THE COLORADO RIVER - A SOURCE OF WATER AND POWER FOR LOS ANGELES.

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- JUNE 2, 1924 -

The Colorado River - A Source of Water and Power for Los Angeles

The rapid growth and development of Los Angeles City and County has been one of the phenomena of the present age. The growth of a city from 50,600 to 576,000, an increase of over 1000 % in thirty years is an unprecedented occurence. It has given rise to a variety of problems of increasing magnitude.

Chief among these are: supply of food, water and shelter development of industry and markets, prevention and removal of downtown congestion and protection of life and property. These, of course, are the problems that any city must face. But in the case of a community which doubles its population every ten years, radical and heroic measures must often be taken.

Perhaps the most vital mainstays of a populous city are an adequate supply of good water and an abundance of power available for industrial expansion. Los Angeles has long been the mecca for tourists, pleasure seekers and home seekers. The time has now come when the steady influx of people cannot continue without a certainty of abundant domestic supply of good, pure water. The report of a shortage of this commodity serves almost constantly to stop the migration from the east. Likewise, a people living in such a district must look for profitable exchange with outside sections for maintenance. The agricultural projects must be developed to their utmost.

More important yet, the industries of the city must be expanded for the complete supply of surrounding markets. Thus we may see that the future prosperity of the city depends in a large measure, on the securing adequate supplies of water and power.

--- The Los Angeles Aqueduct ---

For several years the men, upon whom rested the responsibility of providing the city of Los Angeles with a sufficient water for her people, sought in vain for sources of permanent supply equal to prospective demands. An actual shortage was met in the year 1904. Under the direction of the board of supervisors an investigation into available supplies was carried out by William Mulholland and his associates. From this developed the comprehensive and daring scheme of bringing water from the Owens River valley. Wark was begun in 1908 and water was brought to San Fernando reservoir in 1913.

Following are a few of the aqueduct statistics:

Construction cost		$22,997,600.
Open Canal	61 miles; capacity	900 cu.ft.
Covered conduit	98 " ; "	420 cu.ft.
Lined tunnels	43 " ; "	420 cu.ft.
Siphons	12 " ; "	420 cu.ft.
Miscellaneous	20 " ; "	420 cu.ft.

Total length of aqueduct, intake to San Fernando reservoir ------ 234 miles.

Expenditures.

Pay rolls	$12,500,000.
FREIGHT and express	2,250,000.
Lands and R/W	1,700,000.
Materials,equipment & Misc.	8,150,000.
	$24,600,000.
EStimated Salvage	1,250,000.

Work started --- October 1907
completed --- May 1913

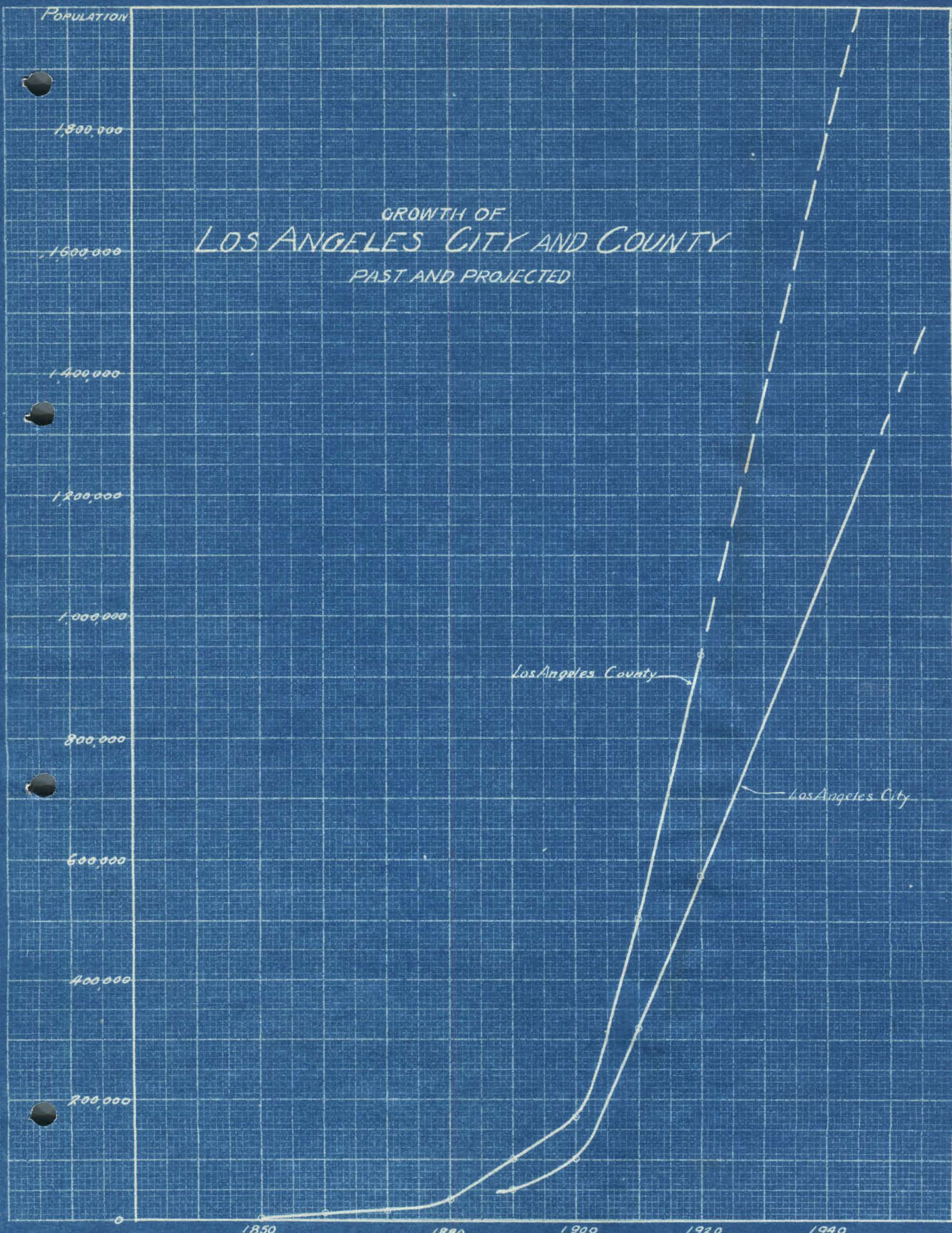
The additional supply of water afforded by the aqueduct was thought to insure the city against shortage for decades to come, if not permenently. However its growth, now that a reliable water supply was guaranteed, took on a new impetus. Manufacturing industries and intensive farming was also developed. The result is that now, in 1924, the city has nearly reached the limit of expansion under the present supply.

An extensive flood control and conservation program has been inaugurated in the county, but this promises only a very slight addition in the dependable supply of the county.

--- Growth of City and County ---

A few figures taken from the census report for the city and county of Los Angeles are as follows:

Year	City population	County population
1850		3,530
1860		11,333



POPULATION
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
GROWTH OF
LOS ANGELES CITY AND COUNTY
PAST AND PROJECTED
Los Angeles County
Los Angeles City
1850
1880
1900
1920
1940

Year	City population	County population
1870		15,309.
1880		33,381.
1890	50,395	101,454.
1900	102,479	170,298.
1910	319,198	504,131.
1920	576,673	936,455.

An inspection of the curves constructed from this data would indicate the following probable population:

Year	City	County
1930	820,000.	1,350,000
1940	1,080,000.	1,780,000
1950	1,330,000.	2,200,000

This is the most conservative estimate that can be made; since a straight line increase in a youthful city is almost unduly on the conservative side.

---- Water supply ----

Mr. Mulholland, the builder of the Los Angeles aqueduct, has conceived the idea of bringing water from the Colorado River, as a source of supply, to the counties of Los Angeles and San Bernardino. This plan is still in the formulative stage. Briefly it is: 1000 second - feet of water will be diverted at a point about 200 miles below Boulder Canyon. This will be pumped a height of about 2000 feet by successive lifts and conveyed a distance of 150 miles across the desert to San Bernardino mountains. Here it will pass by a long tunnel under San Gorgonio pass to the San Bernardino section, thence to be conveyed and distributed to the districts westward to the sea. This plan will be developed more fully in succeeding pages.

---- Power ----

The city of Los Angeles has invested approximately $13,250,000 for power development in connection with the city's aqueduct. The power system was placed in operation in April 1917 and was a financial success from the start. An additional $13,500,000 was voted in 1919 for expansion and the purchase of other systems in the city.

The total hydro-electric power resources owned by Los Angeles in connection with the aqueduct system is 220,000 net horsepower, delivered in the city. Of this total, 72,000 horsepower is available for immediate use. The remainder of the 220,000 horsepower is awaiting development on the Owens River and tributaries and on the aqueduct systen nearby. These combined resources, until recently, were believed to be quite sufficient to provide for the city's commercial, industrial, and domestic needs for many years to come, but so great has been the industrial growth of Los Angeles, that additional large sources of supply must be acquired. With the full 220,000 horsepower available, it is now seen that the city will be hampered industrially by the lack of power as early as 1925. For this reason the city of Los Angeles should co-operate with other nearby municipalities in the development of power on the Colorado River at Boulder Canyon under a program to be subscribed to by the National Government.


MAP SHOWING
COLORADO RIVER PROJECTS
FLAMING GORGE
JUNIPER
DEWEY
BOULDER CANYON
POWER LINES
AQUEDUCT
119
117
115
113
111
109
107

---- The Colorado River ----

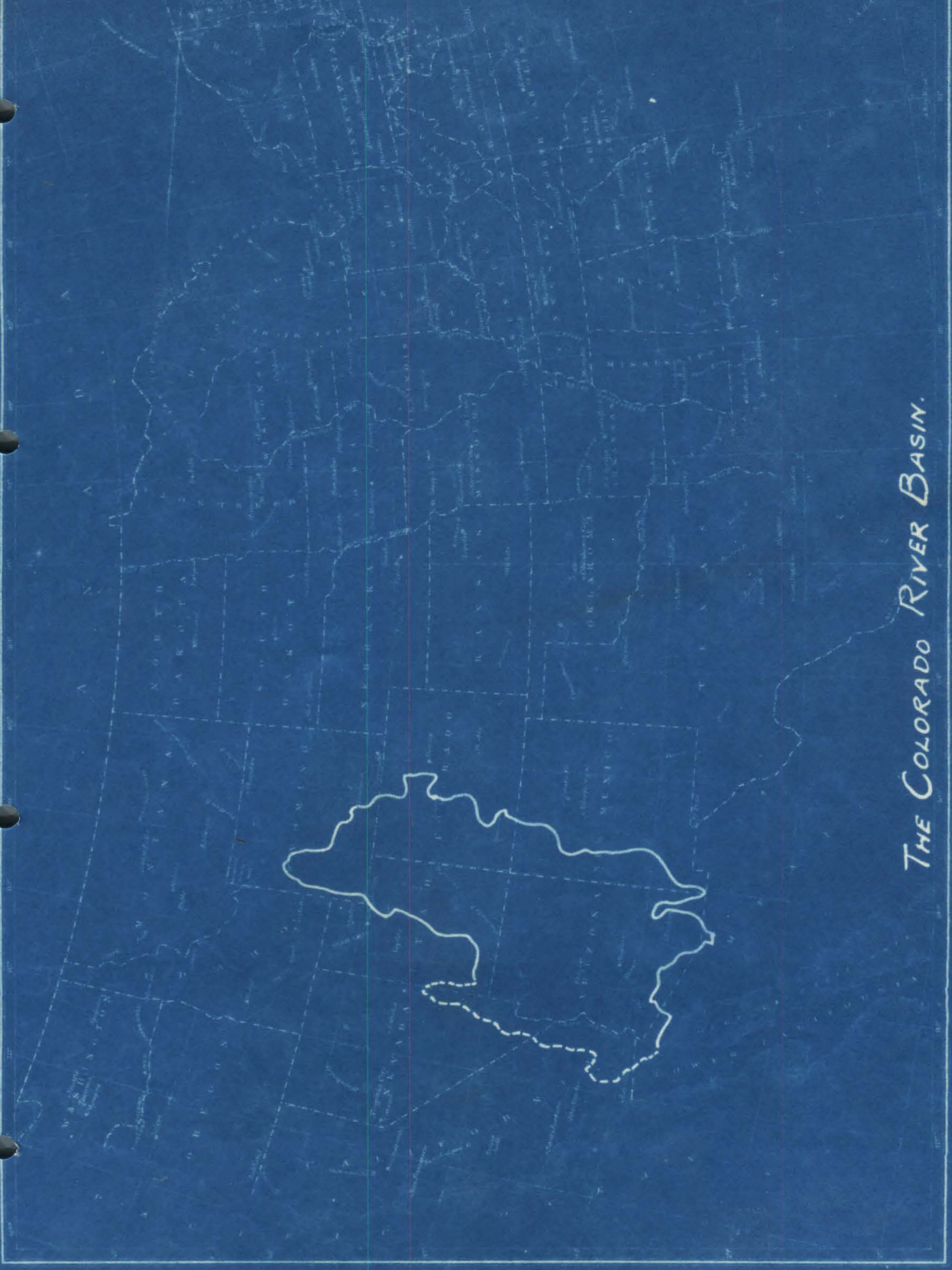
The drainage basin of the Colorado River is shown in the accompanying figure. It includes parts of seven states, - the southwestern part of Wyoming, the western half of Colorado, the eastern half of Utah, a strip along the west side of New Mexico, all of Arizona except the southeast corner, the southeast part of Nevada, the southeast edge of California, and a portion of Mexico - in all, 244,000 square miles. All of the northern half of the basin and part of the southern half, consists of high, mountainous country, on which there is a heavy, annual precipitation. The remainder of the basin embraces an extremely arid region upon which rainfall is rare and spasmodic in occurence.

Until 1921 that part of the stream system draining western Colorado was known as the Grand River (now changed to Colorado). In the southeastern part of Utah that stream unites with the Green River, the headwaters of which are in Wyoming. Below the junction of the Grand and the Green the stream was called the Colorado.

The tributaries which furnish the bulk of the waters of the Green are the Yampa and White Rivers which flow westerly from the Northwest corner of Colorado and the Duchesne, Price, and San Rafael Rivers, draining the central part of Utah from the Wasatch range eastward. The Grand river receives only two large tributaries, the Gunnison and the Dolores which drain the southwestern part of Colorado.

The principal tributaries below the junction of the Green and the Grand are the San Juan, flowing westerly from the northwest corner of New Mexico; the little Colorado, which drains the north side of the Mogollom Rim in Arizona; the the Gila, which drains

The Colorado River Basin.



the central and southern parts of Arizona.

In the upper basin, that is, the basin above the Grand Canyon, there is a large area of land under cultivation, about one million five hundred thousand (1,500,000) acres, mostly on the headwaters and tributaries where diversions from the streams are easily accomplished. The irrigation of the land, however, requires little water on account of the high altitude, cold, climate, and short growing season, and part of the water applied returns underground to the stream. An even greater area, now idle is susceptible of irrigation, part of it, however, at such high cost as to make the projects of doubtful feasibility. Studies made by the United States reclamation service indicate that the irrigated area in the upper basin will be increased to 3,000,000 acres.

In the lower basin, below the Grand Canyon, the areas irrigated in 1920 included 39,000 acres between Needles and Yuma, mostly on the California side; 54,000 acres in the Yuma project; 415,000 acres in the Imperial Valley; and 190,000 acres south of the International boundary line - a total of 698,000 acres. This total is almost exactly double the acreage irrigated in 1913, showing the rapid rate of increase in the use of water in the lower basin. The possible extension of irrigation in the lower basin has not been determined fully, but conservative estimates indicate that the following additional areas can be brought under irrigation: 260,000 acres between Needles and Yuma, 150,000 acres of which is on the Arizona side; 76,000 acres in the Yuma project; 400,000 acres in the Imperial and Cochella Valleys; and 630,000 acres in Mexico, bringing up the total of irrigated and irrigable acreage to well over 2,000,000.

--- Water supply at Boulder Canyon ---

On the Colorado River and its tributaries many gaging stations at carefully chosen locations, have been kept for varying periods of time, some of the records extending over 25 years. The records of stream flow at Yuma have been kept since January,1902. The gaging station is below the Gila River and below the Yuma division dam, but above the headgates of the Imperial Canal. The average annual flow at the gaging station for the period 1902 to 1920 was 17,400,000 acre feet. Had the present irrigated area been under irrigation throughout the period of the record, the average annual flow would have been about 16,000,000 acre feet. The average flow at Boulder Canyon is practically the same amount, since diversions and losses between Boulder Canyon and Yuma are balanced by the inflow of tributaries.

Most of the water comes from the upper basin. At the junction of the Grand and the Green, the average annual discharge of the Grand is 6,900,000 acre feet and of the Green, 5, 500,000. The Green and the Grand and the San Juan rivers together, though draining less than two-fifths of the area of the Colorado basin, furnish 86 percent of the total water supply, By far the greater part of the precipitation in Colorado and Wyoming is in the form of snow. During the winter the snow accumulates to great depths. The melting of the snow during the spring months produces a long period of high water, the annual flood, which lasts from two to three months and reaches its highest point at Yuma usually in June.

A flow of 186,000 cubic feet per second was recorded at Yuma in June 1921. The low water season begins in August and lasts from three to seven months. The minimum flow at Yuma has been below 4,000 cubic feet per second during several low water seasons.

The Gila river drains an area of 57,000 square miles. While the average annual discharge of the river is not great, it is very variable. In 1916, the discharge of the river at its mouth was 4,500,000 acre feet, in some other years the total has been less than 100,000 acre feet. Short lived, "flashy" floods, greater than the highest peak flood on the Colorado occur at times. The flow on January 16, 1916 reached 220,000 cubic feet per second. It is fortunate that the Gila floods do not come at the same time as the Colorado floods, in May or June. Should they coincide, the menace to the Yuma and Imperial valleys would be intensified and the levees would be overwhelmed.

----Reservoir Sites----

There are hundreds of storage sites in the upper and middle parts of the Colorado basin. Many of them have been surveyed, and at several of the sites the depth to bedrock has been ascertained by diamond drilling. The Strawberry Valley sits in Utah and the Roosevelt site in Arizona and some small sites have been occupied already. For the complete regulation and utilization of the river, there are adequate natural opportunities, the real problem is as to which is the best. A few of the largest and most promising sites, those which are of greatest public interest are as follows:

Name	Location	Height. Feet	Bedrock Depth, ft.	Capacity Acre ft.
Dewey	Grand River	215	44	2,270,000.
Flaming Gorge	Green	215	73	3,120,000.
Juniper	Yampa	200	24	1,500,000.
Ouray	Green	210	121	16,000,000.
Junction	Grand & Green	250	120	7,450,000.
Bluff	San Juan	264	---	2,600,000.
Lees Ferry	Colorado	700	---	50,000,000.
Diamond Creek	Colorado	284	40	-- --- ---
Boulder Canyon	Colorado	600	135	31,400,000.
Mojave, or Topock	Colorado	150	---	9,000,000.

Many of these sites are excellent and will undoubtedly be developed in time, both for power purposes and for agricultural diversion.

---- Boulder Canyon Dam ----

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.

Any large reservoir on the Colorado must depend for its financial feasibility upon an availability of an adequate market for not less than 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 in Arizona.

4. The electrification of the Southern Pacific, the Sante Fe and the Union Pacific Railways and their branches.

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

Several proposals have been made for the construction of a dam further up on the river than Boulder canyon. These proposals have come chiefly from interested parties in Arizona who are influenced by the apparent nearness to central Arizona of such a site as Glen Canyon, Lees Ferry or Diamond Creek.

A thorough investigation has shown that from all standpoints the Boulder Canyon site is logically situated for the initial development.

1. The economical reservoir capacity at the Boulder Canyon site is almost ideal for the four purposes: flood control, irrigation, power generation, and silt storage.

2. The site is close to its irrigation load and thereby reduces losses due to uncertainty in regulation to a minimum.

3. Boulder Canyon is centrally located in respect to all of the demands for power that will be made on it and it is the closest feasible site to the heaviest potential consumer of power, Los Angeles city and the surrounding territory.

Other desirable sites may be developed further up the river in the future - there they will be well located to supply markets in the states of Arizona, Utah, Colorado and New Mexico. Development in those states has not at present reached a point where large amounts of energy could be consumed.

---- Statistics, Colorado River Basin ----

Political divisions of Colorado Basin.

Wyoming	19,000 sq. miles.	
Colorado	39,000	
New Mexico	23,000	
ARIzona	103,000	
Utah	40,000	
Nevada	12,000	
California	6,000	
Total, United States		242,000
Total, Mexico		2,000
		244,000

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----Upper Basin, Acreage irrigated and irrigable in future ----

	Irrigated 1920.	ADDitional possible to irrigate	Total
Green River Basin	643,000	1,212,000	1,855,000
Grand River Basin	542,000	412,000	954,000
San Juan River Basin	157,000	729,000	886,000
Price River Basin	30,000	50,000	80,000

	Irrigated 1920	Additional possible to irrigate	Total
San Rafael River Basin	80,000	20,000	100,000
FRemont River Basin	16,000	30,000	46,000
Little Colorado River "	19,000	45,000	64,000
Virgin River Basin	26,000	40,000	66,000
Escalante River Basin	2,000	2,000	4,000
Kanah Creek R	2,000	2,000	4,000
Paria River	2,000	2,000	4,000
Other tributaries	7,000	3,000	10,000
TOTAL	1,526,000	2,547,000	4,073,000

----Lower Basin, Acreage irrigated and irrigable in future----

	I rrigated 1920 - gravity	Future additional possible gravity	Future additional possible pump	Total Ultimate
Above Laguna Dam,	39,000	189,000	77,000	305,000
Below Laguna Dam	469,000	326,000	120,000	915,000
TOTAL United States	508,000	515,000	197,000	1,220,000
Mexico	190,000	547,000	63,000	800,000
GRAND TOTAL Lower Basin	698, 000	1,062,000	260,000	2,020,000
Gila Basin	430, 000	400,000	--- ---	830,000

----Discharge at Boulder Canyon----

The discharge of the river at Boulder Canyon has never been recorded directly. It is arrived at by taking the discharge at Yuma, ARIzona; and adding and subtracting thereto certain losses and gains in the water of the river between the two points.

		Acre feet
Average discharge of Colorado at Yuma, 1903-1920		17,400,000
Diverted above by Yuma project		150,000
Total discharge		17,550,000
Discharge of Gila		1,080,000
Estimated at Boulder Canyon		16,470,000
Past depletion (Average amount discharge would be lessened if cycle reoccured with present development)		560,000
Remainder at Boulder Canyon		15,910,000.
Future depletion		
Development, upper basin (2,547,000)	4,230,000	
additional evaporation, reservoirs in Canyon section. (50% area of possible additional reservoir sites)	1,360,000	
		5,590,000
Remaining water		10,320,000.

---- Demands on water supply at Boulder Canyon----

The demands on water supply at Boulder Canyon will be for irrigation of the entire irrigable area below, both now irrigated and e stimated additional, and diversions from the basin.

In computing the irrigation demands the following assumptions are made: annual gross demand for irrigation, gravity, 440 acre feet per acre; pump 350 acre feet per acre; annual net demand above Laguna Dam, consumptive use, 3 acre feet per acre.

Diversion from the basin will embrace 1000 second feet steady flow for the proposed Los Angeles aqueduct. This will amount to

724,000 acre feet per year.

Estimated ultimate demand

Diversion duty (305,000 acres, duty, 30; 1,532,000 acres, duty, 4.40; 183,000 acres, duty 3.50; total 2,020,000 acres duty 4.10)

Month.	Acre ft. per acre	Total Diversion acre ft.
January	.11	230,000
February	.20	400,000
March	.39	780.000
April	.42	850,000
May	.48	980,000
June	.56	1,140,000
July	.56	1,140,000
AUgust	.47	950,000
September	.39	800,000
October	.27	550,000
November	.16	330,000
December	.09	150,000
	4.10	8,300,000

Diversion to Los Angeles, 1000 second feet ---	724,000
Total demand	9,024,000

Although the foregoing estimates and assumptions rest on many uncertainties, the general conclusion may be drawn in the light of present knowledge that the water supply of the Colorado is equal to all of the demands which will be made on it.

---- Storage required ----

The plan proposed will provide for complete regulation of the river with the idea that surplus water be used to develop powerat Boulder Canyon and that later as development above decreases the discharge available, release for power will be decreased. To compensate for decrease in release for power, there will be less capacity in the reservoir which must be reserved for storage and consequently more head available for power. This works out satisfactorily, especially if the Boulder Canyon plant is tied in with one above where discharge can be regulated according to power needs.

---- Storage computations ----

	Acre feet
Average annual discharge at Boulder Canyon after allowance for past depletion above	15,700,000
Average future depletion from upper basin	4,070,000
Ultimate discharge	11,670,000
Mass computations give the following results:	
Average annual draft	11,670,000
Storage required for complete control	25,000,000
Average annual, evaporation (5 ft depth)	520,000
Average useful annual draft	11,150,000
Ultimate irrigation needs for lower basin	8,300,000
Used for power	2,850,000

The reservoirs which fill feasible government projects for the river regulation are the Dewey, Juniper, Flaming Gorge, and Boulder Canyon. The use of the water for power and flood control at the first three is a problem which must be solved as development above proceeds. Its use at Boulder Canyon will be further traced.

---- Boulder Canyon dam ----

Two dam sites have been investigated and explored in a preliminary way by the United States geological survey. The two sites are about 2,900 feet apart, the upper one being some 3,500. feet down stream from the head of the canyon as determined by Boulder wash. Both sites are feasible and in a way similar. The upper site, however, offers many advantages over the lower one. It is more accessible, less confined and offers a better location for power house, outlet works and spillway.

Two general types of concrete masonry dams have been investigated - the gravity type and the arched type. The two types give nearly identical costs for construction while the arched dam will be much more expensive for power development. For additional stability the gravity type should be arched in plan. With a 31,400,000 acre ft. reservoir the dam will have a maximum height of 735 feet of which 605 feet will be above the original low water surface. The length of top in this case will be about 1,250 feet.

A spillway capacity of 200,000 second feet has been tentatively assumed and the spillway designed to pass this quantity with a flood-water surface elevation of 1,300 with the

31,400,000 acre ft reservoir. A 10 foot encroachment on the freeboard of the dam gives a spillway capacity of 300,000 second feet. The water will be diverted by means of tunnels and shafts to the river below. It is very improbable that a quantity of water greater than 50,000 second feet will ever need to be passed by the spillway with proper regulation of the reservoir level and the supplementary use of flood storage and control gates.

The irrigation demand will require outlet gates of about 25,000 second feet capacity. Preliminary studies indicate that this quantity can be passed through 60 - 72 inch balanced valves. These valves will be located at different levels so that they may be operated under a maximum head of 150 feet for irrigation purposes. A portion of irrigation water would at all times pass through the power plant, which leaves a large excess capacity through outlett gates for irrigation and flood control purposes. The water not so used will discharge into the spillway shafts and tunnels.

----Power development ----

Preliminary studies have been made for power development based on various reservoir capacities. A comparison of power developed with various discharges leads to the conclusion that all lands in the United States and the lands under the All-American and Imperial canals in Mexico and the power development based on the minimum irrigation discharge of 13,500 second feet. If a 31,400,000 acre foot reservoir is provided and the same lands irrigated with the minumum discharge will be 14,300 second feet, which under a minimum head of 394 feet, will develop 563,000 horsepower of firm power. The additional discharge of 1000 second feet for the Los Angeles aqueduct, under a minimum head of 394 feet, will develop 39,400 firm horsepower.

However, materially greater firm horsepower could be developed by a different reservoir operation whereby the amount of water released for power is varied inversely with the head. Under such operation of the reservoir, power water would be conserved at times of full reservoir and high head for use at times of low reservoir and small head.

The two following plates were furnished by Mr. Conkling and show the operation of Boulder Canyon Reservoir of 31,400,000 acre ft. capacity as follows:

a. Operation of Boulder Canyon Reservoir based on the development of 700,000 firm horsepower in connection with the irrigation of 1,505,000 acres in the lower valley.

b. Operation of Boulder Canyon reservoir based on the development of 600,000 firm horsepower in connection with the irrigation of 2,020,000 acres in the lower valley.

Both plates are based upon the assumption that the efficiency at the turbines is 88% and that the discharge at Boulder Canyon is 1,500 second feet more than the recorded flow at Laguna Dam. This figure is based on the estimated evaporation and depletion by development of the waters of the river between the two points.

The plates do not include the additional power developed by the discharge of 1000 second feet of the proposed Los Angeles aqueduct. This source would yield 500,000 additional horsepower.

Although the feasible irrigation projects in the lower basin comprise 2,020,000 acres, the probable development during the next 30 years will not exceed the 1,505,000 acres which is assumed for the development of 700,000 firm horsepower. As developments proceed in the upper and lower basin, the discharge available for power will be gradually decreased, finally with full development, the firm horsepower available will total 650,000.

----Power equipment----

With the 31,400,000 acre ft. reservoir the power installation would consist of 12 - 67,000 horsepower vertical, variable-head turbines direct connected to 50,000- kilowatt, 11,000 - volt, 3 phase, 60 cycle generators, with necessary switching and auxiliary apparatus. The power house would be of concrete construction located at the down stream toe of dam.

Switching apparatus is proposed for two circuits having capacity to transmit the full power output of the plant. Provision should be made for two future circuits. The switching apparatus would be of the outdoor type, located on the plateau north of the dam at elevation of 1,600. The transformer installation would include thirty-six 18,000 - k.v.a. single phase transformers.

The generated voltage of 11,000 will be stepped up to 220,000 volts for transmission to the proposed transformer station near Los Angeles. It is believed that the use of 220,000 volts up to 250,000 volts for transmission would be very desirable both from an economical standpoint and also because it would be possible to more easily tie the systen in with other large systems in the southwest that will undoubtedly be standardized at these voltages in the near future.

---- Costs ----

A preliminary estimate gives the following as the cost of the dam including right of way, railroad, camp, construction plant, river diversion works, spillway, outlet works, and other minor features, together with the power house and transmission lines:

750,000 firm horsepower development.

Dam	$ 55,000,000
Power plant	33,000,000
Transmission line	27,000,000
TOTAL	$115,000,000

650,000 firm horsepower development

Dam	$ 55,000,000
Power plant	29,000,000
Transmission line	24,000,000
TOTAL	$108,000,000

Since the sale of power will necessarily pay for the entire cost of the project it would be desirable to provide for the development of the entire 750,000 firm horsepower. The construction cost would be increased only 7% while the power yield would be increased 15% over the corresponding values for the 650,000 horsepower installation.

---- Los Angeles Aqueduct ----

A tenative plan has been devised for the construction of a system designed to convey water from the Colorado River to the section surrounding Los Angeles, California. A route which has been tenatively selected arranges for the diversion of 1000 second feet from the Colorado River at a point near Blythe, Cal. From there it would be successively pumped and conveyed in conduit by way of Chucawalla valley, Mecca, Indio and the Cochella valley to San Gorgonio pass at a point near Banning. Near Banning the conduit would pass underground and come out in the San Timateo Canyon at a point about 10 miles above Redlands, California. An alternate plan would be to have the tunnel deliver the water into the San Jacinto valley thence to be conveyed into the San Bernardino valley at a point near Riverside. The length of the aqueduct from the point of diversion to Redlands, California would be approximately 185 miles. Pumping to a total height of 2160 feet would be necessary.

---- Volume of Water Needed ----

The present Los Angeles Aqueduct brings to the city an average of 200 second feet of Owens valley water. This is further increased by local sources of supply to not more than 300 second feet of average dependable flow.

The demands made on water supply as metered in Los Angeles is approximately 125 gallons per capita daily. At this rate the Los Angeles Aqueduct would supply a papulation of 1,030,000 people. The number of people supplied from this source at present is nearly 500,000. The remainder of the water together with that developed locally is used for irrigation in San Fernando Valley and on the Coastal Plain near Los Angeles. Adequate provision for agricultural development demands that the water now being used for that purpose be not diminished; rather that additional quantities be put to this use as soon as the water becomes available. Additional irrigation in the foothill districts will be made possible by the construction of the Flood Control projects now under way so that these districts need not be further considered.

An additional supply of 1000 cubic feet per second at an average consumption of 125 gallons per day per capita would supply a population of 5,170,000 people. It seems reasonable to presume that the per capita consumption would increase with time, as it has in the past. The increase in use of modern plumbing facilities and the use of water for industrial purposes increases the demand made on the water supply a very appreciable amount. Making this assumption, it is reasonable to estimate the population which could be supplied in the future from the water supplied by the combined systems at 5,000,000 people.

That Los Angeles City, with its surrounding territory, will soon reach this quota is a probability that has substantial backing in the records of growth in the past and the resources and possibilities of the city and harbor.

The probability that the population and the section would greatly exceed this amount in the next 50 years is a possibility that has too vague a foundation to be considered in the design of a water supply system for the city.

---- Diversion ----

The Black Point diversion dam would be utilized as the intake of the proposed Los Angeles aqueduct. This dam is located at a Rock point known as Blythe Heading where the main canal diverts. Here the river strikes the granite ledge and is diverted to the opposite bank of the channel. The river has always hugged this bank and since the main current strikes the heading it is always free from silt deposit.

The present Blythe Heading is a concrete intake placed in the granite point. Wooden emergency gates with steel screw lifting devices furnish the control at the intake. The intake and main canal is owned by Palos Verdes Valley Irrigation district and is of sufficient capacity to irrigate the 78,000 acres which is the ultimate irrigable acreage.

Additional acres which are proposed to be served from this intake are 30,000 acres on the Palos Verdes Mesa and 72,000 acres in Chucawalla Valley.

The city of Los Angeles would co-operate with the Chucawalla Development Company and the Palos Verde Valley districts in the construction of a diversion dam and main canal which would supply the combined demand for water at this point.

---- Blythe Intake to Eagle Mountains ----

Blythe intake is located 12 miles northwest of the town of Blythe, a town of 2000 population in Riverside county, California. The main canal will extend to a point near the California Southern Railway, five and a half miles north of Blythe. Here it would be divided into several submains, the first and largest will divert south to the lands of the Palos Verde valley; the second will extend southwest to the gravity lands of the Palos Verde Mesa; the remaining water will be pumped a height of 205 feet into a high line canal which will serve the high lands of the Mesa and continue on to the Chucawalla Valley. A portion of this water will be used to irrigate the lower sections of the valley while the remaining water will be pumped an additional 105 feet where it will serve the high level irrigation project and further serve to convey the water of the aqueduct toward its destination. This canal will carry the water as far on the low range of hills known as the Eagle Mountains where the aqueduct water which only remains will be again pumped.

An alternate plan, which will not be further discussed, is to pump the aqueduct water a height of 500 feet directly from the main canal. Thence it would skirt the hills to the north of the Chucawalla Valley, arriving at the same place near the Eagle Mountains where it would again be pumped.

The advantages which favor the first plan are;

a. The same canal may be used to serve both as an irrigation main and as aqueduct thus minimizing conveyance losses and reducing the construction cost.

b. The same pumping plant may be used for both purposes thereby decreasing the plant and operation costs and increasing the flexibility of the system.

c. The route chosen for the irrigation canal is advantageous from a construction standpoint on account of the more regular topography on the southern edge of the Chucawalla Valley.

d. The combined system would permit the use of silt sluiceways in the main canal.

This is particularly advantageous on account of the large silt content of the waters. Skimming boards form an almost ideal way of removing the bulk of the water carried in suspension. In the case of the combined system these could be located at lateral headings, the aqueduct water being skimmed over wooden flash boards while the lower sediment bearing water could be sluiced into the laterals leading to the lands directly below thus serving the double purpose of dessilting the aqueduct water and enriching the valley flow.

The possibility of locating a settling reservoir at one of the dry lakes of the region has been investigated but the calculated loss by evaporation at one of these, Palm Dry Lake, ammunted to approximately 500 second feet which rendered it infeasible.

The factor which favors the second or individual plan is the independence of the pumping works and conveying canal. The water would also be lifted higher at one lift making the unit cost lower. It would also permit of better construction and the covering of the canal to prevent evaporation and contamination.

A summary of the combined system as far as the Eagle Mountains will be given:

Elevation of canal at diversion point	283 feet
Irrigated area served	180,000 acres
Irrigation demand (max. .48 acre feet per acre, per month, based on duty of 3.5 feet)	1,440 sec.ft
Canal capacity at heading	2,500 " "
Length of main canal	9 miles
Elevation at end of main canal	270 feet

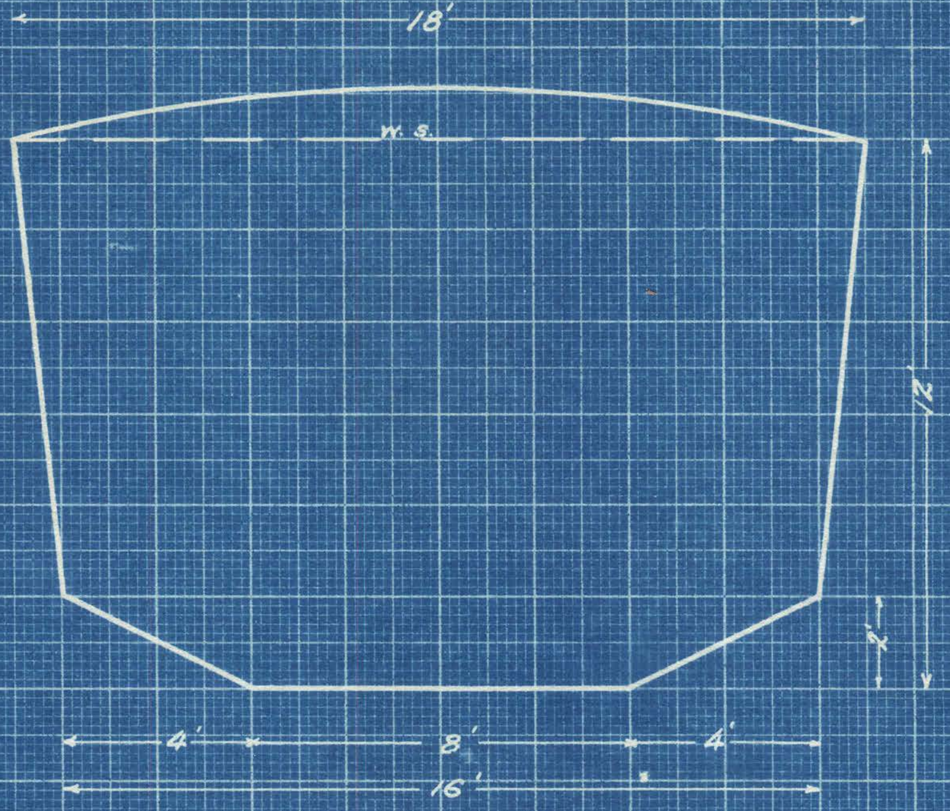
- - - - - - - - - -

Irrigated area served by pumping station #1.	87,000 acres
Irrigation demand (maximum)	696 sec,ft
Canal capacity at head of pump	1,700 " "
Height of lift	205 ft.
Elevation at delivery	475 ft.
Length of canal section	25 mi.
Elevation at end of canal section	446 ft.
- - - - - - - - - - -	
Irrigated area served by pump station #2.	22,000 acres
Irrigation demand (maximum)	196 sec.ft
Canal capacity at head of pump	1,200 " "
Height of lift	105 ft
Elevation at delivery	551 ft
Length of canal section	58 mi.
Elevation at end of canal section	515 ft.
Road distance from Mecca (and of canal section)	40 mi.

---- Eagle Mountains to Banning ----

The elevation at the arbitrarily selected point 40 miles from Mecca on the automobile highway is assumed to be 515 feet. From this point on the aqueduct would be a covered conduit with a slope of 1½ feet per mile, or .000284. The approximate distance traversed by the conduit from the Eagle Mountains point to the pass, 12 miles to the east of Mecca is 34 miles which requires a gradient drop of 50 feet. The elevation at the pass is 1,706 feet. Two lifts would be used in attaining this elevation. The first would be 400 feet which would serve to carry the water a

Section of Covered Conduit.



Elements of Covered Conduit Section

S = $1\frac{1}{2}$ Feet to Mile = .00028

n = .014

A = 194 sq. ft.

R = 5.10 ft.

V = 5.2 ft./sec.

Q = 1010 cu. ft./sec.

distance of approximately 20 miles on the slightly sloping end of the valley. The second lift of 825 feet would carry the water the remaining 14 miles through the steeper portion of the canyon, reaching the summit at elevation 1,690 which would necessitate a cut of 16 feet.

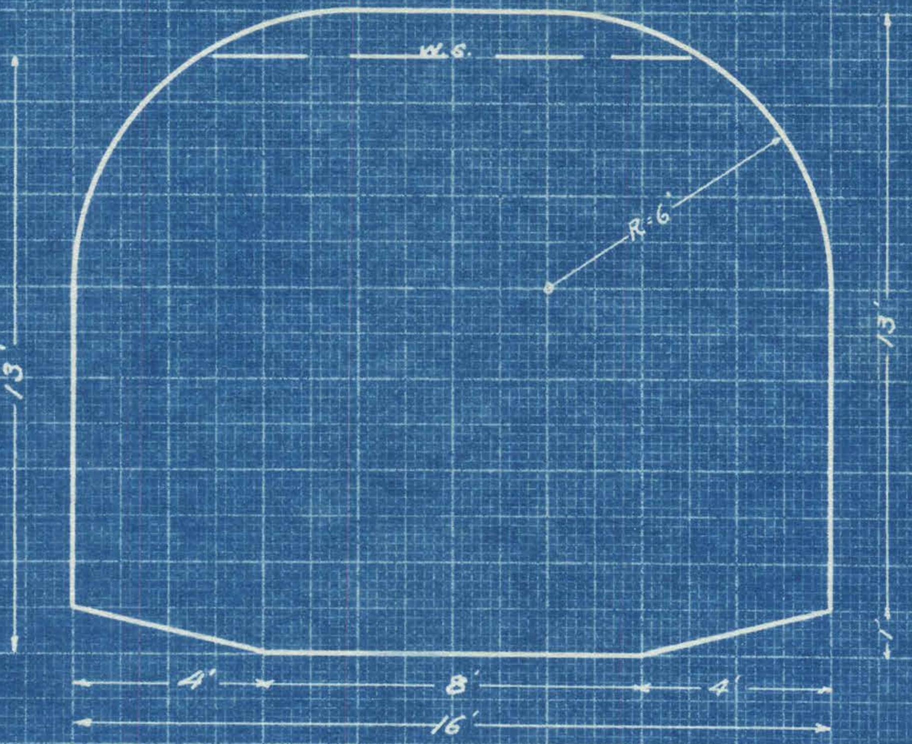
From the summit of the Mecca -Blythe pass the aqueduct would skirt the southern edge of the Cottonwood Mountains and follow the foothills of the San Bernardino Mountains along the north side of Cochella Valley for a distance of 60 miles, entering San Gorgonio Pass at nearly an elevation of 1600. It would pass to the south side of Gorgonio Pass there to be pumped 625 feet to elevation 1625 feet. The conduit would enter the ground near Banning at elevation 1615.

---- Banning to San Bernardino ----

The tunnel which heads at Banning could have either of two termini.

(1) It would be run for a distance of 104 miles, passing under the town of Beaumont, and terminating in the Sand Timoteo Canyon near the Southern Pacific station, Alexis. Thence it would continue under a siphon head either down to the San Bernardino Valley or it would skirt the foothills on the San Bernardino Mountains and arrive in Los Angeles on a high line gradient, depending on the right-of-way concessions which could be obtained.

(2) A 4.2 mile tunnel would bring the water out near the head waters of the Potrero Creek which runs down into the San Jacinto Valley. From this point it would continue either:



Elements of Tunnel Section:

S = 2 feet to Mile = .00038

n = .014

A = 182 □ ft.

R = 4.23 ft.

V = 5.4 ft./sec.

Q = 985 cu. ft./sec.

a. Along the foothills to the north of San Jacinto and Allesandro Valleys to be delivered into the San Bernardino Valley near Riverside.

b. By a nine mile conduit along the Bad Lands Hills to a point to the west of Saborda Canyon there to be conveyed by a 1.7 mile tunnel to a point near Alexis in the San Timateo Canyon.

From all indications the first plan, involving a 104 mile tunnel is the most feasible and also the most desirable.

Summary, Eagle Mountains to San Bernardino.

Grade of canal	.000234	
Elevation of canal at Eagle Mountain	51.5	feet
Height of lift	400	feet
Elevation at point of delivery	915	feet
Length of section	20	miles
Elevation at end of section	885	feet
- - - - - - - -		
Height of lift	825	feet
Elevation at point of delivery	1,710	feet
Length of section to pass	14	miles
Elevation at Mecca Blythe summit	1,690	feet
- - - - - - - -		
Length of section summit to Cabezon	60	miles
Elevation at end of Cabezon station	1600	feet
- - - - - - - -		
Height of lift	625	feet
Elevation at top of lift near Cabezon	2225	feet

Length of section to Banning	7 miles
Elevation at tunnel heading	2,215 feet

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Length of tunnel	10.4 miles
Grade of tunnel (2 ft. 1 mile)	.00038
Elevation at point of emergence	2,194. ft.

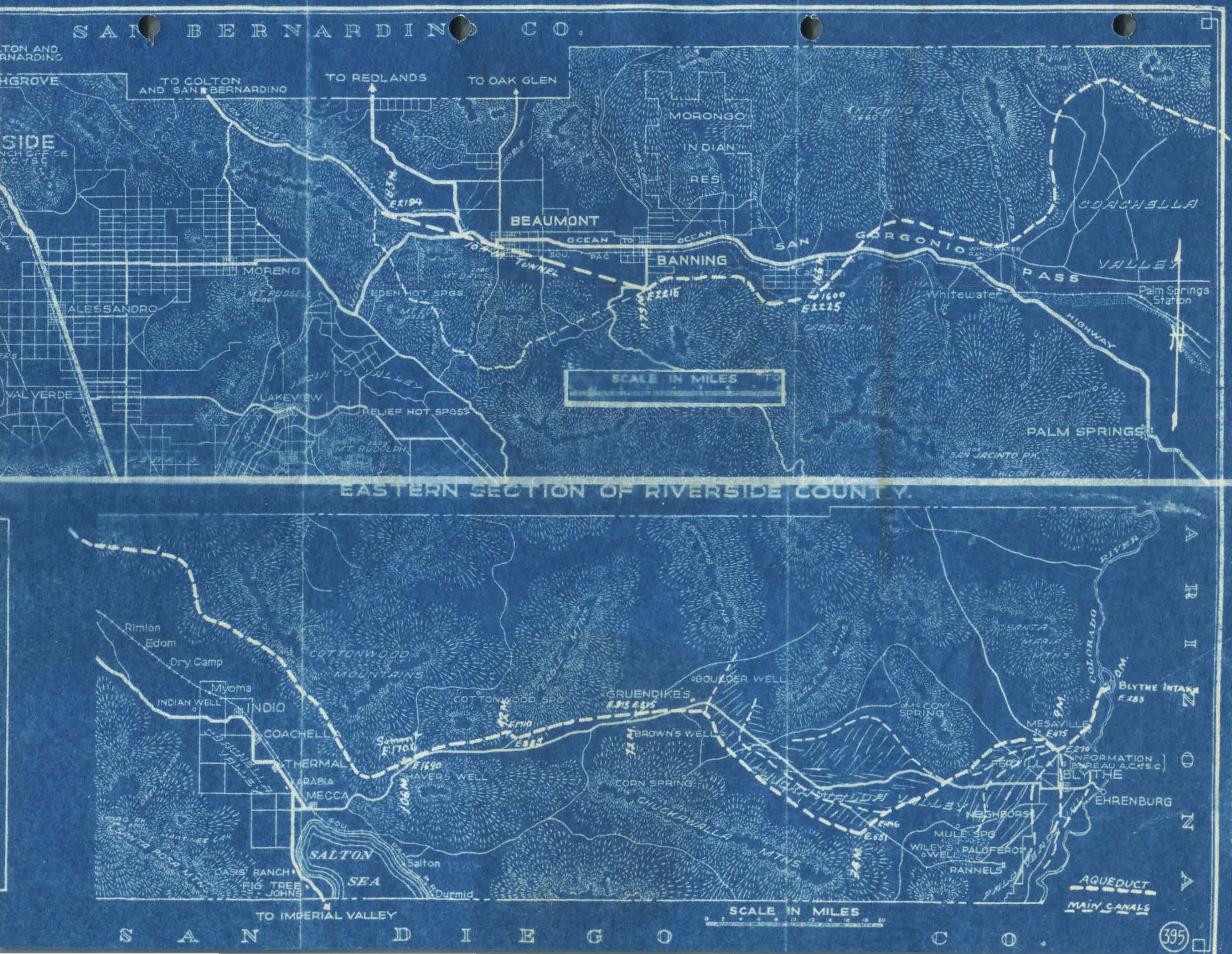
\- - - - - - - - -

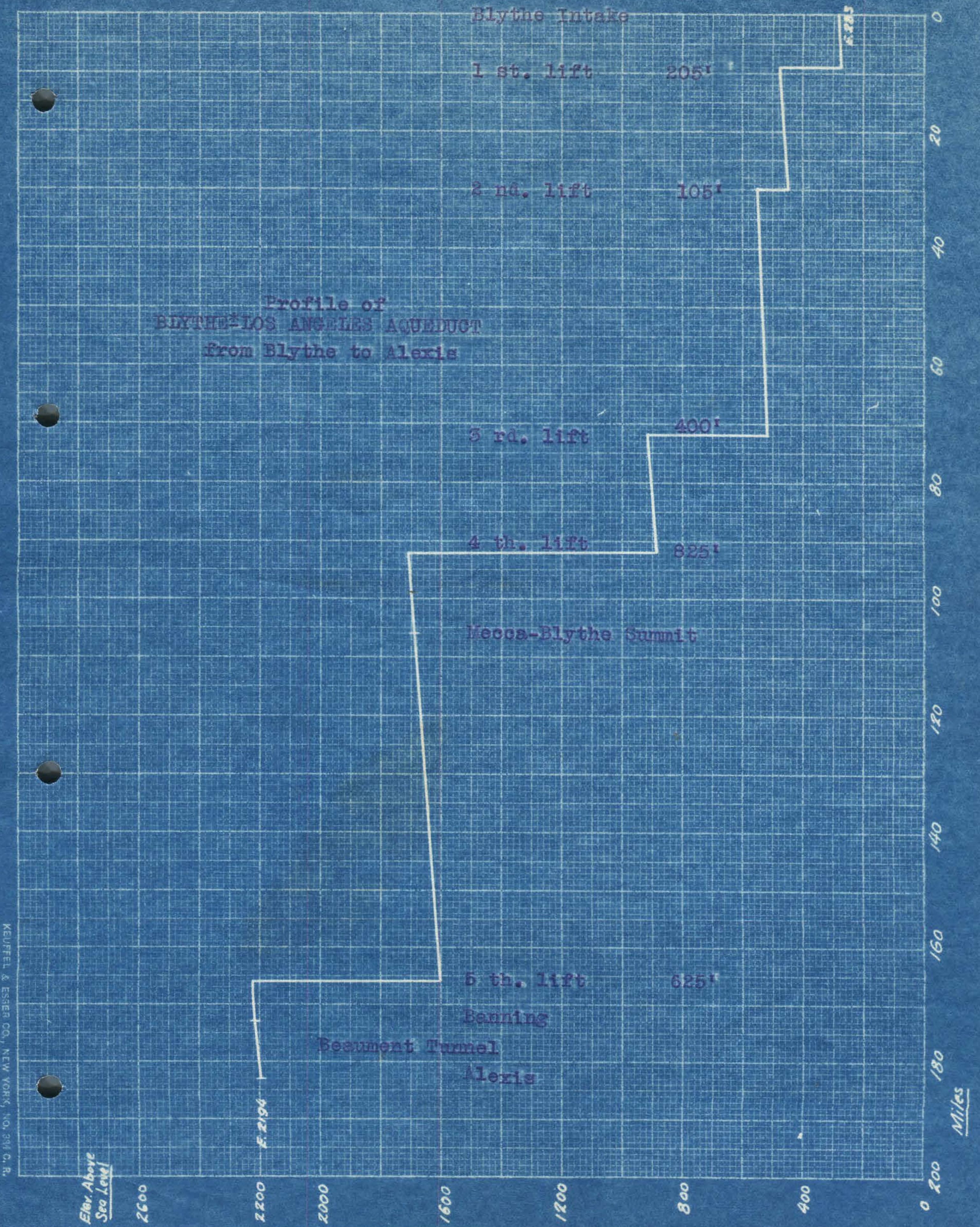
Distance, tunnel end to Redlands	12 miles
Elevation, Redlands	1,300 feet
Distance, Redlands to Los Angeles (Air line)	62 miles
Elevation, Los Angeles	300 feet

Length of aqueduct from Blythe heading

Blythe heading	0 miles
1st lift	9 miles
2nd lift	34 miles
3rd lift (Eagle Mountains)	72 miles
4th lift	92 miles
Mecca Blythe summit pass	106 miles
5th lift - Cabezon	166 miles
Tunnel heading	173 miles
Tunnel end (Alexis)	183 miles
Redlands	195 miles
Los Angeles (Air line)	257 miles
Los Angeles (Foothill)	290 miles

Total combined height of lifts 2160 feet


SAN BERNARDINO CO.
TO COLTON AND SAN BERNARDINO
TO REDLANDS
TO OAK GLEN
MORONGO INDIAN RES
BEAUMONT
BANNING
OCEAN TO OCEAN
SOU. PAC
SAN GORGONIO PASS
COACHELLA VALLEY
Palm Springs Station
Whitewater
HIGHWAY
PALM SPRINGS
SAN JACINTO PK.
CABAZON PK.
E2194
E2216
E2225
TUNNEL
MORENO
ALESSANDRO
VAL VERDE
LAKEVIEW
MT. RUSSELL
EDEN HOT SPGS
RELIEF HOT SPGS
MT. RUDOLPH
SCALE IN MILES
EASTERN SECTION OF RIVERSIDE COUNTY
ARIZONA
BLYTHE INTAKE
E283
COLORADO RIVER
SANTA MARIA MTNS
MESAVILLE
BLYTHE
INFORMATION BUREAU A.C.T.S.C.
EHRENBURG
McCOY SPRING
BOULDER WELL
GRUENDIKES
BROWN'S WELL
CORN SPRING
CHUCKAWALLA MTNS
CHUCKAWALLA VALLEY
NEIGHBORS
MULE SPG
WILEY'S WELL
PALOFERO
RANNELS
COTTONWOOD SPG
COTTONWOOD MOUNTAINS
SHAVERS WELL
Rimlon
Edom
Dry Camp
Myoma
INDIAN WELL
INDIO
COACHELLA
THERMAL
ARABIA
MECCA
SALTON SEA
Salton
Durmid
OASIS RANCH
FIG TREE JOHNS
SANTA ROSA MTNS
TO IMPERIAL VALLEY
AQUEDUCT
MAIN CANALS
SCALE IN MILES
SAN DIEGO CO.
395


Profile of
BLYTHE-LOS ANGELES AQUEDUCT
from Blythe to Alexis
Blythe Intake
E.283
1 st. lift 205'
2 nd. lift 105'
3 rd. lift 400'
4 th. lift 825'
Mecca-Blythe Summit
5 th. lift 625'
Banning
Beaumont Tunnel
Alexis
E.2196
Elev. Above Sea Level
2600
2200
2000
1600
1200
800
400
0
Miles
20
40
60
80
100
120
140
160
180
200
KEUFFEL & ESSER CO., NEW YORK, NO. 359 G. R.

---- Cost ----

The cost of the Los Angeles Owens Valley aqueduct was $23,000,000; its length 233 miles; its capacity 420 second feet. The conditions for construction were similar. Labor 1925 - 1930 will probably be twice as expensive as in 1905 - 1910. The ratio of cost due to size will be about 1.5.

Probable aqueduct cost - $23,000,000 x 2 x 1.5 x $\frac{290}{233}$ = $86,000,000

Cost of pumping plants (1000 second feet x 2160 ft) 14,000,000

Total cost (Probable minimum	100,000,000
Total cost (Probable maximum	150,000,000

---- Cost of water at Los Angeles ----

Cost of pumping:

Horsepower at 88% efficiency	=		280,000.
Kilowatts	=		208,000.
Cost per hour @ ½¢ per K.W.hr	=	$	1,040
Pumping cost per 100 cu. ft	=	$	.0289

Fixed charges:

Cost of aqueduct		$125,000,000.
Interest (4½%)		5,620,000.
Depreciation (3%)		3,750,000.
Yearly charges		9,370,000.
Fixed charges 100 cu. ft.	$	.0296

Cost of 100 cu. ft. delivered to Los Angeles Maximum capacity.	$	.0585
Fixed charges 1oo cu. ft with aqueduct delivery half capacity	$	.0592

Cost of 100 cu. ft. delivered to Los Angeles, half capacity $ .0881

----- Power development ----

The total power developed at Boulder canyon; 750,000 horsepower initial development, decreasing to 650,000 firm horsepower with final development could be used very nicely in a variety of ways: It could be used in the cities of the southwest and in the attendant industries, for electrification of railroads in the southwest, for pumping both on irrigation projects and on the proposed Los Angeles aqueduct system and for use in the cities and mining districts of the states adjacent to Boulder Canyon.

Use in Los Angeles:

The total power output at the Canyon plant could be entirely disposed of in the growing Los Angeles industrial district. The Southern California Edison Company now supplies about 300,000 horsepower to the section. The Los Angeles Municipal system supplies 72,000 horsepower, with a maximum possible ultimate development of 220,000 horsepower.

Until recently these sources were believed to be sufficient to provide for the city's commercial, industrial and domestic needs. But in the short space of two years 150,000 additional horsepower made available by the Southern California Edison Company has been entirely utilized. The production of steel, on a large scale with the attendant manufacturing industries only awaits the time when large blocks of dependable, cheap power is placed on the market. From this it may be inferred that any part of the 750,000 firm horsepower generated at Boulder Canyon would be readily disposed of as quickly as it could be supplied.

Electrification:

Electrification of the railroads of the southwest would not be provided for at this time. Electrification involves a large expenditure of capital which is only occasionally justifiable in the present economic order. The first project was initiated in 1895. At that time it was believed that the steam locomotive would become obsolete in the space of 20 years. Electrification has seen very little progress since that time, however. It is extensively used for terminal operation and under special conditions where the steam locomotive is a nuisance or its capacity is too limited. Electrification on a large scale in the open country has been tried in only one instance in the country, notably on the Chicago, Milwaukee and St. Paul Railroad. On this project competition is absent, water-power on a large scale is cheap, and fuel is very scarce: yet although very successful in operation it has yet to be proved successful financially.

In the southwest, fuel oil and coal are relatively cheap; there are no special terminal conditions which must be met, and the railroads involved are too scattered to permit of economic compact electrification. In the future development of power upon the upper Colorado, nearer to the railroads and further and less useful as a source of power to the southwest, may permit of feasible electrification.

Pumping:

The operation of the Colorado river - Los Angeles aqueduct would require 280,000 horsepower for pumping water under full capacity. The only feasible source of supply of this power is the Boulder Canyon project. The average demand from this source would probably not exceed 200,000 horsepower. This would be furnished, either by a single circuit from the Boulder Canyon dam or by re-transmission from a central distributing point near Los Angeles. The use of electrical energy from this source for pumping on the various irrigation projects on the Los Angeles River seems unjustifiable on account of the small and fluctuating amount of power used and their scattered location.

Other states:

The use of power for the mining and urban districts of other states will not be, for some time to come, larger than can be generated locally. Provision for increased demand with development of these districts would be made with additional power development on the upper Colorado River.

---- Quantity of Power ----

It has already been stated that the initial development of power will be approximately 750,000 horspower, decreasing to 650,000 firm horsepower as development on the river progresses. With increased development and control of the river above the dam, the storage reserved for flood could be decreased and the power output increased with the increase of head. With this modification, it is doubtful if the firm power output would ever be decreased below 700,000 firm horsepower.

The maximum hosepower generated under peak loads would exceed 800,000 horsepower.

The power necessary for pumping on the Los Angeles aqueduct would vary between 200,000 and 300,000 horsepower. A double circuit line carried directly to the aqueduct line in combination with the existing distributing system from Los Angeles would carry this load.

There would remain approximately 500,000 horsepower. Of this, 100,000 horsepower could be used in the nearby sections of Utah, Arizona and Nevada. The remaining 400,000 horsepower would be transmitted to the vicinity of Los Angeles. This would require a triple circuit line. A four circuit line would be provided for emergency use and for future inter-connection.

---- Voltages ----

A rapid increase in transmission voltages used has continued since 1895. At that time, 12,000 volts was the highest considered commercially feasible. An almost steady increase in voltages used since that time has terminated with the use of 220,000 volts on California projects in 1923.

The advantages to be gained by an increase in voltage are: an increase in power transmitted over a given line and a decrease in losses. The limiting voltage which may be used is: conservative practise, the size of unit which is available for charging the line, and problems of insulation. Conservative practise demands that unnecessarily radical designs be not attempted without complete experimental foundation. The size of generating unit used is a limitation of the voltage that may be used on a long line. To charge the 200 mile, 220,000 volt, 60 cycle line of the Pit River development requires a unit of 35,000 K.v.a. delivering normal voltage. The 50,000 K.v.a. unit which would be used in the Boulder Canyon project would charge the necessary 275 mile line at approximately the same voltage, 220 K.v.a. A higher voltage than this would be wasteful of circuits since four circuits will be required regardless to provide at least one spare circuit under normal load. A lower voltage than this would be unnecessarily conservative in the light of present successful operation at high potential and it would be very uheconomical even from the standpoint of the old accepted standard of 1000 volts per mile of transmission line.

----Transmission Lines----

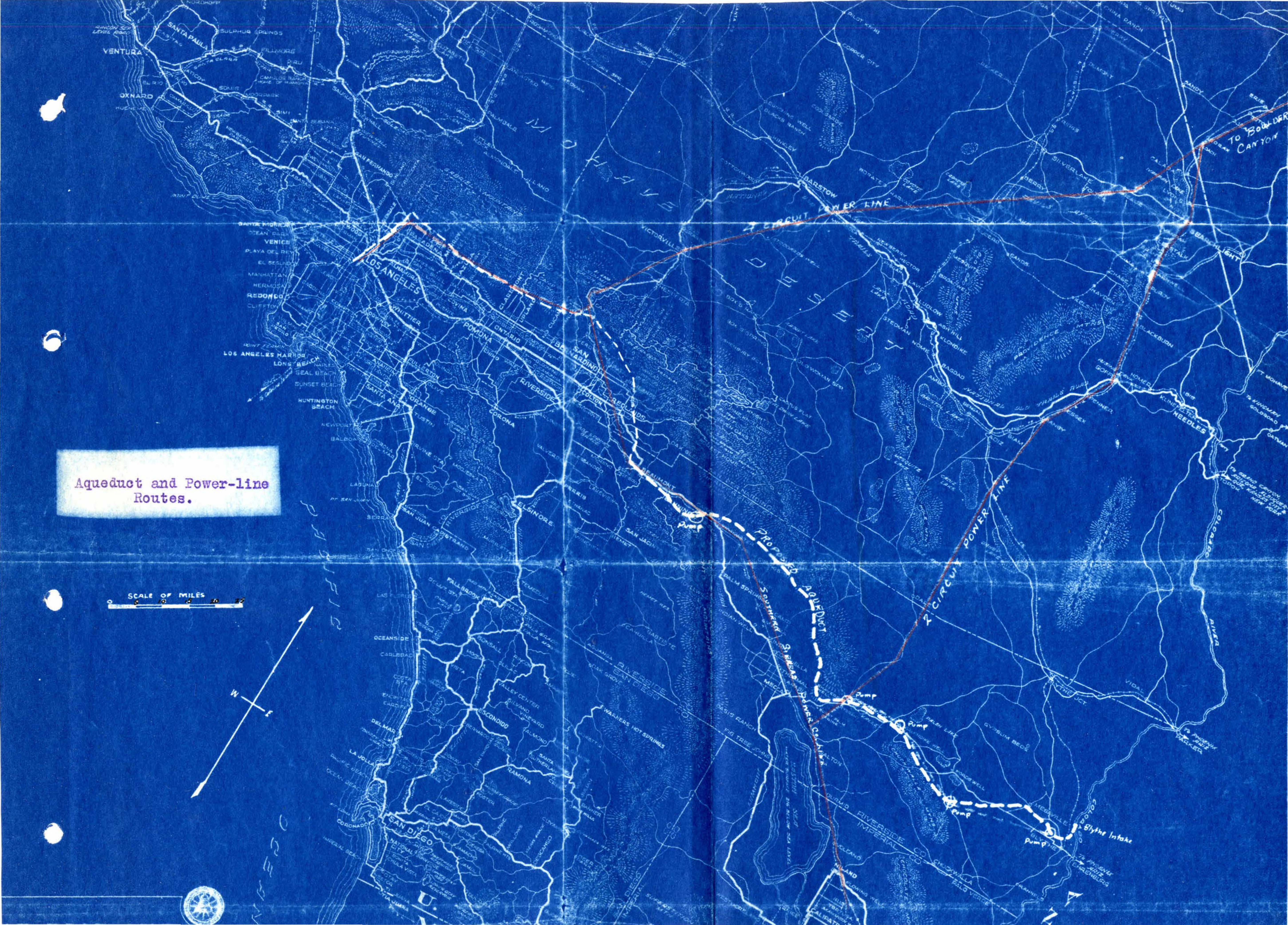
The two double-circuit lines for the Los Angeles section and the single double-circuit lines for the aqueduct pumping districts would extend west from Boulder Canyon to a point near Los Vegas. Thence they would continue south and west along the Union Pacific Railroad. The Los Angeles line would pass near Barstow, through Victorbille, and over the Cajon Pass to the Los Angeles section.

At a point near Searchlight, the aqueduct line would divert and follow the Santa Fe Railroad south to a point near Cadiz where it would leave the railroad and traverse the Mohave Desert and join the aqueduct near the Chucawalla valley, near Mecca. At the point it woild tie in with the San Bernardino Imperial project of the Southern Sierras power Co.

Chronologically the routes would be:

Combined transmission systems:

Boulder Canyon	6 miles
Los Vegas Wash near Colorado River	15 miles



Aqueduct and Power-line Routes.

Arden, Nevada (5 mi. east of)	30 miles
Erie, Nevada (Union Pacific R.R.)	45 miles
Roach, Nevada " " "	63 miles

The two systems diverge at this point.

Los Angeles project:

Summit, Ivanpah Mountains (Elev. 5300)	79 miles
Soda Lake, Calif. (Tonapah and Tidewater R.R.)	110 miles
Harvard, Calif. (Union Pacific R.R.)	126 miles
Dagget, Calif.	140 miles
Victorville	170 miles
San Bernardino	225 miles
Los Angeles	275 miles

Aqueduct project :

Roach, Nevada	63 miles
Goffs, Calif.	110 miles
Danby, Calif.	125 miles
Cadiz, Parker road crossing	140 miles
Dale, Calif.	166 miles
Chucawalla Valley(Mecca-Blythe road)	190 miles
Junction, San Bernardino, Imperial power line	200 miles

----Cost of Power lines----

The cost of a double circuit power line may be taken at approximately $30,000 a mile for 220,000 volts transmission. Paralleling of lines would reduce the unit cost to approximately $25,000 per mile. The country traversed would not be difficult for this construction. Using this as a basis of calculation:

Cost of Boulder Canyon - Los Angeles 275 mile, four-circuit power line -------------- $16,500,000

Cost of Boulder Canyon-Mecca 200 mile, 2 circuit power line --

$5,700,000

Other short one circuit transmission lines in Arizona, Utah and Nevada, and Substations	$4,800,000
Total cost of transmission lines	$27,000,000

---Summary of Project Costs----

Summarizing, we would have as the cost of the projects outlined above.

Boulder Canyon Dam, 31,400,000 acre-foot capacity -	$55,000,000
Power plant, 800,000 horsepower capacity -	33,000,000
Transmission lines and substations- -	27,000,000
Total power development	$115,000,000
Aqueduct, Blythe to Los Angeles, 1000 sec. ft. capacity)	125,000,000
Total cost of combined projects -	$240,000,000

At a total expenditure of approximately $240,000,000, the two chief problems which face the Colorado River section, namely, flood control and irrigation storage would be solved. In addition, the completion of these projects would, by the provision of adequate power and water for Los Angeles and its environs, insure future prosperity and development, on a large scale, of the entire southland.
