling the rocks of the dam into the cavity thus formed.

After such action had proceeded to a point of comparative quiescence another blast from higher tunnels on both sides of the river would blow additional quantities into the river just below the coffer dam and the river required to work upon this mass for a short time. With the high head thus formed the scouring effect of the water upon the toe of the rock fill would be very powerful and would carry away all the finer material, but the large blocks of granite that would thus be provided could not be carried by the river but being undermined would be settled deeper and deeper into the river bed.

This process would be repeated in such manner as to secure the largest possible action of the water in scouring out the foundation and settling the large rock from the cliffs as low as possible into the foundation. This proceeding from upstream to downstream would pave the foundation progressively with large rock as ddeply embedded as possible. The process of blowing rock from the cliffs above by means of tunnels parallel to the river packed with black powder would be repeated at such points that the required rock fill would be built as nearly as pradticable to the height desired on the required slopes, the river being used to the maximum extent in settling the rock into the foundation and all surplus waters drawn off through the tunnels. It is obvious that masses of granite could be secured in this way very much larger than could be feasibly moved by ordinary mechanism.

During the early stages of construction when the mass is of moderate height it would be necessary to take the flood waters of the river over the structure, and this action would be used to the greatest possible extent in thoroughly paving the foundation with the heaviest rock obtainable. As the structure increased in height the storage above it would increase in volume rapidly, and at moderate heights the storage capacity and the tunnel capacity combined would be adequate to prevent the overflow of the dam in times of high water after such overflow became undesirable.

When this structure had reached the designed height and slopes, the entire upstream face would be brought to an even slope by depositing smaller rock until the surface was smooth enough to be paved with concrete. A concrete pavement would then be provided of considerable thickness and reinforced with steel. This would cover the entire face of the dam from the river bed to the top and would be securely sealed to the cliffs on either side to prevent percolation through the dam so far as practicable.

Prior to placing the coffer dam or any of the rock fill, it is proposed to drive a row of sheet steel piling as deeply as practicable across the upstream toe of the dam to be later connected and sealed firmly to the toe of the concrete pavement on the water fade of the dam.

The placing of the rock fill should be completed a year or more before beginning the construction of the concrete pavement. This time would be occupied in sloping up the water face preparatory to placing the pavement. The construction of the pavement would be so planned that the sealing of the pavement to the rock of the abutments would be the last finishing touch of the dam so as to give the mass the maximum time for settlement before making this junction.

The control of the river during construction and immediately after would form a pond of varying magnitude just above the dam filled with the muddy waters of the Colorado and these would deposit their sediment on the river bed and lower toe of the dam in such manner as to form something of a seal and tend to prevent water entering the foundation at any considerable velocity.

This plan of construction was discussed with Secretary Lane in obtaining authority for the extensive investigations of the Colorado River in 1914. It had previously, and has since been discussed by the author with many engineers in order to bring out, if possible, any weak points connected with the plan, and some of the details of this plan have been modified as the result of such discussions. They are of course subject to further modification by further thought, and especially by the experience obtained during construction. The plans were worked out in more detail and estimates made on the basis of such a structure as compared with a dam built of concrete under the direction of the Chief Engineer of the Reclamation Service by Mr. John L. Savage, Designing Engineer, U. S. Reclamation Service, and his assistants.

These investigations seemed to indicate that no material saving could be made by adopting such a plan as compared with a concrete structure carried to bed rock providing the latter proved feasible at all. A depth of 135 feet to bed rock while presenting serious difficulties in foundation work, is believed to be entirely feasible if proper preparations are made and proper plans are followed.

It is not believed that within reasonable cost it is either feasible or necessary to divert the entire flood flow of the Colorado River, which may at times reach 200,000 cubic feet per second. The plan is to design a thin arch of such radius and dimensions as to be safe with its base upon the foundation rock and its summit about 40 feet above the low water level of the river. Within this limit the canyon is quite narrow, being at all points less than 350 feet in width, and therefore a structure of short radius and light section would be safe. After the construction of a coffer dam and of diversion tunnels of sufficient capacity to carry the ordinary flow and moderate floods of the river, excavation would be undertaken of only sufficient width to secure foundation for this thin arch, and this would be completed and the arch poured during the 9 months or so in which it would be possible to unwater the foundation by means of the tunnels and coffer dam.

This thin arch would serve as a subsequent coffer dam and also for the heel of the masonry structure to be built. If this were overtopped by floods they would fill the pit with water only, which could be quickly pumped out when the flood had passed and the excavation of the additional foundation and placing of foundation concrete could proceed at all times when the river flow is below the capacity of the tunnels; and this would mean without serious or expensive interruptions except during the brief season of high water in May and June.

The method just described for meeting foundation conditions in Boulder Canyon has been successfully carried out in placing the foundations for the Shoshone and the Arrowrock dams, the highest yet built by the Reclamation Service. The depth to foundation at Arrowrock was about 100 feet, and on the Shoshone about 90 feet. At Boulder Canyon the depth is greater and the quantities are larger, but it is practicable to assemble a much larger construction outfit and to make more strenuous speed than was found necessary at either of the two locations mentioned. These experiences have led those familiar with them to conclude that the placing of the foundation in Boulder Canyon for a concrete dam by the above method is entirely feasible and not unduly expensive.

If this is true, the plan of blowing the cliffs into place for a rock fill dam is not necessary to solve the problem. It may, however, have advantages of economy, but this is difficult to predict on account of the unprecedented character of the operations.

A structure necessary to solve the problem of the Colorado River by a dam in Boulder Canyon is so high and so far beyond the precedents that it seems advisable with due care for engineering safety and economy, to avoid going outside of such precedents so far as possible. For this reason it seems to be desirable to build the structure of concrete in accordance with well established theory confirmed by numerous and varied precendents. A rock-fill structure might be cheaper but our experience is so limited that we can not be sure that this will be the case, and if some unforeseen difficulties, such as blow-outs under the rock fill, should be encountered, its expense might even be greater than that of a concrete structure, and we can not be sure that it would be entirely safe.

Comparison of Boulder Canyon Reservoir
with other possible sites.

The demand for a large regulating reservoir on the Lower Colorado is urgent and imperative, first, for regulating floods, second, for providing storage water for irrigation, and third, for power. Without the power, the reservoir is not feasible at all, as the expense would be too great to be borne by the other interests alone.

The reservoir site provided by a dam in Boulder Canyon, or its continuation, Black Canyon, is the lowest point on the Colorado River where a site of sufficient capacity can be found. Above this site the Grand Canyon occurs, and no reservoir of capacity sufficient to control the entire flow of the river occurs until we reach a point above the Grand Canyon National Park. A site has been proposed above the mouth of the Paria River in Glen Canyon, and it has been urged that a reservoir formed here would, for a given height of dam provide greater storage capacity, and would so regulate the floods as to facilitate the construction of other dams farther down. These are valid arguments, so far as they go, but such a reservoir would not answer present purposes for several reasons. Between the Glen Canyon and Boulder Canyon sites about 50,000 square miles of drainage flows into the Colorado, including the Little Colorado, the Virgin, the Paria, the Kanab, and many smaller tributaries. This region furnishes about 10 per cent of the water supply passing Boulder Canyon, and most of it is subject to torrential summer rains, and to floods at other times, and the Glen Canyon site would not therefore give satisfactory control of the floods, which is the most urgent of the problems presented. A satisfactory solution of this problem could not be accomplished at any point above Boulder Canyon.

Any large reservoir on the Colorado must depend for its financial feasibility upon the availability of an adequate market for not less than one-half a million horsepower of electric energy, within economical transmission distance. The principal available markets are

1. The Pacific slope of California, including the cities of Los Angeles, San Diego, Riverside, etc.

2. Irrigation pumping in all directions.

3. The mining regions of the mountains of Arizona, extending in a broad way from the northwestern to the southeastern corner of that State, and including the cities of Prescott, Phoenix, and Tuscon.

4. The electrification of the Southern Pacific, the Santa Fe, and the Salt Lake railways and their branches.

5. The cities of Nevada, Utah, Colorado and New Mexico, and the mining regions adjacent to them.

All of the more important markets above listed are more convenient to Boulder Canyon than to Glen Canyon. This is especially true of the most important market, the cities and irrigation districts of southern California. To reach these the most feasible routes for transmission lines, considering the importance of transportation in their construction and maintenance, is approximately along the railroad routes. Those compare about as follows, taking Los Angeles as typical and deducting 20% as the distance that might be saved by cutoffs:

Transmission Distance Boulder Canyon to Los Angeles.

Los Angeles to Las Vegas, by rail	334	Miles
Las Vegas to Boulder Canyon, by rail	40	"
Total	374	"
Less 20%	75	"
Net Transmission Distance	299	Miles

Transmission Distance Glen Canyon to Los Angeles.

Los Angeles to Flagstaff by rail	544	miles
Flagstaff to Junction by rail	30	"
Junction to Glen Canyon by rail	130	"
Total	704	"
Less 20%	141	"
Net Transmission Distance	563	"
	299	"
Difference in favor of Boulder Canyon	264	"

Considering the population and industrial importance of the Pacific Coast region, this market is the largest of all the prospective markets, and neither development could at present be justified financially without it. The advantage in transmission distance of 250 miles is of course decisive. In fact the transmission of so much power a distance of 560 miles, though physically possible, can hardly be considered today commercially feasible under the conditions surrounding this problem.

It would be hard to find a power site in the United

States more remote from adequate markets than the Glen Canyon site, and nearly all its markets are or can be more cheaply served from nearer points.

These facts are so obvious that some of the proponents of Glen Canyon Reservoir tacitly admit its present inavailability as a power site, and extol its virtues as a regulator for power sites to be developed below. The best located of these is that at Boulder Canyon, which as we have seen, can be made to furnish its own regulation, so that <u>two</u> such great undertakings are at present unnecessary, and are in fact financially at present not only very uneconomical, but probably infeasible. In the present state of development of the southwest, the constructions of a large reservoir at Glen Canyon under either plan would encumber the power development with such a heavy charge for construction and maintenance, as to be a serious public misfortune.

The disadvantages from an irrigation standpoint of locating a storage reservoir 650 miles by river from the point of diversion when a site is available at one-half the distance are readily appreciated.

One of the great problems concerning the Colorado is that of silt. The Boulder Canyon dam as planned would store the silt for over three centuries, if all were caught and held, and for nearly a century before greatly impairing its water storage function. It is hoped before that time that other developments above will so regulate the flow that not all of its storage capacity will be needed, but it will always be desirable to control the floods of the region between Boulder Canyon and Glen Canyon, and before the capacity of the Boulder Canyon is entirely destroyed the Glen Canyon regulator can be built to take its place. It will then be fresh and empty of silt and will last to as much later date as the age of the Boulder Canyon reservoir at that time and will, therefore, solve the silt problem for a period of two or three hundred years further into the future than if it is built first, and can, if desired, be employed as a sluicing agency for sluicing out the Boulder Canyon reservoir.

If built first, the Glen Canyon reservoir would immediately begin silting up and if sluiced in the future will discharge its sediment into the reservoir later provided below and thus require sluicing of the same sediment two or more times. This multiple sluicing will not be possible without shutting down the storage and other functions of all the reservoirs below while they are being sluiced out.

By the time silt deposits have begun to encroach upon the storage capacity of the Boulder Canyon reservoir sufficient power earnings will have accrued to amortize its cost and the full height of the dam will still be available for the development of power. The engineers of that future date will then not only be in a better position to build the Glen Canyon dam than we are now, but will be relieved of the expense of a power dam at Boulder Canyon we would now be saddled with and have in addition the advantage of being then free to operate the upper reservoir to best advantage for power alone, the Boulder Canyon reservoir still affording ample capacity for regulation for irrigation.

RECOMMENDATIONS:

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

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

3. It is recommended that through suitable legislation the United States undertake the construction with Government funds of a reservoir at or near Boulder Canyon on the lower Colorado River to be reimbursed by the revenues from leasing the power privileges incident thereto.

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

5. It is recommended that the Secretary of the Interior be empowered after full hearing of all concerned to allow the various applicants their due proportion of the power privileges and to allocate the cost and benefits of a high line canal.

6. It is recommended that every development hereafter authorized to be undertaken on the Colorado River by Federal Government or otherwise be required in both construction and

operation to give priority of right and use:

1st. To river regulation and flood control.

2nd. To use of storage water for irrigation.

3rd. To development of power.